FRI-UW-8417
December 1984

FISHERIES RESEARCH INSTITUTE
School of Fisheries
University of Washington
Seattle, Washington

RENTON SEWAGE TREATMENT PLANT PROJECT:

Duwamish Head

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Final Report
for the period
1 July to 31 December 1984

for

The Municipality of Metropolitan Seattle
Seattle, Washington

Approved:

E. Salo for
Director R. L. Burgner

Submitted: December 1984

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PREFACE

The studies off Duwamish Head were designed to obtain pre-discharge ecological data from inner and outer Elliott Bay to develop a comprehensive and integrated understanding of the marine ecology in the receiving waters to aid future water quality monitoring efforts. However, these studies were abruptly terminated after one quarter of field sampling effort (July-September 1984). The data collected were selectively analyzed in the limited time alotted for completion to aid the final design and siting of the outfall in outer Elliott Bay.

The technical organization of this study is illustrated in Figure 1. The major project divisions which routinely interacted were grouped together under water column, environmental health, sediment investigations and chemistry. The studies of the water column included monitoring of the physical/chemical characteristics of the water and the plankton. Sediment investigations included the ecological studies of the intertidal and subtidal benthos and fishes. Environmental health included the measurement of fish pathology (fish health) and marine toxicology (in the water column, sediments and effluent). The chemical analyses were focused on the presence of trace metals and sediment deposition rates in sediment core samples, in addition to a variety of support services to the entire project. The METRO Water Quality Laboratory was responsible for the analysis of trace organic compounds in sediments. The organizational structure of this study facilitated efficiency, fiscal control, interdisciplinary integration within and between tasks and ensured that the study scope and schedules were met in a timely manner. This report is similarly organized by task.

Statistical expertise was provided on a regular basis to faculty, staff

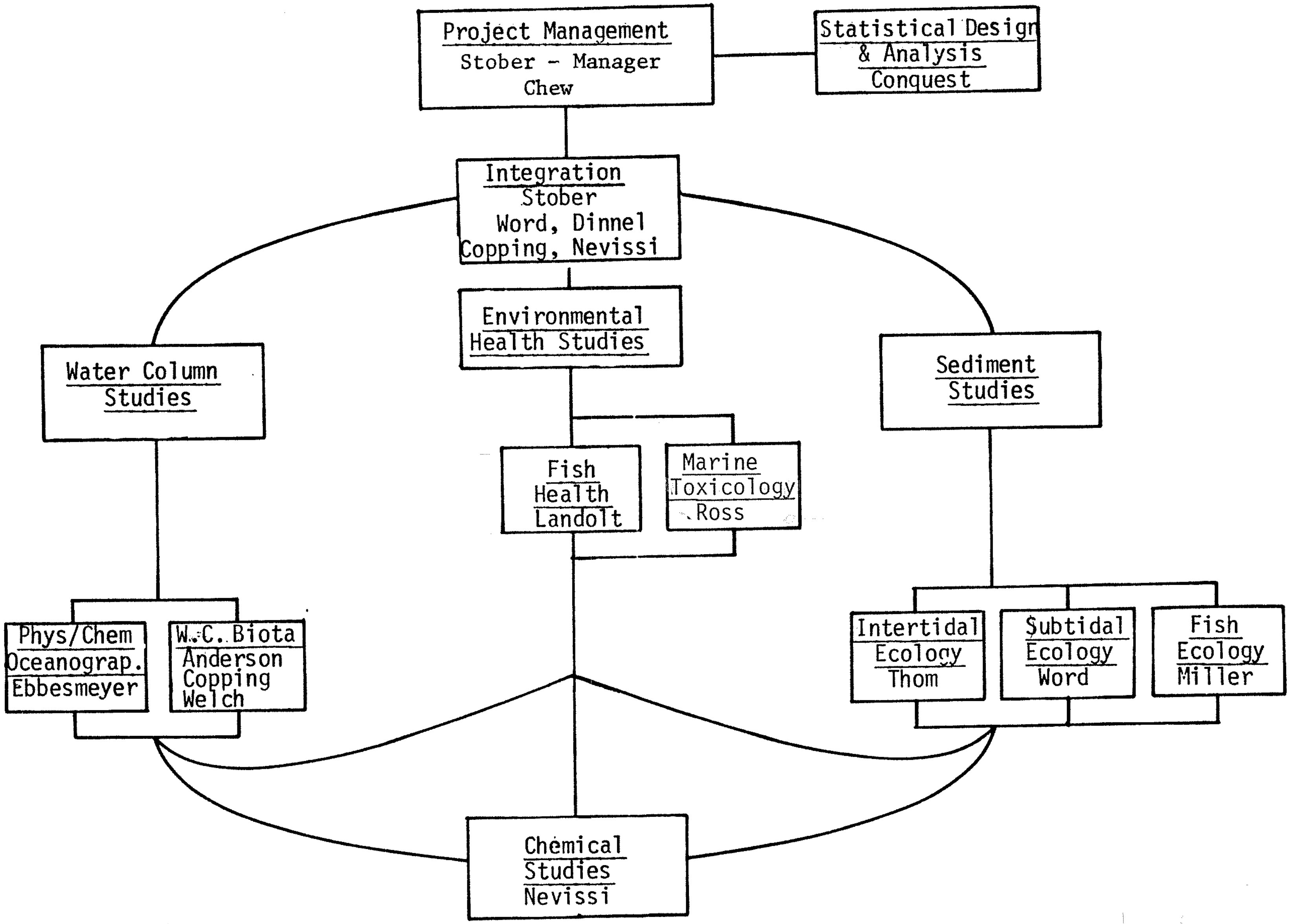


Figure 1. Organization of the Renton Sewage Treatment Plant Project, Duwamish Head study indicating major project divisions, specific tasks, and responsibilities of selected personnel.

and students associated with the project by Dr. Loveday Conquest in the Center for Quantitative Sciences in Forestry, Fisheries and Wildlife. Areas of investigation included computation of required sample sizes in various experimental designs, appropriate transformations of data, use of parametric and nonparametric tests, and general statistical approaches to data analysis.

ACKNOWLEDGMENTS

The Duwamish Head Baseline Study was sponsored by the Municipality of Metropolitan Seattle (METRO) as part of the Renton Sewage Treatment Plant Expansion Project. Mr. Robert Matsuda acted as project manager for METRO.

The success of the Water Column study depended on many people including those from the University of Washington, who helped us with the field work: Marguerite Koch, Raleigh Hood, Michael Strom, Michael Keast and Rochelle Manwaring. Gayle Heron of the School of Oceanography identified and counted the zooplankton. The captain and crew of the research vessels Liberty (METRO) and Barnes (UW) made our task easier and more enjoyable.

We wish to thank the following people without whose help the Subtidal Ecology could not have been done.

Mr. Robert Matsuda (METRO)
Mr. John Buffo (METRO)
Mr. Charles Eaton (RV Kittiwake)
Ms. Julia Schroeder (UW Subtidal Group)
Mr. Steven Hulsman (UW Subtidal Group)
Ms. Pamela Sparks-McConkey (UW Subtidal Group)
Mr. Kevin Li (UW Subtidal Group)
Ms. Pat Bouthalette (UW Subtidal Group)
Ms. Ginger Phalan (UW Subtidal Group)
Ms. Shawn Novick (UW Subtidal Group)
Mr. Mark Reibman (UW Subtidal Group)
Ms. Linda Bentler (UW Subtidal Group)
Ms. Betsy Day (Evans-Hamilton Inc.)

The Fish Ecology and Fish Health tasks wish to thank the many

individuals that contributed to this study. Gary Walters, of the National Marine Fisheries Service, provided invaluable assistance on numerical analysis. Many University of Washington students assisted with field sampling and with the laboratory processing of samples. These students included: Jose R. Borghetti, Bruce Campbell, Thomas Keegan, Jeffrey Lang, Douglas A. Milward and Tamara Ziesmann. Finally, Charles M. Eaton, owner/operator of the research vessel Kittiwake, provided an outstanding service for the project.

The Marine Toxicology section would like to thank Mr. Dennis Brown, Maintenance Division Manager and Mr. Ed Meyers, Equipment Services Supervisor, both of METRO's West Point Sewage Treatment Plant, for their help and cooperation in setting up and maintaining a most useable seawater laboratory facility. Mr. Victor Yoshino, U.S. Army Corps of Engineers, helped secure a variety of laboratory equipment. We would also thank Mr. Hal Beatty (UW), Mr. Chris Dungan (UW), Westcott Bay Seed Farms (San Juan Island), and Mr. Dale Lent (Walla Walla College Marine Station, Deception Pass) for assistance in collecting and holding of test organisms. Mr. Wayne Palsson (UW) helped maintain the seawater intake system. Mr. Henry A. Zebroski (UW) assisted in all phases of laboratory work.

The Marine Chemistry task appreciates the assistance of Dr. George Keller of the School of Oceanography, Oregon State University, for providing a Kasten corer.

1.0 EXECUTIVE SUMMARY

1.1 Introduction

Expansion of the Renton Sewage Treatment Plant to meet the needs of a growing population in the Seattle metropolitan area was begun in 1982. Since its construction in the mid-1960's, the secondary effluent from this plant has been discharged into the Duwamish River near Tukwila, Washington. The increased capacity of this plant from 36 million gallons per day to 72 mgd will not allow continued compliance with required water quality standards in the Duwamish River. A plan was adopted by the METRO Council in April 1984 to construct a pipeline and marine outfall system to divert effluent directly to a site off Duwamish Head in outer Elliott Bay in central Puget Sound.

The studies off Duwamish Head were designed to obtain pre-discharge ecological data from inner and outer Elliott Bay to develop a comprehensive and integrated understanding of the marine ecology in the receiving waters to aid future water quality monitoring efforts. However, these studies were abruptly terminated after one quarter of field sampling effort (July-September 1984). The data collected were selectively analyzed in the limited time alotted for completion to aid the final design and siting of the outfall in outer Elliott Bay.

1.2 Physical Oceanography

Results of CTD casts from 8 cruises, totaling 48 casts, aboard the R/V Liberty are presented. Vertical profiles of temperature and salinity were recorded on each cruise at Station 23 in inner Elliott Bay, Station 22 in outer Elliott Bay and at Station 21 near West Point. On three occasions, CTD profiles were taken at Station 24, south of Alki Point. The probe measuring dissolved oxygen did not function satisfactorily throughout the study. Density profiles were calculated at each station. The Duwamish River plume is discernible in the upper 5 m at Station 23 (inner Elliott Bay). Physical water column properties were very similar at Stations 21, 22, and 24.

1.3 Water Column

Six water column stations, at 3 different geographic locations, were sampled weekly for 10 weeks for water column parameters including: chlorophyll, phaeopigments, dissolved nutrients, primary production, phytoplankton species, zooplankton species and net plankton biomass. Stations 23A and 23B were in inner Elliott Bay, stations 22A and 22B in outer Elliott Bay (in the area of the proposed diffuser), and stations 21A and 21B off West Point. A seventh station (Station 24) was located in mid-channel south of Alki Point and was sampled monthly for the same parameters.

Casts A & B at a single location were found to be not significantly different. Results of plant pigments, dissolved nutrients, and primary production, integrated over the photic zone showed no significant difference among stations, except for chlorophyll. Integrating chlorophyll and ammonia over the upper 5 meters at all stations showed a strong statistical difference between the inner bay stations and all others, due to the influence of the Duwamish River plume. Most zooplankton species and total net plankton biomass were significantly different among stations. The inner bay stations were generally different from the others. The same dominant zooplankton species were present in the Duwamish Head study area as were found in the Seahurst study area.

Monthly investigations were carried out on the surface waters of Elliott Bay using a continuous underway monitoring system measuring temperature, salinity, turbidity, chlorophyll and ammonia at 1 meter depth.

A strong signal from the Duwamish River was seen on all transects in Elliott Bay, as shown by low salinity, high turbidity and high ammonia levels. Less freshwater was evident in the Duwamish plume in August than in July. A chlorophyll and ammonia signal was seen off Alki Point in July and August.

Investigations of the Duwamish plume were carried out on four special cruises, during which simulated *in situ* growth experiments were performed onboard using ambient Duwamish plume water and phytoplankton. In addition, a series of vertical profiles of chlorophyll and dissolved oxygen were taken at 10 stations along the plume from Pier 10 (East Waterway) to Smith Cove.

Results of the growth experiments showed increased phytoplankton productivity with distance from the mouth of the Duwamish River, indicating an inhibitory effect of the river water. Salinity was too high to be considered detrimental to algal growth. The cause of this inhibition is not known.

Individual parcels of Duwamish water were shown by the results of chlorophyll and oxygen analyses from the plume stations, indicating tidal control of plume dynamics in Elliott Bay, as has been implied by other investigators.

1.4 Intertidal/Shallow Subtidal Ecology

Four major study sites were examined, having ecologically important shoreline areas including sand flats, cobble fields and eelgrass meadows. The areas were: Magnolia Bluff, from West Point to Four Mile Rock; Alki Beach, from Duwamish Head to the south side of Alki Point; Rockaway Beach, Bainbridge Island; and Seahurst Park. The latter two areas were control sites.

Core samples were taken at each site and analyzed for small infauna, grain size, volatile solids, BOD, total organic carbon and nitrogen.

Water chemistry samples were also taken at each site and analyzed for temperature, salinity, dissolved nutrients and oxygen.

At each site, samples were collected by appropriate method, to evaluate populations and/or the production of epibenthic zooplankton, periphyton, sediment microalgae, eelgrass and bivalves. Sampling occurred once in July, and again in August.

Water chemistry and sediment parameter data indicated a strong influence of the Duwamish River on the Elliott Bay nearshore environment, particularly along the eastern and northern shorelines. Although not as pronounced, sediment parameters along Alki Beach demonstrated some riverine influence. Finer particles were generally found at Duwamish Head than at sites further west.

Water chemistry values were also influenced by primary producers. Higher levels of dissolved oxygen and decreased inorganic nutrient concentrations indicated higher levels of benthic autotrophic production along the northern beach.

Storm drains and combined sewer overflows (CSO's) caused minor discontinuities in the eelgrass meadows along the southern shore. CSO's may also influence the intertidal sediments and biota at Magnolia Bluff, where pockets of relatively fine sediments, having a reducing layer close to the surface, were noted.

The inner (eastern) portion of Elliott Bay is highly modified. It contains steeply sloping riprap shorelines and piers on pilings. Only a small fraction (2%) of the original tideflat/wetland habitat area of the Duwamish River remains. Relatively unchanged are the habitats along Magnolia Bluff and Alki Beach. Magnolia Bluff is comprised of a gently sloping cobble/boulder habitat containing recreationally important shellfish stocks. The region at the south-end (from 32nd Street to Smith Cove) of Magnolia Bluff contains a dense shallow subtidal kelp bed. In general, benthic macroalgae were abundant on Magnolia Bluff beaches. The region from Duwamish Head to Alki Point is sand with a continuous band of eelgrass in the shallow subtidal zone. Kelp beds and eelgrass meadows are important components of the nearshore ecosystem as primary producers and as structural entities. Fish and motile invertebrates are common in these habitats.

Primary areas of deposition, based on sediment characteristics and the presence of depositional indicators (e.g., drift algae) occur at Smith Cove and in the area at the western end of Alki Beach (i.e., near transect Alki West). Secondary (i.e., smaller) depositional areas, indicated by pockets of fine sediments and a shallow reduced layer, occur at the immediate west side of Duwamish Head just seaward of the boulder wall, and in isolated areas along Magnolia Bluff. These are areas of high organic enrichment, and, as such should be monitored following outfall construction.

1.5 Subtidal Ecology

One hundred and twenty-three biological samples were examined from eighty-three stations in and surrounding the proposed Renton sewage discharge site in Elliott Bay. Each of these stations were characterized by conventional sediment measures (biochemical oxygen demand, % volatile solids, organic carbon, organic nitrogen, oil and grease, and sediment grain size). The community structure information and conventional sediment parameters were compared to information obtained during the Seahurst Baseline Study. Regions at comparable depths in Elliott Bay with greater concentrations of conventional organics and more or less than the expected numbers of species and individuals were identified during this process.

There is a region in the outer part of Elliott Bay at water depths of 350-450 feet that had elevated levels of conventional organic components and decreased numbers of individuals and species. This observation was in contrast with generally accepted models which indicate that increased quantities of organic materials in the sediments are generally accompanied by increases in the abundance of organisms. At present, an adequate explanation is not available for the different condition observed off Duwamish Head.

Analyses performed during the Seahurst Baseline Study were continued in order to help explain the types of chemical measurements that were associated with particular types of infaunal benthic communities. Cluster analysis of major taxonomic groups (mollusca, arthropoda, and annelida) provided information concerning those species responsible for the groupings, and the chemicals associated with those groupings. Communities dominated by certain taxa were dominant in Elliott Bay, in regions with comparable conventional chemical concentrations.

1.6 Fish Ecology

A total of 55 species of fishes were caught in Elliott Bay during the summer of 1984. Fish abundance, groupings, and species diversity showed that each of the nearshore sample sites were different. The offshore sample sites, however, were similar at each depth. A comparison of nearshore and offshore catches showed that species diversity was highest at 50 m and 100 m depths while species richness was highest in the nearshore area. Numerical analysis of species at all sample sites combined revealed that nearshore fish assemblages differed with site and offshore fish assemblages differed with depth. Presence of fin erosion, skin tumors and the bloodworm Philometra were used to monitor general fish health. Incidences of fin erosion and skin tumors were very low and similar to previous studies. Incidences of Philometra were higher than previously found in nearby areas.

1.7 Fish Health

Demersal and pelagic fish were collected during July, 1984 from two sites within Elliott Bay. Each was examined for length, weight, the presence of external lesions and the presence of internal pathological defects. During the study 193 fish were examined. A variety of pathological conditions were noted ranging from minor parasitic infestations to liver cell neoplasms. Outer Elliott Bay appears to be a somewhat transitional area with more serious disease conditions being noted than were seen in the Seahurst area, but fewer than in the heavily contaminated portions of Commencement Bay.

1.8 Marine Chemistry - Sediment Cores

Four Kasten cores were collected in the Elliott Bay area; three from the area surrounding the proposed outfall and one from inner Elliott Bay. Lead-210 dating, trace metal concentrations and other sediment parameters, including grain size, sulfide, carbon and nitrogen content, percent volatile solids and dry/wet weight ratios, were measured throughout the length of each core.

Cores from the proposed outfall area were anaerobic throughout their length and showed signs of surface sediment disturbance and mixing. Sedimentation rates, based on Pb-210 dating, were 1.3, 1.8 and 2.0 cm/yr for the three cores. The depth of the Cs-137 fallout peak (1960-1963) was deeper than expected.

The core from inner Elliott Bay showed substantial disturbance of the surface sediments, and a sedimentation rate of 1.4 cm/yr.

Other sediment parameters showed that the sediment from all four cores was largely clay-sized material with high concentrations of organic carbon and sulfide.

1.9 Marine Toxicology

Baseline acute toxicity of Elliott Bay water from three to five depths at six sampling stations was measured with sand dollar sperm and embryo bioassays. A low background toxicity was found for the week of July 23, 1984. Other (weekly) samples were not analyzed due to the early termination of these studies.

The toxicity of five stages of Renton sewage to sand dollar sperm and embryos was similar to those test results obtained during 1982 and 1983 in the Seahurst Baseline Study. The primary goal of this testing was the cross calibration of the sensitivity of sand dollar embryo to oyster embryo bioassays. This goal was not realized due to the poor quality oyster gametes available for these tests in this study.

The relative acute sediment toxicity at 34 stations in Elliott Bay was most successfully differentiated by liquid phase elutriate bioassays using sand dollar embryos. The sand dollar embryo responses were significantly correlated with overall (summed) organic priority pollutant contamination of the sediments. Areas having a high proportion of toxic sediments included: southern Elliott Bay/Duwamish River mouth, the Four Mile Rock dredge disposal area, and stations to the northeast of Duwamish Head. There appeared to be a spatial trend in sediment toxicity in the area of the proposed outfall, such that stations closer to Duwamish Head (about 400 ft. deep) were more toxic while stations farther west tended to be less toxic.

Solid phase sediment bioassays using amphipods were unable to distinguish sediment toxicity from grain size effects for most sites, when compared to a trial "clean" fine-grained control sediment. If all sediments, regardless of grain size, were compared against the native sand control, over half showed significantly reduced survival and were considered "toxic." Nearly all previous studies have employed the latter approach. The importance of appropriate controls and the need to interpret all solid phase sediment bioassays with caution were discussed.

2.0 Physical/Chemical Oceanography

C. Ebbesmeyer and C. A. Coomes

2.1 Introduction

The location for the Renton effluent transfer system (ETS) outfall diffuser will be off Duwamish Head and discharging effluent into outer Elliott Bay (Figure 2.1). The purposes for studying pre-discharge conditions in the Elliott Bay area are to provide data to monitor post-discharge conditions and determine the success of the outfall placement; assess changes due to the relocation of the discharge, from the Duwamish River entering inner Elliott Bay near the surface to the new diffuser site at a greater depth in outer Elliott Bay. This chapter documents the CTD profiles obtained during 16 July through 24 September 1984.

2.2 Methods

The profiles were obtained at four stations located in and around Elliott Bay (Figure 2.1). Table 2.1 lists the average position and bottom depth for each station.

The stations were occupied at different frequencies. Table 2.2 shows the dates on which CTD profiles were obtained. Stations 21, 22, and 23 were sampled each week, and usually two casts were taken per sample date. Station 24 was sampled only three times.

Collection and calibration of the data were accomplished using the following sequence of procedures. First, values measured by the CTD probes were recorded aboard the R/V Liberty using a microcomputer (Super Brain). On

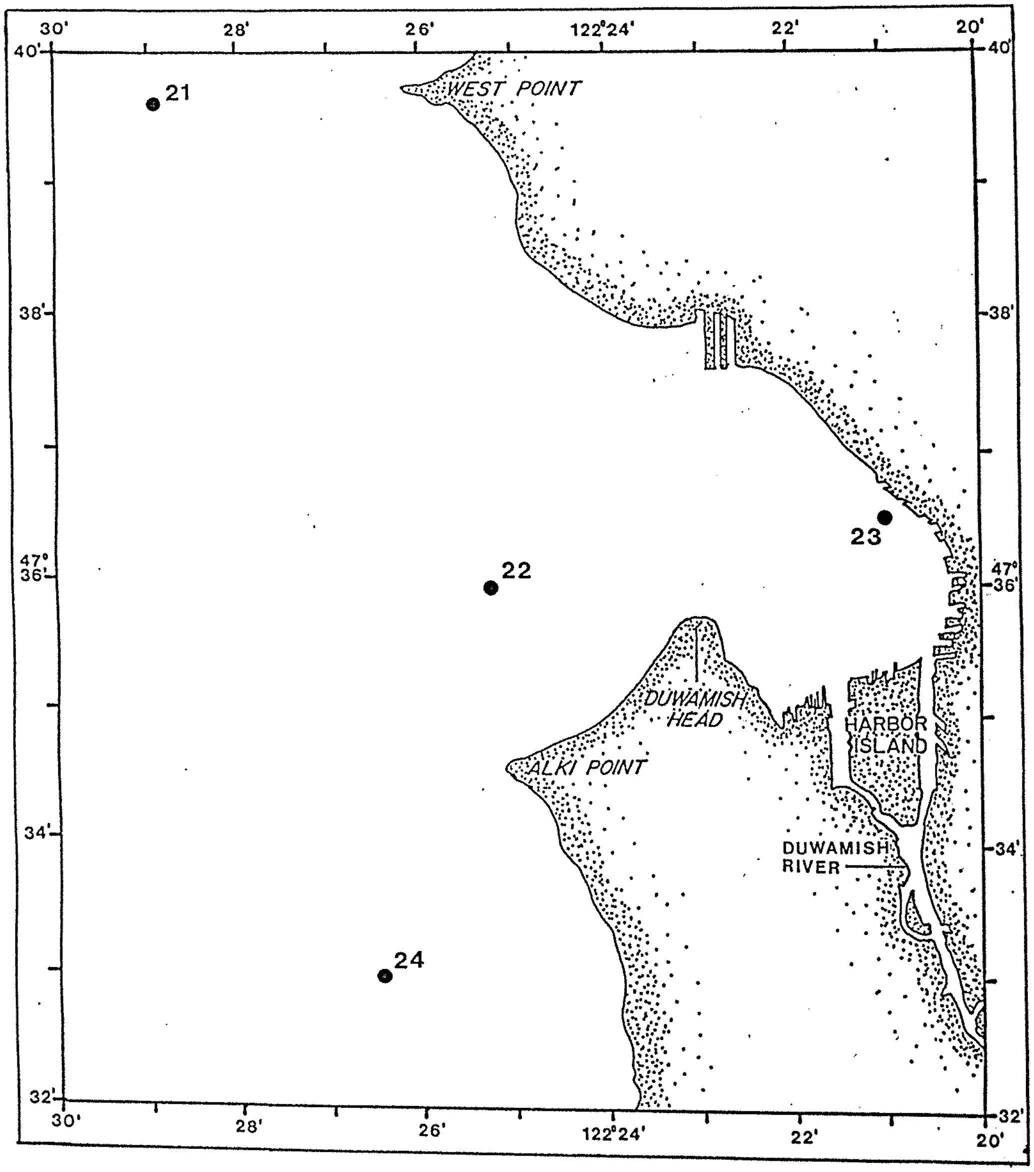


Figure 2.1. Approximate locations of the CTD sampling stations.

Table 2.1. Approximate locations and bottom depth of CTD profile stations.

Station No.	Latitude (°N)	Longitude (°W)	Bottom depth (m)
21	47° 39.60'	122° 28.80'	220
22	47° 35.84'	122° 25.25'	200
23	47° 36.52'	122° 21.03'	75
24	47° 32.95'	122° 26.45'	200

Table 2.2. Dates of CTD profiles.

	STATION						
Date	21 a	21 b	22 a	22 b	23 a	23 b	24
16 July 1984	x	x	x	x	x	x	
23 July 1984	x	x	x	x	x	x	x
30 July 1984	x	x	x	x	x	x	
6 August 1984	x		x	x	x	x	
13 August 1984	x		x	x	x	x	x
20 August 1984		x	x	x	x	x	
17 September 1984	x	x	x	x	x	x	x
24 September 1984	x	x	x	x	x	x	

each CTD cast independent check value samples were obtained using reversing thermometers mounted on Niskin bottles. A check value of temperature was obtained near the bottom of each cast. Water samples were collected near the bottom of each cast and at approximately 20 m depth to obtain check values of salinity and dissolved oxygen.

Second, the CTD profiles were plotted on a computer. The plots were reviewed and spurious values, occurring as spikes, were deleted. The remaining data were averaged within 0.5 m depth intervals.

Finally, the 0.5 m averages were compared with the check values. The check values of salinity were processed by the Department of Oceanography and the check values of dissolved oxygen were processed by the Fisheries Research Institute, both at the University of Washington. The comparisons yield differences of CTD minus check value for temperature and salinity. The mean and standard deviation of the temperature and salinity differences were computed for each sampling interval (Table 2.3). The mean differences of temperature and salinity did not show a significant dependency on depth and were used to offset the CTD profiles.

The oxygen probe malfunctioned throughout the majority of the sampling interval yielding unreliable oxygen data. Therefore, these data have not been presented here.

2.3 Results

Appendix 2.A lists the data at standard depths for temperature, salinity, and density. Appendix 2.B contains vertical profiles of the data. In these profiles the data have been averaged for a given date.

Inspection of these profiles reveals certain characteristics of the water column. The profiles of salinity and density for station 23 shows evidence of

Table 2.3. Calibrations used to adjust the CTD profiles. N denotes sample size.

	TEMPERATURE			SALINITY		
Date	Mean	Standard deviation	N	Mean	Standard deviation	N
16 July 1984	-.355	.0345	10	.447	.0222	8
23 July 1984	-.366	.0455	14	.444	.0291	12
30 July 1984	-.265	.0387	8	.469	.0173	8
6 August 1984	-.286	.0399	6	.467	.0179	10
13 August 1984	-.370	.0329	6	.379	.0306	8
20 August 1984	-.307	.0390	10	.450	.0235	12
17 September 1984	-.196	.0329	10	.032	.0296	11
24 September 1984	-2.39	.0475	10	.061	.0168	10

the Duwamish River plume. This plume remains in approximately the upper five meters of the water column (see data Appendix 2.A). A second feature is how closely the water properties of the three outer stations (21, 22, and 24) follow one another.

APPENDIX 2.A

Reduced set of the calibrated CTD data. The tables are organized chronologically by station number with separate tables for temperature (°C), salinity (^{o}/oo), and density (sigma-t units).

STATION 21A, 21B Temperature (°C)

	Date												
	16-Jul-84	16-Jul-84	23-Jul-84	23-Jul-84	30-Jul-84	30-Jul-84	06-Aug-84	13-Aug-84	20-Aug-84	17-Sep-84	17-Sep-84	24-Sep-84	24-Sep-84
Depth (m)	A	B	A	B	A	B	A	A	B	A	B	A	B
0.5	13.237	13.487	14.377	15.894	13.287	13.934	13.161	13.209	14.453	13.055	13.533	12.771	13.205
2	13.199	13.456	14.383	14.795	13.228	13.894	13.203	13.125	14.325	13.116	13.186	12.784	13.020
5	13.000	13.282	14.419	14.192	13.198	13.772	12.795	12.995	13.802	13.045	12.883	12.811	12.890
10	12.593	12.792	14.271	13.273	13.126	13.514	12.680	12.971	13.257	12.937	12.710	12.718	12.768
20	12.050	12.364	12.766	12.256	12.678	12.910	12.480	12.791	12.883	12.833	12.597	12.512	12.607
30	11.832	11.708	11.976	12.107	12.648	12.547	12.345	12.710	12.524	12.555	12.377	12.443	12.454
40	11.383	11.492	11.477	11.488	11.942	12.196	12.304	12.350	12.264	12.224	12.244	12.134	12.359
50	11.214	11.177	11.009	11.382	11.720	11.861	11.690	11.818	12.059	12.118	12.147	12.000	12.209
60	11.125	11.004	10.954	11.057	11.459	11.427	11.630	11.684	11.904	12.056	12.052	11.986	12.028
70	11.044	10.927	10.947	10.929	11.100	11.352	11.631	11.617	11.801	11.926	11.917	11.967	11.897
80	10.891	10.906	10.874	10.859	11.096	11.186	11.482	11.538	11.757	11.899	11.828	11.921	11.812
90	10.827	10.853	10.880	10.845	11.049	11.082	11.401	11.590	11.765	11.897	11.792	11.825	11.780
100	10.795	10.821	10.856	10.887	11.026	11.046	11.344	11.573	11.803	11.884	11.773	11.758	11.774
110	10.769	10.804	10.851	10.919	10.984	11.011	11.329	11.579	11.801	11.863	11.760	11.733	11.769
120	10.760	10.787	10.860	10.929	10.969	11.006	11.294	11.577	11.734	11.810	11.746	11.722	11.757
130	10.730	10.753	10.869	10.907	10.973	10.961	11.266	11.573	11.703	11.803	11.715	11.699	11.733
140	10.714	10.755	10.920	10.833	10.972	10.957	11.204	11.444	11.724	11.800	11.699	11.673	11.724
150	10.688	10.744	10.952	10.833	10.975	10.958	11.164	11.507	11.729	11.788	11.682	11.635	11.709
160	10.682	10.716	10.986	10.839	10.962	10.951	11.054	11.537	11.708	11.783	11.656	11.618	11.668
170	10.676	10.716	10.984	10.856	10.938	10.952	11.059	11.523	11.688	11.752	11.657	11.556	11.644
180	10.663	10.710	10.989	10.914	10.942	10.948	11.056	11.522	11.667	11.733	11.647	11.482	11.623
190	10.656	10.707	10.989	10.931	10.937	10.947	11.046	11.523	11.659	11.713	11.620	11.422	11.595
200		10.696	10.966	10.943	10.931	10.955	11.029	11.514	11.635	11.685	11.623	11.394	11.426

STATION 21A, 21B Salinity (°/oo)

	Date												
	16-Jul-84	16-Jul-84	23-Jul-84	23-Jul-84	30-Jul-84	30-Jul-84	06-Aug-84	13-Aug-84	20-Aug-84	17-Sep-84	17-Sep-84	24-Sep-84	24-Sep-84
Depth (m)	A	B	A	B	A	B	A	A	B	A	B	A	B
0.5	28.611	28.772	27.721	27.715	28.629	28.753	29.304	29.206	29.214	29.757	29.932	29.980	29.876
2	28.665	28.783	27.827	27.972	29.081	28.768	29.295	29.269	21.827	29.640	29.933	29.974	29.924
5	28.691	28.820	28.144	28.300	29.083	28.943	29.342	29.370	29.429	29.720	29.972	29.982	29.974
10	28.843	28.903	28.278	28.834	29.090	29.073	29.353	29.384	29.544	29.853	29.977	30.051	30.030
20	29.060	28.991	29.059	29.171	29.208	29.204	29.371	29.415	29.611	29.893	30.008	30.131	30.072
30	29.132	29.168	29.246	29.200	29.211	29.274	29.417	29.441	29.677	30.027	30.095	30.156	30.136
40	29.296	29.267	29.441	29.453	29.432	29.353	29.439	29.516	29.767	30.150	30.145	30.294	30.175
50	29.382	29.421	29.657	29.479	29.490	29.423	29.655	29.732	29.848	30.193	30.190	30.351	30.221
60	29.459	29.556	29.741	29.675	29.587	29.583	29.760	29.782	29.948	30.222	30.241	30.355	30.310
70	29.500	29.655	29.740	29.791	29.774	29.613	29.762	29.822	30.127	30.310	30.326	30.363	30.386
80	29.666	29.688	29.816	29.856	29.856	29.722	29.857	29.882	30.156	30.333	30.387	30.393	30.425
90	29.739	29.739	29.857	29.871	29.849	29.817	29.876	29.955	30.187	30.333	30.414	30.440	30.450
100	29.781	29.793	29.883	29.900	29.863	29.899	29.918	30.018	30.210	30.340	30.424	30.482	30.452
110	29.835	29.826	29.896	29.928	29.903	29.930	29.930	30.024	30.258	30.358	30.430	30.490	30.454
120	29.864	29.846	29.924	29.946	29.944	29.951	29.956	30.037	30.261	30.397	30.448	30.503	30.470
130	29.898	29.882	29.934	29.954	29.995	29.992	29.972	30.030	30.286	30.400	30.470	30.529	30.494
140	29.910	29.900	29.982	29.976	30.031	30.045	29.983	30.050	30.347	30.405	30.482	30.548	30.501
150	29.940	29.904	30.029	29.970	30.061	30.044	29.994	30.093	30.371	30.410	30.496	30.579	30.511
160	29.954	29.926	30.049	29.996	30.092	30.049	30.006	30.113	30.414	30.419	30.510	30.593	30.547
170	29.964	29.946	30.069	30.030	30.157	30.055	30.023	30.130	30.462	30.438	30.515	30.642	30.564
180	29.979	29.952	30.081	30.078	30.158	30.071	30.027	30.158	30.492	30.459	30.524	30.699	30.588
190	29.993	29.959	30.097	30.134	30.170	30.088	30.033	30.195	30.509	30.471	30.541	30.750	30.599
200		29.966	30.149	30.169	30.175	30.105	30.046	30.241	30.535	30.491	30.539	30.774	30.743

STATION 21A, 21B Density (sigma-t units)

Date

Depth (m)	16-Jul-84	16-Jul-84	23-Jul-84	23-Jul-84	30-Jul-84	30-Jul-84	06-Aug-84	13-Aug-84	20-Aug-84	17-Sep-84	17-Sep-84	24-Sep-84	24-Sep-84
	A	B	A	B	A	B	A	A	B	A	B	A	B
0.5	21.436	21.512	20.530	20.211	21.441	21.410	21.985	21.900	21.660	22.354	22.396	22.580	22.417
2	21.485	21.527	20.610	20.638	21.800	21.430	21.970	21.964	21.827	22.252	22.464	22.573	22.489
5	21.543	21.589	20.846	21.011	21.807	21.588	21.083	22.067	21.956	22.327	22.552	22.574	22.552
10	21.736	21.745	20.978	21.601	21.826	21.739	22.113	22.082	22.151	22.450	22.589	22.644	22.619
20	22.002	21.892	21.870	22.051	22.002	21.955	22.164	22.140	22.274	22.501	22.634	22.745	22.681
30	22.097	22.147	22.159	22.100	22.010	22.077	22.225	22.175	22.392	22.656	22.742	22.777	22.759
40	22.303	22.261	22.398	22.406	22.309	22.202	22.249	22.300	22.510	22.813	22.805	22.940	22.807
50	22.398	22.435	22.646	22.444	22.394	22.317	22.527	22.563	22.610	22.865	22.858	22.009	22.870
60	22.473	22.569	22.721	22.652	22.515	22.517	22.618	22.626	22.715	22.899	22.914	23.015	22.972
70	22.519	22.659	22.721	22.764	22.722	22.553	22.620	22.669	22.872	22.991	23.005	23.024	23.055
80	22.673	22.688	22.793	22.826	22.786	22.666	22.719	22.729	22.902	23.013	23.068	23.056	23.000
90	22.741	22.736	22.823	22.840	22.788	22.758	22.748	22.776	22.925	23.014	23.095	23.109	23.125
100	22.779	22.784	22.848	22.855	22.800	22.828	22.791	22.828	22.936	23.021	23.106	23.154	23.128
110	22.825	22.812	22.858	22.872	22.841	22.858	22.803	22.832	22.973	23.039	23.113	23.165	23.130
120	22.849	22.831	22.879	22.884	22.876	22.875	22.829	22.842	22.987	23.079	23.130	23.177	23.145
130	22.880	22.864	22.885	22.894	22.914	22.914	22.846	22.837	23.012	23.083	23.152	23.201	23.168
140	22.892	22.878	22.913	22.924	22.943	22.956	22.865	22.876	23.056	23.087	23.165	23.220	23.175
150	22.920	22.883	22.944	22.919	22.965	22.955	22.881	22.898	23.073	23.093	23.178	23.251	23.185
160	22.932	22.904	22.954	22.938	22.992	22.960	22.909	22.908	23.110	23.101	23.194	23.265	23.220
170	22.941	22.920	22.970	22.962	23.037	22.965	22.921	22.924	23.151	23.121	23.198	23.314	23.238
180	22.954	22.926	22.978	22.989	23.046	22.978	22.925	22.945	23.178	23.141	23.206	23.371	23.260
190	22.966	22.932	22.991	23.029	23.056	22.991	22.931	22.974	23.193	23.154	23.224	23.421	23.274
200		22.939	23.035	23.054	23.061	23.003	22.944	23.011	23.217	23.174	23.222	23.445	23.415

STATION 22A, 22B Temperature (°C)

Date

	16-Jul-84	16-Jul-84	23-Jul-84	23-Jul-84	30-Jul-84	30-Jul-84	06-Aug-84	06-Aug-84	13-Aug-84	13-Aug-84	20-Aug-84	20-Aug-84	17-Sep-84	17-Sep-84	24-Sep-84	24-Sep-84
Depth (m)	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
0.5	13.061	13.457	14.762	15.853	13.887	13.505	12.995	13.227	13.163	12.984	13.328	13.707	13.285	13.677	12.708	12.804
2	12.943	13.059	14.519	15.239	13.455	13.356	13.020	13.314	13.122	13.001	13.265	13.468	13.242	13.673	12.710	12.791
5	12.863	12.897	14.455	14.767	13.009	13.263	12.969	13.085	13.049	12.767	13.145	13.108	12.966	13.299	12.692	12.704
10	12.475	12.354	14.043	14.294	12.667	13.267	12.810	12.811	13.011	12.715	12.964	12.716	12.783	12.985	12.672	12.661
20	12.163	12.091	12.847	12.374	12.414	12.705	12.528	12.476	12.921	12.629	12.666	12.502	12.662	12.901	12.643	12.624
30	11.818	12.080	12.460	11.925	12.370	12.416	12.292	12.313	12.796	12.546	12.482	12.337	12.579	12.573	12.594	12.597
40	11.748	11.984	11.977	11.451	12.357	12.364	11.972	12.140	12.760	12.404	12.269	12.239	12.438	12.454	12.506	12.562
50	11.692	11.744	11.224	11.209	12.063	12.308	11.853	11.791	12.272	12.221	11.925	12.176	12.210	12.320	12.464	12.560
60	11.415	11.360	11.033	11.045	11.389	12.095	11.674	11.627	11.696	11.845	11.815	11.896	12.053	12.200	12.443	12.423
70	11.172	10.910	10.943	10.855	11.234	11.405	11.567	11.386	11.535	11.733	11.724	11.729	11.915	11.957	12.174	12.074
80	10.937	10.869	10.839	10.785	11.056	11.265	11.412	11.306	11.530	11.484	11.683	11.705	11.859	11.941	11.822	11.927
90	10.867	10.803	10.813	10.735	10.998	11.002	11.266	11.226	11.465	11.437	11.649	11.588	11.827	11.908	11.726	11.812
100	10.782	10.774	10.787	10.712	10.870	10.969	11.154	11.150	11.442	11.398	11.616	11.623	11.808	11.893	11.719	11.794
110	10.772	10.712	10.729	10.708	10.894	10.915	11.080	10.996	11.400	11.397	11.613	11.609	11.772	11.845	11.719	11.774
120	10.716	10.703	10.742	10.735	10.903	10.906	10.996	10.988	11.437	11.380	11.610	11.595	11.757	11.806	11.693	11.737
130	10.704	10.681	10.773	10.811	10.897	10.907	11.011	11.014	11.465	11.460	11.601	11.607	11.715	11.779	11.611	11.662
140	10.698	10.678	10.805	10.843	10.899	10.910	10.980	10.985	11.448	11.389			11.705	11.751	11.580	11.573
150	10.692	10.654	10.817	10.834	10.905	10.914	10.948	10.957	11.460	11.408			11.698	11.725	11.482	11.566
160	10.670	10.636	10.827	10.845	10.898	10.917	10.946	10.941	11.410	11.435			11.692	11.712	11.455	11.507
170	10.644	10.626	10.860	10.903	10.896	10.918	10.938	10.908	11.359	11.430			11.681	11.707	11.447	11.440
180	10.613	10.627	10.904	10.948	10.897		10.937	10.897	11.390				11.674	11.691	11.421	11.438
190	10.620															
200	10.628															

STATION 22A, 22B Salinity (°/oo)

	Date															
	16-Jul-84	16-Jul-84	23-Jul-84	23-Jul-84	30-Jul-84	30-Jul-84	06-Aug-84	06-Aug-84	13-Aug-84	13-Aug-84	20-Aug-84	20-Aug-84	17-Sep-84	17-Sep-84	24-Sep-84	24-Sep-84
Depth (m)	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
0.5	28.708	28.682	28.582	28.560	28.625	29.134	29.339	29.320	29.378	29.419	29.393	29.516	29.949	29.923	30.033	30.033
2	28.767	28.778	28.632	28.541	28.991	29.156	29.338	29.319	29.376	29.424	29.434	29.542	29.915	29.854	30.027	30.036
5	28.817	28.886	28.663	28.586	29.225	29.165	29.345	29.339	29.389	29.430	29.630	29.648	29.973	29.912	30.035	30.047
10	28.956	28.985	28.733	28.662	29.282	29.167	29.354	29.364	29.395	29.438	29.648	29.691	29.982	29.934	30.044	30.056
20	29.038	29.066	29.110	29.188	29.322	29.238	29.387	29.399	29.408	29.450	29.683	29.713	30.005	29.945	30.064	30.067
30	29.149	29.096	29.173	29.302	29.326	29.295	29.449	29.442	29.433	29.469	29.708	29.757	30.007	30.004	30.093	30.076
40	29.171	29.112	29.322	29.468	29.326	29.301	29.547	29.480	29.445	29.525	29.763	29.787	30.065	30.057	30.125	30.092
50	29.178	29.177	29.602	29.592	29.418	29.324	29.608	29.605	29.567	29.590	29.943	29.811	30.167	30.108	30.135	30.096
60	29.309	29.366	29.676	29.656	29.681	29.405	29.662	29.657	29.728	29.745	30.008	29.962	30.243	30.167	30.151	30.159
70	29.424	29.623	29.706	29.748	29.751	29.663	29.692	29.795	29.829	29.782	30.073	30.053	30.298	30.292	30.266	30.314
80	29.617	29.688	29.793	29.813	29.836	29.724	29.791	29.895	29.850	29.902	30.110	30.072	30.362	30.293	30.446	30.381
90	29.684	29.782	29.806	29.880	29.857	29.872	29.894	29.912	29.936	29.936	30.152	30.143	30.394	30.323	30.503	30.441
100	29.780	29.824	29.823	29.901	29.917	29.906	29.933	29.912	29.973	29.983	30.219	30.183	30.405	30.333	30.498	30.452
110	29.787	29.842	29.885	29.922	29.992	30.011	29.961	29.958	29.984	29.987	30.247	30.226	30.413	30.361	30.500	30.464
120	29.831	29.899	29.915	29.946	30.005	30.037	30.005	30.003	30.037	30.019	30.271	30.253	30.440	30.391	30.517	30.487
130	29.823	29.909	29.958	29.986	30.018	30.073	30.038	30.018	30.071	30.087	30.284	30.285	30.472	30.406	30.572	30.547
140	29.867	29.911	29.987	30.016	30.011	30.064	30.034	30.022	30.105	30.127			30.475	30.428	30.603	30.612
150	29.893	29.887	30.005	30.023	30.036	30.110	30.041	30.024	30.126	30.143			30.483	30.451	30.688	30.614
160	29.907	29.939	30.025	30.038	30.065	30.123	30.040	30.030	30.137	30.161			30.489	30.464	30.713	30.666
170	29.904	29.955	30.043	30.088	30.075	30.147	30.040	30.021	30.159	30.174			30.498	30.469	30.713	30.723
180	29.927	29.951	30.085	30.131	30.080		30.035	30.020	30.185				30.509	30.482	30.735	30.722
190	29.938															
200	29.936															

STATION 22A, 22B Density (sigma-t units)

	Date															
	16-Jul-84	16-Jul-84	23-Jul-84	23-Jul-84	30-Jul-84	30-Jul-84	06-Aug-84	06-Aug-84	13-Aug-84	13-Aug-84	20-Aug-84	20-Aug-84	17-Sep-84	17-Sep-84	24-Sep-84	24-Sep-84
Depth (m)	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
0.5	21.545	21.449	21.112	20.865	21.321	21.787	22.043	21.984	22.041	22.107	22.021	22.042	22.457	22.361	22.632	22.614
2	21.612	21.599	21.200	20.982	21.687	21.833	22.038	21.967	22.047	22.126	22.065	22.108	22.440	22.308	22.627	22.619
5	21.666	21.713	21.237	21.114	21.953	21.858	22.053	22.026	22.071	22.156	22.239	22.260	22.537	22.426	22.637	22.644
10	21.845	21.889	21.373	21.269	22.061	21.859	22.090	22.097	22.086	22.172	22.287	22.367	22.579	22.504	22.648	22.659
20	21.965	22.000	21.895	22.042	22.139	22.020	22.168	22.187	22.110	22.197	22.370	22.424	22.619	22.528	22.669	22.674
30	22.113	22.025	22.015	22.212	22.150	22.117	22.259	22.250	22.153	22.228	22.424	22.488	22.637	22.635	22.700	22.686
40	22.142	22.054	22.218	22.424	22.152	22.132	22.393	22.311	22.169	22.297	22.506	22.530	22.708	22.698	22.741	22.705
50	22.157	22.147	22.567	22.562	22.277	22.160	22.461	22.470	22.354	22.381	22.707	22.560	22.828	22.763	22.757	22.709
60	22.307	22.361	22.657	22.640	22.600	22.261	22.535	22.539	22.582	22.569	22.777	22.727	22.916	22.830	22.773	22.783
70	22.438	22.637	22.696	22.743	22.681	22.583	22.577	22.688	22.689	22.617	22.844	22.827	22.983	22.971	22.912	22.967
80	22.628	22.694	22.781	22.805	22.777	22.654	22.681	22.780	22.706	22.754	22.880	22.846	23.043	22.975	23.115	23.045
90	22.691	22.778	22.795	22.866	22.803	22.814	22.786	22.807	22.784	22.789	22.918	22.922	23.074	23.004	23.176	23.113
100	22.780	22.816	22.813	22.886	22.872	22.846	22.835	22.820	22.816	22.832	22.976	22.947	23.085	23.014	23.173	23.124
110	22.787	22.840	22.870	22.903	22.926	22.937	22.870	22.882	22.832	22.835	22.998	22.983	23.098	23.045	23.175	23.137
120	22.831	22.886	22.892	22.917	22.934	22.958	22.918	22.918	22.867	22.863	23.017	23.006	23.122	23.075	23.193	23.162
130	22.827	22.897	22.920	22.935	22.945	22.986	22.941	22.925	22.888	22.921	23.029	23.029	23.154	23.091	23.250	23.222
140	22.862	22.899	22.937	22.953	22.939	22.979	22.944	22.933	22.917	22.947			23.158	23.114	23.279	23.288
150	22.883	22.885	22.949	22.960	22.958	23.014	22.954	22.940	22.932	22.954			23.166	23.136	23.363	23.291
160	22.897	22.928	22.963	22.970	22.982	23.023	22.954	22.947	22.949	22.963			23.171	23.148	23.387	23.341
170	22.899	22.942	22.971	22.998	22.990	23.042	22.955	22.946	22.975	22.974			23.180	23.153	23.388	23.397
180	22.922	22.939	22.996	23.024	22.993		22.952	22.947	22.990				23.190	23.166	23.410	23.397
190	22.930															
200	22.927															

STATION 23A, 23B   Temperature (°C)

Date

	16-Jul-84	16-Jul-84	23-Jul-84	23-Jul-84	30-Jul-84	30-Jul-84	06-Aug-84	06-Aug-84	13-Aug-84	13-Aug-84	20-Aug-84	20-Aug-84	17-Sep-84	17-Sep-84	24-Sep-84	24-Sep-84
Depth (m)	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
0.5	13.670	14.352	14.268	14.194	13.910	14.367	13.581	13.647	13.532	13.686	14.184	14.321	13.967	13.740	12.875	13.095
2	12.655	13.290	13.870	13.723	13.136	13.816	13.586	13.590	13.445	13.458	13.993	14.180	13.879	13.339	12.871	13.068
5	12.335	12.561	13.553	13.433	12.870	13.169	12.835	12.937	13.194	13.272	13.652	13.293	13.339	13.299	12.972	12.968
10	11.900	11.976	13.249	13.014	12.487	12.749	12.926	12.795	12.799	12.858	12.941	12.980	12.910	12.928	12.888	12.858
20	11.773	11.694	12.388	12.101	12.132	12.233	12.478	12.479	12.395	12.454	12.435	12.443	12.609	12.640	12.553	12.565
30	11.643	11.666	11.931	11.917	11.885	11.896	12.288	12.329	12.049	12.123	12.255	12.267	12.515	12.532	12.387	12.365
40	11.413	11.433	11.833	11.823	11.559	11.703	12.241	12.250	11.847	11.820	12.182	12.194	12.435	12.433	12.288	12.141
50	11.270	11.199	11.769	11.455	11.251	11.473	12.062	12.148	11.694	11.540	12.036	12.067	12.195	12.172	12.016	12.055
60	10.895	10.790	11.446	11.285	11.073	11.273	11.948	11.960	11.458	11.471	11.700	11.765	11.905	11.877	11.909	11.956
70	10.665	10.663	11.069	11.087	10.914	11.182	11.801	11.729	11.242	11.204	11.576	11.754	11.803	11.790	11.844	11.871
								11.612					11.769	11.745		

STATION 23A, 23B Salinity (°/oo)

Depth (m)	Date 16-Jul-84	16-Jul-84	23-Jul-84	23-Jul-84	30-Jul-84	30-Jul-84	06-Aug-84	06-Aug-84	13-Aug-84	13-Aug-84	20-Aug-84	20-Aug-84	17-Sep-84	17-Sep-84	24-Sep-84	24-Sep-84
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
0.5	26.618	26.024	27.463	27.953	28.421	28.297	26.971	26.961	28.222	27.964	28.318	28.513	28.520	28.845	28.832	28.686
2	28.336	27.440	28.398	28.345	28.883	28.598	27.248	27.394	28.273	28.367	28.509	28.650	28.582	29.543	28.830	28.736
5	28.783	28.526	28.691	28.686	29.054	28.899	28.858	28.825	28.998	28.730	29.174	29.350	29.762	29.791	29.737	29.661
10	28.987	29.003	28.841	28.906	29.218	29.099	29.119	29.176	29.389	29.372	29.490	29.471	29.903	29.924	29.968	29.968
20	29.076	29.056	29.040	29.117	29.236	29.221	29.301	29.294	29.443	29.419	29.643	29.625	29.951	29.967	30.074	30.061
30	29.111	29.114	29.147	29.135	29.360	29.333	29.338	29.331	29.506	29.484	29.710	29.676	30.003	30.012	30.107	30.108
40	29.204	29.201	29.166	29.160	29.470	29.405	29.362	29.358	29.582	29.586	29.750	29.732	30.051	30.056	30.145	30.197
50	29.252	29.294	29.208	29.271	29.614	29.533	29.421	29.406	29.650	29.720	29.772	29.763	30.123	30.138	30.257	30.230
60	29.501	29.587	29.336	29.388	29.719	29.592	29.449	29.450	29.774	29.763	29.880	29.840	30.245	30.262	30.303	30.278
70	29.715	29.725	29.502	29.487	29.838	29.653	29.489	29.510	29.920	29.958	29.942	29.840	30.323	30.343	30.344	30.331

STATION 23A, 23B Density (sigma-t units)

Depth (m)	Date 16-Jul-84 A	16-Jul-84 B	23-Jul-84 A	23-Jul-84 B	30-Jul-84 A	30-Jul-84 B	06-Aug-84 A	06-Aug-84 B	13-Aug-84 A	13-Aug-84 B	20-Aug-84 A	20-Aug-84 B	17-Sep-84 A	17-Sep-84 B	24-Sep-84 A	24-Sep-84 B
0.5	19.821	19.233	20.463	20.744	21.160	20.974	20.110	20.089	21.081	20.853	21.027	21.149	21.225	21.519	21.675	21.521
2	21.334	20.525	21.150	21.138	21.665	21.314	20.321	20.433	21.137	21.206	21.211	21.280	21.290	22.134	21.674	21.565
5	21.737	21.498	21.437	21.457	21.847	21.671	21.703	21.658	21.743	21.521	21.789	21.995	22.303	22.333	22.354	22.296
10	21.973	21.972	21.611	21.706	22.045	21.904	21.887	21.955	22.119	22.094	22.170	22.148	22.494	22.507	22.548	22.554
20	22.064	22.063	21.926	22.037	22.124	22.094	22.111	22.105	22.235	22.206	22.382	22.367	22.588	22.594	22.693	22.681
30	22.114	22.112	22.091	22.084	22.264	22.241	22.174	22.161	22.347	22.317	22.467	22.439	22.645	22.649	22.749	22.754
40	22.226	22.220	22.123	22.120	22.407	22.331	22.201	22.196	22.442	22.450	22.511	22.495	22.697	22.702	22.797	22.864
50	22.288	22.333	22.167	22.271	22.572	22.470	22.279	22.252	22.522	22.603	22.555	22.542	22.797	22.813	22.933	22.905
60	22.545	22.629	22.323	22.391	22.684	22.551	22.321	22.320	22.659	22.649	22.700	22.656	22.944	22.962	22.988	22.961
70	22.749	22.757	22.516	22.501	22.803	22.614	22.378	22.407	22.810	22.846	22.769	22.658	23.023	23.041	23.032	23.017

STATION 24

Temperature (°C)

Depth (m)	Date 23-Jul-84	13-Aug-84	17-Sep-84
0.5	16.144	12.879	13.458
2	15.061	12.901	13.294
5	14.105	12.542	13.100
10	13.393	12.507	13.009
20	12.310	12.439	12.930
30	11.881	12.153	12.751
40	11.704	12.163	12.301
50	11.146	11.983	12.239
60	10.969	11.942	12.200
70	10.871	11.859	11.803
80	10.839	11.417	11.800
90	10.829	11.349	11.799
100	10.827	11.299	11.775
110	10.843	11.311	11.769
120	10.923	11.312	11.760
130	10.923	11.348	11.746
140	10.926	11.351	11.725
150	10.935	11.363	11.721
160	10.935	11.380	11.711
170	10.959	11.393	11.705
180	10.964	11.408	11.695
190	10.972	11.428	11.692
200	10.966	11.432	11.684

Salinity (°/oo)

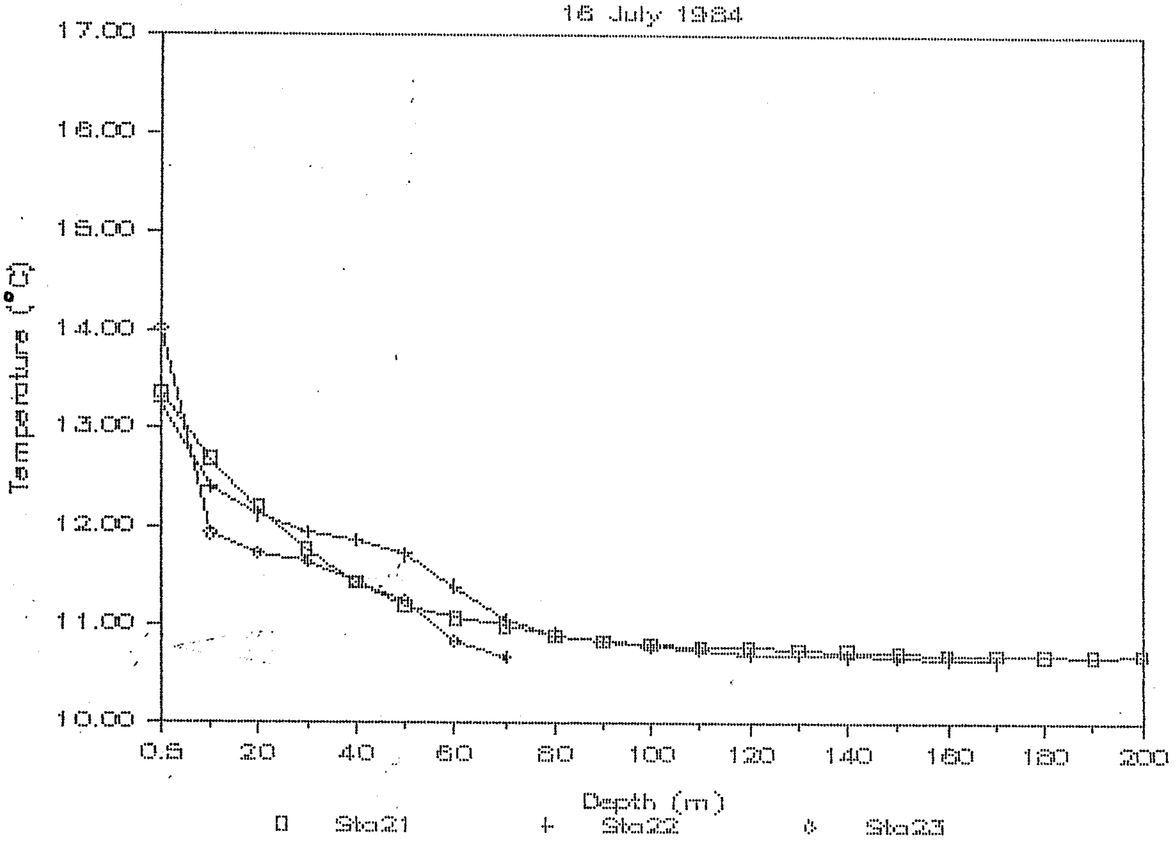
Depth (m)	Date 23-Jul-84	13-Aug-84	17-Sep-84
0.5	28.215	29.450	29.889
2	28.463	29.448	29.886
5	28.540	29.467	29.909
10	28.939	29.462	29.920
20	29.153	29.472	29.928
30	29.262	29.593	29.951
40	29.318	29.579	30.134
50	29.613	29.655	30.165
60	29.713	29.671	30.177
70	29.801	29.703	30.409
80	29.823	29.905	30.405
90	29.890	29.951	30.402
100	29.911	29.979	30.422
110	29.939	30.001	30.429
120	29.998	30.009	30.436
130	30.005	30.069	30.446
140	30.005	30.083	30.459
150	30.009	30.089	30.465
160	30.012	30.105	30.474
170	30.035	30.120	30.481
180	30.066	30.140	30.482
190	30.073	30.156	30.481
200	30.092	30.149	30.491

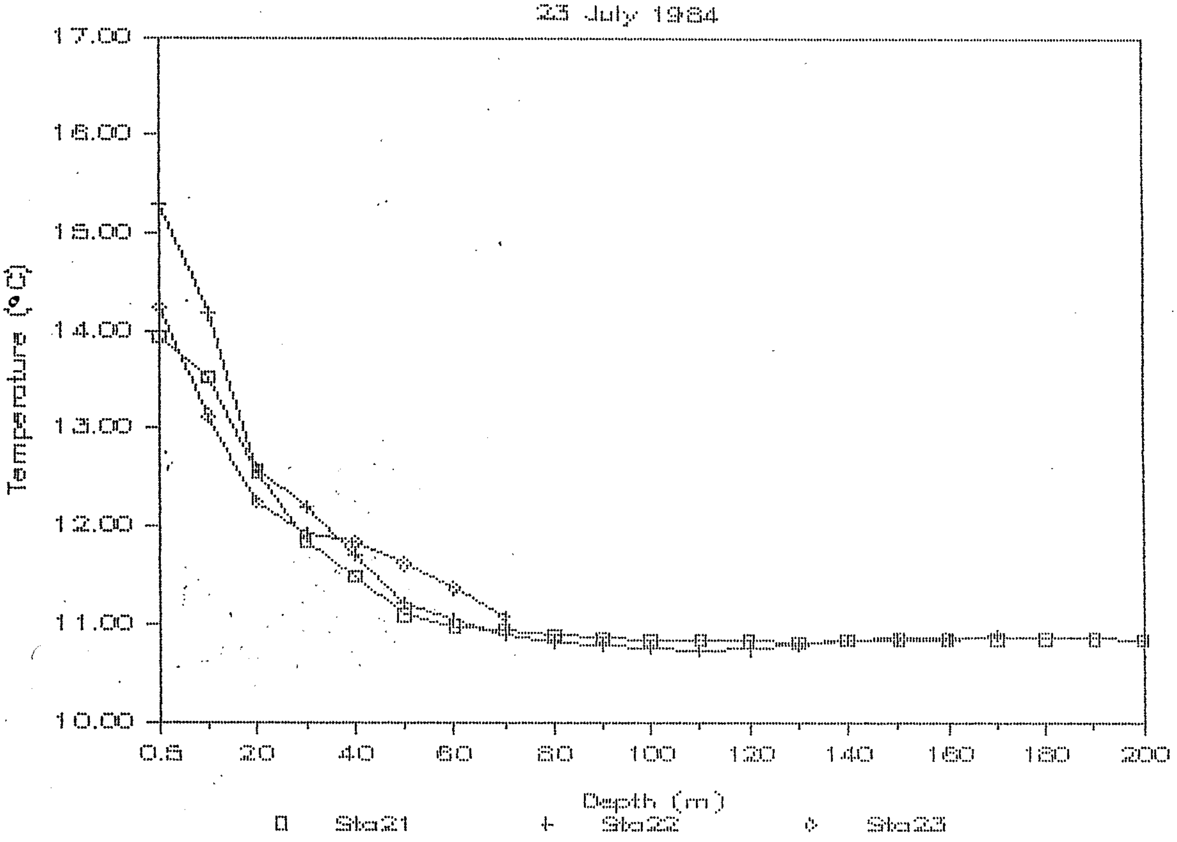
Density (sigma-t units)

Depth (m)	Date 23-Jul-84	13-Aug-84	17-Sep-84
0.5	20.539	22.151	22.378
2	20.959	22.145	22.407
5	21.213	22.227	22.462
10	21.659	22.229	22.488
20	22.027	22.250	22.509
30	22.189	22.395	22.561
40	22.263	22.383	22.786
50	22.589	22.474	22.822
60	22.697	22.494	22.838
70	22.781	22.534	23.089
80	22.804	22.768	23.087
90	22.858	22.816	23.085
100	22.874	22.846	23.105
110	22.893	22.861	23.111
120	22.925	22.867	23.118
130	22.931	22.907	23.128
140	22.930	22.917	23.142
150	22.932	22.920	23.148
160	22.934	22.929	23.156
170	22.948	22.939	23.163
180	22.971	22.952	23.165
190	22.975	22.960	23.165
200	22.991	22.953	23.174

APPENDIX 2.B

Vertical profiles of temperature (°C), salinity (^{o}/oo), and density (sigma-t units) for each sampling data. Data have been averaged for a given date if 2 casts were obtained. The first set of profiles compares stations 21, 22, and 23. The second set compares stations 21, 22, and 24.


16 July 1984
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
Temperature (°C)
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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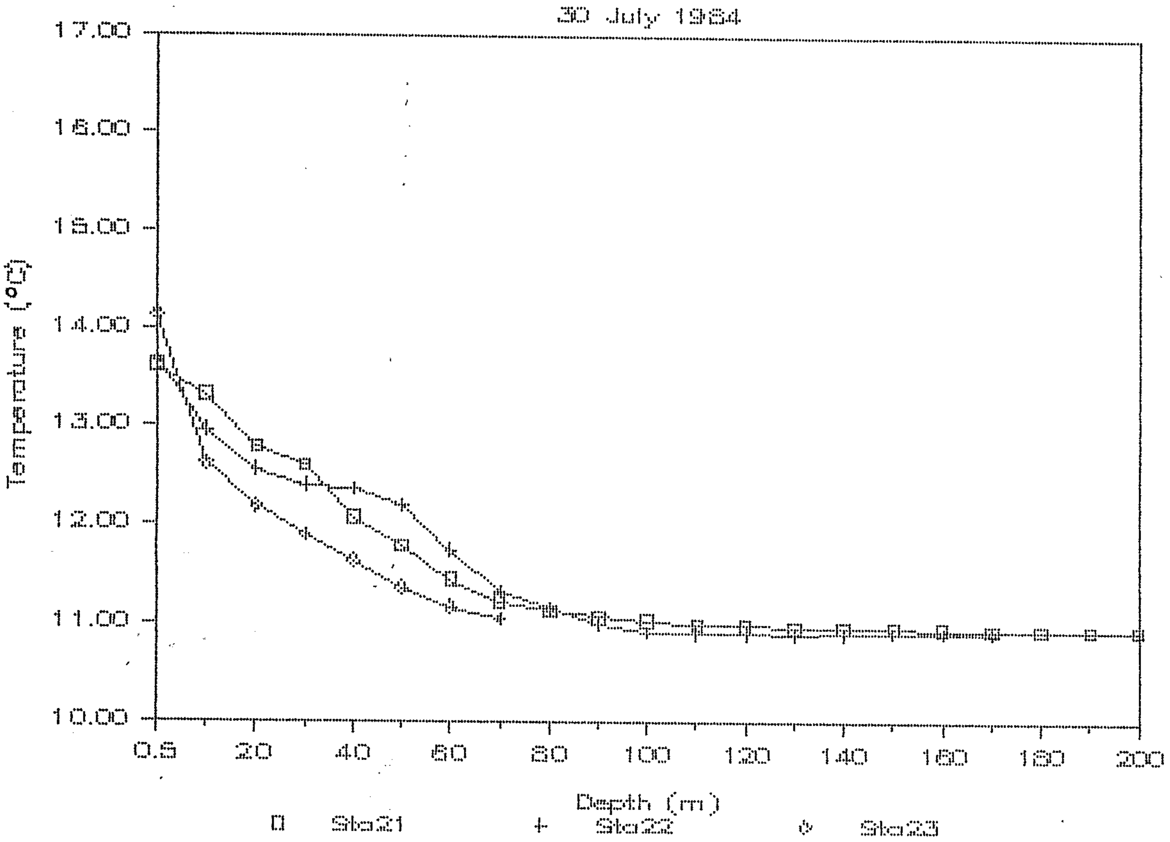
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
Temperature (°C)
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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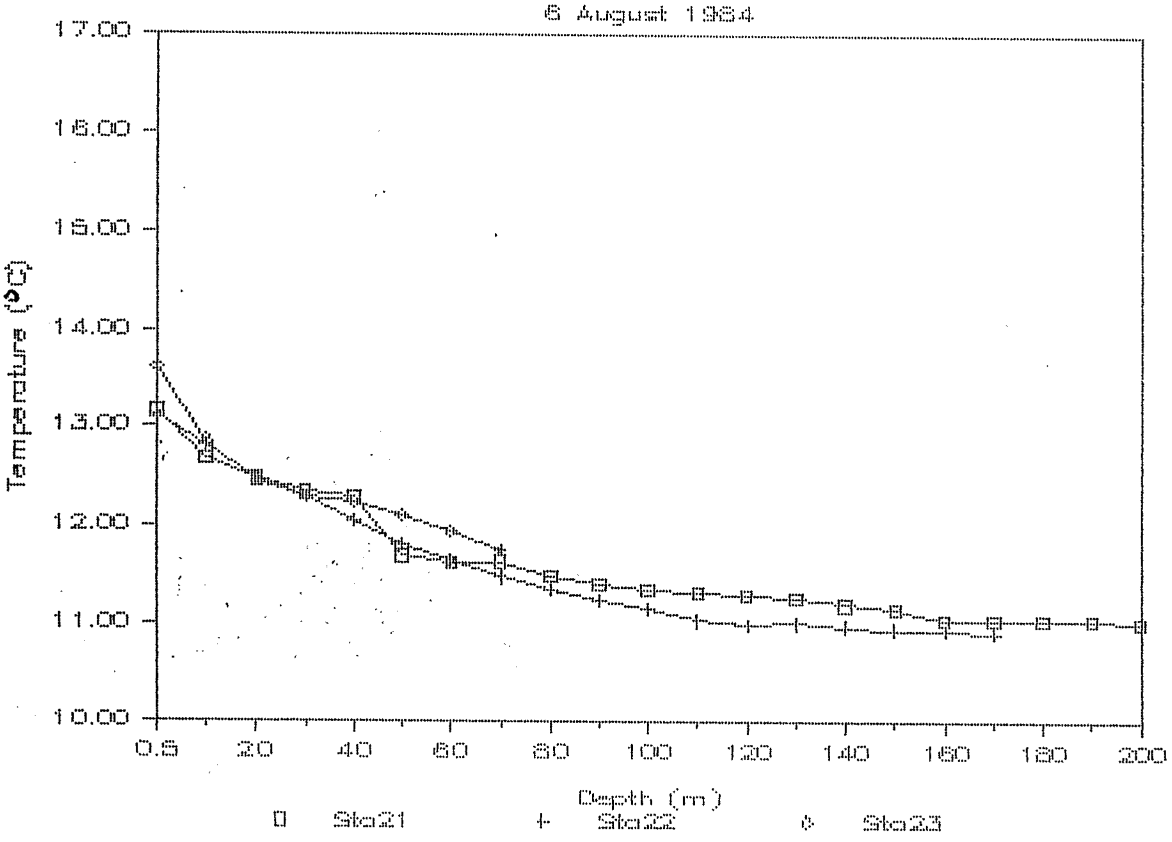
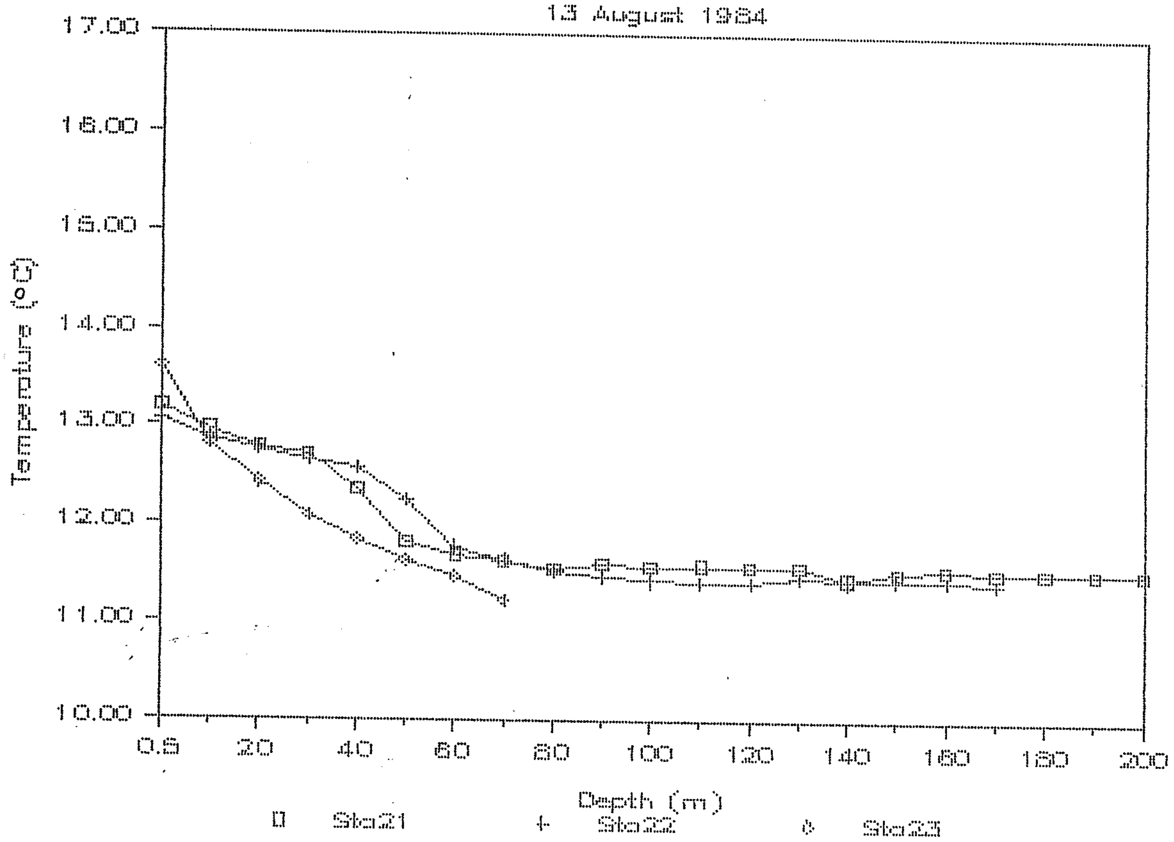
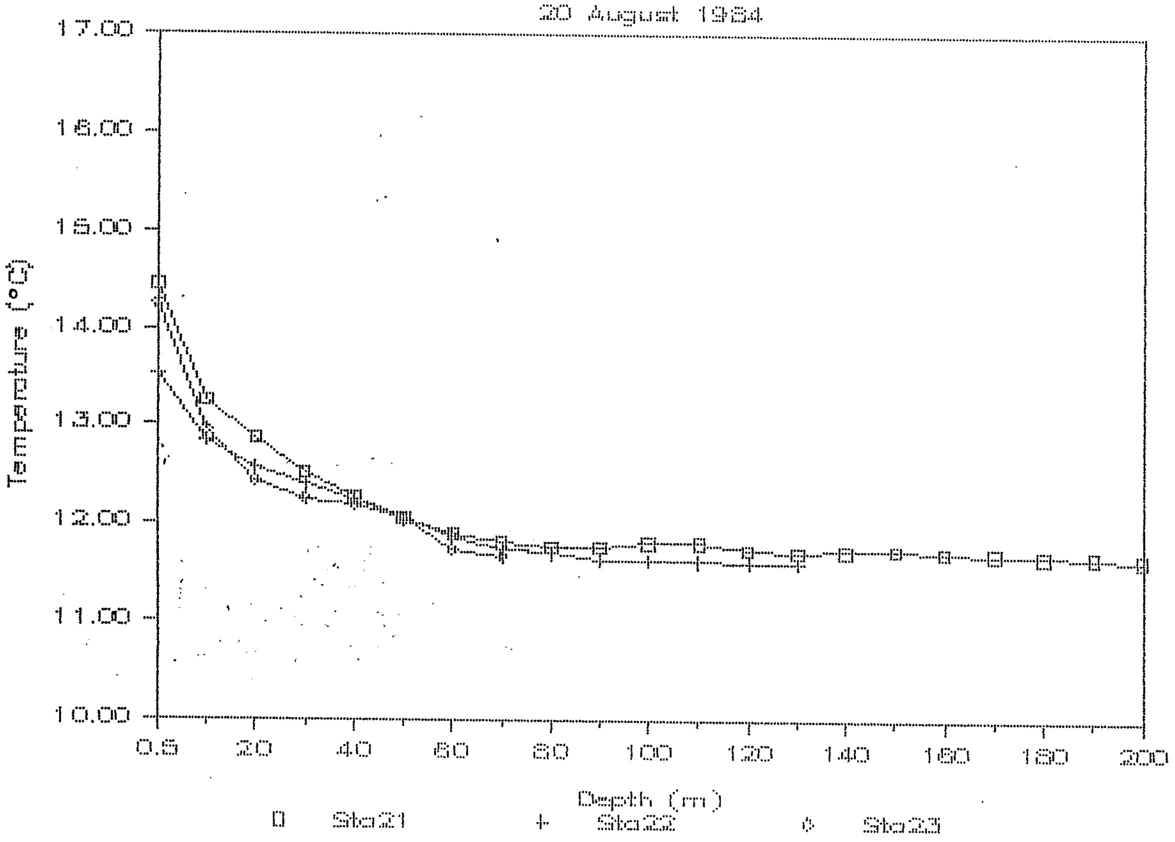
Temperature (°C)
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◊ Sta23


6 August 1984
Temperature (°C)
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◊ Sta23


13 August 1984
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
Temperature (°C)
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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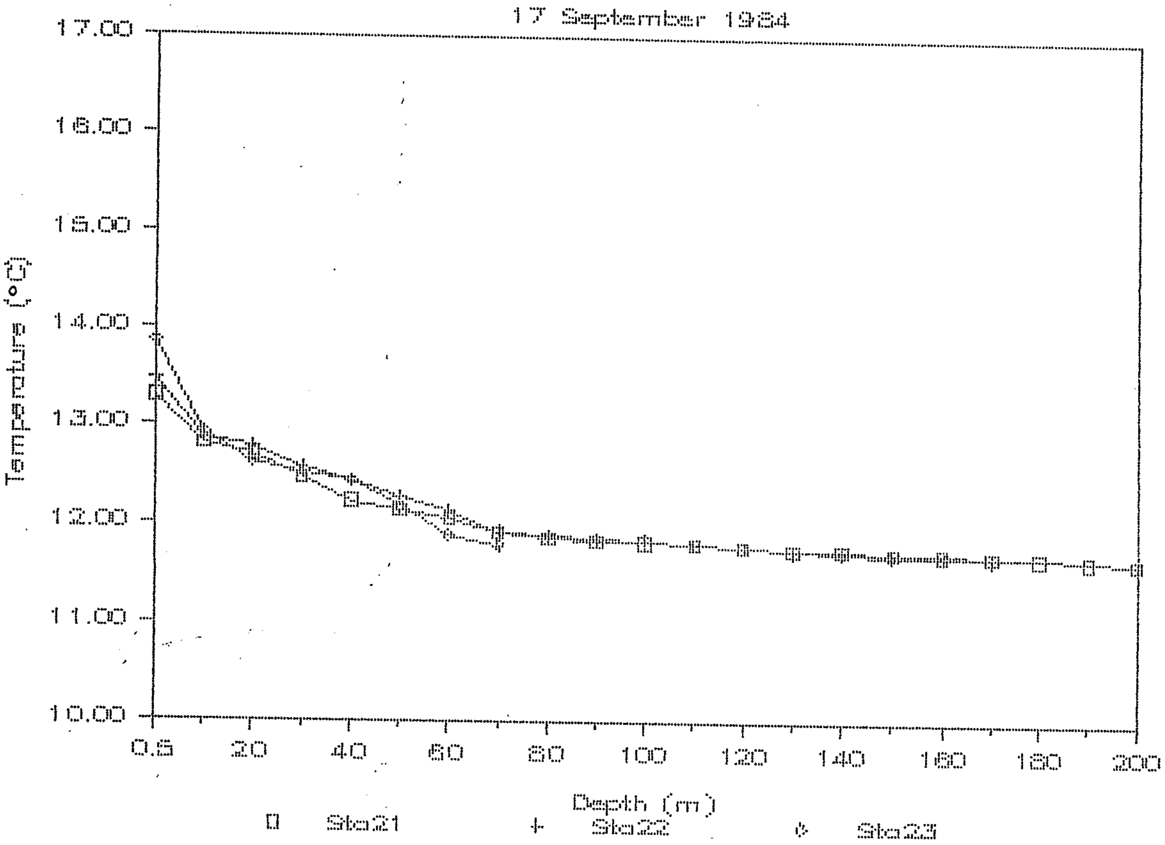
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
Temperature (°C)
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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Temperature (°C)
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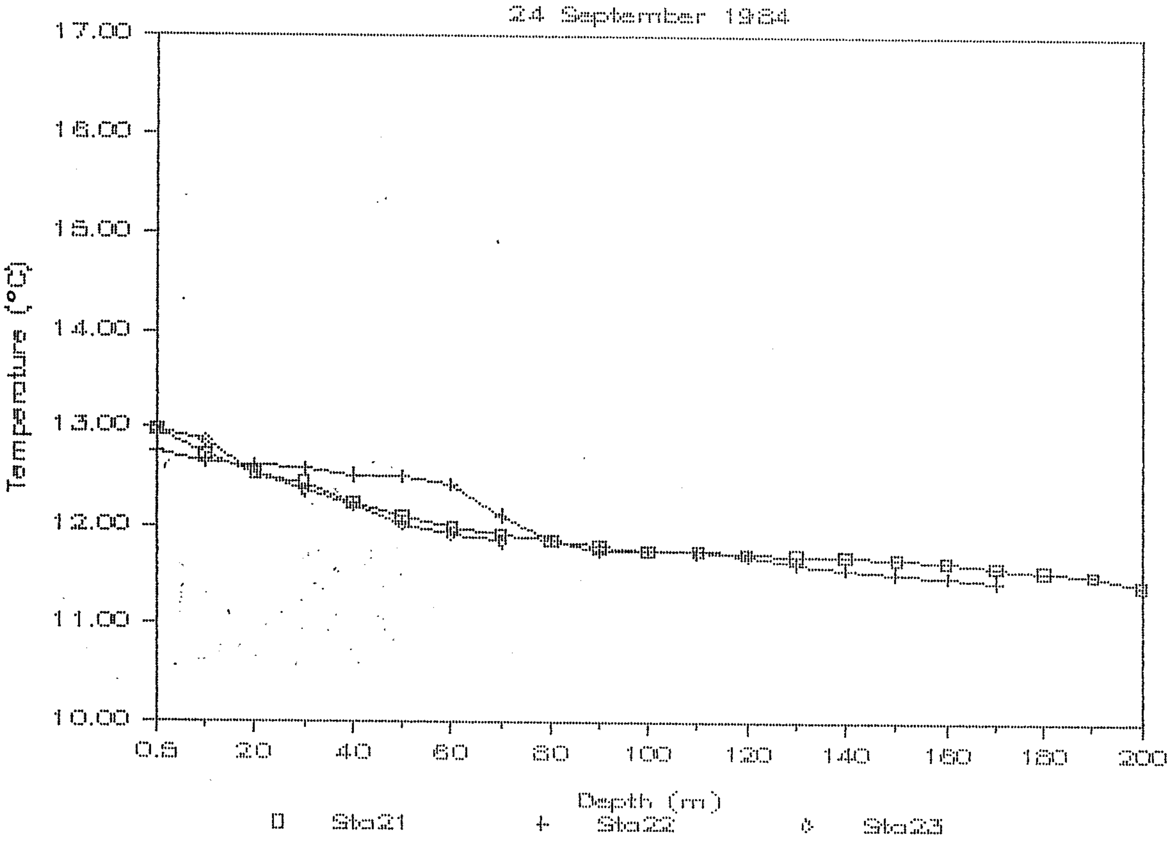
16.00
15.00
14.00
13.00
12.00
11.00
10.00
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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Temperature (°C)
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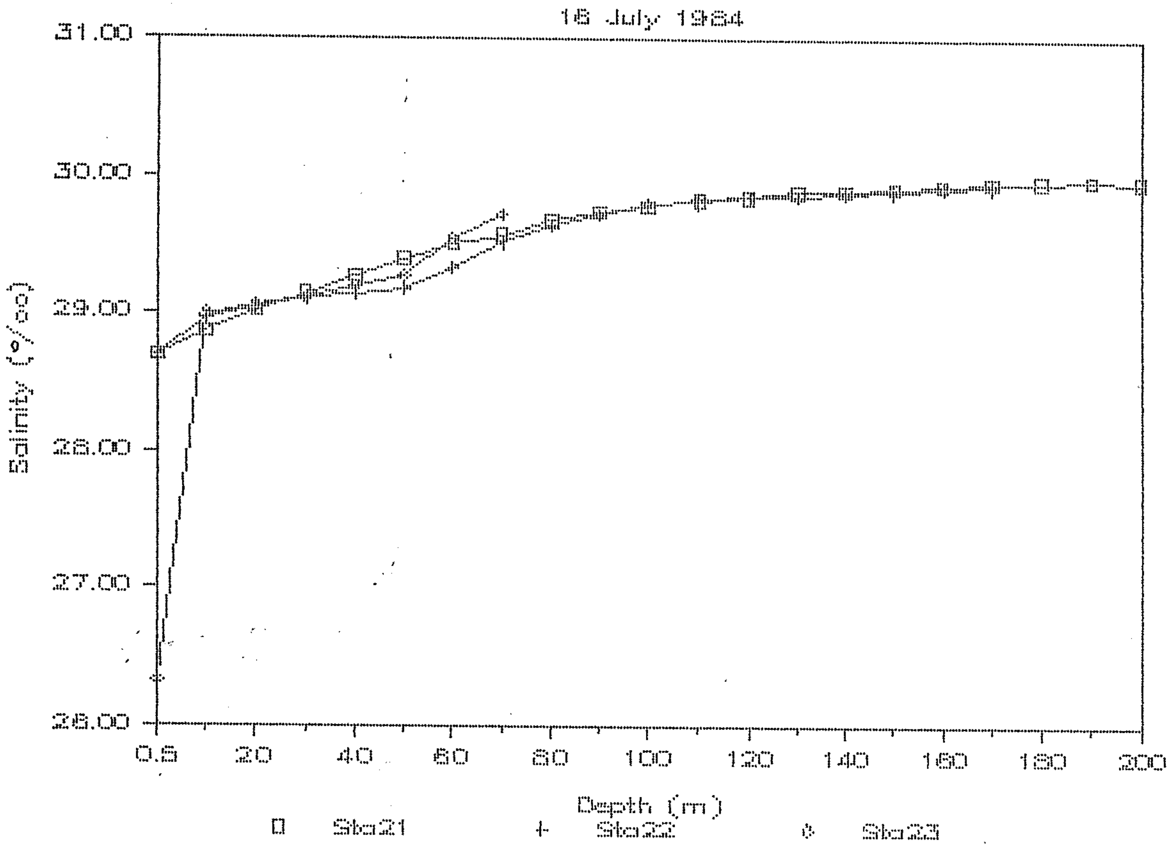
16.00
15.00
14.00
13.00
12.00
11.00
10.00
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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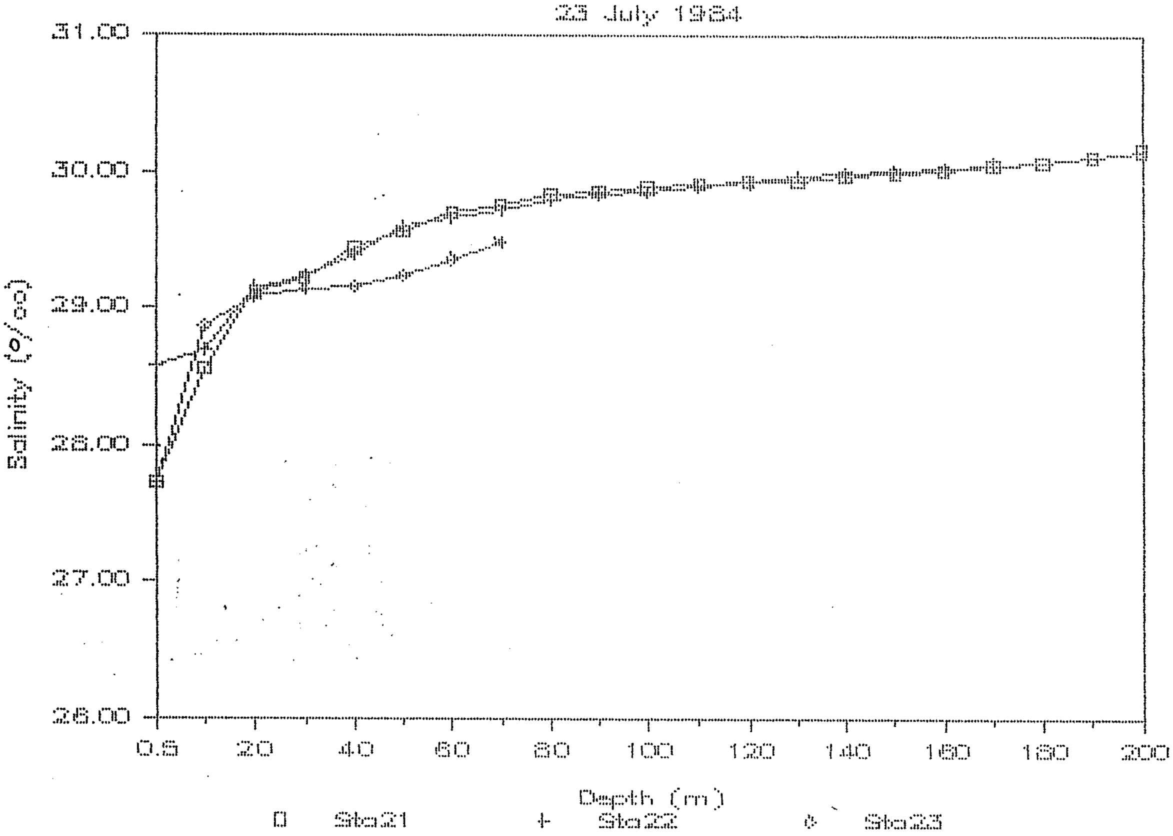
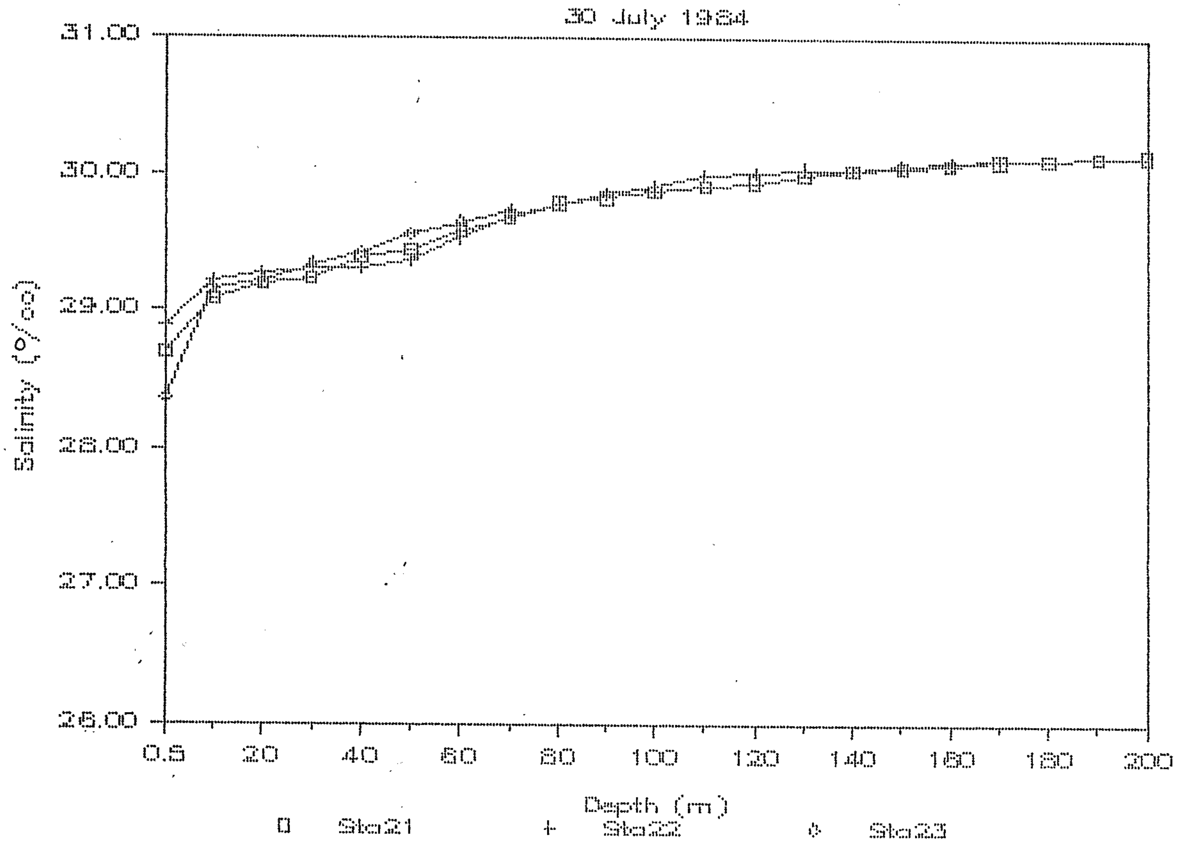
31.00
30.00
29.00
28.00
27.00
26.00
Salinity (°/oo)
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23


23 July 1984
31.00
30.00
29.00
28.00
27.00
26.00
Salinity (°/oo)
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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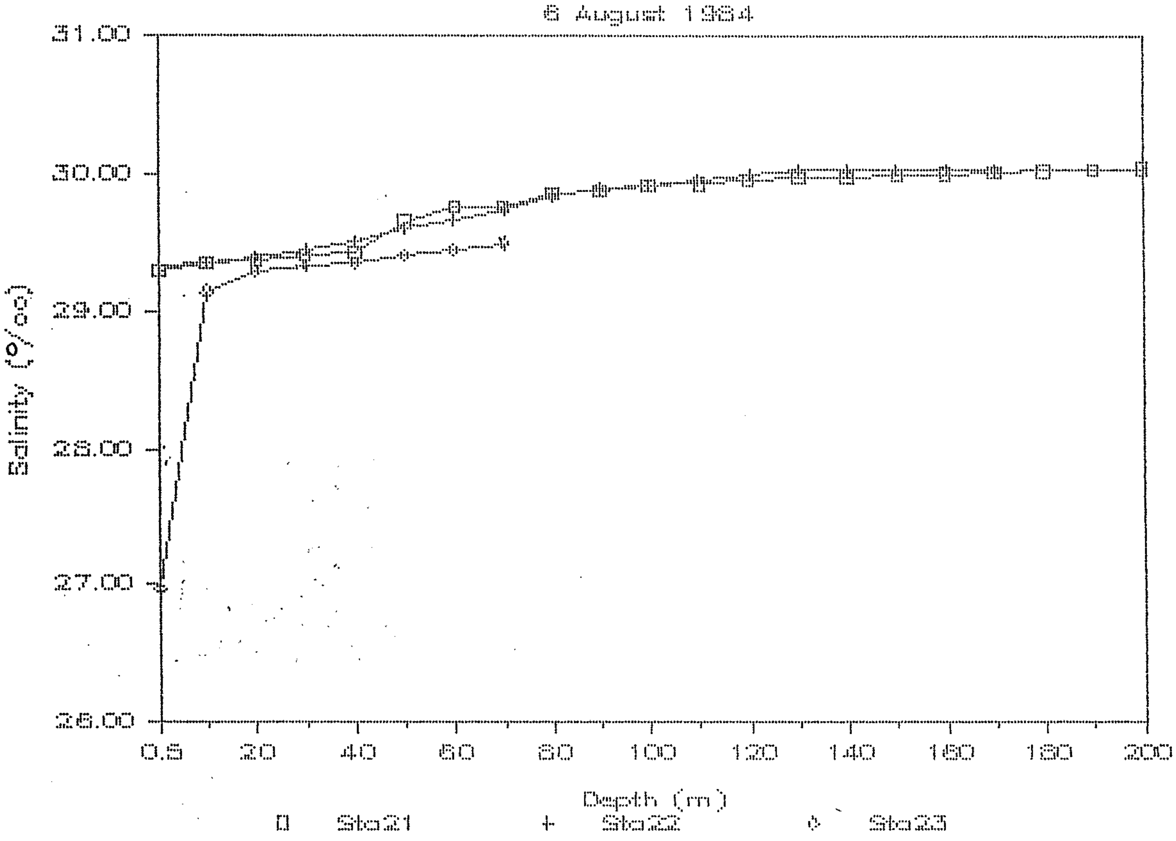
31.00
30.00
29.00
28.00
27.00
26.00
Salinity (°/oo)
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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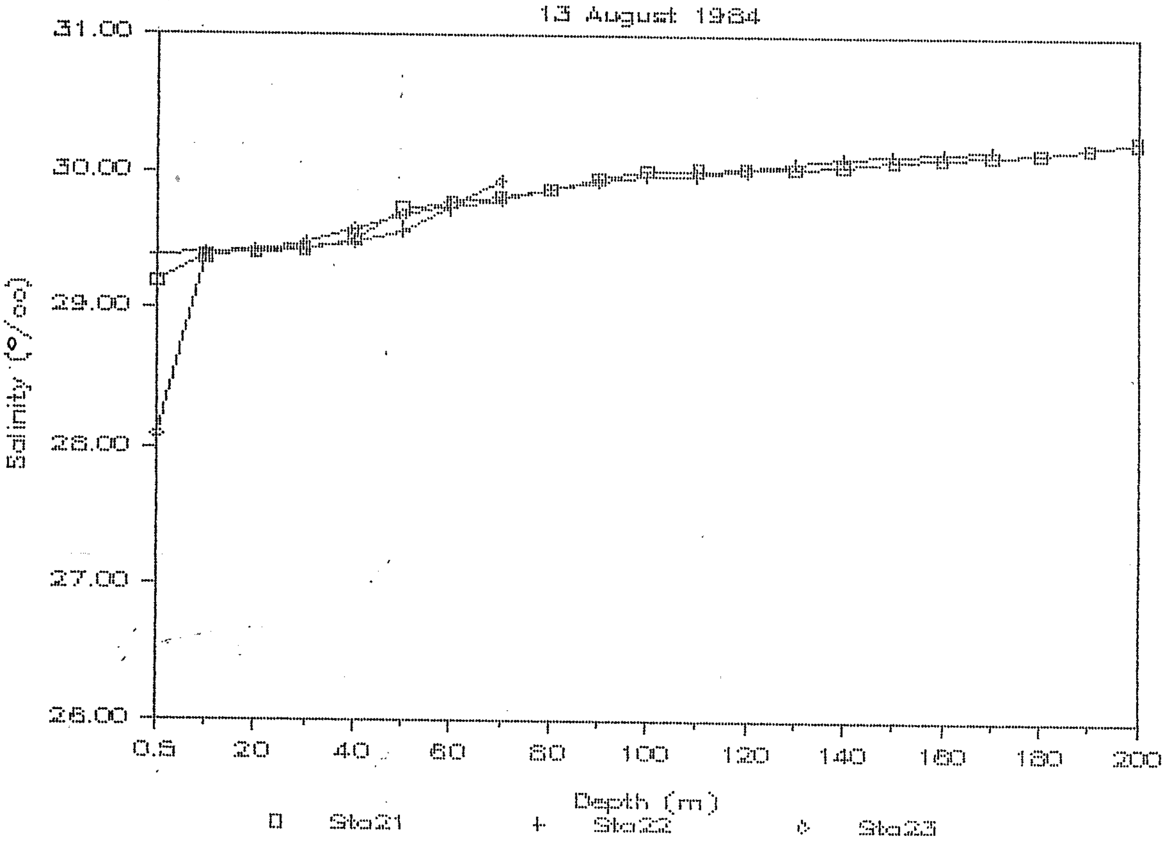
31.00
30.00
29.00
28.00
27.00
26.00
Salinity (°/oo)
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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26.00
Salinity (°/oo)
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80
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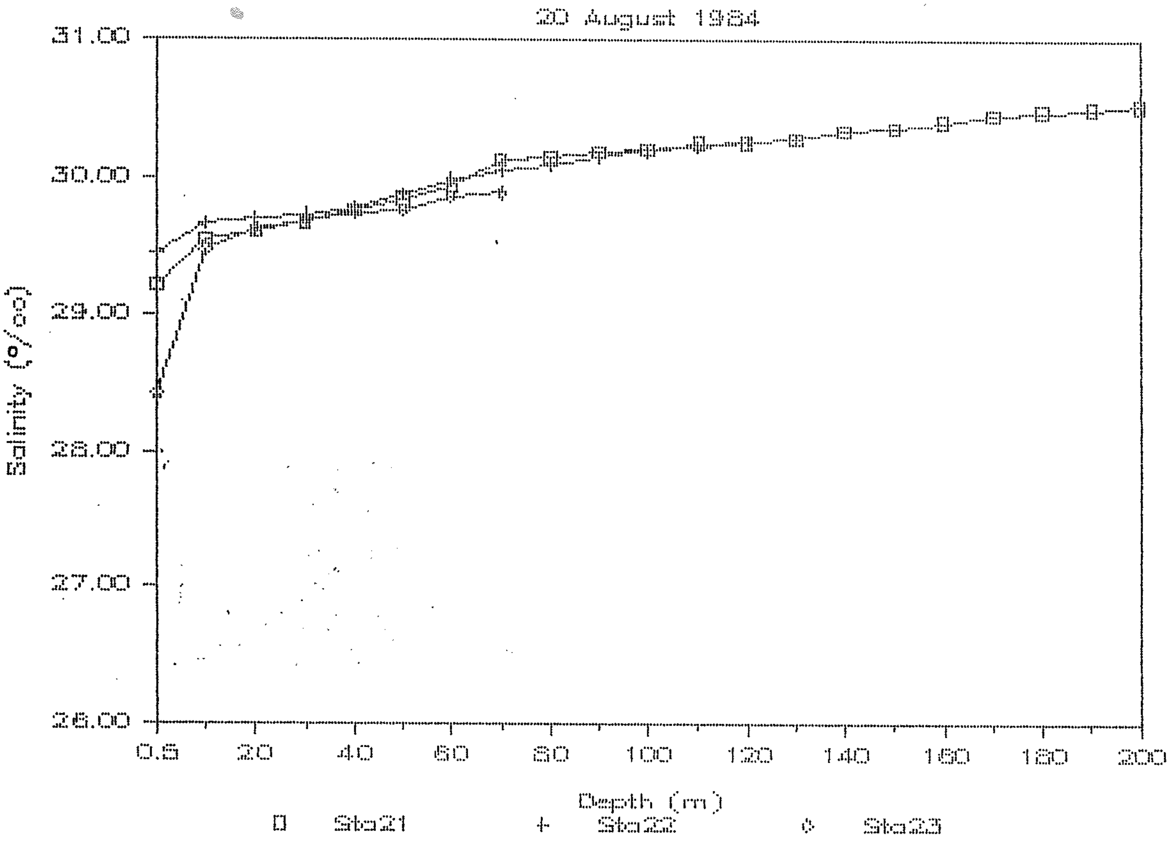
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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27.00
26.00
Salinity (°/oo)
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140
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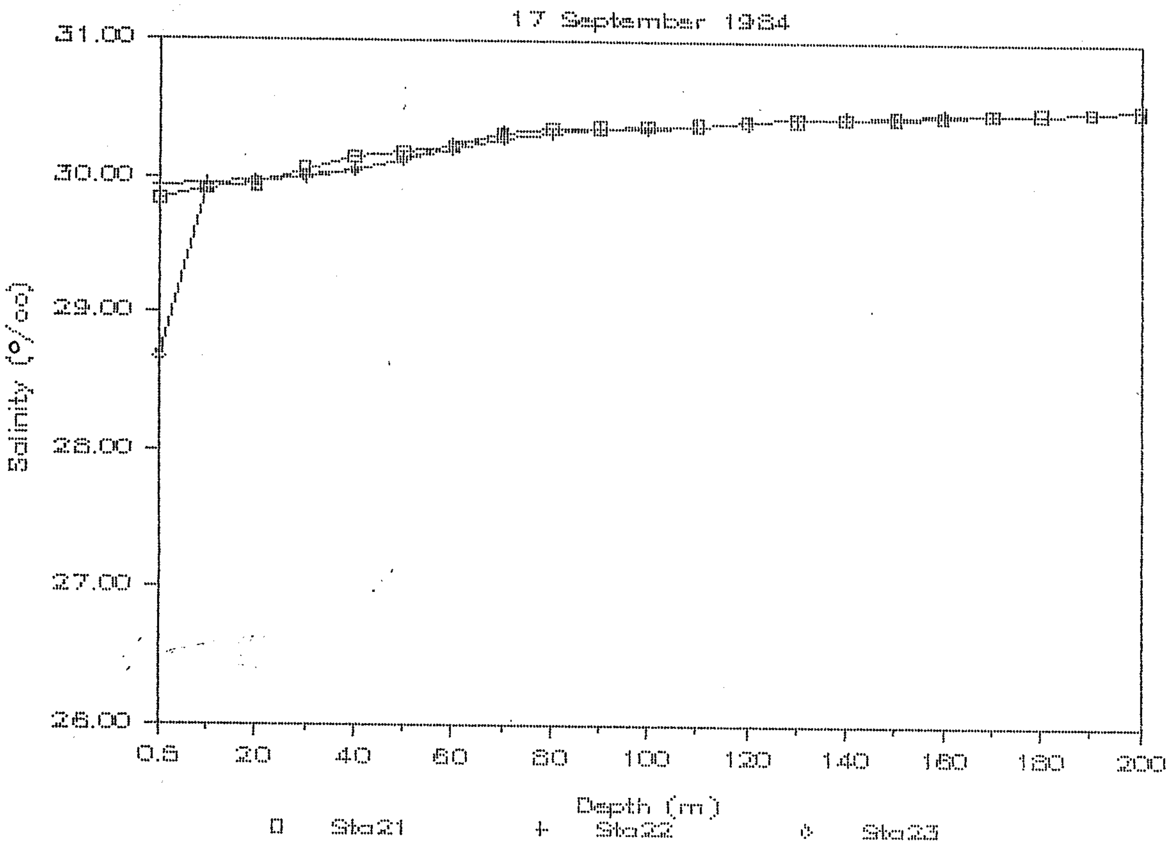
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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Salinity (°/oo)
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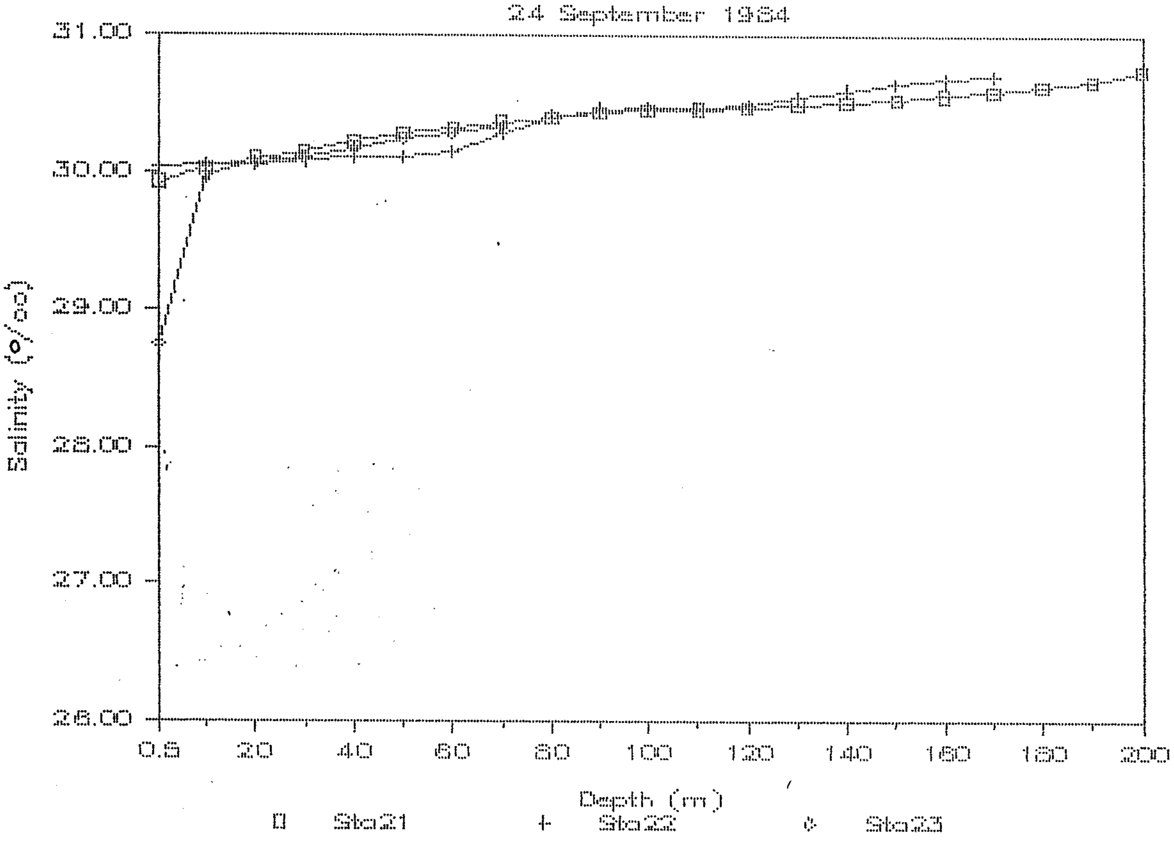
29.00
28.00
27.00
26.00
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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Salinity (°/oo)
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28.00
27.00
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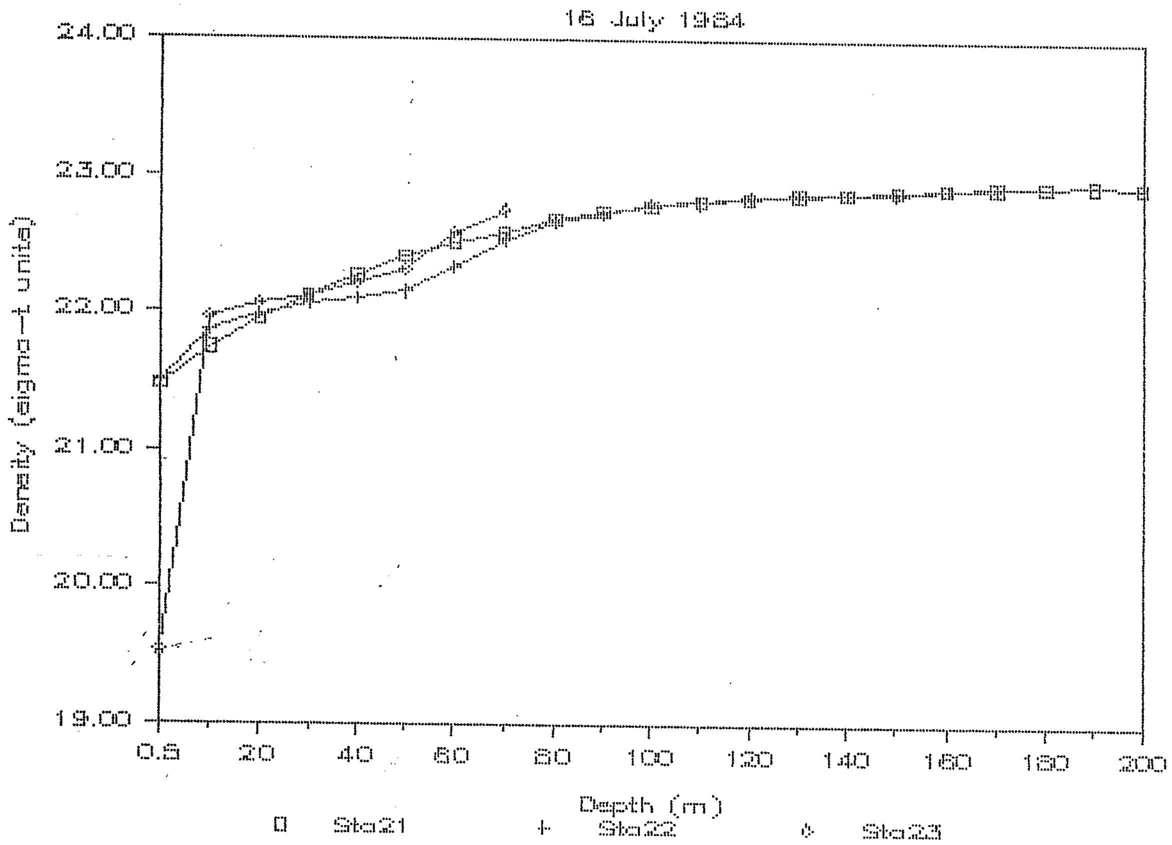
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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23.00
22.00
21.00
20.00
19.00
Density (sigma-t units)
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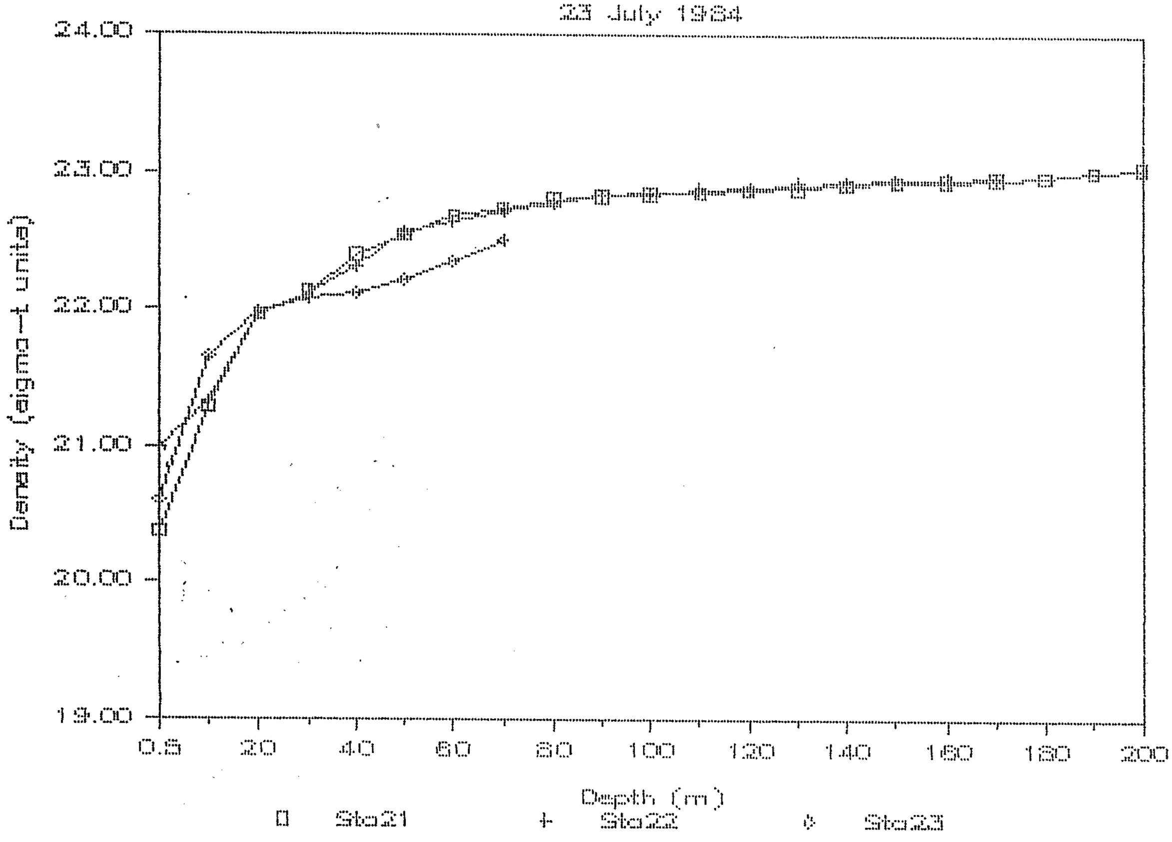
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◊ Sta23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20.00
19.00
Density (sigma-t units)
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100
120
140
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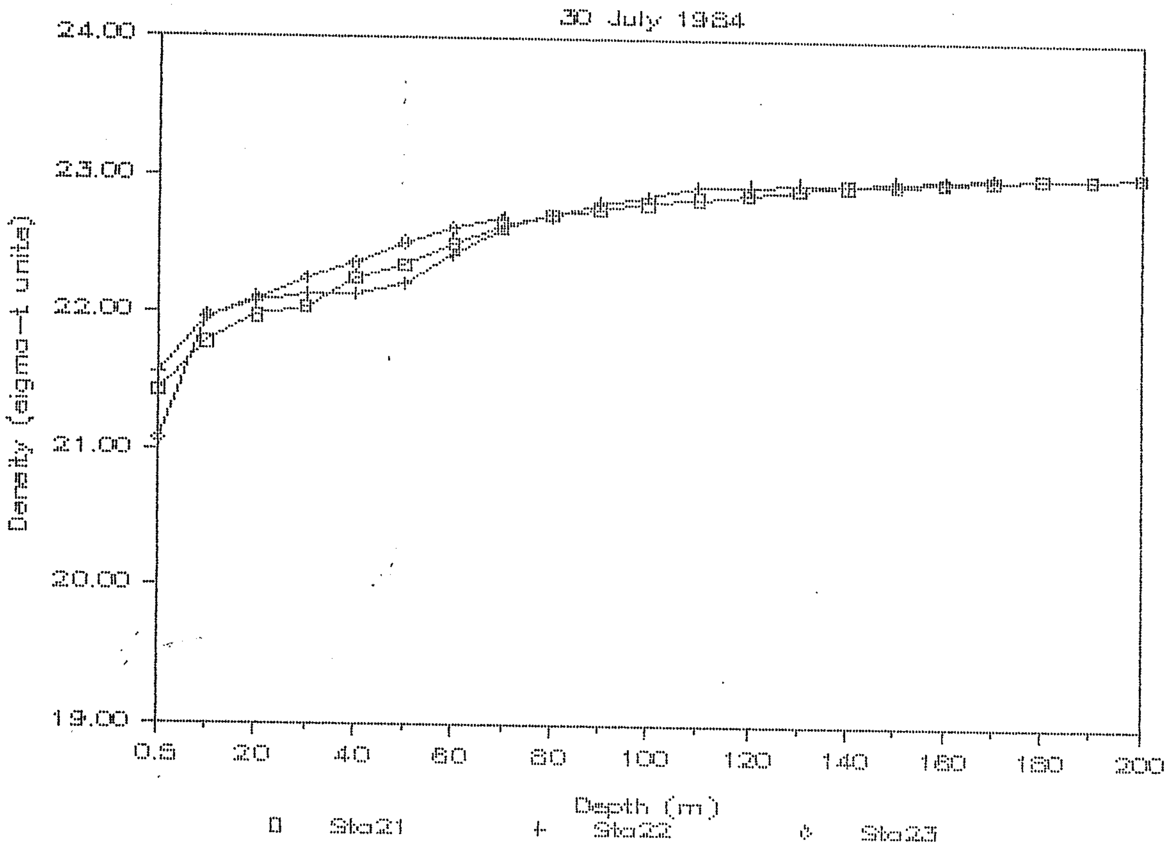
180
200
Depth (m)
□ Sta21
+ Sta22
◊ Sta23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Density (sigma-t units)
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23.00
22.00
21.00
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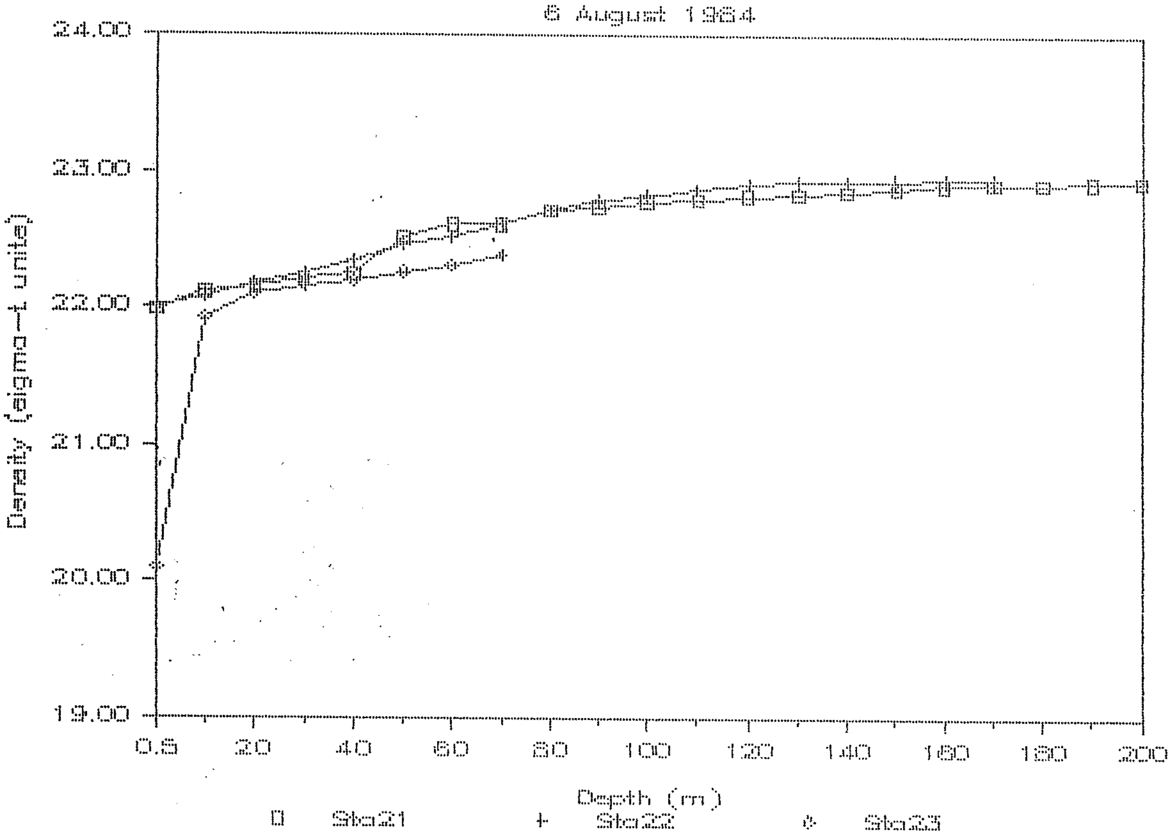
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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Density (sigma-t units)
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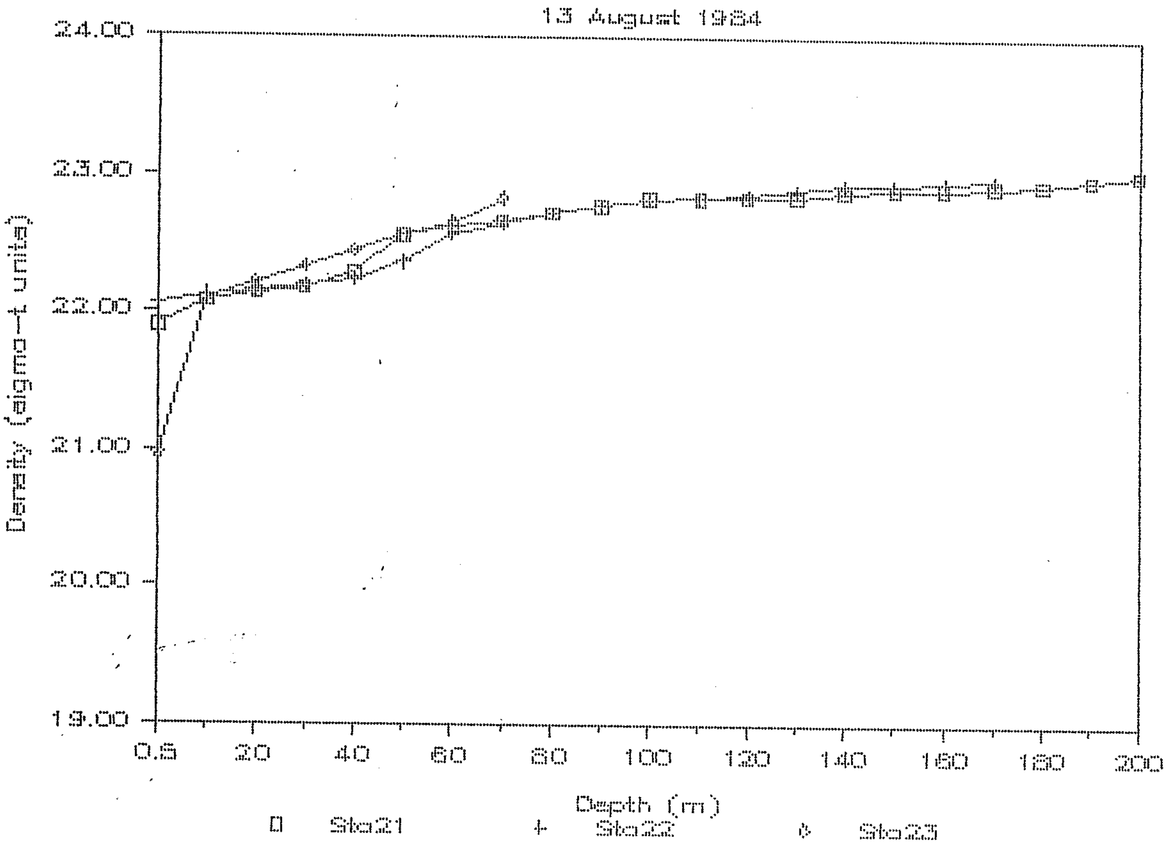
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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Density (sigma-t units)
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23.00
22.00
21.00
20.00
19.00
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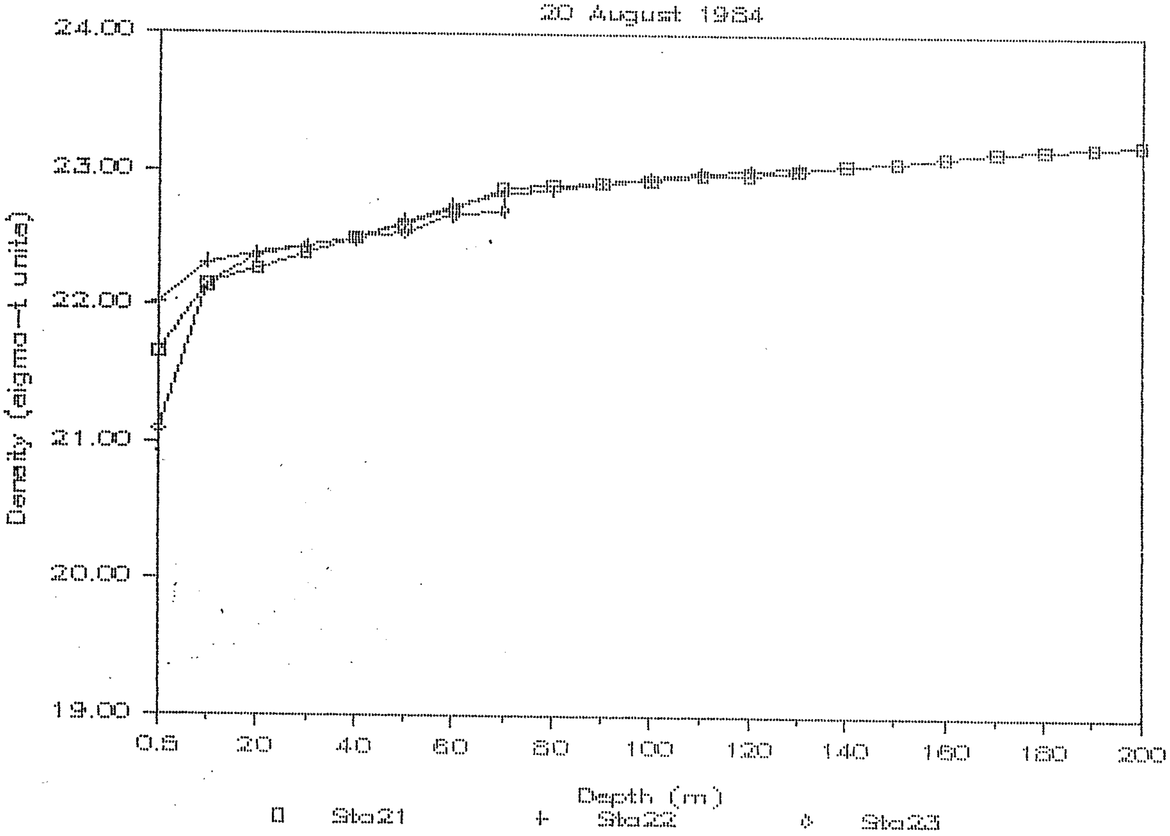
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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Density (sigma-t units)
24.00
23.00
22.00
21.00
20.00
19.00
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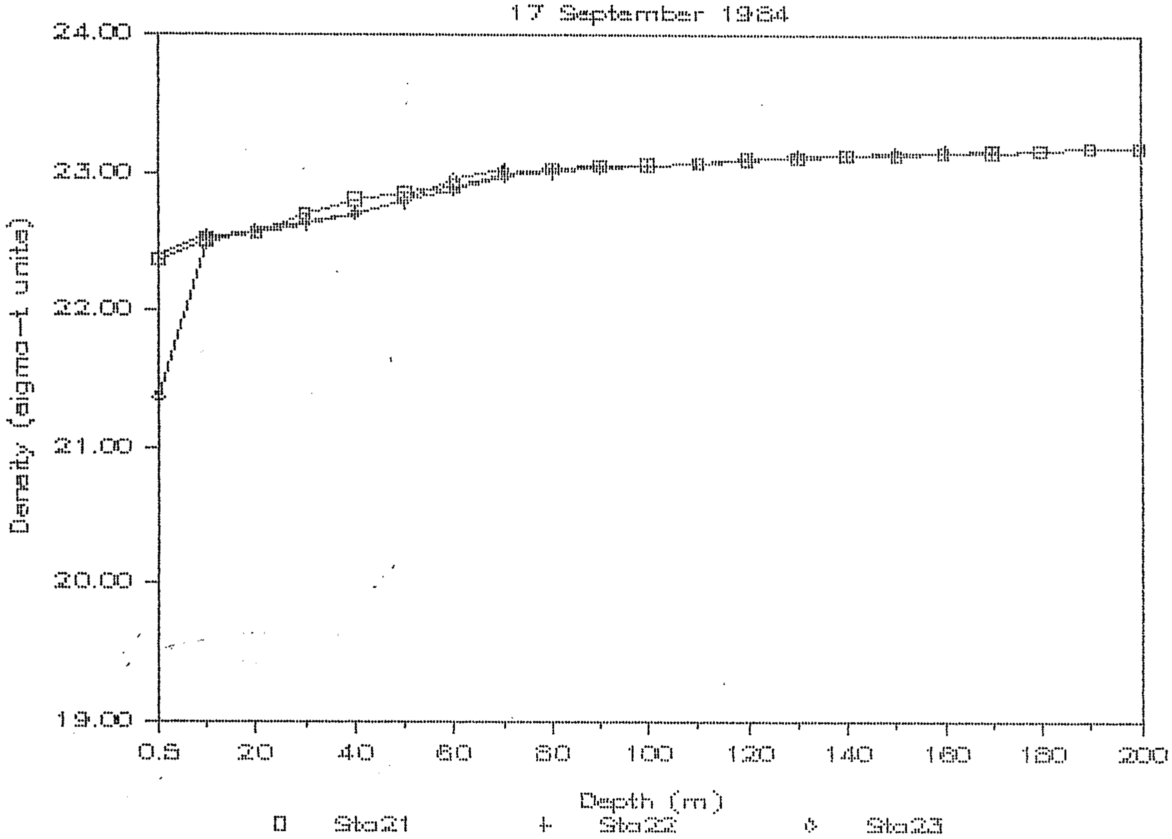
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23


17 September 1984
Density (sigma-t units)
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22.00
21.00
20.00
19.00
0.5
20
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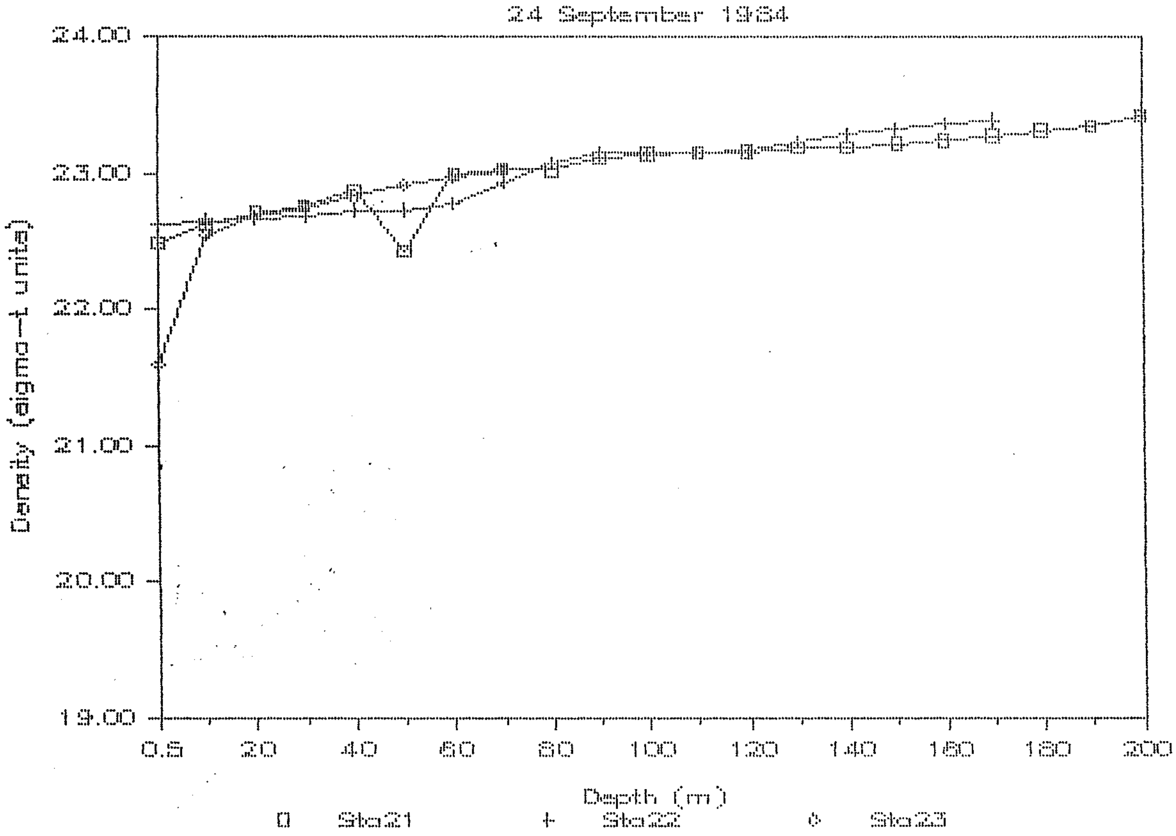
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23


24 September 1984
Density (sigma-t units)
24.00
23.00
22.00
21.00
20.00
19.00
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20
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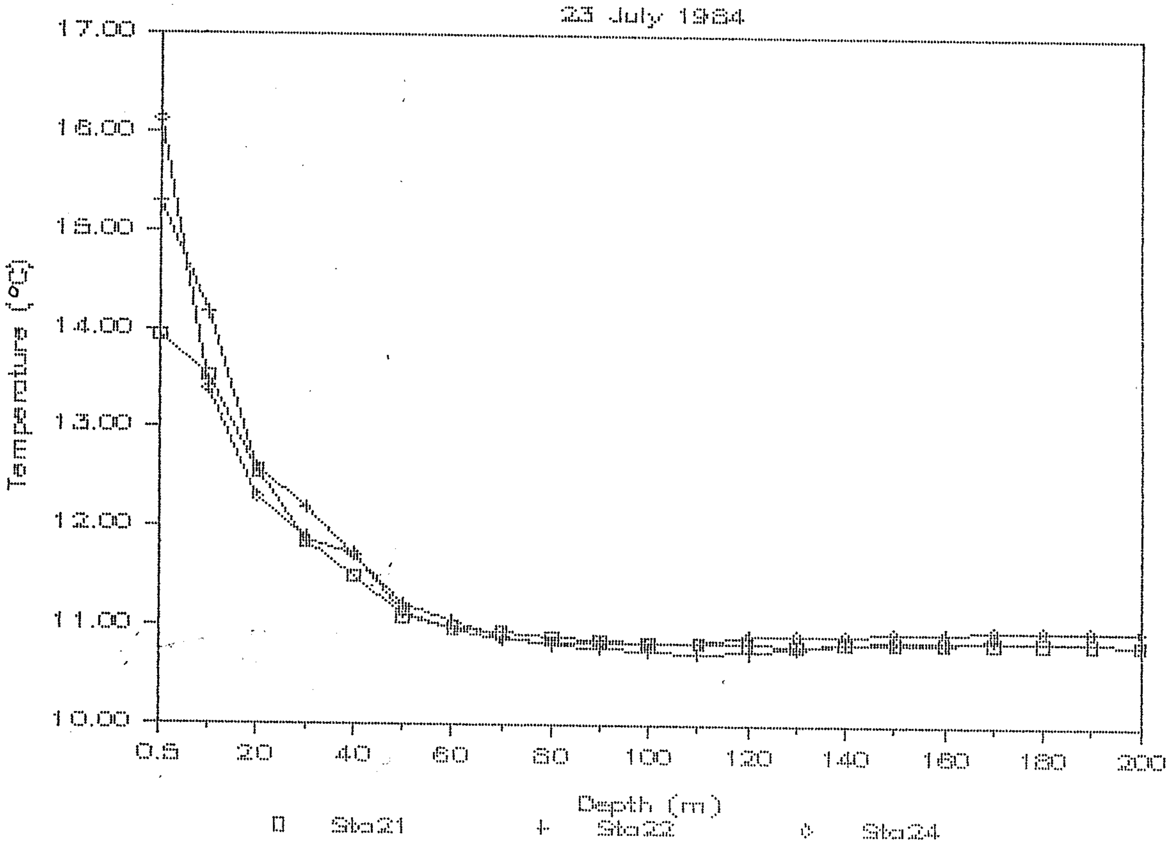
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta23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Temperature (°C)
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16.00
15.00
14.00
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12.00
11.00
10.00
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60
80
100
120
140
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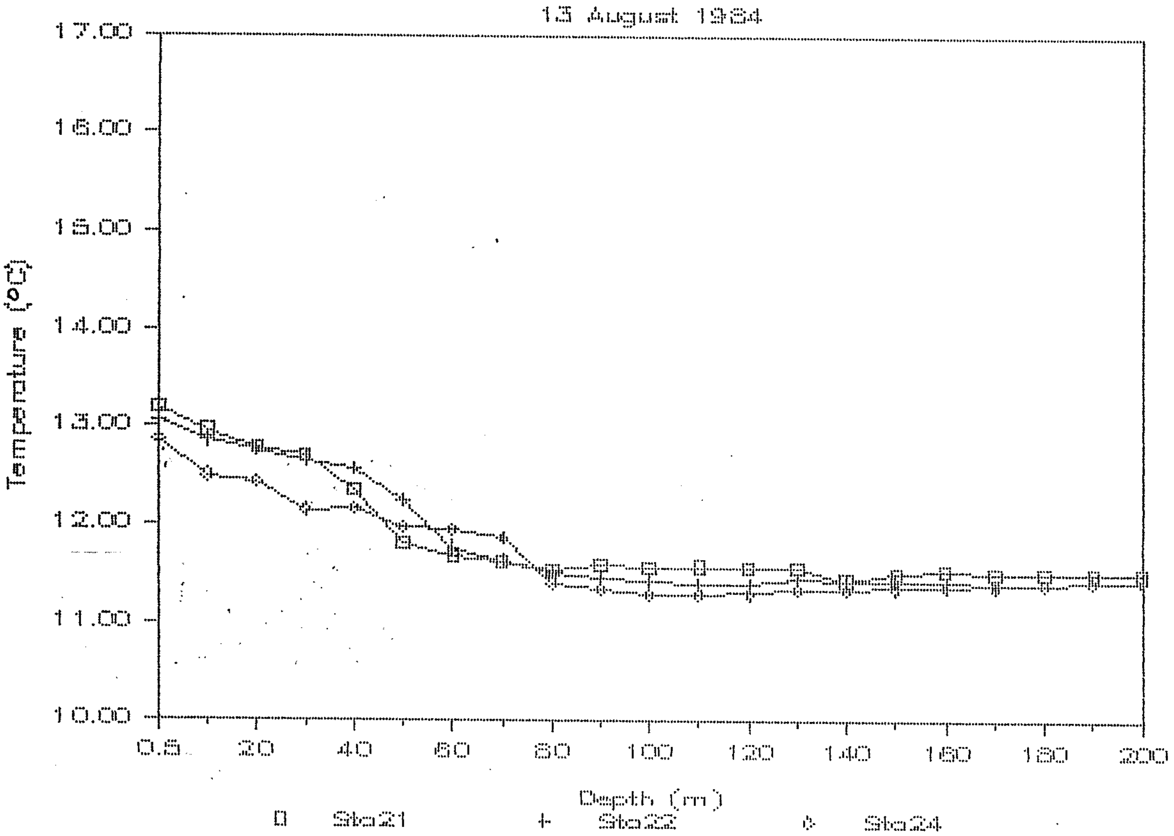
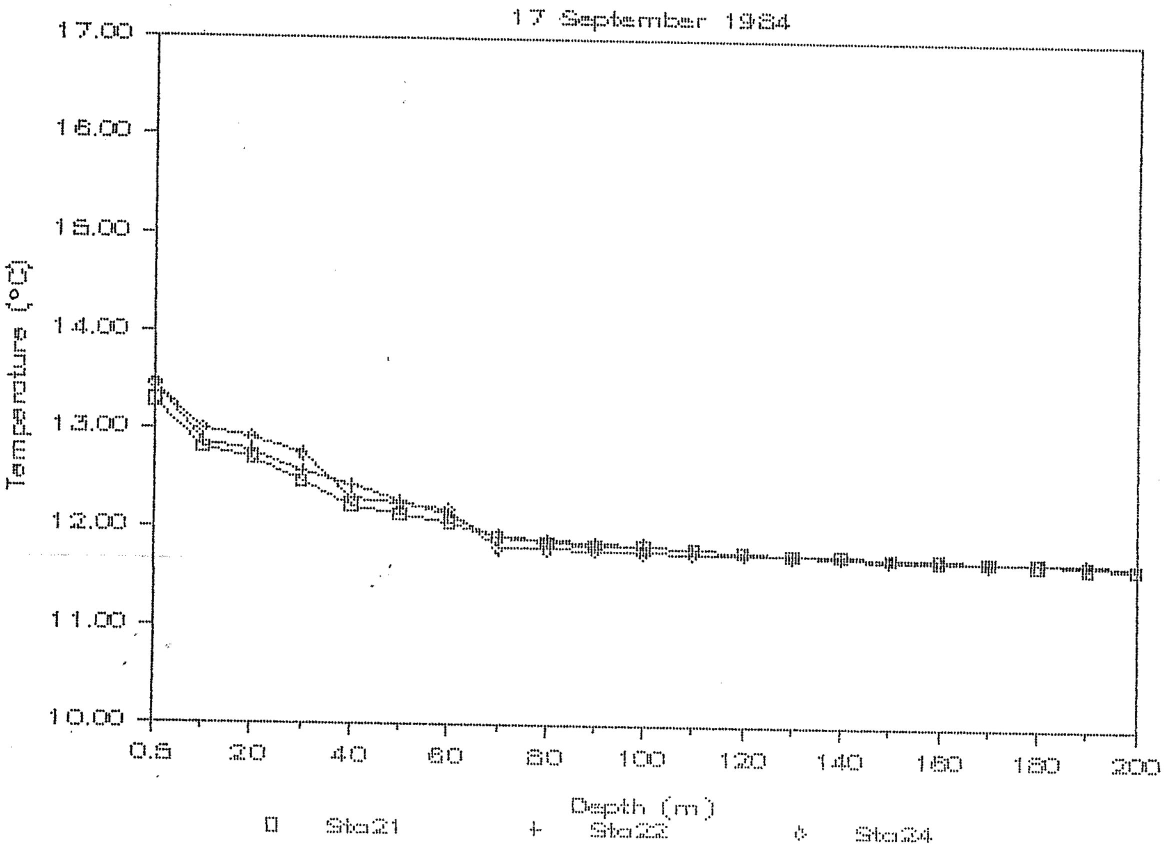
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta24


13 August 1984
Temperature (°C)
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
0.5
20
40
60
80
100
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta24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15.00
14.00
13.00
12.00
11.00
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60
80
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Depth (m)
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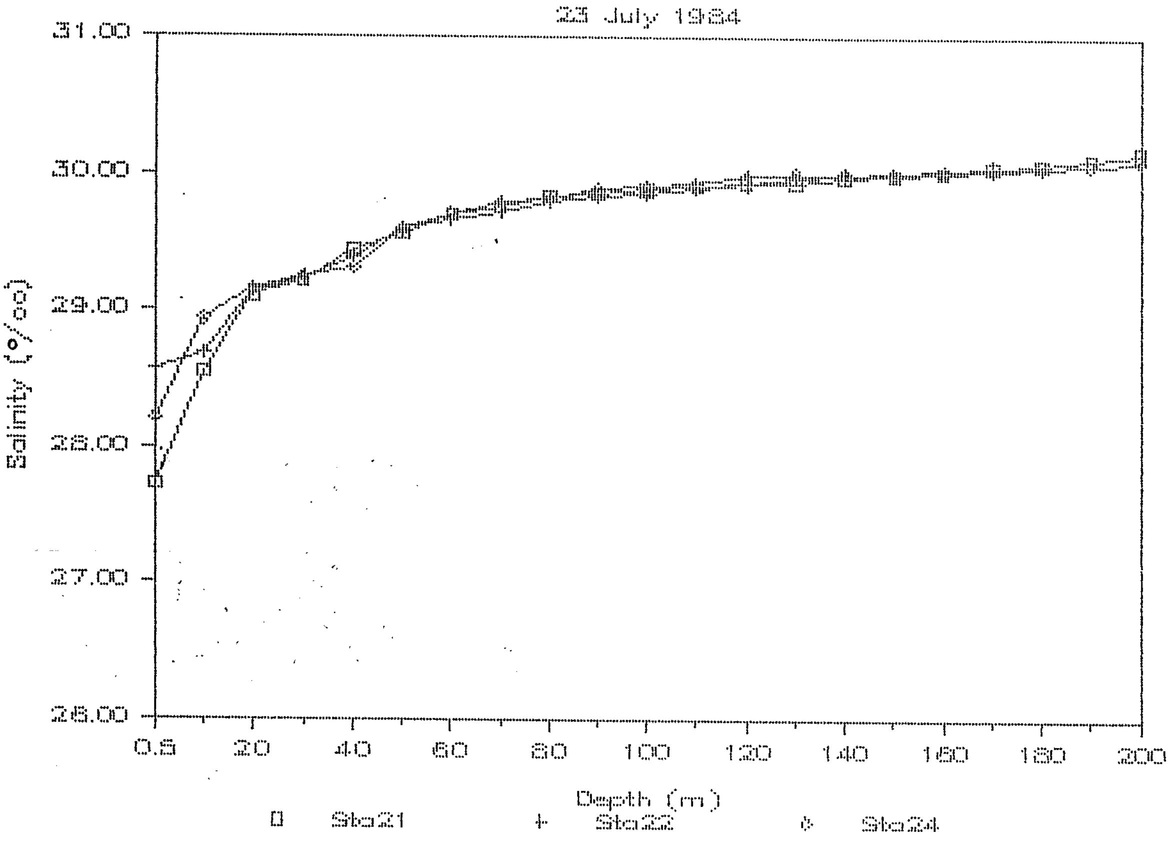
+ Sta22
◇ Sta24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29.00
28.00
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26.00
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120
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160
180
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Depth (m)
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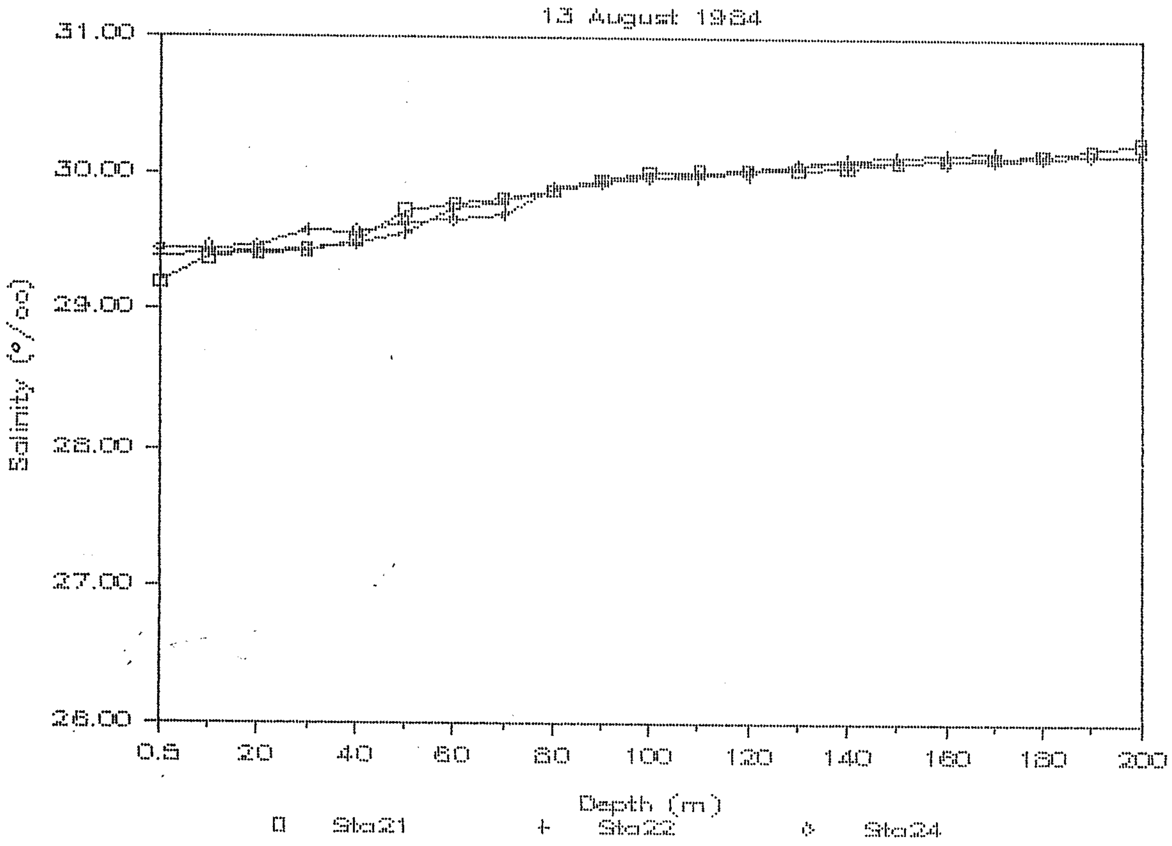
+ Sta22
◇ Sta24


13 August 1984
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30.00
29.00
28.00
27.00
26.00
Salinity (°/oo)
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80
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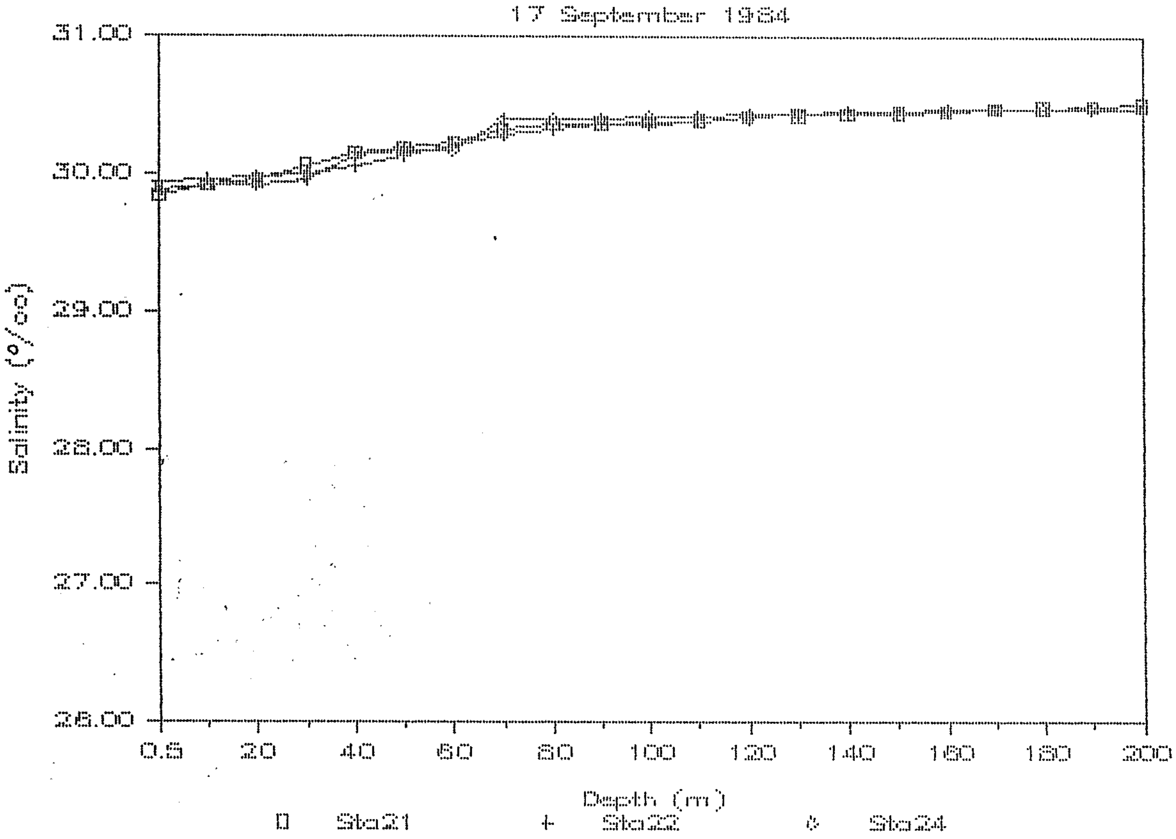
120
140
160
180
200
Depth (m)
□ Sta21
+ Sta22
◇ Sta24


17 September 1984
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Salinity (°/oo)
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Depth (m)
□ Sta21
+ Sta22
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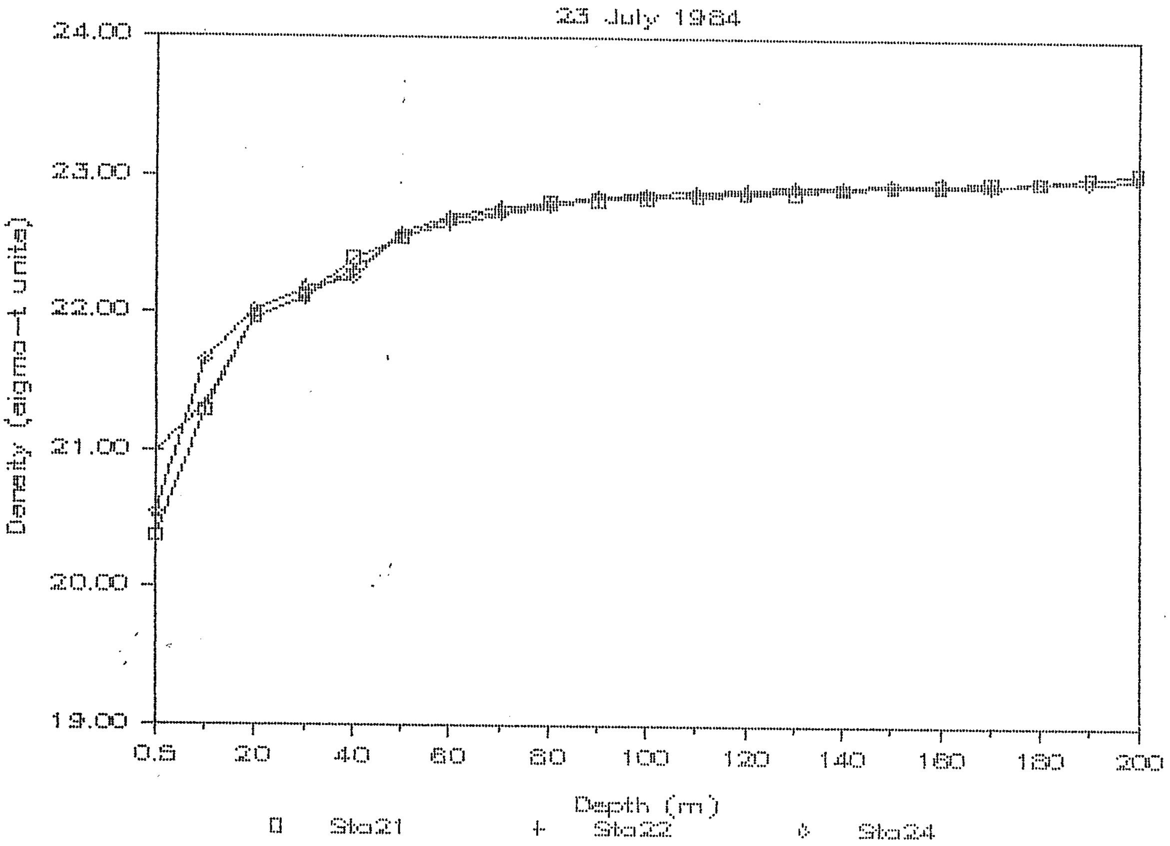
23 July 1984
Density (sigma-t units)
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22.00
21.00
20.00
19.00
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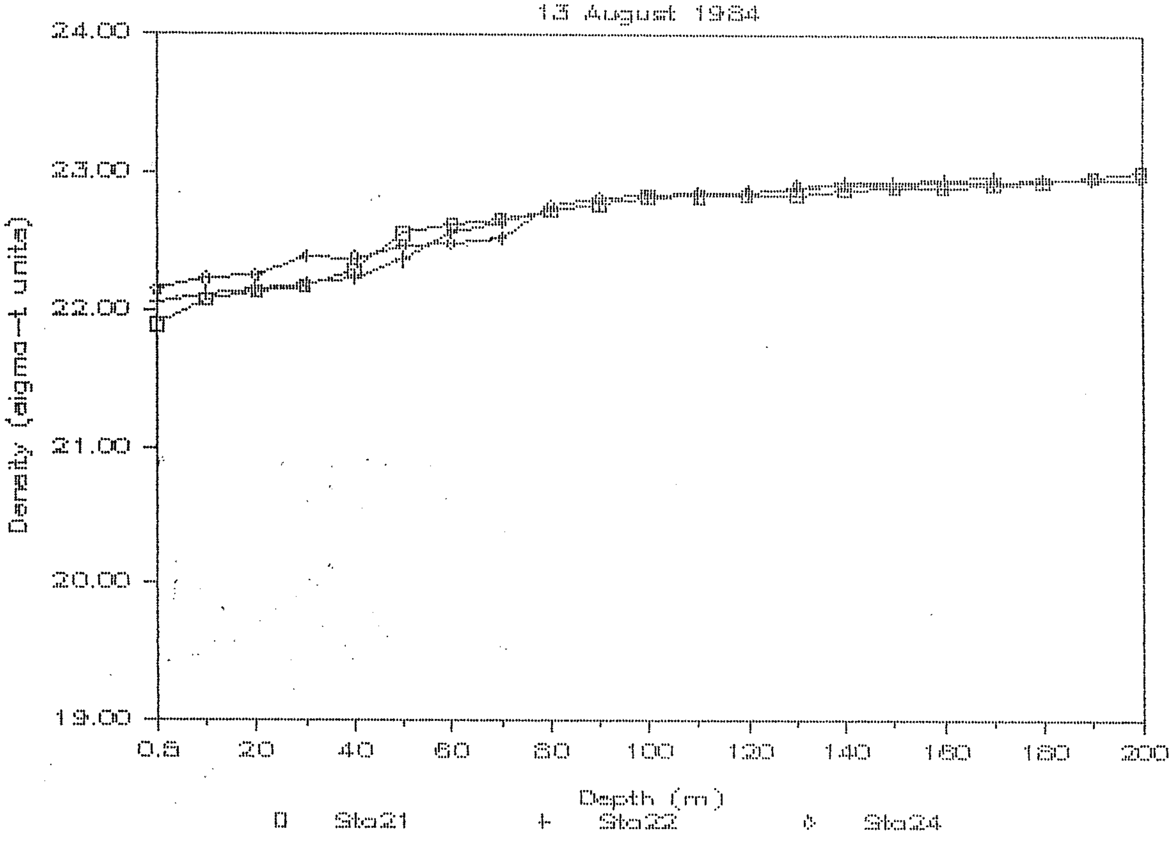
Depth (m)
□ Sta21
+ Sta22
◇ Sta24


13 August 1984
Density (sigma-t units)
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22.00
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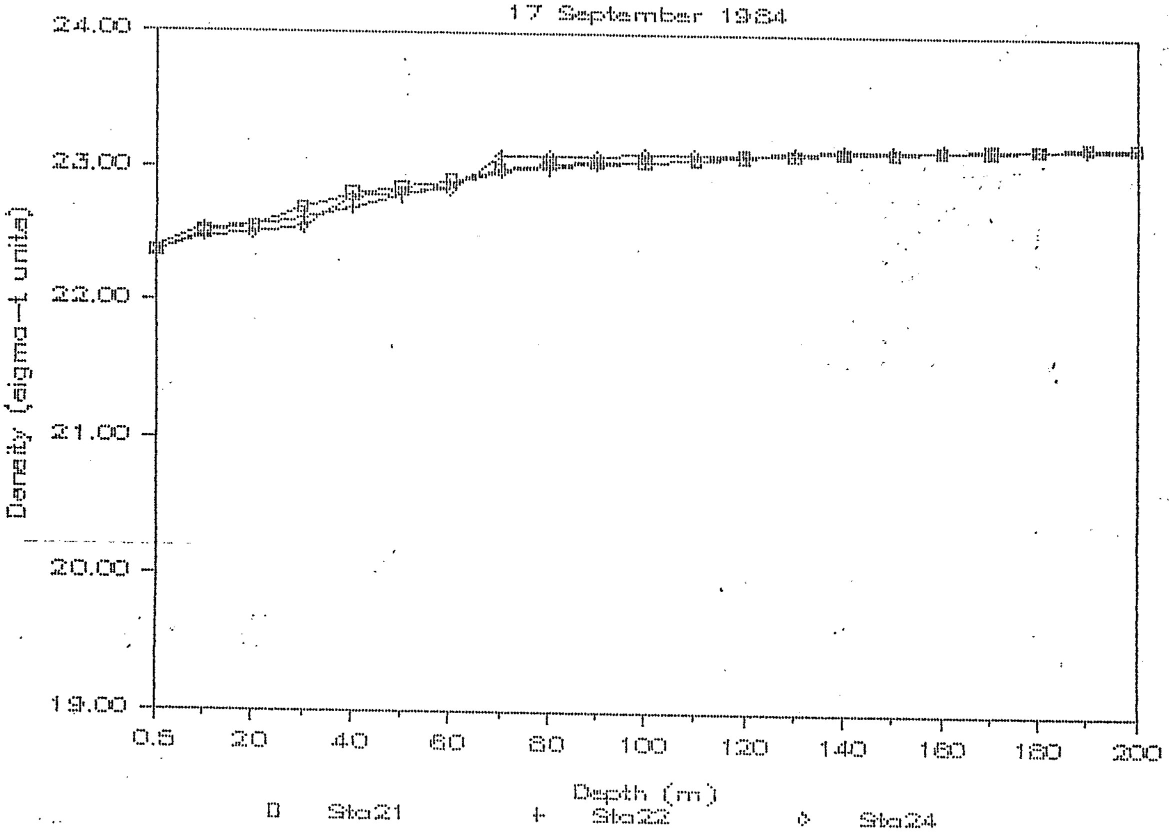
Depth (m)
□ Sta21
+ Sta22
◇ Sta24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Density (sigma-t units)
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160
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200
Depth (m)
□ Sta21
+ Sta22
◇ Sta24

3.0 WATER COLUMN STUDIES

A. Copping, T. Jagielo, B. Dumbauld, E. Welch

3.1 Introduction

The surface waters of Elliott Bay are currently receiving effluent from the Renton Treatment Plant (RTP) via the Duwamish River plume. Primary production in Elliott Bay is not enhanced by nutrients in the effluent, as nutrients are already available in greater than limiting concentrations in Puget Sound surface waters (Campbell et al. 1977). Most particulate and soluble species of chemicals in RTP effluent do not reside in the water column for sufficient periods, or in sufficient quantities to adversely affect plankton levels. Ammonia, however, is discharged at approximately 1,000 ug-at per liter of effluent. Surface mapping during the Seahurst baseline study shows very low levels of phytoplankton (up to 40% lower than ambient levels in Elliott Bay) in the Duwamish River, suggesting a toxic effect of some constituent of the effluent. Removal of RTP effluent from the Duwamish River may alleviate this effect, and may result in higher phytoplankton productivity in the estuary.

3.2 Purpose and Objectives

3.2.1 Purpose

The purpose of the water column study was to provide a baseline of biological, chemical and physical data for Elliott Bay in order to answer three specific questions:

1. When the RTP effluent is removed from the Duwamish River, how will the biological and chemical populations in the water column recover?
2. How successful was the siting of the outfall? (Does the waste field rise above 100 meters at any time, and does the plume enter the

inner part of Elliott Bay as identified by changes in biological and chemical parameters?)

3. What are the prevailing biological, chemical and physical conditions in the water column in inner and outer Elliott Bay, and in the nearby areas of Puget Sound, before sewage discharge off Duwamish Head?

3.2.2 Specific Objectives

1. Determine the levels of plankton in Elliott Bay before the construction of an outfall at Duwamish Head (discrete water column stations).
2. Determine the distribution of Duwamish River water in Elliott Bay and its influence on plankton growth (underway surface mapping and ammonia uptake studies).
3. Determine the ecological differences between the inner and outer parts of Elliott Bay and the main basin of Puget Sound (discrete water column stations).
4. Document nutrient and plankton levels in the Duwamish estuary prior to the removal of RTP effluent from the river (discrete stations and underway surface mapping).
5. Determine the levels of ammonia which are toxic/stimulatory to phytoplankton (ammonia studies).

3.3 Methods and Materials

3.3.1 Field Program

The goals of the water column study were approached by sampling six water column stations (21A, 21B, 22A, 22B, 23A, and 23B) weekly, in Elliott Bay and the surrounding area. A and B casts at a single station were repetitive casts separated by 1 to 4 hours in time. A seventh station (24) was sampled monthly. Each station was sampled in order to determine levels of physical and chemical parameters, and their spatial variability. Levels of phytoplankton biomass and production, zooplankton biomass and dissolved nutrients were measured for comparison with post-discharge conditions.

Stations 21A, 21B, and 24 were chosen in the main basin of Puget Sound, north and south of Elliott Bay, in order to compare water column conditions in the Bay with those of neighboring waters. Similarly, stations in the outer portion of Elliott Bay (22A and 22B) were compared with those of inner Elliott Bay (23A and 23B). Station locations and depths are summarized in Table 3.1 and Figure 3.1.

A cruise track for underway mapping was chosen to circumnavigate Elliott Bay from north of Four Mile Rock (off Magnolia Bluff), clockwise past downtown Seattle, around Alki Point and south into the next embayment (Figure 3.1).

3.3.1.1 Discrete Water Samples and CTD Calibration

Water samples were collected with a General Oceanics Rosette containing eleven 5-liter bottles. The Interocean CTD and rosette were mounted together in a frame containing a Martek transmissometer and a Licor quantum meter. One bottle was equipped with reversing thermometer racks. The depths sampled at each station are summarized in Table 3.2. Temperature, conductivity, dissolved oxygen, light transmittance, irradiance and depth were measured continuously on each cast with the CTD. Calibration samples for temperature, salinity and dissolved oxygen were taken manually at intermediate and bottom sampling depths.

3.3.1.2 Temperature Calibration

Temperature was measured using duplicate reversing thermometers. The thermometers were read onboard, and the CTD temperature values corrected by computer, based on periodic calibration checks for each thermometer tested at

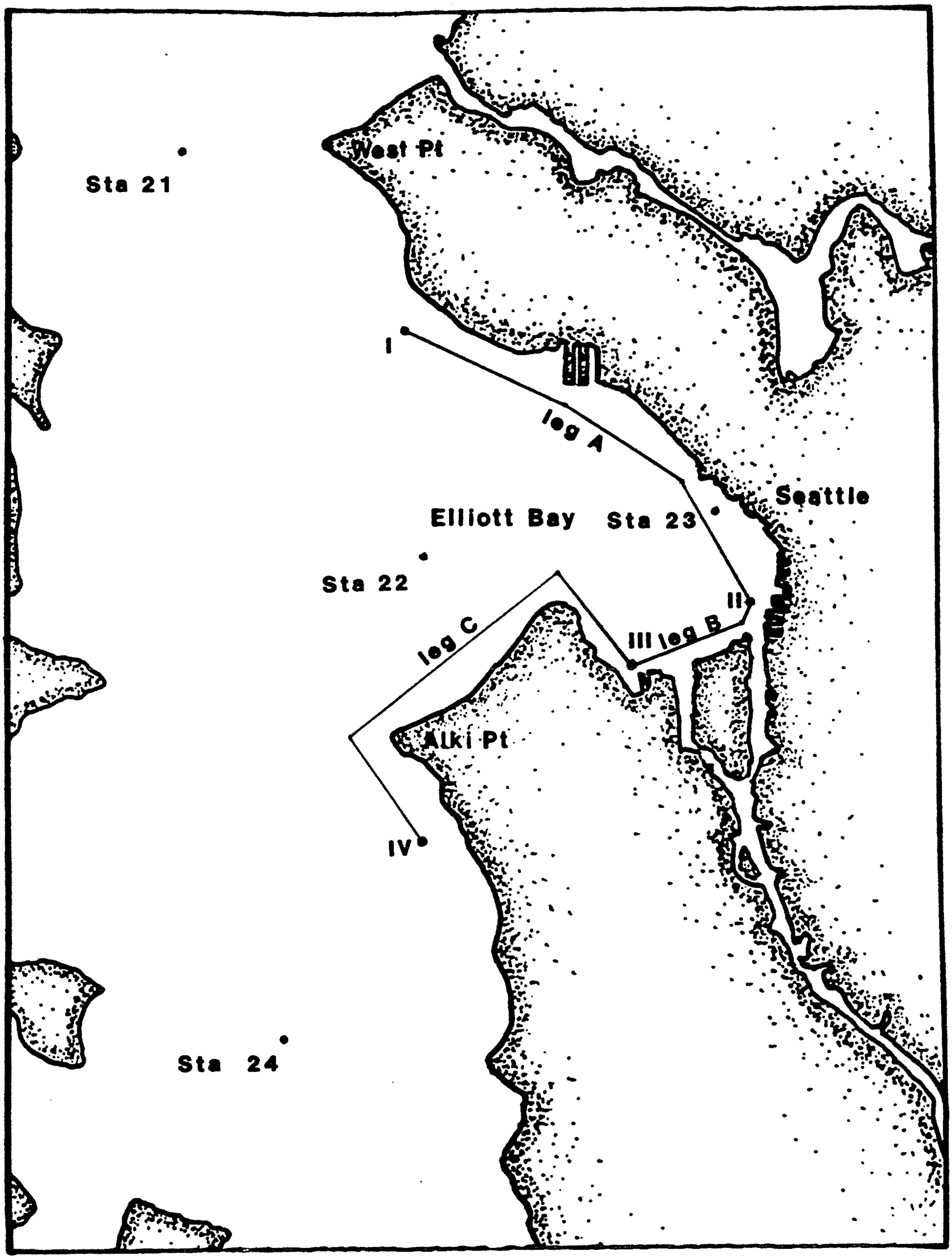

Figure 3.1. Map of Elliott Bay and neighboring water of Puget Sound. Water column station numbers 21 through 24, and underway cruise track are shown.

Table 3.1. Location of discrete water column stations and bottom depths.

Station No.	Latitude	Longitude	Bottom Depth (m)	Location
21	47° 39.6'N	122° 28.8'W	220	West Point
22	47° 35.8'N	122° 25.2'W	180	Outer Elliott Bay
23	47° 36.5'N	122° 21.2'W	75	Inner Elliott Bay
24	47° 32.9'N	122° 26.4'W	220	South of Alki

Table 3.2. Water bottle sampling depths for Duwamish Head Baseline.

	STATION NUMBER							
Z	21A	21B	22A	22B	23A	23B	24	
*0	np	n	npc	n	npc	n	n	
*3	np	n	npc	n	npc	n	n	
*5	np	n	npc	n	npc	n	n	
*10	np	n	npc	n	npc	n	n	
*20	npo	no	npco	no	npco	no	no	
50	n	n	n	n	n	n	n	
75	n	n	n	n	no	no	n	
100	n	n	n	n			n	
150	n	n	n	n			n	
200	no	no	no	no			no	Totals
	10n	10n	10n	10n	7n	7n	10n	570n
	5p	2o	5p	2o	5p	2o	2o	126o
	2o		2o		2o			150p
			5c		5c			100c

n = chlorophyll and nutrient
o = oxygen and salinity calibration samples
p = phytoplankton species samples
c = carbon-14 productivity experiments

*At stations 22A and 22B and 23A and 23B, these depths are replaced by 100%, 50%, 25%, 10% and 1% light depths respectively.

the School of Oceanography, University of Washington.

3.3.1.3 Salinity Calibration

Salinity samples were collected in standard salinity bottles and were analyzed on the University of Washington conductance salinometer. Each batch run was standardized using Copenhagen standard seawater.

3.3.1.4 Dissolved Oxygen Calibration

Water was collected in Carpenter oxygen bottles, treated according to Carpenter (1964) and the samples kept cool and dark until analyzed by the Water Column group using the method of Carpenter (1964).

3.3.1.5 Nutrients

Nutrient samples were collected in acid-washed 250 ml plastic bottles and frozen immediately on board.

Nitrate, nitrite, ammonia, phosphate and silicate were analyzed as soon as possible after each cruise, and not later than one month. Analysis was performed by autoanalyzer by the routine chemistry laboratory of the School of Oceanography using the methods of Strickland and Parsons (1972). The instrument was standardized every 4 hours with standards made with low nutrient North Pacific seawater. Unknown standards were included with the analyses to maintain additional checks on the data quality.

3.3.1.6 Chlorophyll

Chlorophyll samples were collected at each depth. Up to 280 ml were filtered over glass fiber filters and analyzed by the fluorometric method of Strickland and Parsons (1972).

3.3.1.7 Zooplankton

Vertical net hauls were made using a 1/2 m, 209 um Puget Sound closing net according to the schedule in Table 3.3. Hauls were split with a Folsom splitter. One half was filtered for dry weight analysis and the other

Table 3.3. Schedule of zooplankton net hauls for Duwamish Head Baseline Study.

	STATION NUMBER				
	21	22	23	24	Totals
Archived	2	2	2	1	63
No. of hauls	2	2	2	1	63
Dry weight analysis	2	2	2	1	63
Species identification	1	1	1	1	63

preserved with formalin for species identification.

Zooplankton biomass estimates were obtained by dry weight analysis. One quarter to one half split from each zooplankton haul was filtered over a pre-weighed glass-fiber filter. The filters were oven-dried on board and weighed again when completely dry to obtain a dry weight estimate (Lovegrove 1966).

Zooplankton species were identified and the dominant species counted. Dominant copepod species were further divided into life-stages.

3.3.1.8 Phytoplankton

Phytoplankton species samples were preserved with 4% formalin and archived.

3.3.1.9 Primary Production

Primary productivity was determined by the C-14 uptake method as outlined in Strickland and Parsons (1972). Samples were taken from five light depths as determined by quantum meter traces, or secchi disc casts. The samples were incubated on deck using neutral density light filters, from local apparent noon (LAN) until sunset. Carbon-14 activity was measured using a Packard Tricarb Liquid Scintillation Spectrometer Model at the School of Fisheries. Surface incident radiation was measured using a Licor quantum meter and integrator, throughout each incubation day.

3.3.1.10 Underway Sampling

The underway sampling system measured surface water properties using the sea water pumping system onboard the R/V Liberty. Continuous measurement of ammonia and *in vivo* fluorescence followed that of Strickland and Parsons (1972). Temperature and salinity was measured using an Ocean Data Equipment instrument. Chlorophyll was measured on a Sequoia-Turner Model 112 fluorometer with a flow-through sampling cell. Particle scattering was measured using a Monitek Model 31 continuous-flow nephelometer. All sensors are computer compatible and were monitored with an HP-41CV programmable calculator and interface loop, controlling a data acquisition system.

3.3.2 Ammonia Toxicity Experiments

Three types of experiments were carried out to examine the relationship between high ammonia levels in the Duwamish River plume and the growth of phytoplankton in Elliott Bay: two sets were laboratory experiments, one a field experiment.

3.3.2.1 Continuous Short-Term Laboratory Experiments

The marine diatom Skeletonema costatum was grown in filtered seawater collected from Dabob Bay, an unimpacted fjord in Puget sound. IMR medium was added to maintain growth (Eppley et al. 1967).

A control and an experimental vessel, each containing 4 liters of seawater and culture, were used for each experiment. The experimental vessel had 1200 ug-at/l ammonia added in the form of NH_4Cl. During the second experiment, approximately 25 uCi/l C-14 were added to the experimental vessel.

Each beaker was monitored continuously for ammonia by Autoanalyzer, over the course of a 3-hour experiment. A preserved sample for cell counts, a nutrient sample (nutrient samples were frozen until analysis) and a salinity sample were taken from each beaker at the start of the experiment. Chlorophyll was monitored in both vessels every 15 minutes. During the second experiment, C-14 was also sampled every 15 minutes. The experiments were carried out under constant light of 150-200 $uE/m^2/s$ and a constant temperature of 21°C.

3.3.2.2 Batch Laboratory Experiments

Seawater was collected in the field at three locations and filtered. Skeletonema costatum and ammonia (as NH_4Cl) were added to 14 one-liter flasks, containing 600 mls of seawater, according to the following experimental design:

Beaker No.	Location of Water	Addition of NH_4 (as ug-at/l-N)
1, 2	Station 22, 1 m	0
3, 4	Station 22, 1 m	10
5, 6	Station 22, 1 m	215
7, 8	West Waterway, 1 m	0
9, 10	West Waterway, 1 m	215
11, 12	West Waterway, 10 m	0
13, 14	West Waterway, 10 m	215

The flasks were incubated at 18°C under 150-200 uE/m^2/s constant light for 4 to 5 days. A preserved sample was taken at the start of each experiment for future determination of cell types. A total of three experiments were completed. Approximately 25 u Ci/l C-14 was added to all flasks during the third experiment. Once a day, each flask was sampled as follows:

Experiment 1:	chlorophyll, nutrients
2:	chlorophyll
3:	chlorophyll, C-14

3.3.2.3 Continuous Field Experiments

On four occasions, water was collected in the Duwamish River plume and incubated on board to continuously monitor ammonia levels and phytoplankton growth under ambient conditions.

During each experiment, ten liters of 1 m depth plume water was placed in 20-liter polypropylene carbuoys, C-14 added, and the carbuoys incubated in running seawater under ambient light for 4-6 hours. Incident radiation was monitored throughout the course of each experiment. Temperature, salinity, dissolved nutrients and preserved cells were sampled at the start and finish of every experiment. Ammonia concentration was monitored continuously by Autoanalyzer; C-14 was sampled every 15 minutes and chlorophyll every half hour. The following table details the origin of experimental water and C-14 addition to each experiment:

Expt. #	Date	Carbuoy #	Location of Sample	Approx. C-14 addition (in uCi/l)
1	8/21/84	1	Station 23	11
		2	No Sample	--
2	8/24/84	1	Station 22 (control)	28
		2	mouth of W. Waterway	28
3	9/07/84	1	mouth of W. Waterway	29
		2	off Ferry Terminal	29
4	9/21/84	1	upper West Waterway	38
		2	mouth of W. Waterway	38

Phytoplankton rates were calculated for each experiment in $mgC/m^2/hr$ and normalized to mg chlorophyll. Correlations between ammonia and growth rate, and incident radiation and growth rate were examined.

3.3.3 Data Analysis

3.3.3.1 Data Analysis of Discrete Water Column Station Measurements

The water column data were analyzed primarily to distinguish differences at stations in inner and outer Elliott Bay and in the open Sound.

Measurements of water column parameters including chlorophyll, phaeopigments and primary production were integrated over the photic zone. Dissolved nutrient values were integrated to 50 meters depth.

Measurements of zooplankton species and plankton biomass are estimates integrated over the depth of the net tow.

Summary statistics (mean, standard deviation and number of observations) were calculated for each parameter, for each station over the three month sampling period. Kruskal-Wallis non-parametric tests (Zar 1984) were performed on each parameter, in order to distinguish a difference among stations. Based on the results of the Kruskal-Wallis tests, multiple comparison testing (Zar 1984) determined which stations were significantly different from one another.

3.3.3.2 Quality Control

Quality control of data analysis was performed in five steps:

1. On-board cross-checks of sample numbers.

Each discrete sample taken on-board ship was recorded on two separate log forms, to allow cross-checks for accuracy of sample identification. Underway transect data was checked by frequent time and location notations independent of the computerized system.

2. Duplicate sample analysis.

Duplicate oxygen, salinity, nutrient and chlorophyll samples were taken regularly and analyzed "blind" in order to check the precision of analyses. C-14 experimental results and temperature determinations were the result of two measurements at each depth. Rejection levels for difference between duplicate samples differs with the type of sample, and summarized in the Seahurst Baseline Final Report. Rejection levels have been calculated based on confidence limits of sampling and analysis procedures (Strickland and Parsons 1972).

3. Removal of outliers from the data set.

After analysis, data were reviewed and questionable values rechecked for sample identification accuracy. Unacceptable values were removed from the data set before going onto keypunch forms.

4. Computer entry of data.

Keypunching of data was carried out by experienced personnel of the water column group. Hardcopies of all data files were made after entry and all numbers were checked for accuracy.

5. Graphical check of the data.

Data files were plotted by computer and the results reviewed by trained personnel in order to establish trends in the data and to act as an additional screening process for outliers and unlikely trends. Cross-checks to original data forms resulted from errors spotted at this stage. This step provided an important check on the underway data points which were handled by computer up to this point.

3.3.3.3 Underway Data Analysis

Data acquisition of underway instruments was controlled by a Hewlett-Packard system which monitored each channel every 13 seconds and recorded the data on a mini data cassette. The data was transferred to a Hewlett-Packard model 87 microcomputer and stored on 5-1/4" disc.

Chlorophyll and ammonia channels were calibrated on each cruise. Turbidity calibrations were performed periodically in the laboratory and temperature and salinity calibrations were checked against field samples. All calibrations were applied to raw data on the microcomputer. Plots of concentration versus distance were constructed to check for instrument error. The information was stored on flexible disc, resulting in one calibrated and one uncalibrated copy of the data.

3.4 Results

3.4.1 Discrete Hydrographic Samples

3.4.1.1 Grouping of Casts at a Single Location

Two CTD and hydrographic casts were carried out at stations 21, 22 and 23 during each weekly cruise in order to obtain sufficient measures of water column properties for statistical testing. In order to compare results of inner Elliott Bay (stations 23A and 23B), outer Elliott Bay (stations 22A and

22B) and open Puget Sound (stations 21A, 21B, and 24), it was necessary to show that repeated casts at a single location (A and B casts), although separated in time, were measuring the same water mass. Mann Whitney tests (Zar 1984) were applied to the means of integrated chlorophyll and phaeopigment measures from A and B casts at stations 21, 22 and 23. Results of the tests show that there was no significant difference between A and B casts at any of the three stations, at the 95% confidence level (Table 3.4).

3.4.1.2 Variability of Biological and Chemical Parameters

Basic statistics were calculated for chlorophyll, phaeopigments, dissolved nutrients and primary productivity in the water column at stations 21, 22, 23 and 24 (Table 3.5). Measures of biological activity in the water column (chlorophyll, phaeopigments and primary productivity) demonstrated high levels of variability, indicated by standard deviations which are greater than the arithmetic means. (Table 3.6 shows the coefficients of variation for the water column parameters.) This is a standard feature of biological populations in general, and marine plankton populations in particular, due to the temporal variability of phytoplankton communities and the mass movement of water parcels with entrained populations. Chemical constituents of seawater, such as dissolved nutrients, are less variable over time, with coefficients of variation less than 1 (Table 3.6). In particular, dissolved nutrients which are not limiting to phytoplankton growth in temperate waters, such as PO_4 and SiO_4, show lower variability compared to those which are strongly affected by phytoplankton growth such as NO_3, NO_2 and NH_4. Additional variability in ammonia concentration is caused by its chemically transient nature and highly variable input rates, as evidenced at station 23 in the Duwamish River plume.

3.4.1.3 Differences Among Stations

In order to distinguish between inner and outer Elliott Bay, and open

Table 3.4. Mann Whitney tests on chlorophyll and phaeopigment integrated to the 1% light depths at Sta. 21, 22, and 23. Test is used to determine significant differences between A and B hydro casts.

Sta.	Variable	df	Test Statistic U,U'	Tabled Value U .05,(2), df, df	Result
21	Chlorophyll	8, 11	57, 31	69	Cannot reject H_0*
	Phaeopigment	8, 11	48.5, 39.5	69	Cannot reject H_0
22	Chlorophyll	9, 10	53, 37	70	Cannot reject H_0
	Phaeopigment	9, 10	48.5, 41.5	70	Cannot reject H_0
23	Chlorophyll	9, 9	46, 35	64	Cannot reject H_0
	Phaeopigment	9, 9	45, 36	64	Cannot reject H_0

---

*H_0: the mean value of the given variable is the same for both replicate hauls.

Table 3.5. Statistics for water column parameters, integrated to the 1% light depth.

Variable	Sta. 21			Sta. 22			Sta. 23			Sta. 24		
	n	mean	Std. dev.	n	mean	Std. dev.	n	mean	Std. dev.	n	mean	Std. dev.
Chlorophyll a (mg/m^3)	19	3.93	4.61	19	3.53	4.56	18	1.62	1.96	3	3.97	4.87
Phaeopigment (mg/m^3)	19	0.98	1.27	19	0.91	1.30	18	0.62	0.67	3	1.28	1.52
PO_4 ($mg\text{-}at/m^3$)	11	1.55	0.46	10	1.60	0.39	10	1.71	0.31	3	1.49	0.53
SiO_4($mg\text{-}at/m^3$)	14	35.65	10.80	13	37.55	9.31	13	40.0	5.90	3	34.68	12.36
NO_3($mg\text{-}at/m^3$)	14	13.45	5.59	13	14.04	5.15	13	16.12	3.70	3	11.52	5.24
NO_2($mg\text{-}at/m^3$)	11	0.36	0.13	10	0.34	0.11	10	0.46	0.10	3	0.28	0.14
NH_4($mg\text{-}at/m^3$)	11	0.64	0.28	10	0.74	0.32	12	1.28	0.92	3	0.63	0.38
Primary Productivity ($mgC/m^3/d$)	1	59.01	-	8	142.91	217.30	8	111.37	196.52	-	-	-

Table 3.6. Coefficients of variation $(\frac{S}{\bar{X}})$ for water column parameters integrated to the 1% light depth.

Variable	Station 21	Station 22	Station 23	Station 24
Chlorophyll (mg/m^3)	1.17	1.29	1.21	1.23
Phaeopigments (mg/m^3)	1.30	1.43	1.08	1.19
PO_4 (mg/m^3)	.30	.24	.18	.36
S_iO_4 (mg/m^3)	.30	.25	.15	.36
NO_3 (mg/m^3)	.42	.37	.23	.46
NO_2 (mg/m^3)	.36	.32	.22	.50
NH_4 (mg/m^3)	.44	.43	.72	.60
Primary Productivity (mgC/m^3/d)	–	1.52	1.76	–

Puget Sound stations, non-parametric Kruskal-Wallis tests were performed on water column parameters at stations 21, 22 and 23, integrated to the 1% light depth (Zar 1984). Station 24 was not included in the analysis due to the small sample size (n=3). Results of these tests show that there was no significant difference among stations, at the 95% confidence level, for any of the parameters except chlorophyll. A multiple comparison test on the integrated chlorophyll data failed to separate any particular station from the others (Table 3.7). The more powerful Mann Whitney test, however, distinguishes station 23 chlorophyll from that of the collective grouping of stations 21, 22 and 24.

Further distinction between the inner Elliott Bay station (23) and open water stations 21 and 22 is found by examining chlorophyll and ammonia in the upper few meters of the water column - the area likely to be affected by the Duwamish River plume. Results of the non-parametric Kruskal-Wallis ANOVA and multiple comparison tests show a significant difference for both chlorophyll and ammonia, integrated to 5 meters, for station 23 (Table 3.8).

3.4.2 Zooplankton

3.4.2.1 Dominant Species of Zooplankton in Elliott Bay

The dominant species of zooplankton in Elliott Bay and neighboring waters are copepods. The same dominant species are found at stations 23 (inner Elliott Bay), 22 (outer Elliott Bay), 21 (West Point) and 24 (south of Alki Point), and correspond to those found in previous studies of the main basin of Puget Sound (Campbell et al. 1977) and in East Passage (Seahurst Baseline Study, 1984). These species include *Calanus pacificus*, *Pseudocalanus* spp., *Aetidius divergens*, *Oithona similis*, *Corycaeus anglicus*, *Microcalanus* sp., and *Paracalanus* sp. (Figure 3.2). Additionally, two larvaceans, *Oikopleura dioica* and *Fritillaria borealis*, were abundant during the summer and early fall of

Table 3.7. Kruskall-Wallis test results for water column parameters integrated to the 1% light depth at Sta. 21, 22 and 23. (Note Mann Whitney Test used for primary productivity at Sta. 22 and 23 only.)

Variable	df	Test Statistic (4)	χ^2 .05, df	Result	Multiple Comparison Test Results
Chl a	2	7.39	5.991	Reject H_0 $.01\ p < .025$	$\underline{23\quad 21\quad 22}$
Phaeopigment	2	4.95	5.991	Cannot Reject H_0 $.05 < p < .10$	———
PO_4	2	0.594	5.991	Cannot Reject H_0 $.75 < p < .90$	———
S_iO_4	2	1.94	5.991	Cannot Reject H_0 $.25 < p < .50$	———
NO_3	2	1.87	5.991	Cannot Reject H_0 $.25 < p < .50$	———
NO_2	2	4.58	5.991	Cannot Reject H_0 $.10 < p < .25$	———
NH_4	2	5.69	5.991	Cannot Reject H_0 $.05 < p < .10$	———
Primary Productivity	2	$U = 33$ $U^1 = 31$	U .058, 8 (2) = 59	Cannot Reject H_0 $.20 < 1$	———

H_0: the mean value of the given variable is the same at all three stations.

*Multiple comparisons procedure for unequal sample sizes after Zar, 1984; Dunn 1964.

Table 3.8. Kruskal-Wallis test results for water column parameters integrated to 5 m depth at stations 21, 22 and 23.

Variable	df	Test statistic (H)	χ^2 .05, df	Result	Multiple Comparison Test Result
Chlorophyll	2	8.282	5.991	Reject H_0	$\underline{23\quad 22}\quad 21$ $\underline{22\quad 21}$
Ammonia	2	18.980	5.991	Reject H_0	$23\quad \underline{22\quad 21}$

H_0: The mean values of each variable is the same for stations 21, 22 and 23.

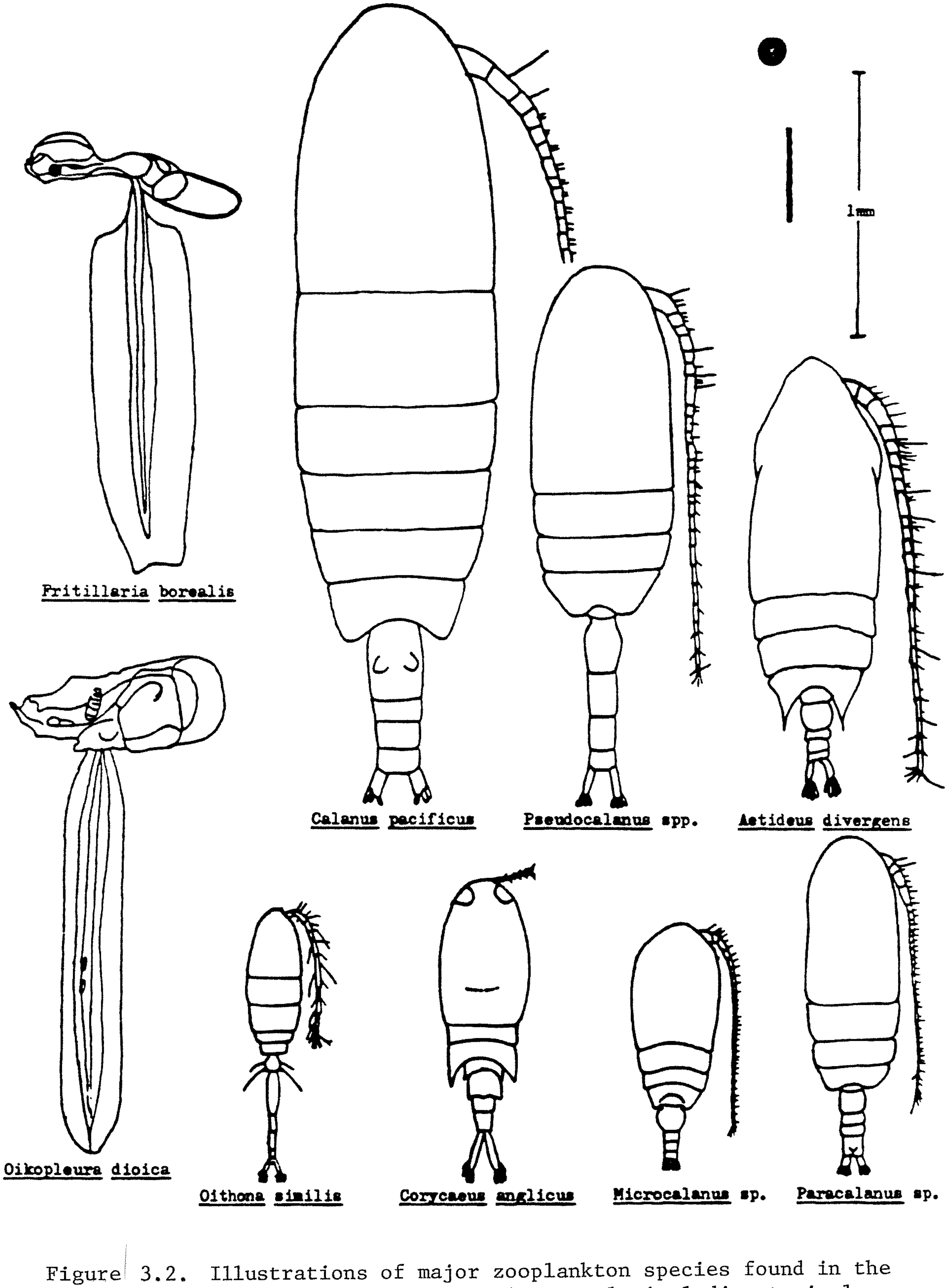

Figure 3.2. Illustrations of major zooplankton species found in the study area. Drawn to a 1 mm scale including typical phytoplankton cells.

1984.

Basic statistics for the nine dominant species of zooplankton were calculated at stations 21, 22, 23 and 24 (Table 3.9). Using dry weight conversions from the literature (Appendix A), the zooplankton species data were calculated as biomass, and means and standard deviations determined (Table 3.10). Biomass data obtained from measurements of net plankton dry weight were included in Table 3.10.

A small calanoid copepod (*Paracalanus* sp.) and a small cyclopoid copepod (*Corycaeus anglicus*) were numerically dominant at the four Duwamish Head stations. In terms of biomass, however, the much larger calanoid *Calanus pacificus* was important (Tables 3.9 and 3.10).

3.4.2.2 Variability of Zooplankton Species and Biomass

In general, there was a high degree of variability in the zooplankton species data with the standard deviation increasing proportionally to the mean. The natural variability of a growing marine zooplankton population is necessarily large when one considers that life stages of a single species may change in length and weight by orders of magnitude over a few month period. Measures of net plankton dry weight exhibit a lower degree of variability due to the masking effect of water column phytoplankton and seston on zooplankton abundance.

3.4.2.3 Species and Biomass Differences Among Stations

Zooplankton species differences among stations were examined using the non-parametric Kruskal-Wallis one-way analysis of variance test (Zar 1984). Multiple comparison tests were run on species showing a difference among stations (Table 3.11). Most species (except *Oithona similis* and the two larvaceans) were significantly different, at the 90% confidence level, at stations 21 (West Point) and 23 (inner Elliott Bay), with station 22 (outer

Table 3.9. Statistics for zooplankton species data (# animals/m^3).

Species	Sta. 21			Sta. 22			Sta. 23			Sta. 24		
	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.
Calanus pacificus	9	302	319	10	179	307	10	191	106	3	766	1231
Microcalanus sp.	9	645	308	10	316	196	10	105	145	3	129	74
Paracalanus sp.	9	2492	1866	10	1543	1114	10	1028	819	3	3416	4243
Pseudocalanus spp.	9	50	34	10	19	29	9	11	13	3	30	38
Aetidius divergens	9	91	88	10	60	44	10	26	50	3	76	43
Oithona similis	9	626	448	10	392	191	10	665	295	3	682	627
Corycaeus anglicus	9	2787	3281	10	1618	1438	10	767	285	3	4602	6264
Oikopleura dioica	6	457	662	8	255	495	5	22	30	3	1104	1867
Fritillaria borealis	4	1533	2853	6	285	392	3	10	11	2	757	1018

Table 3.10. Statistics for zooplankton species data converted to dry weight biomass (mg/m^3) also listed is net plankton dry weight from direct measurement.

	Sta. 21			Sta. 22			Sta. 33			Sta. 24		
Species	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.	n	Mean	Std. Dev.
Calanus pacificus	9	22.46	14.10	10	11.49	14.42	10	10.06	4.97	3	37.90	56.44
Microcalanus sp.	9	2.14	1.08	10	1.02	0.62	10	0.31	0.43	3	0.43	0.25
Paracalanus sp.	9	8.41	7.87	10	4.37	3.45	10	2.64	2.03	3	9.68	12.02
Pseudocalanus spp.	9	0.61	0.49	10	0.19	0.37	9	0.12	0.19	3	0.41	0.50
Aetidius divergens	9	3.40	3.42	10	1.71	1.22	10	0.49	0.97	3	2.16	1.04
Oithona similis	9	0.99	0.68	10	0.60	0.27	10	1.07	0.52	3	1.08	1.11
Corycaeus anglicus	9	9.0	9.65	10	4.70	3.30	10	2.49	0.91	3	10.27	11.78
Oikopleura dioica	6	1.37	1.99	8	0.77	1.48	5	0.07	0.09	3	3.31	5.60
Fritillaria borealis	4	4.60	8.56	6	0.85	1.18	3	0.03	0.03	2	2.27	3.05
Plankton dry weight	17	104.8	24.1	22	74.2	20.7	18	49.4	25.1	3	70.2	31.5

Table 3.11. Kruskall-Wallis test results for zooplankton species data ($\#/m^3$) and plankton biomass ($\mu g/m^3$) data at Stations 21, 22, and 23.

Species	df	Test statistic (H)	X^2 .10, df	Result	Multiple comparison test results		
Calanus pacificus	2	6.665	4.605	Reject Ho $.025 < p < .05$	22	23	21
Microcalanus sp.	2	16.160	4.605	Reject Ho $p < .001$	23	22	21
Paracalanus sp.	2	6.083	4.605	Reject Ho $.025 < p < .05$	23	22	21
Pseudocalanus spp.	2	6.377	4.605	Reject Ho $.025 < p < .05$	23	22	21
Aetidius divergens	2	8.279	4.605	Reject Ho $.01 < p < .025$	23	22	21
Oithona similis	2	3.532	4.605	cannot reject Ho			
Corycaeus anglicus	2	10.955	4.605	Reject Ho $.001 < p < .005$	23	22	21
Oikopleura dioica	2	3.803	4.605	cannot reject Ho			
Fritillaria borealis	2	4.330	4.605	cannot reject Ho			
Plankton dry weight	2	26.436	4.605	Reject Ho $p < .001$	23	22	21

Ho: the mean $\#/m^3$ of the given species or the mean plankton biomass is the same at all three stations.

Elliott Bay) falling somewhere in between. Plankton dry weight was similarly tested and found to be statistically different at each of the three stations (Table 3.11). Station 24 was not included in the analysis due to the statistically small number of data points.

3.4.2.4 Estimation of Net Haul Accuracy

On August 24, 1984, overlapping depth interval tows were carried out at station 22. The intervals chosen were: 52-0 m, 100-52 m, 152-100 m, 175-152 m and 175-0 m. Results of zooplankton species and plankton dry weight analyses are presented in Table 3.12. This exercise points to an underestimate of net plankton biomass as measured by vertical net hauls from sea floor to surface. Addition of the separate depth interval data yields a more accurate measure of the greater than 209 um fraction of the water column. Biomass of the major zooplankton species, however, are more accurately represented by the bottom to surface net hauls. Net clogging and avoidance are the principle causes of the underestimate of net plankton, leading to a lower capture of phytoplankton, seston and large, rare zooplankters.

3.4.2.5 Stratification of Copepod Species in the Water Column

Species specific stratification of the water column is apparent in the kite diagram (Figure 3.3) of copepod vertical distribution. Certain species of copepod are known to be evenly distributed throughout the water column, or congregated in the near surface layer (*Corycaeus anglicus* and *Paracalanus* sp.), while others are mid-depth and deep-water inhabitants (*Microcalanus* sp., *Pseudocalanus* spp., *Oithona similis*, *Aetidius divergens* and *Calanus pacificus*). The apparently even distribution of *Calanus pacificus* is due to the presence of copepodids in the upper layer, while the adults reside below 50 m.

Table 3.12. Zooplankton species and net plankton biomass results from overlapping depth interval vertical hauls. The calculated total is the sume of the depth interval hauls and the measured total is from hauls through the while water column.

Depth Interval (m)	Plankton Biomass g/m^2	Species Biomass g/m^2
0-52	2.5610	.1595
52-100	1.2812	.2854
100-152.5	1.1004	.3004
152.5-175	.4261	.0465
Calculated total	5.3687	.7918
Measured total 175-0m	3.8225	.8217

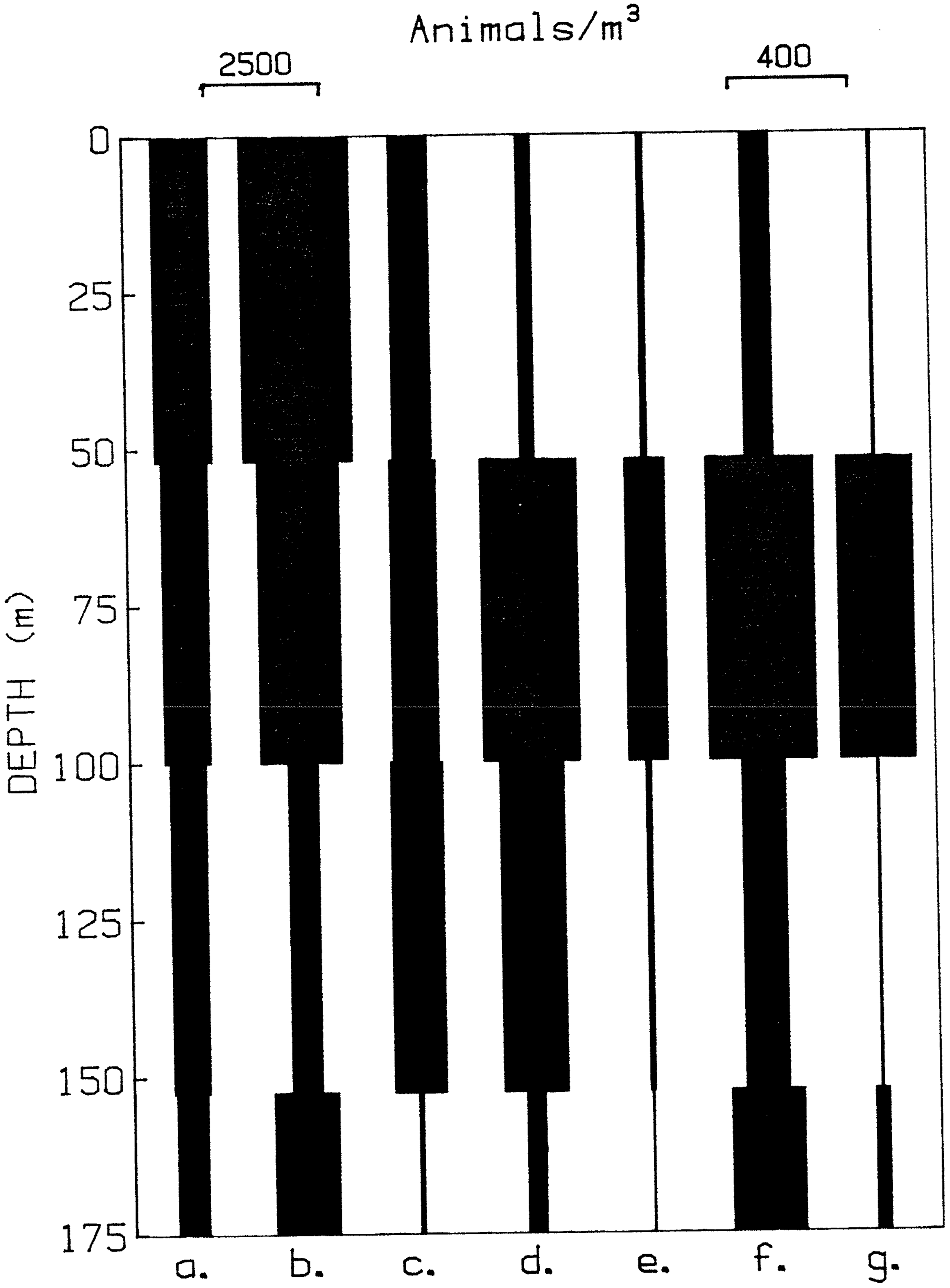

Figure 3.3. Depth distribution of major copepod species at Sta. 22, August 24, 1984. a) *Corycaeus anglicus*, b) *Paracalanus* sp., c) *Calanus pacificus*, d) *Microcalanus* sp., e) *Pseudocalanus* spp., f) *Oithona simulis*, g) *Astideus divergens*.
a & b scale = 2500 animals/m^3
c-g scale = 400 animals/m^3

3.4.3 Underway Sampling

3.4.3.1 Underway Cruise Track

Two underway sampling transects produced complete data during the summer 1984 period (July 24th and August 21st). A breakdown in the ammonia system made data from a third cruise (September 24th) less useful. The same cruise track was followed on each occasion (Figure 3.1) and the results were analyzed by leg: from Magnolia Bluff to the downtown ferry terminal-leg A; across the Duwamish River mouth and Harbor Island-leg B; from the west bank of the Duwamish to Alki Point and beyond-leg C. Plots of each parameter measured over distance are presented for the July cruise in Figure 3.4 and for the August cruise in Figure 3.5.

3.4.3.2 General Characteristics of Elliott Bay Surface Water

The strongest feature of Elliott Bay surface water on both transects was a persistent river plume signal from the Duwamish River, characterized by low salinity and temperature, and high turbidity and ammonia concentration. The signal appeared to be coming mainly from the West Waterway, with little contribution from the East Waterway, but may in fact represent a mixing of the water from each side of Harbor Island. A distinctive parcel of water was seen in the vicinity of Alki Point on both cruises, as indicated by elevated turbidity on July 24th and by high temperature, chlorophyll and ammonia on August 21st. This water parcel may have been formed by circulatory processes concentrating particles from south of Alki, or may reflect effluent from the Alki sewage treatment plant. Histograms of chlorophyll and ammonia data from inner and outer Elliott Bay were constructed for both cruises (Figures 3.6 and Figure 3.7). Generally, chlorophyll and ammonia were higher in the inner bay. Ammonia differences are most apparent during the August cruise when ammonia concentrations were highest in the Duwamish River, due to low flow conditions.

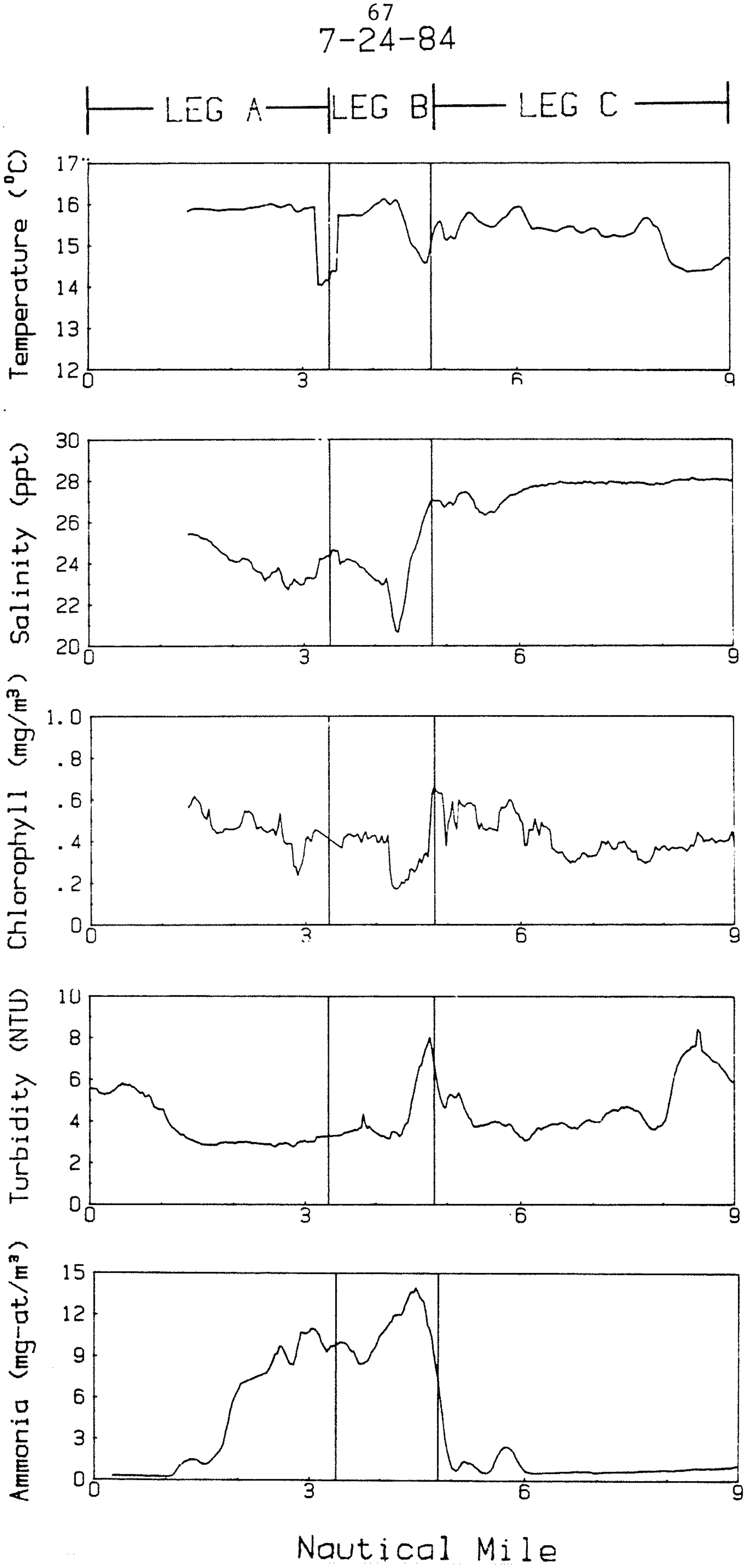

Figure 3.4. Plots of calibrated data obtained on an underway transect August 21, 1984. Individual channels are plotted over distance in nautical miles, with mile 0 being at Four-Mile Rock (Magnolia Bluff) and mile 9 south of Alki Point. The transect is broken into legs A, B, and C as indicated in Figure 3.1. The Duwamish River mouth is illustrated by a sharp drop in salinity and rises in turbidity and ammonia along leg B.

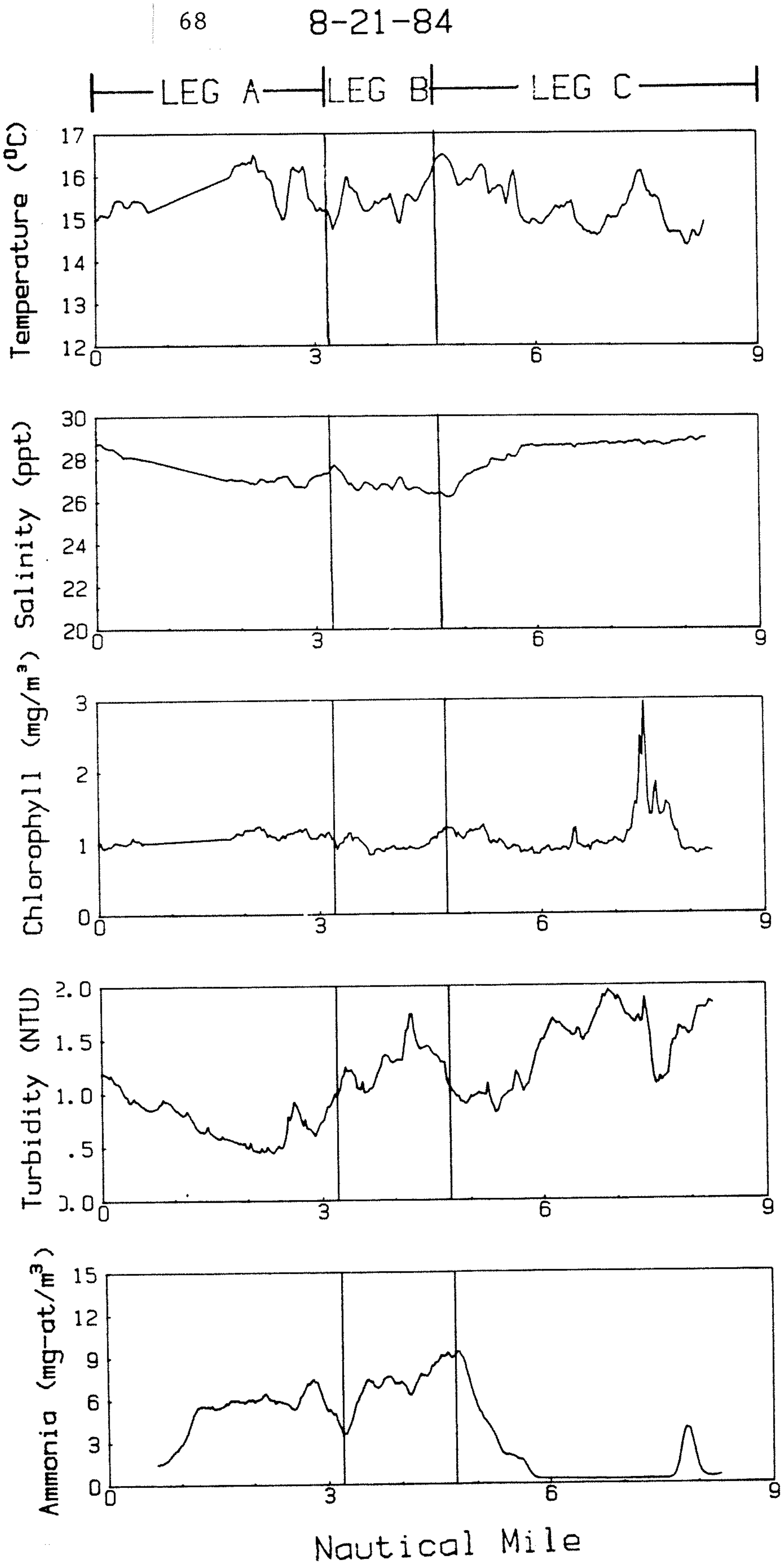

Figure 3.5. Plots of calibrated data obtained on an underway transect August 21 1984. Individual channels are plotted over distance in nautical miles, with mile 0 being at Four-Mile Rock (Magnolia Bluff) and mile 9 south of Alki Point. The transect is broken into legs A, B, and C as indicated in Figure 3.1. The Duwamish River mouth is shown as a rise in turbidity and ammonia. The salinity signal is less obvious due to low flow conditions. Note scale differences in turbidity and chlorophyll, compared to Figure 3.4.

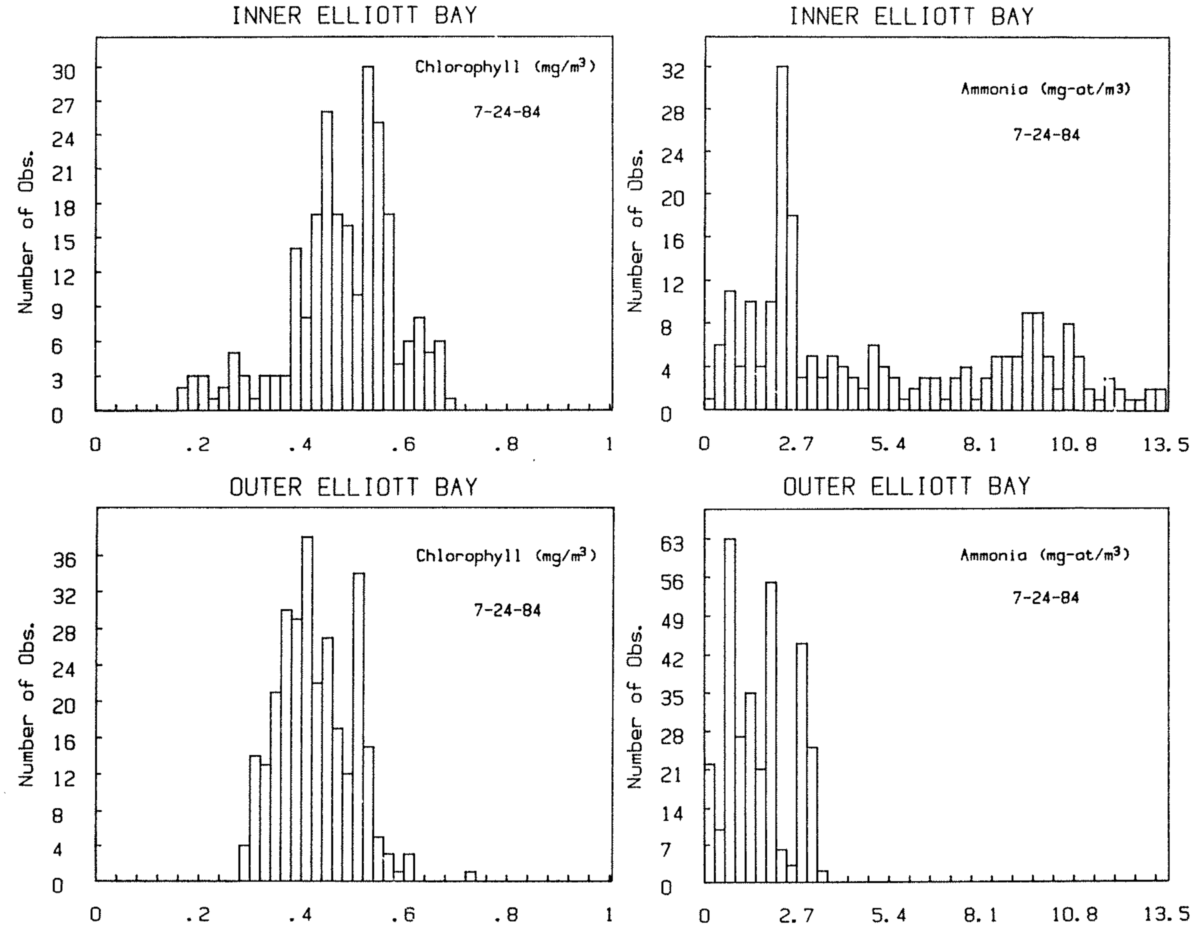

Figure 3.6. Probability distributions of chlorophyll and ammonia constructed from underway surface transect data collected July 24, 1984, for inner and outer Elliott Bay. An imaginary line drawn from Pier 90 to Duwamish Head separate the inner and outer bays. The y-axis is the number of observations at each level of chlorophyll, in mg/m^3, or ammonia in $mg\text{-}at/m^3$.

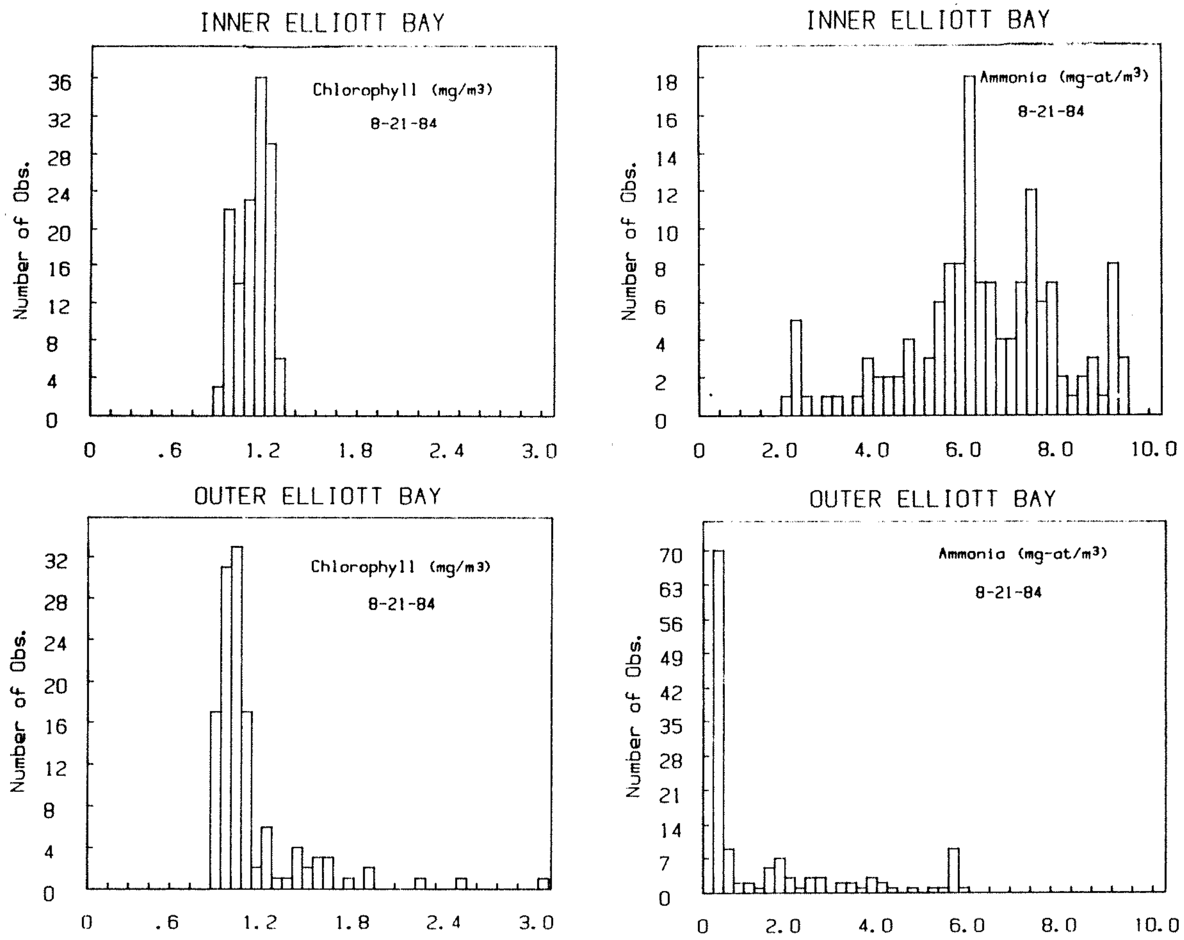

Figure 3.7. Probability distributions of chlorophyll and ammonia constructed from underway surface transect data collected August 21, 1984, for inner and outer Elliott Bay. An imaginary line drawn from Pier 90 to Duwamish Head separate the inner and outer bays. The y-axis is the number of observations at each level of chlorophyll, in mg/m^3, or ammonia, in mg-at/m^3.

Higher chlorophyll levels in the inner bay reflect the slower circulation which allows phytoplankton populations to build up near shore, rather than being swept away with each tidal cycle, as occurs in open water outside the bay (Campbell et al. 1977).

3.4.3.3 Differences in Surface Water Properties Between Cruises

Some general differences occurred between sampling in July and August: in July, Elliott Bay surface waters were lower in salinity and chlorophyll, and higher in turbidity and ammonia. Temperature was approximately the same during both cruises. Sampling began immediately after slack tide on both occasions with the July cruise following an ebb tide and the August cruise after a flood tide. The relatively higher salinity during the August cruise may have been due to the low volume of freshwater flowing from the Duwamish, while the preceding flood tide kept ammonia and particle-laden water trapped in the river mouth.

3.4.4 Duwamish River Plume

The purpose of the ammonia toxicity experiments was to examine the possible inhibitory (or stimulatory) effects of dissolved ammonia on phytoplankton growth in the Duwamish estuary. Due to the shortened project length, only a small portion of the necessary laboratory and field work was completed. In consequence, the role of ammonia inhibition or stimulation could not be fully explored. There are certain results of the shipboard experiments, however, which can be used to describe the extent and effect of the Duwamish River plume in Elliott Bay. These results will be considered in conjunction with data from a series of water column stations, numbered F-1 through F-10, occupied on three cruise days (August 21, September 7 and September 20, 1984).

3.4.4.1 Shipboard Ammonia Toxicity Experiments

Specific growth rates, calculated from primary productivity and chlorophyll measurements taken during each shipboard experiment, are summarized in Table 3.13. Each sample was taken at a regular water column station or at one of the "F" stations along the Duwamish River plume (Figures 3.1 and 3.8). Chlorophyll and dissolved nutrient concentrations, and salinity were recorded during each experiment (Table 3.14) and are in agreement with values measure at the same stations in preceding days. Little change was found in chlorphyll or ammonia concentrations over the course of an experiment, so that a mean value was used for each carbuoy. A plot of specific growth rate, (that is, carbon assimilated, per unit chlorophyll, per unit time), of phytoplankton at the experimental sites shows an increase in specific growth rate with distance downstream in the river plume, closely fitting a log relationship (Figure 3.9). By including the specific growth rate in outer Elliott Bay (station 22), a linear relationship is seen (Figure 3.10). Results of a multilinear correlation of specific growth rate with light, chlorophyll, salinity and ammonia show a positive but weak correlation with light (r=.369).

Salinity differences among the stations were not great (Table 3.14) and, with the possible exception of the "upper West Waterway" location, not low enough to inhibit the growth of estuarine phytoplankton. Also, the salinity of the experimental sites is high enough to ensure that virtually all dissolved ammonia is present in the ionized (NH_4^+) form. Some of the phytoplankton measured in the West Waterway, and further downstream, is probably of river origin.

It is apparent that phytoplankton growth is inhibited by some aspect of the Duwamish River plume, but it is not possible to assign a specific cause.

Table 3.13. Basic statistics for specific growth rates of phytoplankton in field ammonia toxicity experiments. Specific growth rate is in units of mg C/mg Chl/m^3/hr. See Figure for station locations.

Experiment number	Origin of sample	Date	n	Mean	Standard deviation	95% confidence interval
1	^{1}Station 23	8/21/84	18	19.33	3.35	16.66 → 19.99
2	^{1}Station 22	8/24/84	3	20.84	2.56	14.52 → 27.17
	^{2}Mouth of (f-8) West Waterway		10	3.16	0.38	2.88 → 3.43
3	^{1}Mouth of (f-8) West Waterway	9/07/84	19	3.80	1.05	3.29 → 4.30
	^{2}Off ferry (f-2) terminal		19	10.72	2.47	9.53 → 11.91
4	^{1}Upper West (f-8) Waterway	9/21/84	12	3.87	0.48	3.56 → 4.18
	^{2}Mouth of (f-8) West Waterway		10	5.07	0.41	4.78 → 5.38

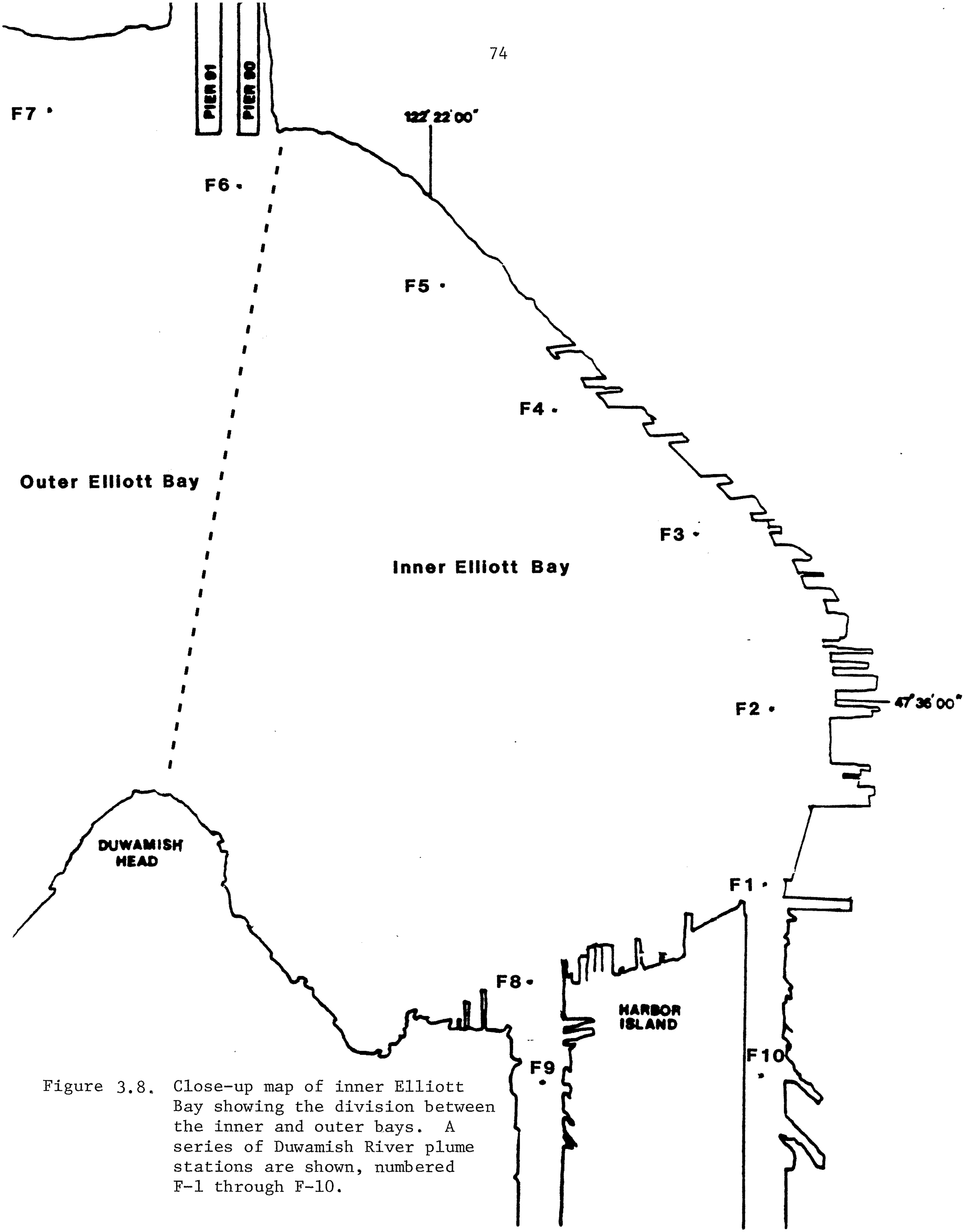

Figure 3.8. Close-up map of inner Elliott Bay showing the division between the inner and outer bays. A series of Duwamish River plume stations are shown, numbered F-1 through F-10.

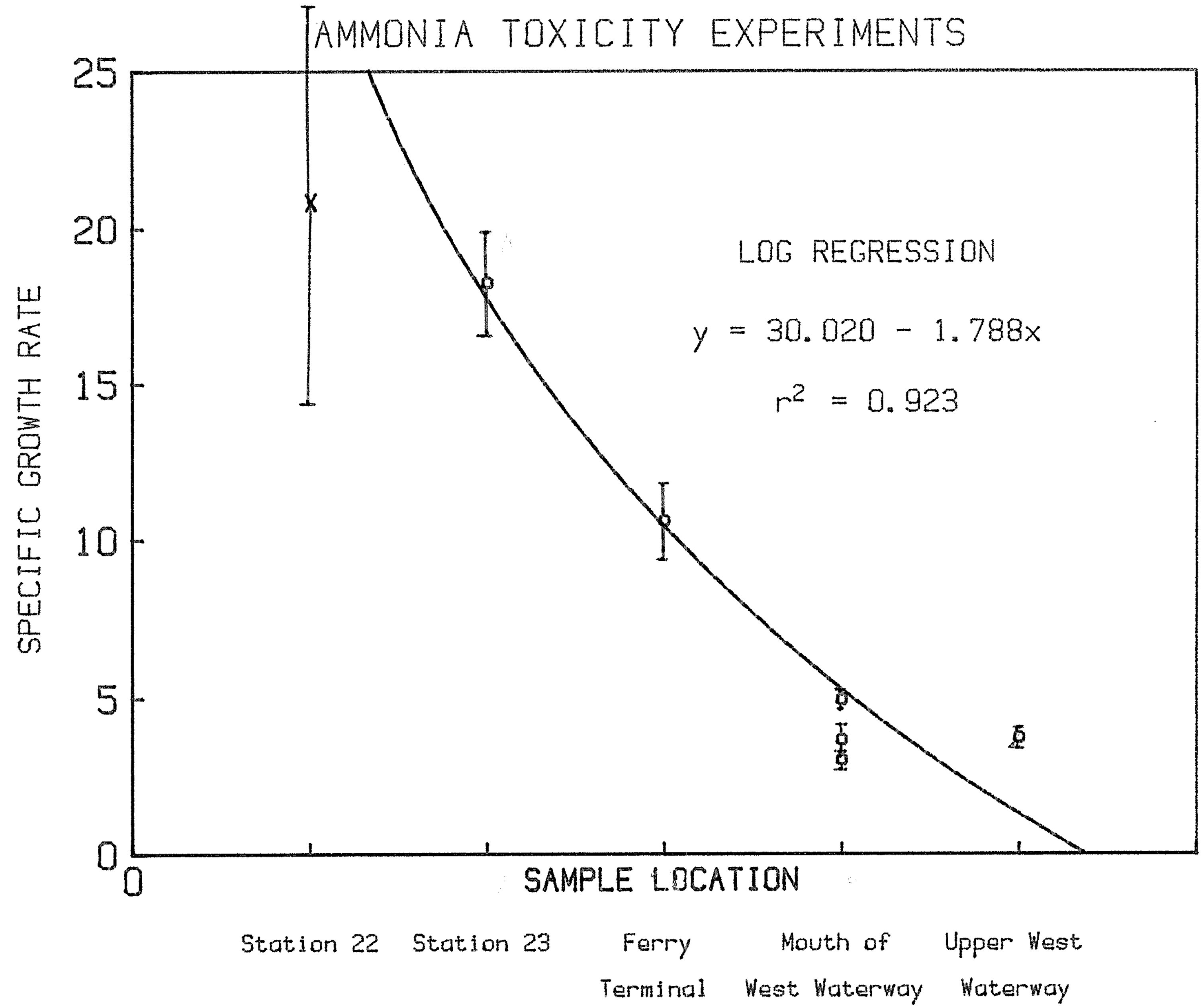

Figure 3.9. Plot of specific growth rate of algae grown under simulated in situ conditions on board ship during the ammonia toxicity experiments, over the different sampling locations, plotted in order downstream in the Duwamish River plume. A log regression has been fit to the points from the upper West Waterway to station 23. Station 22 was included in the plot but omitted from the regression. Specific growth rate is in mg C/mg chlorophyll/hour, and have 95% confidence intervals drawn about them.

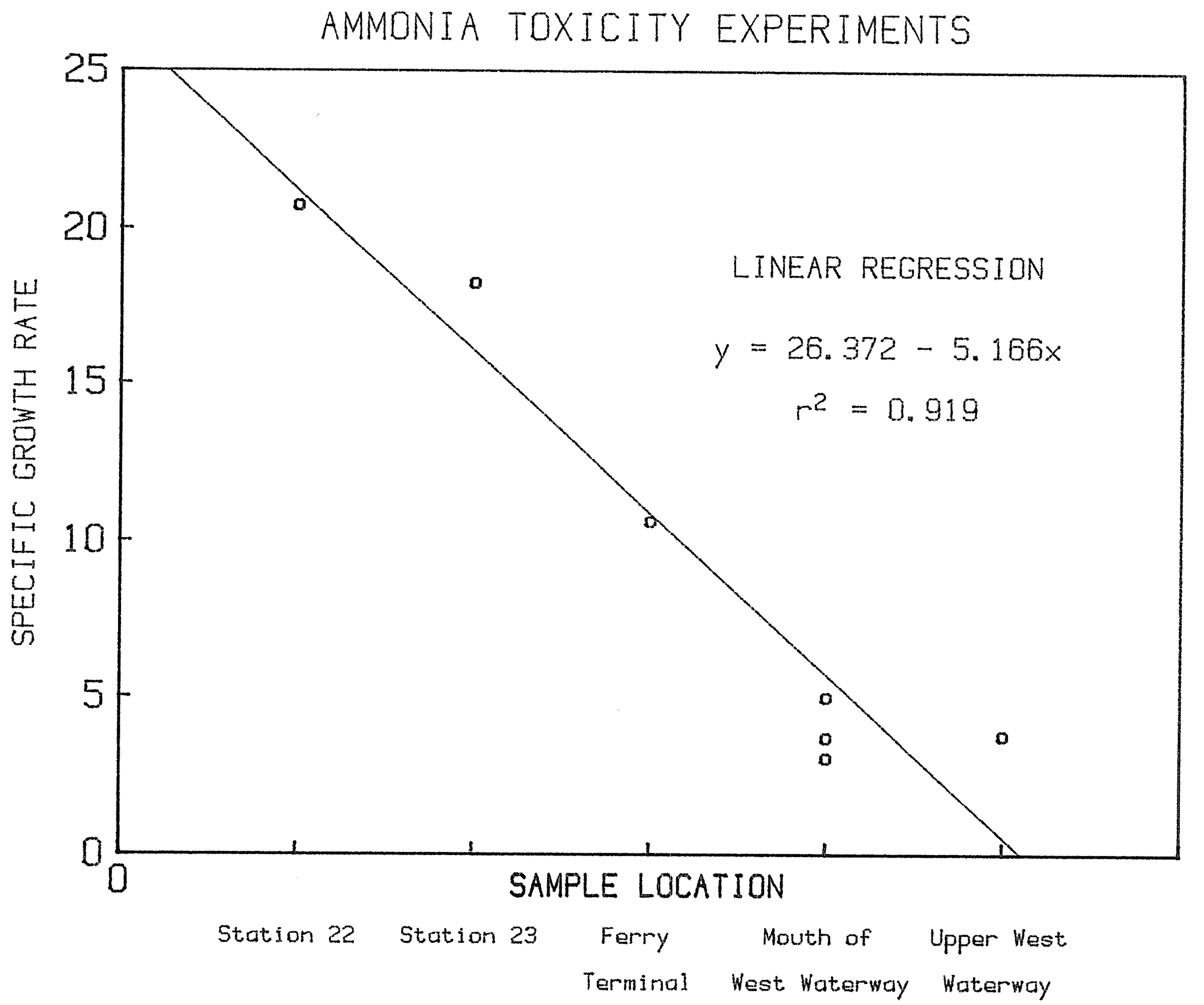

Figure 3.10. Plot of specific growth rate of algae grown under simulated <u>in situ</u> conditions on board ship during the ammonia toxicity experiments, over the different sampling locations, plotted in order downstream in the Duwamish River plume. A linear regression has been fit to the points, including station 22. Specific growth rate is in mg C/mg chlorophyll/hour.

Table 3.14. Chlorophyll, dissolved nutrients and salinity values for each field ammonia toxicity experiment.

Experiment number	Origin of sample	Chlorophyll (µg/1)	NO_3 (µg-at/1)	NO_2 (µg-at/1)	NH_4 (µg-at/1)	PO_4 (µg-at/1)	S_iO_4 (µg-at/1)	S ^{o}/oo
1	[1]Station 23	0.79	18.58	0.95	8.23	2.32	60.89	26.94
2	[1]Station 22	1.70	-	-	0.17	-	-	29.04
	[2]Mouth of West Waterway (F-8)	1.22	-	-	8.25	-	-	25.88
3	[1]Mouth of West Waterway (F-8)	2.00	18.97	0.78	10.57	2.73	57.03	28.41
	[2]Off ferry terminal (F-2)	0.55	18.93	0.76	7.24	2.46	53.69	28.33
4	[1]Upper West Waterway (F-9)	1.00	24.63	1.65	38.60	4.02	105.58	23.91
	[2]Mouth of West Waterway (F-8)	0.72	25.91	1.70	37.43	3.98	105.57	24.70

Ammonia concentration, in general decreases away from the river mouth, but the few measurements taken in this study were so variable that no evidence for ammonia inhibition was seen. Further investigations, including rigorous measurement of ammonia along the river plume, may help to define the inhibitory relationship of Duwamish plume water to phytoplankton growth.

3.4.4.2 Chlorophyll in the Duwamish River Plume

Vertical profiles of chlorophyll were made at 10 discrete stations in the Duwamish River plume, over three sampling dates: August 21st, September 7th and September 20th (Figure 3.8). Chlorophyll was integrated to the 1% light depth at each station and plotted by distance (station) along the river plume (Figure 3.11). Three distinct patterns of chlorophyll along the plume were found: one for each sampling date. On closer examination, patterns for August 21st and September 20th show similar characteristics with higher chlorophyll at the river mouth, decreasing to a minimum in the downtown area, and increasing again towards Smith Cove. The third sampling day, September 7th, would resemble the others if the plot were shifted 1/2 cycle upstream (to the left). An examination of the tidal cycles for the three dates shows that all sampling took place during or shortly after the low tide of the day. On August 21st and September 20th, low tide was in the early morning (0609 and 0621, 0.1 and -0.3 feet height, respectively) while on September 7th, low tide occurred at 0900 (height 0 feet). Sampling of all "F" stations occurred between 0915 and 1200. The similarities in tidal height and stage indicates that the timing of the event is of importance in explaining differences in water parcel location.

Dissolved oxygen data were collected on September 7th from 2 to 5 depths at each "F" station, and integrated over the water column. The results show a small decrease in water column dissolved oxygen downstream from the river

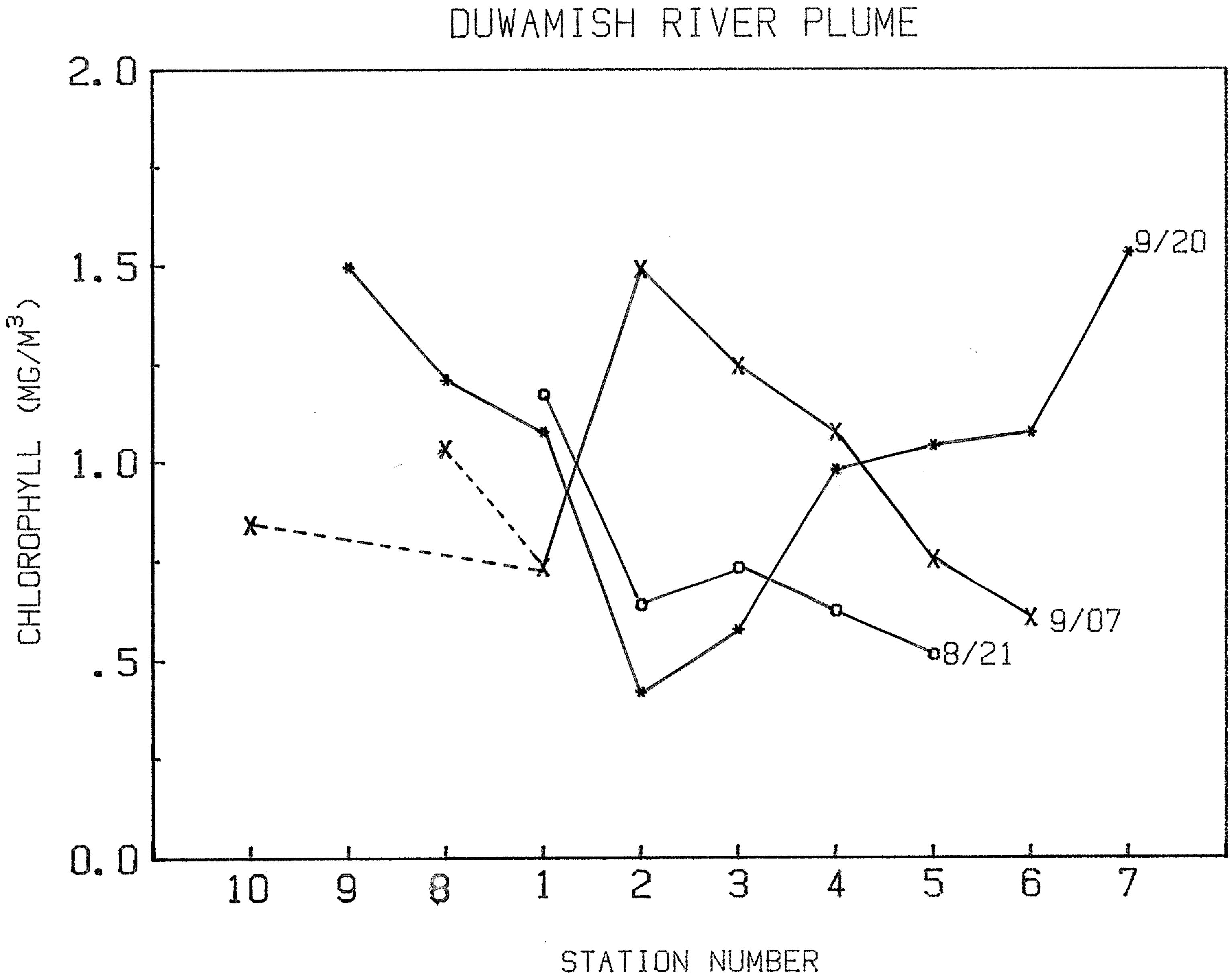

Figure 3.11. Plot of chlorophyll integrated to the 1% light depth, in mg/m^3, over the "F" stations of the Duwamish River plume, for three sampling dates: August 21, 1984, September 7, 1984 and September 20, 1984. The stations are plotted in order, going downstream in the river plume.

mouth, with the largest drop occurring from the ferry terminal past downtown Seattle to Pier 71 (Figure 3.12). This drop corresponds to a steady decrease in chlorophyll along the plume for that day, indicating that the dissolved oxygen concentration was depleted by respiration in the water column, as the input rate of O_2 (by photosynthesis) decreased. Stable dissolved oxygen values are seen near the river mouth and again approaching Smith Cove, indicating two separate water masses produced at the river mouth at different times. The transition zone between these water masses appears as a sharp decrease in the downtown area.

Previous studies of the Duwamish River plume (Harper-Owes, 1983; Pavlou et al., 1973) have indicated that tidal influences are the major factor determining the location and extent of the plume, particularly during times of low flow (late summer). The chlorophyll and dissolved oxygen data presented here indicate that parcels of river water are held back or expedited across the inner bay by tidal forces, and that each parcel maintains its own biological population.

3.5 Conclusions and Recommendations

Lower levels of phytoplankton and zooplankton were found in inner Elliott Bay (station 23) than in the outer bay (station 22) and the open Sound (stations 21 and 24), indicating that different water masses persist in the inner bay. The strongest influence in the inner bay is the Duwamish River plume, the characteristics of which may be altered following diversion of the RTP effluent.

Studies of circulation in Elliott Bay indicate a long residence time for inner bay water (Physical Oceanography section, this report). Should effluent wash into the inner bay, further depression of plankton levels could result

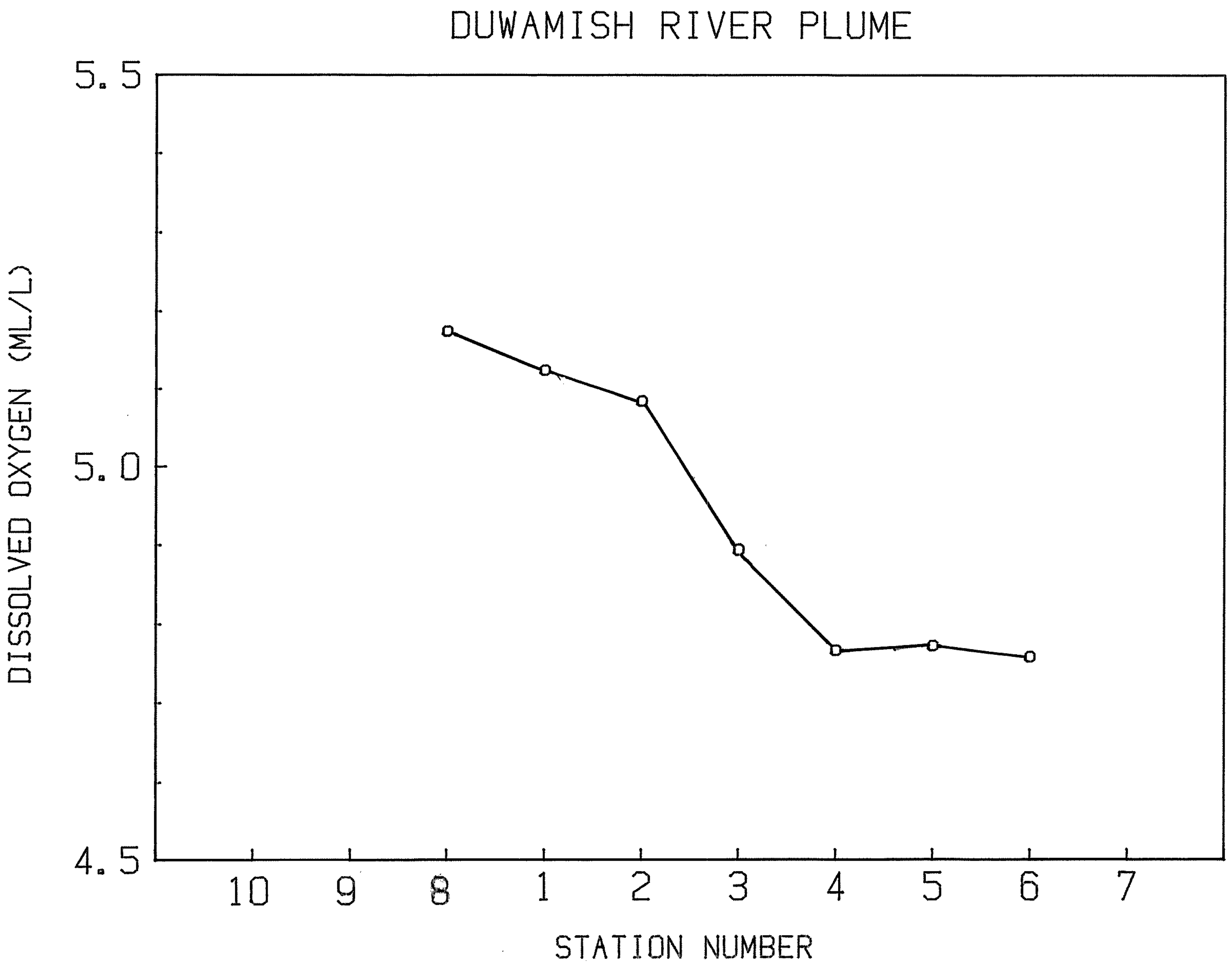

Figure 3.12. Plot of dissolved oxygen in ml/l, integrated over the water column, collected at the "F" stations along the Duwamish River plume, on September 7, 1984.

due to the toxic nature of the plume (as is presently seen in the Duwamish estuary) and due to a shallower photic zone caused by increased turbidity. Lower phytoplankton standing stocks would translate into smaller zooplankton and benthic populations, and eventually into a diminished food supply for juvenile and adult fish. The greatest potential problem would be decreased food availability to juvenile salmonids emerging from the Green/Duwamish River. This problem must be faced in light of expected higher survival of juveniles following the removal of toxic NH_3 concentrations from the river.

The problem of decreased phytoplankton biomass in the inner bay may be lessened by the removal of potential toxicants from the river (RTP effluent), which may allow for large algal blooms at the river mouth, at certain times of the year. While the diatom blooms that were seen in the lower Duwamish estuary in the late 1960's and early 1970's caused complaints by local residents, their restoration may provide a base for increased production at higher trophic levels such as salmonids and other fish of commercial and recreational importance.

Siting of the Renton Treatment Plant outfall should be in the area least likely to allow any backwash towards the inner bay. The water column at the site chosen for the outfall, as exemplified by station 22, appears to be much like that of the main basin of Puget Sound, at West Point and south of Alki Point. It is unlikely, therefore, that the discharge of effluent at depth will seriously affect plankton levels in the area. Increases of ammonia and other dissolved nutrients in the water column are likely to be small and non-toxic to plankton.

The low numbers of particles in secondary effluent, when released at great depth, should not concentrate in the surface layer in a rapidly circulating area like outer Elliott Bay (unlike the case of the slow-moving waters of the inner bay), and thus would be unlikely to affect light penetration in the photic zone. It is predicted that there will not be a decrease of phytoplankton production and food chain accrual in the area following the construction of an outfall offshore from Duwamish Head.

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Appendix 3A.

DRY WEIGHT CONVERSION FACTORS

Species	Adults	Dry Weight (µg) Copepodid Stages 5	4	3	2	1	ave.	Average all stages	References
Calanus pacificus	170	127	55	23	9.3	4.3	44	65	Vidal, 1978, 1980
Pseudocalanus spp.	15	8.6	4.2	2.4	2.0	1.0	3.6	5.5	Vidal, 1978, 1980
Paracalanus sp.	5.9	3.8	2.1	1.3	.5	.2	1.6	2.3	*1
Corycaeus anglicus	4	2.2	1.6	1.0	.7	.2	1.1	1.6	*2
Microcalanus sp.	3.8	-	-	-	-	-	1.1	1.6	*1
Oithona similis	2.0	-	-	-	-	-	.6	.8	Uye, 1982
Oikopleura dioica	3	-	-	-	-	-	-	-	Uye, 1982
Aetideus divergens	47	-	-	-	-	-	12.2	-	*3

*1 Derived from length-weight relationship using Vidals' (1978) data for *Pseudocalanus* and *Calanus* and some mean lengths from this study.

*2 Derived from length-weight relationship for *Oithona* (Uye 1982 and lengths reported for *Corycaeus* (Gibson & Grice 1978).

*3 Adult value from Robertson & Frost (1977). Copepodid average based on weight relationship for *Calanus*.

4.0 INTERTIDAL AND SHALLOW SUBTIDAL BENTHIC ECOLOGY

R. Thom, R. Albright, C. Simenstad and K. Chew

4.1 Introduction

The purpose of the present report is to briefly summarize data taken at nearshore study sites during July-September 1984. The data are from several samplings of water, sediment and biota properties. The bulk of the collected samples await analysis. However, some conclusions useful in characterizing aspects of major habitats in Elliott Bay and identifying areas of ecological importance are possible. The data are examined with regard to outfall siting alternatives.

4.2 Study Beaches and Sites

Shoreline study areas (Figure 4.1) were selected primarily on the basis of the probablity of impact from effluent discharged from the proposed outfall, and secondarily for purposes of documenting changes following effluent diversion from the Duwamish River. Recent observations on surface and subsurface current movement by Dr. Curt Ebbesmeyer (unpublished data) were used in determining the location of study beaches. The shoreline areas chosen for benthic sediment studies, depending on access, were:

A. West Point to Fourmile Rock (Magnolia Bluff);
B. Duwamish Head and around Alki Point to the south side;
C. Rockaway Beach (Bainbridge Island); and,
D. Seahurst Park

In addition, walks (see below) were conducted along portions of the beaches to document sediment conditions, and studies on periphyton and water chemistry were conducted along the eastern shoreline of Elliott Bay to provide baseline data to measure recovery following effluent diversion.

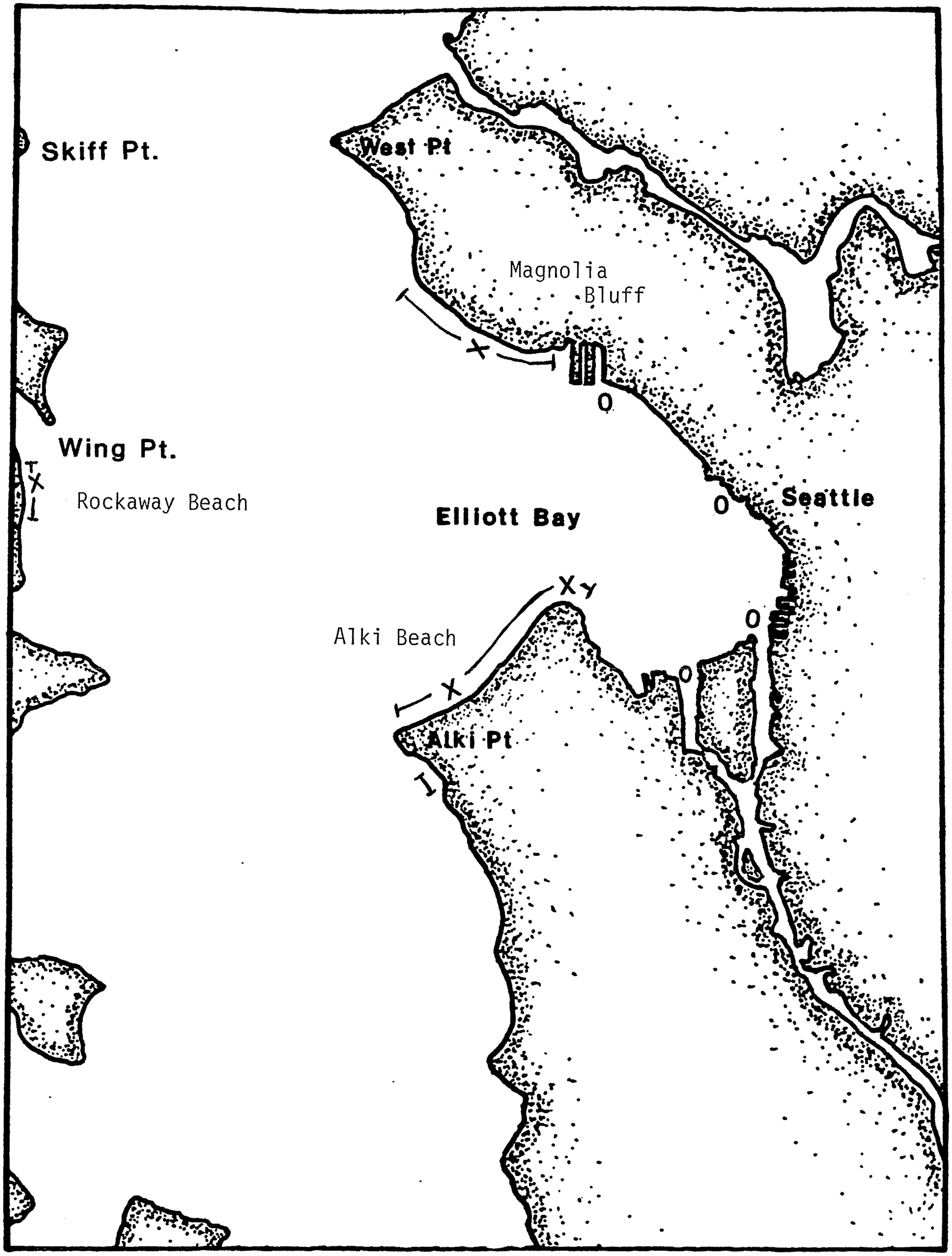

Figure 4.1. Intertidal/Shallow Subtidal study sites. ├──┤ = benthic;
X = water chemistry, 0 = periphyton

The study sites were located in major ecologically important nearshore habitats at the study beaches (Figure 4.2-4.5, Table 4.1). Seahurst sites were selected for reference to previous baseline data. Habitats included sand flats, cobble fields, and eelgrass (*Zostera marina*) meadows. Sandflats were the most widespread habitat. Eelgrass meadows constituted a very rich and important habitat. Intertidal sites were located at approximately MLLW (mean lower low water). Shallow subtidal sites in eelgrass meadows were located between -1 and -12 ft MLLW. Coordinants for the sites are given in Appendix 4.1.

4.3 Methods

4.3.1 Water Chemistry

Water chemistry samples (collected 0.3 m below the water surface) were taken biweekly using a hand held Van Dorn water sampler at the sites shown in Figure 4.1 and at Seahurst Park. Additional water samples between these sites were taken on two occasions to detect gradients in water chemistry values along Alki Beach and Magnolia Bluff. Water samples at each site were analyzed for temperature, salinity, dissolved oxygen, nitrate, nitrite, ammonia, phosphate and silicate using methods employed during the Seahurst baseline study (Stober and Chew 1984).

4.3.2 Sediment Chemistry

Core samples were collected from sites where and when infauna were sampled. These samples were analyzed for grain size, volatile solids, BOD, total organic carbon, and total nitrogen. Methods were identical to those employed during the Seahurst baseline study.

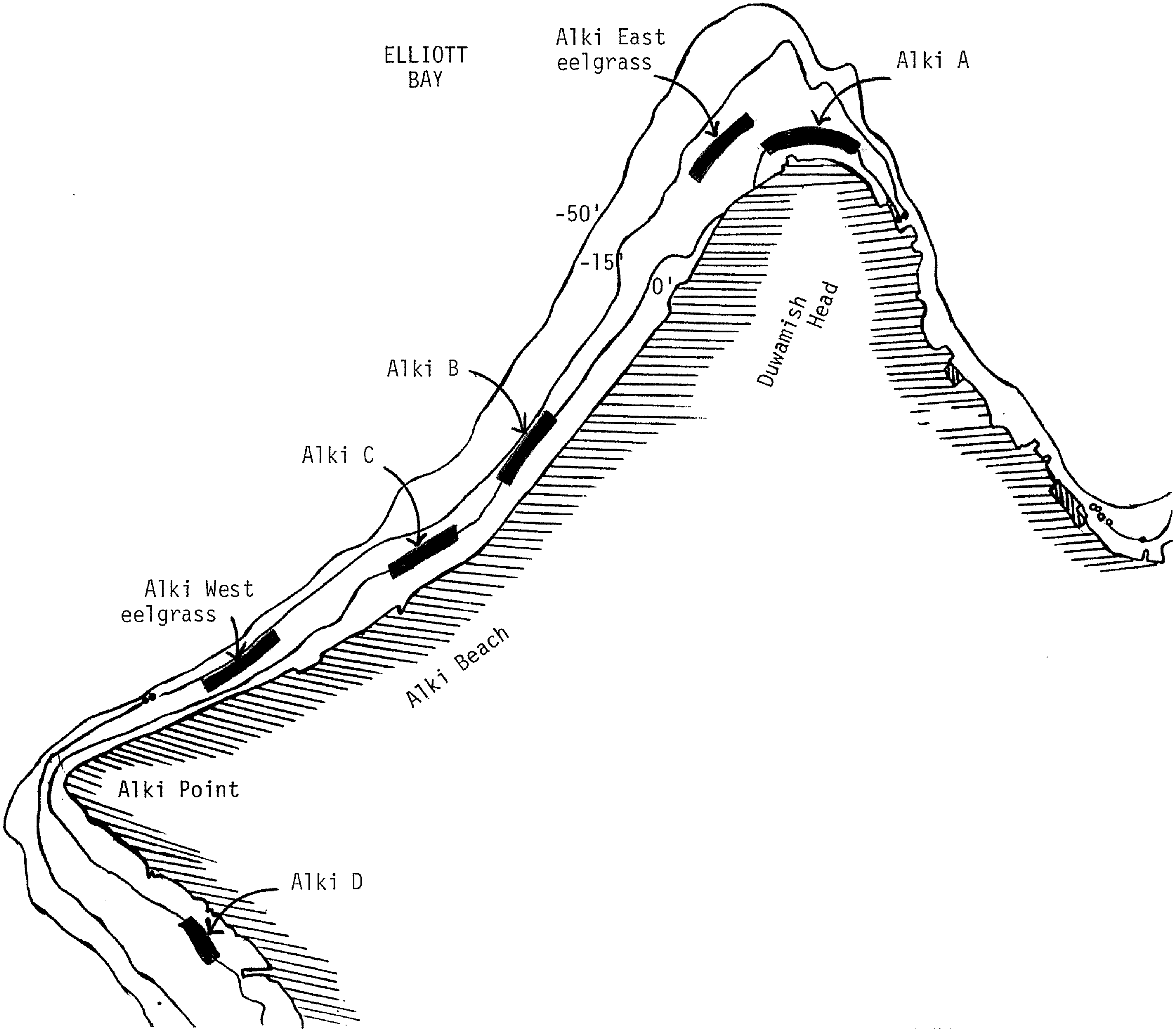

Figure 4.2. Transect locations along Alki Beach.

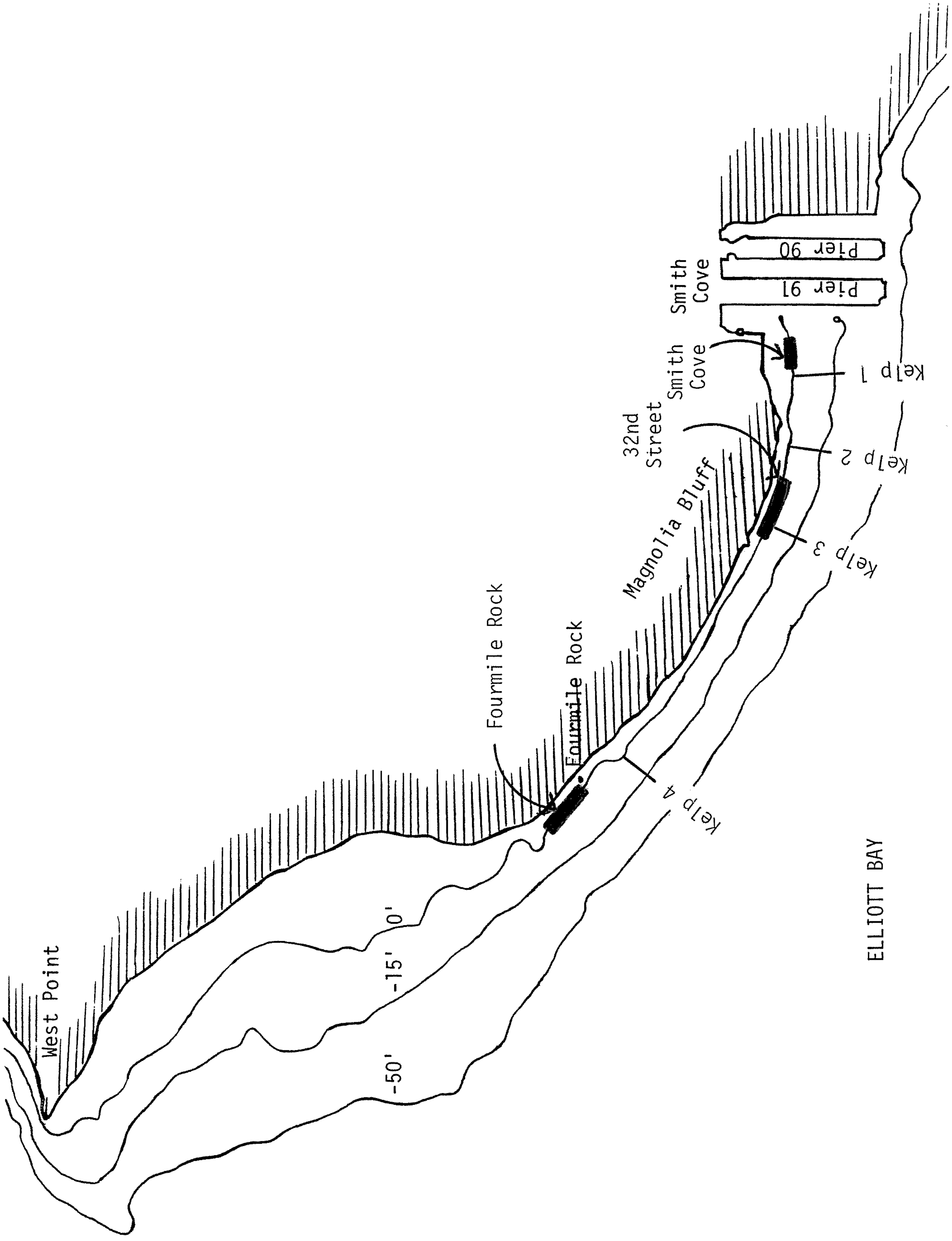

Figure 4.3. Transect locations along Magnolia Bluff.

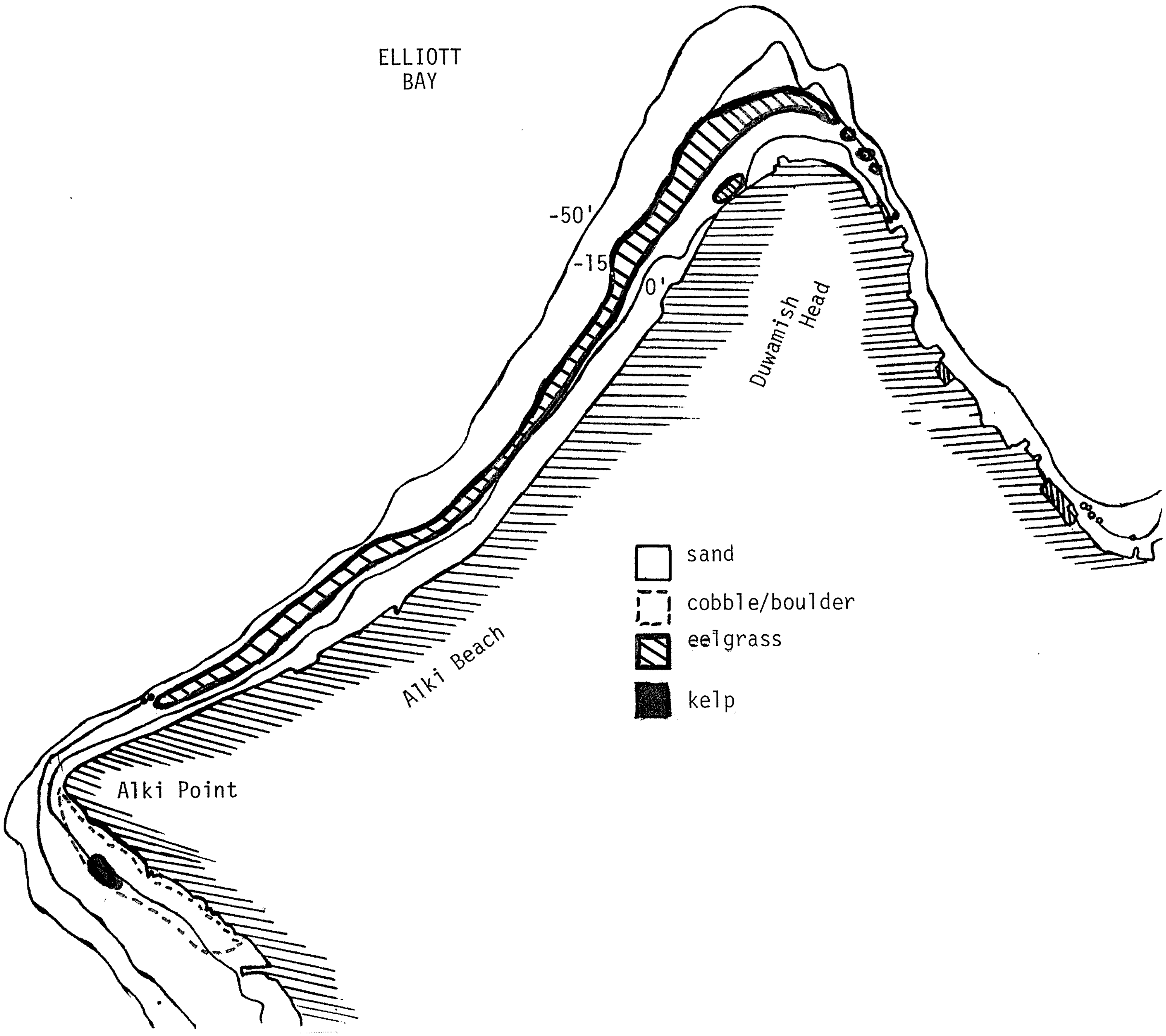

Figure 4.4. Major nearshore habitats at Alki Beach.

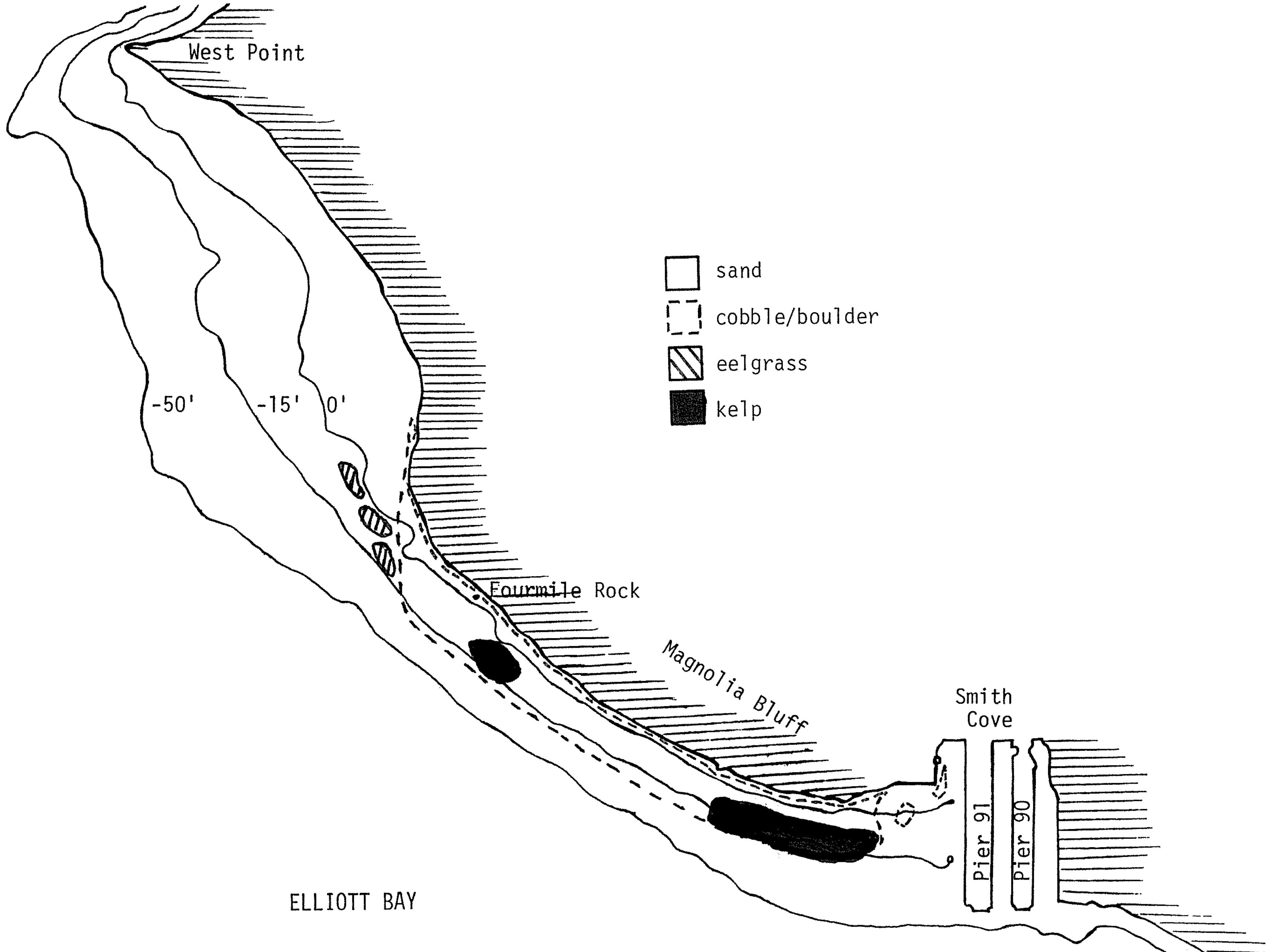

Figure 4.5. Major nearshore habitats along Magnolia Bluff.

Table 4.1. Nearshore habitats, study sites and transect lengths.

Site/Habitat	Transect Length (m)
Magnolia Bluff:	
intertidal sand - Smith Cove	120
intertidal cobble - 32nd St.	300
- Four mile Rock	300
kelp bed - four transects	
Alki Point - Duwamish Head:	
intertidal sand - at Duwamish Head (A)	300
- mid beach (B)	300
- main beach (C)	300
subtidal eelgrass - at Duwamish Head (east)	300
- main beach (west)	300
intertidal cobble (D)	150
Rockaway Beach:	
intertidal cobble	490
Seahurst Park:	
intertidal sand	30
intertidal cobble	30
subtidal eelgrass	30

4.3.3 Benthic Assemblage Structure and Production

4.3.3.1 Sediment Microalgae

Primary productivity of microalgae in intertidal sediments was measured. Cylindrical core samples (10.75 cm^2 surface area) were collected from the sites with clear plexiglass tubes. Water from the site was added to the tubes. After taking initial DO measurements, the tubes were capped at both ends with rubber bungs and incubated at ambient light for 1-3 hours. Oxygen flux in the tubes was used to calculate primary productivity. A PQ = 1 and RQ = 1 were used in the calculations (Strickland 1960). Darkened tubes treated similarly were used to measure community respiration. Pigment concentration was determined fluorometrically following the experiments from a 7 mm diameter x 1 cm deep subsample of the sediment in the plexiglass tubes.

4.3.3.2 Epibenthic Crustaceans

Epibenthic crustacean composition and standing stock were sampled using the epibenthic suction pump sampler that was used for the Seahurst baseline study (Stober and Chew, 1984). Five replicate samples each were collected at a subtidal sandflat and eelgrass site at Alki West (Figure 4.2) three times during July-August 1984; only the July collections were processed, however. Sample processing was identical to that used in the Seahurst baseline study (Stober and Chew 1984).

4.3.3.3 Epibenthic Predators

Specimens of fish and motile macroinvertebrate species that occurred within sandflat and eelgrass habitats along Alki Beach and Magnolia Bluff were obtained from samples taken by the fish studies group in summer 1984. The stomach contents of at least 5 specimens of 10 known epibenthic predators were analyzed from the July collections. These organisms included several species of fish and shrimp (Table 4.2).

Table 4.2. Epibenthic predators collected from sand and eelgrass habitats at Alki West on July 11, 1984, which were analyzed for stomach contents composition.

Species	Sample Size (n)	Size (mm)[1]
Crangon nigricauda, blacktail shrimp	8	48.5 ± 4.84
Pandalus danae, coon stripe shrimp	6	51.8 ± 17.24
Oncorhynchus tshawytscha, chinook salmon (juvenile)	5	91.0 ± 6.32
Aulorhynchus flavidus, tube-snout	5	58.0 ± 1.87
Blepsias cirrhosus, silverspotted sculpin	5	73.6 ± 4.28
Cymatogaster aggregata, shiner perch	5	97.0 ± 2.74
Embiotoca lateralis, striped perch (juvenile)	6	72.8 ± 1.94
Apodichthys flavidus, penpoint gunnel	5	73.2 ± 2.68
Pholis laeta, crescent gunnel	5	194.2 ± 8.32
Parophrys vetulus, English sole	6	101.7 ± 36.4

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[1] Length ± 1 standard deviation; carapace length in the case of shrimp; fork length in the case of juvenile salmon; and total length for all other fishes.

4.3.3.4 Small Infauna

Small infauna species composition and abundances were sampled using a cylindrical core sampler (23 cm^2 x 10 cm deep) and seived through a 1 mm mesh screen as was done in the Seahurst baseline studies. Twenty random replicate samples were taken within eelgrass, cobble, and sand habitats. Sampling was conducted once during July and once in August 1984 in each habitat. Samples were processed fully using the Seahurst baseline study methods. Twelve replicate random samples were taken at the Seahurst sites to maintain consistency with the Seahurst study methods.

4.3.3.5 Wide-Area Beach Surveys

Considerable information now suggests that floatable material from deepwater outfalls may accumulate in significant quantities on beaches in Puget Sound. These materials include oils and greases with associated micro-organisms (i.e., bacteria), and perhaps fat soluable contaminants. A beach walk was conducted along the shoreline areas listed above for the purpose of documenting the present conditions of the beaches with regard to these factors. Sediment and interstitial water samples were taken at several spots on each beach, and water samples of visible slicks were taken where present. These samples were analyzed for hexane or pentane extractables. Qualitative observations on sediment color and odor were made at at least 10 points on each beach and the location of drift vegetative matter was documented.

4.3.3.6 Periphyton

Plexiglass periphyton collection plates (12 x 3 cm) were hung at -3 ft MLLW from piers at four locations along the inner Elliott Bay shoreline during July (Figure 4.1). After one month of exposure, one plate from each site was analyzed for dry weight. Four of the periphyton plates from each site were incubated in light and dark bottles to measure primary production and community respiration.

4.3.3.7 Eelgrass Studies

The location (depth range), density, and biomass of the eelgrass meadows at Alki Point and Seahurst Park were sampled once during July and once in August 1984. Divers collected 20 random samples along transects within the meadows for laboratory processing as was done for the Seahurst baseline studies.

4.3.3.8 Habitat Mapping

The areal coverages of intertidal habitats were determined in Elliott Bay once (summer) using field observations on the beach, from a boat and from the air.

4.3.3.9 Bivalve

Twenty random replicate cores (0.06 m^2 x 30 cm deep) were collected in cobble habitats during August 1984. All bivalves retained on a 0.5 in (13 mm) mesh screen were placed in labeled plastic bags and frozen.

4.4 Data Analysis

Raw data were stored in two places (i.e., the author's homes and at the School of Fisheries) and entered onto flexible computer discs. Analysis consisted of calculating basic statistics (means, standard deviations) for all parameters.

4.5 Results and Discussion

4.5.1 Elliott Bay Habitats

The nearshore habitat distributions in Elliott Bay were presented earlier (Stober and Pearson 1983). The major remaining natural habitats include cobble/boulder fields, sand flats, kelp beds and eelgrass meadows. The location of these habitats are indicated on Figures 4.4 and 4.5. All of these habitats are important ecologically. In particular, kelp beds, eelgrass meadows and cobble fields form habitats for a large number of other benthic organisms. Recreationally important bivalve populations exist in the cobble habitat along Magnolia Bluff. As well as providing habitat for fish and large motile benthic invertebrates, kelp beds and eelgrass meadows constitute a primary source of food to the nearshore system. Sand flats contain sediment microflora with high production rates, which also contribute significant amounts of energy to the nearshore environment.

4.5.2 Sediment Chemistry

The results of sediment grain size analyses appear to be best summarized by mean phi sizes (Figure 4.6). Sites with sediments having a mean phi size of less than 1.0 were characterized by substrates consisting of a mixture of sand, gravel, and cobble. Sites with sediments having a mean phi size greater than 2.0 were characterized by sand substrates (including those sites with eelgrass). The two sites with mean phi sizes falling between 1.0 and 2.0, Alki C and Four Mile Rock, were both sites where the randomly selected locations for sediment sample collection were in pockets atypical of most of the site. The sediment sample collected at Four Mile Rock, which has primarily a cobble-gravel-sand substrate, was located in a sand pocket. The sediment sample collected at Alki C, primarily a sand habitat, fell in a gravel-sand pocket.

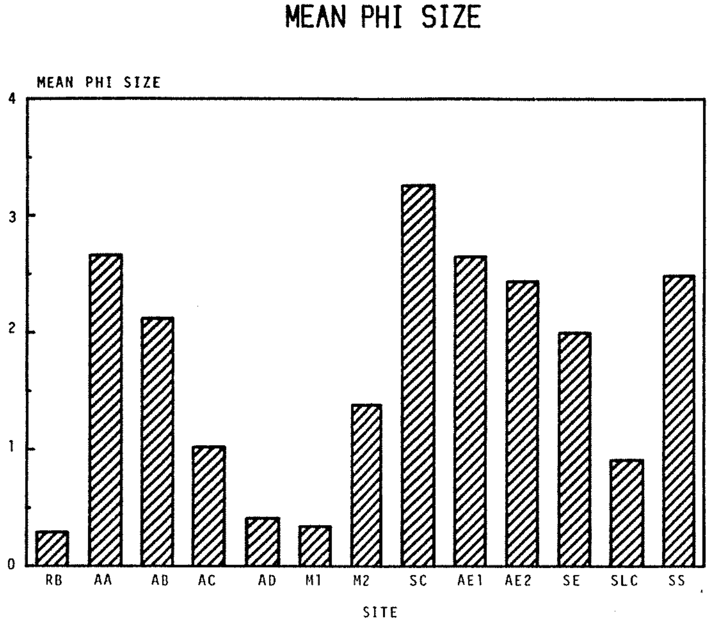

Figure 4.6. Mean phi size of sediments for the intertidal/shallow subtidal study sites. Site codes are as follows: RB = Rockaway Beach; AA = Alki A; AB = Alki B; AC = Alki C; AD = Alki D; M1 = 32nd St. W.; M2 = Four Mile Rock; SC = Smith Cove; AE1 = Alki East Eelgrass; AE2 = Alki West Eelgrass; SE = Seahurst Eelgrass; SLC = Seahurst Cobble; SS = Seahurst Sand.

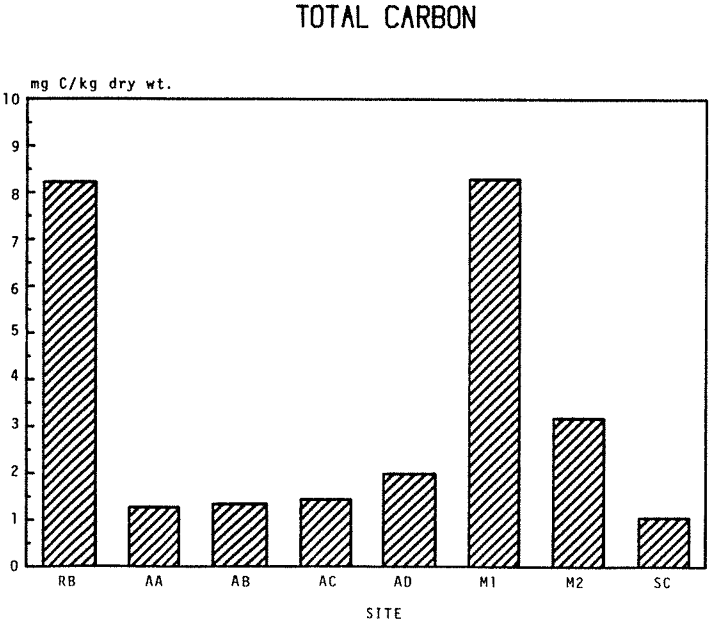

Figure 4.7. Total carbon in sediments at the intertidal study sites. For an explanation of site codes refer to the caption for Figure 4.6.

Sediments from cobble sites had higher total carbon content than sand or sand/eelgrass sites (Figure 4.7), with values ranging from 1.1-1.4 mg/kg sediment dry wt. at sand and sand/eelgrass sites, and 2.0-8.3 mg/kg at cobble sites. Carbon:nitrogen ratios also appear to correlate well with substrate, increasing with decreasing phi size (Figure 4.8). This correlation apparently results entirely from the correlation between grain size and total carbon, as nitrogen shows no obvious relationship to mean phi size (Figure 4.9).

The elevated amounts of carbon in sediments at cobble beaches probably resulted from the high levels of primary production by macroalgae and high standing crops of infaunal organisms present. BOD and percent volatile solids of sediments were also generally high at the cobble beaches (Figures 4.1 and 4.11), although there was not as strong a trend as observed in the Seahurst Baseline study.

4.5.3 Water Chemistry

It appears that the two major factors affecting water chemistry values in nearshore areas of Elliott Bay are the flow of freshwater from the Duwamish River, and primary production by plants (particularly macroalgae). This was apparent in both the water samples collected at the five locations selected for long-term study, and those collected to observe gradients in water chemistry along the shorelines of Alki Beach and Magnolia Bluff. The effect of the Duwamish River flow, which runs along the west and north shorelines of Elliott Bay (and along Magnolia Bluff), can best be illustrated by comparing the salinities along Alki Beach with those along Magnolia Bluff (Figure 4.12). During July, when flows in the Duwamish River were fairly high, salinities along Magnolia Bluff were reduced relative to salinities along Alki Beach. During August, when river flows were at low levels, there was no observable difference in salinity between Alki Beach and along Magnolia Bluff. Silicate

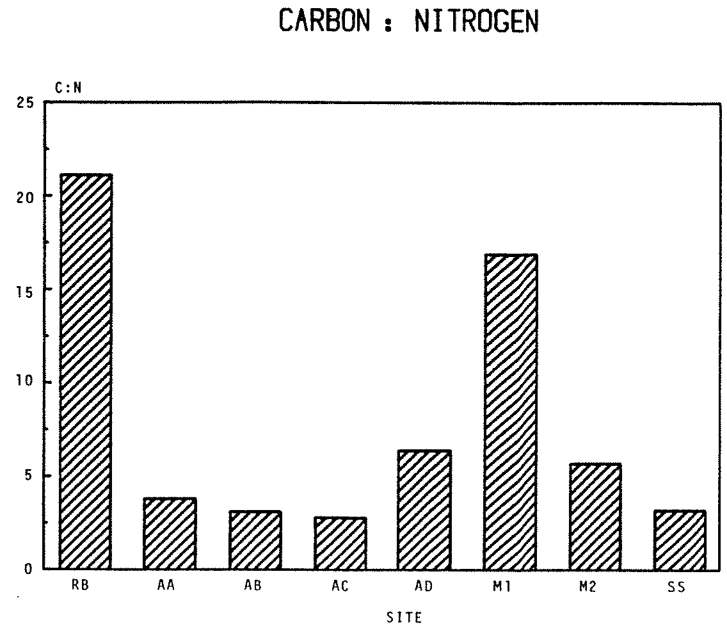

Figure 4.8. Carbon:nitrogen ratios of sediments at the intertidal study sites. For an explanation of site codes refer to the caption for Figure 4.6.

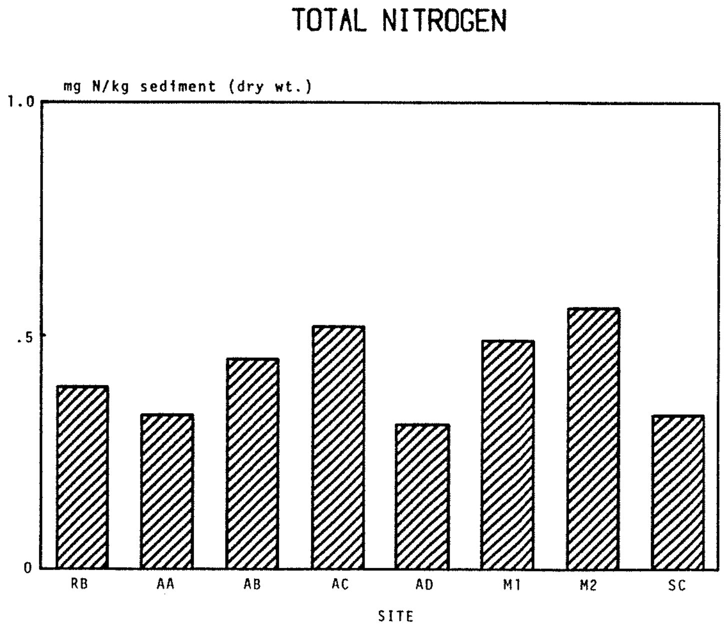

Figure 4.9. Nitrogen content of sediments at the intertidal study sites. For an explanation of site codes refer to the caption for Figure 4.6.

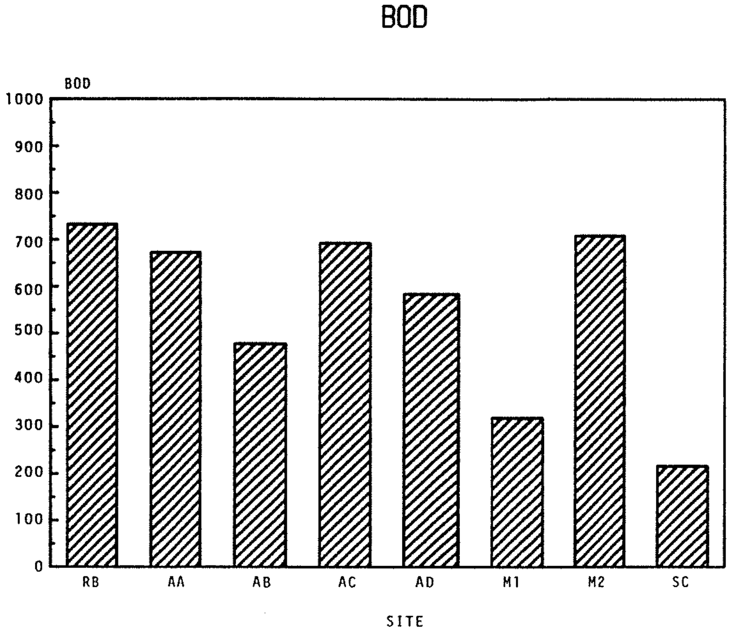

Figure 4.10. Sediment BOD (mg/kg sediment dry wt.) for the intertidal study sites. For an explanation of site codes refer to the caption for Figure 4.6.

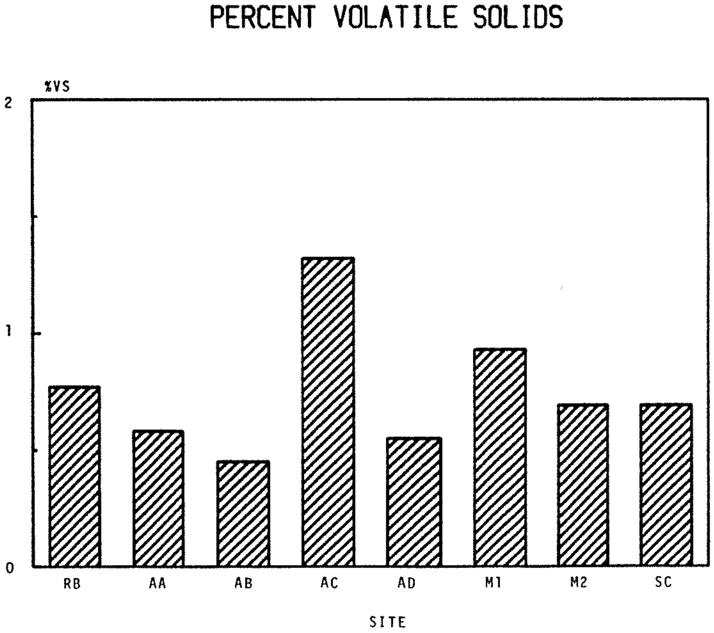

Figure 4.11. Percent volatile solids of sediments at the intertidal study sites. For an explanation of site codes refer to the caption for Figure 4.6.

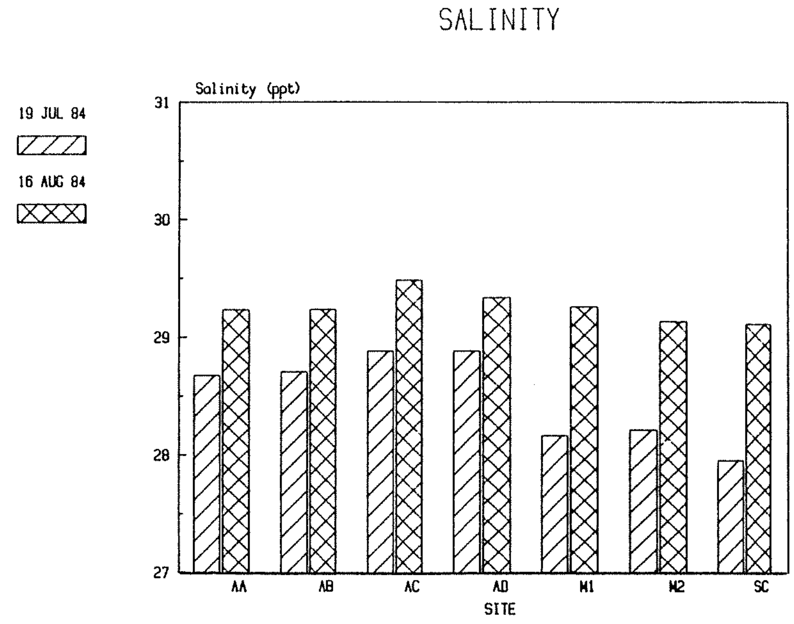

Figure 4.12. Salinities at the Alki Beach and Magnolia Bluff study sites. For an explanation of site codes refer to the caption for Figure 4.6. See also Figures 4.2 and 4.3.

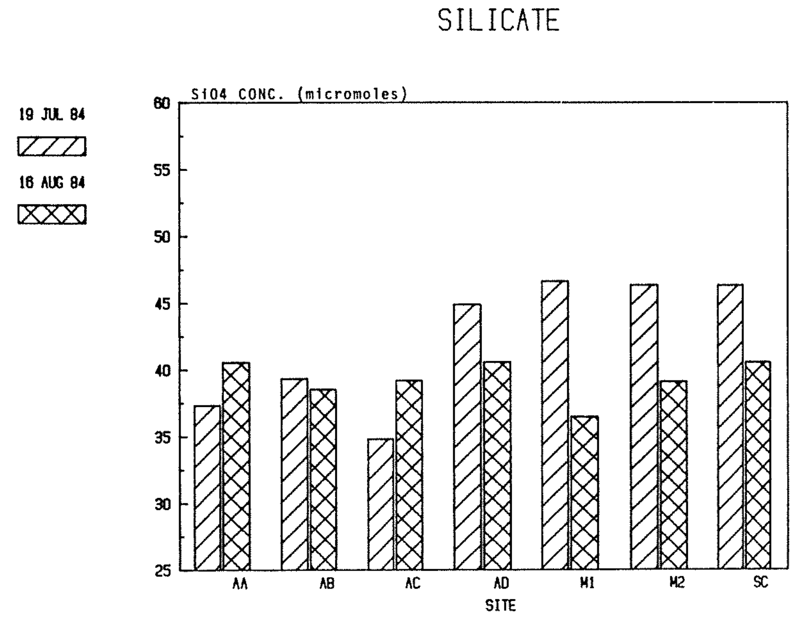

Figure 4.13. Silicate concentrations at the Alki Beach and Magnolia Bluff study sites. For an explanation of site codes refer to the caption for Figure 4.6. See also Figures 4.2 and 4.3.

concentrations also illustrate the influence of Duwamish River water on nearshore water chemistry (Figure 4.13). Concentrations during July were higher along Magnolia Bluff than along Alki Beach (silicate concentrations are higher in freshwater than in seawater), while during August there was little difference in concentrations between beaches.

The affect of primary production on nearshore water chemistry values is illustrated best by changes in dissolved oxygen and nitrate concentrations. During summer, DO concentrations were highest (although concentrations were erratic) in areas such as cobble beaches where the standing stock of primary producers was greatest (Figures 4.14 and 4.15). (The primary producers release oxygen into the water as a result of photosynthesis.) The erratic DO concentrations in these highly productive nearshore areas are not surprizing. The time at which DO samples were collected in relation to the exchange rate of the water could greatly affect DO concentrations. For example, if periods of high primary production coincided with slack tides, DO would be expected to increase rapidly to higher than typical values. In the less productive areas, such as adjacent to sand beaches, DO concentrations probably increase more slowly during slack tides, and thus tend to fluctuate much less than concentrations near areas of higher production.

Under these same conditions where high DO concentrations occur, high levels of primary production should also result in lowering of nutrient concentrations, especially when nutrient concentrations are at or near levels which inhibit primary production (either on a large-scale or in local pockets). Of the nutrient levels monitored during this study (phosphate, silicate, nitrate, nitrite, and ammonia), nitrate appears to be nearest to levels potentially limiting primary production. If so, it would be expected that nitrate concentrations should be reduced in situations where DO

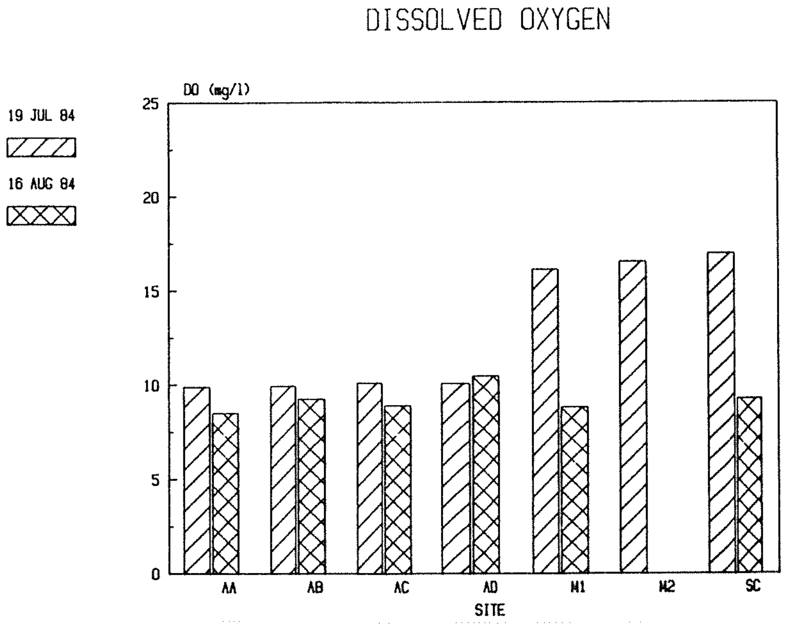

Figure 4.14. Dissolved oxygen concentrations at the Alki Beach and Magnolia Bluff study sites. For an explanation of site codes refer to the caption for Figure 4.6.

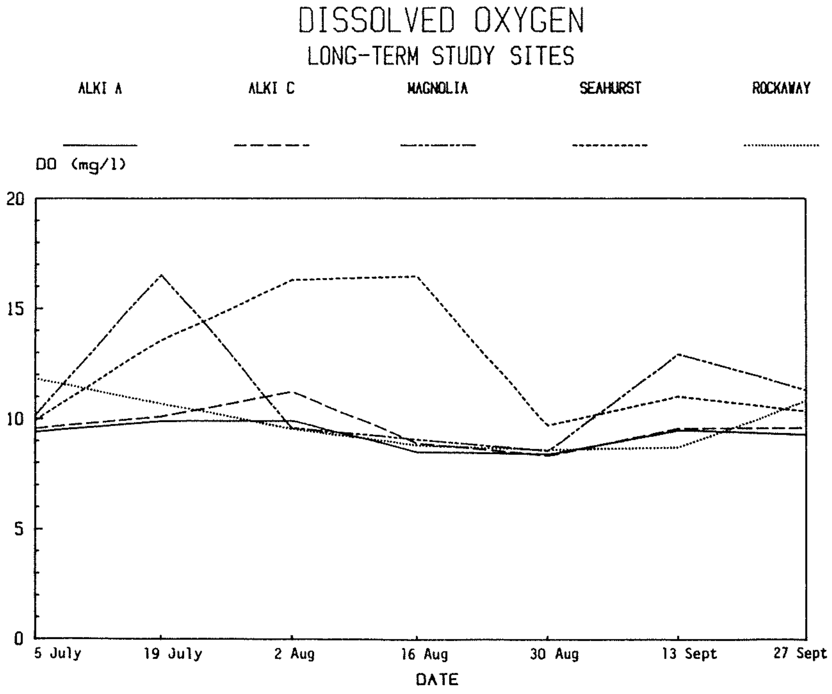

Figure 4.15. Dissolved oxygen concentrations at the intertidal study sites.

concentrations are unusually high, and this does appear to be the case (Figures 4.16 and 4.17), as there was a statistically significant negative correlation ($r = -.60$; $p < .01$) between DO and nitrate.

4.5.4 Sediment Microalgae

Nearshore sandy sediments contained substantial microalgal populations as indicated by sediment chlorophyll a concentrations (Figure 4.18). The sediments at Duwamish Head contained the greatest concentration. The differences in mean concentrations among sites may be partially explained by sediment quality. Finer sediments generally contained higher chlorophyll a concentrations. Histograms of chlorophyll a and phaeopigment illustrate the non-normal distribution of pigment data using all measurements (Figures 4.19 and 4.20).

Net productivity tended to be greatest at sites with finer sediments (Figure 4.21). However, net productivity was not correlated with sediment pigment concentration ($r = -0.20$ for chlorphyll a; $r = -0.33$ for phaeopigments). Net productivity was distributed approximately normally (Figure 4.22). Negative values were recorded which indicated a heterotrophic condition in the sediment.

4.5.5 Settling Plates

Periphyton samples collected in September, after approximately one month of exposure, indicated several trends. First, standing stock increased with increasing distance from the mouth of the Duwamish River (Figure 4.23). The flora on the plates also showed a trend from a diatom film at Terminal 5 to a macrophyte/tubular diatom assemblage at Pier 90. Productivity per unit area was greatest at the sites with greatest biomass (Figure 4.24). Conversely, productivity per unit biomass was greatest at the sites with least biomass, which indicates a relatively high turnover rate at these latter sites (Figure

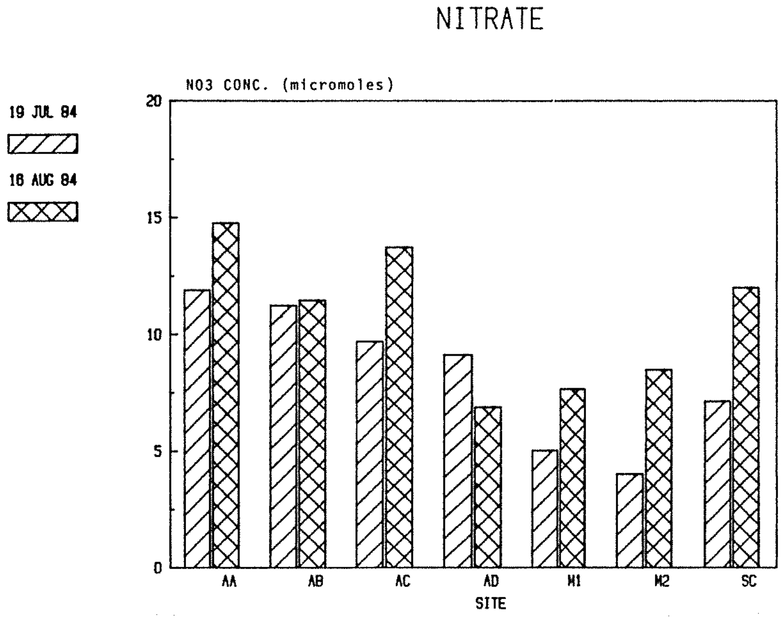

Figure 4.16. Nitrate concentrations at the Alki Beach and Magnolia Bluff study sites. For an explanation of site codes refer to the caption for Figure 4.6.

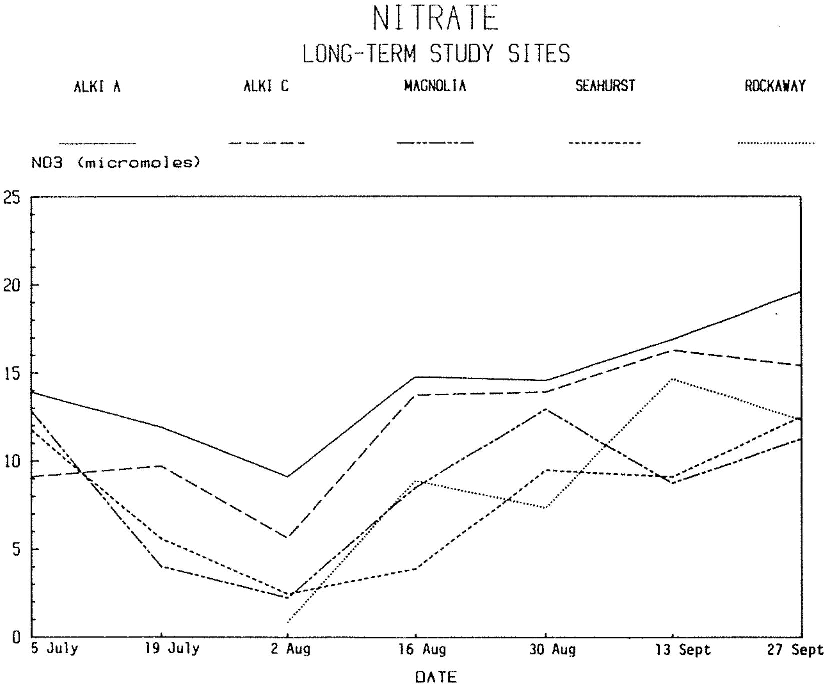

Figure 4.17. Nitrate concentrations the intertidal study sites.

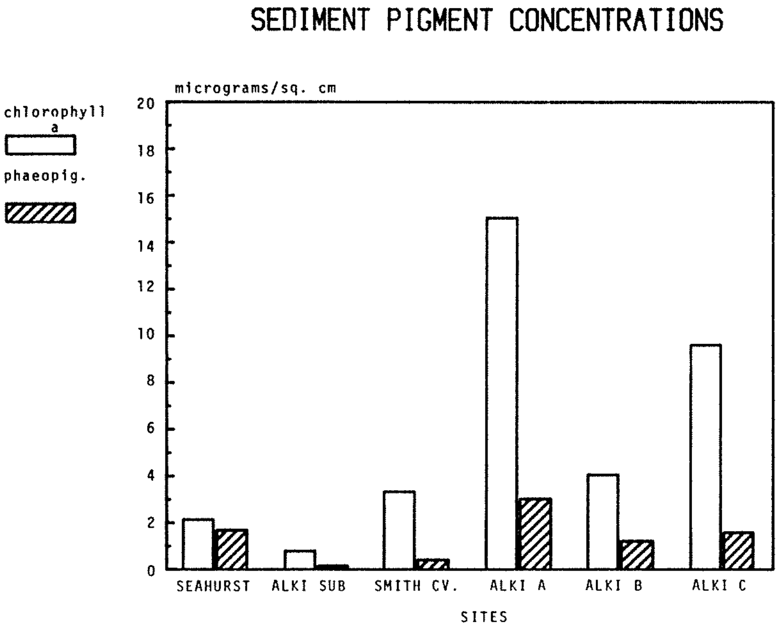

Figure 4.18. Mean sediment microalgal pigment concentrations at sand habitats. Alki Sub. = a single sampling of four replicates 3 m inshore from inshore edge of eelgrass meadow near transect Alki C.

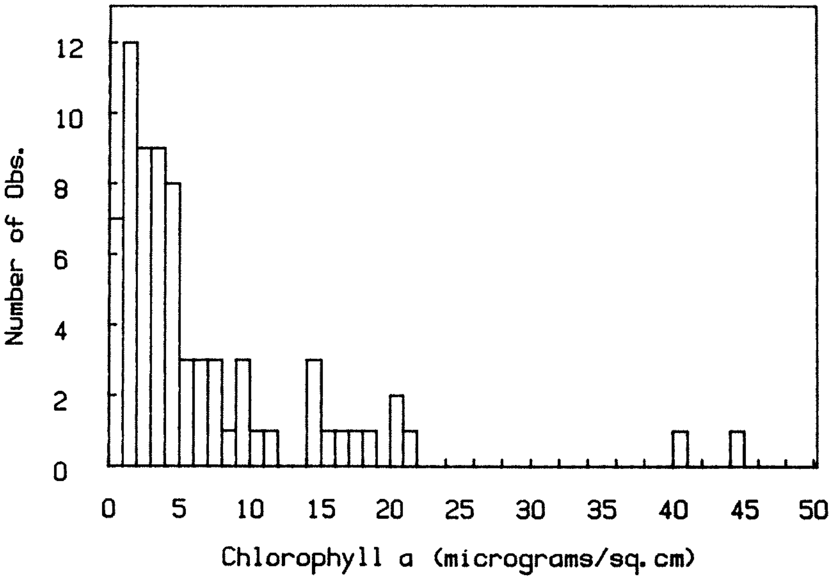

Figure 4.19. Histogram of chlorophyll a concentrations in sandy sediments from Elliott Bay.

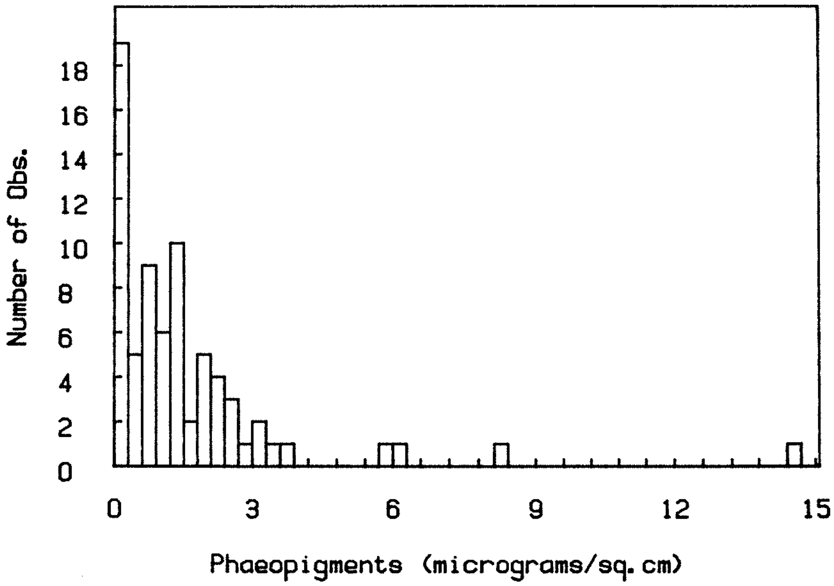

Figure 4.20. Histogram of phaeopigment concentration in sandy sediments from Elliott Bay.

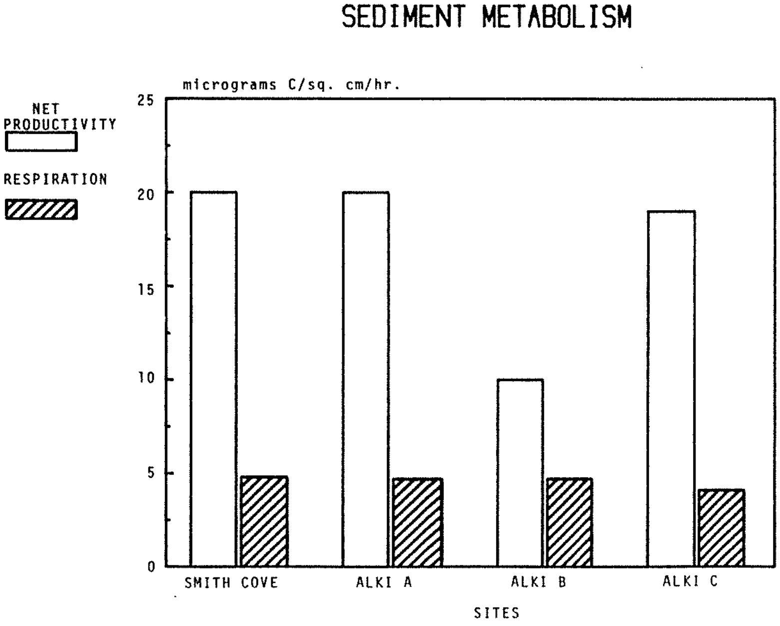

Figure 4.21. Mean net productivity and assemblage respiration of sandy sediments from Elliott Bay.

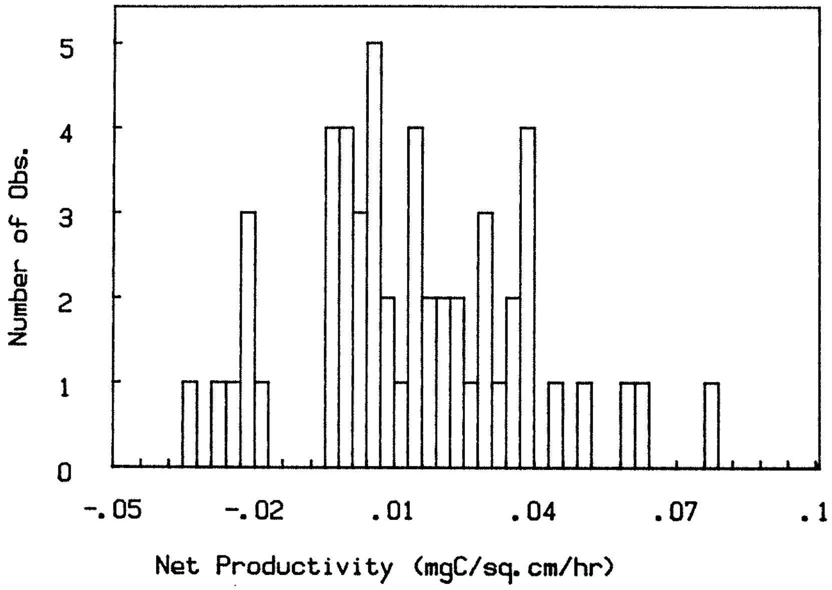

Figure 4.22. Histogram of net productivity of sandy sediments from Elliott Bay.

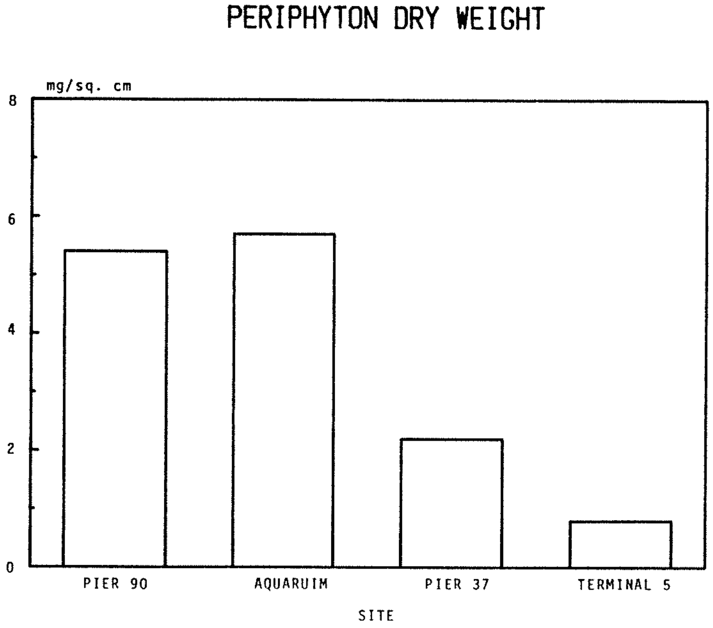

Figure 4.23. Mean standing stock of periphyton on settling plates in Elliott Bay.

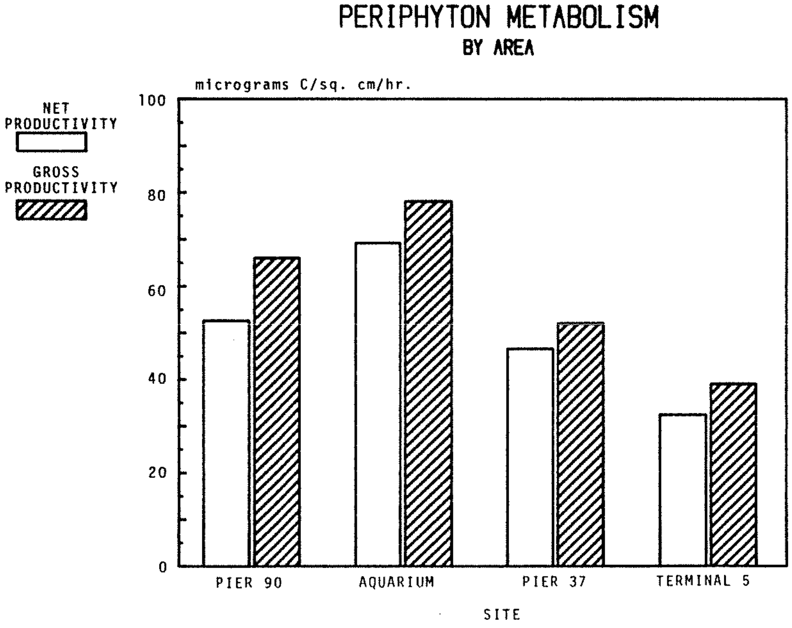

Figure 4.24. Mean periphyton metabolism per unit area on settling plates in Elliott Bay.

4.25). The periphyton assemblages indicate strong spatial water quality gradients in Elliott Bay. Relationships among biological and physical-chemical parameters require further study.

4.5.6 Seaweed Assemblages

Seaweed assemblages dominate intertidal and shallow subtidal rocky areas along Magnolia Bluff, the south side of Alki Point, Rockaway Beach and at Seahurst Park. Species most often encountered at the beaches are shown in Table 4.3. Magnolia Bluff beaches had an extensive seaweed habitat due to the presence of intertidal cobble/boulder fields. Based on Seahurst baseline study information, it is likely that seaweed production was either directly (via herbivory) or indirectly (through utilization of seaweed detritus) the major food resource for nearshore benthic animals. Production rates were recorded on eight occasions (not summarized here) and were on the order of those recorded at the sites in East Passage.

4.5.7 Kelp Bed

Nereocystis luetkeana, the annual brown alga, forms beds along Magnolia Bluff, and along the southern side of Alki Point. Isolated plants occur along Rockaway Beach. The bed at Magnolia Bluff is located primarily between Smith Cove and 32nd Street with a small patch near Four Mile Rock (Figure 4.5; Table 4.4). It is a dominant component (surface area = 13 ha) of the nearshore environment in these areas. Aerial photographs and diving reconnaissance provided standing crop estimates of ca. 20 g dry wt/m^2, and ca. 2,600 kg for the entire bed (Table 4.5).

4.5.8 Eelgrass

Eelgrass forms an almost continuous band at a depth of ca. -4 to -18 ft MLLW between Duwamish Head and Alki Point (Figure 4.4; Table 4.6). The meadow occupied approximately 11 ha, and contained a standing stock of ca. 7,100 kg

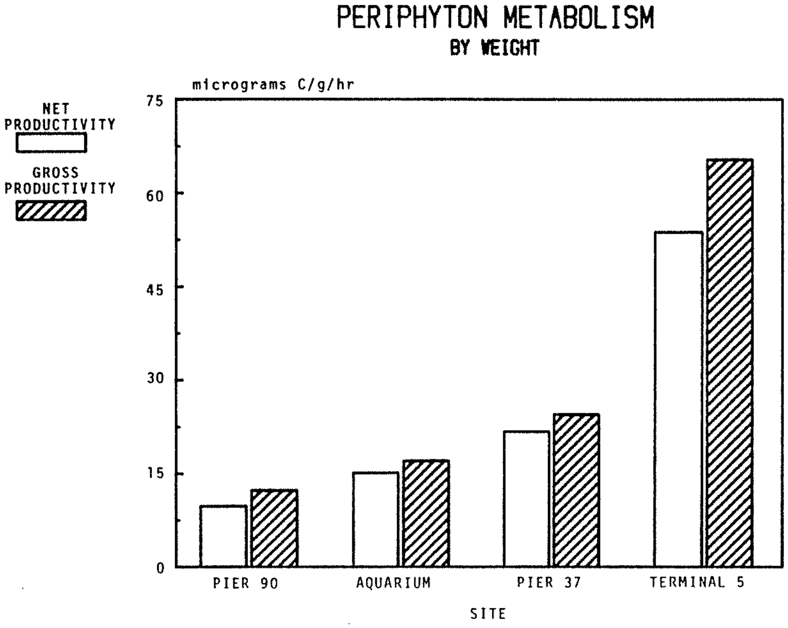

Figure 4.25. Mean periphyton metabolism per unit biomass on settling plates in Elliott Bay.

Table 4.3. Macroalgal taxa and abundance estimates at the study sites. C = common; R = rare. All are cobble habitats except where noted otherwise.

Taxa	Seahurst	Duwamish[1] Head	Alki[2] A	Alki[2] B	Alki D	Rockaway	32nd St.	Four Mile Rock
Alaria sp.		R						
Caulacanthus ustulatus								
Constantinea subulifera							R	
Cryptosiphonia woodii						C		
Enteromorpha intestinalis	R	R	R	R	R			
E. linza	R	C			C		R	R
Fucus evanescens			C	C		C	C	C
Gigartina papillata		R	R	R	R	R	R	R
Hildenbrandia sp.							R	R
Iridaea heterocarpa		R				C		
Laminaria saccharina							C	C
Monostroma sp.						C		
Nereocystis luetkeana		R			R	R	C	C
Polysiphonia sp.					R			
Porphyra sanjaunensis		R			R		R	R
Rhodomela larix						R		
Pterosiphomia bipinnata		R	R	R			R	R
Sargassum muticum							C	C
Ulva exansa	C	C			C		R	R
U. fenestrata	C					C	C	C

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[1] broken pilings

[2] riprap wall

Table 4.4. *Nereocystis luetkeana* depth distribution and density. Depths relative to MLLW.

Transect	Depth Distribution			Density	
	inner edge	outer edge	Width (m)	No/m^2	Transect total
1. Admirals House	-3 ft.	-18 ft	100	0.2	20
2. Flag Pole	-2	-18	117	0.6	74
3. 32nd St.	-2	-19	150	1.0	153
4. Four Mile Rock	-4	-8	43	2.2	95
Mean	-3	-16	103	1.0	

Table 4.5. *Nereocystis luetkeana* plant length, biomass and total bed standing stock at Magnolia Bluff.

	Mean	S.D.	95% CI
Stripe length	590.9 cm	124.7	± 66.4 cm
Dry wt./plant	19.787 g	9.430	± 23.427 g

Area of Bed[1] = (1270 m long) (103 m wide)
= 130,810 m^2
= 13 ha
= 32 acres

Standing stock = (1.0 plant/m^2) (19.787 g/plant) (130,810 m^2)
= 2,588,337 g dry wt.
= 2,588 kg dry wt.
= 199 kg dry wt./ha of bed
= 19.8 g dry wt./m^2
= 80.9 kg dry wt./acre

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[1] From aerial photos and bed dimensions in Table 5.

Table 4.6. Eelgrass (*Zostera marina*) meadow dimensions, densities, and standing stock.

A. Meadow length[1] = 3,556 m
Meadow surface area = (3,556 m)(31 m) = 110,236 m^2
= 11.02 ha
= 22.24 acres

B. Dimensions:

Transect		Depth (rel. to MLLW) inner edge	outer edge	Width	Density[2] No/m^2	Biomass[3] g dry/m^2
West:	west end	-9 ft	-18 ft	43.5 m	222	68.3
	east end	-5	-14	31.5		
East:	west end	-4	-13	16.0	112	60.8
	east end	-7	-13	32.0		
Mean		-6	-15	31.0	167	64.6

C. Standing stock = (length of bed)(mean width)(mean biomass)
= (3,556 m)(31.0 m)(64.6 g/m^2)
= 7,121 kg dry wt.
= 646 kg/ha
= 261 kg/acre

D.

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[1] From field observations between Duwamish Head and Alki Point.

[2] Maximum mean value of July and August samplings.

[3] Data available for August only.

dry wt (= 646 kg/ha). Above ground blade length data indicated the presence of at least two size classes within the meadow (Figure 4.26). The meadow at this beach was less dense than that at Seahurst. This may be due to the fact that currents are stronger along Alki Beach and may slough older tissue from the plants at a greater rate (Figure 4.27).

The animals observed within the bed by divers were quantified (Table 4.7). The meadow appears to be utilized by several larger mobile invertebrates including the economically important Dungeness crab.

Epibenthic Crustaceans

Epibenthic crustacean assemblages in the eelgrass meadow and sandflat habitats at Alki Point West were comparable in composition and standing stock to Seahurst Park expect for an additional prominence of caprellid amphipods at Alki. Total densities of epibenthic organisms averaged 64,656 ± 22,904 individuals m^3 in the eelgrass meadow and 82,688 ± 62,016 in the sandflat; corresponding standing crop values were 39.88 ± 31.8 and 1.76 ± 0.76 g wet weight M^3, respectively.

As at Seahurst, harpacticoid copepods (predominantly Ectinosomidae, *Halectinosoma* sp., *H. inermis*, *Ectinosoma* spp., *Harpacticus spinulosus*, and *Tisbe* sp.) dominated both assemblages. However, harpacticoid densities in the sandflat habitat were more than three times greater than in the eelgrass meadow (71,016 vs. 20,656 m^3, respectively). This was generally due to higher densities of *H. spinulosus* in the sandflat samples. Both gammarid and caprellid amphipod assemblages were qualitatively and quantitatively enhanced in the eelgrass meadow compared to the sandflat. In the seagrass meadow gammarids such as *Ischyrocerus* sp., *Megamphopus* sp., and *Aoroides* sp. averaged 11,064 m^3, as compared to *Pontogeneia* sp., *Paracalliopiella pratti*, and *Synchelidium shoemakeri* averaging only 936 m^3 in the sandflat habitat. The

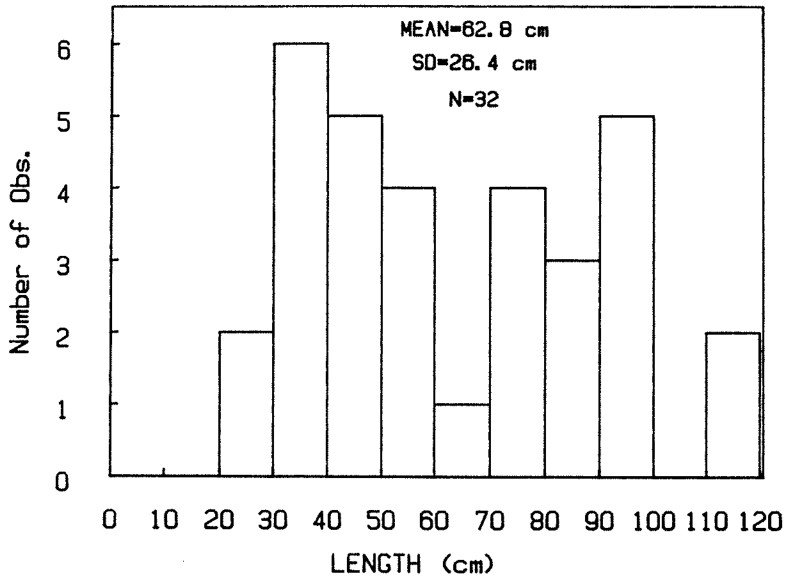

Figure 4.26. Histogram of above ground blade length of <u>Zostera marina</u> from transects Alki East and Alki West.

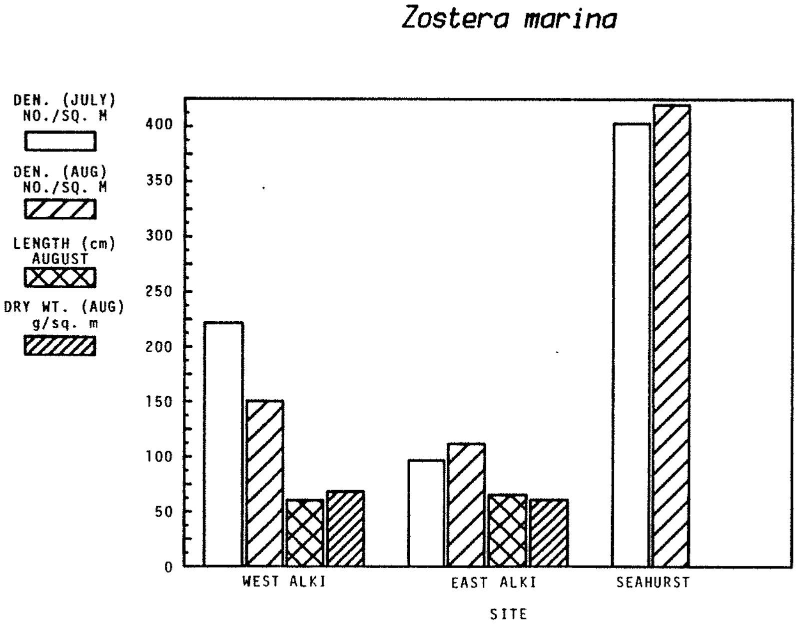

Figure 4.27. <u>Zostera marina</u> turion density and standing stock at transects Alki East and Alki West.

Table 4.7. Epifauna observed by a diver along transects in the *Zostera marina* meadow. Maximum density recorded is given.

Taxa	Density (No./ha)		
	West transect	East transect	Total[1]
Armina californica (nudibranch)	0	20	110
Cancer magister (Dungeness crab)	0	30	165
C. productus (red crab)	20	0	110
Ptilosarcus gurneyi (sea pen)	20	30	275
Pugettia producta (kelp crab)	50	0	275

[1] Total estimated for eelgrass meadow between Duwamish Head and Alki Point = mean density x eelgrass meadow surface area.

most dramatic contrast occurred in the standing crop of the caprellids, Caprella laeviscula and Metacaprella kennerlyi. In the eelgrass meadow, their densities averaged 9,360 m^3 and they contributed over 75% (30.4 g wet m^3) of the total epibenthic standing crop. In contrast, caprellid densities in the sandflat were 456 m^3 and they comprised only about 14% of the total standing crop.

This microhabitat comparison, although limited to one series of analyzed samples, indicated that eelgrass meadows were associated with increased diversity and standing stock (principally through enhanced standing crop) of epibenthic crustaceans. This increase was effected principally through the augmentation of gammarid and caprellid amphipod taxa. Further quantitative (multivariate) analysis is required to statistically differentiate these assemblages and compare them to the longer-term data on epibenthic crustacean assemblages from Seahurst and the central basin of Puget Sound (Thom et al. 1984).

Epibenthic Predators

As predicted, the diet compositions of the ten macroinvertebrate and fish predators were focused predominately upon epibenthic crustaceans (Table 4.8). In terms of the Index of Relative Importance (IRI; Pinkas et al. 1971; Cailliet 1977), epibenthic crustacea (including harpacticoid copepods, gammarid amphipods, caprellid amphipods, mysids, ostracods, cumaceans) accounted for between 53% and 100% of the stomach contents. Harpacticoid copepods were important to two predators, tube-snout and penpoint gunnels, while the other eight predators focused their foraging on either gammarid and/or caprellid amphipods. The other epibenthic prey fauna were comparatively unimportant.

The prominence of specific prey taxa in the predators' diets suggested

Table 4.8. Summary of relative importance (% total IRI) of epibenthic crustaceans in the diets of ten nearshore predators; see Table 5.2 for more complete information on predator taxa.

Predator taxa	% Total IRI of Epibenthic Crustacean Taxa harpacticoid copepods	gammarid amphipods	caprellid amphipods	mysids	ostracods	cumaceans
Shrimp						
C. nigricauda	0	10.0	81.1	0	8.9	0
P. danae	0	0	100.0	0	0	0
Fish						
O. tshawytscha	0	80.6	4.7	0.1	0	0.4
Apodichthys flavidus	53.3	0	0	0	0	0
B. cirrhosus	0.2	36.0	63.2	0.6	0	0
C. aggreagata	0.2	18.8	80.6	0	0	0
E. lateralis	0.2	98.5	1.3	0	0	0
Aulorhynchus flavidus	22.3	77.7	0	0	0	0
P. laeta	0	48.2	51.6	0	0	0
P. vetulus	67.5	2.3	9.4	0	0	0
ave. IRI	14.4	37.3	31.1	0.1	0.9	<0.1

that their food resources were associated principally with the eelgrass meadow habitat rather than the sandflat habitats. Caprellids such as *Caprella laeviuscula* and *Metacaprella kennerlyi* occur almost exclusively upon eelgrass blades and the gammarids which were prominent in their diets (particularly *Ischyrocerus* sp., *Anisogammarus pugettensis*, and *Aoroides* sp.) are also most representative of that habitat (Thom et al. 1984). Even the blacktail shrimp, which is commonly perceived to be representative of sandflat habitats, derived 81.1% of its diet (IRI) from the caprellid *M. kennerlyi*.

Thus, in addition to providing a structural habitat for an enhanced fish and macroinvertebrate fauna, eelgrass meadows also appear to be the principal foraging site for epibenthic predators from outside the habitat. Statistical tests of overlap between eelgrass meadow and sandflat epibenthos and fish diet compositions will further quantify these associations.

4.5.9 Small Infauna

Densities of infaunal organisms determined from counts made during sorting are listed in Table 4.9. These counts provide an overestimate of actual invertebrate abundances due to occasional misidentification of polychaete fragments and dead molluscs as living individuals. Abundances obtained from these counts can be compared to abundances obtained from complete identification (to species) of subsets of the samples at 13 of the sites (Table 4.10). While the counts listed in Table 4.9 should not be used to indicate absolute densities of invertebrates, the completeness of the data provides a useful tool for making relative comparisons of infaunal densities between sites.

Patterns of relative abundances parallel those observed in the Seahurst Baseline study. Intertidal sand habitats generally contain the lowest densities of infauna, eelgrass habitats had slightly higher densities, and

Table 4.9. Mean abundances of small infaunal organisms recorded during sorting of samples. Abundances are number per 23.76 cm^2.

	SITE												
Date	Alki A	Alki B	Alki C	Alki D	Alki Eelgrass 1	Alki Eelgrass 2	Magnolia 1	Magnolia 2	Smith Cove	Seahurst Sand	Seahurst Cobble	Seahurst Eelgrass	Rockaway Beach
May 1984	x[1]	x	x	x	x	x	x	x	x	5.2	59.1	x	x
S.D.										4.6	31.3		
n										12	11		
July 1984	5.0	8.0	5.7	64.1	10.1	15.0	52.0	88.4	4.3	5.4	49.4	26.8	-[2]
S.D.	4.4	4.7	3.3	52.5	5.1	18.5	33.2	51.3	3.1	3.1	52.5	8.9	
n	17	20	20	8	20	20	20	20	19	12	12	12	
August 1984	3.6	10.8	6.3	-	10.9	11.4	-	60.0	6.8	6.2	44.5	14.8	-
S.D.	1.9	6.1	4.7		6.2	4.7		56.7	3.9	3.3	22.0	12.0	
n	20	20	20		20	20		20	12	12	11	12	

[1] x = no samples collected.

[2] - = samples collected, but not sampled.

Table 4.10. Mean abundances of small infaunal organisms obtained after complete identification of invertebrates (to species). Abundances are number per 23.76 cm^2.

	SITE							
Date	Alki A	Alki B	Alki C	Alki Eelgrass 1	Alki Eelgrass 2	Magnolia 2	Seahurst Sand	Seahurst Cobble
May 1984	x[1]	x	x	x	x	x	5.2	41.9
S.D.							4.6	26.5
n							12	11
July 1984	3.2	7.7	5.1	10.0	7.3	72.8	-[2]	-
S.D.	3.1	3.7	2.7	3.8	4.4	37.6		
n	10	10	10	10	10	10		
August 1984	2.9	9.4	4.9	10.1	10.3	-	-	-
S.D.	1.5	3.7	4.2	6.8	5.0			
n	10	10	10	10	10			

[1] x = no samples collected

[2] - = samples collected but not analyzed.

cobble habitats had the highest densities (Table 4.9; Figure 4.28). Within the nearshore area between Duwamish Head and Alki Point, the sites located nearest to Duwamish Head (Alki A in the intertidal and Alki East eelgrass in the shallow subtidal) had the lowest abundances of organisms.

Abundances of invertebrates at the sites for which samples were identified to species showed that infaunal densities in sand habitats ranged from 1200 to 4000 organisms/m^2 (Table 4.10). Densities in eelgrass habitats ranged from 3100 to 4300/m^2, while in cobble habitats densities were much higher (17,600 to 30,600/m^2). The number of taxa present in each site showed a similar pattern, with highest species richness in cobble habitats (46-48 species), followed by eelgrass (25-33 species) and sand (10-19 species) (Table 4.11).

The numerically dominant infaunal species present in each of the major habitat types sampled indicate that the infaunal communities in Elliott Bay were similar to communities in other areas of central Puget Sound (Table 4.12). While the numerically dominant species in the sand habitats showed considerable variation between sample sites and sample dates, this appears to be typical of intertidal sand communities (see Seahurst Baseline Study Report).

4.5.10 Beach Walks

The beach walks were conducted only once at each of the four beaches where study sites were located (along Magnolia Bluff, along Alki Beach between Duwamish Head and Alki Point, Rockaway Beach, and Seahurst Beach). Anoxic conditions did not appear to be a significant problem on any of the beaches at the time of the walks (August 1984), although at most locations examined a weak to moderate reducing layer was evident 2-10 cm below the sediment surface.

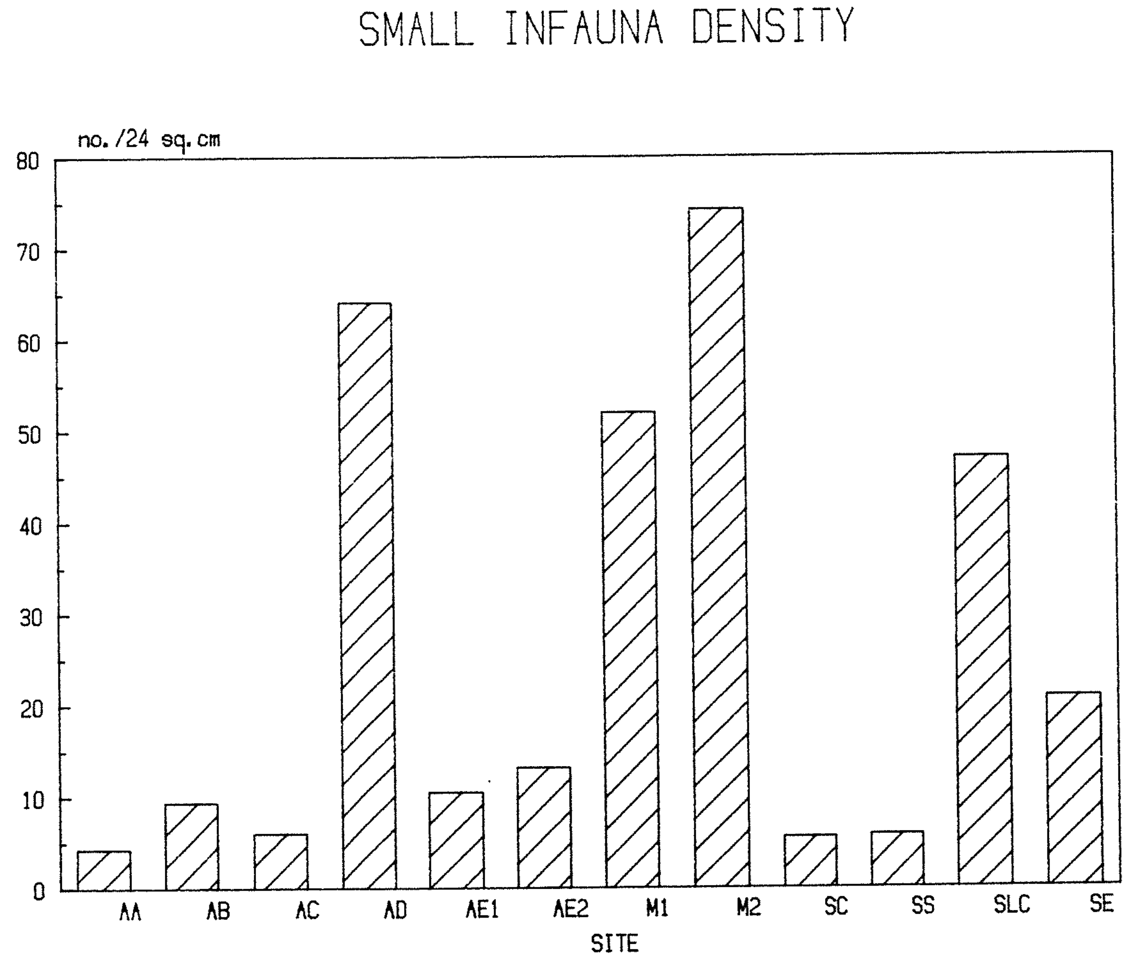

Figure 4.28. Mean densities for July and August samplings combined of small infaunal organisms recorded during sorting. For an explanation of site codes refer to the caption for Figure 5.6.

Table 4.11. Total number of small infaunal taxa.

	SITE							
Date	Alki A	Alki B	Alki C	Alki Eelgrass 1	Alki Eelgrass 2	Magnolia 2	Seahurst Sand	Seahurst Cobble
May 1984	x[1.]	x	x	x	x	x	17	16
July 1984	19	17	12	25	27	28	-[2.]	-
August 1984	13	14	10	25	33	-	-	-

1. x = no samples collected.

2. - = samples collected but not analyzed.

Table 4.12. Numerically dominant infauna along transects where species identification were completed. Organisms for a particular date and site are listed in decreasing order of abundance. P = polychaete, C = crustacean, M = mollusc.

	SITE							
Date	Alki A	Alki B	Alki C	Alki eelgrass 1	Alki eelgrass 2	Magnolia 2	Seahurst sand	Seahurst cobble
May 1984	x[1]	x	x	x	x	x	Scoloplos armiger (P) Transennela tantilla (M) Psephidia lordi (M) Tellina Modesta (M)	Mediomastus sp. (P) Leptochelia dubia (C) Malacocerus glutaeus (P) Notomastus tenuis (P)
July 1984	Heteropodarke heteromorpha (P) Armandia brevis (P) Paranonella platybranchia (P) Synchelidium shoemakeri (C)	Psephidia lordi (M) Heteropodarke heteromorpha (P) Transennella tantilla (M) Nematoda	Paraonella platybranchia (P) Heteropodarke heteromorpha (P) Scoloplos armiger (P) Eteone longa (P)	Caprella laeviuscula (C) Psephidia lordi (M) Tellina modesta (M) Mediomastus sp. (P) Diastylopsis tenuis (C) Photis brevipes (C)	Synchelidium shoemakeri (C) Tellina modesta (M) Mediomastus sp. (P) Diastylopis tenuis (C) Photis brevipes (C)	Leptochelia dubia (C) Malacocerus glutaeus (P) Mediomastus sp. (P) Armandia brevis (P)	-[2]	-
August 1984	Nephtys sp. A (P) Synchelidium shoemakeri (C) Scoloplos armiger (P) Euphilomedes carcharodonta (C)	Psephidia lordi (M) Transennella tantila (M) Armandia brevis (P) Streptosyllis latipalpa (P)	Eteone longa (P) Paraonella platybranchia (P) Armandia brevis (P) Scoloplos armiger (P)	Tellina modesta (M) Mediomastus sp. (P) Synchelidium shoemakeri (C) Macoma juv. (M)	Euphilomedes carcharodonta (C) Psephidia lordi (M) Synchelidium shoemakeri (C) Clinocardium sp. (M) Tellina modesta (M)	-	-	-

Several sites were identified, however, where the reducing layer was moderate to strong and perhaps reaches the sediment surface under certain conditions. A list of these sites is presented in Table 4.13. These sites appear to comprise potential monitoring sites for future studies concerned with the effects of activities altering loads of organic matter to beaches.

Evidence of oils or greases was rarely seen on the sediment or water surfaces during the beach walks. The only such observations recorded were a small patch of oil at the sediment surface along Magnolia Bluff 100 m west of the base of 32nd Street W., and a scum on the surface of the water at Smith Cove (which might have been due to causes other than oils or greases). During collection of interstitial water samples, however, what appeared to be oil and grease particles were typically observed at the surface of the sample at all beaches.

4.6 Conclusion

4.6.1 Nearshore Environment

Water chemistry and sediment parameter data indicate the strong influence of the Duwamish River on the Elliott Bay nearshore environment. This influence is especially evident along the eastern and northern shoreline. Although sampling was conducted during a period of minimum flow, low salinity, and elevated silicate concentrations were recorded along Magnolia Bluff in July. The influence appeared to be reduced in August during the driest period. Riverine influence on water properties was never as pronounced during the sampling period in the Duwamish Head-Alki Point area.

Sediment parameters along Alki Beach appeared to be influenced by sediment from the Duwamish River. Finer particle sizes were generally found at Duwamish Head as compared to sites further west. Exceptions were pockets

Table 4.13. Potential sites for monitoring of anoxic conditions in intertidal sediments within the study area.

Site	Substrate	Depth of anoxic layer	Sediment color	Odor	Amnt. of plant debris	Comments
Smith Cove	sand	1 cm	light gray	weak	moderate	
Just west of outfall at base of 32nd St. W., Magnolia	sand	2.5 cm to 6 cm	black-dark gray	strong-moderate	little	Runoff from storm drain flows over this area.
Several hundred feet west of 32nd St., in front of blue house adjacent to slide area	sand	1 cm	black-dark gray	strong-moderate	little	Clay mixed in with sand below surface, probably resulting from past slides.
About 300 m northwest of Fourmile Rock, near CSO pipeline	sand and clay	≥1 cm	dark gray	moderate	little	Site abuts outfall pipe.
Rockaway Beach, at 2nd pt. south of north end of our sampling transect	Sand	≥1 cm	dark gray	moderate-strong	little	
Rockaway Beach; 200 m north of northern most rock outcrop	coarse sand overlaying hard-packed clay	0-5 cm	gray	weak	moderate-large	Small indentation in shoreline where algal debris collects.
Rockaway Beach; between rock outcroppings	sand	reaches surface	gray	weak	moderate-large	

Table 4.13 (continued).

Site	Substrate	Depth of anoxic layer	Sediment color	Odor	Amnt. of plant debris	Comments
Duwamish Head; about 200-250 m east of bulkhead and fill; in lower intertidal on seaward side of sandbar	sand	$\geq$1 cm	dark gray	moderate-strong	little	
Alki Beach, just in front of statue of Chief Sealth	sand	1-3 cm	dark gray	moderate-strong	large (debris accumulations up to 10 cm thick)	Adjacent to intertidal eel-grass bed
Seahurst Beach; just no. of high school marine lab	fine sand	<1 cm	light gray (some marbling at surface)	moderate	none	

of deposition at various locations along this beach.

Water property values were also affected by primary producers, primarily in the region of dense kelp beds along Magnolia Bluff. During the low flow period (August), increased dissolved oxygen and decreased inorganic nutrient concentrations indicated vigorous levels of net primary production in the area. Benthic autotrophs (i.e., sediment microalgae and eelgrass beds) did not show as strong an influence along the southern beach.

Other influences on the nearshore environment that were discernable from field observations were storm drains and combined sewer overflows (CSO's). Along the southern shore, storm drains appeared to cause minor discontinuities in the otherwise continuous eelgrass meadow. CSO's may influence the intertidal sediments and biota at Magnolia Bluff. Pockets of relatively fine sediments having a reducing layer close to the sediment surface were noted very near the CSO's at 32nd Street and Perkins Lane (north of Four mile Rock). The impact of dredged material disposal seaward of Four Mile Rock on the nearshore environment is the subject of recent agency and public concern. The present data set does not address this question specifically.

4.6.2 Major Habitats

The inner (eastern) portion of Elliott Bay is highly modified. It contains steeply sloping riprap shorelines and piers on pilings. Only a small fraction (2%) of the original tideflat/wetland habitat area of the Duwamish River remains. Relatively unchanged are the habitats along Magnolia Bluff and Alki Beach. Magnolia Bluff is comprised of a gently sloping cobble/boulder habitat containing recreationally important shellfish stocks. The region at the south-end (from 32nd Street to Smith Cove) of Magnolia Bluff contains a dense shallow subtidal kelp bed. In general, benthic macroalgae were abundant on Magnolia Bluff beaches. The region from Duwamish Head to Alki Point is sand with a continuous band of eelgrass in the shallow subtidal zone. Kelp beds and eelgrass meadows are important components of the nearshore ecosystem as primary producers and as structural habitat. Fish and motile invertebrates are common in these habitats.

4.6.3 Areas of Desposition

Primary areas of deposition, based on sediment characteristics and presence of depositional indicators (e.g., drift algae) occur at Smith Cove and in the area at the western end of Alki Beach (i.e., near transect Alki West). Secondary (i.e., smaller) depositional areas, indicated by pockets of fine sediments and a shallow reduced layer, occur at the immediate west side of Duwamish Head just seaward of the boulder wall, and in isolated areas along Magnolia Bluff. These are areas of high organic enrichment, and, as such should be monitored following outfall construction.

4.6.4 Siting of the Outfall

The recommendations, based on the present data, regarding the outfall siting that will minimize construction and long-term impacts to the nearshore system in Elliott Bay are as follows:

1. The outfall pipe should cross the intertidal zone as close to Duwamish Head as possible. It is best to cross this zone on the east side of Duwamish Head to minimize impacts on eelgrass. It should be noted, however, that recovery of the eelgrass meadow in this region may be slower than in the area further west due to the marginal nature of the environment for eelgrass (i.e., intense riverine influence). Sediment microalgal production is relatively high in this area. However, recovery of this assemblage following construction should be rapid if sediment similar to that now present is used to cover the pipe.

2. It is important not to modify longshore current movements to minimize the probability of development of pockets of organically enriched and anoxic sediments.
3. The outfall terminus should be located in an area that maximizes the flushing and dilution of the effluent. Significant biological assemblages, which are sensitive to effluent, exist in Elliott Bay, and the probability of effluent contact in these assemblages should be minimized.

4.7 Literature Cited

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Appendix 4.1

Page 1 of

METRO STATION LOCATION INFORMATION

Elliot Base Baseline: → samples collected June 1984 to Sept. 1984

PROJECT: Nearshore studies DATE: 10-12-84 VESSEL: ________ PERSONNEL: Ron Thom/Rick Albright GROUP: Univ. of Washington School of Fisheries

STATION	* METRO GRID NAME	DEPTH (M)	LORAN 1 LORAN 2	** LAT. LONG.	Transect Descriptions
Rockaway Beach		0'		Start: lat 122° 29' 45" long 47° 36' 35" End 122° 29' 49" 47° 36' 21"	North stake of transect is located directly seaward and in line with Northern side of second house on beach South of Creosote Pt. The stake is 183 ft from cement wall at this point on beach.
Alki A		0'		Start 122° 23' 00" 47° 35' 46" End 122° 23' 12" 47° 35' 46"	Transect wraps around Duwamish Head. East stake is 225 ft seaward of seawall in line with first street light west of metal railing. The railing is east of Hamilton viewpoint at street level located at the apex of Duwamish Head.
Alki B		-1'		start 122° 23' 53" 47° 35' 12" End 122° 24' 01" 47° 35' 05"	Transect lies on beach in front of Alki Shores Apartments. East end is 59 ft 5 in. seaward of seawall and in line with fourth light post east of stairway leading to beach
Alki C		0'		start 122° 24' 07" 47° 35' 01" End 122° 24' 18" 47° 34' 55"	Transect lies between 55th and 58th street. East stake is 267 ft 4 in. seaward of junction of concrete stairs leading to beach and concrete bunker located directly accross the street from 55th street.
Alki D		0'		start 122° 24' 58" 47° 34' 22" End 122° 24' 46" 47° 34' 19"	Transect lies approximately 700 m south of Alki Pt. and crosses over a storm drain pipe that runs over beach. The North stake is 25.3 m shoreward and south of large boulder located approx. 100 m north of pipe. The stake is
Smith Cove		0'		start 122° 23' 05" 47° 37' 53" End 122° 23' 11" 47° 37' 52"	Transect lies seaward of turn-around at Smith Cove Park. North stake is 45.8 ft from base of rip rap wall and 54.7 ft south and seaward of concrete cylinder located below Admiral's house on cliff. 61.21 m seaward of seawall
32nd St. W		0'		Start 122° 23' 51" 47° 37' 55" End 122° 23' 39" 47° 37' 52"	At base of 32nd St. North stake is located 10 m south of 5th joint in large pipe crossing the beach.

COMMENTS

Latitude and longitude were calculated by measuring off ~~USGS~~ NOAA National Ocean Survey map # 18449.

* TO BE ASSIGNED BY METRO

** PLEASE NOTE IN COMMENT SECTION HOW LAT. LONGS. WERE OBTAINED AND SPECIFY MAP SOURCES

Appendix 4.1 (cont.)

Page 2 of 2

METRO STATION LOCATION INFORMATION

PROJECT: Elliot Bay Baseline: Nearshore Studies DATE: 10-12-84 VESSEL: ________ PERSONNEL: Ron Thom/Rick Albright GROUP: Univ. of Washington School of Fisheries

STATION	* METRO GRID NAME	DEPTH (M)	LORAN 1 LORAN 2	** LAT. LONG.	TRANSECT Descriptions
4-mi. rock		0'		Start 122° 24' 45" 47° 38' 21" End 122° 24' 53" 47° 38' 26"	South stake is 73 ft 7 in. seaward of Fourmile Rock
Eelgrass west		-6'		Start 122° 24' 12" 47° 35' 03" End 122° 24' 01" 47° 35' 09"	West end was seaward of eastern wall of beach bath house located at intersection of Alki Avenue S.W. and 56th Ave. S.W.
Eelgrass East		-6'		Start 122° 23' 06" 47° 35' 53" End 122° 23' 13" 47° 35' 45"	East end was seaward of western wall or bulkhead of Hamilton Viewpoint on Duwamish Head.

COMMENTS

* TO BE ASSIGNED BY METRO

** PLEASE NOTE IN COMMENT SECTION HOW LAT. LONGS. WERE OBTAINED AND SPECIFY MAP SOURCES

5.0 SUBTIDAL BENTHIC ECOLOGY

J. Word, P. Striplin, J. Ward, K. Keeley and K. Chew

5.1 Materials and Methods

The Duwamish Head Baseline study conducted within Elliott Bay, Washington extended from West Point south to Vashon Island. Eighty-three benthic stations were sampled. Seventy-six of these were located on eighteen transect lines while seven others occurred at specific points. The transect lines were oriented perpendicular to shorelines in depths ranging from 50 to 800 feet. The location of these transects and point stations is presented in Figure 5.1.

Stations and transects from other METRO sponsored studies were used when creating the Elliott Bay Baseline sampling grid. The use of previously sampled benthic stations allows comparison of biological and chemical information between the Duwamish Head and previous studies. Twelve METRO/TPPS stations located along five transect lines were included in the sampling grid (Transects 7, 8, 9, 10 and 11). These transects are located just south of West Point and following the shoreline into Elliott Bay where they connect with the new sampling regime. Seahurst Transect A, containing seven stations and located between Point Williams and Vashon Island and Seahurst Point stations SS-3, 4, 5, 7 and 11, surrounding Blake Island were also included in this study.

Four van Veen grabs were collected at each benthic station: three for biological analysis, one for chemical analysis. Due to the difficulty of obtaining acceptable grab samples one biological and one chemical sample were collected at station B-X-50E.

The total number of samples collected during the Duwamish Head Baseline study was 330; 247 biological and 83 chemical samples. One hundred and

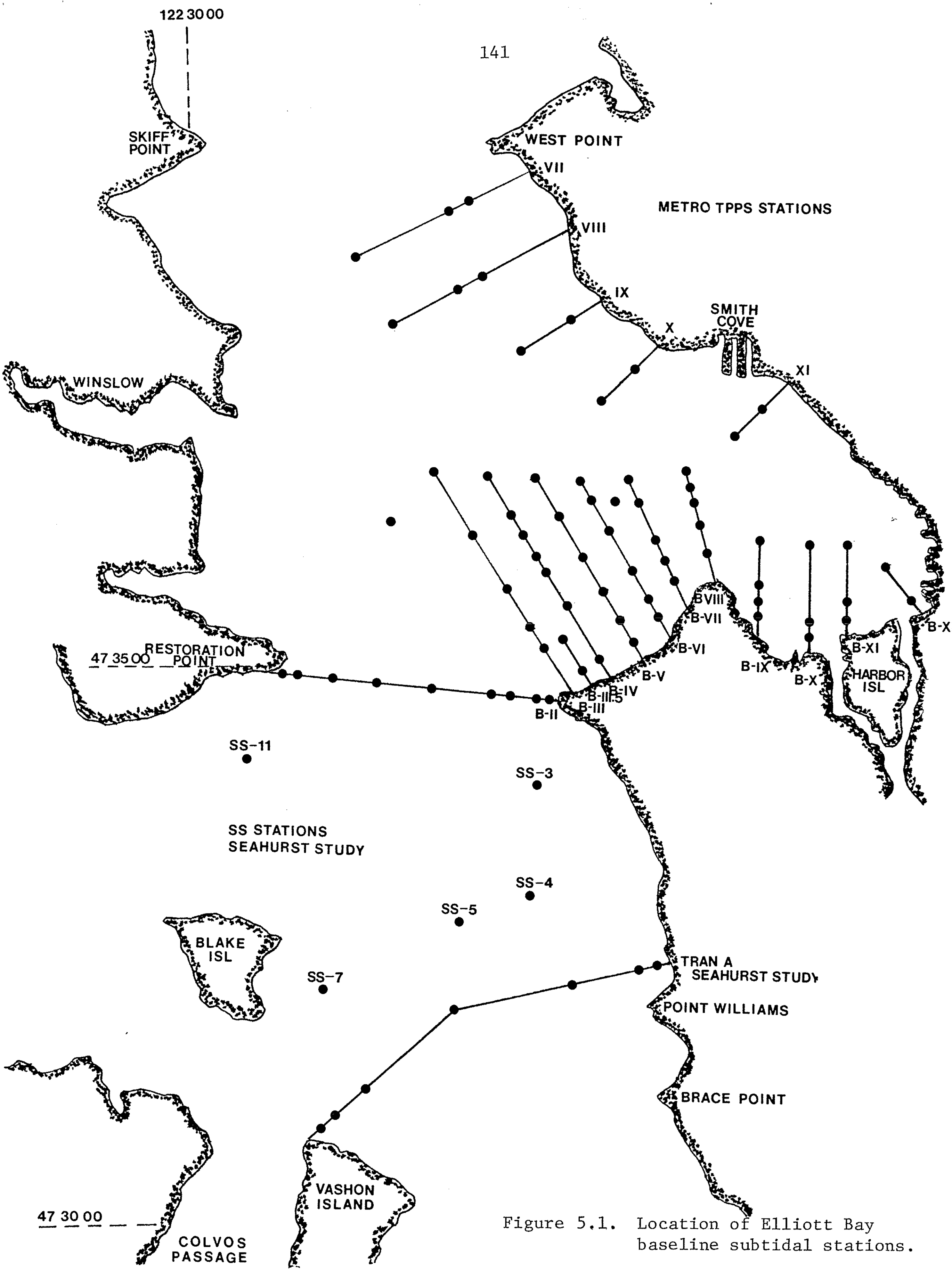


Figure 5.1. Location of Elliott Bay baseline subtidal stations.

twenty-three biological samples were sorted and identified.

5.1.1 Sampling at Sea

The bottom topography of outer Elliott Bay is typical of glacially formed fjords with steep slopes and relatively wide basins. Stations were established to obtain a distribution of potentially depositional and erosional sites through the use of fine scale bathymetric charts for finding these topographical features (NOAA 1935).

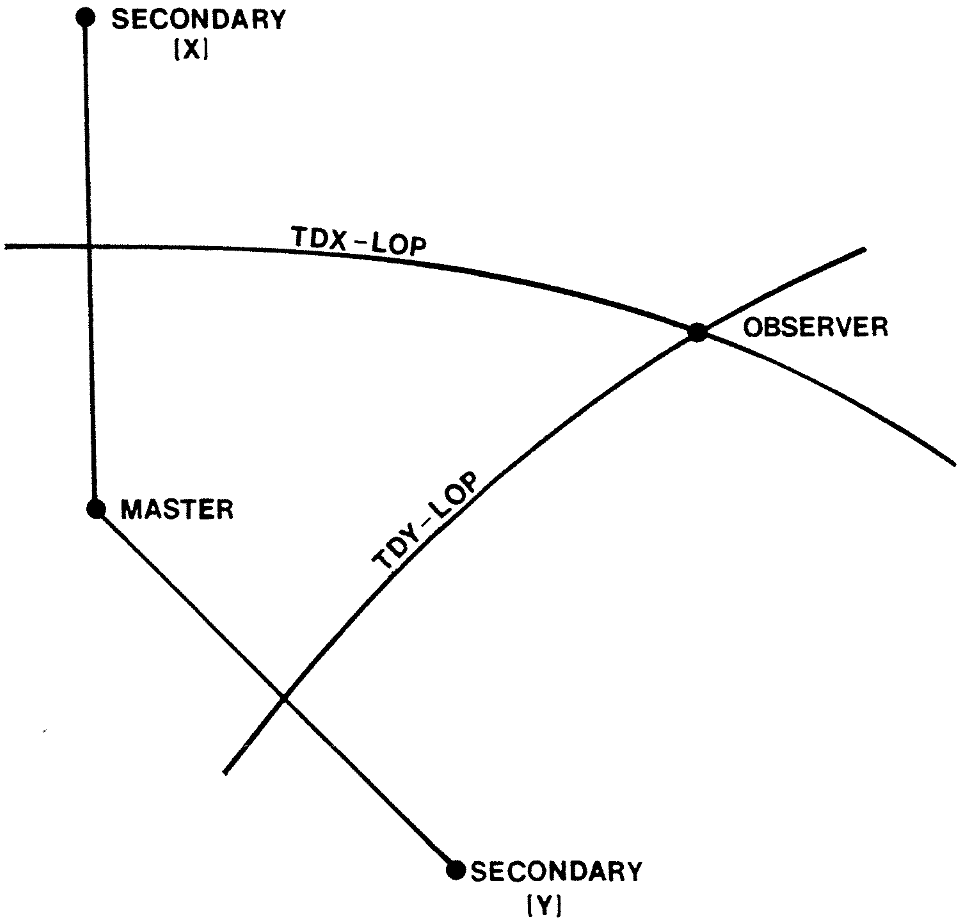
Station location consisted of establishing information on each of the following navigational aids:

1. LORAN C
2. Variable range radar fixes to two-four targets.
3. Visual ranges - a minimum of two.
4. Water depth.

5.1.1.1 LORAN C

LORAN C is an accurate long range radio navigation system originally developed for the U.S. Navy to replace the outdated LORAN A system. It is now used extensively throughout the world. The system produces a pulsed, time delayed signal which is received and translated into a unique navigational position. The transmission system consists of a master transmitter and at least two slaves or secondary transmitters separated in space (Figure 5.2). The time delayed radio waves produced by these slaves produce an x, y coordinate system (TDX and TDY). The LORAN receiver then converts these radio signals into a unique position on the grid.

The LORAN C signal chain used in this geographical region is designated the 5990 chain, and it consists of one master at Williams Lake, B.C. and two slave transmitters, located at George, Washington and Port Hardy, B.C. The radio signals produced by this chain may become distorted by mountain ranges,



Bowditch, Nathanial
American practical navigator
Defense Mapping Agency
Hydrographic Center 1977

Figure 5.2. Schematic diagram of a LORAN C transmission system (After Bowditch 1977).

points of land or headlands, large buildings, or radio towers (especially those transmitting on the same frequency as LORAN C at 100 kHz). The stronger signal ground waves are slowed down enough that the receiver can become fooled and will read the weaker air waves that have traveled greater distances. This can result in apparently confusing readings on the LORAN monitor. Since these forms of disturbance are constant the alteration in the normal reading of the signals is consistent and thus reoccupation of stations using these signals are still accurate. Placement of the stations on charts of the area based upon the LORAN C signal is not a simple task in Puget Sound because these areas of altered LORAN readings must be identified and their affects mapped accurately.

When LORAN C signals become weak or interference with the signal is strong, the ratio of signal strength to noise strength decreases and the accuracy of the LORAN C signal decreases. When this happens, alternative measures of navigation which are at least as accurate as the 20 m diameter signal provided by LORAN C become the primary rather than secondary navigational aids.

5.1.1.2 Variable Range Radar

This device is being used in conjunction with LORAN C station coordinates. It is a special addition to the vessel's Furuno Radar system that allows accurate measurement of distance to identifiable radar targets. The accuracy of the unit is 0.01 nautical mile or approximately 18.5 meters which is equivalent to the accuracy of the LORAN C unit. This device does not negate the use of the LORAN C system because it also has a problem when shore targets are used. Tidal fluctuations and distance from the shoreline results in topography changes that can greatly influence the measurement of distances. A shoreline that is completely covered at high tide may expose a hundred meters of shoreline at low tide to the radar unit. Therefore targets for the radar are generally made on identifiable permanent targets in the water, e.g., buoys or the edges of piers. Both of these electronic navigational aids are essential to proper reoccupation of benthic stations.

5.1.1.3 Visual Ranges

Visual ranges are not a compass alignment to a specific, identifiable target. They require two objects to be in alignment so that the vessel extends in a straight line away from the targets. A minimum of two sets of visual ranges are required to assure accuracy of location. The level of accuracy rests on the quality of the visual ranges chosen, the distances down each range, and the distance and angle between the two ranges. As an example, ranges which were 180° apart would not provide a line which crossed the other range line. Ideally, sets of visual ranges should provide intersections of the two extended lines which cross as close to 90° as possible (Figure 5.3).

5.1.1.4 Water Depth

The depth of a station should remain constant once tidal fluctuations have been accounted for. The criteria used during this project for acceptable depth variations were either 10% of the established depth or 20 feet, whichever was less. Depths were measured using two types of fathometers; a recording paper type and a digital output. Combining this type of navigational measurement with the radar, LORAN C, and visual ranges allows for very accurate positioning.

5.2.2 Field Sampling Procedures

Sediment samples were collected consistently with a 0.1 m^2 modified van Veen grab sampling device, and were carefully processed and preserved. The sampler was opened and the chain warp tripping mechanism set while the grab was in a metal sieving stand located at the stern of the research vessel. It

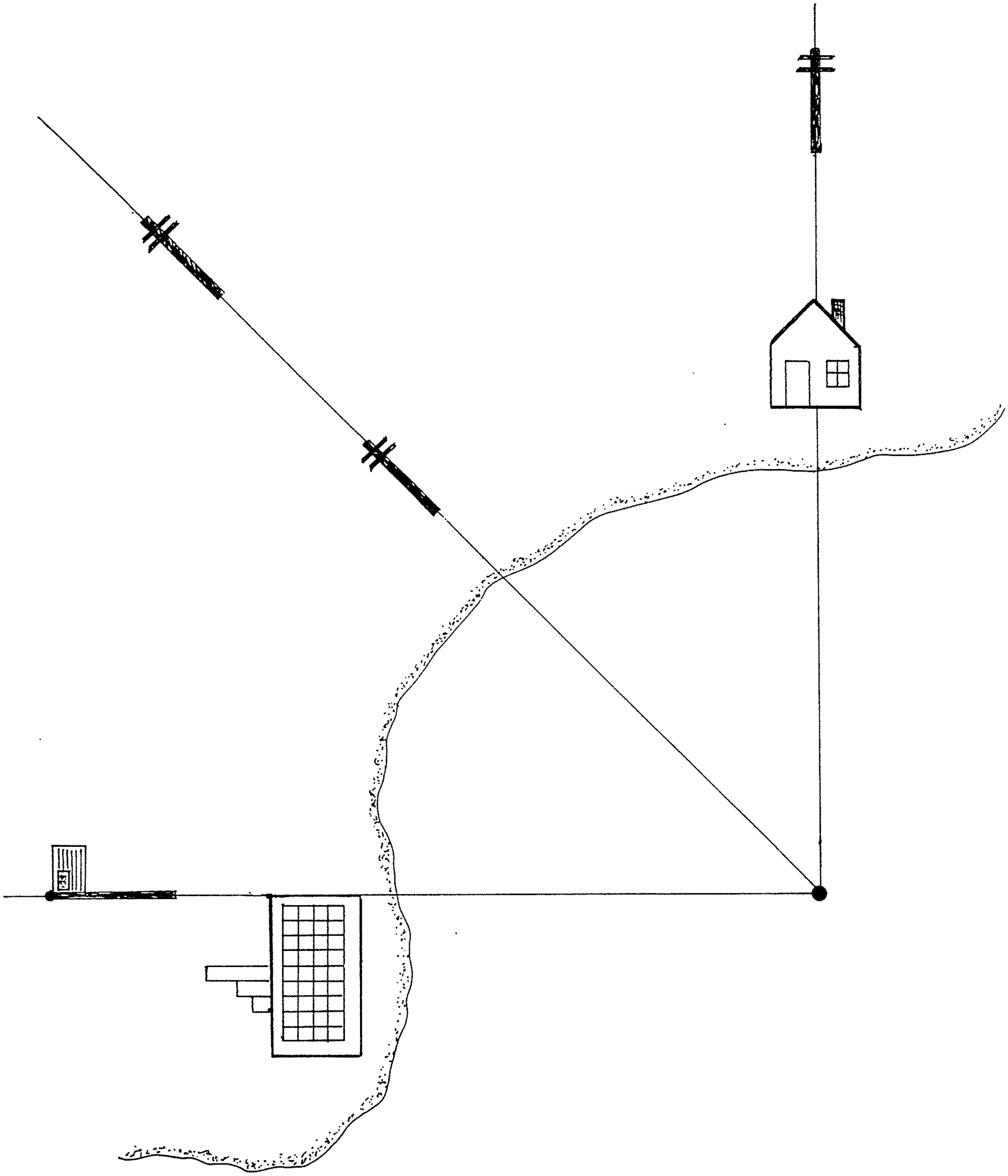


Figure 5.3. Diagram of an ideal visual range fix.

was then lowered through the water column at a rate approximately 20 meters per minute. When it struck the bottom the weight of the device forced it into the sediments where the action of retrieving the sampler caused the chain warp tripping mechanism to close the jaws around the sediment. A hydraulic system provided the mechanism for raising and lowering the sampler. Once the sample was brought on board, it was placed into the metal sieving stand and access doors in the top of the grab allowed characterization of sediments. Once this information was determined, the sampler was opened and reset, lifted slightly above the metal tray flow where the jaws of the sampler were washed free of any attached sediments. The device was then ready for its next descent.

The following physical characteristics of the sediments were described and recorded for each sample on a special form (Figure 5.4): sediment texture, sediment color, presence, type, and strength of odors, grab penetration depth, degree of leakage or sediment surface disturbance, and any obvious abnormalities such as large animals or wood debris. Samples which showed excessive leakage from inside the grab through the jaws or excessive disturbance of the sediment surface were rejected. Samples were also rejected if they did not meet the following minimum penetration depths:

4 cm	Coarse sand and gravel
5 cm	Coarse to medium sand
7 cm	Fine sand
10 cm	Silt with sand or clay

5.2.3 Biological Field Methods

Once these characteristics were recorded the jaws of the sampler were opened and the sediment released into the top section of the sieving stand (Figure 5.5) where it was gently sprayed with seawater and the larger masses of sediment broken apart. This material was washed into one or two stacked

SURVEY __________ DATE __________

AREA __________ TRANSECT __________ STATION __________

CREW ____________________ WEATHER ____________________

REPLICATE NO: LORAN COORDINATES:

BIO/CHEM BOTTOM DEPTH: PENETRATION DEPTH:

SEDIMENT TYPE: COBBLE GRAVEL SAND C M F SILT CLAY WOOD CHIPS

SEDIMENT COLOR: D.O. GRAY BLACK BROWN BROWN SURFACE

SEDIMENT ODOR: H_2S PETROLEUM NONE
SLIGHT MODERATE STRONG OVERWHELMING

COMMENTS:

REPLICATE NO: LORAN COORDINATES:

BIO/CHEM BOTTOM DEPTH: PENETRATION DEPTH:

SEDIMENT TYPE: COBBLE GRAVEL SAND C M F SILT CLAY WOOD CHIPS

SEDIMENT COLOR: D.O. GRAY BLACK BROWN BROWN SURFACE

SEDIMENT ODOR: H_2S PETROLEUM NONE
SLIGHT MODERATE STRONG OVERWHELMING

COMMENTS:

REPLICATE NO: LORAN COORDINATES:

BIO/CHEM BOTTOM DEPTH: PENETRATION DEPTH:

SEDIMENT TYPE: COBBLE GRAVEL SAND C M F SILT CLAY WOOD CHIPS

SEDIMENT COLOR: D.O. GRAY BLACK BROWN BROWN SURFACE

SEDIMENT ODOR: H_2S PETROLEUM NONE
SLIGHT MODERATE STRONG OVERWHELMING

COMMENTS:

Figure 5.4. Example of field data form used by subtidal baseline group.

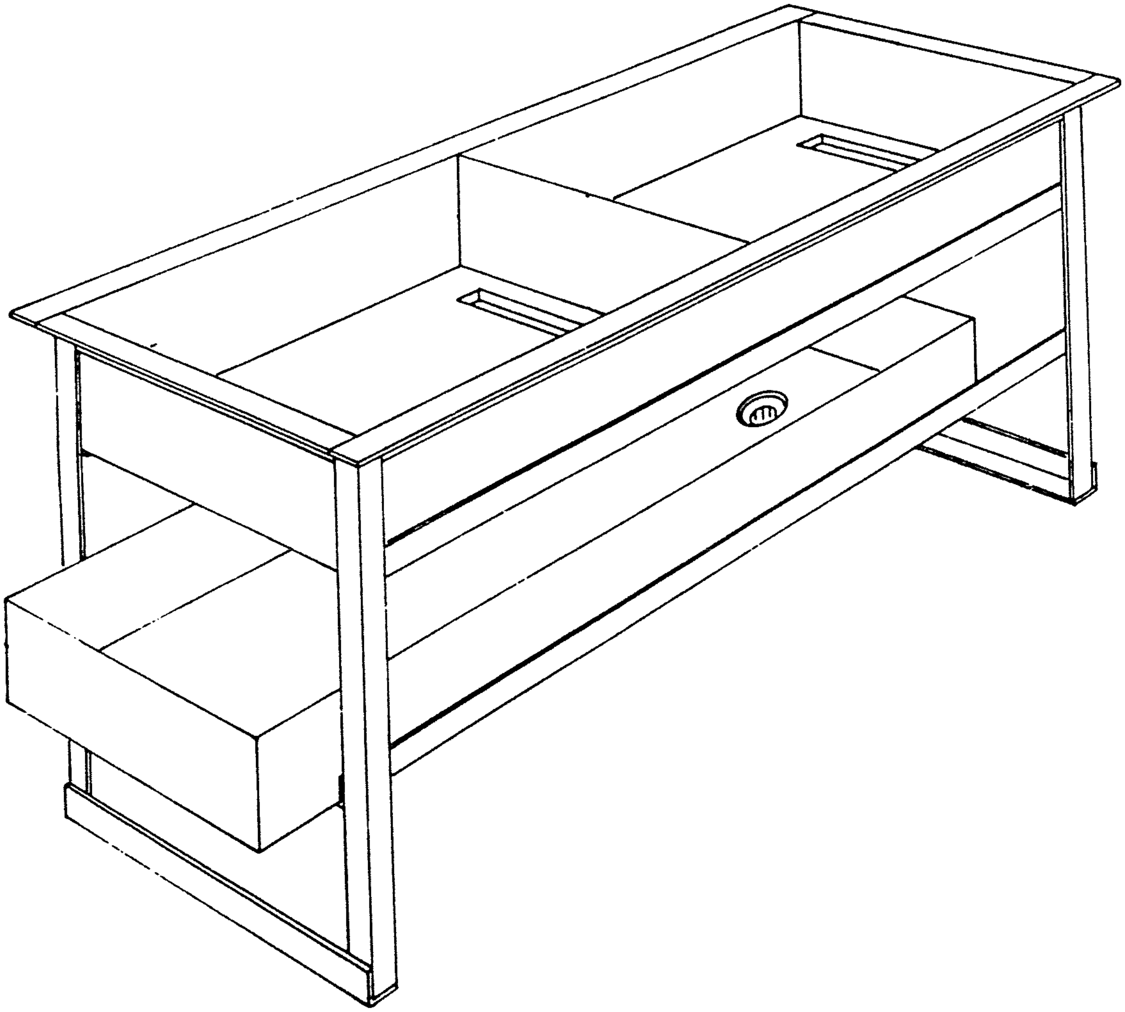


Figure 5.5. Sieving stand constructed by METRO and used by the METRO Baseline Subtidal group (screen boxes not shown).

screen boxes in the lower level of the sieving stand where it was completely washed until materials no longer passed through the 1.0 mm mesh openings.

The remaining material captured on the screen was transferred into thick plastic bags labeled with external and internal tags. Formalin solution buffered with sodium borate at a concentration of 1/2 cup per gallon of full strength formalin was used to fix the tissues of organisms in the field. Other buffers limit the erosion of shell due to the acidic nature of the formalin but we have found that many of these also leave a precipitate on body tissues and setae that hinders abilities to identify these animals. The formalin was further buffered by dilution with seawater to a formalin concentration of approximately 15%. Dilution with seawater also resulted in the fixative solution being more isotonic to the tissues of organisms decreasing the potential for animal tissues to swell and break apart as they often did with freshwater dilutions of formalin. The preserved and fixed organisms and debris inside the plastic bags were then inventoried as they were placed into a five gallon plastic bucket for return to the laboratory.

5.2.4 Chemical Field Methods

Samples designated for chemical analyses were handled differently than those used for biological analysis. Since an undisturbed surface was necessary the physical descriptions of the sediment was delayed until after the necessary samples have been taken. We did not use the same sample for biological and chemical analyses for the following reasons.

While sediments can be evenly separated within the sampler resulting in two or four subsamples of the material it was not possible to effectively separate all types of organisms. The low density microcrustacea that live near the surface of the sediments and any mobile organisms were more likely to travel in the direction of any water movement. As subsamples were removed from the sampler or as water drains from the grab these organisms tended to move in the direction of the water movement. These organisms were not dispersed through the sampler as they were when collected and thus subsamples of the grab resulted in minimizing or maximizing their loss to the biological sample. This effect results in recommendations that subsampling biological samples for chemistry was not appropriate.

The second consideration was that most of the programs examining benthic communities generally take more than one sample at a station. We accept the amount of variation between individual samples for biological studies and think that chemistry samples should share this same variation. We grant that it is advisable to obtain chemistry and physical samples from as close as possible to the community being studied but we must also realize that subsampling biological grab samples for these measurements increases the amount of non-interpretable noise in the biological data.

Chemistry samples were taken from the upper two centimeters of the sediments using METRO's toxicant cookie cutter. The cookie cutter is an inverted stainless pan with an attached handle. The cookie cutter was placed on the surface of the sediment, gently pushed into the sediments, and a flat plate slid just underneath the edge of the device. Material extending outside the device was sliced away and the material within the cookie cutter was transferred to an appropriately cleaned container.

The two centimeter sampling depth was chosen because several studies in other areas indicated that the majority of species and individuals sampled by grab samplers are concentrated in the upper few centimeters of the substrate (Word 1976; Word 1977; Thom 1983). Since part of the chemical objectives were to discover the effects of these materials on the distribution of organisms it was sensible to sample these chemicals in the zone of maximum organism abundance. The other reason for selecting the upper layers of the sediment was to obtain information on the more recently deposited material.

Great care is required in collecting samples of sediments that will be measured for pollutant concentrations in the parts per million or billion range in order to ensure that contamination does not occur. The cookie cutters, sample containers and sediment handling devices were cleaned as appropriate for each type of chemical measurements. Sampling materials for METRO priority pollutant analyses using the G-C Mass Spectrophotometer were cleaned by METRO using their standard procedures (Romberg et al. 1984). These materials were foil capped or covered and kiln cleaned prior to being brought into the field. The cookie cutters were double rinsed with a solution of deionized organic free water between samples at a station and replaced with a new cookie cutter at each station.

Materials for the collection of samples for other chemical measurements were kiln cleaned and acid rinsed for metals analysis. The samples taken for organic carbon, nitrogen, biochemical oxygen demand, and volatile solids were stored on ice until frozen at the University. Samples for measurements of grain size were refrigerated but not frozen because water in the interstices of the sediment grains can expand when frozen and fracture the grain resulting in smaller sediment coarseness.

5.2.5 Laboratory Procedures: Biological Samples

Biological samples returned to the laboratory were stored in formalin for at least two days but less than two weeks. They were then transferred to a screening device with slightly smaller mesh openings than originally used in the field, and where the formalin was washed away with freshwater. Due to the hazards of formalin, this procedure was performed under a hood, with the technician wearing protective clothing, gloves and a respirator. In this way, contact with formalin was minimized. The screened material was transferred into clean sample containers, with an internal and an external label and filled with 70% ethanol. Each sample was cataloged in a Rescreening Log (Figure 5.6) to be checked later against field inventory notes so that all samples were accounted for.

5.2.5.1 Sample Sorting: Quality Control

Samples selected for analysis were sorted in one of two manners. Samples containing larger quantities of coarse substrate were handled by a flotation technique where the sediment is rinsed in freshwater in a large flat tray. The organic matter that became suspended in the water (soft bodied organisms and arthropods) was carefully poured into a sieve screen. This material was sorted by viewing through a binocular dissecting microscope at a minimum of 10X power. The remaining portion of more dense material was then sorted using a 5X hand lens. Organisms remaining in this portion generally consisted of molluscs and some tube dwelling or encrusting organisms associated with the sediment grains. Samples that contained less dense materials were not handled by the flotation technique but were sorted, in the same manner as the floatable materials, under 10X magnification using a binocular dissecting microscope.

Organisms were sorted into major taxonomic groups: annelida, arthropoda, mollusca, echinodermata, and other phyla. Quality control of this sorting process was performed by resorting 20 percent of each sample (Figure 5.7). Any sample that indicated 5 percent or more organisms remaining in the entire sample was considered a QA/QC failure and was completely resorted until it passed the QA/QC process.

5.2.6 Identification

Identification and enumeration of sorted organisms was to the lowest

SURVEY NAME	LOCATION	STATION No. AND REP.	DATE COLLECTED	No. JARS/BAGS COLLECTED	DATE SCREENED	No. JARS SCREENED	INITIALS

Figure 5.6. Rescreening log used by METRO Baseline Subtidal group.

Task ______________________ Page _____ of _____

QA/QC Process Data Reporting Form

Site Station Code _______________ Rep ______

Approximate Sample Volume _______________ Sort QC Volume _______________

Sort By/Date _______________ Sort QC By/Date _______________

ID By/Date(s) _______________ _______________ _______________

ID QC By/Date _______________

SORT QA/QC RESULTS (individuals found in QC fraction)

	TAXON CODE	TAXON NAME	LS	COUNT QC	 Final	COMMENTS
1						
2						
3						
4						
5						
.						
8						
9						
10						
11						
12						
13						
14						
15						

RESORT INDICATED _____ yes _____ no _______________ by

Detailed Description of Departures from ID QA/QC, if any:

Figure 5.7. QA/QC sheet used by subtidal baseline group.

by _______________

taxonomic unit possible, generally to species level. This was accomplished using dissecting and compound microscopes, through the use of the extensive taxonomic library available at this laboratory, and the museum collection verified by outside experts which consists of approximately 750 species from Puget Sound, Washington. Assurance of consistent identification between different individuals within the laboratory was accomplished by the continuous interaction of individuals, by the use of the voucher museum collection, and by the specially designed in-house taxonomic keys to difficult genera and species. Additional QA/QC consisted of individuals performing identifications of the same samples and a laboratory supervisor comparing the identifications between individuals. This improves consistency of identification within the laboratory and also indicates where there may be taxonomic problems.

5.2.7 Conventional Chemistry Patterns

Conventional chemical measures consist of volatile solids, biochemical oxygen demand, organic carbon, organic nitrogen, and percentage of water in the sediments. These parameters were measured in each of the sediment samples by methods consistent with those used during the Seahurst Baseline Study.

The patterns exhibited by these chemical parameters were examined in two ways. First contour intervals were determined by plotting the concentrations of each parameter on individual charts. In the majority of cases these contour intervals were aligned with water depth. The second examination of the data consisted of comparing the observed concentrations of the parameters with the predicted concentration for that depth and seasonal sampling period in the East Passage area. Those stations which exceeded 1.96 standard normal deviates from the mean concentration for that depth in East Passage were identified. All stations showing excess concentrations of the materials were then grouped.

5.3 Results

5.3.1 Conventional Chemistry

Sediment volatile solids concentrations ranged from values less than 1 to 12.8%. In general, the concentration of volatile solids increased with increasing water depth (Figure 5.8). Concentrations in excess of 9% were found in inner Elliott Bay in relatively shallow water, in outer Elliott Bay in the deeper depths, and just north of Point Williams in the East Passage area in water depths of 600 feet.

Volatile solids concentrations exceeding 1.96 standard normal deviates above the mean for the East Passage area at comparable depths and seasonal sampling periods occurred in an elipse between transects 4-7 at water depths of 400-500 feet (Figure 5.9). These concentrations were also exceeded in much of the area of inner Elliott Bay (Figure 5.9).

The organic nitrogen content of the sediment also showed patterns that were consistent with increasing concentrations at deeper depths (Figure 5.10). Comparisons of the organic nitrogen content of the sediment with that parameter in the Seahurst Baseline Study were not performed because the methods were not consistent.

The biochemical oxygen demand of the sediments increased with increasing water depth (Figure 5.11). Maximum concentrations were found in the deepest depths and minimum values in the shallowest water. Comparison of these measurements to those made at comparable depths in the East Passage area showed that the concentrations of BOD exceeded the 1.96 standard normal deviate levels in three general areas (Figure 5.12). These areas are in the shallowest waters of the inner bay, in a region between transects 4-7 at water depths of 400-500 feet, and at one location on transect 7 at 50 feet.

Total organic carbon content of the sediments showed the common trend of

Sediment Volatile Solids

(% combustible)

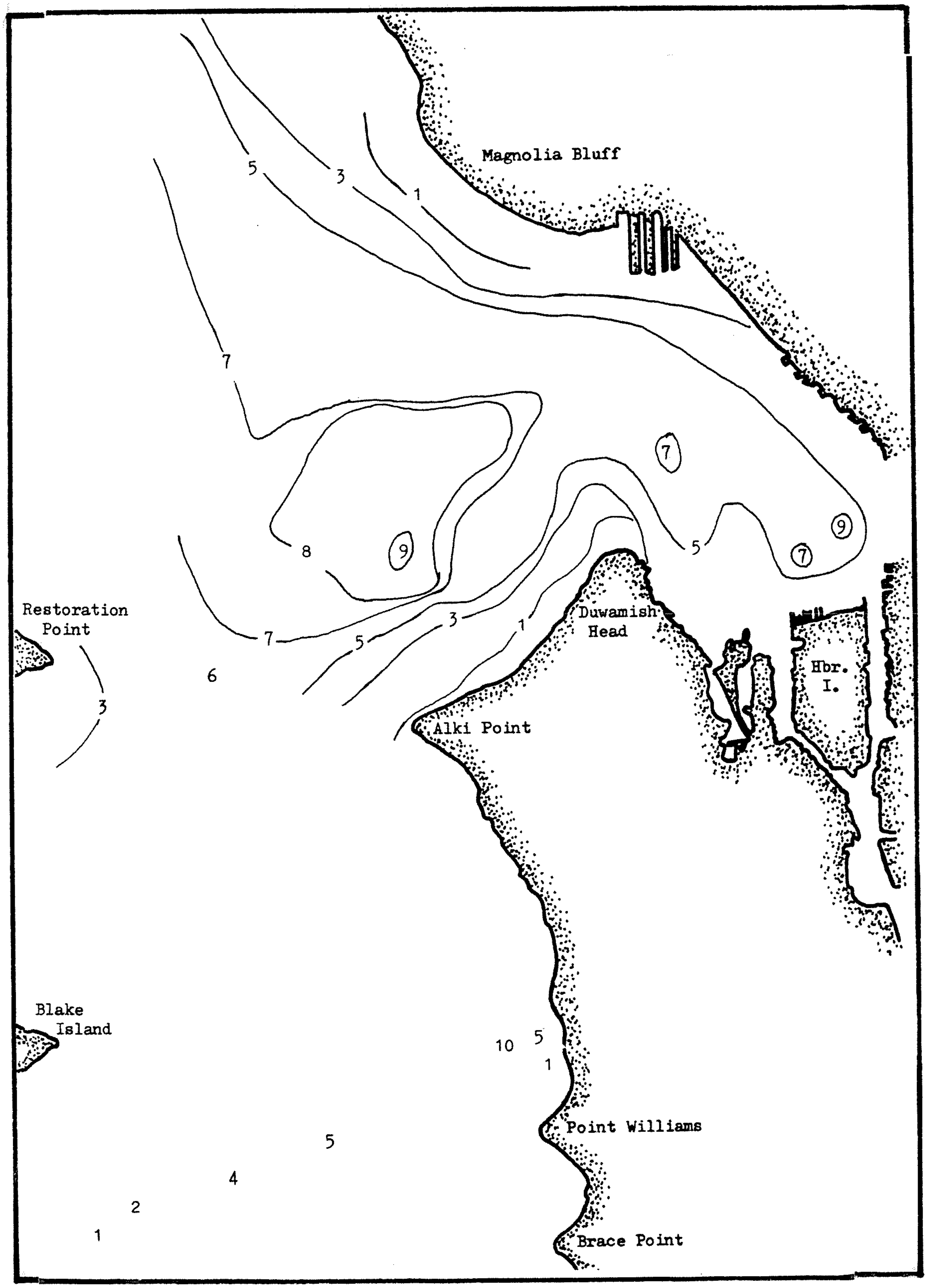


Figure 5.8. Contour intervals for percent volatile solids values (% VS) found in sediment samples collected at stations from the July 1984 Elliott Bay Baseline Subtidal Survey.

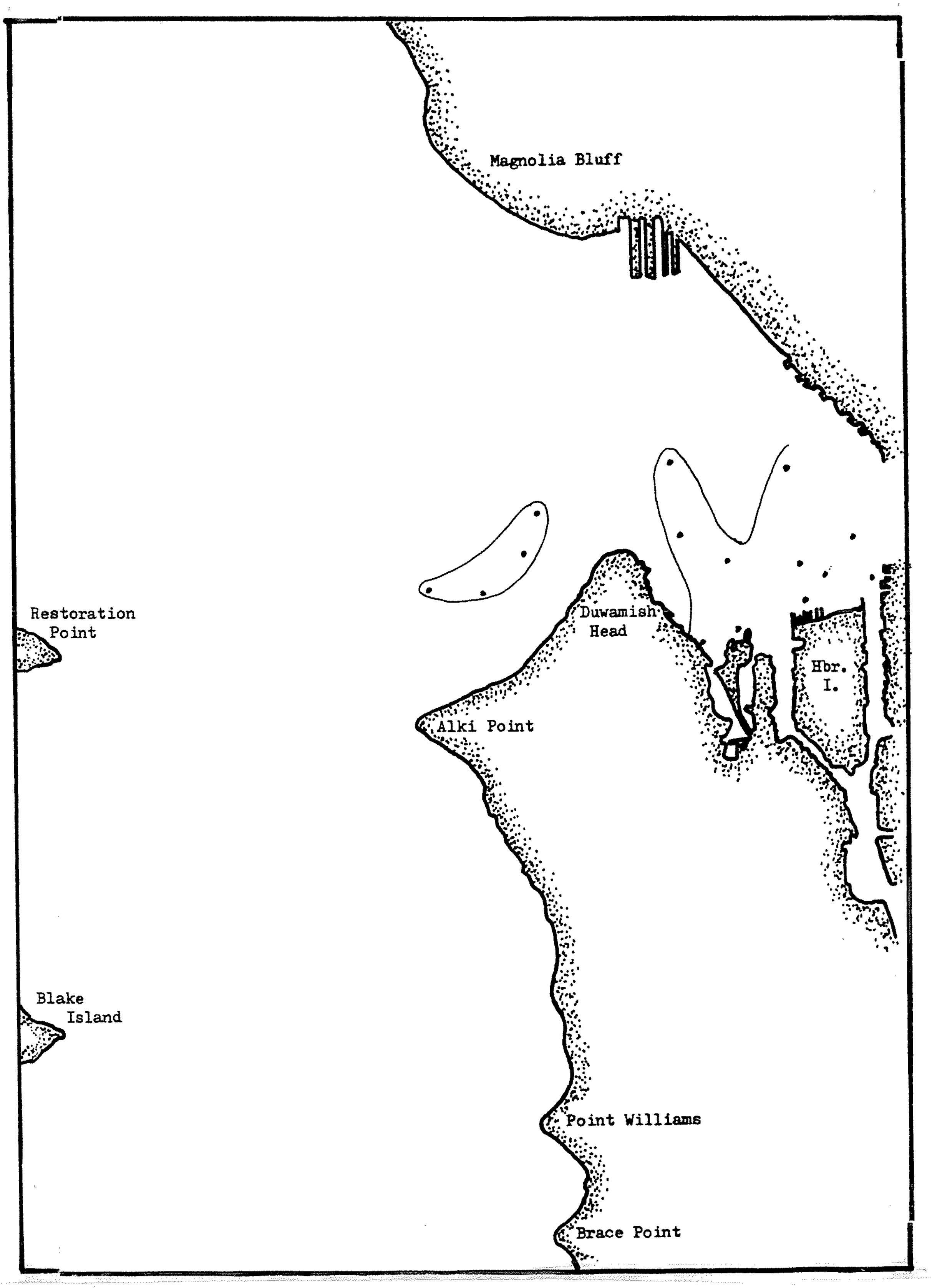


Figure 5.9. Contour pattern of enhanced % VS values found in Elliott Bay during the July 1984 Elliott Bay Baseline Subtidal survey. Enhanced areas identified by stations exceeding the mean + 1.96 standard normal deviates for stations at the same depth interval in the Seahurst study area.

Sediment Organic Nitrogen

(mg/g dry wt.)

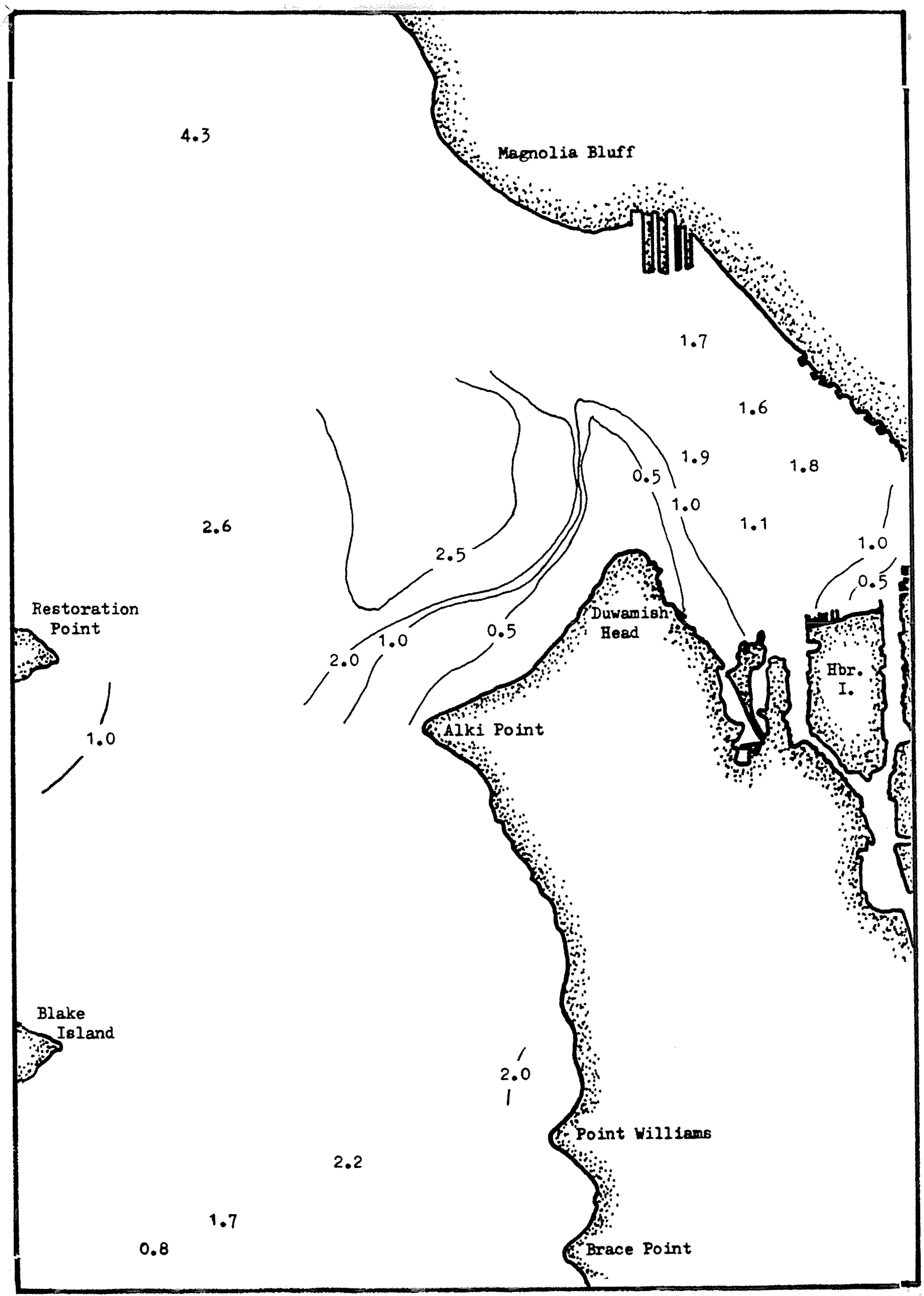


Figure 5.10. Contour intervals for concentrations of organic nitrogen found in sediment samples collected at stations from the July 1984 Elliott Bay Baseline Subtidal survey. (Concentrations = mg/g dry wt.)

Sediment Biochemical Oxygen Demand

(mg/kg dry wt./5 days)

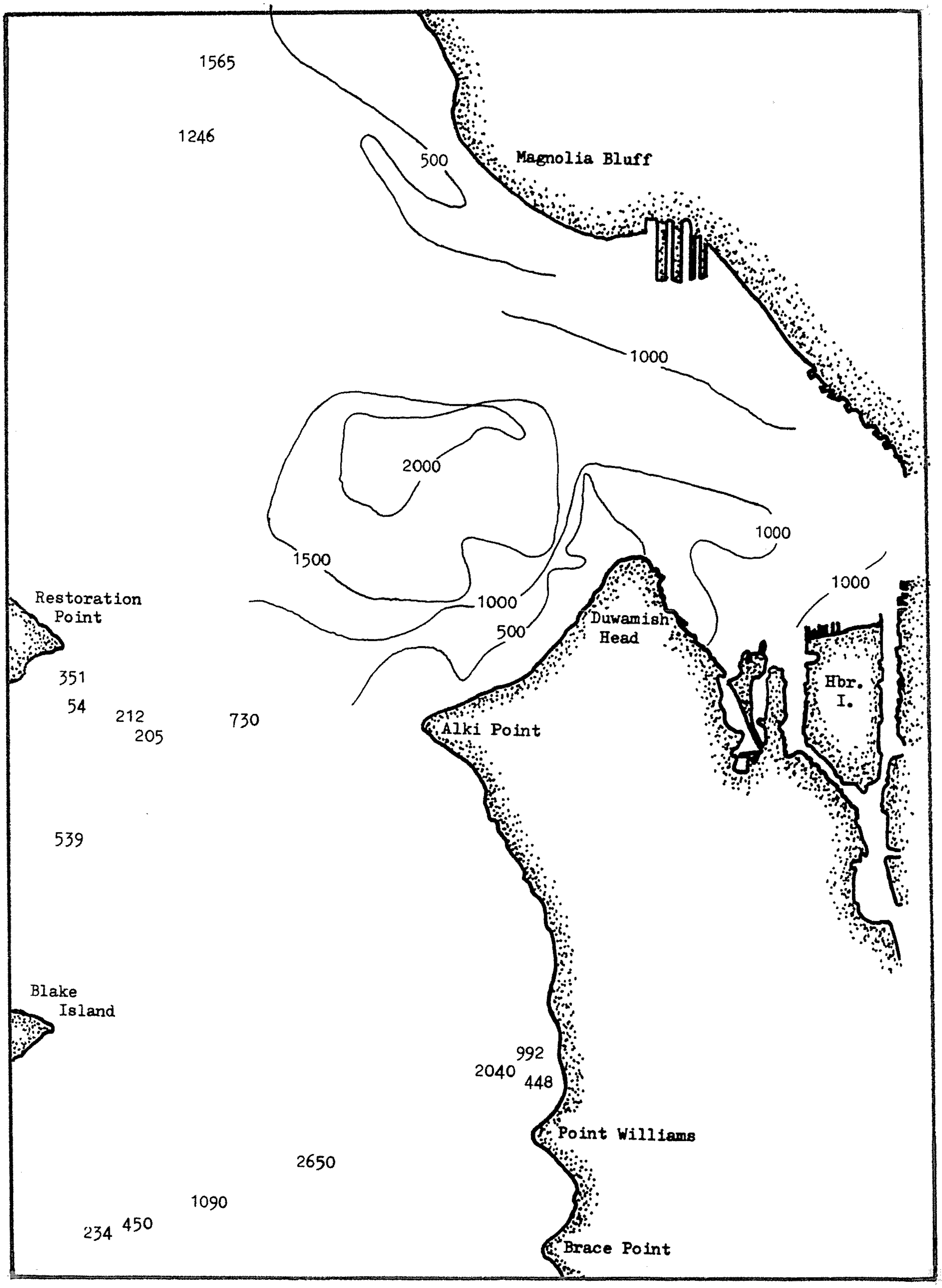


Figure 5.11. Contour intervals for concentrations of biochemical oxygen demand (BODs) found in sediment samples collected at stations from the July 1984 Elliott Bay baseline subtidal survey. (Concentration mgO_2/dry kg sediment.)

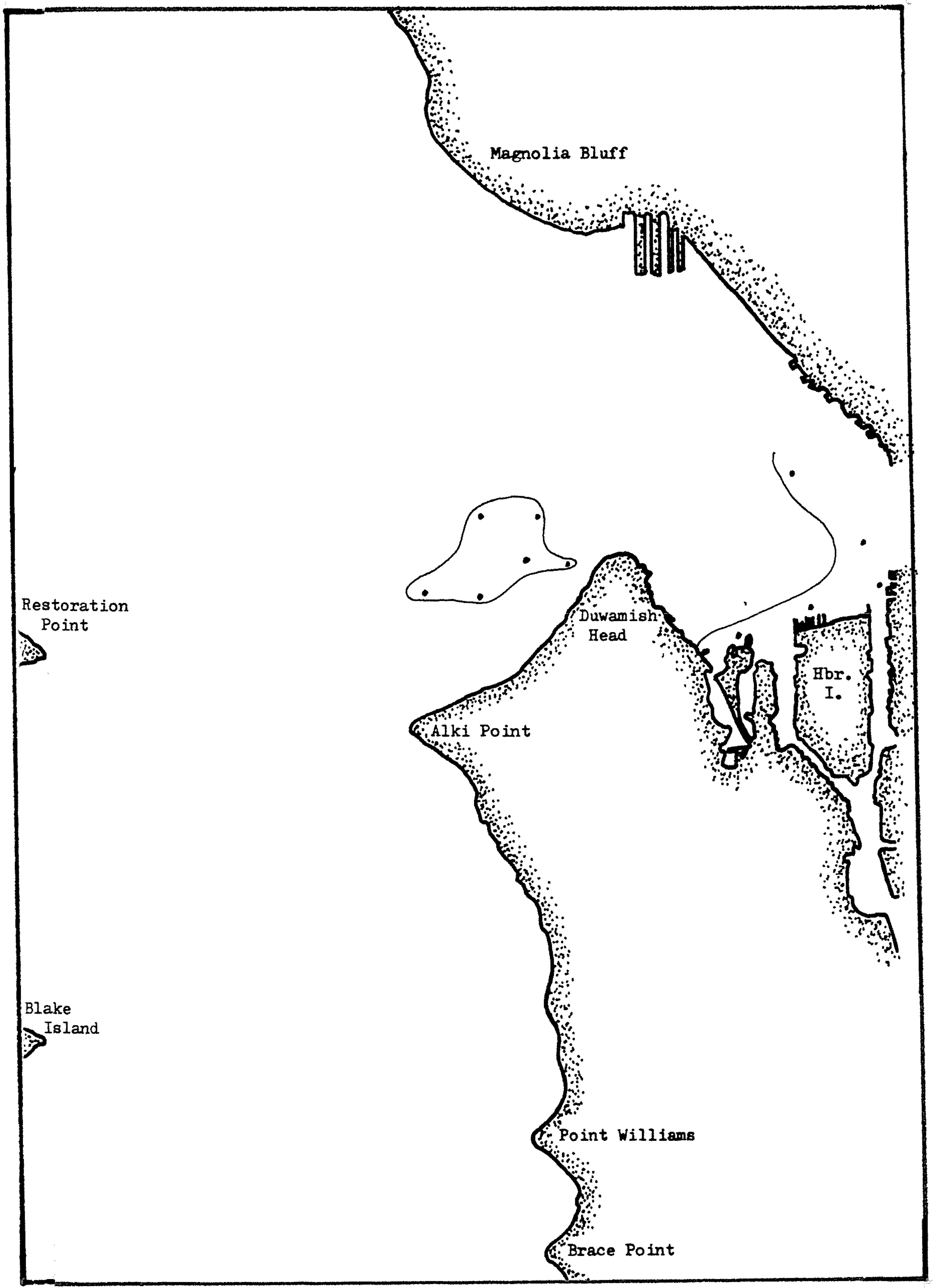


Figure 5.12. Contour patterns of enhanced BODs values found in Elliott Bay during the July 1984 Elliott Bay Baseline Subtidal survey. Enhanced areas identified by stations exceeding the mean + 1.96 standard normal deviates for stations at the same depth interval in the Seahurst study area.

increasing concentrations with increasing water depth (Figure 5.13). Inner Elliott Bay was found to exceed the 1.96 standard normal deviate range at all stations for comparable depths in East Passage (Figure 5.14). The outer bay environment showed the same general pattern of elevated levels in the region between transects 4-7 at 400-500 feet of water depth.

The percentage of water in the sediments increased with increasing water depth (Figure 5.15). Stations which had greater concentrations of water for comparable water depths with the East Passage area were found in most of the inner bay and also in the same region between transects 4-7 in the outer bay at depths of 400 feet (Figure 5.16).

Elliott Bay appears to be divisible into an inner and outer bay based upon the distribution of conventional chemical characteristics. The inner bay environment had greater concentrations of % VS, organic nitrogen, BODs, total organic carbon and % water, for each of the depths selected than does the outer bay. The outer bay environment seems to have equivalent concentrations of these materials at comparable depths to the East Passage area. The only region of the outer bay environment that did not show this pattern is the region between transects 4-7 at water depths of 400 to 500 feet (Figure 5.17).

Plotting these regions showing elevated concentrations on fine scale bathymetric charts (NOAA 1935) of the Elliott Bay area may aid in explaining these observations.

This zone of enhanced organic levels in outer Elliott Bay is situated at the point where the slope flattens just prior to meeting the basin floor forming a region that is relatively flat when compared to other areas of Puget Sound at comparable depths. This region may naturally tend to accumulate materials rather than transport them further down slope and away from Duwamish Head.

Sediment Total Organic Carbon

(mg/g dry wt.)

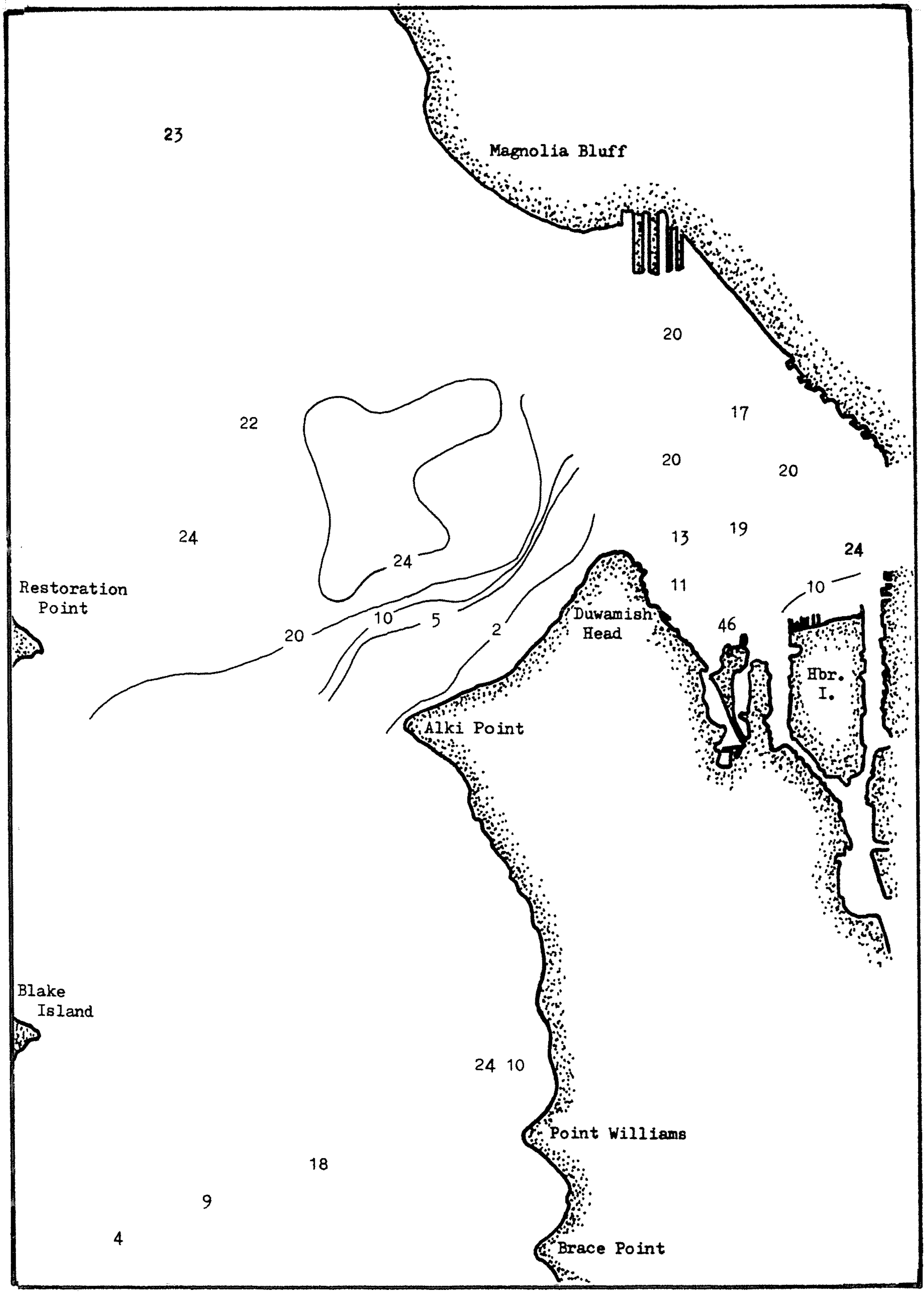


Figure 5.13. Contour interval for concentrations of total organic carbon found in sediment samples collected at stations from the July 1984 Elliott Bay Baseline Survey (concentrations = mg/g dry wt.).

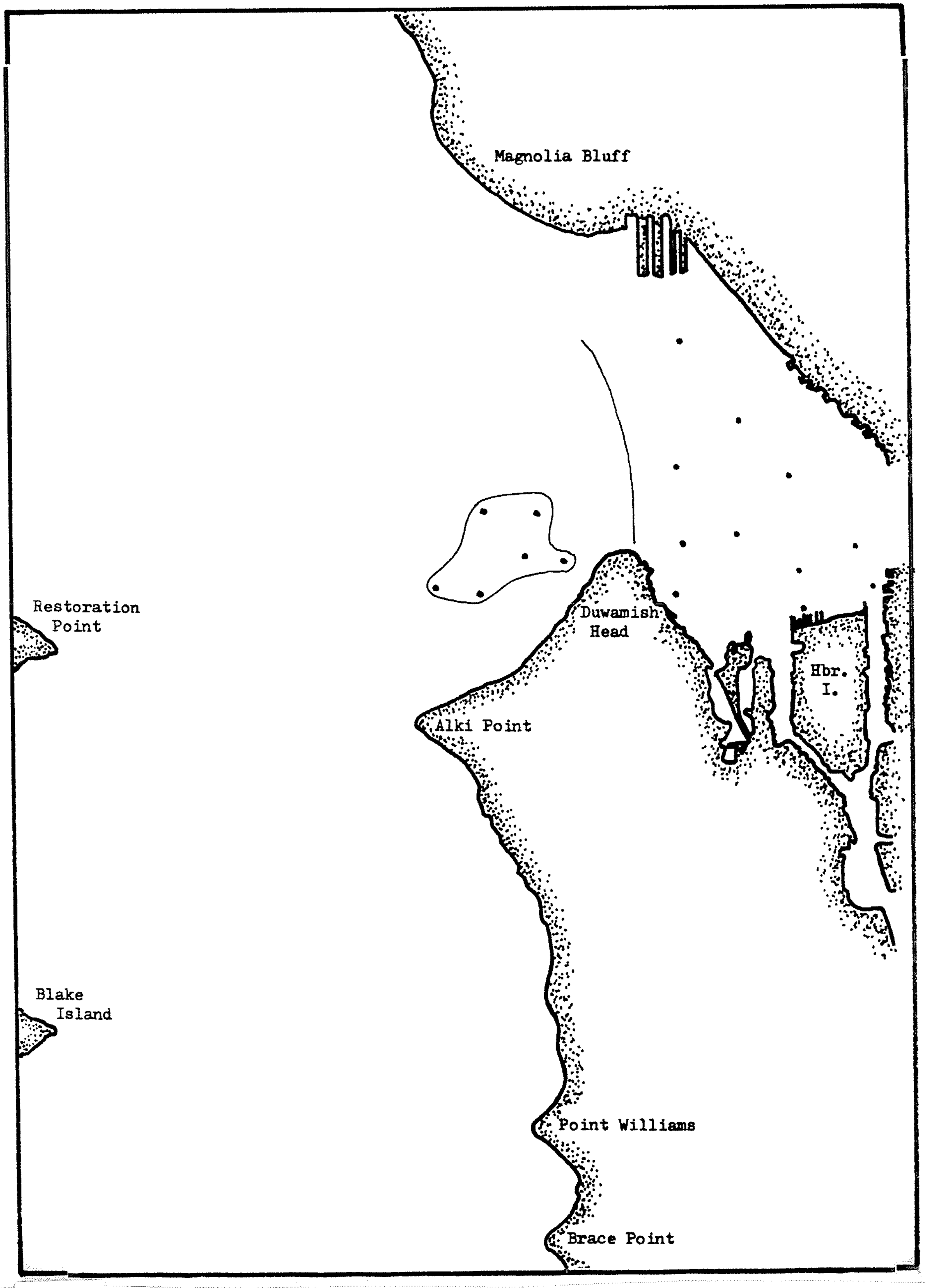


Figure 5.14. Contour pattern of enhanced total organic carbon values found in Elliott Bay during the July 1984 Elliott Bay Baseline Subtidal survey. Enhanced areas identified by stations exceeding the mean + 1.96 standard normal deviates for stations at the same depth interval in the Seahurst study area.

Sediment Dry Wt./Wet Wt. Ratio

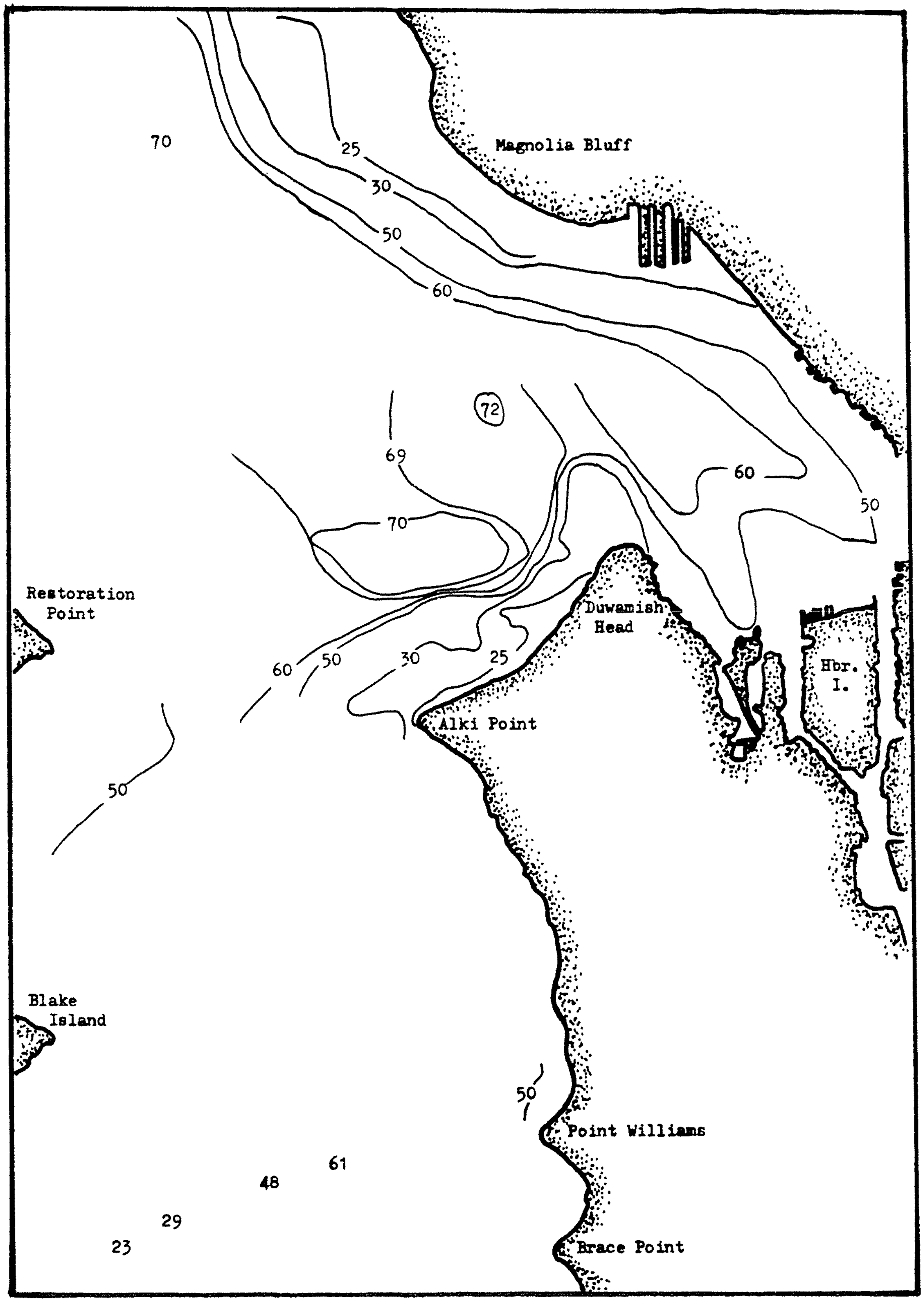


Figure 5.15. Contour interval for percent water found in sediment samples collected at stations from the July 1984 Elliott Bay Baseline Subtidal survey.

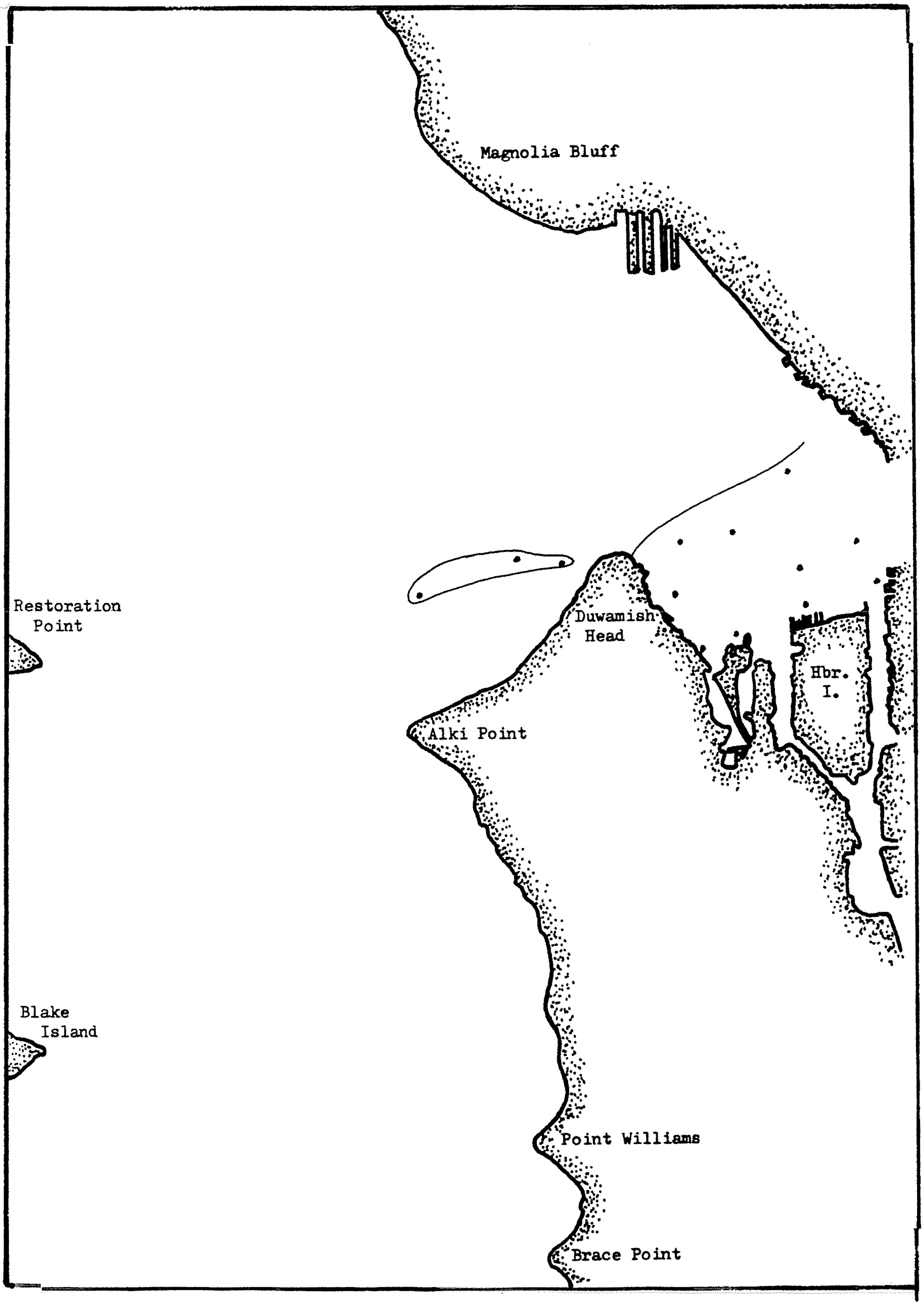


Figure 5.16. Contour pattern of enhanced percent water values found in Elliott Bay during the July 1984 Elliott Bay Baseline Subtidal survey. Enhanced areas identified by stations exceeding 1.96 standard normal deviates for stations at the same depth interval in the Seahurst study area.

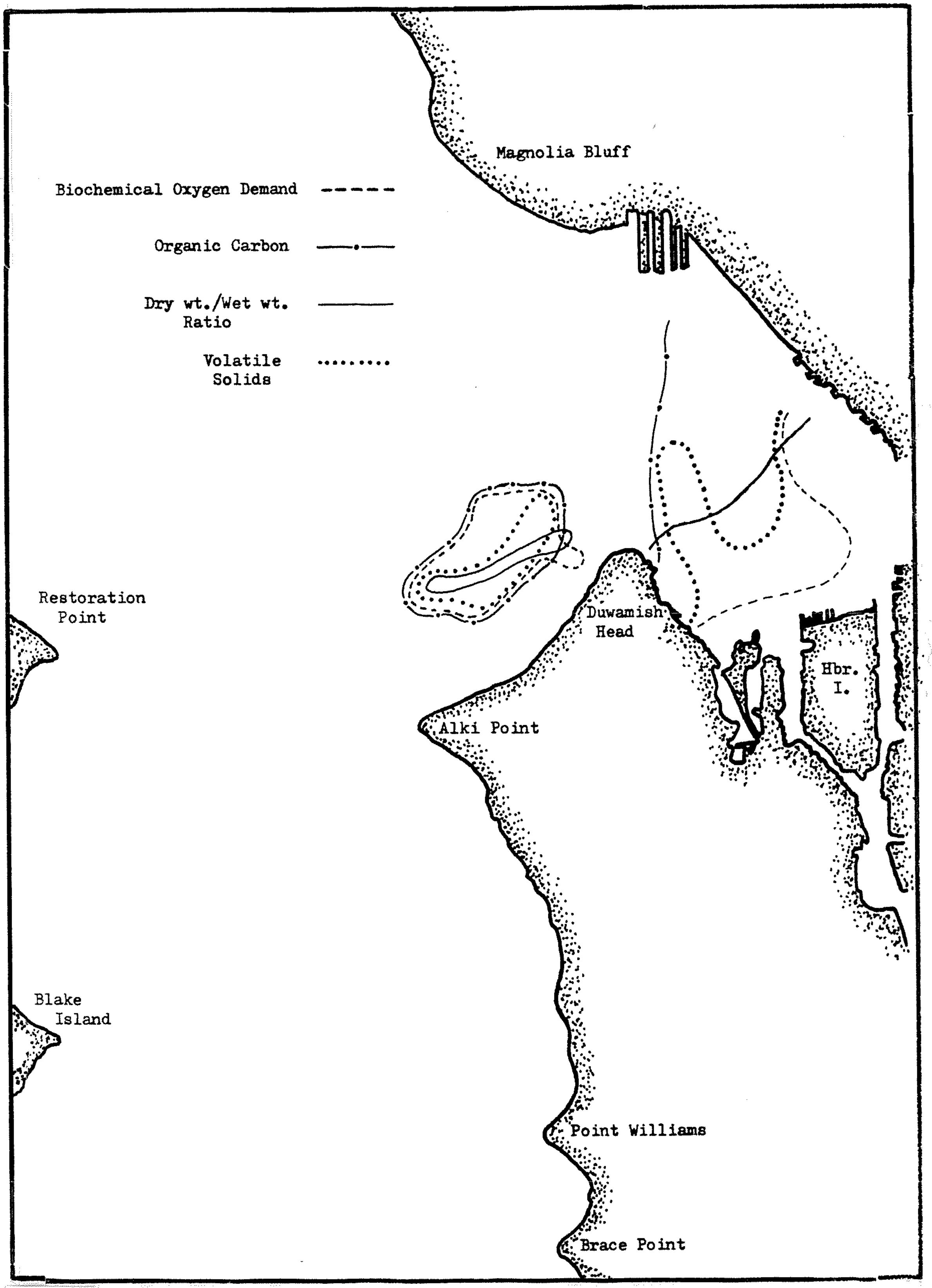


Figure 5.17. Contour patterns of depositional areas found in Elliott Bay as identified by the composite pattern of enhanced values of BODs, total organic carbon, % volatile solids and percent water. (Enhanced = X + 1.96 standard normal deviates for stations at the same depth interval in the Seahurst study area.)

The increased levels of organic materials in the inner bay environment cannot be explained based only on bottom topography. Slower circulation and greater input of materials from the Duwamish River are probably the source for much of the greater levels of organic materials found in the sediments of this area. This supposition is supported by examining the distribution of diatom frustules and foraminifera skeletons in the sediments. Harmon and Serwald (unpublished manuscript) found that the inner bay sediments were dominated by diatom remains that are more closely related to freshwater environments while the outer bay sediments were more dominated by foraminifera and diatom skeletons consistent with more marine environments.

5.3.2 Biological Patterns

Biological samples were summarized based upon the number of species or abundance of organisms contained within each of the 122, 0.1 m^2 samples identified for this program. The total number of species ranged from 15 at A-50W to 178 at BII-200E. The total number of individuals ranged from 39 at A-50W to 1445 at BX-50E (Table 5.1A).

These data were divided into three regions, inner Elliott Bay, outer Elliott Bay, and stations outside of Elliott Bay. For the purposes of this analysis stations on transects A, SS1, SS2, BII, and T 7-11 are considered to be outside of the bay or in the northern quadrant of the outer bay. Transects BIII through BVIII are considered to be outer Elliott Bay stations, and stations on transects BIX through BXII are considered to be inner Elliott Bay.

In each of these regions the total number of benthic infaunal organisms were greatest in the shallowest stations and fewest in the deepest (Figure 5.18). A decreasing trend in the abundance of infaunal organisms was found with the greatest number in the inner bay and the fewest in the region outside of Elliott Bay (Table 5.1B). Although not statistically significant a

Table 5.1A. Number of taxa and abundance of major taxonomic group found at stations sampled during the July 1984 Elliott Bay baseline subtidal survey.

Station	(Rep)	# TAXA/#INDIVIDUALS													
		Polychate		Arth		Moll		Ophiur		Echino		Misc		Total	
A-200E	(1)	49	159	20	75	13	49	-	-	7	28	12	14	101	325
A-400E	(3)	17	59	19	74	8	132	2	3	1	1	4	9	51	278
A-600E	(2)	12	19	9	63	9	19	-	-	2	6	2	2	34	109
A-720	(1)	11	25	13	83	8	101	-	-	-	-	1	1	35	210
A-400W	(1)	30	67	14	44	10	274	1	1	2	2	3	3	60	391
A-200W	(1)	45	184	23	93	16	159	-	-	3	7	6	13	93	178
A-50W	(2)	7	10	6	14	2	15	-	-	-	-	-	-	15	39
SS-3	(2)	14	32	10	109	8	36	-	-	-	-	1	3	33	180
SS-4	(3)	12	19	8	57	11	51	-	-	1	2	3	4	35	133
SS-5	(1)	12	16	9	56	8	111	-	-	-	-	2	3	31	186
SS-7	(1)	56	234	25	126	15	42	-	-	11	114	11	33	118	549
SS-11	(2)	40	107	12	70	9	147	-	-	2	3	5	13	68	340
VII-100	(1)	49	301	24	206	24	212	1	6	2	15	13	19	113	759
VII-300	(3)	33	151	16	23	7	18	-	-	-	-	3	4	59	196
VII-750	(1)	19	59	11	72	10	254	2	2	1	2	-	-	43	389
VIII-100	(1)	57	117	25	141	15	135	1	1	3	9	13	38	114	441
VIII-300	(3)	58	228	23	74	14	147	1	7	-	-	9	52	105	508
VIII-750	(1)	12	13	8	68	10	79	-	-	2	3	2	2	34	165
IX-100	(3)	57	482	28	134	21	137	2	4	4	47	16	40	128	844
IX-300	(1)	57	309	21	39	13	362	1	1	2	3	5	6	99	720
X-100	(1)	54	327	17	119	13	235	1	1	-	-	4	7	89	689
X-300	(2)	37	337	8	11	5	57	-	-	1	1	5	13	56	419
XI-100	(1)	41	255	7	78	15	203	1	1	1	1	10	14	75	552
XI-300	(3)	25	38	10	37	3	204	-	-	-	-	1	1	39	280
BII-50E	(2)	43	142	31	439	19	71	-	-	1	1	8	30	102	683
BII-200E	(3)	78	563	51	222	24	126	2	3	3	15	20	60	178	989
BII-400E	(3)	44	148	20	35	13	84	1	14	-	-	2	18	80	299
BII-600E	(2)	43	171	23	61	12	124	1	2	-	-	7	83	86	441
BII-800	(1)	34	137	21	133	11	177	-	-	-	-	3	11	69	458
BII-600W	(1)	39	100	23	56	15	107	2	2	-	-	7	17	86	282
BII-400W	(1)	23	122	17	52	12	111	1	9	3	4	6	45	62	343
BII-200W	(3)	41	151	22	160	19	433	1	1	-	-	4	12	138	757
BII-50W	(1)	64	517	27	185	28	222	1	4	6	55	12	23	138	1006
BIII-5-50E	(1)	43	197	27	359	18	83	1	3	6	32	7	7	102	681
	(3)	38	146	30	832	20	266	-	-	1	1	5	5	94	1250
BIII-5-200E	(1)	57	228	27	119	17	148	-	-	3	24	9	34	113	553
	(2)	64	243	29	150	20	145	-	-	6	29	17	46	135	613
BIII-400E	(1)	43	274	20	47	14	151	1	10	3	3	6	65	87	550
	(2)	41	177	16	38	10	160	1	7	2	3	4	35	74	420
BIII-640E	(1)	8	11	8	96	9	362	-	-	-	-	4	6	29	475
	(3)	14	19	15	64	10	278	-	-	2	7	-	-	41	368
BIII-600E	(1)	14	22	11	43	9	191	-	-	1	1	1	1	36	258
	(2)	9	10	13	46	7	198	-	-	1	1	2	2	32	257

Table 5.1A (continued).

		# TAXA/# INDIVIDUALS													
Station	(Rep)	Poly		Arth		Moll		Ophiur		Echino		Misc		Total	
BIII-600C	(2)	19	38	6	76	6	273	–	–	1	2	2	3	34	392
	(3)	13	17	16	122	10	262	1	1	1	1	6	8	47	411
BIII-600N	(2)	19	33	10	101	8	205	–	–	2	2	3	4	42	345
	(3)	15	19	11	75	10	261	–	–	1	2	1	1	38	358
BIV-34	(2)	12	18	9	21	10	30	1	1	2	7	–	–	34	77
	(3)	16	26	15	53	10	35	–	–	2	8	3	5	46	127
BIV-35	(1)	23	47	16	73	10	249	1	1	1	3	2	4	53	377
	(2)	14	26	9	56	8	296	–	–	–	–	2	2	33	324
BIV-50E	(1)	24	79	17	381	17	157	–	–	–	–	1	1	59	618
	(2)	34	86	18	539	18	264	–	–	1	1	2	2	73	892
BIV-200E	(1)	58	194	20	127	17	266	1	1	4	7	7	15	107	610
	(3)	45	154	22	158	18	273	1	1	3	13	10	22	99	621
BIV-400E	(2)	33	95	16	46	12	152	1	11	3	5	4	16	69	325
BIV-600E	(1)	13	18	11	32	5	47	–	–	2	4	2	2	33	103
	(2)	12	14	7	19	5	36	–	–	2	2	3	4	29	75
BIV-600N	(1)	15	20	11	57	12	320	–	–	2	2	1	1	41	400
	(3)	6	6	11	29	9	244	–	–	–	–	–	–	26	279
BV-24	(1)	18	30	12	39	9	144	–	–	1	1	3	3	43	217
	(3)	11	22	6	30	9	182	–	–	1	1	–	–	27	235
BV-32	(1)	19	30	7	57	12	419	1	1	1	1	1	3	41	511
	(3)	17	37	12	41	12	209	1	1	1	1	3	6	45	294
BV-50E	(1)	24	63	15	383	10	88	–	–	–	–	1	1	50	535
	(3)	27	68	25	619	13	198	–	–	–	–	6	13	71	898
BV-200E	(1)	50	141	22	111	17	151	–	–	1	1	3	7	93	411
	(2)	29	85	12	72	13	88	–	–	1	1	3	5	58	251
BV-400E	(1)	27	40	6	28	8	240	1	1	–	–	2	2	43	311
	(2)	22	39	12	32	8	172	1	1	–	–	2	2	45	246
BV-600N	(1)	19	38	8	43	9	169	–	–	–	–	3	3	39	253
	(2)	19	43	11	74	10	269	–	–	–	–	3	4	43	290
BVI-50E	(1)	47	229	20	475	18	137	1	5	2	6	6	11	94	863
	(2)	46	343	22	539	20	96	1	12	7	40	11	28	106	1058
BVI-200E	(1)	49	176	24	131	16	193	1	2	2	4	13	96	105	602
	(2)	53	203	26	166	12	205	2	2	2	2	6	23	101	601
BVI-400E	(1)	15	27	17	31	5	93	–	–	–	–	2	3	39	154
	(3)	22	42	5	17	7	370	1	1	–	–	3	3	38	432
BVI-522E	(2)	20	46	13	63	11	237	–	–	1	1	2	3	47	350
	(3)	19	53	12	56	6	169	–	–	1	1	1	1	39	280
BVI-600E	(1)	11	18	8	26	12	134	–	–	2	5	1	1	34	184
	(2)	15	30	7	38	8	238	–	–	1	1	2	2	33	309
BVI-600N	(2)	21	58	11	65	8	287	1	1	2	3	–	–	43	414
	(3)	17	27	12	57	10	244	–	–	1	2	–	–	40	330
BVII-50E	(2)	41	168	23	565	17	159	2	3	4	17	12	20	99	932
	(3)	36	106	17	632	20	174	–	–	–	–	7	18	80	930

Table 5.1A (continued).

		# TAXA/# INDIVIDUALS													
Station	(Rep)	Poly		Arth		Moll		Ophiur		Echino		Misc		Total	
BVII-200E	(1)	47	251	23	148	21	219	1	1	2	3	7	15	101	637
	(2)	41	158	16	114	18	146	-	-	1	1	5	8	81	427
BVII-400E	(1)	24	96	12	45	6	193	-	-	1	1	2	2	45	337
	(2)	21	38	7	20	6	166	-	-	1	1	1	1	36	226
#25	(1)	14	34	6	54	12	230	-	-	-	-	-	-	32	318
	(2)	17	24	9	91	9	341	-	-	1	1	2	2	38	459
	(3)	15	42	13	96	8	339	1	1	1	1	2	4	40	483
#37	(1)	7	11	4	31	10	160	-	-	-	-	-	-	21	202
	(2)	22	54	13	73	8	233	-	-	2	5	3	4	48	369
BVII-600E	(1)	16	32	11	34	10	123	1	1	-	-	2	3	40	193
	(2)	13	20	10	36	9	145	-	-	2	4	-	-	34	205
BVII-600N	(1)	20	52	8	42	10	292	-	-	2	2	2	2	42	390
	(3)	17	64	12	54	11	305	-	-	1	2	2	2	43	427
BVIII-50															
BVIII-50E	(1)	45	342	37	316	24	84	1	2	4	38	13	21	124	803
	(3)	57	790	39	328	21	111	1	9	6	80	10	24	134	1342
BVIII-200E	(1)	42	204	12	28	13	30	-	-	5	9	9	19	81	290
	(2)	50	216	22	54	15	125	1	2	6	115	6	33	100	545
BVIII-400E	(2)	25	104	17	34	13	233	-	-	1	1	1	1	57	373
	(3)	26	69	4	4	11	158	-	-	1	1	2	3	44	235
BVIII-600N	(1)	23	63	13	74	9	266	1	1	-	-	2	4	48	408
	(3)	20	55	16	80	10	376	-	-	-	-	1	1	47	512
BVIII-600E	(2)	20	77	14	96	11	266	1	1	-	-	2	3	48	443
	(3)	23	60	10	71	10	291	-	-	1	1	3	8	47	431
BIX-50E	(1)	54	412	17	320	17	490	1	3	-	-	11	17	100	1242
BIX-200E	(1)	39	172	13	81	14	484	2	3	1	1	7	21	76	762
	(3)	51	182	14	80	14	483	-	-	1	1	6	17	86	763
BIX282E	(2)	34	156	20	36	8	170	-	-	1	1	3	4	66	367
BIX-400E	(2)	20	41	10	34	5	317	-	-	1	2	2	3	38	397
BX-50E	(1)	66	842	19	385	14	184	1	1	2	16	5	17	102	1445
BX-200E	(1)	36	154	19	74	11	104	-	-	1	1	3	13	70	333
BX-420M	(3)	31	88	13	39	6	126	-	-	-	-	2	5	52	258
BXI-50E	(2)	22	148	10	21	8	15	1	1	-	-	4	16	45	201
BXI-200E	(2)	15	60	7	10	4	36	-	-	-	-	-	-	26	106
BXI-336M	(2)	24	45	12	36	5	147	-	-	1	1	1	2	43	231
BXII-50E	(2)	37	263	14	227	14	271	1	3	-	-	7	8	73	772
BXII-200E	(3)	34	125	13	42	7	620	-	-	1	1	4	4	59	792

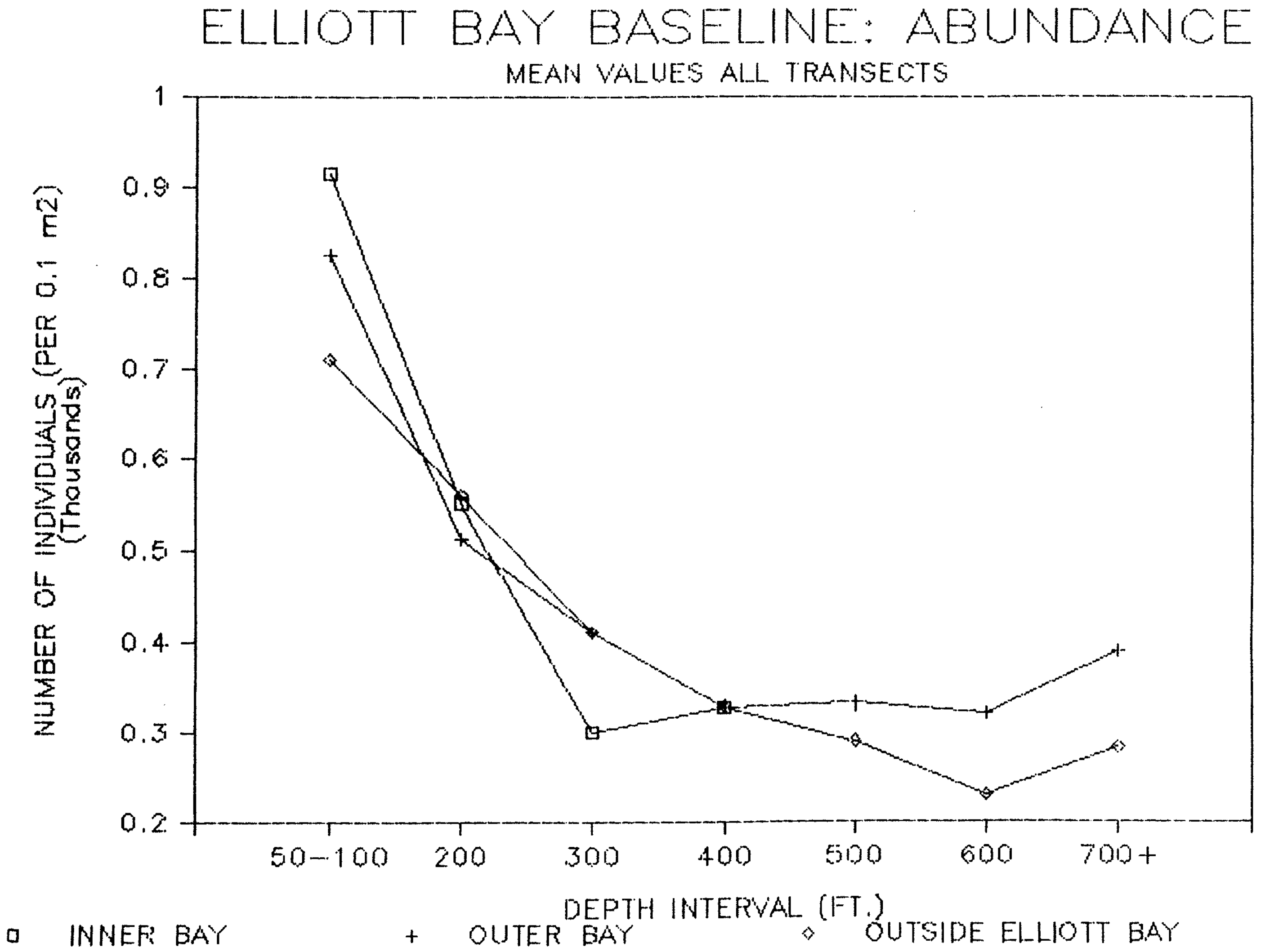


Figure 5.18. Mean total abundance (mean values all transects) for each depth contour at stations sampled during the July 1984 Elliott Bay Baseline survey.

Table 5.1B. Anova analysis of mean total abundance along depth contours at station sampled during the July 1984 Elliott Bay baseline subtidal survey. The stations were divided into three regions (see text for details).

	Inner Bay			Outer Bay			Outside Elliott Bay			DF_1	DF_2	F_{Calc}
Depth	N	$\bar{x}$	S.D.	N	$\bar{x}$	S.D.	N	$\bar{x}$	S.D.			
50-100	4	915.0	553.2	12	825.2	344.5	7	710.6	185.5	2	20	0.48
200	5	551.2	313.5	12	513.4	135.2	5	559.6	325.6	2	19	0.09
300	2	299.0	96.2	0	-	-	6	410.5	186.2	1	6	0.61
400	2	327.5	98.3	11	328.1	112.7	4	327.8	50.1	2	14	<0.00
500	0	-	-	4	332.8	41.3	0	-	-	-	-	-
600	0	-	-	39	320.6	118.4	5	229.0	135.8	1	42	2.58
700+	0	-	-	2	388.5	99.7	5	281.6	132.8	1	5	1.01

logarithmic regression line was fitted to the data giving a coefficient of determination of 0.87 (a correlation coefficient of 0.93 with n=16 (y = 1840.71 + -244.99 (depth)).

The total number of species captured in these different locations did show significantly different mean values at water depths of 600 and 200 feet (Table 5.2). Examination of the non-significant differences indicated that similar trends in the mean values occurred at the other sampling depths. In all cases greater numbers of species were observed outside of Elliott Bay than in the outer part of Elliott Bay which in turn had more species than the inner Elliott Bay region. Maximum number of species occurred in shallower waters and fewer in the deeper depths. In the outer Elliott Bay and at stations outside of Elliott Bay the maximum number of species occurred at water depths of 200 feet (Figure 5.19). Inner Elliott Bay had on the average approximately 50-70 percent of the species found at comparable depths outside of the bay environment.

One further examination was made to determine the locations of stations having more than the expected number of species or individuals. These analysis consisted of using the characteristics of the benthic infauna at comparable depths and sampling periods obtained in the East Passage area during the Seahurst Baseline Study. Those stations within the present study which had species numbers or abundance values in excess of 1.96 standard normal deviates from the mean at comparable depths within the East Passage area were plotted and are presented in Figures 5.20.

Increased numbers of species, especially arthropods were found near Alki Point and Duwamish Head. Increased species of polychaetes and molluscs occurred in shallow waters; at 100 feet, between West Point and Magnolia Bluff; at 50 ft on the southwest edge of the Duwamish River; at 50 feet off

Table 5.2. Anova Analysis of the mean total number of taxa along depth contours at stations sampled during the July 1984 Elliott Bay baseline subtidal survey. The stations were divided into three regions (see text for details).

	Inner Bay			Outer Bay			Outside Elliott Bay			DF_1	DF_2	F_{Calc}
Depth	N	$\bar{x}$	S.D.	N	$\bar{x}$	S.D.	N	$\bar{x}$	S.D.			
50-100	4	80.0	26.4	12	90.5	25.1	7	108.4	21.8	2	15	1.67
200	5	63.4	23.1	12	97.8	18.9	5	125.6	34.0	2	19	8.64*
300	2	54.5	16.3	0	-	-	6	71.0	25.9	1	6	0.68
400	2	45.0	9.9	11	52.5	16.9	4	63.3	12.2	2	14	1.08
500	0	-	-	4	43.0	8.8	0	-	-	-	-	-
600	0	-	-	36	38.2	6.8	5	54.8	28.5	1	39	9.64**
700+	0	-	-	2	35.0	4.2	5	42.4	15.5	1	5	0.40

* significant at >0.005
** significant at >0.01

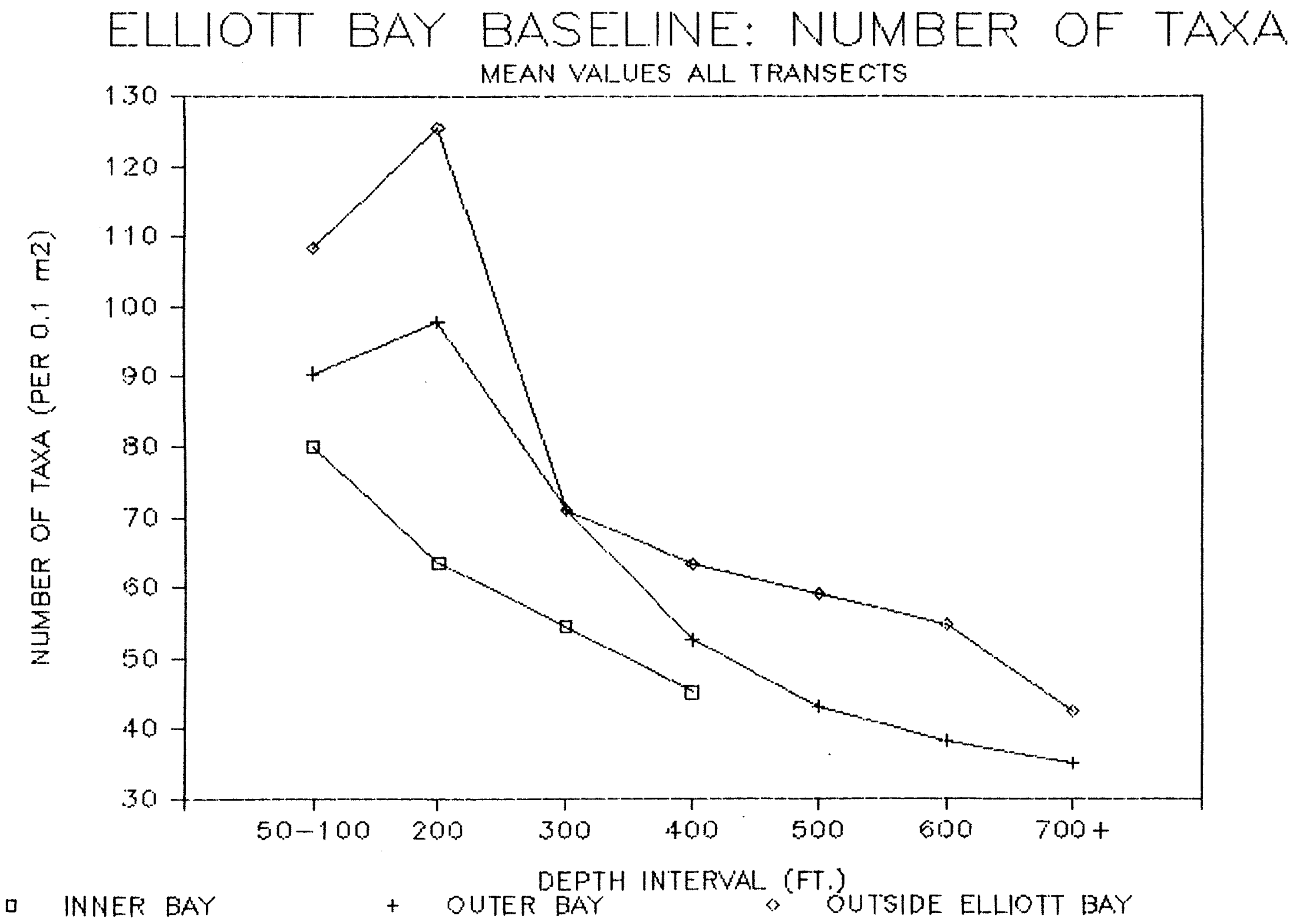


Figure 5.19. Mean total number of taxa (mean values all transects) for each depth contour at stations sampled during the July 1984 Elliott Bay Baseline survey.

Benthos Species Patterns

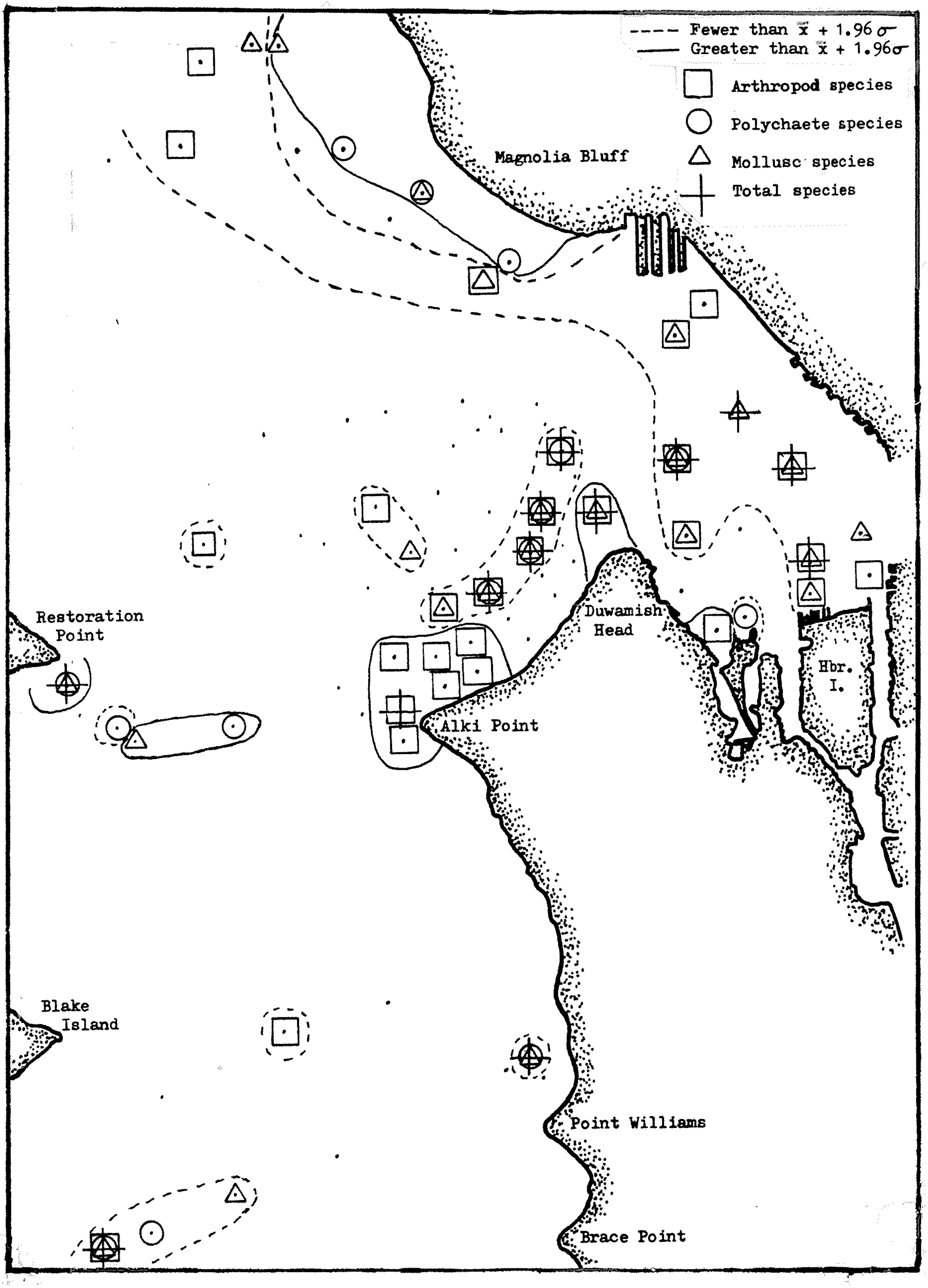


Figure 5.20. Species map.

Restoration Point; and in the center of the region between Alki and Restoration Points in water depths greater than 600 feet.

Depressions in the number of species occurred over a much wider area. Most of Elliott Bay showed fewer species of arthropods than expected for comparable depths outside of Elliott Bay. In many cases these same stations also showed fewer species of molluscs. A region between transects 4-8 at water depths of 400-500 feet had fewer species of most of the taxonomic groups. Isolated stations occurred throughout the rest of the study area for certain taxa groups.

Fewer polychaetes were found in the region between transects 5-7 at water depths of 400 feet. Other stations with fewer numbers of individuals than expected are indicated on Figure 5.21. Stations with greater numbers of individuals occurred at 50 feet near Duwamish Head in the southwest corner of inner Elliott Bay, between West Point and Magnolia Bluff at 100 feet, and in the center of the main basin between Elliott Bay and Bainbridge Island in water depths greater than 600 feet.

Common patterns of species and abundance enrichment are that: the region between West Point and Magnolia Bluff at water depths of 100 feet, the points near Duwamish Head, Alki Point, and Restoration Point, and the station closest to the West Waterway of the Duwamish River all have greater numbers than expected. Stations situated at 400 to 500 feet between Alki Point and Duwamish Head have fewer species and individuals than expected for that depth.

It should be noted that the region with depressed abundance and species richness between Alki Point and Duwamish Head at 400-500 feet is in the same region where increased quantities of conventional chemical materials were identified. These chemical enhancements were greater than anticipated based upon the quantities of these materials at comparable depths and seasons of

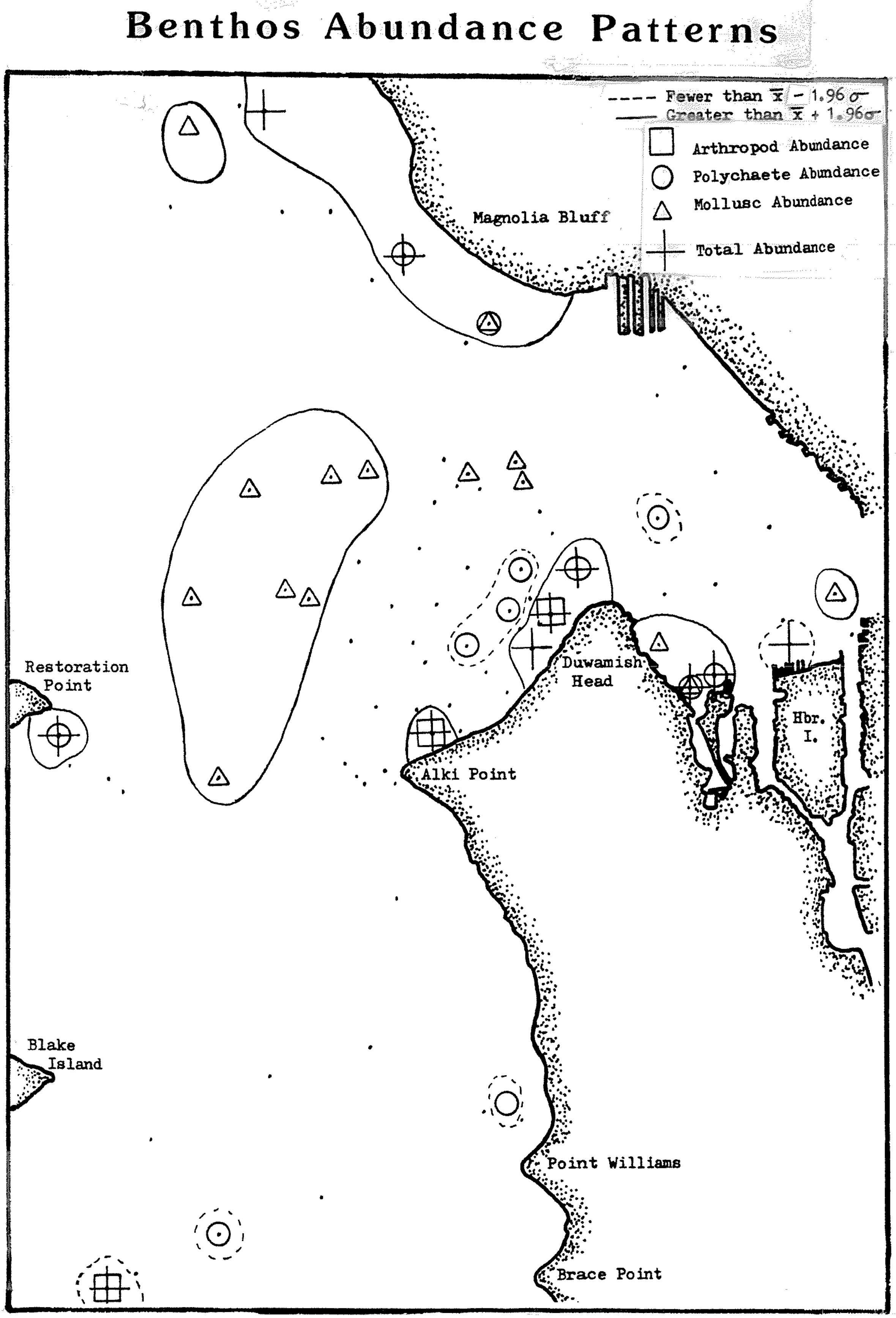


Figure 5.21. Abundance map.

sampling in the East Passage area.

5.3.3 Biological Communities - Cluster Analyses

Communities of organisms were determined by performing cluster analyses on untransformed abundance information using the Bray-Curtis formula. These clusters were performed on three major taxonomic groups; mollusca (Figure 5.22, Table 5.3), arthropoda (Figure 5.23, Table 5.4), and polychaeta (Figure 5.24, Table 5.5). The groups will be discussed based upon several levels of the dendrograms produced, using a flexible sorting strategy.

Mollusca were grouped into four dominant communities. These communities were numerically dominated by *Axinopsida serricata*, *Psephidia lordi*, and various other species (Table 5.6). *Psephidia lordi* dominated stations in water depths of 50 feet in fine sands with average BOD values of 450 mg/kg, volatile solids less than 1%, and organic carbon content of 2.3 mg/g. *Axinopsida serricata* dominated stations at water depths of 300-600 feet in sediments with equal mixtures of fine sand and silt or mainly silts with BOD values ranging from averages of 515-2005 mg/kg, volatile solids from 2.2-7.8 percent, and organic carbon concentrations of 5.4 to 23.3 mg/g. *Macoma carlottensis* was a subdominant species in the majority of the stations dominated by *Axinopsida serricata* when the conventional organic measures were in the higher ranges of those just indicated. BOD values at those stations ranged from 1000-2000 mg/kg, volatile solids from 5.3-7.8 percent, and carbon from 16.6-23.3. Stations with less than these values were subdominated by *Medacrenella columbiana*, *Nemocardium centifilosum*, or *Adontornina cyclia*. These latter three species became the dominant taxa with a few others at deeper depths and moderate levels of organic enrichment (Table 5.6).

Arthropod communities were divisible into stations dominated by either *Euphilomedes producta* or *Euphilomedes carcharodonta*. Stations at depths in

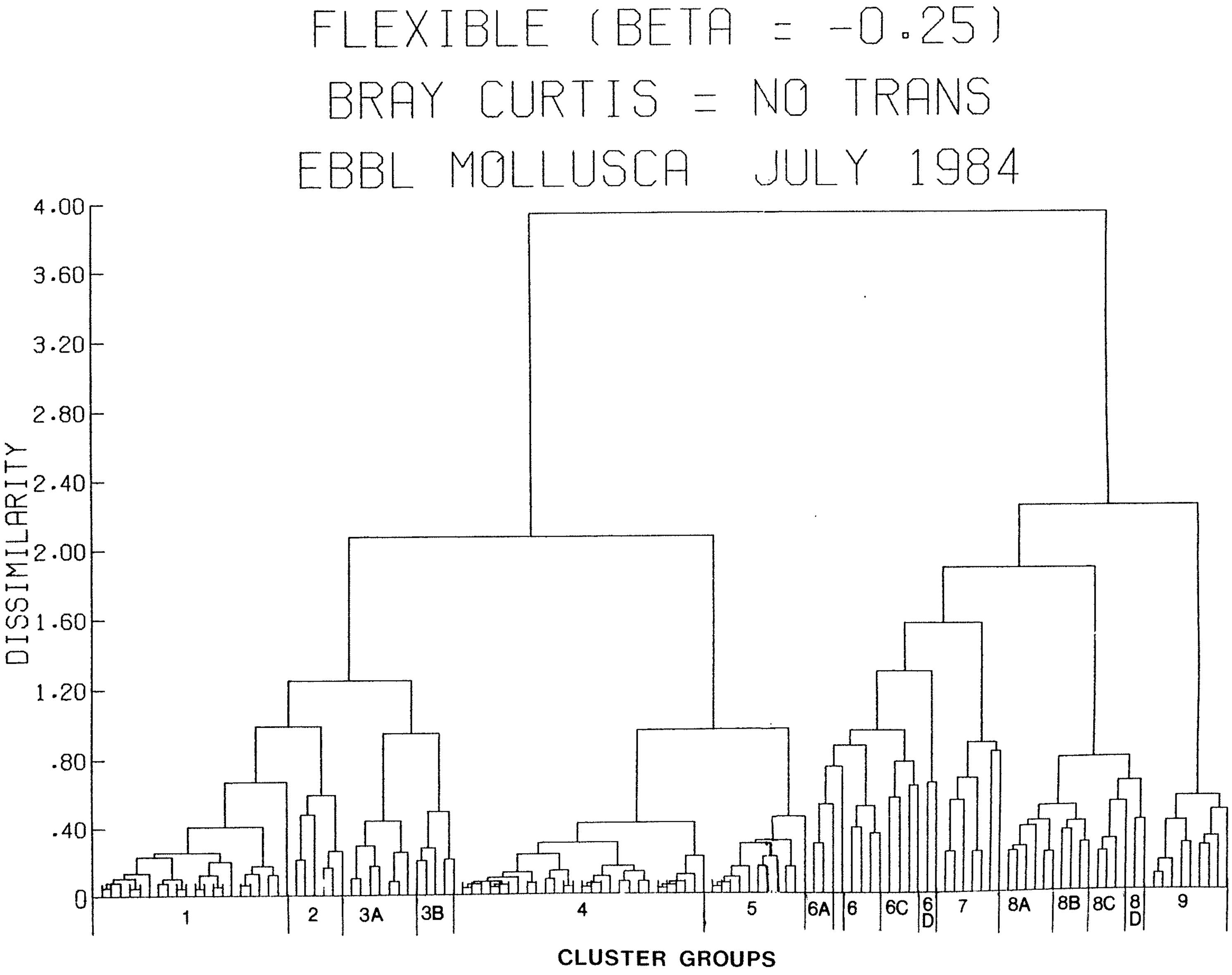


Figure 5.22. Station cluster of mollusca showing major cluster groups.

Table 5.3. Station cluster groups for Mollusca, Bray-Curtis, no transformation.

Group	Station
1	B-V #32 C
	B-VII-400E A
	B-III-600E A
	B-III-600E B
	B-III-600N B
	B-V #24 C
	B-II-800 A
	B-V-400E B
	B-VI-522E C
	B-VII-400E B
	B-V-600N B
	B-IX-282E B
	B-VIII-400E C
	B-XI-336M B
	B-X-50E A
	A-400E C
	B-X-420 C
	SS-11 B
	B-V #24 A
	B-VI-600E A
	X-100 A
2	B-IV-200E A
	B-IV-200E C
	XI-100 A
	B-111-400E B
	B-IV-400E B
	B-III-400E A
3A	A-720 A
	SS-5 A
	B-VI-400 E A
	B-VII-600E A
	B-VII-600E B
	B #37A
	B #25 A
	SS-4 C
3B	B-IV-600E A
	B-XI-200E B
	VIII-750 A
	X-300 B
4	B-III-600C B
	B-VIII-600E C
	B-IV #35 B
	B-IV-600N B
	B-VIII-600N A
	B-VI-600N B
	B-IV-600N A
	A-400W A
	B-III-640E C
	B-VII-600N A
	B-VII-600N C
	B #25 B
	B #25 C
	VII-750 A
	B-V-400E A
	B-VI-522E B
	B-VIII-600E B
	XI-300 C
	B-VIII-400E B
	B-III-600C C
	B-IV-600N C
	B-VI-600E B
	B-VI-600N C
	B-III-600N C
	B-IV #35
	B #37 B
	B-XII-50E B
5	B-VI-400E C
	B-VIII-600N C
	B-III-640E A
	B-IX-400E B
	B-V #32 A
	B-IX-200E A
	B-IX-200E C
	B-IX-50E A
	IX-300 A
	B-II-200W C
	B-XII-200E C
6A	VII-100 A
	VIII-100 A
	IX-100 C
OL	B-II-200E C
6B	B-III-5-50E A
	B-VI-50E B
	B-VII-50E A
	B-VIII-50E C
6C	A-200E A
	VII-300 C
	SS-7 A
	B-VIII-200E A
6D	A-50W B
	B-II-50E B
7	B-IV #34 B
	B-IV #34 C
	A-600E B
	SS-3 B
	B-IV-600E B
	B-IV-400E A
	B-XI-50E B
8A	B-III-5-200E A
	B-III-5-200E B
	B-VI-200E B
	B-VIII-200E B
	B-VI-200E A
	B-VII-200E A
8B	A-200W A
	B-VII-200E B
	B-V-200E A
	B-V-200E B
8C	B-II-600E A
	B-X-200E A
	B-II-400W A
	B-II-600W A
8D	VIII-300 C
	B-II-400E C
9	B-IV-50E A
	B-V-50E A
	B-VII-50E C
	B-III-5-50E C
	B-IV-50E B
	B-VI-50E A
	B-VII-50E A
	B-V-50E C
	B-II-50W A

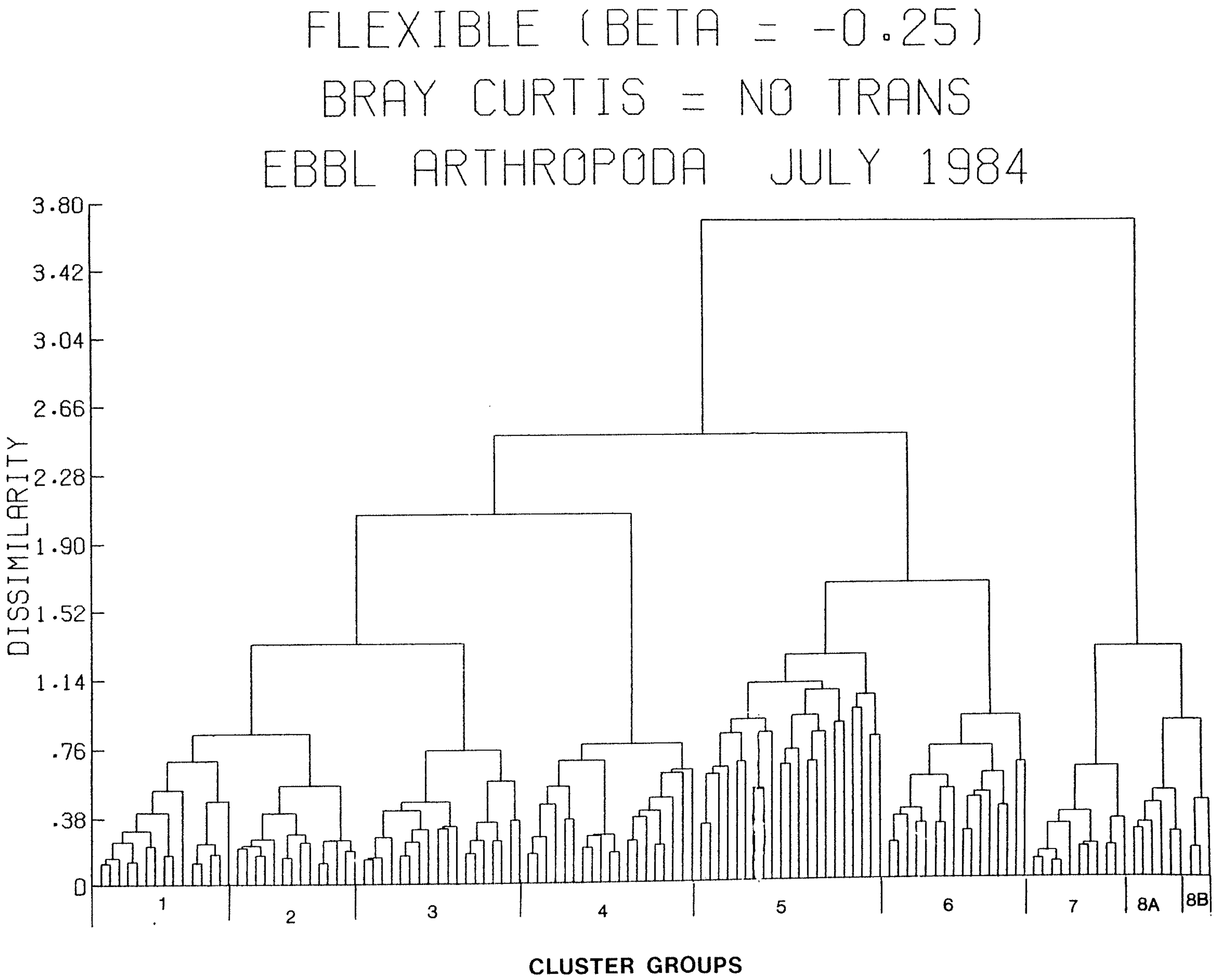


Figure 5.23. Station cluster of arthropoda showing major cluster groups.

Table 5.4. Station cluster groups for Authropoda, Bray-Curtis, No transformation.

Group	Station
1	A-720 A
	VIII-750 A
	B-VI-600N B
	SS-5 A
	B-IV #35 B
	B-IV #35 A
	B #25 A
	SS-4 C
	VII-750 A
	SS-11 B
	B-III-600C B
	B #25 B
	B-III-600C C
	B #25 C
	A-400E C
2	B-V #32 A
	B-VIII-600N A
	B-VIII-600E C
	B-VIII-600N C
	B-VI-522E C
	B-V-600N A
	B-VI-600N C
	B-V-600N B
	B #37 B
	SS-3 B
	B-III-600N B
	B-III-600N C
	B-III-640E A
	B-VIII-600E B
3	B-III-600E A
	B-VII-600N A
	B-VI-600E B
	B-VII-600N C
	B-V #24 C
	B # 37 A
	B-V #32 C
	B-V-400E B
	B-IV-600N A
	B-VI-522 B
	B-III-640E C
	B-VI-600E A
	B-IX-400E B
	B-IV #34 C
	B-IV-600E A
	B-V #24 A
	B-IV #34 B
	B-X-420M C
4	B-IX-200E A
	B-IX-200E C
	XI-100 A
	B-X-200E A
	B-II-800 A
	B-III-5-200E B
	B-II-200W C
	B-VI-200E B
	B-VII-200E A
	B-IV-200E A
	B-IV-200E C
	B-III-5-200E A
	B-VII-200E B
	A-200W A
	B-V-200E A
	B-V-200E B
	A-200E A
	B-VI-200E A
	B-II-200E C
5	B-III-400E A
	B-III-400E B
	B-II-600E A
	B-II-400W A
	VIII-700 C
	B-II-600W A
	B-IV-400E B
	B-VIII-200E B
	A-400W A
	VII-300 C
	IX-300 A
	B-XI-50E B
	X-300 B
	B-IV-400E A
	B-VIII-200E A
	SS-7 A
	B-II-400E C
	A-50W B
	B-V-50E A
	B-VIII-400E C
	B-XI-200E B
6	B-III-600E B
	B-XII-200E C
	B-V-400E A
	B-IV-600N C
	B-VII-400E A
	B-VI-400E A
	B-VII-400E B
	B-VI-400E C
	XI-300 C
	B-VII-600E B
	B-IV-600E B
	B-VIII-400E B
	B-IX-282E B
	A-600E B
	B-XI-336M B
7	B-V-50E C
	B-VI-50E B
	B-VII-50E B
	B-VII-50E C
	B-III-5-50E C
	B-IV-50E A
	B-VI-50E A
	B-IV-50E B
	B-IX-50E A
	B-X-50E A
	B-III-5-50E A
8A	VIII-100 A
	IX-100 C
	X-100 A
	B-II-50W A
	VII-100 A
	B-XII-50E B
8B	B-VIII-50E A
	B-VIII-50E C
	B-II-50E B

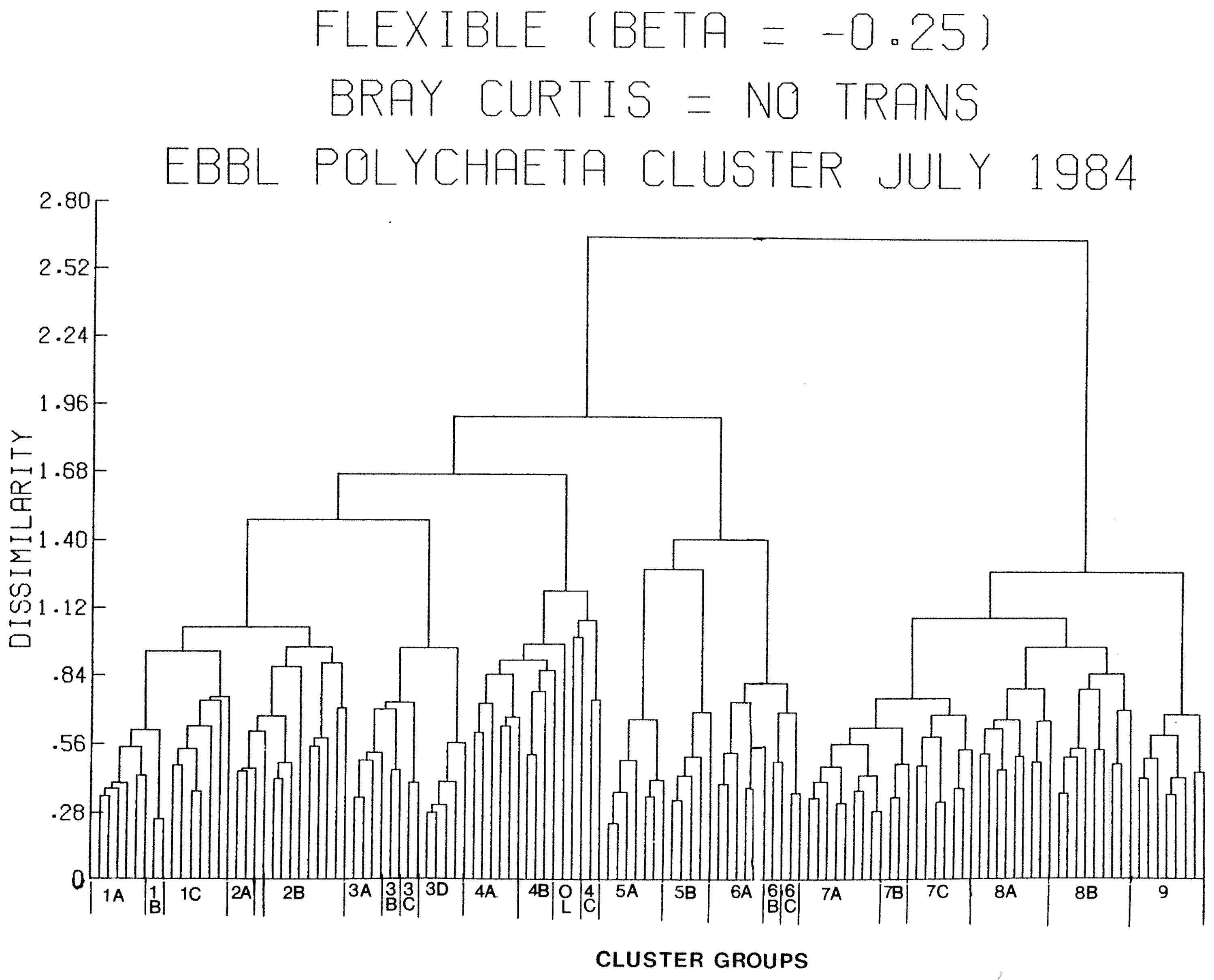


Figure 5.24. Station cluster of polychaete showing major cluster groups.

Table 5.5. Station cluster groups for Polychaets, Bray-Curtis, No transformation.

Group	Station
1A	B-VII-200E A
	B-VII-200E B
	B-VI-200E B
	B-VI-200E A
	B-V-200E A
	B-V-200E B
1B	B-IV-200E A
	B-IV-200E C
	A-200E A
	A-200W A
	B-III-5-200E A
	B-III-5-200E B
	VIII-100A
	B-II-400E C
	VII-300 C
2A	VIII-300 C
	B-VIII-200E B
	IX-300 A
OL	B-II-600E A
2B	B-II-200W C
	B-III-400E B
	B-III-400E A
OL	X-300 B
2C	SS-11 B
	B-IV-400E B
	A-400W A
2D	A-400E C
	B-II-400W A
3A	B-IX-200E A
	B-IX-200E C
	B-X-200E A
	XI-100 A
	B-XI-200E B
	B-XII-200E C
3C	B-II-800 A
	B-IX-282E B
3D	B-VII-400E A
	B-VIII-600E B
	B-VIII-400E B
	B-VIII-400E C
	B-II-600W A
4A	A-600E B
	B-III-600C C
	SS-5 A
	B-III-600E B
	B-IV-600E B
	B-III-600N C
4B	B-V-600N B
	B #25 A
	A-720 A
	B #25 C
OL	B-IV-600N C
	A-50W B
	B-IV-400E A
4C	SS-7 A
	B-VIII-200E A
5A	B-VI-50E B
	B-VIII-50E A
	B-II-50W A
	B-VIII-50E B
	IX-100 C
	B-II-200E C
	VII-100 A
5B	B-IX-50E A
	B-XII-50E B
	X-100 A
	B-XI-50E B
	B-X-50E A
6A	B-III-5-50E A
	B-III-5-50E C
	B-II-50E B
	B-IV-50E B
	B-V-50E C
	B-IV-50E A
6B	B-V-50E A
	B-VII-50E C
6C	B-VI-50E A
	B-VII-50E B
7A	B-VIII-600E C
	B-VIII-600N C
	B-VI-522E B
	B-V-600N A
	B-VI-400E C
	VII-750 A
	B-X-420M C
	B-VI-522E C
	B-VIII-600N A
7B	B #35 A
	B-V #32 C
	B-VII-400E B
7C	B-V #32 A
	B #37 B
	B-VII-600N A
	B-VII-600N C
	B-V #24 C
	B-VI-600E B
	B-VI-400E A
8A	B-III-600C B
	B-VI-600N B
	B-IX-400E B
	B-XI-336M B
	B-III-600E A
	B #25 B
	SS-4 C
	B-III-600N B
	SS-3 B
8B	B-VI-600N C
	B-VII-600E B
	B-VII-600E A
	B #37 A
	VIII-750 A
	B-IV #35 B
	B-V-400E A
	B-V-400E B
	XI-300 C
9	B-III-640E C
	B-IV-600N A
	B-IV #34 B
	B-IV #34 C
	B-V #24 A
	B-VI-600E A
	B-III-640E A
	B-IV-600E A

Table 5.6. Physical, chemical and biological characteristics of the station cluster groups seen in Figure 6.22 indicating which factors drive the cluster.

MOLLUSCA							SUB GROUP CHARACTERISTICS													
Group	Dominant Mollusca	Subdominant Mollusca	BOD	VS	BOD/ VS	Carbon	Sediment Desc.	Mean Depth		# Samp.	Dominant	Subdominant	Abundance of Dom.	Sub.	BOD	VS	BOD/ VS	Carbon	Mollusca # Species	Abun
I 84 samp.	Axinopsida serricata	(mainly) Macoma carlottensis	1471	6.9	241	20.2	fine sand and silt	457	IA	21	A. serricata	M. carlottensis	137	22	1422	7.2	202	23.3	9	172
								283	IIB	6	A. serricata	Magacrenella & Nemocardium	86	32/15	515	2.2	234	5.4	14	201
									B		A. serricata	Adontorhina & Nemocardium	86	27/18						
								574	IIIC	12	A. serricata	M. carlottensis	58	31	2005	7.8	248	23.1	8	103
								544	IVD	27	A. serricata	M. carlottensis	210	42	1435	7.3	198	22.0	9	269
								339	VE	11	A. serricata	M. carlottensis	324	52	986	5.3	185	16.6	12	435
								493	VII	7	A. serricata	M. carlottensis	6	8	1507	7.0	224	17.7	8	27
II	No dominant		317	1.5	306	3.8	fine sand	100	VIA		Crenella decussata		39						20	161
								305	VIA	OL	M. moesta alaskana		18		305	1.79	170	7.73		
											Hiatella arctica		18		"	"	"	"	24	126
											Odostomia spp.		15		"	"	"	"		
											Nemocardium centifilosum		15		"	"	"	"		
								50	VIB		Axinopsida, Psephidia Lyonsia, Crenella, Macoma Moesta Megacrenella		8		"	"	"	"	21	69
								234	VIC		Bittium, Lyonsia, Nemocardium, Adontorhyna Megacrenella, Macoma Moesta		3		242	2.69	89	5.64	12	35
								50	VID		Tellina Modesta	Tellina nuculordes or Mysella tumida	15	8or10	304	0.44	691	1.90	11	43
III	Several species dominant or co-dominant		398	2.0	238	6.1	fine sand	200	VIIIA		Magacrenella columbiana	Lyonsia, Cyclocardia + group B	19		293 518	1.55 1.18	202 442	3.49 3.59	17 16	172 161
								200	VIIIB		Axinopsida Macoma moesta	Nemocardium Nuculana fossa								
								450	VIIIC		Axinopsida	Nemocardium	35	24	480	3.54	129	12.93	13	112
								205	VIIIC	OL	Acila castrensis	Nemocardium/ Axinopsida	27	24/21					15	107
								350	VIIID		Nemocardium	Nuculana fossa	35	31	336	1.25	269	2.59	14	116
IV	Psephidia lord	Not needed	450	0.9	473	2.3	fine sand	50	IX none				99						19	175

excess of 500 feet in sediments of silt or fine sand containing BOD levels in excess of 1200 mg/kg, volatile solids of 7.1 percent, and organic carbon concentrations exceeding 22.3 mg/g also contained relatively high abundance levels of the cumacean *Eudorella pacifica* and *Eudorellopsis carcharodonta* and the cumacean *Eudorellpsis longirostris* became more abundant. At water depths of 50-100 feet the ostracod *Euphilomedes carcharodonta* completely dominated the samples. Moderate water depths between 200 and 400 feet were dominated by a variety of taxa types. These groupings were not sufficiently distinct to identify other groups of arthropod species (Table 5.7).

Fine sand and gravel sediments at depths ranging from 50-200 feet with concentrations of BOD ranged from 350-641 mg/kg, volatile solids concentrations of about 1 percent, and organic carbon concentrations approximating 3 mg/g were generally dominated by the tube dwelling polychaete *Phyllochaetopterus prolifica*. Towed underwater video revealed that these organisms were extremely abundant in this depth range throughout a large percentage of the proposed alignment for the pipe. These worm tubes appeared to lie in windrows that were often piled several inches over the bottom (Table 5.8).

Prionospio steenstrupi numerically dominated fine sandy sediments at the deeper end of the latter community, approximately at water depths of 200 feet or in shallower water where there was an increase in the quantity of organic materials in the sediments. In the deeper water areas the conventional organic measures approximated those found in the *Phyllochaetopterus prolifica* region so that an average BOD is 300-400 mg/kg, volatile solids between 1.3 and 1.5 percent, and carbon content of 3.2-3.4 mg/g. In shallower waters *Prionospio steenstrupi* dominated the samples when the concentrations of BOD exceed 1000 mg/kg, volatile solids are 5.5 percent, and organic carbon

Table 5.7. Physical, chemical and biological characteristics of the station cluster groups seen in Figure 6.23 indicating which factors drive the cluster.

ARTHROPODA							SUB GROUP CHARACTERISTICS													
Group	Dominant Arthropoda	Subdominant Arthropoda	BOD	VS	BOD/ VS	Carbon	Sediment Desc.	Mean Depth		# Samp.	Dominant	Subdominant	Abundance of Dom.	Abundance of Sub.	BOD	VS	BOD/ VS	Carbon	Arthropoda Taxa	Arthropoda Abun
1	Euphilomedes producta	Eudorellopsis integra	1659	7.3	223	27.7	silt and sand	606			Euphilomedes producta	Eudorellopsis integra	28.1	9.5	1659	7.3	223	27.7	9.4	72.2
	Endorella pacifica									15	Eudorella pacifica		21.9							
2	Euphilomedes producta	Endorella pacifica	1223	7.1	172	22.3	silt and sand	600		14	Euphilomedes producta	Eudorella pacifica	38.5	12.4	1223	7.1	172	22.3	11.2	74.0
		Eudorellopsis integra										Eudorellopsis integra		5.1						
		Heterophoxus oculata										Heterophoxus oculatus		4.7						
		Paraphoxus oculatus										Paraphoxus oculatus		3.8						
3	Euphilomedes producta	Eudorella pacifica	1677	8.1	208	23.1	silt and sand	567		18	Euphilomedes producta	Eudorella pacifica	17.1	5.1	1677	8.1	207	23.1	10.5	41.0
		Haupiniopsis fulgens										Haupiniopsis fulgens		3.2						
		Heterophoxus oculatus										Heterophoxus oculatus		3.8						
4	Euphilomedes producta	Eudorellopsis longirostris	451	2.01	250	6.4	fine sand	225		19	Euphilomedes producta	Eudorellopsis longirostris	60.9	6.6	451	2.01	250	6.4	21.6	120
		Euphilomedes carcharondonta										Euphilomedes carcharondonta		7.2						
5	Various species		542	3.2	189	9.0	fine sand with some silt	406	5A	8	Eudorellopsis longirostris	Euphilomedes producta	7.3	5.6	416	2.9	142	8.8	18.9	52
								400	5A OL	1	Orchomene pacifica	Euphilomedes producta	18	7		No measure			14	44
								258	5B	6	Euphilomedes producta	None	2.3	-	587	2.8	200	7.6	10	19.2
								290	5C	2	Ampelisca agazzizi or	Dulichia sp.	63	4	315	2.2	181	2.59	23	122
											Dulichia sp.	Ampelisca caryo	5	3					20	35
								50	5D	2	Rhepoxynius abronius	Euphilomedes carcharondonta	8	2	460	.88	523	1.5	4	12
											Euphilomedes producta	Rhepoxynius abronius	319	30					14	382
								300	5E	2	NA									
6	Eudorella pacifica	NA	1738	7.5	237	22.3	silt with fine sand	440		16	Eudorella pacifica	NA	9.4	-	1738	7.5	237	22.3	11.3	34.6
	Euphilomedes producta										Euphilomedes producta		4.1	-						
	Heterophoxus oculatus										Heterophoxus oculatus		3.6	-						
	Harpiniopsis fulgens										Harpiniopsis fulgens		5.3	-						
7	Euphilomedes charcharondonta		598	2.3	369	7.3	fine sand	50		11	Euphilomedes charcharondonta	Rhepoxynius abronius	395	24.5	598	2.3	369	7.3	21.2	516
												Leptochelia dubia	-	18.6						
8	Euphilomedes charcharondonta		457	1.5	473	3.9	fine sand	50	8A	6	Euphilomedes charcharondonta	Euphilomedes producta	86	27	584	2.1	508	5.8	21	166
								100	8B	3	Euphilomedes charcharondonta	Pontogenia rostrada	140	69	373	.77	522	2.0	27	360

Table 5.8. Physical, chemical and biological characteristics of the station cluster groups seen in Figure 6.24 indicating which factors drive the cluster.

MAJOR GROUP CHARACTERISTICS

POLYCHAETA

SUB GROUP CHARACTERICS

Group	Dominant Polychaeta	Subdominant Polychaeta	BOD	VS	BOD/ VS	Carbon	Sediment Desc.	Mean Depth	Subgroups		Dominant	Subdominant	Abundance of		BOD	VS	BOD/ VS	Carbon	Polychaeta	
										# Samp.			Dom.	Sub.					# Taxa	Abu
I	Prionospio steenstrupi Myriochele gracilis		411	1.4	300	3.44		213		15										
							fine sand	200	A	6	P. Steenstrupi	M. Gracilis Ampharete spp. P. Steenstrupi	39.8	8.0 5.7 19.5	416	1.3	337	3.2	44.8	169.
							fine sand	200	B	2	M. Gracilis	Leitoscoloplos	28.5	17.0	532	1.8	289	4.6	51.5	174.
							fine sand	200	C	4	P. Steenstrupi	Ampharete Acutifrons	21.5	8.3	317	1.5	212	3.4	53.5	204.
											Notomastus Tenuis	Syllis Heterochaeta	28.5	6.8						
							fine sand	267	O.L.	3	A. Acutifrons Polycirrus spp.	M. Gracilis Spiophanes Berkeleyorum N. Tenuis P. Steenstrupi	18.3 17.0	3.8 6.5 14.7 5.3	336	1.3	209	2.6	44.7	139.
II	Mediomastus spp. Myriochele gracilis		485	2.8	159	7.8		352		13										
							fine sand	267	A	3	Mediomastus spp. M. Gracilis	Proclea Graffi S. Heterochaeta N. Tenuis	30.7 21.7	17.3 16.7 14.0	189	2.2	86.3	5.6	55.0	251.
							fine sand	333	B	3	M. Gracilis	P. Graffi S.Berkeleyorum Diopatra ornata	59.7	11.3 11.0 9.0	256	2.0	117	4.8	41.7	201.
							silty sand	363	C	3	Leitoscoloplos pugettensis	Barantolla americana Pectinaria californiensis	7.3	3.7 3.3	960	3.3	290	8.9	34.3	90.
							fine sand w/gravel	400	D	2	D. Ornata	Mediomastus spp. S.Heterochaeta	21.5	8.5 6.5	212	2.9	73.9	13.6	20.0	91.
								50	O.L.	2	Mediomastus spp.	P. Steenstrupi M. Gracilis	1145	10.0 9.5	798	4.3	185	12.2	40.0	254
III	Euclymeninae Tauberia gracilis Mediomastus spp.		1034	5.5	187	17.9		363		13										
							silt with some clay	175	A	4	Euclymeninae	N. Tenuis P.Steenstrupi	23.3	17.8 34.0	673	3.1	218	11.7	41.8	191.
											Mediomastus spp.	T. Gracilis	20.0	36.0						
							silt with some clay	268	B	2	Euclymeninae	T. Gracilis	24.0	6.5	1232	8.6	144	21.4	29.0	85.
								541	C	2	T. Gracilis	Mediomastus spp	44.5	24.0	924	5.8	160	18.8	34.0	146.
								480	D	5	Mediomastus spp.		34.8	-	1128	5.9	179	19.0	27.0	82.
IV	No Dominance		1406	6.6	200	20.3	silt and clay	522		14										
								625	A	6	None	None			1870	8.2	229	23.5	12.2	15.
								660	B	4	Prionospio cirrifera Barantolla americana Polydora branchycephala	Mediomastos spp	20 12 10	5.5	1249	6.9	176	23.1	14.8	36.
							silt and clay		O.L.	1	Laonice cirrata	None	5		2653	8.6	309	23.0	6	
							fine sand & gravel	190	C	2	Polydora brachycephala	Polydora spp.	59	11	242	207	89	5.6	49.0	219.
											Polydora socialis	Polydora sp.x	45	12						
											Pholoides aspera	Tharyx spp.	36	12						
											Pionosyllis oraga		30							
											Spiophanes berkeleyorum	Thalanessa spinosa	3.0	2.0	234	1.3	175	1.8	7	1
V	Phyllochaetopterus prolifica Prionospio steenstrupi		658	3.0	342	10.4	fine sand	75		12										
								86	A	7	P. Prolifica	Prionospio steenstrupi	220	31.7	347	0.97	438	3.4	56.6	477.0
								60		5	P. Steenstrupi	Notomastus Tenuis Mediomastus spp.	106.6	62.6 18.6	1046	5.5	222	19.3	46.6	398
VI	Phyllochaetopteros prolifica Prionospio steenstrupi		449	1.0	449	2.2		50		10										
							fine sand	50	A	6	P. Steenstrupi	Platynereis Bicanaliculata	19.2	10.0	353	1.0	388	1.7	34.7	119.5
							fine sand	50	B	2	P. Prolifica P. Steenstrupi		10.0 9.5		641	1.1	585	2.9	30.0	84.5
							fine sand	50	C	2	P. Prolifica	P. Steenstrupi	78.0	17.5	544	1.0	496	2.8	44.0	198.5
VII	Mediomastus spp. (Low abundance)		1580	7.6	206	22.9		554		19										
							silt and clay	557	A	9	Mediomastus spp.	Tauberia gracilis	9.9	6.2	1348	6.8	196	21.1	19.8	47.
								507	B	3	Mediomastus spp.	Tauberia gracilis	12.1	7.3	1560	7.8	200	23.1	21.8	56.
							"	568	C	7	Mediomastus spp.	Tauberia	8.7	7.3	1746	8.1	212	24.1	20.3	40.
VIII	Tauberia gracilis		1617	7.4	217	22.5		534												
							silt and clay	586	A	8	Tauberia gracilis		5.0		1549	7.7	194	22.5	17.0	33.
								530	B		T. Gracilis Mediomastus spp.		1.6 2.2		1685	7.1	240	22.4	17.0	27.
IX	Cossura spp. (Low abundance)		1659	8.4	196	23.2	silt and clay	610	A	8	Cossura spp.	Tauberia gracilis	3.1	2.2	1659	8.4	196	23.2	13.4	20.

concentrations were 19.3 mg/g. *Prionospio steenstrupi* was a co-dominant or subdominant species in those stations dominated by *Phyllochaetopterus prolifica* (Table 5.8).

Myriochele gracilis dominated or was a sub or codominant taxon in sandy sediments at water depths of 200-300 feet. These sediments contained greater volatile solids concentrations in the sediments than seen in the latter communities, averaging in excess of 2 percent, with BOD values ranging from 256-532 mg/kg and organic carbon values ranging from 4.6-5.6 mg/g. *Mediomastus* spp. was an important subdominant species in some of these communities and became more numerically important in deeper depths, approximating 400-500 feet. These fine sandy sediments had higher BOD values, 189-798 mg/kg, volatile solids concentrations of 2-4 percent, and organic carbon concentrations of 5-12 mg/g.

In deeper siltier sediments at water depths in excess of 450 feet *Mediomastus* spp. numerically dominated those stations with BOD values of 673-1128 mg/kg, volatile solids concentrations of 3-6 percent, and organic carbon concentrations in the range of 12-19 mg/g.

As the depth increased and the concentrations of these conventional organic measures increase the number of polychaete individuals decrease and the relative importance of numerically dominant taxa decreased. The following list of taxa showed some signs of dominance in silty sediments at water depths in excess of 500 feet; *Prionospio cirrifera*, *Barontolla american*, *Polydora brachycephala*, *Laonice cirrata*, *Tauberia gracilis*, *Cossura* sp. or members of the polychaete subfamily Euclymeninae (Table 5.8). These species generally accounted for less than 30 individuals in a grab sample.

5.4 Conclusions

The potential for deposition of organic material to the sediments from secondarily treated effluents is less than for primary treated wastes. It has been shown that 10-15 percent of secondary effluent material settles at rapid enough rates to accumulate in the nearby sediments. If enough material settles in a region, anaerobic conditions may result as well as changes in the benthic communities. The primary concerns addressed by the subtidal biology group were to identify regions in the Duwamish Head area where greater deposition may be occurring naturally in order to minimize the potential for siting a discharge in an inappropriate environment. The types of benthic communities in the surrounding area were also examined.

To identify regions of deposition, samples from 83 benthic stations were examined for conventional chemistry measures (%VS, BOD, carbon, organic nitrogen, and %water). General trends in these data showed that the concentration of each measure increased with increasing depth. Stations considered to be organically enriched were identified as having concentrations that were greater than +1.96 standard normal deviates of the value at that depth contour in the Seahurst study area. Each chemical measure identified a region between transects IV and VII at a depth of 400 to 480 feet as being enriched. Additionally the inner Elliott Bay region was considered to be enriched, based on the above criteria.

In general, the abundance and species richness of infaunal organisms showed a decreasing trend with increasing depth. The greatest species richness occurred at a depth of 200 feet, while the greatest abundance occurred at the shallowest depths. Trends in the species richness shows that the entire study area was divided into three distinct regions; an inner bay with low mean numbers of taxa, an outer bay with slightly higher mean numbers of taxa, and an area outside of the bay with an even greater mean number of taxa (Figure 5.19). This trend in species richness is consistent with the Pearson-Rosenberg model of the effects of organic enrichment. The mean total abundance of infaunal organisms showed a similar trend at the shallowest depths (50-100 ft.), but was not as clear in the deeper depths.

Area of enhanced or depressed abundance and species richness were identified as those stations where these values were greater or less than ± 1.96 standard normal deviates of the mean value found at that depth contour in the Seahurst study. As found with the conventional chemistry measures, an area between transects IV and VII at a water of 400 to 480 ft., and the inner Elliott Bay region showed depressed abundance and species richness. Enhancements were found associated with points and headlands.

The conventional chemistry and benthic biological data indicated that the region between transects IV and VII at a depth of 400-480 ft. was an area that should not receive more organic material. This same area was identified as an area of increased toxicity based on sea urchin and amphipod sediment bioassays (Marine Toxicology section, this report). The enhanced levels of organic material in this area indicated that there would be larger numbers of individuals present than were actually found. Current meter studies carried out by the Physical Oceanography group suggested that of the two locations designated as possible diffuser sites, the inner location had a greater probability of affecting this area than did the outer site. The mean current speed at the inner site was about 7 cm/sec. and vectored to the south-southeast at a speed of 1-2 cm/sec. Since the plume will rise from 600 ft. to a depth of 300 ft., there was a good chance that it would impact this area. The mean current speed at the outer site was about 9 cm/sec. and vectored to the south-southwest at a speed of 2-3 cm/sec. Thus the probability of the plume impacting the area was less than for the inner site. The reason for not discharging in this zone of greater organic sediment concentrations was not principally due to an increase in the organic materials. The main reason was that present understanding suggests that this region should have greater abundance of benthic infauna rather than lower levels. The lack of understanding as to why this difference exists suggests that we should be cautious about exacerbating presently incomprehensible conditions.

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6.0 FISH ECOLOGY

R. Donnelly, B. Miller, R. Lauth

6.1 Introduction

The aquatic ecosystem of the Duwamish Head area can be subdivided into assemblages composed of species groupings (e.g., zooplankton assemblage, fish assemblage, etc.). The relative significance of each assemblage within the ecosystem is dependent upon a variety of factors. Clearly the fish assemblage is significant to the commercial and recreational fisheries. The diversity of the fish assemblage and the physical health of its inhabitants are also very important in pollution evaluations. Flatfish exhibiting infections of bloodworms, skin tumors or fin erosion are considered undesirable food fish and may indicate pollution problems (Amish 1976). The fish ecology study was designed to provide baseline information on the composition and health of the assemblage in the Duwamish Head area.

6.1.1 Objectives

The goal of the fish ecology study was to provide a baseline of information for siting a sewage outfall and for post-discharge follow-up studies. To accomplish the goal the following specific objectives were proposed:

1. To establish a baseline of information on fish species assemblages.
2. To establish a baseline of information on the external parasites and diseases of flatfishes by determining the incidence of:
    a. Philometra ("bloodworm")
    b. skin tumors
    c. fin erosion

6.1.2 Description of the Study Area and Stations

The study area included inner and outer Elliott Bay, specifically, the Alki-Duwamish Head area, Smith Cove, and one station near the center of inner Elliott Bay (Figure 6.1). The underwater bathymetry is steep (METRO 1983) and is transected by small rocky hills and valleys. The bottom is flat and mud covered.

Study sites were selected on the basis of the proposed Duwamish Head outfall location, known or predicted oceanographic conditions and historical fish assemblage data in central Puget Sound. Two nearshore and four offshore stations (15 m, 50 m, 100 m, and 200 m depths) were located in the Alki-Duwamish Head area. One nearshore and four offshore stations at the same depths were also located at Smith Cove. One offshore station at 70 m was located in inner Elliott Bay. Sampling occurred during the last half of July and the first half of August, 1984. "Nearshore" in this report refers to the shoreline, which was sampled by beach seine, and "offshore" refers to subtidal sampling by a small otter trawl.

The substrate composition of all the nearshore stations was sand/eelgrass with some cobble and gravel. Alki Point had an extensive eelgrass bed; other sites had little or no eelgrass. Smith Cove had some nereocystis (kelp) in addition to a small amount of eelgrass. Adjacent to Smith Cove, an extensive nereocystis bed that extended along the entire length of Magnolia Bluff. The offshore station substrates varied by depth. Shallow (15 m) substrates were sandy with some of cobble and gravel. The 50 meter sediments were finer; mud and little or no cobble or gravel. At 70, 100 and 200 m the substrate was composed almost entirely of mud.

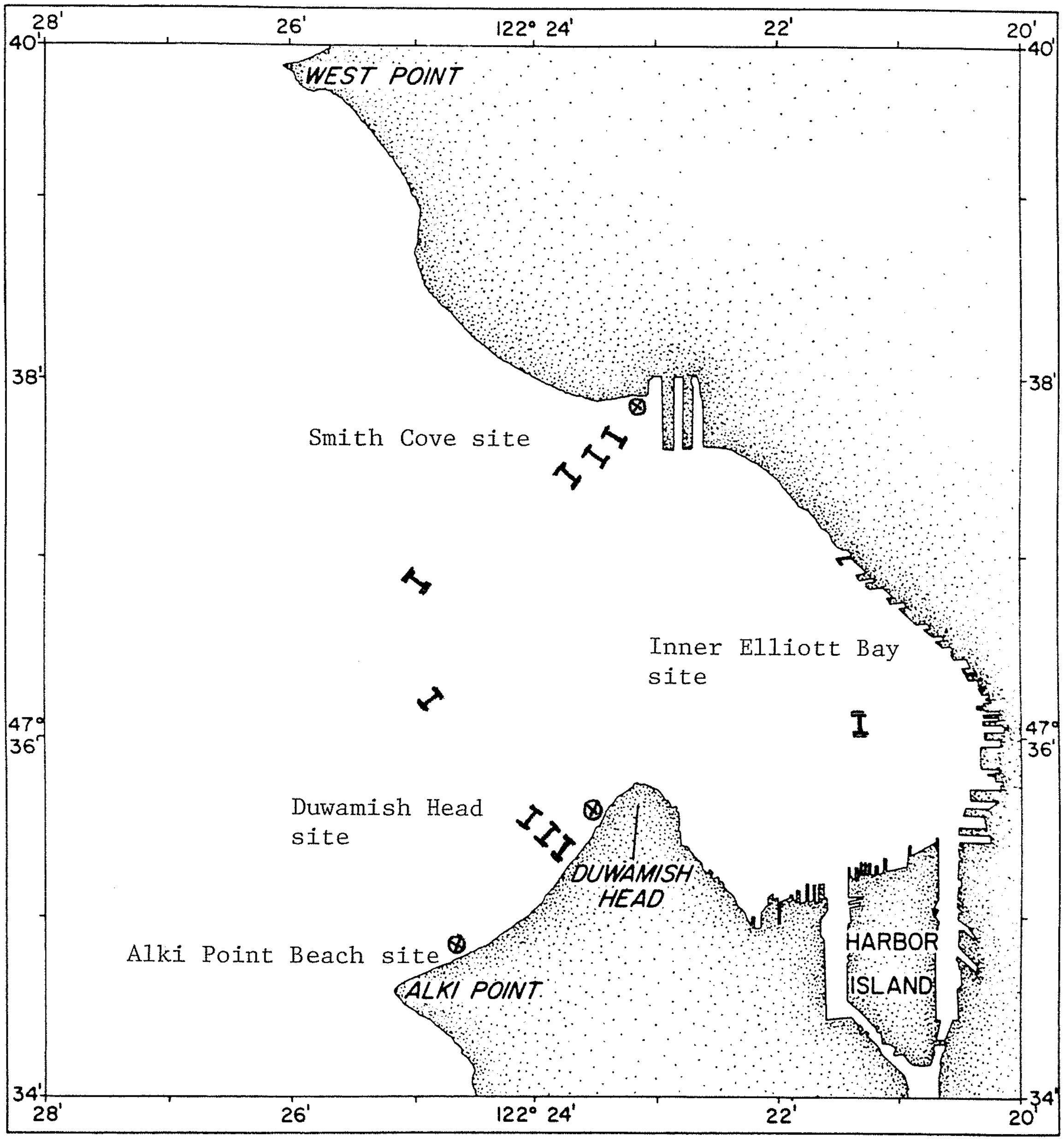

Figure 6.1. Fish ecology sampling sites. Nearshore stations are designated by ⊠, offshore stations by ├┤.

6.2 Materials and Methods

6.2.1 Fish Populations

6.2.1.1 Nearshore Fishes

Sampling of nearshore fishes was carried out using a 37 m convertible floating-sinking beach seine (Miller et al. 1977). The only difference between sinking and floating beach seines was the addition of seven crab pot floats to the top of the net so the net would float when the water depth exceeded the height of the net. At Alki-Duwamish Head the sinking beach seine was set first and as close to low tide as possible (usually within 0.5 hours before low tide). The sinking beach seine was set 30 m from the shore with a small rowboat and retrieved at a rate of 10 m/minute. At Smith Cove the sinking beach seine was set 60 m from the shore due to the shallow nature of the beach. Lines attached to the bridles at each wing end were initially retrieved from a distance of 40 m apart. When 10 m of line were left to be retrieved, the net opening was closed to 12 m and retrieval completed. The floating beach seine was set 60 m from the shore (90 m at Smith Cove) and retrieved in the same manner as the sinking beach seine. Replicate sinking beach seine sets were taken on adjacent sections of the shoreline at each study site. The floating beach seine sets were taken following the sinking beach seine sets on the same portions of the shoreline. Contents of each haul were placed in plastic bags, labeled, placed on ice in coolers, transported to the laboratory, and stored at 0°C until processed.

6.2.1.2 Offshore Demersal Fishes

Quarterly sampling of offshore demersal fishes was carried out using a 7.6 m otter trawl deployed from the R.V. Kittiwake. For a detailed description of trawl and its operation, see Mearns and Allen (1978). Duplicate 5 minute trawls were made at each offshore demersal station.

6.2.1.3 Laboratory Fish Processing

Each bag of fish was allowed to thaw and its contents separated by species and life history stage. Total length (in mm) of each fish and total weight (gm) of each life history stage was recorded. In the case of very large numbers of individuals per species and/or life history stage, the total number of individuals was recorded and 100 randomly selected individuals measured and recorded. The length and weight of up to 100 English sole, Dover sole, and shiner perch from each sample haul was recorded. Since the tips of ratfish tails were often missing, a length from snout to the end of the second dorsal fin as well as total length (when possible) were recorded.

6.2.1.4 Flatfish Health

Flatfish Parasites. Marine flatfishes are known to be infected by the parasite nematode Philometra (a bloodworm). The bloodworms are clearly visible and are typically located in the subcutaneous areas near or at the base of the fins. The bloodworm can be large - up to 100 mm in length and 2 mm in diameter, and bright red in color (Amish 1976). The external appearance of the parasite on the fish resembles a dull red blister, less than 1 cm long.

Flatfish Skin Tumors. Several species of flatfish are known to be infected by skin tumors (Angell and Miller 1975; McArn et al. 1968; Miller and Wellings 1971). Flatfish skin tumors were found as two main types: angioepithelial nodules (AEN) and epidermal papillomas (EP). Field and laboratory experiments have shown the two types to be different stages of the same disease (McArn et al. 1968). AEN were located anywhere on the external surface of the fish, 1 mm to 5 mm in diameter, hemispherical, pink to red, smooth surfaced, and sessile lesions (Miller et al. 1977). They were typically found on small (usually juvenile) flatfish. EP were circular, 0.5 cm to 5 cm in greatest dimension, brown to black, and their outer surfaces cauliflower-like in appearance.

Flatfish Fin Erosion. Fin erosion typically affects the anal and dorsal fins and varies in severity from minor defects to extensive destruction of the fins. The less severe cases exhibit partial loss, fusion, or distortion of the fin rays, typically accompanied by hemorrhages and granulation tissue on the surface of the fin. Along the free edge of the diseased tissue, there is usually a line of hyperpigmentation. In the most severe cases, parts of the fins exhibit complete loss of fin rays and the remaining tissue becomes greatly scarred, retracted, flaccid and deformed (Wellings et al. 1976).

Laboratory Processing. All flatfish were examined at the time of laboratory processing for the presence of skin tumors and blood worms. Examination for the presence of fin erosion was conducted in the field. When fin erosion was found, the fish was tagged, a record made of which fin was eroded and the degree of severity. The fin eroded fish were bagged separately from the rest of the catch, held on ice for transport to the laboratory and stored at 0°C until processed (see section 6.2.1.3).

6.2.2 Environmental Measurements

Environmental measurements were taken at each sampling location; these measurements included water temperature, salinity and dissolved oxygen. In addition light penetration was measured at the offshore demersal stations.

6.2.2.1 Water Temperature

Surface and nearshore station water temperature was measured with a hand held thermometer directly from the surface water or from a bucket of surface water.

Subsurface water temperature was measured with a bathythermograph (BT). The BT was attached to a cable and lowered at a constant speed of 1.5 m per second to the desired depth. As the BT moved vertically through the water column it inscribed a line showing temperature and depth onto a gold covered glass slide. A new slide was used for each vertical sampling or cast. Each slide was individually labeled and read through a viewer calibrated for the BT. The slides were then archived for future use.

6.2.2.2 Salinity and Dissolved Oxygen Measurements

A plastic Niskin bottle was used to collect water for salinity and dissolved oxygen measurements. Subsamples of surface and subsurface water were transferred into standard salinity and dissolved oxygen bottles. The salinity bottles were stored at $2^{\circ}C$ until the field work was completed at all sites. Salinity was determined using a Wheatstone bridge at the School of Oceanography, University of Washington. Dissolved oxygen samples were fixed and analyzed after the method of Carpenter (1965). Analysis was carried out by the School of Fisheries Water Quality Laboratory, University of Washington.

6.2.2.3 Light Penetration Measurements

Light penetration was measured with a secchi disc at all offshore locations. At nearshore locations, light reached the sea bottom, so secchi disc measurements were not taken.

6.2.3 Data Analysis

The data were analyzed graphically, with hand calculator and by computer program.

Species diversity was calculated using the Shannon-Wiener diversity index H' (Pielou 1978) as follows:

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

where p_i was the proportion of the community that belonged to the ith species and s was the number of species. As a consequence of the mathematical formula, H' increases with an increase in the number of species and/or as all species present are represented in increasingly equal proportions.

Species richness was defined as the total number of species caught.

The average of abundance, species number and biomass per haul, at each sample site, was computed and organized into tables.

A numerical classification (or cluster analysis) technique was used to identify species assemblages and similarities between sampling sites. Advantages of the technique included: 1) objective criteria could be applied to a large data set to arrive at a simple summary; 2) the technique was based upon quantitative catch data (e.g., numbers or weight of each species) instead of presence or absence; and 3) the results could be evaluated at different levels of statistical similarities.

Data preparation involved creating a data matrix composed of catch data (numbers or weight) for a set of species among a set of collection sites. A transformation [$\log_{10}$ (observation + 1)] was applied to the data matrix to reduce variability. After transformation, resemblance measures were computed between sites or species that resulted in a matrix of resemblance values. Two numerical classifications were done: 1) locations were classified based upon measures of resemblance between samples, and 2) an "inverse" classification based upon resemblance between species in terms of their distribution among samples.

A hierarchical clustering technique was used (Boesch 1977; Clifford and Stephenson 1975) to stepwise combine elements based upon similarity (or dissimilarity) of their attributes. The dissimilarities were computed using the Bray-Curtis distance measure. The results were summarized in the form of dendrograms.

It is worth noting that numerical classification is not an end in itself but a means of gaining insight into a complex data set.

6.3 Results

6.3.1 Fish Populations

6.3.1.1 Nearshore Fishes

A total of 35 species of fish were collected in the nearshore areas during the study (Table 6.1). Twenty-two were found exclusively in the nearshore samples, the other 13 were found in both the nearshore and offshore samples. Thirteen of the 35 species were found at all three nearshore sampling sites, 10 species were found at two of the three sites, while 12 species occurred at only one of the stations. The five most abundant species differed from station to station (Table 6.2).

Generally adult fishes were dominant by weight in the catches at all three sites, while neither adult or juvenile fished dominated the catches by abundance at these same sites. At Smith Cove, juvenile English sole and juvenile striped seaperch were the two most abundant species and comprised a considerable portion of the average biomass. At Duwamish Head, juvenile English sole, juvenile shiner perch and juvenile striped seaperch were prevalent by numbers while the adults of these same species dominated the average biomass statistics, especially the striped seaperch. The same was true for striped seaperch and shiner perch at Alki Point.

Location clusters. Numerical analysis of individual beach seine hauls at all sample sites showed that each individual haul had the greatest affinity for its replicate haul. Thus, the individual hauls were most similar by site and the greatest dissimilarities were found between sites (Figure 6.2). The two hauls at Duwamish Head were most similar, while the two hauls at Smith Cove were the least similar of the replicate pairs.

Species clusters. Numerical analysis of species abundance indicated that

Table 6.1. Species occurring in 1984 summer beach seine and trawl catches.

Common Name	Scientific Name	Occurrence	
		Nearshore	Offshore
Spiny dogfish	*Squalus acanthias*		x
Ratfish	*Hydrolagus colliei*		x
Pacific herring	*Clupea harengus pallasi*	x	
Chum salmon	*Oncorhynchus keta*	x	
Coho salmon	*Oncorhynchus kisutch*	x	
Chinook salmon	*Oncorhynchus tshawytscha*	x	
Cutthroat trout	*Salmo clarki*	x	
Unidentified salmon		x	
Surf smelt	*Hypomesus pretiosus*	x	
Unidentified smelt		x	
Plainfin midshipman	*Porichthys notatus*		x
Pacific cod	*Gadus macrocephalus*	x	x
Pacific hake	*Merluccius productus*		x
Pacific tomcod	*Microgadus proximus*	x	x
Walleye pollock	*Theragra chalcogramma*		x
Red brotula	*Brosmophycis marginata*		x
Pallied eelpout	*Lycodapus mandibularis*		x
Black eelpout	*Lycodes diapterus*		x
Blackbelly eelpout	*Lycodopsis pacifica*		x
Tubesnout	*Aulorhynchus flavidus*	x	
Bay pipefish	*Syngnathus griseolineatus*	x	
Shiner perch	*Cymatogaster aggregata*	x	x
Striped seaperch	*Embiotoca lateralis*	x	x
Pile perch	*Rhacochilus vacca*	x	
Northern ronquil	*Ronquilus jordani*		x
Snake prickleback	*Lumpenus sagitta*	x	
Bluebarred prickleback	*Plectobranchus evides*		x
Penpoint gunnel	*Aprodichthys flavidus*	x	
Crescent gunnel	*Pholis leata*	x	
Saddleback gunnel	*Pholis ornata*	x	
Pacific sand lance	*Ammodytes hexapterus*	x	
Brown rockfish	*Sebastes auriculatus*	x	x
Copper rockfish	*Sebastes caurinus*	x	x
Quillback rockfish	*Sebastes maliger*	x	x
Unidentified rockfish		x	x
Whitespotted greenling	*Hexagrammos stelleri*	x	
Padded sculpin	*Artedius fenestralis*	x	x
Silverspotted sculpin	*Blepsias cirrhosus*	x	
Roughback sculpin	*Chitonotus pugetensis*		x
Spinyhead sculpin	*Dasycottus setiger*		x
Buffalo sculpin	*Enophrys bison*	x	
Pac. staghorn sculpin	*Leptocottus armatus*	x	
Tidepool sculpin	*Oligocottus maculosus*	x	
Slim sculpin	*Radulinus asprellus*		x
Cabezon	*Scorpaenichthys maroratus*	x	

Table 6.1 (continued).

Common Name	Scientific Name	Occurrence Nearshore	Offshore
Unidentified sculpin		x	
Blacktip poacher	*Xeneretmus latifroms*		x
Bluespotted poacher	*Xeneretmus triacanthus*		x
Pacific sanddab	*Citharichthys sordidus*	x	x
Speckled sanddab	*Citharichthys stigmaeus*	x	x
Rex sole	*Glyptocephalus zachirus*		x
Flathead sole	*Hippoglossoides elassodon*		x
Rock sole	*Lepidopsetta bilineata*	x	x
Slender sole	*Lyopsetta exilis*		x
Dover sole	*Microstomus pacificus*		x
English sole	*Parophrys vetulus*	x	x
Starry flounder	*Platichthys stellatus*	x	
C-O sole	*Pleuronichthys coenosus*	x	x
Sand sole	*Psettichthys melanostictus*	x	
Unidentified bony fish		x	

Table 6.2. The five most abundant fish species by average catch per haul (CPH) in numbers and average biomass per haul (BPH) at each nearshore sampling station during summer 1984. For additional information see Appendix Tables 6.1-6.3.

Species	Average CPH	Species	Average BPH (grams)
A. Smith Cove			
English sole (juv)	186.5	Sand sole	473.5
Striped sea perch (juv)	61.0	English sole (juv)	357.3
Staghorn sculpin	16.0	English sole	270.1
Surf smelt (juv)	3.5	Striped sea perch (juv)	211.5
Penpoint gunnel	3.5	Staghorn sculpin	184.4
B. Duwamish Head			
Shiner perch	93.0	Striped sea perch	12,627.5
English sole (juv)	89.0	Rock sole	7,376.1
Rock sole	67.0	C-O sole	2,743.0
Shiner perch (juv)	63.5	English sole	2,073.2
Striped seaperch (juv)	570.0	Shiner perch	2,041.1
C. Alki Point			
Tubesnout	103.5	Striped sea perch	20,219.5
Shiner perch (juv)	90.5	Rock sole	3,858.1
Striped sea perch (juv)	87.5	C-O sole	2,453.7
Shiner perch	81.5	Shiner perch	1,749.1
Striped sea perch	65.5	Shiner perch (juv)	1,088.7

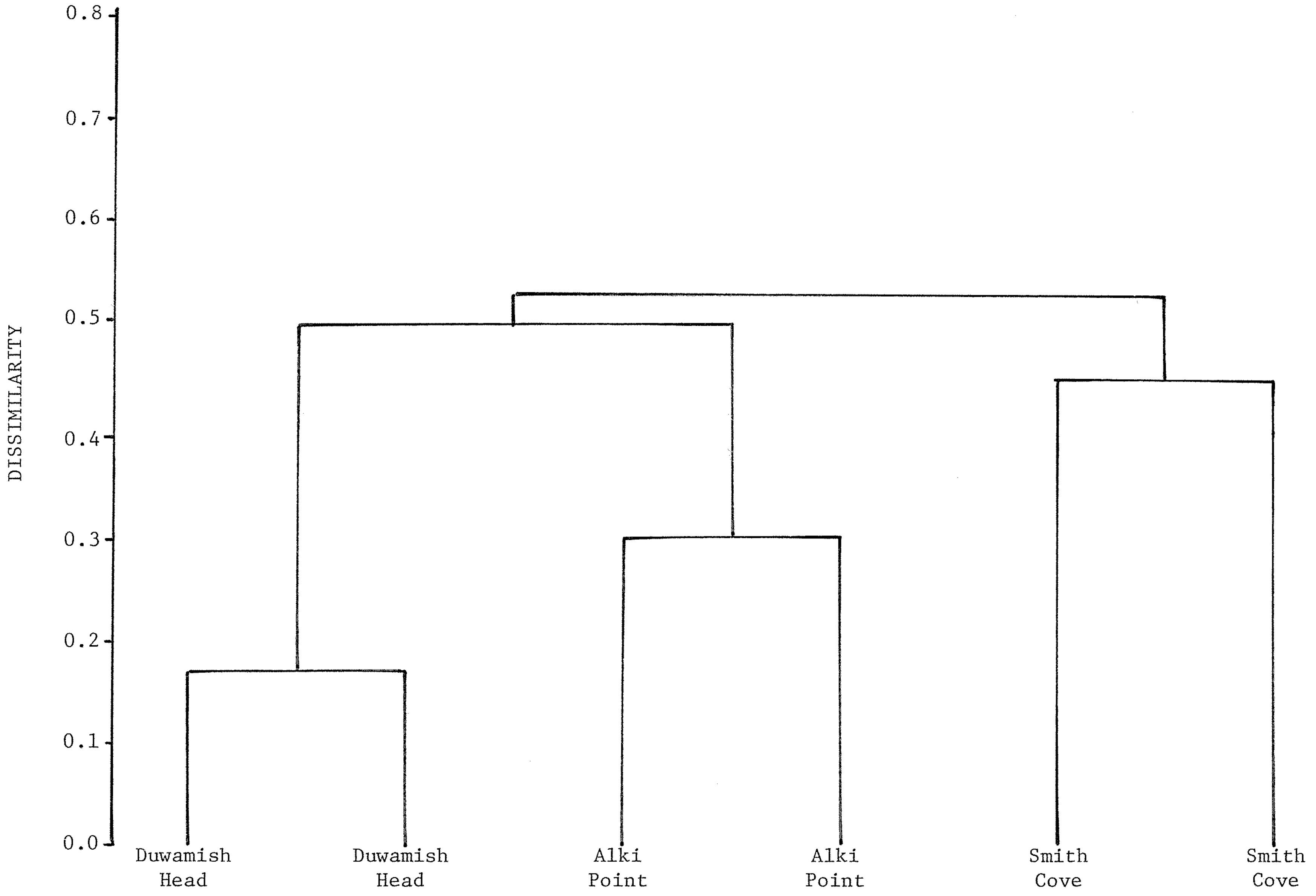

Figure 6.2. Numerical analysis of sinking beach seine sites, summer 1984.

nine different species groups with up to four subgroups appeared to inhabit the nearshore area at all sites (Table 6.3). The affinities of member species was greatest in group I and least in group IX. The members of group I: silverspotted sculpin, penpoint gunnel, crescent gunnel, staghorn sculpin, and padded sculpin were consistently found at each site and haul, but their abundance did not get as large or fluctuate as much as other species such as English sole, shiner perch or striped seaperch found in groups II and III.

Average abundance and biomass per sample. Alki Point had the largest average number of fish per haul and the largest average biomass per haul (Table 6.4). Smith Cove had the smallest of these two measures. Duwamish Head was intermediate.

6.3.1.2 Offshore Fishes

A total of 33 species of fish were collected in the offshore area during the study (Table 6.1). Nineteen species were found exclusively in the offshore samples, the other 14 species were found in both the nearshore and offshore samples. Fourteen of the 33 species were found at all three offshore sampling sites, nine species were found at two of the three sites while 10 species were found at only one of the sites.

In contrast to the nearshore sites, the offshore sites were similar at each depth based upon the five most abundant species at each station (Tables 6.5-6.9). The five most abundant species (by numbers and weight) at the 70 m inner Elliott Bay station were intermediate between the 50 m and 100 m collections at the other sites. Spiny dogfish occurred only at inner Elliott Bay and flathead sole had the largest abundance at the inner Elliott Bay site.

Location clusters. Numerical analyses of species abundance of sampling locations showed that clustering was by depth (Figure 6.3). The depth relationship was strongest at 15 m and 50 m and less strong at 100 m and 200

Table 6.3. Summer 1984 nearshore species groups.

Species Group	Member Species
Analysis of species abundance	
I	Silverspotted sculpin, penpoint gunnel, crescent gunnel, staghorn sculpin, padded sculpin
II a	Tubesnout, pile perch
II b	English sole, C-O sole
III a	Shiner perch (juv), shiner perch, striped perch (juv), English sole (juv)
III b	Striped perch, rock sole
IV	Surf smelt, Pacific tomcod (juv), Speckled sanddab, C-O sole (juv), speckled sanddab (juv)
V	Snake prickleback, starry flounder, bay pipefish, Salmon (juv), sand sole, chum salmon (juv)
VI a	Copper rockfish, rock sole (juv), stone cockscomb
VI b	Brown rockfish, Pacific cod (juv)
VI c	Snake prickleback, Pacific sanddab
VI d	Chinook salmon (juv), Pacific sandlance
VII	Whitespotted greenling, cutthroat trout, Cabezon (juv), Pacific herring
VIII	Cabezon, crescent gunnel (juv), tidepool sculpin, penpoint gunnel (juv)
IX	Tubesnout (juv), bay pipefish, Pacific staghorn sculpin

Table 6.4. Average catch per haul (CPH) in numbers and average biomass per haul (BPH) of nearshore sinking beach seines at each site during summer 1984.

Nearshore	Numbers	Weight (grams)
Duwamish Head	490.5	30,257.75
Alki Point	696.0	35,992.77
Smith Cove	309.5	2,806.35

Table 6.5. The five most abundant species by average catch per haul (CPH) in numbers and average biomass per haul (BPH) at 15 m stations during summer 1984. For additional information see Appendix Tables 6.4 - 6.5.

Species	Average CPH	Species	Average BPH (grams)
	Duwamish Head		
Rock sole	59.0	English sole	5,523.5
English sole	35.5	Rock sole	4,160.0
Speckled sanddab (juv)	10.0	Pacific sanddab	639.7
Pacific sanddab	6.5	Ratfish	378.7
Rock sole (juv)	4.5	Dover sole	180.2
	Smith Cove		
English sole	18.0	English sole	1,282.3
Speckled sanddab (juv)	5.5	Copper rockfish	384.1
Rock sole	4.0	Striped seaperch	306.7
Rock sole (juv)	4.0	Pacific sanddab	305.7
Pacific sanddab	3.5	Rock sole	227.7

Table 6.6. The five most abundant species by average catch per haul (CPH) in numbers and average biomass per haul (BPH) at 50 m stations during summer 1984. For additional information see Appendix Tables 6.6-6.7.

Species	Average CPH	Species	Average BPH (grams)
	Duwamish Head		
Rex sole	20.5	English sole	1,161.9
Dover sole	12.0	Dover sole	994.6
Slender sole	10.0	Rex sole	856.8
Blackbelly eelpout	8.5	Pacific sanddab	592.1
Pacific sanddab	7.0	Slender sole	363.0
	Smith Cove		
Walleye pollock (juv)	43.0	Dover sole	1,784.8
Dover sole	27.0	English sole	859.9
Slender sole	12.0	Slender sole	392.7
Blackbelly eelpout	9.5	Copper rockfish	369.9
Rock sole	7.0	Rock sole	345.3

Table 6.7. The five most abundant species by average catch per haul (CPH) in numbers and average biomass per haul (BPH) at 100 m stations during summer 1984. For additional information see Appendix Tables 6.8-6.9.

Species	Average CPH	Species	Average BPH (grams)
	Duwamish Head		
Ratfish	10.5	Ratfish	4,680.3
Slender sole	8.0	Pacific cod	514.4
Dover sole	2.5	Slender sole	467.1
Black eelpout	2.5	Quillback rockfish	424.4
Quillback rockfish	1.5	Dover sole	356.5
	Smith Cove		
Slender sole	8.5	Ratfish	695.5
Ratfish	5.0	Pacific cod	415.9
Dover sole	2.5	Slender sole	372.8
Ratfish (juv)	2.5	Dover sole	200.2
Blackbelly eelpout	1.5	Quillback rockfish	172.9

Table 6.8. The five most abundant species by average catch per haul (CPH) in numbers and average biomass per haul (BPH) at 200 m stations during summer 1984. For additional information see Appendix Tables 6.10-6.11.

Species	Average CPH	Species	Average BPH (grams)
	Duwamish Head		
Slender sole	8.0	Ratfish	3,990.0
Ratfish	7.5	Dover sole	1,649.1
Dover sole	4.5	Slender sole	459.7
Ratfish (juv)	4.0	Walleye pollock	203.9
Black eelpout	1.5	Ratfish (juv)	43.5
	Smith Cove		
Ratfish	21.0	Ratfish	6,147.6
Ratfish (juv)	17.0	Walleye pollock	692.0
Slender sole	2.0	Ratfish (juv)	257.0
Dover sole	1.0	Dover sole	166.8
Walleye pollock	1.0	Slender sole	90.7

Table 6.9. The five most abundant species by average catch per haul (CPH) in numbers and average biomass per haul (BPH) at the Inner Elliott Bay station (70 m) during summer 1984. For additional information see Appendix Table 6.12.

Species	Average CPH	Species	Average BPH (grams)
Slender sole	20.5	Ratfish	2,185.0
Dover sole	17.5	Spiny dogfish	1,570.0
Blackbelly eelpout	14.0	Dover sole	945.7
Flathead sole	9.0	Flathead sole	915.2
Rex sole	7.0	Pacific cod	776.5

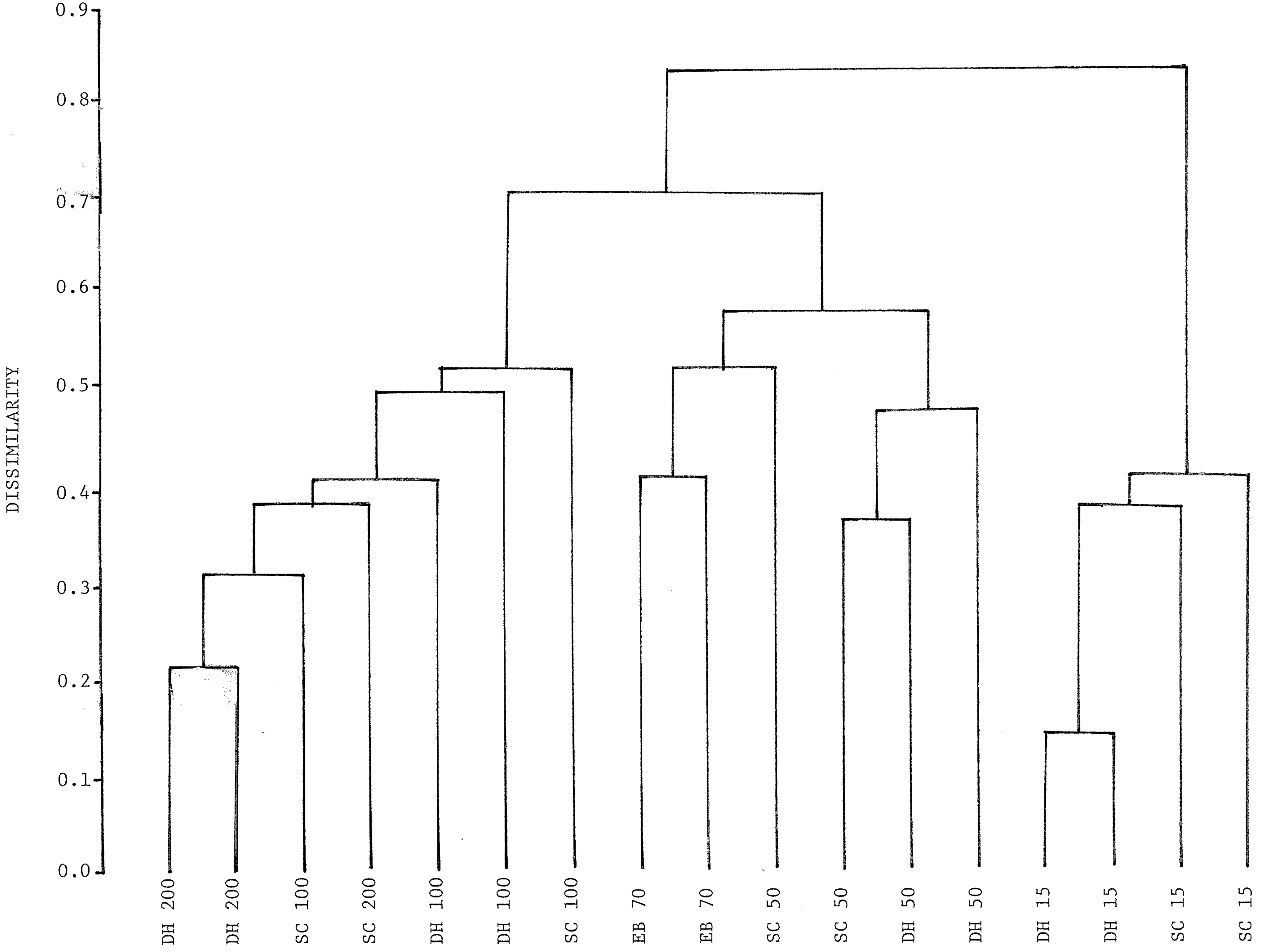

Figure 6.3. Numerical analysis of offshore sites, summer 1984. DH = Duwamish Head, SC = Smith Cove, EB = Elliott Bay and numbers are station depths.

m. There was no apparent clustering based upon sites.

Species clusters. Numerical analysis of species abundance indicated that seven different species groups with up to two subgroups inhabit the offshore areas at both sites (Table 6.10). Most groupings appeared to reflect species composition by depth. The members of group I: dogfish, Pacific cod, spinyhead sculpin, Pacific hake, rex sole (juv) and flathead sole were all found together at 70 m and all but dogfish were found at several other sites and depths. Members of group VII: speckled sanddabs (adults and juv.), rock sole (adults and juv.), Pacific sanddab, English sole and plainfin midshipman were found most often at 15 m.

Average abundance and biomass per sample. The average number of fish per sample was higher at the 15 m and 50 m depths than the 100 m and 200 m depths (Table 6.11). The inner Elliott Bay station had average numbers per haul comparable to the 15 m and 50 m depths at the other offshore sites. In terms of numbers no site appeared to be dominant over another. The average biomass per haul did not appear to show any depth stratification (Table 6.12).

6.3.1.3 Bathymetric Distribution of Four Frequently Occurring Species

Four frequently occurring species were English sole, rock sole, staghorn sculpin and ratfish. Depth distributions of these species are shown in Tables 6.13, 6.14, 6.15, and 6.16. English sole and rock sole were typically found together and ranged from the nearshore to 50 m. Staghorn sculpins were found only in nearshore while ratfish were found from 50 m to 200 m.

6.3.1.4 Species Diversity

Shannon-Weiner (H') diversity indices were computed for all nearshore and offshore stations. Species diversities ranged from 2.5 at Duwamish Head (50 m), to 0.51 at Smith Cove (200 m) (Table 6.17). In general, the largest diversity indices occurred at 50 m and 100 m stations. Other stations had

Table 6.10. Offshore demersal species clusters during summer 1984.

Species group	Member species
I a	Dogfish, Pacific cod, spinyhead sculpin
I b	Pacific hake, rex sole (juv), flathead sole
II	Pacific tomcod, bluebarred prickleback (juv)
III	Quillback rockfish, plainfin midshipman
	Slender sole (juv), blackbelly ellpout, northern ronquil
IV	Slender sole, dover sole, ratfish, ratfish (juv), rex sole
V a	Blacktip poacher, blackbelly eelpout
V b	Northern ronquil, bluebarred prickleback
VI	Brown rockfish, slim sculpin, Dover sole (juv)
VII	Speckled sanddab (juv), rock sole (juv), speckled sanddab, plainfin midshipman, rock sole, English sole, Pacific sanddab

Table 6.11. Average catch per haul in numbers of fish from offshore stations by site and depth during summer 1984.

Offshore	15 m	50 m	70 m	100 m	200 m
Duwamish/Alki	127	94.5		34.0	26.5
Smith Cove	45.5	132		25.5	43
Elliott Bay			97		

Table 6.12. Average biomass per haul in grams of fish from offshore stations by site and depth during summer 1984.

Offshore	15 m	50 m	70 m	100 m	200 m
Duwamish/Alki	11,451.5	5,144.70		7,269.05	6,334.8
Smith Cove	3,773.1	4,989.2		2,104.6	7,388.4
Elliott Bay			9,220.05		

Table 6.13. Bathymetric distribution of ratfish by depth and location (average catch per haul) during summer 1984.

	Smith Cove	Duwamish Head	Alki Point	Inner Elliott Bay
N.S.	0.0	0.0	0.0	
15 m	0.0	0.5		
50 m	0.0	4.0		
70 m				6.0
100 m	5.0	10.5		
200 m	17.0	7.5		

Table 6.14. Bathymetric distribution of staghorn sculpin by depth and location (average catch per haul) during summer 1984.

	Smith Cove	Duwamish Head	Alki Point	Inner Elliott Bay
N.S	16.0	6.0	10.0	
15 m	0.0	0.0		
50 m	0.0	0.0		
70 m				0.0
100 m	0.0	0.0		
200 m	0.0	0.0		

Table 6.15. Bathymetric distribution of English sole by depth and location (average catch per haul) during summer 1984.

	Smith Cove	Duwamish Head	Alki Point	Inner Elliott Bay
N.S.	1.5	16.0	7.5	
15 m	18.0	17.5		
50 m	4.5	7.0		
70 m				0.0
100 m	0.0	1.0		
200 m	0.0	0.0		

Table 6.16. Bathymetric distribution of rock sole by depth and location (average catch per haul) during summer 1984.

	Smith Cove	Duwamish Head	Alki Point	Inner Elliott Bay
N.S.	1.5	67.0	26.5	
15 m	5.5	59.0		
50 m	7.0	6.5		
70 m				0.0
100 m	0.0	0.0		
200 m	0.0	0.0		

Table 6.17. Shannon-Weiner species diversities during summer 1984.

	Smith Cove	Duwamish Head	Alki Point	Inner Elliott Bay
N.S.	1.39	1.85	2.37	
15 m	1.85	0.74		
50 m	2.07	2.50		
70 m				2.19
100 m	1.73	2.10		
200 m	0.51*	1.34		

*only one sample taken

Table 6.18. Species richness during summer 1984.

	Smith Cove	Duwamish Head	Alki Point	Inner Elliott Bay
N.S.	25	17	30	
15 m	12	9		
50 m	18	19		
70 m				19
100 m	10	16		
200 m	5*	6		

*only one sample taken

lower diversity indices except nearshore at Alki Point (2.37).

6.3.1.5 Species Richness

Species richness (number of species) was tabulated for all nearshore and offshore stations. Species richness ranged from 30 at Alki Point (nearshore), to 5 at Smith Cove (200 m) (Table 6.18). In general, species richness was highest at nearshore stations, intermediate at 50 m, 70 m and 100 m stations and lowest at 15 m and 200 m stations.

6.3.1.6 Flatfish Health

Philometra infections. Eleven species of flatfish were caught during the study; only three species, English sole, rock sole and speckled sanddab were found to be infected with Philometra. English sole total incidence of infection was 52%, rock sole 38%, and speckled sanddab 5% (Table 6.19). Philometra infestation rates were higher in the offshore than the nearshore samples, 54% vs. 16% for English sole and 61% vs. 21% for rock sole (Table 6.20). There was also a slightly greater incidence of Philometra in the rock sole compared to the English sole in both the nearshore and offshore samples.

Flatfish skin tumors. Only one skin tumor was found, an AEN on an adult English sole. This individual was caught in the nearshore at Alki Point.

Flatfish fin erosion. The incidence of fin erosion was low (Table 6.21). Fin erosion was found on English sole, rock sole, slender sole, Dover sole, starry flounder and Pacific sanddab. The incidence of fin erosion ranged from 1% (rock sole) to 14% (starry flounder). There were no apparent differences between sites.

6.3.2 Environmental Data Collection

Seawater temperature, salinity, dissolved oxygen and light penetration were measured at fish sampling stations where appropriate. Seawater temperature was highest at nearshore stations and lower at offshore stations

Table 6.19. Percent occurrence (% occur) of Philometra in adult flatfish (N = sample size) from nearshore and offshore catches during summer 1984.

	English sole		Rock sole		Speckled sanddab	
	% occur	N	% occur	N	% occur	N
Smith Cove	47	47	21	28	0	4
Duwamish Head	61	84	45	262	0	26
Alki Point	19	16	15	53	50	4
Inner Elliott Bay	0	0	0	0	0	0
Total	52	147	38	343	5	34

Table 6.20. Percent occurrence (% occur) of bloodworm *Philometra* in adult flatfish (N = sample size) during summer 1984.

Nearshore

	English sole		Rock sole	
	% occur	N	% occur	N
Smith Cove	0	3	33	3
Duwamish Head	17	30	23	131
Alki Point	19	16	15	53
Total	16	49	21	187

Offshore

	English sole		Rock sole	
	% occur	N	% occur	N
Smith Cove	50	44	24	25
Duwamish Head	56	84	68	131
Inner Elliott Bay	0	0	0	0
Total	54	128	61	156

Table 6.21. Percent occurrence (% occur) of fin erosion of adult flatfish (N = sample size) from nearshore and offshore catches during summer 1984.

	English sole		Rock sole		Dover sole		Rex sole		Pacific sanddab		Starry flounder	
	% occur	N	% occur	N	% occur	N	% occur	N	% occur	N	% occur	N
Smith Cove	2	47	0	28	0	60	0	11	0	8	17	6
Duwamish Head	7	84	1	262	11	45	0	38	3	36	0	0
Alki Point	0	16	0	53	0	0	0	0	0	13	0	1
Inner Elliott Bay	0	0	0	0	3	35	13	14	0	0	0	0
Total	5	147	1	343	4	140	3	63	2	57	14	7

(Table 6.22). Seawater temperatures at offshore stations showed only minor variation. Light penetration (surface measurement at offshore stations only) was about 4.0 m, except for the 100 m station at Duwamish Head which had a reading of 6.0 m (Table 6.22). Dissolved oxygen (D.O.) levels were generally highest at nearshore stations and surface waters; the D.O. levels decreased with depth to about 70 m where they appeared to remain the same with increased depths (Table 6.22). Salinity was generally the reverse of temperature and D.O. in that the offshore stations at depth had the highest values, while the nearshore stations the lowest values (Table 6.22).

6.4 Discussion and Summary

6.4.1 Fish Populations

6.4.1.1 Nearshore Fishes

The results of the numerical analyses of location clusters as well as species diversity, species richness, average abundance and biomass all indicated that the sample sites in Elliott Bay were different from one another. The number of samples at each site was limited (2 hauls), thus all sites were lumped together for the numerical analysis of species. The species found in this study were similar to those found during the Seahurst study (Stober and Chew 1984); however, the composition of the species clusters differed. The different composition of the species groups found in this study compared to those found during the Seahurst study may have been related to the habitat differences between sample sites of the present study, while the habitats of the Seahurst study sampling sites were all similar.

Alki Point was sampled because of its extensive eelgrass bed, lacking at the other sites. Borton (1982) showed that more fish and fish species inhabit eelgrass areas than exposed sand bottom. The high values of species diversity, species richness, and average abundance and biomass were expected

Table 6.22. Water temperature (°C), dissolved oxygen (mg-at/l), and salinity (ppt) for each site and depth and surface light penetration (m) for each site during summer 1984.

Location	Temperature (°C)	Visibility (secchi)	Dissolved oxygen (mg-at/l)	Salinity (ppt)
Inner Elliott Bay				
70 m	11.18	4.25 m	0.450	29.838
Smith Cove†				
Nearshore	15.0	*	0.776	26.86
200 m	*	4.0 m	0.438	30.15
Duwamish Head				
Nearshore	14.0	*	0.734	27.06
15 m	11.9	4.0 m	0.605	29.14
50 m	12.5	4.0 m	0.576	29.04
100 m	11.0	6.0 m	0.457	29.18
200 m	11.0	4.5 m	0.468	29.73
Alki Point				
Nearshore	14.0	*	0.861	28.12

†Environmental data for the 15 m, 50 m, and 100 m were not collected.

*Data not collected.

at Alki Point compared to the other sites. Smith Cove had an extensive, level, shallow area extending offshore for about 60 m from the low tide line not found at the other sites. The preponderance of the catch at Smith Cove were juvenile fish. The range of values of the various measures (species diversity: 1.39-2.37, species richness 17-30) were similar to those found during the two previous summers of the Seahurst study (Chew and Stober 1984).

English sole, rock sole and staghorn sculpin were found at all sample sites. An earlier study of West Point, Alki Point and Point Pully (Miller et al. 1977) found that these same species were dominant. These authors further indicated that English sole, rock sole, and staghorn sculpins would be the most probable candidates as indicator species of future nearshore pollution related studies, and would be particularly useful in food chain investigations because of the high level carnivore position of the staghorn sculpin and the demersal nature of English sole and rock sole. These species are widespread in Puget Sound (Miller and Borton 1974) making them useful in studies of possible contamination throughout the sound.

Juvenile English sole, juvenile striped seaperch, and juvenile shiner perch were present in large numbers in the nearshore samples during the summer of 1984. These areas are important during their life history. Newly metamorphosed English sole inhabit shallow intertidal areas where they feed, migrating to deeper waters as they mature (Hart 1973). The striped seaperch and shiner perch are both viviparous inhabiting inshore areas where they give birth during summer months (Hart 1973). Juvenile fish inhabiting nearshore regions during the summer may be susceptible to any potential adversities posed by an outfall and should be monitored in future studies.

6.4.1.2 Offshore Demersal Fishes

Sampling of offshore demersal fish populations and numerical analysis indicated that sample stations were clustered on depth. The differences between the depths is explained by the different species assemblages found to occupy the different depth strata by this study and other studies (Miller et al. 1977; Wingert and Miller 1979).

All of the species that composed the species groups found at Point Pully by Wingert and Miller (1979), summer months only, were generally similar to the species that were found during the present study and the Seahurst study (Stober and Chew 1984). However, the actual species groups differed somewhat between the studies. The Seahurst study (Stober and Chew 1984) generally found fewer species groups composed of more species than either Miller and Wingert (1979) or the present study.

Species diversity, species richness, and average abundance and biomass were all generally highest at the 50 and 100 meter depths and lowest at the 15 and 200 meter depths. All of these measures were similar to those found during the summer sampling for the Seahurst study (Stober and Chew 1984). At any given depth there were no apparent significant differences between sites.

6.4.1.3 Comparison of Nearshore and Offshore Demersal Fishes

The comparison of nearshore and offshore demersal fish populations was possible through the Shannon-Wiener species diversity index and species richness. The underlying assumption was that the beach seine and otter trawl captured whatever was in the path of the gear irrespective of their efficiencies. The two gear types were generally comparable through the two measures because the two measures are independent of absolute abundance of the catch. The results show that species diversity was generally highest at 50 to 100 meters while species richness was generally highest in the nearshore area. The nearshore populations were generally dominated by an abundance of a few species even though the total number of species was greater than the offshore stations. The abundance of each species at offshore stations tended to be more uniform, without large abundances of a few species, than the nearshore stations. These results were similar to those of the Seahurst study (Stober and Chew 1984).

Many of the same species were caught at both the nearshore and offshore stations. Two examples were English sole and rock sole and both were abundant members of nearshore and offshore fish assemblages, although at different life history stages. The nearshore and offshore areas clearly are ecologically related and both must be studied to obtain as complete a picture as possible of the entire fish assemblage at any site.

6.4.1.4 Flatfish Health

In the METRO Seahurst study (Stober and Chew 1984), there was a significant east-west difference for the English sole with the western sites having a higher incidence of infection. This present study revealed a nearshore-offshore differences for English sole and rock sole with the offshore populations having a higher occurrence. Why a preponderance of infected fish would be present in the offshore areas is unknown. When the nearshore and offshore incidences combined, there was a higher incidence of *Philometra* in English sole and rock sole at Duwamish head and Smith Cove during the summer of 1984 than there was in a similar study done during the summer of 1975 at Alki Point and West Point (Miller et al. 1977). Since Duwamish Head and Smith Cove are between Alki Point and West Point, it would seem that the incidences should be similar. The reasons for the differences are unknown and would require further study.

The overall incidences of infection generally agree with those found earlier by Amish (1976) and Stober and Chew (1984) for summertime. However, the nearshore offshore differences found in this study were not seen before.

English sole and rock sole are known to undergo annual onshore-offshore migration (Alverson et al. 1964; McCracken 1962 and SCCWRP 1973). One possible cause of this variation might be related to the seasonal migrations of English sole and rock sole.

Skin tumor and fin erosion incidences were both low. However, a single season of sampling for such diseases is known to be inadequate (e.g., see Angel et al. 1975). The tumors are usually first noticed on young of the year in September (Miller et al. 1977) and by the following summer the individuals that contracted the disease are usually dead or otherwise unavailable. Thus summer is a poor time to enumerate tumor incidence.

6.4.2 Summary

Because of an unanticipated and abrupt ending of the Duwamish Head study, it was only possible to analyze the fisheries data for general relationships. Much of the detailed analyses originally intended could not be accomplished due to time and financial constraints; however, the data were given to METRO and a copy retained. The general summary and conclusions are as follows:

1. Based on measures of fish abundance and biomass, species diversity, species richness and numerical analyses, the nearshore sample sites at Alki Point, Duwamish Head and Smith Cove were dissimilar.
2. Based on measures of fish abundance and biomass, species diversity, species richness and numerical analyses the offshore sites at Duwamish Head, Smith Cove and inner and outer Elliott Bay were similar at each sample depth.
3. The summer incidence of <u>Philometra</u> was high. Summer sampling only is not adequate for reliable estimates of skin tumors and fin erosion incidence.
4. Species composition for the Duwamish Head study was similar to that found during the Seahurst study.

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Appendix Table 6.1. Smith Cove Sinking Beach Seine, Summer 1984

		numbers		weight	
Species	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Penpoint gunnel	0	3.5	2.12	76.8	46.53
Shiner perch	8	3	1.41	40.7	12.30
Shiner perch	7	3	4.24	29.7	42.00
Rock sole	8	1.5	2.12	133.1	188.23
Rock sole	7	0.5	0.71	7.8	11.03
Starry flounder	8	1.5	2.12	71.5	101.12
C-O sole	8	0.5	0.71	125	176.78
C-O sole	7	0.5	0.71	3.6	5.09
Silverspotted sculpin	0	3	2.83	6.45	5.87
Buffalo sculpin	0	0.5	0.71	23.8	33.66
Staghorn sculpin	0	16	16.97	184.35	74.46
Padded sculpin	0	3.5	0.71	7.5	2.12
Snake prickleback	0	1	1.41	35.15	49.71
Pipefish	0	3	2.83	6.1	5.80
Tubesnout	0	0.5	0.71	0.15	0.21
Striped perch	8	1.5	2.12	373	527.50
Striped perch	7	61	48.08	211.55	173.88
English sole	8	1.5	2.12	270.05	381.71
English sole	7	186.5	86.97	357.3	217.65
Saddleback gunnel	0	1	1.41	5.45	7.91
Crescent gunnel	0	3	1.41	37.15	21.71
Pacific tomcod	7	0.5	0.71	0.5	0.71
Chum salmon	7	2	2.83	10.05	14.21
Chinook salmon	7	1.5	2.12	39	55.15
Salmonid spp.	7	2.5	3.54	28	39.60
Sand sole	8	1.0	1.41	487.0	688.72
Sp. sanddab	8	0.5	0.71	22	31.11
Pacific sanddab	8	0.5	0.71	17	24.04
Pacific herring	0	0.5	0.71	16	22.63
Surf smelt	7	3.5	4.95	0.6	0.85
Red rock crab	0	1.0	1.41	180.0	254.56

Appendix Table 6.2. Duwamish Head Sinking Beach Seine,
Summer 1984

Species	LH	numbers $\overline{X}$	numbers S.D.	weight $\overline{X}$	weight S.D.
Striped perch	8	37	7.07	12627.5	1263.60
Striped perch	7	57	45.05	232.4	202.37
Shiner perch	8	93	36.77	2041.05	809.71
Shiner perch	7	63.5	2.12	710.25	19.02
Pile perch	8	4.5	4.95	547.75	427.45
English sole	8	16	12.73	2073.2	1754.19
English sole	7	89	26.87	222.0	107.34
Rock sole	8	67	2.83	7376.05	1501.82
C-O sole	8	13	0	2743.0	24.04
C-O sole	7	2.5	2.12	25.15	12.80
Speckled sanddab	8	6.5	3.54	239.9	111.72
Speckled sanddab	7	12	9.90	177.25	107.83
Penpoint gunnel	0	3.5	3.54	188.40	230.23
Crescent gunnel	0	2	2.83	34.95	49.43
Staghorn sculpin	0	6	1.41	853.6	21.07
Silverspotted sculpin	0	0.5	0.71	2.45	3.46
Sculpin spp.	0	0.5	0.71	1.15	1.63
Pacific tomcod	7	2	0	3.3	0.42
Tubesnout	0	6.5	6.36	2.0	1.70
Surf smelt	0	2.5	0.71	3.9	0.85
Chum salmon	7	3.5	3.54	35.3	18.81
Bony fishes	7	2	2.83	0.95	1.34
Dungeness crab	0	0.5	0.71	116	164.05

Appendix Table 6.3. Alki Point Sinking Beach Seine,
Summer 1984

		numbers		weight	
Species	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Striped perch	8	65.5	7.78	20,219.5	6,689.94
Striped perch	7	87.5	47.38	332.22	154.83
Pile perch	8	16.5	7.78	822.44	401.27
Pile perch	7	1	1.41	1.15	1.63
Shiner perch	8	81.5	16.26	1,749.13	509.72
Shiner perch	7	90.5	7.78	1,088.69	83.00
Rock sole	8	26.5	7.78	3,858.07	1,026.20
Rock sole	7	4	1.41	17.59	18.11
C-O sole	8	14	7.07	2,453.75	995.25
C-O sole	7	1.5	2.12	20.1	28.43
English sole	8	7.5	3.54	934.29	838.32
English sole	7	8	9.90	35.65	46.60
Pacific sanddab	8	6.5	6.36	278.07	291.24
Pacific sanddab	7	0.5	0.71	9.3	13.15
Sp. sanddab	8	2	2.83	87.0	123.04
Sp. sanddab	7	1.5	2.12	16.95	23.97
Snake prickleback	0	22.5	13.45	697.63	341.07
Penpoint gunnel	0	32.5	7.78	570.72	34.20
Crescent gunnel	0	15	5.66	437.75	109.96
Silverspotted sculpin	0	34.5	16.26	109.09	40.32
Staghorn sculpin	0	10	12.73	132.55	62.30
Padded sculpin	0	5	7.07	16.35	23.12
Cabezon	0	1	0	551.2	776.12
Copper rockfish	0	3.5	0.71	153.95	65.12
Brown rockfish	0	3	1.41	110.95	134.00
Quillback rockfish	0	3	1.41	36.54	23.96
Rockfish spp.	0	6	8.49	137.55	194.53
Whitespot greenling	0	1	0	138.5	190.21
Tidepool sculpin	0	1	1.41	1.65	2.33
Pipefish	0	2.5	2.12	10.59	3.98
Tubesnout	0	103.5	86.97	36.38	11.43
Pac. sand lance	0	33.5	45.96	48.1	65.34
Pacific herring	0	0.5	0.71	0.4	0.57
Pacific cod	7	2	2.83	3.55	5.02
Cutthroat trout	0	1	0	363.35	447.81
Chinook salmon	0	8	11.31	136.6	193.18
Coho salmon	0	1.5	2.12	253.5	358.50
Starry flounder	0	0.5	0.71	41.0	57.98
Dungeness carb	0	0.5	0.71	59.0	83.44
Red rock crab	0	0.5	0.71	22.0	31.11

Appendix Table 6.4. Smith Cove 15 m trawl, Summer 1984.

		Numbers		Weight	
	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
English sole	8	18.0	8.49	2,336.10	1,282.27
Rock sole	8	5.0	2.83	218.35	164.54
Rock sole	7	3.0	2.83	21.4	12.30
Pacific sanddab	8	3.5	3.54	278.75	305.68
Speckled sanddab	8	1.5	0.71	44.95	27.08
Speckled sanddab	7	5.5	4.95	54.05	30.48
Roughback sculpin	0	2.5	2.12	12.85	8.27
Blackbelly eelpout	0	1.5	0.71	1.65	0.21
Walleye pollock	0	1.5	0.71	1.95	1.06
Copper rockfish	0	1.5	0.71	539.4	384.1
Striped seaperch	0	0.5	0.71	216.85	306.67
Dover sole	8	0.5	0.71	8.95	12.66
Quillback rockfish	0	0.5	0.71	20.05	28.35
Plainfin midshipman	0	0.5	0.71	17.8	25.17

Appendix Table 6.5. Smith Cove 50 m trawl, Summer 1984.

		Numbers		Weight	
	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Rock sole	8	7.0	0.0	345.25	36.98
English sole	8	4.5	2.12	858.9	274.64
Flathead sole	8	1.0	1.41	163.3	230.94
Rex sole	8	5.0	1.41	206.25	12.37
Rex sole	7	2.5	0.71	21.40	12.02
Slender sole	8	12.0	7.07	392.7	220.33
Slender sole	7	1.5	2.12	10.4	14.71
Dover sole	8	27.0	5.66	1,784.75	186.46
Dover sole	7	0.5	0.71	3.5	4.95
Copper rockfish	0	1.0	1.41	369.85	523.05
Quillback rockfish	0	1.0	1.41	143.0	202.23
Brown rockfish	0	1.5	0.71	61.0	21.21
Slim sculpin	0	1.5	0.71	9.35	3.89
Planfin midshipman	0	0.5	0.71	88.05	124.52
Pacific hake	0	1.5	0.71	66.15	50.42
Northern ronquil	0	7.0	1.41	67.5	56.00
Blackbelly eelpout	0	9.5	2.12	214.3	7.50
Bluebarred prickleback	0	3.50	3.54	22.5	25.17
Walleye pollock	7	43.0	8.49	140.4	47.52
Blacktip poacher	0	0.5	0.71	4.65	6.58
Ratfish	0	0.5	0.71	16.0	22.63

Appendix Table 6.6. Smith Cove 100 m trawl, Summer 1984.

		Numbers		Weight	
	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Rex sole	8	0.5	0.71	7.55	10.68
Slender sole	8	8.5	0.71	372.8	110.31
Slender sole	7	1.0	0.0	8.2	1.27
Dover sole	8	2.5	0.71	200.2	34.22
Blackbelly eelpout	0	1.50	0.00	43.95	3.18
Ratfish	8	5.0	5.66	695.5	925.6
Ratfish	7	2.5	2.12	80.6	86.27
Red brotula	0	1.0	0.0	19.5	13.29
Brown rockfish	0	0.5	0.71	23.3	32.95
Quillback rockfish	0	1.0	1.41	172.85	244.45
Walleye pollock	7	1.0	1.41	63.5	89.8
Pacific cod	8	0.5	0.71	415.85	588.10

Appendix Table 6.7. Smith Cove 200 m trawl, Summer 1984. (One trawl only)

		Numbers		Weight	
	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Ratfish	8	17	-	6,174.6	-
Ratfish	7	21	-	257.0	-
Dover sole	8	1	-	166.8	-
Slender sole	8	2	-	90.7	-
Pallid eelpout	0	1	-	7.3	-
Walleye pollock	8	1	-	692.0	-

Appendix Table 6.8. Duwamish Head 15 m trawl, Summer 1984.

		Numbers		Weight	
	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Dover sole	8	2	0.0	180.18	35.64
English sole	8	35.5	2.12	5,523.7	945.12
Rock sole	8	59.0	25.46	4,160.0	1,202.08
Rock sole	7	4.5	0.71	77.5	14.28
Pacific sanddab	8	6.5	3.54	639.65	176.85
Speckled sanddab	8	4.0	1.41	107.45	35.43
Speckled sanddab	7	10.0	1.41	106.0	12.45
C-O sole	8	0.5	0.71	86.65	122.54
Roughback sculpin	0	0.5	0.71	1.95	2.75
Plainfin midshipman	0	3.5	0.71	150.6	51.48
Ratfish	8	0.5	0.71	378.7	548.29

Appendix Table 6.9. Duwamish Head 50 m trawl, Summer 1984.

		Numbers		Weight	
	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Copper rockfish	0	1.0	0.0	218.55	69.93
Rex sole	8	20.5	3.54	856.75	155.92
Dover sole	8	12.0	2.83	994.55	142.20
Dover sole	7	1.0	1.41	8.50	12.02
Slender sole	8	10.0	5.66	363.0	176.21
Slender sole	7	1.0	1.41	6.8	9.62
English sole	8	6.0	0.0	1,161.9	64.06
Pacific sanddab	8	7.0	5.66	592.02	534.22
Rock sole	8	6.5	4.95	383.25	423.20
Shiner perch	8	0.5	0.71	11.10	15.70
Quillback rockfish	0	1.5	0.71	68.8	12.45
Plainfin midshipman	0	0.5	0.71	27.75	39.24
Ratfish	8	4.0	2.83	241.65	121.69
Blackbelly eelpout	0	8.5	6.36	83.9	20.36
Roughback sculpin	0	1.5	2.12	17.3	24.47
Blacktip poacher	0	4.5	0.71	36.45	10.39
Pacific tomcod	0	3.0	4.24	12.40	17.54
Northern ronquil	0	1.5	2.12	38.80	54.87
Bluebarred prickleback	0	0.5	0.71	2.60	3.68
Slim sculpin	0	1.0	1.41	4.65	6.58
Walleye pollock	8	0.5	0.71	9.75	13.79
Walleye pollock	7	2.0	2.83	4.20	5.94

Appendix Table 6.10. Duwamish Head 100 m trawl, Summer 1984.

		Numbers		Weight	
	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Ratfish	8	10.50	6.36	4,680.3	2,772.28
Ratfish	7	1.0	0.0	15.9	0.14
Quillback rockfish	0	1.5	0.71	424.35	247.84
Pacific cod	8	0.5	0.71	514.35	727.40
Walleye pollock	8	0.5	0.71	104.75	148.14
Pacific hake	8	0.5	0.71	180.05	254.63
Copper rockfish	0	0.5	0.71	189.0	267.29
Dover sole	8	2.5	2.12	356.45	416.56
Slender sole	8	8.0	0.0	467.05	169.49
English sole	8	1.0	0.0	64.2	21.92
Rex sole	8	1.0	0.0	92.1	23.76
Rex sole	7	0.5	0.71	3.35	4.74
Slim sculpin	0	0.5	0.71	1.90	2.69
Red brotula	0	0.5	0.71	77.0	108.89
Blackbelly eelpout	0	1.5	2.12	53.05	75.02
Black eelpout	0	2.5	3.54	30.35	42.92
Roughback sculpin	0	0.5	0.71	8.9	12.59
Bluespotted poacher	0	0.5	0.71	6.0	8.49

Appendix Table 6.11. Duwamish Head 200 m trawl, Summer 1984.

		Numbers		Weight	
	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Ratfish	8	7.5	0.71	3,990.0	1,852.62
Ratfish	7	4.0	1.41	43.45	23.83
Dover sole	8	4.5	0.71	1,649.10	197.71
Slender sole	8	8.0	1.41	459.65	68.24
Rex sole	8	0.5	0.71	5.95	8.41
Blackfin eelpout	0	1.5	2.12	2.80	3.96
Walleye pollock	8	0.5	0.71	203.85	288.29

Appendix Table 6.12. Inner Elliott Bay 70 m trawl, Summer 1984.

		Numbers		Weight	
	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Ratfish	8	6.0	7.07	2,185.0	1,675.84
Spiny dogfish	8	1.5	0.71	1,570.0	480.83
Dover sole	8	17.5	6.36	950.15	52.68
Slender sole	8	20.5	0.71	544.35	87.19
Slender sole	7	1.0	0.41	12.7	17.96
Rex sole	8	7.0	1.41	143.3	25.6
Rex sole	7	4.0	2.83	23.4	16.83
Flathead sole	8	9.0	2.83	915.15	445.27
Blackbelly eelpout	0	14.0	8.49	356.55	60.46
Bluebarred prickleback	0	4.5	0.71	19.6	4.38
Northern ronquil	0	0.5	0.71	4.35	6.15
Blacktip poacher	0	1.5	0.71	4.8	2.12
Spinyhead sculpin	0	1.0	0.0	1.4	0.42
Padded sculpin	0	0.5	0.71	2.1	2.97
Copper rockfish	0	1.0	1.41	478.5	676.7
Pacific cod	0	1.0	0.0	776.45	355.6
Walleye pollock	0	0.5	0.71	54.5	77.07
Quillback rockfish	0	1.0	1.41	187.1	264.6
Pacific hake	0	3.5	3.54	916.85	796.98
Pacific tomcod	0	1.0	1.41	2.15	3.04
Plainfin midshipman	0	0.5	0.71	71.65	101.33

Appendix Table 6.13. Smith Cove Floating Beach Seine, Summer 1984

		numbers		weight	
Species	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
C-O sole	8	3	4.24	780.0	1103.09
C-O sole	7	0.5	0.71	7.55	10.68
Starry flounder	8	3.5	0.71	304.6	229.10
Starry flounder	7	0.5	0.71	0.6	0.85
Sand sole	8	1	1.41	478.5	676.70
Rock sole	8	8.5	4.95	889.6	771.31
English sole	8	3	2.83	250.65	328.17
English sole	7	215	46.67	426.35	108.12
Shiner perch	8	17.5	4.95	340.41	80.47
Shiner perch	7	9	4.24	114.25	25.24
Striped perch	8	0.5	0.71	23.5	33.23
Striped perch	7	17.5	9.19	56.3	16.69
Staghorn sculpin	0	12.5	2.12	145.35	146.44
Silverspotted sculpin	0	3	0	8.5	2.12
Padded sculpin	0	2	1.41	3.65	3.46
Pipefish	0	3.5	2.12	5.9	2.83
Snake Prickleback	0	6.5	4.95	158.6	170.41
Crescent gunnel	0	5.5	4.95	92.95	96.09
Penpoint gunnel	0	3.5	0.71	49.25	22.98
Pacific herring	7	0.5	0.71	0.45	0.64
Pacific tomcod	7	0.5	0.71	0.95	1.34
Chum salmon	7	4	0	36.05	6.58
Salmonid spp.	7	1	1.41	26.5	37.48
Surf smelt	7	6.5	7.78	1.45	1.77

Appendix Table 6.14. Duwamish Head Floating Beach Seine,
Summer 1984

		numbers		weight	
Species	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Striped perch	8	7.5	2.12	1405	148.49
Striped perch	7	9	0	37.95	1.34
Shiner perch	8	191	130.12	3590.0	2489.02
Shiner perch	7	94.5	34.65	1142.5	449.01
Pile perch	8	3	0	370.4	400.51
English sole	7	73.5	40.31	123.65	45.47
Rock sole	8	1.5	0.71	105.3	49.92
Speckled sanddab	7	1.5	0.71	19.3	16.69
Penpoint gunnel	0	0.5	0.71	15.2	21.50
Staghorn sculpin	0	0.5	0.71	2.55	3.61
Tubesnout	0	1	1.41	0.3	0.42
Pipefish	0	1	1.41	1.85	2.62
Pacific tomcod	7	0.5	0.71	0.75	1.06
Pacific herring	8	0.5	0.71	30.7	43.42
Surf smelt	0	1	1.41	0.35	0.49
Chum salmon	7	15	19.80	154.6	208.74
Chinook salmon	7	1.5	2.12	126.65	179.11

Appendix Table 6.15. Alki Point Floating Beach Seine
Summer 1984

		numbers		weight	
Species	LH	$\overline{X}$	S.D.	$\overline{X}$	S.D.
Striped perch	8	13.5	2.12	4695	1138.44
Striped perch	7	11.5	6.36	46.45	22.57
Pile perch	8	2	2.83	128.35	181.51
Shiner perch	8	27.5	10.61	596	187.24
Shiner perch	7	30.5	17.68	363.15	225.50
Snake Prickleback	0	4	2.83	139.85	95.39
Penpoint gunnel	0	13	4.24	75.6	14.99
Crescent gunnel	0	3.5	3.54	72.0	52.18
Saddleback gunnel	0	0.5	0.71	6.3	8.91
Pacific sanddab	8	2.5	0.71	117.65	3.89
Pacific sanddab	7	1	0	13.25	0.92
Rock sole	8	4	4.25	505.5	642.76
English sole	8	2	2.83	72.0	101.82
English sole	7	47.5	30.41	183.5	98.15
C-O sole	7	0.5	0.71	8.2	11.60
Silverspotted sculpin	0	5	1.41	15.45	3.04
Padded sculpin	0	3	0	7.85	1.91
Staghorn sculpin	0	3.5	3.54	54.25	7.57
Quillback rockfish	0	1	1.41	24.85	35.14
Brown rockfish	0	0.5	0.71	5.3	7.49
Pacific sand lance	0	7	9.90	9.75	13.79
Tubesnout	0	1.5	0.71	2.3	2.97
Pipefish	0	0.5	0.71	0.85	1.20
Chinook salmon	7	5	2.83	619.15	411.32
Pacific herring	7	0.5	0.71	6.95	9.83
Pacific cod	7	0.5	0.71	1.40	1.99

7.0 FISH HEALTH

Marsha L. Landolt

7.1 Introduction

The purpose of this study was to assemble predischarge information on pathological conditions existing in demersal and pelagic fishes inhabiting the area surrounding a proposed sewage outfall near Duwamish Head in outer Elliott Bay. Assessment of predischarge conditions was designed to provide an opportunity to determine whether post-discharge alterations might be attributable to changes in environmental quality in the receiving waters.

7.2 Study Area

Duwamish Head

Demersal Fish Studies

Demersal fish were collected near Duwamish Head on July 31, 1984. Collections were made at station depths of 50 m and 200 m.

Pelagic Fish Studies

Pelagic fish were collected by beach seine at Alki Point on July 10, 1984.

Magnolia Bluff

Demersal Fish Studies

Demersal fish were collected near Magnolia Bluff on July 31, 1984. Collections were made of station depths of 50 m and 200 m.

Pelagic Fish Studies

Pelagic fish were collected by beach seine on July 12, 1984.

7.3 Materials and Methods

7.3.1 Fish Collection

7.3.1.1 Demersal Fish Studies

Demersal fish were collected by otter trawl (24 ft.) aboard the research vessel Kittiwake (38 ft. L.O.A.). Trawling times were 20 minutes at the 50 and 100 meter stations, and 40 minutes at the 200 meter stations. The fish were brought on board the vessel, the four target species were sorted into separate containers and the remaining fish were discarded following examination by personnel from the Fish Ecology task group.

7.3.1.2 Pelagic Fish Studies

Pelagic fish were collected by sinking (set 30 meters from the shore) and floating (set 60 meters from the shore) beach seines (37 meter; bag mesh 18 mm; wing mesh 29 mm). The target species were sorted into containers and the remaining fish were examined by personnel from the Fish Ecology task group.

7.3.2 Fish Species

7.3.2.1 Demersal Fish Studies

Four species of fish were chosen as target organisms for this study (Fig. 7.1). These were English sole (*Parophrys vetulus*), Dover sole (*Microstomus pacificus*), slender sole (*Lyopsetta exilis*), and quillback rockfish (*Sebastes maliger*). These species were selected because they are benthic organisms which live in contact with the bottom substrate, because they are resident in the Duwamish Head area, and because they can be collected in reasonable numbers year round. In addition, all of these species have been used by other investigators to assess possible environmentally-mediated illnesses (Mearns and Sherwood 1974; Sherwood and Mearns 1977; Miller et al. 1977; Malins et al. 1982). After trawl contents were brought on board, the target species were sorted into separate containers, assigned an accession number, weighed (total

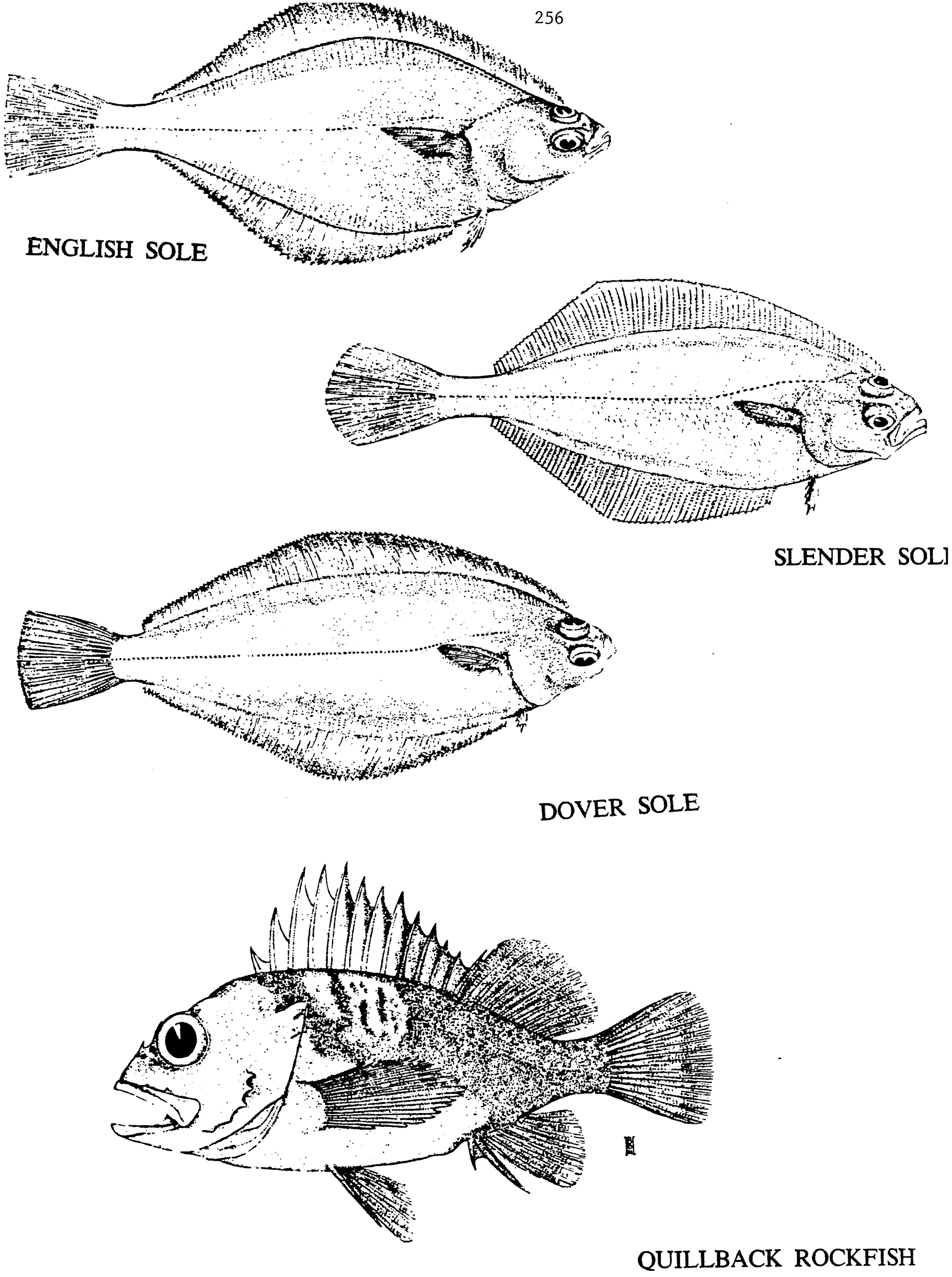


Figure 7.1. Target species used in the demersal fish health studies.

weight in grams), measured (total length in mm), bled and sacrificed by a blow to the head.

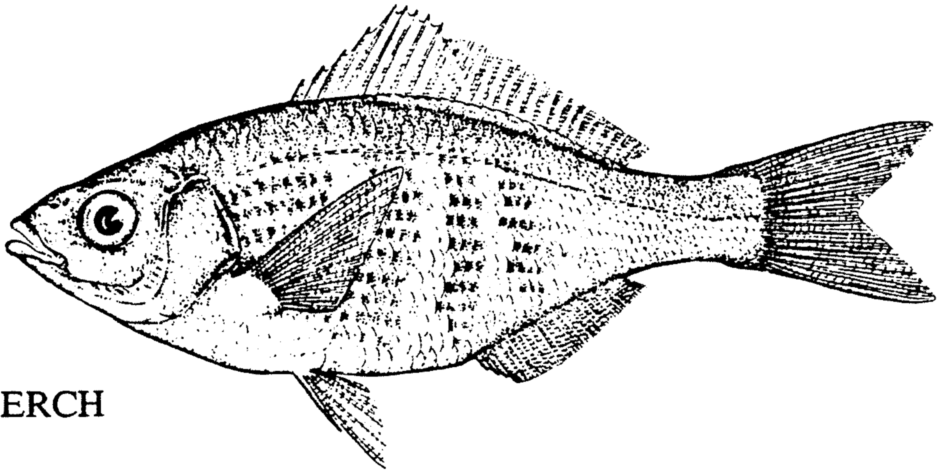
7.3.2.2 Pelagic Fish Studies

Two species of fish were chosen as target species for this portion (Figure 7.2). These were striped sea perch (*Embiotoca lateralis*) and shiner perch (*Cymatogaster aggregata*). Unlike the demersal target species which were selected in part because comparable data were available from other studies of environmentally mediated disease, these two species have not been commonly used by investigators. Previous studies have focused little attention on nearshore pelagic fish and these species were selected for use in the current study primarily on the basis of their abundance and reliable presence in the area throughout the year. In addition, true cod (*Gadus macrocephalus*), tomcod (*Microgadus proximus*), walleye pollock (*Theragra chalcogramma*), steelhead trout (*Salmo gairdneri*), and chum salmon (*Oncorhynchus keta*) were collected when present. The target organisms were assigned an accession number, weighed (total weight in grams), measured (total length in mm) and sacrificed by a blow to the head.

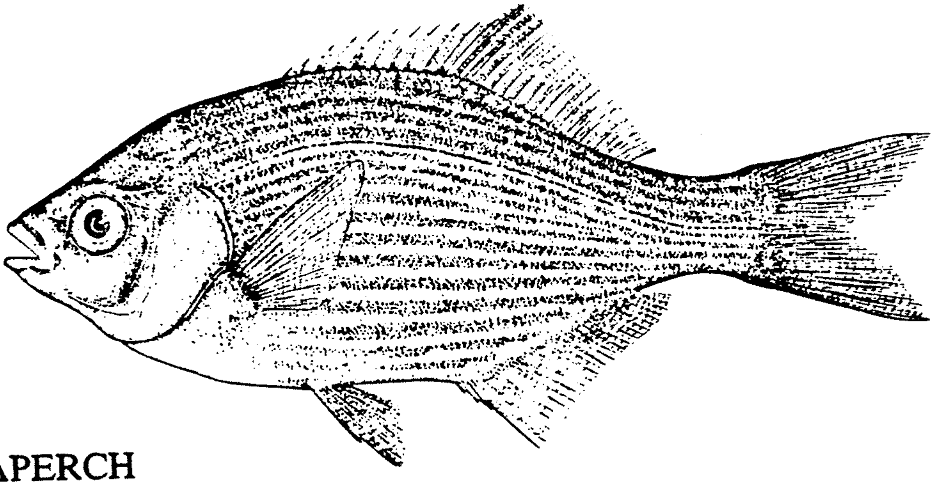
7.3.3 Tissue Collection and Processing

At necropsy demersal and pelagic fish were examined for the presence of external lesions. Upon primary incision the general condition of the internal organs was noted and any unusual structures or lesions were collected.

Five target organs (liver, kidney, spleen, gills, gonad) were routinely excised and placed in 10% neutral buffered formalin. These organs were chosen for several reasons. The liver is a major organ which is involved in a wide variety of physiological activities. In fish this organ has been shown to be extremely sensitive to the effects of contaminants (Sinnhuber et al. 1977). The kidney and spleen are important blood filtering organs which are involved,



SHINER PERCH



STRIPED SEAPERCH

Figure 7.2. Target species used in the pelagic fish health studies.

at different times, in hematopoiesis. The kidney, because of its excretory function, is a frequent site of absorption, excretion and retention of contaminants, and its epithelia and glomeruli are very sensitive to injury. The gill is a large, delicate organ whose tremendous surface area is exposed to the marine environment. It is essentially unprotected and subject to environmental damage. Finally, the gonad is a lipid rich organ which can act as a sump for lipid soluble contaminants. Examination of this organ permits evaluation of reproductive status and may, in addition, show injury from the presence of certain toxic compounds. After allowing sufficient time for fixation the tissues of randomly selected fish were trimmed, cleared, embedded in paraffin, sectioned (4 um) and stained (hematoxylin and eosin). Blood smears were fixed in methanol, air dried and stained by the Leishman-Giemsa method.

7.3.4 Histopathological Evaluation

Prepared slides were examined histologically by Dr. Landolt. Using a numerical coding system, tissues were identified by organ and suborgan and were examined for the presence of lesions. Lesions were described verbally and then scored in terms of their severity and degree of host response (low of 1, high of 5) and in terms of their pattern of distribution.

7.4 Results

7.4.1 Numbers of Fish Collected

Demersal Fish Studies

During the sampling period 139 demersal fish were collected (Table 7.1). Among those collected, 73 were examined histologically (Table 7.2).

Pelagic Fish Studies

During July, 1984, 44 pelagic fish were collected (Table 7.3). Among those collected, 27 were examined histologically (Table 7.4).

Table 7.1. Number of demersal fish collected during the Duwamish Head fish health study.

Species	Number of Fish Duwamish Head	 Magnolia Bluff
English Sole	21	7
Dover Sole	24	24
Slender Sole	24	24
Quillback Rockfish	8	7
Total	77	62

Table 7.2. Number of demersal fish examined histologically during the Duwamish Head fish health study.

Species	Number of Fish Duwamish Head	 Magnolia Bluff
English Sole	16	7
Dover Sole	10	10
Slender Sole	10	10
Quillback Rockfish	5	5
Total	41	32

Table 7.3. Number of pelagic fish collected during the Duwamish Head fish health study.

Species	Number of Fish Duwamish Head	 Magnolia Bluff
Shiner perch	10	10
Striped sea perch	10	1
Chum salmon	6	7
Total	26	18

Table 7.4. Number of pelagic fish examined histologically during the Duwamish Head fish health study.

Species	Number of Fish Duwamish Head	 Magnolia Bluff
Shiner perch	5	5
Striped sea perch	5	1
Chum salmon	5	6
Total	15	12

7.4.2 Length/Weight Data

Demersal Fish Studies

The total length (mm) and weight (g) were recorded for all demersal fish collected. Average values are summarized in Tables 7.5 and 7.6. One way analysis of variance showed that the fish from both sites were of similar length and weight.

Pelagic Fish Studies

The total length (mm) and weight (g) of pelagic fish were recorded. Average values are presented in Tables 7.7 and 7.8. One way analysis of variance showed that the fish from both sites were of similar length and weight where comparable numbers of fish were available.

7.4.3 Lesion Frequency

Demersal Fish Studies

Although a variety of tissue changes were noted most could be grouped into one of the categories presented in Tables 7.9 and 7.10. The majority of tissue changes represented either normal physiological variation (e.g., lipid storage in hepatocytes) or minor pathological processes (e.g., external protozoan parasitism). Others (e.g., necrosis) represented more serious changes that could, if severe, be life threatening.

Several degenerative, preneoplastic or neoplastic conditions that have been linked to contaminant exposure were detected in the livers of English sole at both sites. Megalocytic hepatosis, noted in one fish at each site, is a dengenerative condition in which hepatocytes and their nuclei become markedly hypertrophic and hyperchromatic. Both instances noted were of mild intensity. One English sole taken from each site had basophilic nodules in its hepotic tissue. The nodules are spherical areas of increased basophilia which contain morphologically normal hepatocytes. They are generally reported

Table 7.5. Average total length (mm) of demersal fish collected during the Duwamish Head fish health study.

Site	English Sole	Dover Sole	Slender Sole	Quillback Rockfish
Duwamish Head	257*	280	193	182
	252-375	183-448	153-223	106-285
	24	24	24	8
Magnolia Bluff	263	285	196	221
	151-313	194-505	130-275	131-288
	7	24	24	7

* The data are presented in the following order: average, range, number of fish examined.

Table 7.6. Average weight (g) of demersal fish collected during the Duwamish Head fish health study.

Site	English Sole	Dover Sole	Slender Sole	Quillback Rockfish
Duwamish Head	199*	247	59	134
	140-430	60-950	30-100	35-315
	24	24	24	8
Magnolia Bluff	180	288	54	231
	110-250	70-1450	20-85	40-400
	7	24	24	7

* The data are presented in the following order: average, range, number of fish.

Table 7.7. Average total length (mm) of pelagic fish collected during the Duwamish Head fish health study.

Site	Shiner Perch	Striped Sea Perch	Chum Salmon
Duwamish Head	13*	34	11
	10-16	27-50	9-14
	10	10	6
Magnolis Bluff	10	29	11
	9-12	-	10-16
	10	1	7

* The data are presented in the following order: average, range, number of fish.

Table 7.8. Average weight (g) of pelagic fish collected during the Duwamish Head fish health study.

Site	Shiner Perch	Striped Sea Perch	Chum Salmon
Duwamish Head	31*	570	10
	12-54	350-700	6-22
	10	10	6
Magnolia Bluff	18	470	15
	10-30	-	8-38
	10	1	7

* The data are presented in the following order: average, range, number of animals.

Table 7.9. Prevalence (mean) of significant lesions in demersal fish collected at Duwamish Head.

Organ	Pathological Condition	English Sole	Dover Sole	Slender Sole	Quillback Rockfish
Liver	Lipid deposits in hepatocytes				
	Mild	13/16*	3/10	0/10	1/5
	Moderate	1/16	1/10	1/10	2/5
	Heavy	2/16	5/10	9/10	2/5
	Mononuclear infiltrates	4/16	6/10	4/10	3/5
	Necrosis	0/16	1/10	0/10	1/5
	Pyknosis	1/16	1/10	1/10	0/5
	Magalocytic hepatosis	1/16	1/10	0/10	0/5
	Regenerative foci	1/16	0/10	0/10	0/5
	Clean cell foci	0/16	0/10	1/10	0/5
	Eosinophilic nodules	0/16	1/10	0/10	0/5
	Basophilic nodules	1/16	0/10	0/10	2/5
	Liver cell adenoma	1/16	0/10	0/10	0/5
	Nuclear pleiomorphism	0/16	0/10	0/10	0/5
Gills	Aneurysms	2/16	5/10	1/10	1/5
	Epithelial hyperplasia	0/16	0/10	0/10	0/5
	Inflammation	6/16	4/10	0/10	3/5
General	External protozoan parasites	0/16	0/10	0/10	0/5
	Internal protozoan parasites	11/16	1/10	3/10	0/5
	External metazoan parasites	7/21	0/24	0/24	2/8
	Internal metazoan parasites	4/16	0/10	6/10	0/5
	Fin erosion	1/21	1/24	2/24	0/8
	Papilloma	0/21	0/24	0/24	0/8
	Increased number of mmc	13/16	3/10	1/10	0/5
	Renal calculi	0/16	0/10	1/10	0/5
	Epitheliocystis	0/16	0/10	0/10	2/5

* Data are expressed as the number of positives out of the number of fish examined histologically or, in the case of external lesions, out of the total number of fish examined.

Table 7.10. Prevalence of significant lesions in demersal fish collected at Magnolia Bluff.

Organ	Pathological Condition	English Sole	Dover Sole	Slender Sole	Quillback Rockfish
Liver	Lipid deposits in hepatocytes				
	Mild	3/7*	1/10	2/10	0/5
	Moderate	3/7	5/10	3/10	2/5
	Heavy	1/7	4/10	4/10	3/5
	Mononuclear infiltrates	3/7	5/10	6/10	4/5
	Necrosis	1/7	0/10	0/10	0/5
	Pyknosis	0/7	1/10	0/10	0/5
	Megalocytic hepatosis	1/7	1/10	0/10	1/5
	Regenerative foci	1/7	0/10	0/10	0/5
	Clean cell foci	0/7	1/10	0/10	0/5
	Eosinophilic nodules	0/7	0/10	0/10	0/5
	Basophilic nodules	1/7	0/10	0/10	0/5
	Liver cell adenoma	0/7	0/10	0/10	0/5
	Nuclear pleiomorphism	0/7	1/10	0/10	0/5
Gills	Aneurysms	2/7	3/10	1/10	1/5
	Epithelial hyperplasia	0/7	0/10	0/10	0/5
	Inflammation	2/7	1/10	0/10	0/5
General	External protozoan parasites	1/7	0/10	0/10	0/5
	Internal protozoan parasites	2/7	1/10	0/10	1/5
	External metazoan parasites	2/7	1/24	0/24	0/7
	Internal metazoan parasites	2/7	1/10	5/10	0/5
	Fin erosion	0/7	0/24	0/24	0/7
	Papilloma	0/7	0/24	0/24	0/7
	Increased number of mmc	6/7	2/10	0/10	0/5
	Renal calculi	0/7	0/10	0/10	0/5
	Epitheliocystis	0/7	0/10	0/10	3/5

* Data are expressed as the number of positives out of the number examined histologically or, in the case of external changes, out of the total number of fish examined.

to be a preneoplastic change. Only one fish (taken from Duwamish Head) had a true neoplasm. The tumor, a liver cell adenoma, was a single spherical lesion which protruded above the capsular surface. The lesion compressed the adjacent normal parenchyma and was devoid of hepatopancreatic tissue.

Lesions morphologically similar to megalocytic hepatosis, clear cell foci, eosinophilic nodules and basophilic nodules were seen in the other target species. These lesions are indicated as questionable observations in Tables 7.9 and 7.10 because they have not been well described (or in some cases previously described) in those species.

Pelagic Fish Studies

Very few lesions were noted in pelagic fish, and most were of minor health risk (Tables 7.11 and 7.12). No neoplasms or preneoplasms were observed. Only one fish, a chum salmon from Magnolia Bluff, was seriously ill. That fish had severe hepatitis, possibly of bacterial origin.

7.5 Discussion

Pathological examination of demersal and pelagic fish from outer Elliott Bay revealed a population of animals experiencing some evidence of environmental stress. Although most fish were in good health, the finding of degenerative, pre-neoplastic and neoplastic changes similar to those described by Malins et al. (1982) is disturbing. The brevity of the study period precluded valid assessment of the prevalence of preneoplastic/neoplastic alterations in English sole because samples taken during fall or early winter usually contain a greater number of diseased individuals. Similarly it prevented further analysis of the idiopathic lesions detected in Dover sole, slender sole and quillback rockfish.

Table 7.11. Prevalence of significant lesions in pelagic fish collected at Duwamish Head.

Organ	Pathological Condition	Shiner Perch	Striped Sea Perch	Chum Salmon
Liver	Lipid deposits in hepatocytes			
	Mild	2/5*	2/5	4/5
	Moderate	3/5	1/5	1/5
	Heavy	0/5	2/5	0/5
	Mononuclear infiltrates	1/5	0/5	0/5
	Necrosis	0/5	0/5	1/5
Gills	Aneurysms	4/5	1/5	0/5
	Epithelial hyperplasia	0/5	0/5	0/5
	Inflammation	0/5	3/5	2/5
General	External protozoan parasites	0/5	0/5	0/5
	Internal protozoan parasites	0/5	0/5	0/5
	Internal metazoan parasites	0/5	0/5	0/5
	Renal calculi	0/5	0/5	0/5
	Neoplasia	0/5	0/5	0/5
	Increased number of mmc	2/5	1/5	0/5

* Data are expressed as the number of positives out of the number examined.

Table 7.12. Prevalence of significant lesions in pelagic fish collected at Magnolia Bluff.

Organ	Pathological Condition	Shiner Perch	Striped Sea Perch	Chum Salmon
Liver	Lipid deposits in hepatocytes			
	Mild	1/5	1/1	6/6
	Moderate	2/5	0/1	0/6
	Heavy	1/5	0/1	0/6
	Mononuclear infiltrates	0/5	0/1	1/6
	Necrosis	0/5	0/1	1/6
Gills	Aneurysms	2/5	0/1	3/6
	Epithelial hyperplasia	0/5	0/1	0/6
	Inflammation	1/5	0/1	1/6
General	External protozoan parasites	0/5	0/1	0/6
	Internal protozoan parasites	0/5	0/1	0/6
	Internal metazoan parasites	0/5	0/1	0/6
	Renal calculi	0/5	0/1	0/6
	Neoplasia	0/5	0/1	0/6
	Increased number of mmc	0/5	1/1	0/6
	Epitheliocystis	2/5	0/1	0/6

* Data are expressed as the number of positives out of the number examined.

7.6 Literature Cited

Malins, D. C., B. B. McCain, D. W. Brown, A. K. Sparks, H. O. Hodgins and S-L Chan. 1982. Chemical contaminants and abnormalities in fish and invertebrates from Puget Sound. NOAA Technical Memorandum OMPA-19, National Oceanic and Atmospheric Administration, Boulder, CO. 168 pp.

8.0 MARINE CHEMISTRY

A. Nevissi and R. McClain

8.1 Methods and Materials

8.1.1 Sample Collection and Preparation

The sampling program consisted of collection of sediment cores for measurement of sedimentation rate in the study area. On 26 September 1984, four Kasten cores were collected from Elliott Bay. Three cores (K-4, K-6, K-7) were collected at the proposed outfall site and the fourth core (K-5) was collected near the grain elevator in inner Elliott Bay (Figure 8.1).

The latitude, longitude, and depth of the cores collected are as follows:

Core #	Latitude	Longitude	Depth, fm
K-4	47°, 35.7'	122°, 25.3'	105
K-5	47°, 37.2'	122°, 22.1'	50
K-6	47°, 35.7'	122°, 24.8'	82
K-7	47°, 36.05'	122°, 25.2'	104

The sediments at the outfall site were strongly anaerobic down to the depth of sediment column that was sampled (270 cm). The top sediments were soft and it appeared that considerable mixing of the sediments had occurred. There was no sign of biota in the samples.

8.1.2 Surface sediment samples

Sediment samples from intertidal and subtidal areas were collected by the Intertidal Ecology and Subtidal Ecology tasks. Intertidal samples were collected by shovel and subtidal samples by Van Veen grab. The samples were put in pre-cleaned glass jars and forwarded to the Chemistry task for measurement of grain size, carbon and nitrogen, % volatile solids, biochemical oxygen demand, and trace metals. To avoid bacterial degradation, the samples

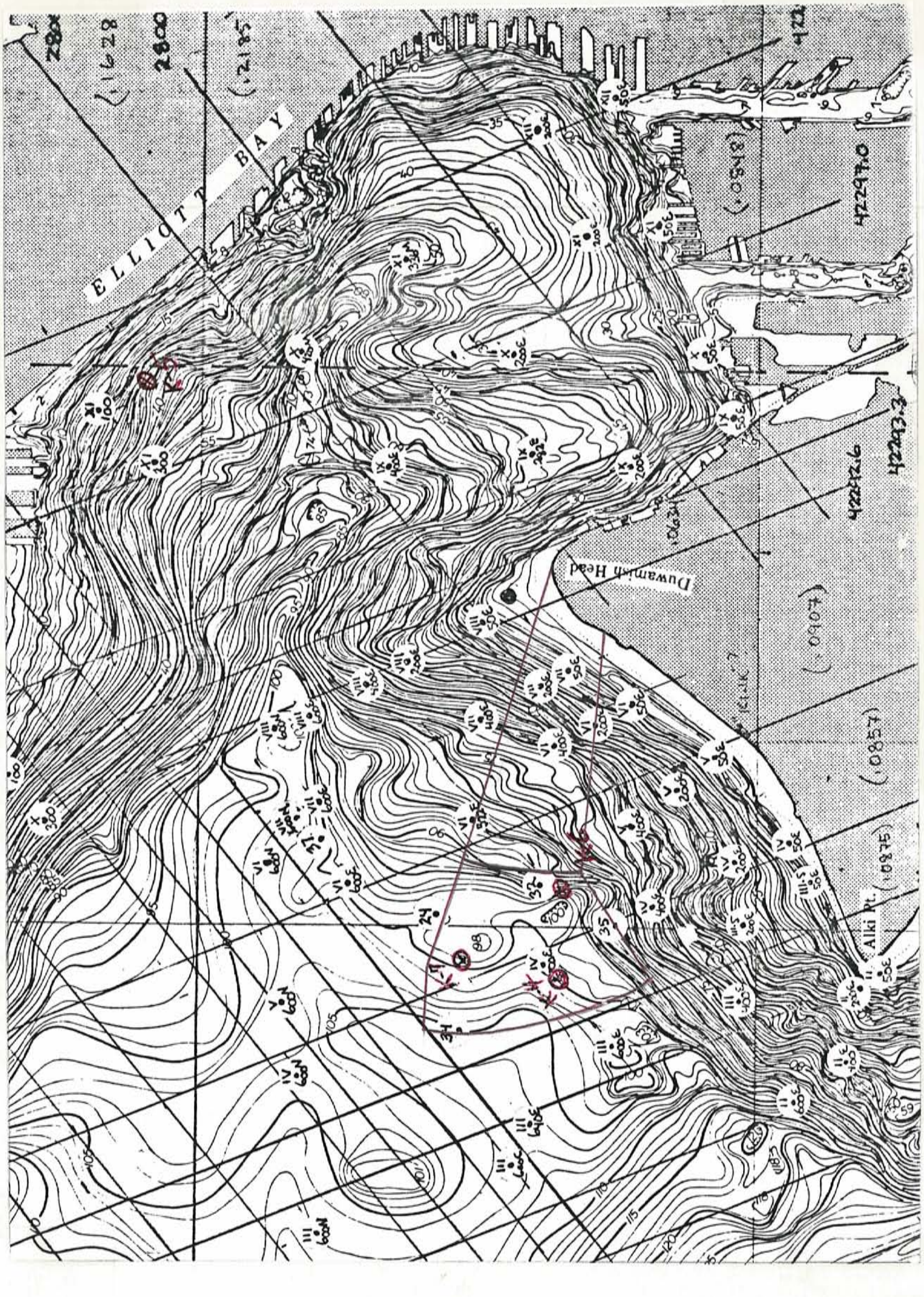


Figure 8.1. Location of Kasten core samples in Elliott Bay.

were kept frozen until the analysis.

8.1.3 Measurement of sedimentation rate by Pb-210 dating

Sections of sediment samples were weighed, dried at 100°C, and the dry sediments reweighed to calculate the sediment water content (Appendix Table 8A.4). For Pb-210 measurements a 2-3 g aliquot of each core section was spiked with Po-208 (a chemical yield tracer), digested with concentrated $HNO_3/HClO_4$, and centrifuged to remove the undissolved material. The leachate was evaporated and the residue converted to chloride form. The sample was diluted to 0.3 M HCL, and Polonium isotopes were plated spontaneously from this solution on a silver disc coated on one side with an inert film of varnish. The discs were rinsed, air dried, and alpha counted. The counting was done using silicon surface-barrier detectors and a computerized data reduction system. The results of Pb-210 measurements are shown in Appendix Table 8A.5-8A.6.

For Ra-226 and Cs-137 measurements, 25-50 g of dry sediment was pressed and sealed into standard counting geometry and gamma counted by Ge(Li) detection system. The amount of Ra-226 supported Pb-210 was subtracted from each sub-sample.

When the log of excess Pb-210 activity (pCi/g) of dry sediment was plotted as a function of depth of sediment accumulated (cm) the slope of this line represented the linear sedimentation rate (cm/yr). This sedimentation rate was related to the deposition rate w ($g/cm^2/yr$) using the following equation:

$$W = S(1 - \phi)\rho$$

where ϕ is the porosity* and ρ is the density of sediment. The mathematical approach for the above equation is described by Robbins and Edgington (1975).

8.1.4 Measurement of trace metals in sediments

The sample quantity required for trace metal analysis is 0.3 to 1 g of dry sediment. Since sediment is intrinsically heterogeneous material, a small fraction taken from an inhomogeneous mixture, even from a well-mixed sample, may not constitute a representative sample. For example, the NBS Standard Reference Material 1645 (river Sediment) is freeze-dried, homogenized, sieved to pass a No. 80 (180 um) screen, and thoroughly mixed in a V-blender. Still the total uncertainties, both measurement and material variability, for the elements range from ±2% to ±45%.

Sediment samples were dried, mixed well, and digested using $HNO_3/HClO_4$ mixture. For comparison between HNO_3/HF and $HNO_3/HCLO_4$ methods, two duplicate samples were digested using both methods. The results show higher recovery for some trace metals using HNO_3/HF digestion.

8.1.5 Sediment Grain Size

The stepwise procedure for the sediment grain size determination was based on the U.S. Geological Survey Procedure (Guy 1969) and the University of Washington's General Oceanography Laboratory Manual (Krumbein and Pettijohn 1938). Sediment samples were initially dried and the water content measured. The particles larger than 62 um were measured by dry sieving, whereas particles smaller than 62 um were measured by the wet pipetting technique. The results were classified by percentage: Cobble (156-64 mm), gravel (64-2 mm), coarse sand (2-0.5 mm), fine sand (0.5-0.062 mm), silt (0.062-0.004 mm), and clay (less than 0.004 mm). Metric standard sieve designation and size classes according to Lang et al. (1947), were used throughout the study.

8.1.6 Sediment Biochemical Oxygen Demands and Percent Volatile Solids

The 5-day BOD was determined following procedures of Standard Methods for the Examination of Water and Wastewater (1980) with the following modifications. Dilution Water: Seawater was collected and filtered through gravel, sand and charcoal filters. The water was then stored in a 50-gallon container in the dark for quality improvement.

Seeding: Seed was developed in the laboratory by continuously aerating a three liter culture medium composed initially of one liter of aquarium sand collected from the School of Fisheries' saltwater aquarium gravity filter beds and two liters of the supernatant of equal parts sand and salt water which had been violently stirred. For the duration of the study the culture received 100 ml of salinity-adjusted West Point unchlorinated sewage effluent and about 10 mg of tetra-min baby fish food daily. As needed, the seed was violently stirred and a portion transferred to a one-liter glass jar, the particulates were allowed to settle and the supernatant used for analysis. A seed concentration of 1 ml per 0.3 liters of diluted sample was used.

Dilution Technique: The frozen samples were thawed at room temperature and homogenized by stirring. Two representative aliquots of a sediment sample were weighed within 10 mg of each other and transferred quantitatively into incubation bottles. One milliliter of seed was introduced into each bottle. The bottles were then filled with dilution water. One bottle was fixed for DO determination immediately upon dilution of the sediment; the other bottle was incubated for five days in the dark at $20 \pm 1^{\circ}C$.

8.1.7 Total Sulfide in Sediment

Sulfide is present in sediment as a result of the decomposition of organic matter and bacterial reduction of sulfate. Total sulfide (i.e., the sum of dissolved H_2S, HS^-, as well as acid-soluble metalic sulfides) present in the sediment was measured.

Hydrogen sulfide was volatilized from sediment samples by treating known quantities of each sample with concentrated hydrochloric acid. The sample was continuously stirred at 85°C while nitrogen gas was bubbled through the mixture to ensure complete removal of hydrogen sulfide from the sample. The hydrogen sulfide gas was then trapped in three collection flasks in tandem containing zinc acetate and sodium hydroxide. The trap contents were kept refrigerated until sulfide analysis was performed. Sulfide was determined in the combined trap contents using the methylene blue procedure (Standard Methods 1980). After the color developed, the light absorption was measured at 670nm on a Gilford 300-N photospectometer. Laboratory sulfide standards were made using sodium sulfide, and the standards calibrated by iodometric method.

8.1.8 Organic Carbon and Nitrogen Content of Sediment

The frozen sediment sample was thawed, mixed, and a subsample removed for drying at 60°C for 48 hours. About 100 mg of dried sediment was weighed on a CAHN electrobalance for analysis. The weighed sample was placed on the precombusted square of aluminum foil and 50 ul of concentrated phosphoric or hydrochloric acid was added to remove inorganic carbon (Froelich 1980). The sample was heated on a 60°C hotplate for a minimum of four hours. This allowed time for the acid to react with the carbonate present in the sample and for evaporation of the excess acid. The sample was then combusted at 950°C and the combustion products (N_2 and CO_2) were analyzed by thermal conductivity detectors.

The instrument was calibrated daily with acetanelide which contains 10.36% nitrogen and 71.09% carbon.

The combustion and carrier gas used for the measurements was compressed oxygen. The gas contained some nitrogen and CO_2 as impurities. However, the background values were constant because the same cylinder of oxygen has been used for the past five years. The blank values were measured daily prior to and during analysis of the samples.

8.1.9 Oil and Grease

Interstitial water samples were analyzed by the partition infrared method, Standard Methods (1980). The sample, 150-200 ml, was acidified to pH < 2.0 with HCl and extracted twice with a mixture of one part methanol and three parts methylene chloride. After two extractions in a separatory funnel, the solvents were combined and evaporated in a water bath at 70°C. The residue was dissolved in a measured volume of carbon tetrachloride and the absorbance was measured at 2930 cm^{-1} using an infrared spectrophotometer. The absorbance was converted to oil and grease using a standard curve prepared from crude oil. The concentrations were expressed as ul of oil and grease per liter of water sample.

The sediments were weighed wet and acidified to pH <2.0 with HCl. The extraction was conducted in 250 ml poly bottles. A blank test showed no measurable oil and grease from the bottle. The methylene chloride methanol solvent mixture was used for the sediment extraction. The sediment was placed in the poly bottles with 75 ml of the solvent mixture and placed on an automatic shaker for 15 minutes. After allowing the sediments to settle the solvent was aspirated into a 200 ml vacuum flask and then poured through a clean extraction thimble into a 200 ml beaker. The extraction was repeated and the combined extracts were evaporated in a 70°C water bath. The residue was dissolved in a measured volume of carbon tetrachloride and measured as above. The results were expressed as ul oil and grease in a gram, dry weight, of sediment.

To compare the methylene chloride methanol solvent to trichlorotrifluoroethane, the solvent recommended in Standard Methods, five samples were analyzed using both solvents. The freon extracts were done on samples dried with anhydrous sodium sulfate. The crude oil standards were dissolved in freon for infrared analysis on the samples extracted with freon. The other samples were dissolved in carbon tetrachloride following the procedure described above. The results are shown in Table 8.1. The freon extracted samples show consistently lower results.

8.2 Results

8.2.1 Sedimentation Rates

The results of Pb-210 dating of four kasten cores collected in the Elliott Bay area are shown in Figures 8.2-8.5. In addition to Pb-210 measurement (Table 8.2), sections of kasten cores were also gamma counted to measure Cs-137, Ra-226, and K-40 concentrations (Table 8.3).

Core No. K-7 (Figure 8.5), show a sedimentation rate of 1.8 cm/yr with almost no mixing of Pb-210 in surface sediments. Whereas cores K-4, K-5, and K-6 (Figures 8.2-8.4), show mixing of surface sediments to certain depths. This could be due to a very rapid sediment accumulation rate or mixing of sediments by other processes, release of methane, including agitation of sediments by the corer. Mixing of sediments as a result of bioturbation seems to be very unlikely. This is due to the existence of sulfide at all depths and lack of any evidence of biota during the visual examination of sediment columns. The results of Cs-137 measurements show that the concentration of this radionuclide is almost constant, within the counting statistics, to a certain depth and then abruptly falls to zero.

The depth of constant Cs-137 for all four kasten cores is marked on the corresponding figure. This depth is equal or greater than the depth of mixed layer. The date corresponding to the depths of Cs-137 (Figures 8.2-8.5) are also lower than the date of the Cs-137 fallout peak, 1960-1963. This may be due to the conservative character, low reactivity of the element in seawater

Table 8.1. Comparison of two different solvents for oil and grease extraction.

	Freon Extract	Methylene Chloride & Methanol	
(Sample)	(ul/gR)	(ul/gR)	Ratio
45	0.468	0.819	1.75
55	0.233	0.261	1.12
70	0.267	0.409	1.53
76	1.623	3.441	2.12
80	1.113	1.423	1.28
			Avg. 1.56

Table 8.2. Lead-210 activity measured in Kasten Cove sections.

Sediment depth (cm)	Pb-210 (Pci/g dry)*			
	K-4	K-5	K-6	K-7
0-1	-	1.30 ± 0.12	-	-
2-3	3.66 ± 0.35	-	-	3.75 ± 0.42
6-7	3.93 ± 0.42	-	-	3.88 ± 0.40
8-9	-	-	3.93 ± 0.37	-
9-10	3.70 ± 0.32	-	-	-
10-11	-	-	-	3.39 ± 0.30
12-13	-	-	3.66 ± 0.40	-
15-16	-	0.92 ± 0.10	3.15 ± 0.30	2.99 ± 0.26
19-20	2.44 ± 0.21	-	3.18 ± 0.39	-
20-21	-	0.45 ± 0.05	-	2.67 ± 0.28
25-26	-	0.42 ± 0.05	-	-
30-31	-	0.62 ± 0.06	3.25 ± 0.40	2.76 ± 0.24
35-36	3.76 ± 0.40	0.92 ± 0.09	-	-
45-46	3.95 ± 0.58	0.85 ± 0.08	-	3.96 ± 0.84
50-51	-	-	2.0 ± 0.20	-
55-56	-	-	-	1.95 ± 0.21
60-61	2.48 ± 0.24	0.71 ± 0.13	1.73 ± 0.15	-
70-71	2.08 ± 0.38	-	2.75 ± 0.33	2.11 + 0.23
75-76	-	0.52 ± 0.09	-	-
80-81	-	-	0.92 ± 0.17	1.07 ± 0.24
90-91	-	0.60 ± 0.14	-	-
100-101	1.79 ± 0.20	-	3.00 ± 0.29	1.22 ± 0.13
110-111	-	0.48 ± 0.13	2.22 ± 0.27	-
120-121	1.46 ± 0.18	-	1.83 ± 0.23	-
130-131	1.42 ± 0.13	0.22 ± 0.08	1.48 ± 0.13	-
140-141	-	-	1.18 ± 0.11	0.70 ± 0.08
150-151	0.97 ± 0.12	0.23 ± 0.03	0.83 ± 0.08	-
160-161	0.73 ± 0.14 0.68 ± 0.10	-	-	0.71 ± 0.06
170-171	0.96 ± 0.21	-	-	-
180-181	-	-	-	0.62 ± 0.06
200-201	-	-	-	0.40 ± 0.07
230-231	0.35 ± 0.06	0.22 ± 0.04	-	-

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* The average concentration of Pb-210 supported by Ra-226 is considered to be 0.43 Pci/g of dry sediment.

Table 8.3. Concentrations of Cs-137, Ra-226 and K-40 measured in Kasten Cove sections.

	K-4			K-5			K-6			K-7		
	Pci/g			Pci/g			Pci/g			Pci/g		
(cm)	Cs-137	Ra-226	K-40	Cs-137	Ra-226	K-40	Cs-137	Ra-226	K-40	Cs-137	Ra-226	K-40
1-5	0.27 ± 0.03	-	12.6 ± 0.7	0.2 ± 0.02	0.4 ± 0.04	12.3 ± 0.6	-	-	-	0.28 ± 0.02	-	12.8 ± 0.6
10-15	0.26 ± 0.03	0.41 ± 0.05	12.4 ± 0.7	-	-	-	0.23 ± 0.03	0.52 ± 0.06	-	0.28 ± 0.02	0.39 ± 0.04	12.9 ± 0.6
20-25	-	-	-	-	-	-	0.21 ± 0.02	0.33 ± 0.04	11.3 ± 0.6	0.30 ± 0.03	0.58 ± 0.06	
25-30	0.33 ± 0.02	0.32 ± 0.05	11.7 ± 0.7	N.D.	-	9.0 ± 0.6	-	-	-	-	-	
35-40	0.30 ± 0.03	0.41 ± 0.05	13.6 ± 0.7	0.2 ± 0.02	-	11.0 ± 0.8	0.20 ± 0.03	0.46 ± 0.07	-	-	-	-
50-55	-	-	-	-	-	-	0.12 ± 0.02	0.21 ± 0.04	10.4 ± 0.6	0.23 ± 0.03		
55-60	0.31 ± 0.02	0.44 ± 0.06	13.2 ± 0.7	-	-	-	-	-	-	-	-	
70-75	0.23 ± 0.02	0.46 ± 0.05	13.0 ± 0.7	N.D.	-	12.5 ± 0.6			14.1 ± 0.7	0.24 ± 0.03	0.33 ± 0.05	12.0 ± 0.6
75-80	-	-	-	-	-	-	-	-	-	-	-	-
100-105	-	-	-	N.D.	-	-	0.21 ± 0.01		12.6 ± 0.5	ND	0.30 ± 0.05	12.6 ± 0.6
110-115	ND	-	13.1 ± 0.9	-	-	-	-	-	-	-	-	
130-135	-	-	-	N.D.	-	10.5 ± 0.5	ND		14.2 ± 0.5	-	-	
140-145	ND	0.44 ± 0.05	13.0 ± 0.7	-	-	-	-	-	-	ND	0.55 ± 0.07	
160-165	-	-	-	-	-	-	ND		13.0 ± 0.7	-	-	-
170-175	-	-	-	N.D.	-	10.5 ± 0.5	-	-	-	ND	0.35 ± 0.06	12.6 ± 0.6
180-185							-	-	-	-	-	-
220-225	-	-	-	N.D.	-	-	-	-	-	ND	0.56 ± 0.07	13.7 ± 0.7
250-255	ND	0.39 ± 0.05	12.5 ± 0.8	-	-	-	-	-	-	-	-	-
260-265	-	-	-	-	-	-	-	-	-	-	-	-
270-275	-	-	-	-	-	-	-	-	-	ND	0.58 ± 0.07	13.5 ± 0.8

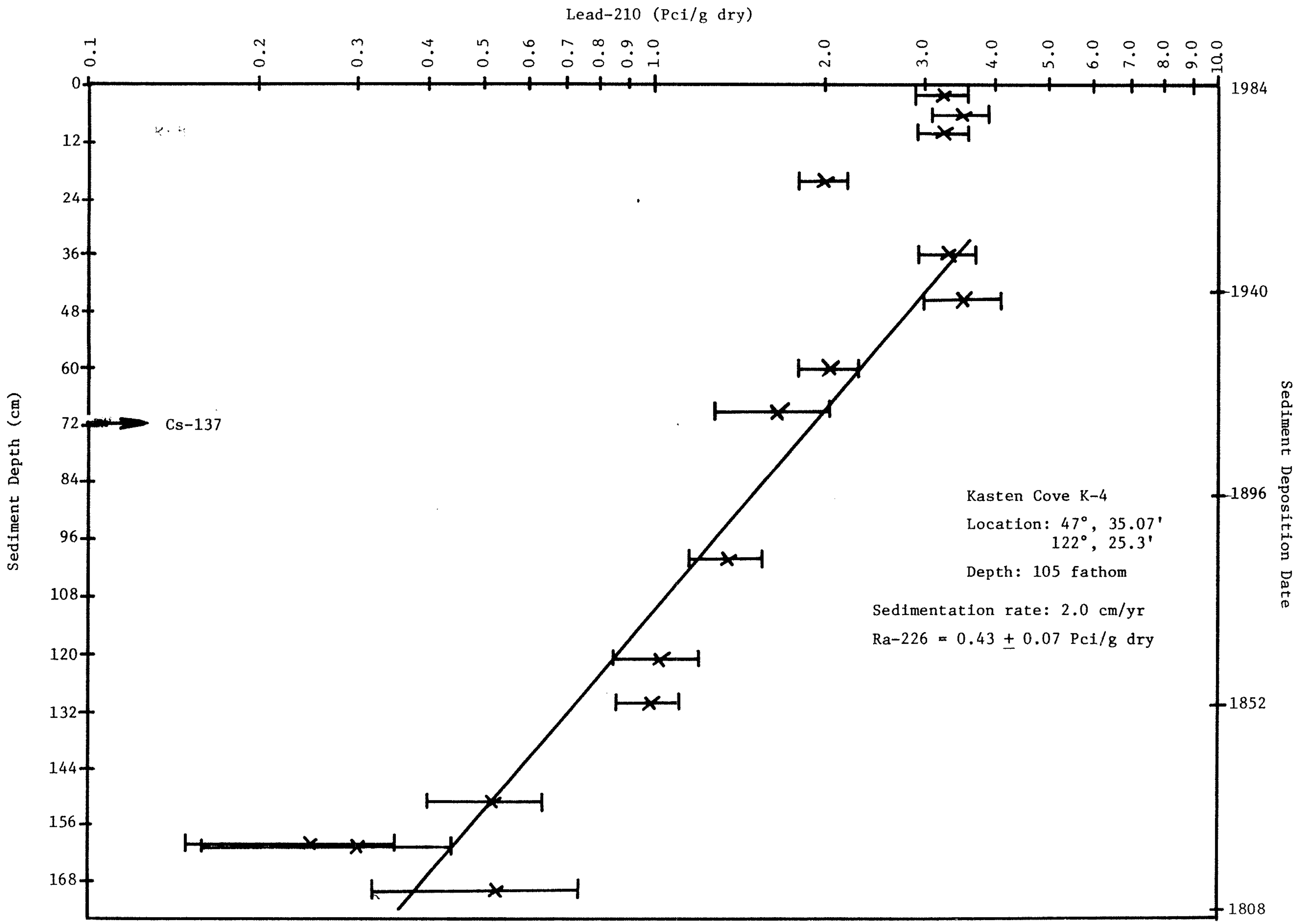


Figure 6.2. Lead-210 dating of Kasten core K-4 collected in Elliott Bay at a depth of 105 fathom. Sedimentation rate, 2.0 cm/yr.

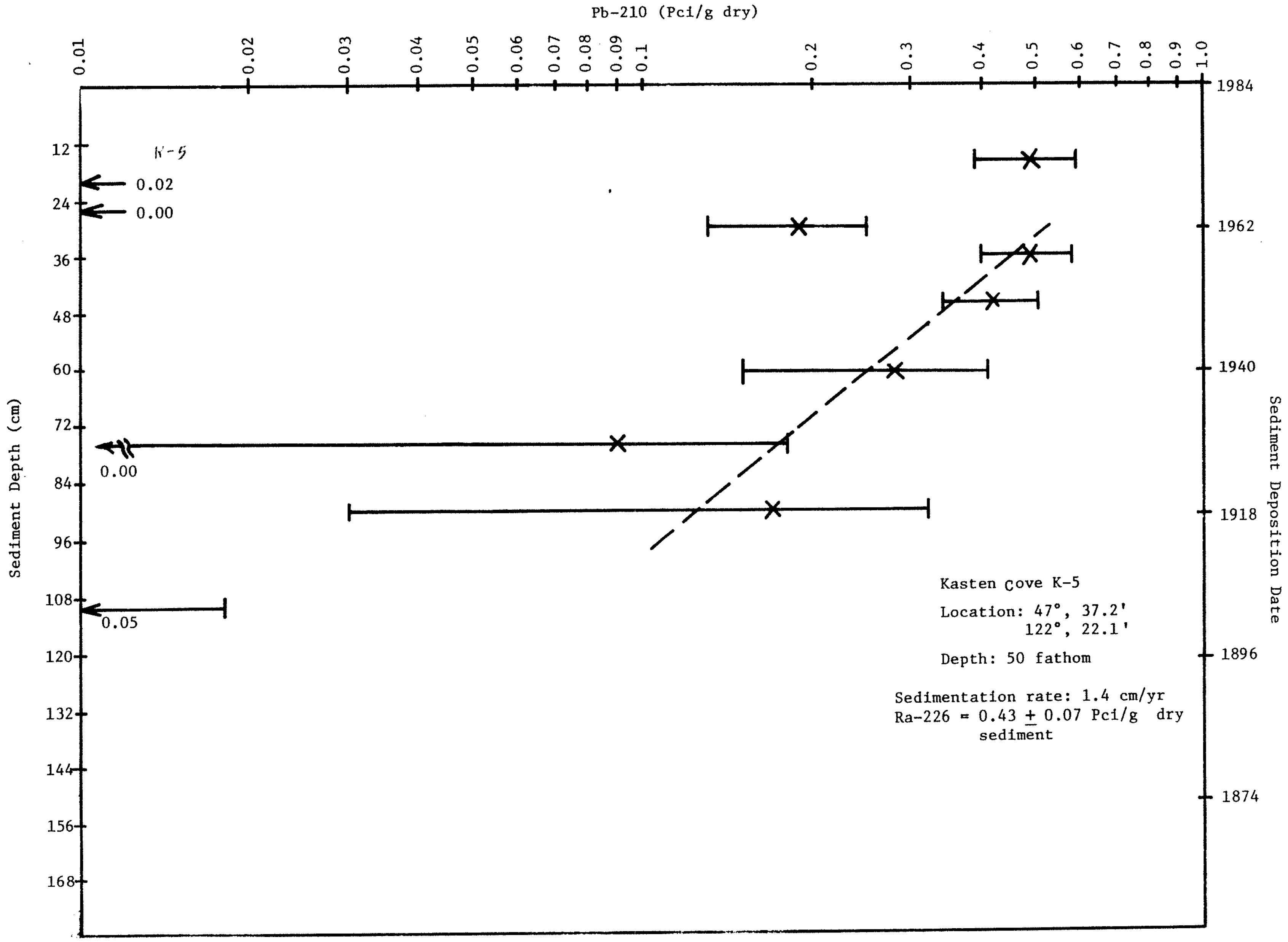
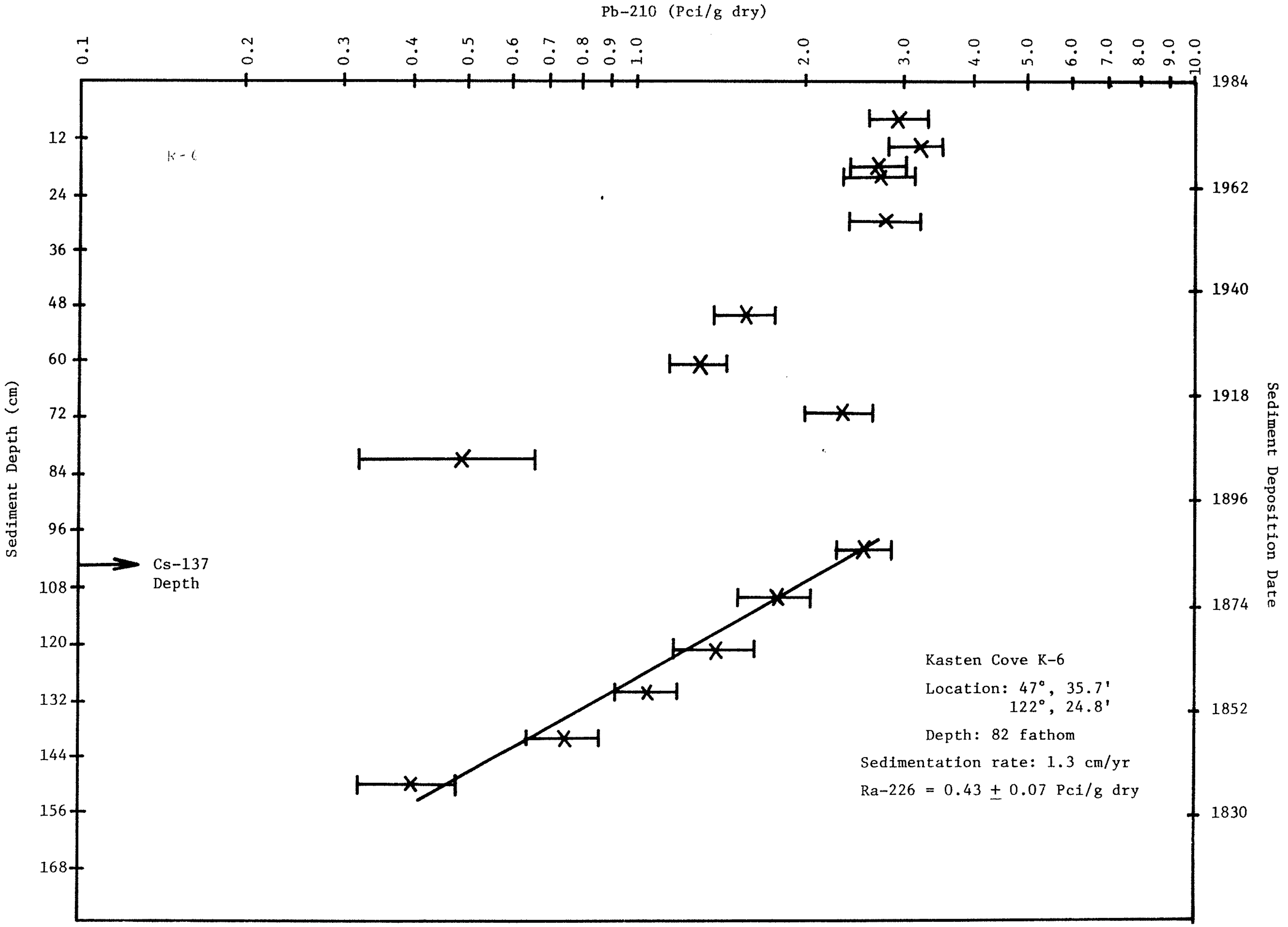


Figure 8.3. Lead-210 dating of Kasten core K-5 collected in Elliott Bay at a depth of 50 fathom. Sedimentation rate, 1-4 cm/yr. Due to extreme mixing, the sedimentation rate could not be measured accurately. (→) indicate where the concentration of unsupported Pb-210 is <0.01 pci/g.



Kasten Cove K-6

Location: 47°, 35.7'
122°, 24.8'

Depth: 82 fathom

Sedimentation rate: 1.3 cm/yr

Ra-226 = 0.43 ± 0.07 Pci/g dry

Figure 8.4. Lead-210 dating of Kasten core K-6 collected in Elliott Bay at a depth of 82 fathom. Sedimentation rate, 1-3 cm/yr.

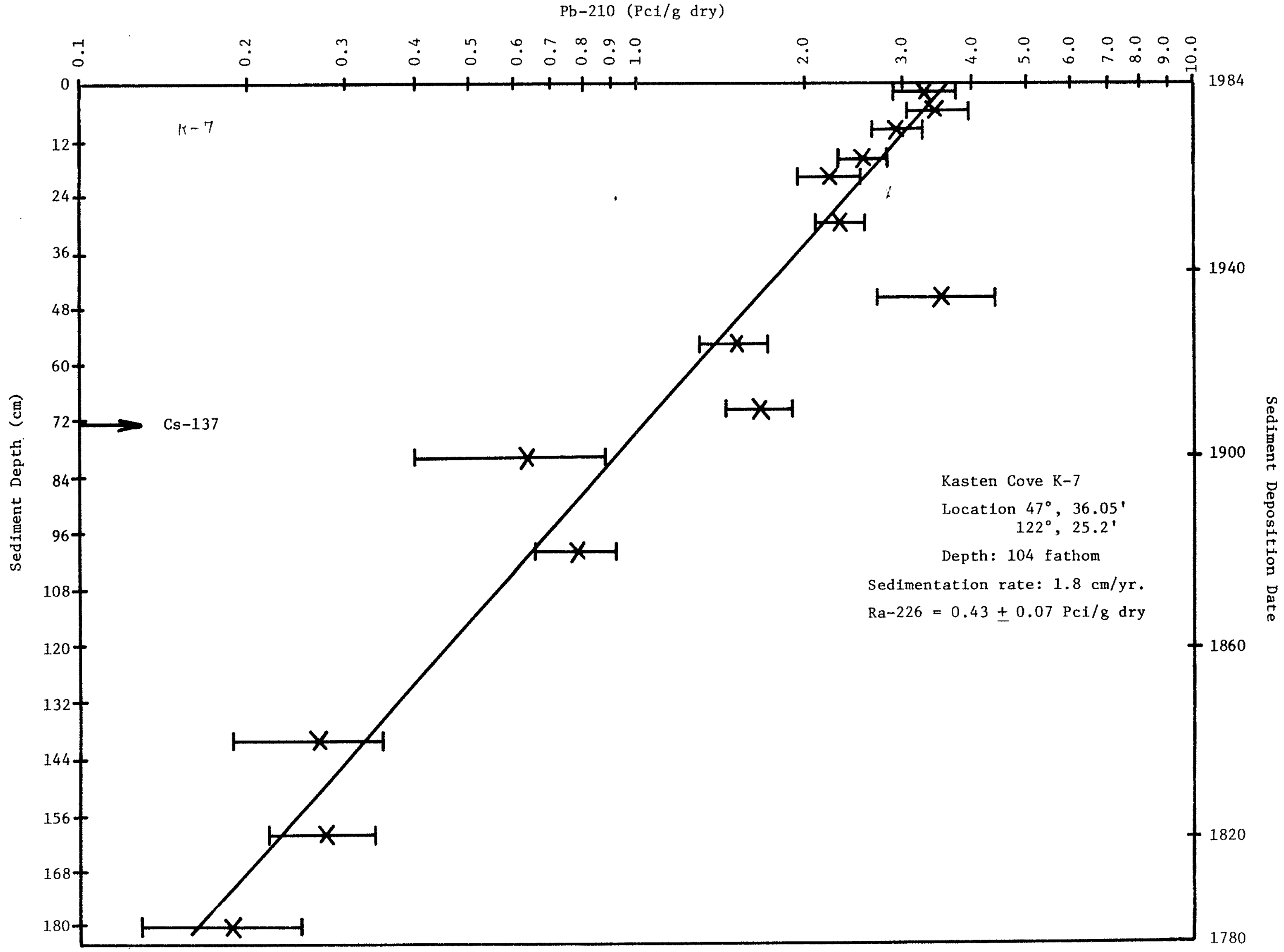


Figure 8.5. Lead-210 dating of Kasten core K-7 collected in Elliott Bay at a depth of 104 fathom. Sedimentation rate 1-8 cm/yr.

as compared to Pb-210 (Bruland 1983).

Figure 8.2 shows that, based upon the present data points, the depth of the sediment mixed layer and the sedimentation rate obtained from K-4 are 46 cm and 2.0 cm/yr. Figure 8.4 (K-6) shows a sedimentation rate of 1.3 cm/yr, however, the depth of mixed layer, 98 cm, is considerably higher than for both cores K-4 and K-7. Cores K-4 and K-7 collected at deepest area of the proposed outfall show higher sedimentation rates than core K-6 collected at a relatively shallower (82 fathoms) area.

Core K-5, collected inside Elliott Bay near the grain elevator shows substantial disturbance of surface sediments. This is evident from the low concentration of Pb-210 of surface sediments, 0.5 pci/g versus 3.5 pci/g in other cores, and the value of unsupported Pb-210 at depths of 20 cm and 26 cm depth which approaches zero. The sedimentation rate, 1.4 cm/yr, could not be measured accurately in this core. Based on the present data points, this sedimentation rate should be considered as the first approximation until enough data points are measured.

8.2.2 Other Sediment Parameters

Profiles of sulfide, carbon and nitrogen content, percent volatile solids, and dry/wet ratios were measured in sediment cores (Table 8.4). In addition, sediment grain sizes were measured in two different sections of each core (Table 8.5). The results show that the sediments are composed mainly of clay size material with a high concentration of organic carbon which seems to be responsible for depletion of oxygen in the sediment column. The high concentration of sulfide observed in the sediment column may affect the sediment water interface and to some extent the overlying water.

8.3 Summary and Conclusions

Cores from the proposed outfall area were anaerobic throughout their

Table 8.4. Sediment parameters measured in sections of Kasten Coves.

(SAMPLE)	(NITROGEN)	(CARBON)	(DRY/WET)	(%VOL.SOL)	(SULFIDE)
	µg/mg dry	µg/mg dry			mg/kg dry
(K-4)					
2-3	3.06	25.6	0.369	6.99	<.20
6-7	4.06	30.5	0.369	7.28	1.02
9-10	3.34	28.8	0.367	7.29	0.92
19-20	3.38	22.5	0.372	7.05	1.77
30-31	2.94	22.1	0.357	7.04	23.54
35-36	2.93	28.1	0.379	6.93	14.19
60-61	2.11	28.3	0.388	6.76	20.41
100-101	2.49	26.3	0.403	6.40	5.32
160-161	2.45	19.2	0.445	5.97	3.53
230-231	2.02	16.8	0.419	5.60	2.62
(K-5)					
0-1	2.18	17.9	0.466	5.01	<.20
15-16	1.47	15.4	0.504	4.59	<.20
25-26	1.38	7.4	0.611	2.78	<.20
35-36	1.65	20.9	0.495	5.53	<.20
45-46	1.68	18.8	0.489	7.03	<.20
90-91	1.68	16.6	0.537	4.13	0.47
150-151	1.27	11.0	0.537	3.63	0.90
200-201	1.15	10.4	0.534	3.78	0.59
230-231	1.08	9.7	0.527	3.74	0.56
(K-6)					
8-9	2.79	32.8	0.376	7.89	1.29
12-13	2.09	21.9	0.359	7.98	1.03
15-16	2.56	24.3	0.363	7.71	1.08
19-20	2.72	23.7	0.387	7.20	<.20
30-31	2.28	24.1	0.408	6.94	0.51
50-51	2.13	23.9	0.407	6.87	1.48
70-71	2.28	23.2	0.376	7.23	<.20
100-101	2.34	22.2	0.425	6.99	1.18
130-131	2.05	23.0	0.427	6.41	2.55
150-151	1.94	20.6	0.443	6.00	0.82
(K-7)					
2-3	2.84	31.0	0.229	14.46	2.96
6-7	3.38	23.4	0.372	7.38	1.52
15-16	2.49	25.3	0.399	7.10	3.46
20-21	2.71	22.6	0.371	7.08	3.98
30-31	2.52	24.3	0.416	6.89	3.39
55-56	2.41	23.0	0.399	6.85	2.86
100-101	2.26	22.0	0.392	6.36	5.80
140-141	2.01	20.2	0.424	5.85	3.39
200-201	3.72	18.6	0.393	5.74	5.49

Table 8.5. Grain size analysis of the core samples.

Sample	Dry/Wet	% gravel	% coarse sand	% fine sand	% silt	% clay	(Phi) Mean grainsize	(Phi) Mode
K4,1-5cm	0.37	0.04	0.28	2.62	44.60	52.47	7.79	10.0
K4,250-255cm	0.42	0.00	0.07	1.12	45.06	53.75	7.94	10.0
K5,1-5cm	0.50	0.20	0.78	19.10	43.01	36.92	6.61	10.0
K5,260-265cm	0.53	0.06	0.02	0.58	56.06	43.28	7.61	10.0
K6,1-5cm	0.78							
K6,160-165cm	0.44	0.00	0.15	5.65	51.46	42.73	7.51	10.0
K7,1-5cm	0.23	0.00	0.04	1.77	44.88	53.21	7.92	10.0
K7,270-275cm	0.39	0.00	0.00	0.92	44.79	54.29	8.01	10.0

length and showed signs of surface sediment disturbance and mixing. Sedimentation rates, based on Pb-210 dating, were 1.3, 1.8 and 2.0 cm/yr for the three cores. The depth of the Cs-137 fallout peak (1960-1963) was deeper than expected.

The core from inner Elliott Bay showed substantial disturbance of the surface sediments, and a sedimentation rate of 1.4 cm/yr.

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9.0 MARINE TOXICOLOGY

B. Ross, P. Dinnel and Q. Stober

9.1 Description of the Study Area and Stations

METRO's present plans call for the construction of a deep outfall for discharge of Renton Sewage Treatment Plant secondary effluent off Duwamish Head in southwestern Elliott Bay. The primary study area is thus Elliott Bay and Central Puget Sound between Alki Point and West Point (Figure 9.1).

Six water column sample stations were established in inner and outer Elliott Bay, off West Point, and off Alki Point (Figure 9.1). Two of these sites (#31, at Pier 90-91, and #32, at the mouth of the Duwamish West Waterway) are historical receiving water quality sampling sites of the Washington State Department of Fisheries. In addition to these six water column stations, 34 sediment sample stations were established (Figure 9.2). Thirty of these correspond to 30 of the stations sampled by the Subtidal Ecology group (see section 5.0). The additional four sites were utilized as control samples, or to cross-reference with other studies.

9.1.1 General

All bioassays were conducted at a marine laboratory located at METRO's West Point Sewage Treatment Plant, Seattle, Washington.

Seawater from Puget Sound was continuously supplied to the laboratory by 7.5-hp cast-iron pumps. The seawater was pumped from a depth of approximately 7 to 10 m (depending on tide level) to an 1800-liter fiberglass head-tank which supplied seawater to the laboratory via gravity flow. All laboratory plumbing was constructed of polyvinyl chloride (PVC) pipe and fittings conditioned in seawater for at least two weeks.

Seawater temperatures were monitored with a standard mercury or

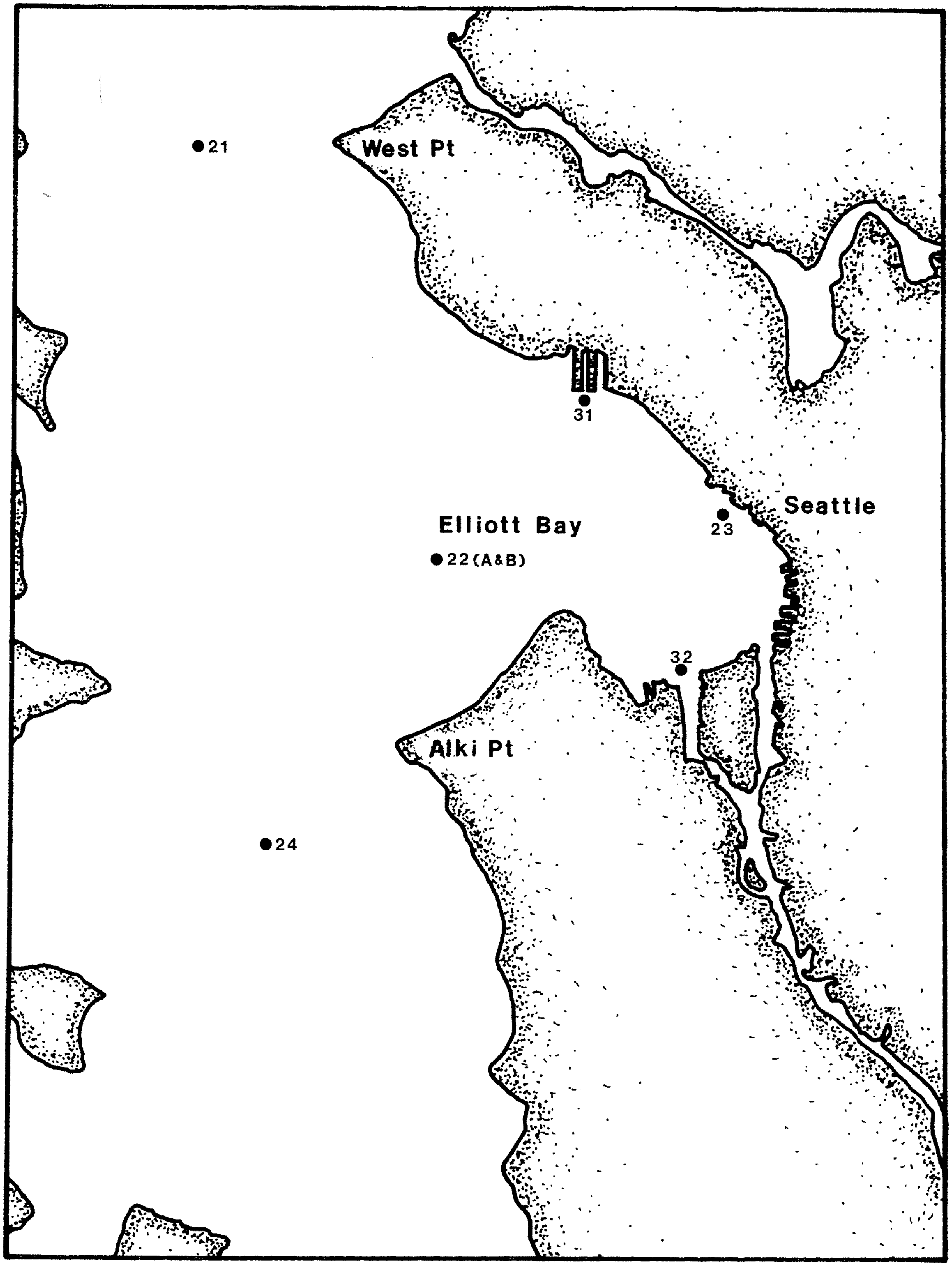

Figure 9.1. Study area, showing water column sampling locations (● 21).

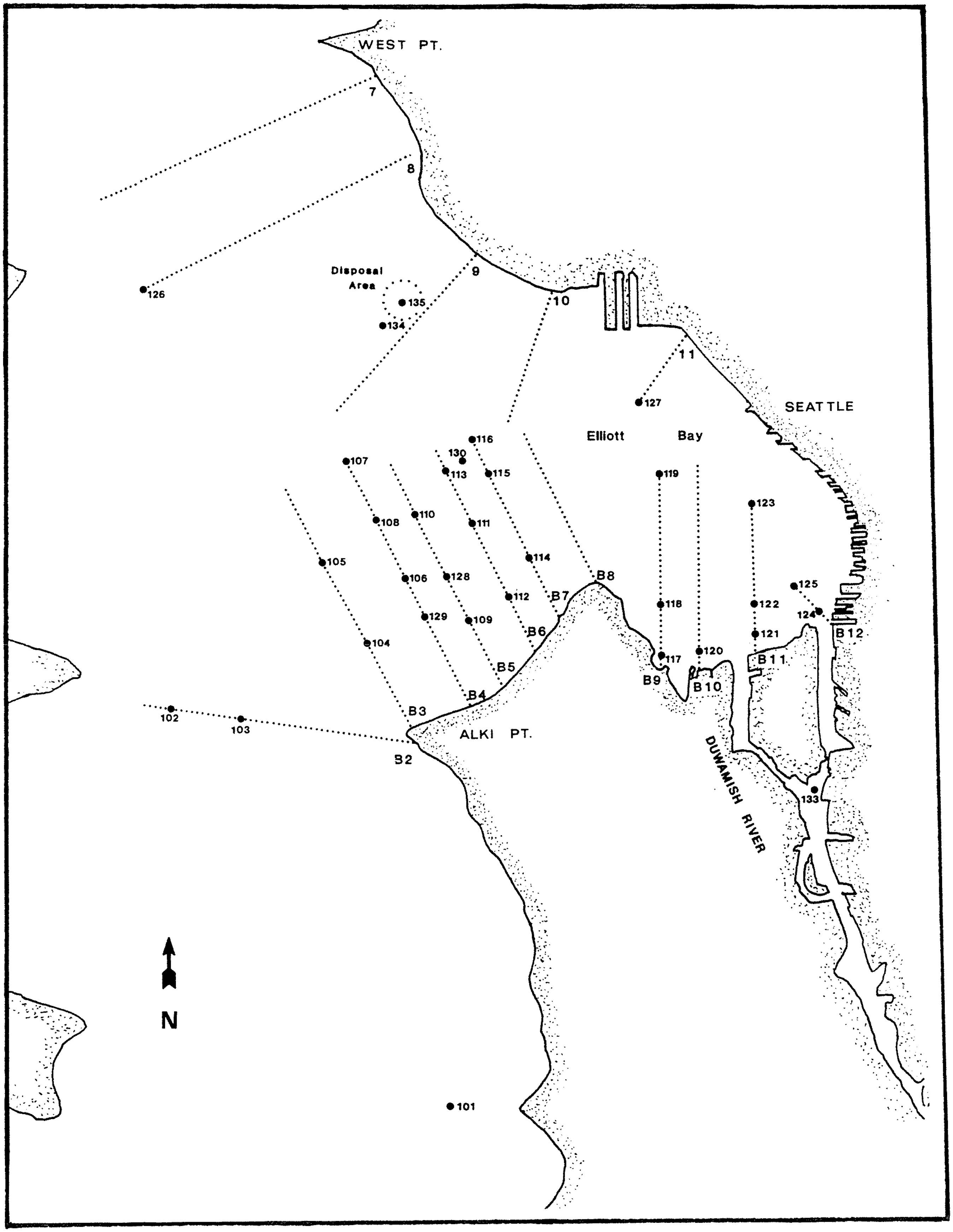

Figure 9.2. Study area, showing transects (B2-B12, 7-11) and sediment sampling (● 101) locations.

electronic thermometer. Salinity was measured by a YSI model 33 S.C.T meter calibrated against laboratory standards. An Orion research model 407A specific ion meter with appropriate electrode and standard calibrating solutions was used to measure pH. Dissolved oxygen (DO) concentrations in sediment elutriates were determined with a Yellow Springs model 51B oxygen meter and model 5739 dissolved oxygen probe after "saturated air" calibration.

9.2 Sample Collection, Handling, and Preparation

9.2.1 Receiving Water

Receiving water samples were generally collected monthly at site 24 (Alki Point) and weekly at all other sites by the Water Column group on board METRO's R/V Liberty. Samples were collected by PVC Niskin bottles at several depths at stations 21, 22, 23 and 24 and at one depth (surface) at stations 31 and 32. The samples were drained into clean, seawater-aged 4-liter polyethylene bottles, packed in ice, and transported to the West Point Laboratory upon docking at Shilshole Marina. All receiving water bioassays were started immediately upon reception of the samples at the West Point Laboratory.

Four types of "control" water were tested along side each set of receiving water samples. The "primary" control water (used as the "standard" for comparing all other water types) was obtained from underground storage tanks at Kincaid Hall (Zoology) at the University. This water is collected by the truckload once or twice per year from the Anacortes ferry dock at high tide and is used for routine marine embryological work by the Zoology department. Kincaid Hall seawater was selected as the "primary" control water since it was readily available and its quality was reasonably consistent through time. A "carry-along" control sample of Kincaid Hall seawater was sent along with the ice chests during each cruise. This sample was used to monitor any possible sources of sample contamination due to handling in the field. A third "control" sample consisted of West Point seawater collected from the laboratory seawater system just prior to each bioassay. The fourth "control" sample was seawater previously collected at the University's Friday Harbor Marine Laboratory on San Juan Island. This water was collected on June 29, 1984 in 20 clean polyethylene 4-liter bottles, quickly frozen in a commercial food locker at 0°F, transported back to the University in ice chests, and stored in the Fisheries cold storage room at 0°F. Friday Harbor seawater often gives the best overall results as control water (Dinnel et al. 1984, Vol. X, in Stober and Chew 1984) since it comes from an area well outside urban/industrial development. The quality is very constant between tests because it was frozen quickly. This water was not, however, used as the "primary" control during these tests because the effect of freezing on water quality is not yet fully determined.

Test sample preparation was accomplished by thoroughly mixing each sample by repeated inversion of its unopened 4-liter bottle. Each new 600 ml disposable polypropylene beaker was rinsed with the sample water; six replicate beakers were then filled with 500 ml of the sample or control water to be tested (three replicates for oyster embryos and 3 for sand dollar embryos). Three 10-ml samples were put into borosilicate glass test tubes (16 x 100 mm) for the sand dollar sperm assays. The beakers and test tubes were maintained in water baths during their respective exposure periods. Sperm assay tubes and sand dollar embryo beakers were held at ambient seawater temperature; oyster embryo beakers were held at 20°C.

9.2.2 Sewage

Sewage samples were collected on three separate occasions from the Renton Treatment Plant. Four-liter grab samples were collected at five steps in the treatment process including influent sewage, primary sewage, secondary sewage, chlorinated secondary sewage, and dechlorinated secondary effluent (Figure 9.3). Each batch of samples was packed in ice and transported (along with a bottle of Kincaid Hall "control" seawater) to the West Point Laboratory where bioassays were immediately started. For each bioassay a series of eleven seawater dilutions (0.41 to 20.00% sewage) of each sewage sample was prepared on a volume/volume basis using West Point filtered (5-um in-line filter) seawater as the diluent. Each dilution was put into one 500 ml beaker for each of the oyster and sand dollar embryo assays, and 10-ml subsamples were removed to glass test tubes for the sperm assay. An additional test series was similiarly prepared using deionized freshwater instead of sewage so that the effects of reduced salinity alone could be separated from the overall "toxic" responses observed for each sewage type. Triplicate samples of three types of "control" water (Kincaid Hall, Friday Harbor, and West Point filtered seawaters) were tested with each sewage bioassay. Each set of beakers and test tubes were incubated in water baths at the respective test temperatures noted above.

9.2.3 Sediment

Baseline sediment samples were collected with a modified 0.1-m^2 vanVeen grab from 30 depositional (as identified by the Subtidal Ecology Group) sites (Figure 9.2) in the Elliott Bay/Duwamish Head study area and from four additional sites: Duwamish South Harbor, the Four Mile Rock dump site, "JC-20" (near the Four Mile Rock site) and I690E from the Seahurst Baseline studies (Dinnel et al. 1984, Vol. X, *in* Stober and Chew 1984). Station locations are further detailed in Appendix Table 9.1. Duwamish South Harbor, Four Mile Rock and JC-20 were chosen for use as "toxic" controls and/or to cross reference with previous studies (Dinnel et al. 1984, Vol. X, *in* Stober

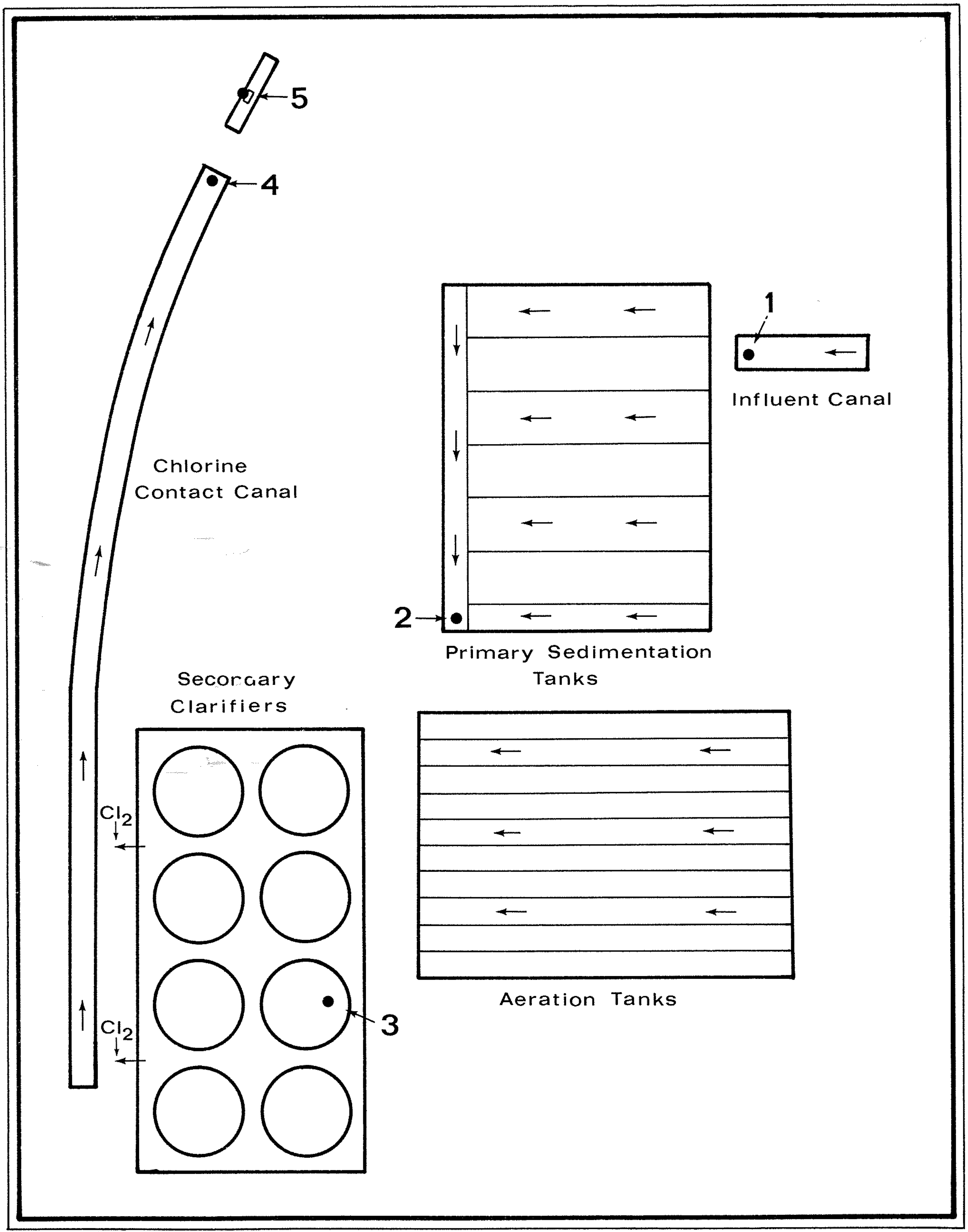

Figure 9.3. Diagrammatic map of the Renton sewage treatment plant showing sampling points for the sewage bioassays. 1 = influent sewage; 2 = primary sewage; 3 = secondary sewage; 4 = chlorinated secondary sewage; 5 = dechlorinated effluent (sampled at the composite sampler).

and Chew 1984; J. Strand, pers. comm.). The I690E site was chosen as a trial "clean" fine-grained control sediment (primarily for the amphipod bioassays) based on Seahurst Baseline study results (Dinnel et al. 1984, Vol. X, in Stober and Chew 1984). A sediment sample for each site consisted of the top 2 cm removed from three replicate grabs. At certain sites (Duwamish South Harbor, Four Mile Rock, Seahurst I690E) the entire grab was collected. All sediment retained from a site was thoroughly mixed, and then divided into at least two plastic bags (for separate solid and liquid phase testing) which were sealed and kept on ice until frozen at the University at 0°F (a period not exceeding 10 hrs). Sediment from West Beach State Park (North Whidbey Island) was obtained during animal collection by repeatedly lowering a small benthic dredge along a transect parallel to the shore at a depth of about 5 m. This sediment was placed in plastic bags, which were sealed and kept on ice until frozen. Prior to initiation of a bioassay, all sediments were thawed at room temperature overnight. West Beach sediment was sieved (1.0 mm mesh) prior to use in amphipod (solid phase) tests.

Sediment liquid phase elutriates were prepared as outlined in EPA/COE (1977). A sediment sample from each site was thawed overnight and rehomogenized by kneading prior to unsealing the plastic bags. Measured aliquots of sediment were removed and placed in clean 4-liter polyethylene containers. The desired amount of freshly drawn, filtered (5-um in-line filter) West Point seawater was added to the containers, and the slurries mixed vigorously for 30 minutes by high speed stirring motors equipped with stainless steel shafts and blades. The concentration of the slurries thus created depended on the bioassay. During the first test, 2:1 (seawater to sediment, by volume) or "33.3%" stock slurries were prepared for each site. For the second test, 9:1 (seawater to sediment, by volume) or "10%" slurries were prepared for most sites. Certain sites had 19:1 (or "5%") stock slurries prepared when too little sediment remained to create "10%" slurries. For both bioassays, all slurries were allowed to settle undisturbed for at least one hour prior to decanting of the supernatant. The supernatant from each site was filtered through 4.5-um pore size Whatman GF/C glass microfiber filters to create the "liquid phase" elutriate. In some cases, supernatants were centrifuged for one minute at 7,000 rpm to help remove fine suspended particulates prior to filtering. The elutriate concentrations were defined as the volume:volume concentration of the slurries from which they were prepared. Hence, an undiluted elutriate from a "33.3%" slurry was designated a "33.3%" elutriate. Diluted 1:1 (vol:vol), it would be a 16.6%" elutriate, and so on. Liquid phase elutriates thus prepared were added to new, rinsed 600 ml disposable polypropylene beakers, or new 10 ml test tubes (for the sperm assay), and diluted with filtered West Point seawater to create the test concentrations. For the first bioassay, six sites were chosen to test a "dilution series" of the following unreplicated concentrations: 33% (sperm assay only), 16.6%, 3.3%, 1.66% and 0.17% liquid phase elutriate, by volume. All other sites were tested at a single concentration (16.6%), with three replicates when sufficient elutriate could be prepared. For the second bioassay, unreplicated concentrations of 10%, 5%, 2.5% and 1% were prepared for most of the sites tested. Due to the limited quantity of sediments from most sites, the second elutriate bioassay used "refrozen" material. This was unused sediment left over from the first elutriate or the amphipod bioassays, which was refrozen within 24 hours of its original thawing. As a control for refreezing/rethawing, "new" Four Mile Rock sediment (an aliquot never thawed previously) was tested alongside refrozen/rethawed sediment from the same site.

9.3 Test Animal Collection and Handling

9.3.1 Oysters

Adult Pacific oysters (*Crassostrea gigas*) were collected intertidally from several areas. Sites of collection included; Mud Bay on South Puget Sound, Big Beef Creek on Hood Canal, Dungeness Spit on the Strait of Juan de Fuca, and Westcott Bay seed farms on San Juan Island. All adult oysters were transported to the West Point Laboratory in a "dry" condition and held a maximum of eight weeks in ambient flowing seawater until used for testing.

9.3.2 Sand Dollars

Sand dollars (*Dendraster excentricus*) were collected intertidally from South Alki Point on central Puget Sound, transported to the lab on sand covered with damp algae, and maintained on beds of sand in ambient flowing seawater. Ambient planktonic organisms in the seawater and detritus in the sand served as the only food sources.

9.3.3 Amphipods

The infaunal amphipod *Rhepoxynius abronius* (Phoxocephalidae, formerly named *Paraphoxus epistomus*) was collected subtidally at West Beach, Whidbey Island by towing a small benthic dredge along a transect parallel to shore at approximately 3-10 m depth. After capture, sediment was sieved underwater through a 1.0-mm screen to separate the amphipods from their native substrate. Amphipods were transported in approximately 5 cm of sand in covered 20-liter plastic buckets filled with seawater and placed on ice. At the lab, amphipods were held in 20-liter plastic buckets which received approximately 750 ml/minute of ambient flowing seawater and contained about 3-5 cm of West Beach sediment. Amphipods were held for 48 hr prior to use in the first bioassay to remove damaged individuals and to acclimate the amphipods to the test conditions.

9.3.4 Testing Procedures

9.3.4.1 Oyster Embryo Bioassays

For each embryo bioassay ten adult oysters were spawned by raising the water temperature to 28-30°C for 2-4 hours and then adding sperm from a sacrificed male to the water. Spawning normally occurred in 30-60 minutes in some of the conditioned oysters. The eggs were fertilized and added to the 500 ml test volumes at a density of approximately 25,000-35,000 per liter within two hours of fertilization. The embryos were incubated at 20°C for 48 hours. At the conclusion of each test a 10-ml subsample was removed from each beaker after thorough mixing and fixed with 10% formalin in glass test tubes.

Embryo samples were later examined under a compound microscope and tabulated for number of embryos in each sample and number of embryos failing to mature to the normal straight-hinge veliger stage (Woelke 1972).

9.3.4.2 Sand Dollar Sperm Bioassays

For each set of sperm bioassays male and female sand dollars were spawned separately by injecting approximately 0.5 ml of 0.5-molar potassium chloride (KCl) through the oral opening. The eggs were washed several times and adjusted to a density of 2,000/ml. The sperm from one male were mixed and subsampled; the subsample was killed in 10% acetic acid, counted with a hemacytometer at 400x magnification and diluted to a density of 2.0×10^7/ml. For each bioassay series 0.1 ml of the sperm solution (2.0×10^6 sperm) was added to each test tube and allowed to incubate at ambient seawater temperature (13.0 ± 1°C) for 60 min followed by addition of 1 ml of the egg solution (2,000 eggs) and further incubation for 20 min to allow fertilization of the eggs. The samples were then fixed with 10% formalin to arrest further fertilization and to preserve the samples until analyzed (Figure 9.4).

The exact sperm assay time schedule has been standardize as follows

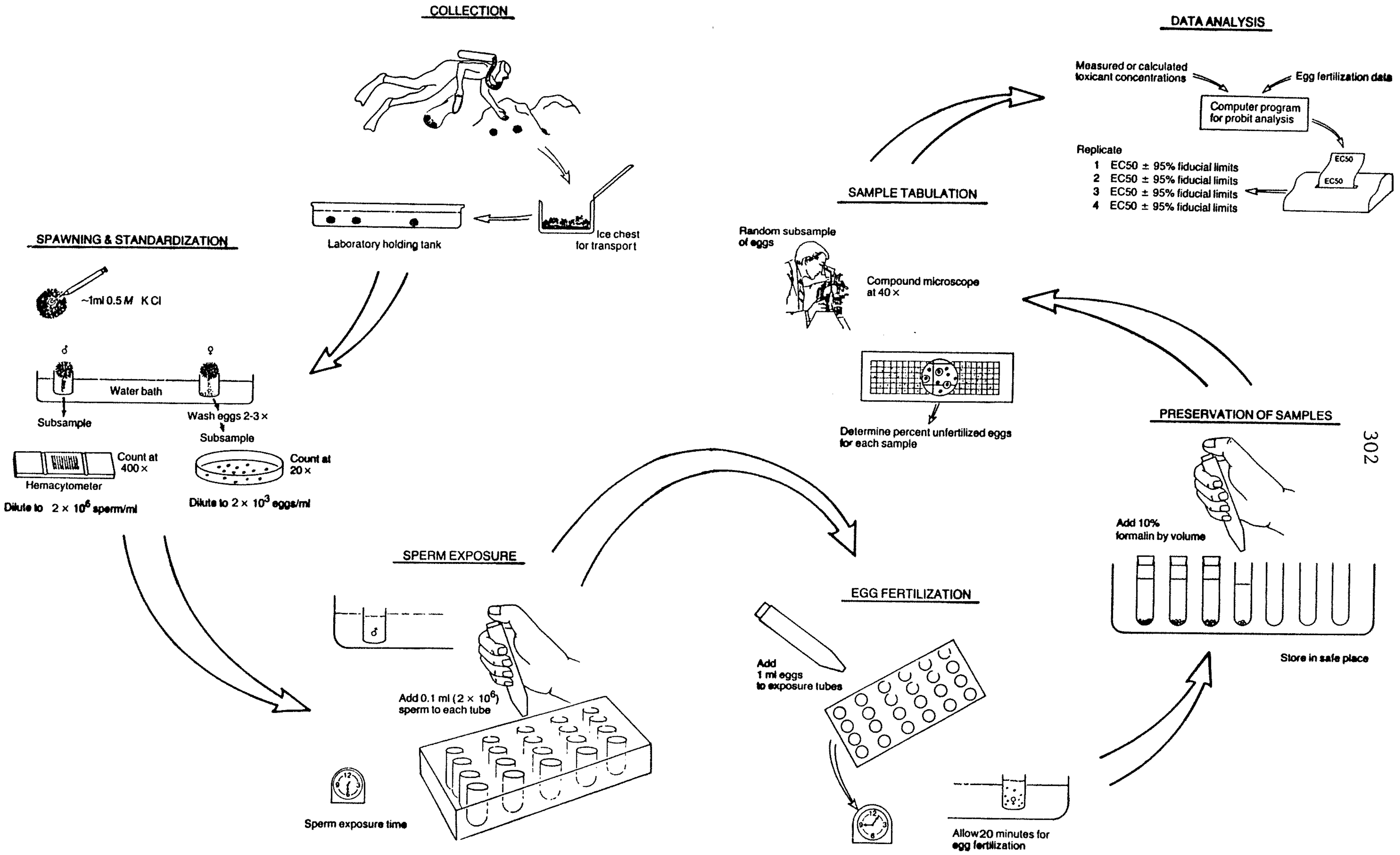

Figure 9.4. Sperm bioassay flow diagram (from Dinnel et al., 1983).

(Dinnel et al. 1983) (time in minutes).

T 0: spawn animals

T30: mix sperm, subsample for counts

T30-T150: wash eggs and dilute to 2,000/ml

T90: dilute sperm to 2×10^7 sperm/ml (density is species-dependent).

T120: Add 0.1 ml sperm solution to each test tube at 5 sec intervals.

T180: Add 1 ml of mixed egg solution to each test tube at 5 sec intervals.

T210: Fix each test tube with 10% formalin at 5 sec intervals and cork.

The sperm and egg densities cited above provide for a nominal sperm:egg ratio in each test tube of 1,000:1. For sand dollars this ratio optimizes the sensitivity of the test by assuring enough sperm to fertilize most eggs in the controls, but prevents the introduction of excess sperm which could reduce the test sensitivity (see Dinnel et al. 1983 for specific details regarding refined test methodology).

Later, samples were tabulated for percentage of fertilized eggs in the sample as indicated by the presence or absence of a normal fertilization (vitelline) membrane around each egg in a subsample of 100-200 eggs.

9.3.4.3 Amphipod-Sediment Bioassays

In general, bioassays were conducted in 15-liter aquaria each containing four replicate test chambers as in the Seahurst Baseline studies (Dinnel et al. 1984, Vol. X, in Stober and Chew 1984). Aquaria received ambient, filtered (5-um in-line filter) flowing West Point seawater at a rate of about 750 ml/minute.

Test chambers were constructed from 10-cm diameter polyvinyl chloride (PVC) pipe cut to 10-cm lengths. Two windows were cut in each 10-cm piece and Nitex screen (500-um mesh) glued around the outer circumference (Figure 9.5).

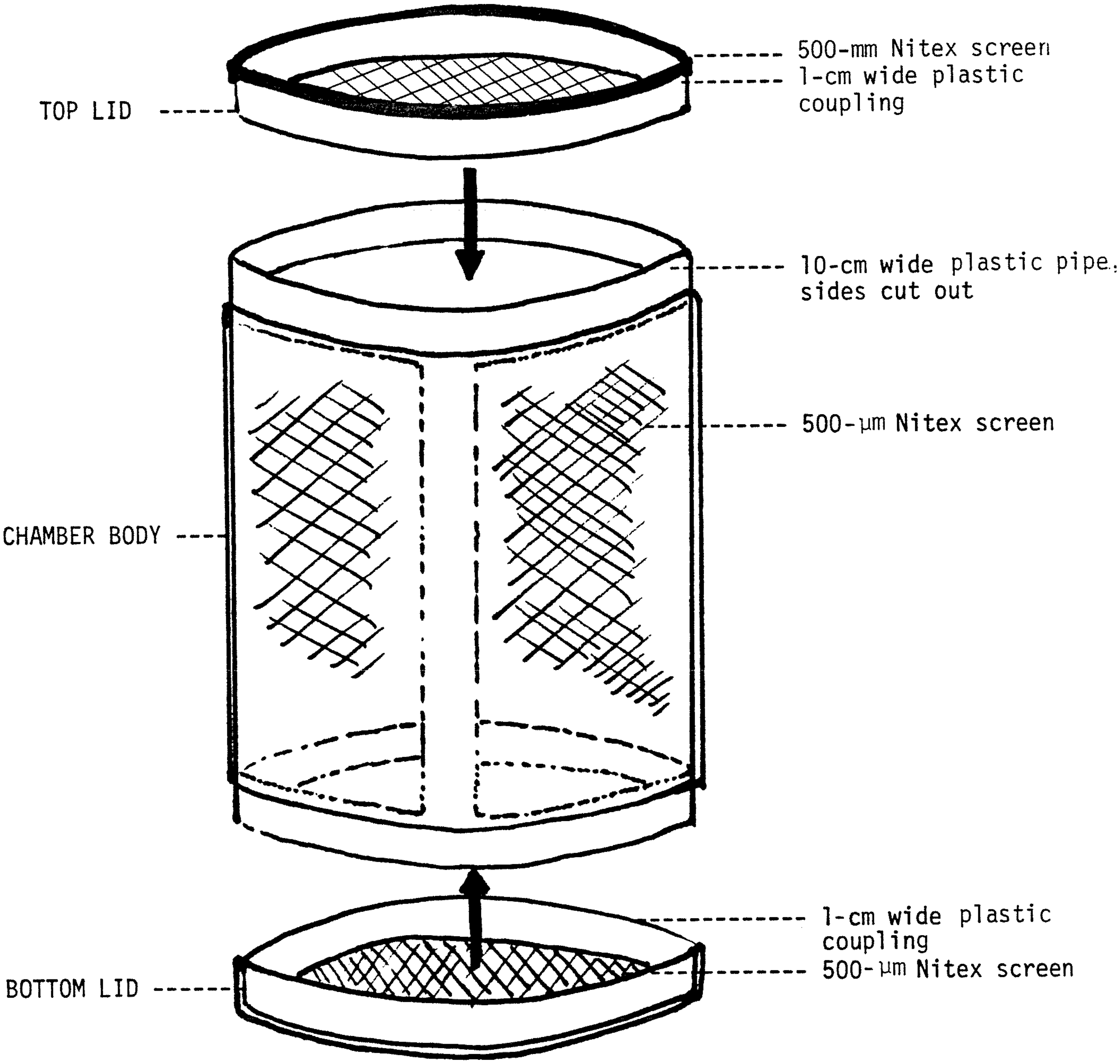

Figure 9.5. Amphipod-sediment bioassay exposure chamber.

The screen allowed water circulation through the test chambers. Close fitting lids for both ends of the test chambers were manufactured from 10-cm diameter PVC pipe coupling cut into 1.5-cm widths. Generally, the upper lid was covered with 500-um Nitex mesh and the lower lid (on which the sediment rested) with 37-um Nitex. All newly constructed or repaired test chambers and lids were aged in flowing seawater for several days prior to use in bioassays. Test sediment was placed inside the replicate chambers which were set on 1-cm diameter glass tubes to elevate the chambers above the aquarium bottom. This arrangement prevented test sediment from becoming anoxic by improving water circulation around the sediment.

Amphipods were screened (1.0-mm mesh) underwater from the holding buckets and 20 amphipods of a selected size range (2-3 mm) were placed in each of the four bioassay test chambers. The chambers contained 150 ml of test sediment (approximately 1.5 cm depth) and aquaria were held in an ambient seawater bath. With the exception of West Beach control sand, test sediments were not sieved prior to placing aliquots into each chamber. Bioassays were run for 10 days under a constant light regime.

Upon termination of an experiment, chamber contents were rinsed onto a 1.0-mm mesh screen and amphipods counted. Survivors were placed in petri dishes containing sieved (1.0-mm mesh) West Beach sediment and ambient filtered seawater. Amphipods incapable of burying in five minutes, even with gentle prodding, were considered moribund.

For sediment bioassays, water quality parameters recorded daily included temperature, pH, and salinity. Control sediments included West Beach, Duwamish South Harbor ("toxic" control) and Seahurst I690E. The latter was chosen as a trial "clean" fine-grained sediment control on the basis of results from the Seahurst Baseline studies (Dinnel et al. 1984, Vol. X, in

Stober and Chew 1984), which showed it to be the least contaminated of the very fine-grained sediments analyzed. Amphipod survival in this sediment was usually high (>85%) in those studies.

9.3.5 Data Analysis

9.3.5.1 Receiving Water Bioassays

The biological responses observed in the receiving water samples and the "secondary" control samples (carry-along, West Point filtered, and frozen Friday Harbor seawaters) were adjusted for average net response relative to the "primary" control water from Kincaid Hall.

Two indices were calculated for the oyster and sand dollar embryo assays; average percent mortality and average adjusted percent abnormal. The average mortality for each set of replicates (N=3) was determined by first calculating the arithmetic mean of the survival:

$$\text{Average survival} = \frac{X_1 + X_2 + X_3}{N}$$

where X = number of embryos in each replicate

N = number of replicates

and then determining the percent mortality relative to the average "primary" control survival:

$$\text{Percent embryo mortality} = 100 - \left[\frac{\text{Average Sample Survival}}{\text{Average Control Survival}}\right] \times 100$$

Positive mortality values indicate higher mortality than the control responses while negative values are indicative of better survival in the sample water.

The percent abnormal index was determined in much the same way as above except the weighted mean instead of the arithmetic mean was used to calculate average abnormal response in each set of replicates since the arithmetic mean tends to vary in relation to the degree of mortality in each set of replicates (Cardwell and Woelke 1979).

$$\text{Average weighted abnormal} = \frac{(X_1Y_1) + (X_2Y_2) + (X_3Y_3)}{X_1 + X_2 + X_3}$$

where X = number of embryos in each replicate

Y = number of abnormal embryos in each replicate

The <u>average</u> percent abnormal was then determined by:

$$\underline{\text{Average}}\ \text{percent abnormal} = \frac{\text{Average Weighted Abnormal}}{\text{Average Survival}} \times 100$$

Finally, the <u>adjusted</u> percent abnormal response for each set of replicates was established by adjusting for the "primary" control responses using Abbott's formula (Finney 1971):

$$\underline{\text{Adjusted}}\ \text{percent abnormal} = \frac{(\text{Ave. \% Sample Abnormal})-(\text{Ave. \% Control Abnormal})}{100 - (\text{Ave. \% Control Abnormal})} \times 100$$

Again, the adjusted percent abnormal values may be either positive or negative since they are entirely relative to the "primary" control responses.

The sperm assay responses in the receiving water samples and the "secondary" control samples were also related to the "primary" control responses in much the same way as detailed for the embryo indices above. Specifically, the arithmetic mean was calculated for each set of replicates (sample and control) to yield an <u>average</u> percent response (percent eggs unfertilized) for each set. These responses were then adjusted to the "primary" control response using Abbott's formula:

$$\frac{\text{Adjusted percent}}{\text{Eggs unfertilized}} = \frac{(\text{Ave. \% Sample Unfert.})-(\text{Ave. \% Control Unfert.})}{100 - (\text{Ave. \% Control Unfert.})} \times 100$$

to again yield either a positive or negative value.

9.3.5.2 Sewage Bioassays

Renton sewage bioassays were designed to yield an average EC50 (concentration of sewage equivalent to a 50 percent effective response) for each type of sewage tested based on a series of repetitive tests with oyster embryo, sand dollar embryo, and sand dollar sperm bioassays.

Three bioassays (N=2 for oyster assays - one test did not achieve spawning) were conducted which tested ten dilutions of sewage (0.41, 0.64, 1.0, 1.5, 2.3, 3.6, 5.5, 8.4, 13.0, and 20.0 percent by volume sewage in seawater). The average responses for each test type at each sewage concentration over the repetitive tests were designed to be calculated by methods similar to those discussed above and the responses adjusted for the controls (in this case West Point filtered seawater, as this was used for the sewage dilution water). The average adjusted responses were then used to calculate the average EC50's using a computer program (BMDO3S) for probit analysis (a type of non-linear regression analysis) (Finney 1971) with an attached FORTRAN program to calculate 95 percent fiducial limits by the method of Litchfield and Wilcoxon (1949).

9.3.5.3 Sediment Elutriate Bioassays

Data from the sediment elutriate bioassays was handled as described above for sewage bioassays.

9.3.5.4 Amphipod-Sediment Bioassays

Baseline sediment bioassay data were generated as proportions F1/N and F2/F1, where N = total number of amphipods, F1 = total number of survivors (number able to rebury plus number unable to rebury), and F2 = number of moribund (number unable to rebury). The fractions which yielded proportion of survivors and proportion of moribund, respectively, were transformed ($X' = \arcsin \sqrt{x'}$) to obtain a more normal distribution of the variances (Zar 1974). Data were then analyzed by a one-way analysis of variance (ANOVA) to test for differences in survival between sediments (Zar 1974). If ANOVA results were significant at $p = 0.05$, data were further analyzed by Dunnett's test (Zar 1974) to determine which survival means differed from the mean of the West Beach controls and the Seahurst I690E fine sediment controls at $p = 0.05$.

Simple linear regressions were calculated with the arcsin transformed survival means against the sediment chemistry data. Regressions included five different grain size characteristics (gravel, sand, silt, clay and mean phi: arcsin transformed percentages), as well as oil and grease, volatile solids, carbon, nitrogen, biochemical oxygen demand (BOD), arcsin transformed percent water, and depth.

9.4 Results

9.4.1 Receiving Water Bioassays

Bioassays of receiving water from one to five depths at each of the sampling stations were performed weekly (monthly at station 24). Samples were completely analyzed only for the week of 23 July, 1984, due to early termination of the baseline studies. Results from this bioassay are presented in Table 9.1. No trends or differences are apparent based on the one bioassay from this date.

Table 9.1. Results of the one analyzed sand dollar sperm bioassay of 1984 receiving water stations in and around Elliott Bay, WA.

Date	Station	Depth (meters)	Adjusted mean % eggs unfertilized
7-23	21	0	3.5
		100	-0.2
		200	0.4
	22A	0	1.8
		150	0.0
		175	4.6
	22B	0	-0.5
		50	0.3
		100	2.8
		150	1.4
		175	0.6
	23	0	5.1
		65	2.5
	24	0	1.6
		50	1.4
		200	-0.6
	Kincaid Lab	-	0.0
	Kincaid Carry-Along	-	0.9
	Friday Harbor	-	0.2
	West Point	-	4.2

Preliminary post-inoculation counts and/or control responses from several of the receiving water bioassays are shown in Table 9.2 as an indication of the dates for which "good" bioassays (acceptable control survival, etc.) would have been available should these studies have been extended.

9.4.2 Sewage Bioassays

Oyster embryo control mortality was unacceptably high in each of the three tests of Renton sewage. Because of this, the primary goal of these sewage tests - side by side comparison of the relative sensitivities of oyster embryos vs. sand dollar embryos - could not be realized. Consequently, most of the samples from these tests were not analyzed. Results from the two bioassays that were completely read for sand dollar sperm embryos are shown in Table 9.3.

9.4.3 Sediment Elutriate Bioassays

Oyster control mortality in the two elutriate bioassays was unacceptably high. Results are therefore presented for the sand dollar sperm and embryo bioassays for the first elutriate test, and only the sand dollar embryo bioassay for the second elutriate test. Raw data for sand dollar embryos are given in Appendix Table 9.2.

First Elutriate Test

Results from the first elutriate test - a range finding experiment in which all sites were tested, most at only one concentration - are presented in Tables 9.4 and 9.5, and in Figures 9.6 and 9.7.

The sand dollar sperm assay responded over the entire broad range of concentrations tested (0.17 to 33.3 percent elutriates), by volume (Table 9.4, Figure 9.6). Among the sediments producing the greatest effects (highest percent unfertilized eggs) were those from the "clean" fine-grained control sediment (Seahurst I690E) and the "clean" (West Beach) control sand,

Table 9.2. Some preliminary control responses for receiving water bioassays that were otherwise not completely analyzed.

Date	Bioassay	Water source	% survival	% abnormal	% unfertilized eggs
7-23-84	Sand dollar sperm	- See Table 12.1			
	Sand dollar embryo	WP	88.6	5.3	-
	Oyster embryo	KL	110.6	3.7	-
7-30-84	Oyster embryo	KL	90.7	3.1	-
8-6-84	Sand dollar sperm	KL	-	-	15.1
	Sand dollar embryo	Sta 21/0 m	107.0	4.1	-
	Oyster embryo	KL	73.3	2.2	-
8-13-84	Oyster embryo	KL	79.7	4.4	-
8-20-84	Sand dollar embryo	25.5%	91.3	1.6	-
	Oyster embryo	KL	58.5	7.4	-
9-4-84		- No samples analyzed -			
9-11-84	Oyster embryo	KL	50.4	12.3	-
9-17-84		- No samples analyzed -			

WP = West Point control water
KL = Kincaid Lab control water
25.5% = A lowered salinity WP control water

Table 9.3. Comparison of the 50% effective concentrations (EC50's) and 95% fiducial limits for sand dollar sperm and embryo bioassays of five stages of sewage and equivalent freshwater dilutions of seawater from the Renton Treatment Plant, 24 August, 1984.

Renton sewage stage	EC50 (95% fiducial limits) as % sewage, vol:vol	
	Sand dollar sperm	Sand dollar embryos
Influent	9.4 (3.6-24.4)	12.4 (11.8-13.0)
Primary	5.1 (1.0-25.7)	14[a] (-)
Secondary	>20.0	15.9 (-)
Chlorinated Secondary	2.9 (2.8-3.1)	12.6 (11.9-13.2)
Dechlorinated Secondary	>20.0	16.2 (-)
Freshwater dilutions	>20.0	>20.0

[a] EC50 estimated graphically by log-probit plot of the data.

Table 9.4. Results of sand dollar sperm bioassay of sediment elutriates from stations in and around Elliott Bay, WA. Elutriate test No. 1, 26 September, 1984.

Station	Elutriate concentration (% by volume)	Mean % unfertilized eggs (unadjusted)[a]
Kincaid Lab water	-	1.7
Seahurst I690E (131)	33.3	100.0
	16.6	98.7
	8.3	89.5
	1.7	45.1
	0.17	36.4
Duwamish South Harbor (133)	16.6	99.5
	8.3	88.0
	1.7	40.6
	0.17	26.0
101	33.3	100.0
	16.6	96.1
	8.3	46.4
	1.7	20.8
	0.17	3.7
West Beach (132)	33.3	92.3
	16.6	93.5
	8.3	76.6
	1.7	54.8
	0.17	5.0
134	33.3	52.0
	16.6	15.1
	8.3	13.5
	1.7	5.2
	0.17	3.1
135	33.3	98.1
	16.6	37.8
	8.3	30.3
	1.7	3.7
	0.17	5.1

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a) Primary control water for this assay was West Point dilution water. West Point water samples were not analyzed, therefore only raw or unadjusted responses are presented here.

Table 9.5. Responses of sand dollar embryos sediment elutriates from stations in and around Elliott Bay, WA. Elutriate test No. 1, 26 September, 1984.

Station	Mean adjusted % abnormality (16.6% elutriate)	EC50 (% elutriate, by volume)[a]
West Point control water	0.0	
Kincaid Lab water	4.0	
Friday Harbor water	1.8	
Seahurst I690E (131)	38.1[b]	>16.6
West Beach Sand (132)	2.6[b]	>16.6
Duwamish South Harbor (133)	99.8[b]	4.7
101	100.0[b]	3.3 < EC50 < 16.6
104	21.3	
105	100.0	
106	20.1	
107	26.8	
108	46.7	
109	100.0	
110	53.9	
111	88.9	
112	62.2	
113	77.0	
114	100.0	
115	100.0	
116	99.6	
117	100.0	
118	25.2	
119	11.2	
120	100.0	
121	87.1	
122	100.0	
123	97.8	
124	97.6	
125	78.4	
126	81.2	
127	25.2	
128	59.1	
129	90.6	
130	100.0	
134	97.8[b]	10.2
135	100.0[b]	5.8

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[a] EC50's calculated only for stations tested in dilution series.

[b] Tested in a dilution series including 16.6, 3.3, 1.7, and 0.17 percent elutriates, by volume.

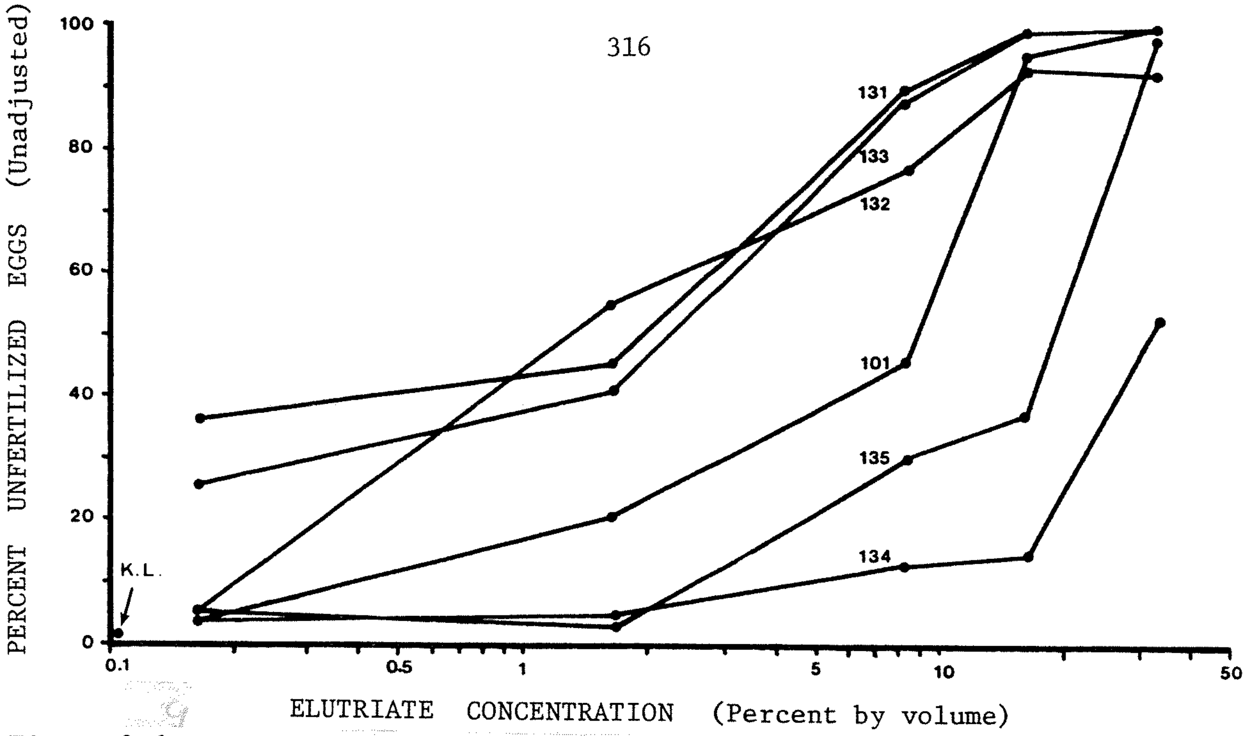

Figure 9.6. Fertilization success of sand dollar sperm exposed to sediment elutriates from in and around Elliott Bay, WA. Elutriate test No. 1, 26 September, 1984 (see text for station location/descriptions). K.L. = Kincaid Lab control seawater. Stations 131 and 132 are Seahurst I690E and West Beach "clean" control sediments, respectively, and Station 133 is Duwamish South Harbor "toxic" control sediment.

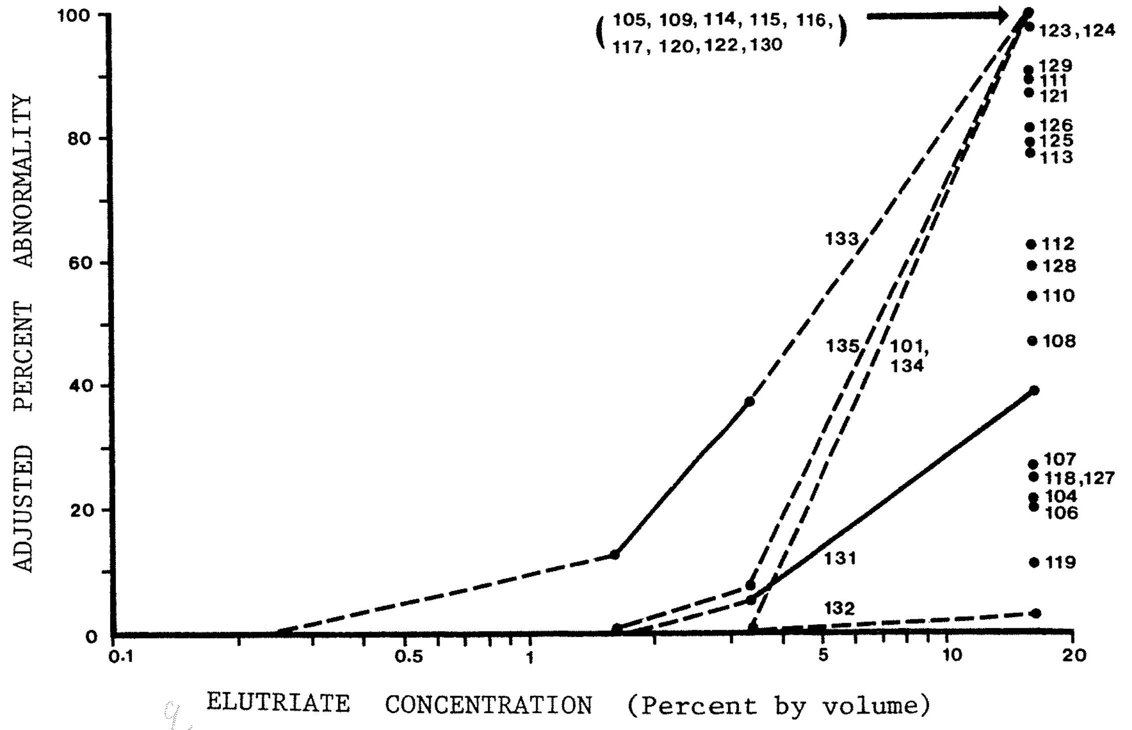

Figure 9.7. Adjusted percentage of abnormal sand dollar embryos exposed to sediment elutriates from in and around Elliott Bay, WA. Elutriate test No. 1, 26 September, 1984 (see text for station location/descriptions). Stations 131 and 132 are Seahurst I690E and West Beach "clean" control sediments, respectively, and Station 133 is Duwamish South Harbor "toxic" control sediment.

respectively. Some of the more heavily polluted sediments (i.e., stations 101, 134, and 135) gave much lower responses. Apparently, sperm were affected in these elutriates at least in part by some factor other than chemical contamination. Consequently, the remaining sites that were not tested with the broad range of concentrations were not analyzed, and the sperm bioassay was not repeated during the second elutriate test.

Sand dollar embryos, on other hand, responded much differently (Figure 9.7, Table 9.5). Elutriate from West Beach sand did not affect survival or development of the embryos at the highest concentration tested (16.6% by volume). Similarly, Seahurst I690E sediment elutriate produced much lower effects (about 38% abnormality in 16.6% elutriate, and no effect at lower concentrations) compared to sites suspected before testing of being chemically contaminated (stations 101, 133, 134, and 135). These contaminated sites all produced nearly 100% abnormality in 16.6% elutriates, and varying abnormalities in 3.3% elutriates. One of these, site 135 (Four Mile Rock disposal site), also produced high mortality (81%) in the highest concentration. Three of the sites tested at only one concentration also produced high mortality, in addition to high abnormality. These included 117 (64.8% mortality), 124 (80.6%), and 130 (70.0%). Based on abnormality, the order of toxicity of elutriates from the sites bioassayed in the first elutriate test is: Duwamish South Harbor > 135 > 101 and 134 > Seahurst I690E > West Beach.

Analysis of variance determined all sites to exhibit significantly different mean abnormality rates compared to the West Beach control station. West Beach sand on the other hand, was not significantly different from any control water.

For nearly all stations organic priority pollutants (Appendix Table 9.4), trace metals (Appendix Table 9.5) and other parameters (BOD, oil and grease, grain size, etc.) (Appendix Table 9.6) were analyzed. Integration of these data with elutriate bioassay responses could not be completed, but certain trends emerge.

Principal component analysis (PCA) was performed on the organic priority pollutant data. Table 9.6 lists the composition of the 14 resulting "factors". From this information, "Bray-Curtis" cluster analysis grouped the stations, primarily on the basis of concentration (i.e., overall organic priority pollutant contamination) (Figure 9.8). Analysis of variance was performed comparing mean adjusted percent abnormal sand dollar embryos for each site (at 16.6% elutriate concentration) against the station groups from the cluster analysis. Mean abnormalities for each of the four major cluster groups were significantly different from the control (station 132). Dunnets' test (1-tailed, p=0.05) separated group "one" as having a lower mean abnormality rate than the other three groups (Figure 9.8). Further, there was a significant trend for increasing abnormality with increasing overall concentration of organic pollutants (linear regression, percent abnormality vs. summed organics concentration for each site; $r = 0.684$, $p < 0.01$).

Similar analyses (PCA, followed by Bray-Curtis clustering and analysis of variance with bioassay responses) were performed for trace metals data (see Appendix Table 9.5). The PCA determined the "factors: shown in Table 9.7. Figure 9.9 shows the Bray-Curtis cluster groups based on PCA with the "full list" of 14 metals analyzed:

Ag, Al, As, Be, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, V, and Zn.

Clusters were also determined based on PCA with an "abbreviated list" of nine of the most toxicologically significant metals analyzed (Figure 9.10):

Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn.

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Table 9.6. Organic chemical composition of the 14 principal components for sediments from stations in and around Elliott Bay, WA.

Factor	N	
1	17	2-4-Dinitrotoluene, Acenaphthene, Anthracene, Benzo(a) anthracene, Benzo(a) pyrene, Benzo(a) fluoranthene, Benzo (g-h-i) perylene, Benzo(k) fluoranthene, Chrysene, Dibenzo (a-h) anthracene, Fluoranthene, Fluocene, Indeno (1-2-3-C-D) Pyrene, Naphthalene, Nitrobenzene, Phenanthrene, Pyrene
2	5	2-4-Dimethylphenol, Acenaphthylene, Carbon tetrachloride, Toluene, Ethylbenzene
3	5	Di-*n*-butylphthalate, 1-1-Dichloroethylene, Benzene, Chlorobenzene, Trichloroethylene
4	4	2-4-6-Trichlorophenol, 4-Chloro-3-methyl phenol, 4-Nitrophenol, Dichlorobiomoethane
5	5	Phenol, Di-octyl phthalates, 4-4-DDE, Aroclor 1254, Aroclor 1260
6	3	1-4-Dichlorobenzene, Aroclor 1242, Aroclor 1248
7	2	Dimethyl phthalate, Chloroform
8	3	1-2-*Trans*-Dichloroethylene, Chlorodibromoethane, Tetrachloroethylene
9	1	1-2-Dichlorobenzene
10	2	1-1-2-Trichloroethane, 1-1-Dichloroethane
11	2	Pentachlorophenol, Diethyl phthalate
12	2	Nitrophenol, 1-1-1-Trichloroethane
13	2	1-2-Dichloroethane, Methylene chloride
14	1	Bromoform

N = Number of organic chemicals in each factor.

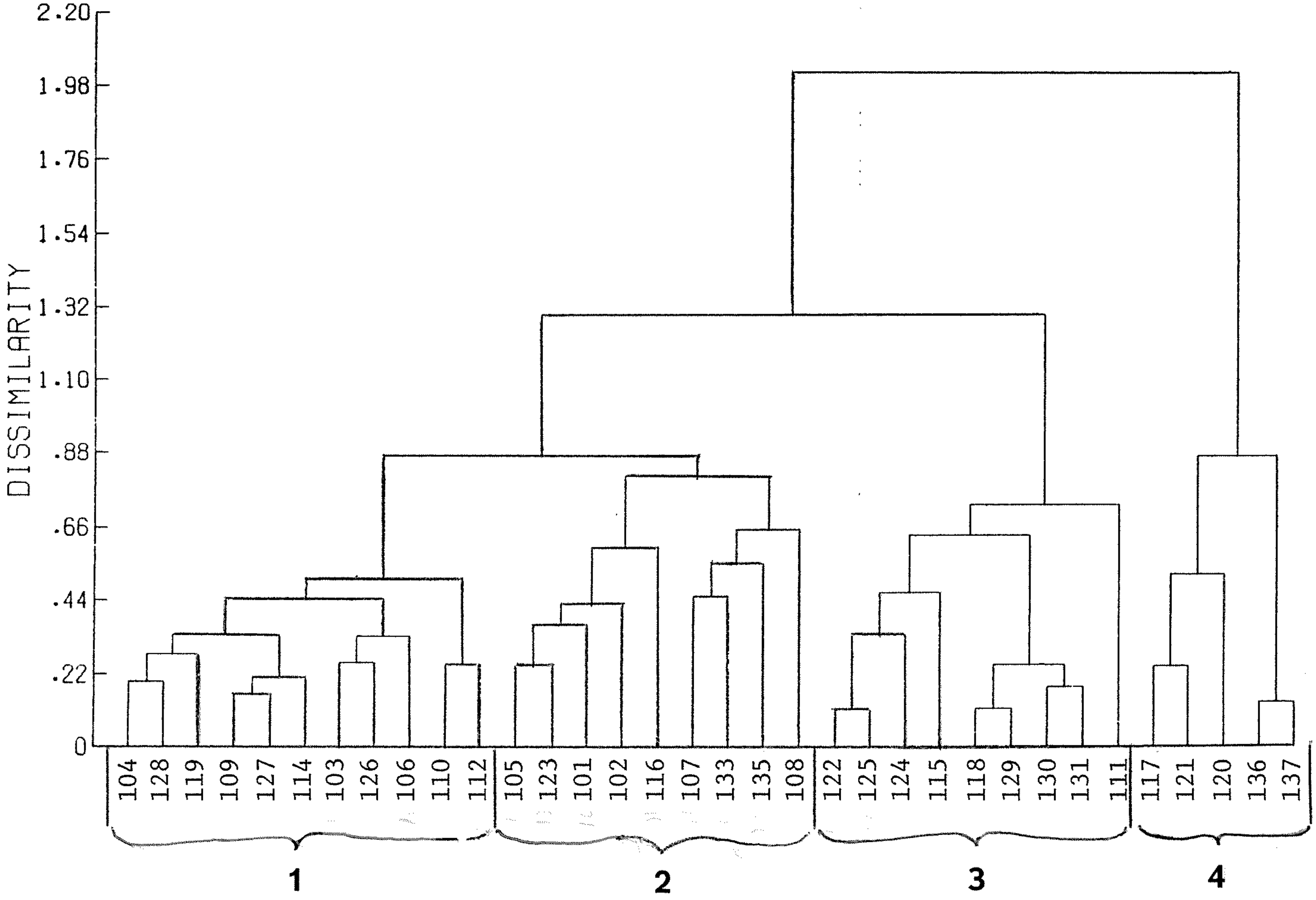

Figure 9.8. "Bray-Curtis" cluster of subtidal sediments used in toxicity bioassays, based on organic priority pollutant loading; groups are ranked in order of increasing contamination.

Table 9.7. Heavy metal composition of the principal components for sediments for stations in and around Elliott Bay, WA. A) "Full list" - five principal components. B) "Abbreviated list" - four principal components.

A) <u>"Full list" of metals</u>:

Factor	N	
1	4	beryllium, copper, nickel, vanadium
2	3	aluminum, arsenic, mercury
3	3	chromium, copper, lead
4	2	manganese, zinc
5	2	cadmium, silver

B) <u>"Abreviated list" of metals</u>:

Factor	N	
1	4	chromium, copper, lead, zinc[a)]
2	2	mercury, arsenic
3	3	nickel, cadmium, zinc[a)]
4	1	silver

Notes: a) zinc grouped with both factor 1 and factor 3.

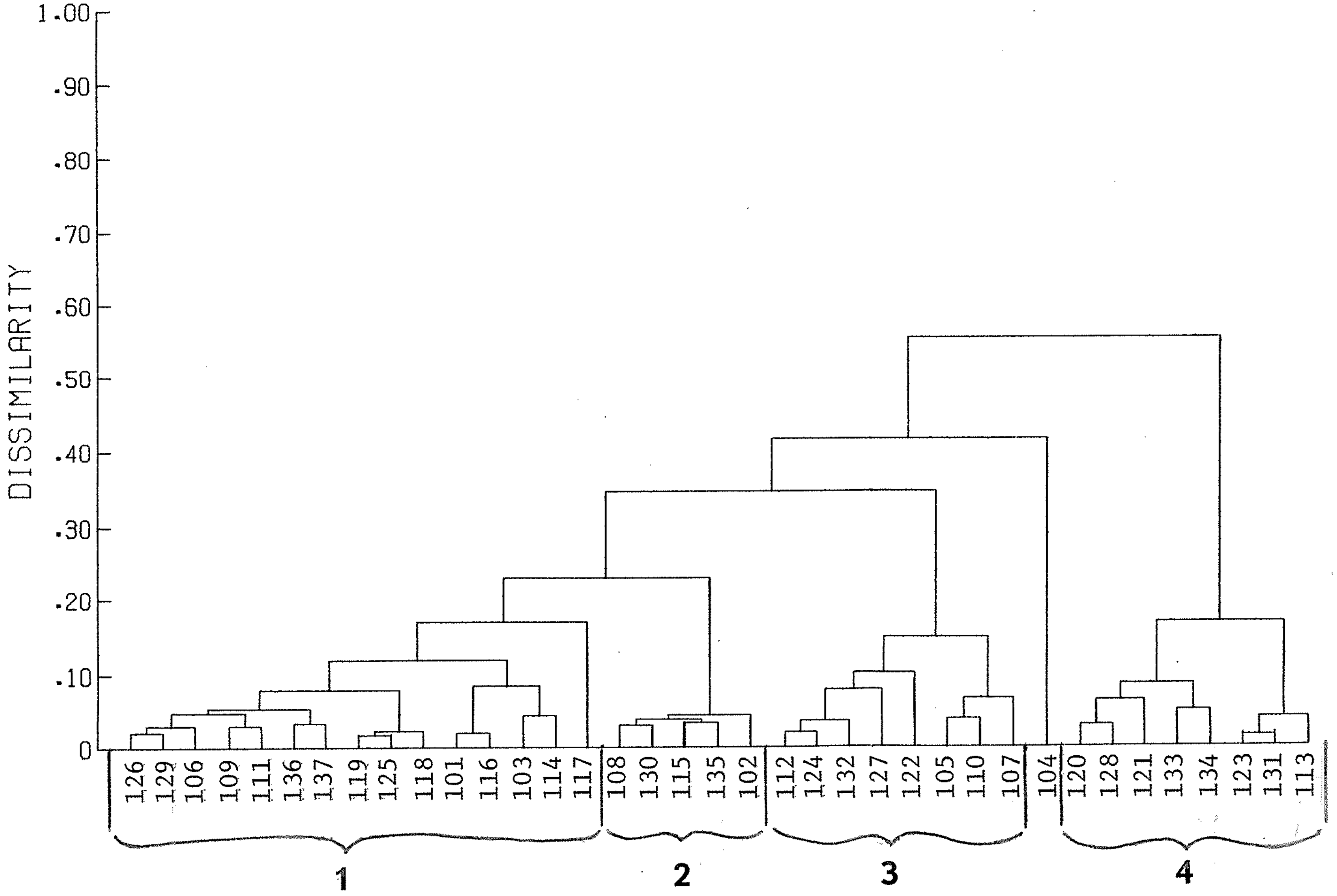

Figure 9.9. "Bray-Curtis" cluster of heavy metals in subtidal sediments used in toxicity bioassays: based on the "full list" of 14 metals analyzed.

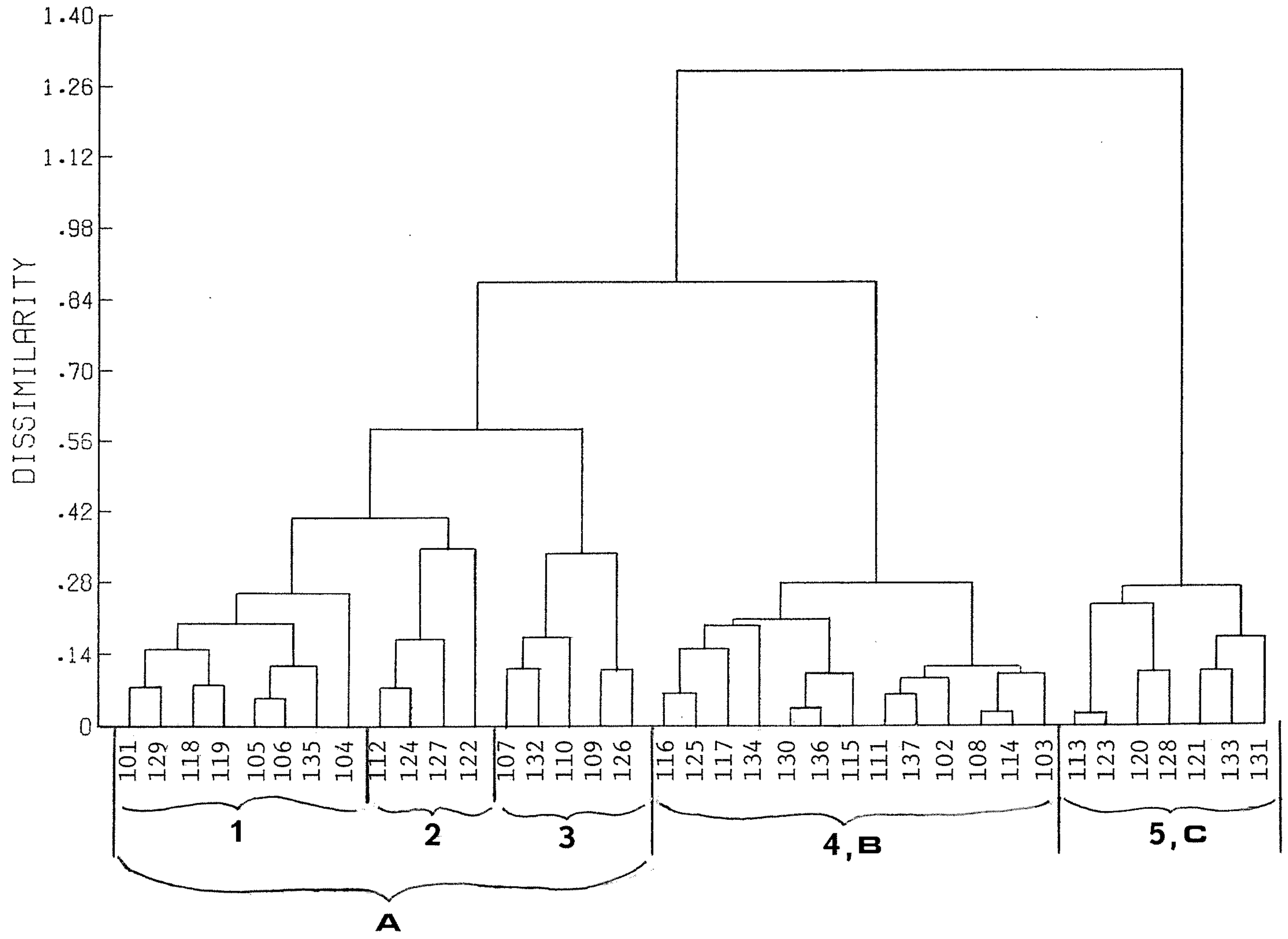

Figure 9.10. Bray-Curtis cluster of heavy metals in subtidal sediments used in toxicity bioassays: based on an "abbreviated list" of nine of the most toxicologically significant metals analyzed. Alternate grouping schemes shown did not affect ANOVA against biological responses.

Analysis of variance revealed no significant differences in amphipod survival or sand dollar embryos abnormalities among the cluster groups based on either the "full list" or the "abbreviated list" of metals.

In addition to these analyses, simple linear regressions were performed comparing sand dollar embryo responses in sediment elutriates with the "Other Sediment Parameters" given in Appendix Table 9.6. Responses did not significantly correlate (at p = 0.05) with particle size characteristics, oil and grease, volatile solids, biochemical oxygen demand, carbon, nitrogen, or dry/wet weight ratio (Appendix Table 9.7A). A significant negative correlation with depth, explaining about 14% of the variation in response, was detected however.

Based on these analyses of the chemical data, it is reasonable to conclude that sand dollar embryos responded in a manner generally related to the overall organic priority pollutant contamination of the sediments from which the elutriates were prepared - i.e., that chemical toxicity was indeed being measured. (Undoubtedly, trace metal concentration contributed to the observed effects, though not in any one manner that could be easily identified by the types of analyses performed.) Consequently, results from the sites which were tested only at the highest concentration (16.6%), represent a first-cut ranking of the chemical toxicity of elutriates from those sites. As can be seen in Figure 9.7, the 16.6% elutriates from over half of these sites did indeed produce intermediate levels of effect on sand dollar embryos, grading from about 11% to over 99% adjusted abnormality. In addition, several sites produced 100% abnormality. These more toxic sediments could not be distinguished from each other (or the other toxic sites tested in the dilution series, such as Duwamish South Harbor or Four Mile Rock) on the basis of a single concentration bioassay. It was decided, therefore, to perform a second bioassay with these sediments using multiple concentrations.

Second Elutriate Test

For most of the stations used in the second elutriate bioassay, only previously thawed sediment was available for testing. This was material remaining in the bags after aliquots were removed for earlier testing (in the amphipod or first elutriate bioassay), and which was refrozen within 24 hours of its original thawing. Because the effects of refreezing sediment were unknown, station 135 (Four Mile Rock) was bioassayed both once-frozen, as were all sites in the first elutriate bioassays, and refrozen. West Beach sand was included as an uncontaminated "refrozen" elutriate control.

Results from the second elutriate bioassay are presented in Table 9.8. Two general outcomes of this test are important. First, the responses in elutriate from West Beach sand were significant: 42.5 percent adjusted abnormality in 10 percent elutriate. An EC50 of 10.4% elutriate was calculated for this site. Also, sediment from station 135 (Four Mile Rock) had EC50's of 20.9 and 6.6 percent for once-frozen and refrozen samples, respectively. Both "clean" and contaminated sediments were apparently made more toxic by the process of thawing, refreezing, and rethawing; in other words, responses unrelated to chemical contamination alone occurred. Most sites, therefore, could not be distinguished as being toxic in this second test. However, two sites stood out. Stations 117 and 120, both shallow (15.2 m) stations near the mouth of the Duwamish West Waterway, produced 100% abnormality in 10% and in 5% elutriates. These responses were much greater than can be explained by a refreezing effect alone. Furthermore, these responses were much greater than those in Duwamish South Harbor ("toxic" control) sediment which was also tested refrozen (Table 9.6). On this basis, stations 117 and 120 would appear to produce the most toxic elutriates of all

Table 9.8. Comparison of the 50% effective concentrations (EC50's) for sand dollar embryos in sediment elutriates from stations in and around Elliott Bay, WA. Elutriate test No. 2, 22 October, 1984.

Station	Sediment type[a]	EC50 (% elutriate by volume)
West Beach (132)	refrozen/rethawed	10.4
Duwamish S. Harbor (133)	refrozen/rethawed	14.4
103[b]	refrozen/rethawed	9.8
105	refrozen/rethawed	13.9
109	refrozen/rethawed	>10.0
114	refrozen/rethawed	>10.0
115	refrozen/rethawed	>10.0
116	refrozen/rethawed	7.8
117	refrozen/rethawed	3.0
120	refrozen/rethawed	2.5 < EC50 < 5.0
122	refrozen/rethawed	<10.0
123	refrozen/rethawed	13.3
124	refrozen/rethawed	<10.0
130	refrozen/rethawed	<10.0
135	refrozen/rethawed	6.6
135	frozen (not previously thawed)	20.9

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[a] All sediments were originally frozen. Most in this test were thawed, refrozen and rethawed before elutriates were prepared.

[b] Not tested in elutriate test No. 1 (i.e., only tested refrozen/ rethawed).

the stations sampled.

The second aspect of this test is that the overall sensitivity of the sand dollar embryos was lower than during the first test. This can be seen by comparing the once-frozen sediment from site 135 in both tests. Calculated EC50's are 5.8% elutriate in the first test versus 20.9% in the second. This lower sensitivity could be related to the fact that the second test was performed at the end of the natural spawning season for sand dollars. Indeed, only extra individuals which had been held under relatively constant conditions in the lab since the first bioassay, spawned for the second. Adults collected from the field after the first elutriate bioassay had already spawned naturally. The ambient temperature for the second bioassay was slightly lower (9.5 vs. 13.1°C), which could also have affected overall sensitivity of the embryos.

9.4.4 Amphipod - Sediment Bioassays

The responses of amphipods to the sediment samples tested are presented in Table 9.9. Analysis of variance showed there to be no signficant differences ($p = 0.05$) in amphipod survival for any of the sediments when all were included in the analysis. However, Ott (in preparation) observed a threshold response for survival of *R. abronius* tested in clean foundry sands ground to 30 um mean particle diameter. Therefore, the 6 stations having a mean particle size of greater than 30 um (mean phi < 5.0) were reanalyzed separately from those stations having a finer particle size. Coarse sediments were compared to West Beach sand, and fine sediments were compared to the Seahurst I690E sediment. Analysis of variance showed that there were significant differences among the coarser-grained sites. Dunnets' test (Table 9.10) determined that only station 135, the Four Mile Rock disposal site had significantly reduced survival relative to West Beach control sand. Survivals

Table 9.9. Responses of amphipods exposed to sediments from stations in and around Elliott Bay, WA. (20 amphipods/chamber, 4 chambers/treatment).

Station[a]	$\bar{X}$ No. alive (S.D.)	$\bar{X}$ % survival	$\bar{X}$ % moribund
121	19.75 (0.05)	98.75	0.0
117	19.25 (1.50)	96.25	3.8
West Beach[b]	18.50 (1.93)	92.50	0.6
120	18.50 (1.73)	92.50	0.0
124	17.50 (1.00)	87.50	0.0
115	17.25 (1.89)	86.25	1.3
103	16.75 (2.50)	83.75	0.0
123	16.75 (2.20)	83.75	0.0
119	16.75 (3.20)	83.75	3.8
127	16.25 (3.86)	81.25	0.0
126	16.25 (1.71)	81.25	0.0
111	16.25 (1.26)	81.25	1.3
110	15.75 (3.40)	78.75	2.5
134	15.75 (2.87)	78.75	0.0
116	15.75 (1.26)	78.75	0.0
105	15.50 (1.29)	77.50	1.3
Seahurst I690E[c]	14.50 (2.20)	72.50	0.0
Duwamish S. Harbor[d]	14.50 (4.69)	72.50	2.5
130	14.25 (2.99)	71.25	1.3
125	14.25 (0.96)	71.25	0.0
112	14.00 (2.00)	70.00	2.5
108	13.75 (1.25)	68.75	0.0
101	13.75 (1.26)	68.75	5.0
107	13.25 (2.20)	66.25	5.0
122	13.25 (2.36)	66.25	3.8
106	12.75 (3.50)	63.75	1.3
104	12.50 (4.35)	62.50	0.0
135	12.50 (5.90)	62.50	0.0
129	12.50 (2.40)	62.50	1.3
128	11.75 (5.25)	58.75	1.3
113	11.50 (2.89)	57.50	1.3
109	11.25 (1.71)	56.25	2.5
118	11.00 (2.70)	55.00	1.3
114	10.25 (2.75)	51.25	1.3

Notes:

a) See text and Appendix Table 12.1 for station location/descriptions.

b) Clean native sand control.

c) "Clean" fine-grained sediment control.

d) "Toxic" control.

Table 9.10. Comparison of amphipod survivals in selected sediments from stations in and around Elliott Bay, Wa. Only sediments having a mean particle diameter >30µm (mean phi <5.0) are compared to the West Beach sand control (Station 132). Finer-grained stations were not significantly different from the fine-grain sediment control (station 131), and were not further analyzed. Bar indicates non-significantly different from control (Dunnet's test, p = 0.05).

Station	Mean Phi Size	Mean Percent Survival
121	3.66	98.75
117	3.92	96.25
West Beach Sand (132)	2.23	92.50
120	4.64	92.50
124	3.82	87.50
135	____ a)	62.50

a) Particle size analysis was not performed during this project for this site; analyses performed previously (J. Strand, Pers. Comm.) showed sites 135 to be composed of 82.2 percent sand.

in none of the fine sediments were significantly different from the Seahurst I690E sediment. Survival in many of the fine sediments was significantly different from that in West Beach control sand (see Discussion). Also, there were significant correlations between survival and grain-size measurement, depth, dry/wet weight ratio, nitrogen, and biochemical oxygen demand (Appendix Table 9.7B). Survival also positively correlated with summed organic priority pollutants (Appendix Table 12.7B).

9.5 Discussion

9.5.1 Water Column Toxicity

Too few water column bioassay results were analyzed to arrive at any conclusions for Elliott Bay area stations. Each of the eight test dates resulted in "good" tests (acceptable control responses, based on preliminary counts) for every bioassay checked. The unanalyzed samples represent a valuable baseline data set and extend the historic baseline data set of the Washington State Department of Fisheries. Special care, however, would be required to preserve the unread samples if they were to be stored for an appreciable length of time. Even then, sperm bioassay samples would probably be lost due to the increasing fragility of the fertilization membrane with time. Sand dollar and oyster embryo samples could, with proper storage, be archived much longer.

9.5.2 Sewage Toxicity

Results from the Renton sewage bioassays analyzed are in good agreement with those performed in 1982 and in 1983 (Dinnel et al. 1984, Vol. X, in Stober and Chew 1984). These data provide valuable information in two important ways. First, they serve to calibrate the other sand dollar sperm and embryo bioassays performed during this project by showing that the general sensitivity of those bioassays was high and was similar to previous tests.

Second, they compare the relative sensitivity of the sand dollar sperm and sand dollar embryo bioassays, and, through comparison with Seahurst results (Dinnel et al. 1984, Vol. X, *in* Stober and Chew 1984), suggest that the sand dollar embryo bioassay is similarly sensitive to other echinoderm embryo bioassays. Due to unacceptably high oyster embryo control mortalities, no direct comparison can be made with this bioassay. The difficulty of procuring well conditioned adult oysters in 1984 (see discussion below) underlines the practical utility of the echinoderm bioassays in general. It also speaks for the importance of further work to define the relative sensitivity of these tests so that acceptable, comparable, bioassay material is available at all times of the year.

9.5.3 Sediment Toxicity

Several bioassays were performed in these baseline studies which attempted to define the relative acute toxicity of sediments from within and near Elliott Bay. Sediments were tested both in the solid phase (with the amphipod, *Rhepoxynius abronius*) and as liquid phase elutriates (with sperm and embryos of the sand dollar, *Dendraster excentricus*, and embryos of the Pacific oyster, *Crassostrea gigas*).

Solid phase testing ideally exposes animals that live in contact with the sediment itself. A problem with testing a variety of field-collected sediments, however, is the difficulty in separating any toxic effects of chemical contamination (the goal of the testing) from the impacts on the test organisms of other parameters associated with the solid phase material. These other potentially confounding parameters may include grain size characteristics, the availability of food organisms, anoxia, natural organic compounds, sulfides, etc.

Some of these factors can be eliminated by preparing elutriates from the sediment and testing with water column organisms. Other potentially confounding aspects still remain, however, with elutriate assays. One major factor is the uncertainty, without additional expensive chemical analyses on the elutriates themselves, regarding the chemical contamination of those elutriates compared to the original sediments. Generally, the more water soluble of the compounds present in the sediment would be expected to be of more importance in elutriates than compounds which are highly insoluble in water, or are strongly associated with the particulates. Handling of the sediment and preparation of the elutriate can also influence the results. For example, Pierson et al. (1982) conducted liquid phase bioassays with Commencement Bay sediments using Pacific oyster embryos. In that study, the water layer which formed atop the sediment when the buckets of sediment were thawed (comprised of what had been interstitial water) was decanted and bioassayed separately from the prepared elutriates. Decanted "interstitial" water from several sites were toxic to the oyster embryos, but 20% prepared elutriates were not. Handling methods that allow the loss of the sediments' interstitial water (which may be closest to some form of equilibrium with sediment-bound chemicals) may result in underestimates of the toxicity of the sediment, and should be avoided when preparing elutriates. In this study, such loss was minimized by initial collection with a van Veen grab and by rehomogenizing thawed sediments prior to unsealing, without removing any material present.

Other workers (e.g., Chapman and Morgan 1983) attempt to measure sediment toxicity with sensitive water column organisms such as oyster embryos, but in the presence of the sediment. Such an approach was decided against in these studies for two major reasons. First is the difficulty in obtaining reliable mortality estimates: dead oyster embryos which settle to the sediment surface would not be accounted for since not all the water can be decanted at the end of the experiment. Second is the possibility of biasing the results toward non-toxicity since an unknown number of abnormal embryos could sink, or could pass through the screen at the concentration step (Cardwell et al. 1978), and thus not be detected. It was considered important in this project that there be no question that sampling from the entire population of organisms in each test container occurred, in order that such potential biases as mentioned above were excluded. The main objective of this acute bioassay program was not to attempt to mimic "natural" conditions of exposure, since any number of such scenarios could be imagined. Rather, this testing was designed to provide as sensitive, controlled, and bias-free indication of the potential for acute toxicity associated with the sediments, regardless of the exposure scenario envisioned.

No bioassay yet developed can be used by itself to adequately describe sediment toxicity. An attempt was made in this project to use a variety of bioassays, and to compare and combine their results, to measure sediment toxicity.

Amphipod-Sediment Bioassay

The amphipod bioassay identified only one site as "toxic" - the Four Mile Rock dredge disposal site off Magnolia Bluff. Several other sediments produced similar results (mortalities), but could not be considered toxic to the amphipods due to the very fine particle size ranges of the sediments, and the known effects of even clean fine-grained sediments on this amphipod species. Indeed, amphipod survival in this study was significantly correlated with each of the grain-size measurements (Appendix Table 9.7B). The results of this study support those of other workers (Ott, in preparation; Pierson et al. 1982) in this regard, as no statistical differences existed between the "clean" fine-grained control and any of the fine-grained stations tested, including the "toxic" control sediment from the Duwamish South Harbor. The Seahurst I690E sediment, used herein as the "clean" fine-grained control sediment, was confirmed to have a low degree of contamination. Organic priority pollutant loading was minimal (Appendix Table 9.4), and metals levels were low with the possible exceptions of zinc and manganese (Appendix Table 9.5). Total volatile solids were somewhat elevated as well (Appendix Table 12.6). Overall, this site was among the least contaminated of all the sites analyzed in these studies. It is unlikely that the amphipod mortality in this sediment was due primarily to chemical contamination; therefore, this sediment was considered a suitable clean fine-grained control. Interestingly, some of the most heavily contaminated (in terms of organics) of all the stations were shallow, sandy sites near the mouth of the Duwamish River (stations 117, 120, and 121). These sites had no significant impact on the 10 day survival of the amphipods. Such data, in conjunction with the significant positive correlation between amphipod survival and organic priority pollutant contamination, support the findings of Ott (in preparation) that *R. abronius* may in general be relatively insensitive to organic contaminants as compared to heavy metals.

Had this study not included a clean, fine-grained reference sediment and instead compared all sediments against the sand control, as nearly all previous studies with amphipods have done, the results would have been quite different. Well over half (21 of 34) of the sediments would have produced significant mortalities, and would have been considered toxic (Table 9.11). These results, so different depending upon the method of analysis, emphasize the necessity of including an uncontaminated, suitably fine-grained control sediment in any future sediment toxicity studies using amphipods (when fine-

Table 9.11. Amphipod survivals in Elliott Bay area sediments. All sediments, regardless of particle size characteristics, are compared to West Beach sand control. This represents the manner in which results have been presented in most sediment toxicity studies using amphipods, and should be contrasted with Table 9.10. Bar indicates non-significantly different from West Beach sand (Dunnett's Test, p = 0.05).

Station	Mean Phi size	Mean % survival
121	3.66	98.75
117	3.92	96.25
West Beach (132)	2.23	92.50
120	4.64	92.50
124	3.82	87.50
115	6.94	86.25
103	5.99	83.75
123	7.44	83.75
119	6.77	83.75
127	6.33	81.25
126	7.47	81.25
111	7.48	81.25
110	7.12	78.75
134	a	78.75
116	6.90	78.75
105	7.60	77.50
Seahurst I690E (131)	7.64	72.50
Duwamish South Harbor (133)	5.45	72.50
130	6.83	71.25
125	5.71	71.25
112	7.17	70.00
108	7.49	68.75
101	8.08	68.75
107	7.40	66.25
122	5.76	66.25
106	7.87	63.75
104	7.05	62.50
135	b	62.50
129	7.28	62.50
128	7.54	58.75
113	7.00	57.50
109	6.59	56.25
118	6.15	55.00
114	6.93	51.25

a) Particle size analysis not performed for this station. A recent study (J. Strand, pers. comm.) found this site to be: 37.88% sand, 44.2% silt, and 17.88% clay.

b) Particle size analysis not performed for this station. A recent study (J. Strand, pers. comm.) found this site to be: 3.5% gravel, 82.2% sand, 9.3% silt, and 5.0% clay.

grained test sediments are involved). Results from any studies for which fine-grained controls would be appropriate, but which were not included, should be reviewed with caution.

Sediment Elutriate Bioassays

Elutriate tests were conducted using three bioassay methods. The oyster embryo bioassay results were unacceptable due to high control mortalities on both testing occasions. Overall, 5 of 12 attempted oyster embryo bioassays were either unacceptable, or the oysters did not spawn: two during the elutriate testing and three during sewage tests, as described earlier (Table 9.12). Throughout the summer of testing, well-conditioned adult oysters were difficult to procure. Collections from July through September from as far south as Mud Bay near Olympia, and north to San Juan Island all resulted in high percentages of "overripe" animals that appeared to be resorbing their gametes. This may be attributed, at least in part, to the unusually early and warm spring experienced in the Puget Sound area. Indeed, as early as the first bioassay in July, ambient West Point near-surface water reached 14.5^{o}C. Because the laboratory at West Point had no capability for long-term thermal conditioning of adult oysters, field collection of ripe oysters had to be relied upon.

Such difficulties were not generally experienced with sand dollars. Because they are spawned by KCl injection and not by thermal stimulation, all that was required for their successful testing was early collection of sufficient numbers of adults. Although the native population had spawned out prior to the second elutriate bioassay, individuals collected earlier and held under controlled conditions in the lab continued to produce gametes of acceptable quality for testing (Table 9.12) (also see Table 9.2).

Even though acceptable-quality sand dollar gametes were available, the

Table 9.12. Comparison of oyster embryo and sand dollar embryo bioassay control responses for all testing combined. Acceptable oyster control responses occurred for 7 of 10 tests. Acceptable sand dollar control responses in all 10 of the tests analyzed.

		Oyster embryos		Sand dollar embryos	
Date	Assay	% control survival	% control abnormal	% control survival	% control abnormal
7/23/84	Receiving[a)] water	110.6	3.7	88.6	5.3
7/30/84	Receiving water	90.7	3.1	?	?
7/31/84	Renton sewage	52.9	75.5*	?	2.6
8/6/84	Receiving water	73.3	2.2	107.0	4.1
8/13/84	Receiving water	79.7	4.4	100.5	5.6
8/17/84	Renton sewage	No spawn		91.8	3.1
8/20/84	Receiving water	58.5	7.4	91.3	1.6
8/24/84	Renton sewage	14.1	37.5*	94.9	2.9
9/4/84	Receiving water	No spawn		?	?
9/11/84	Receiving water	50.4	12.3	?	?
9/17/84	Receiving water	80.5	6.6	78.9	4.2
9/26/84	Elutriate (1)	Not tested		101.8	4.3
10/22/84	Elutriate (2)	27.4	89.2*	87.2	7.3

a)- Elliott Bay receiving water bioassays.

* - Unacceptable control response.

? - Samples available, but not analyzed.

bioassays using them were not similarly successful at measuring elutriate toxicity. The sperm bioassay produced anomalous responses, apparently related to some factor other than chemical contamination. Sperm have a high affinity for surfaces, and it is possible that very fine sediment particles and/or naturally occurring organic compounds or sulfides passing through the 4.5-um filters used in preparing the elutriates could have effectively lowered the sperm:egg ratios in the test tubes. This would result in decreased fertilization and apparent toxicity, even for uncontaminated sediments. Indeed, elutriates from several stations had slight yellowish tints even after filtering. The sperm bioassay produced markedly different results from the sand dollar embryo bioassay. Embryos were inoculated 1 to 2 hours after fertilization; whatever blocked fertilization in the sperm bioassay did not affect the embryos similarly. The sperm bioassay deserves more attention as a test for sediment toxicity due to its known high sensitivity to a variety of toxicants, particularly metals (Dinnel et al. 1980; 1983). Future tests should, however, give special consideration to centrifugation (or other preparation methods) as opposed to filtration in preparing sediment elutriates.

The sand dollar embryo bioassay produced results generally correlated to the overall organic priority pollutant loading of the sediments. As a screening test, this bioassay was successful in ranking the acute toxicity of the sediments. It must be emphasized, however, that both of the sediment elutriate bioassays performed with sand dollar embryos were range-finding in nature. The necessity of testing many sites simultaneously, with elutriates which are relatively labor intensive to prepare, precluded replication of most test concentrations for most sites. Ideally, follow-up bioassays involving more replication would be performed on selected sediments. Ultimately, acute toxicity is not the sole concern; bioaccumulation, life-cycle (including reproduction), and other chronic effects studies would be required to more thoroughly identify the potential for biological problems to be associated with the sediments. Such studies were beyond the scope of this project; still, they are warranted in the future due to the demonstrated acute toxicity and the composition of the (organic, at least) chemical contamination at many of the sites. (Many of the compounds present are known mammalian carcinogens, mutagens, and/or teratogens.)

On the basis of the two range-finding sand dollar-sediment elutriate bioassays, most of the stations can be ranked. In decreasing order of toxicity:

117 = 120 > 133 > 135 > 101 = 105 = 109 = 114 = 115 = 116 = 122 = 123 = 124 = 130 = 134.

Sediments from all the above stations produced essentially 100% abnormality at 16.6% or lower elutriate concentrations. All must be considered toxic, and all are more toxic than the following stations:

111 = 113 = 121 = 125 = 126 = 129 > 108 = 110 = 112 = 128 = 131 > 104 = 106 = 107 = 118 = 119 = 127 = 132.

These last stations are arbitrarily grouped as producing 75-90%, 25-75%, and <25% responses, respectively. Finer differentiation should not be attempted on the basis of these range-finding tests. The last group (stations 104, 106, 107, 118, 119, 127) could be considered relatively non-toxic; the others must be considered as potentially toxic.

There is little to compare between the solid phase (amphipod) and liquid phase elutriate (sand dollar embryo) bioassays. The one station that was significantly toxic to amphipods (the Four Mile Rock disposal site) was also one of the most toxic to sand dollar embryos. On this basis, the tests are in agreement. However, the stations most toxic to sand dollar embryos, 117 and 120, which were also among the most heavily contaminated with organic priority pollutants, had no impact on amphipod survival. Such results emphasize the importance of having more than one biological indicator of potential toxicity, especially relating to sediments.

A final important result of these elutriate bioassays concerns the handling of the sediments themselves. The testing of fresh (unfrozen) sediments is probably ideal, but is often unfeasible. Freezing of sediment samples has been analyzed in a variety of circumstances, and has become generally accepted as a means of storing samples and controlling for variability that can be caused by testing sediments that have been, of necessity, collected at different times. This study has shown, however, that sediments should not be frozen more than once: significant differences arise when sediments are thawed, refrozen, and rethawed before testing. These differences occur with both "clean" and contaminated sediments, and can overshadow toxic responses. On this basis, the usefullness of collecting as much sediment as is practical at the beginning of a study, and of splitting the homogenized sediment into as many subsamples as possible before freezing, cannot be overemphasized.

9.5.4 Sediment Toxicity in the Area of the Proposed Outfall

Sampling effort was not uniformly distributed throughout the study area, but focused on the general area of the proposed outfall. Nearly half (16/35) of the sediments used in the acute toxicity bioassays were from stations in this area: north of a line drawn between Duwamish Head and Alki Point. These sites, as measured by sand dollar embryo abnormalities in sediment elutriates, ranged from "relatively non-toxic" to "toxic". These data are presented in Figure 9.11. There were three "relatively non-toxic" stations: 104, 106 and

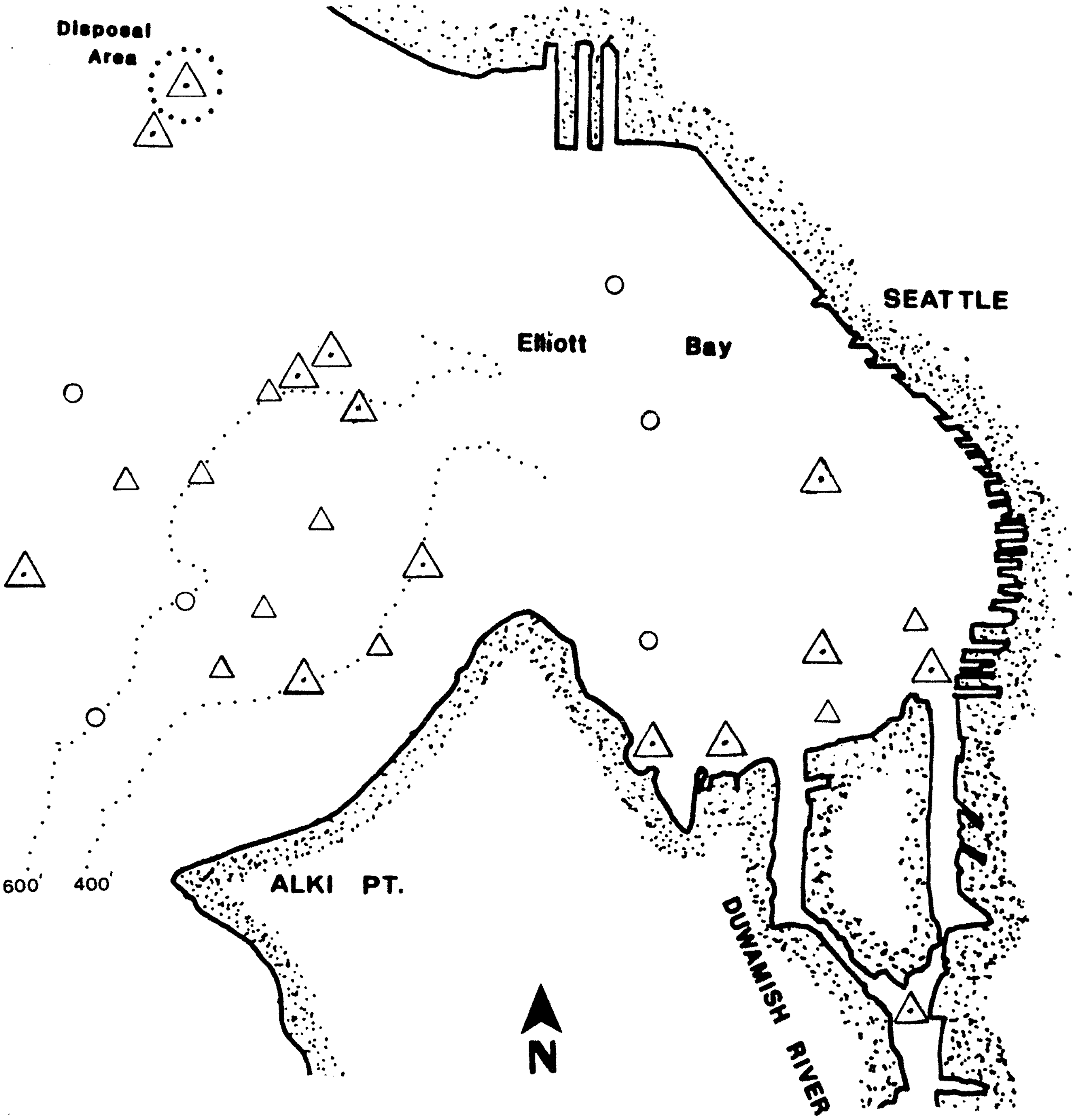

Figure 9.11. Identification of the acute toxicity of sediments from stations in and around Elliott Bay, Wa. Sediments are considered "toxic" (◬) if elutriates produced 100% abnormal sand dollar embryos at or below 16.6% concentration, by volume. "Potentially toxic" sediments (△) produced 25 - 90% abnormal embryos. "Relatively non-toxic" sediments (○) produced few (<25%) abnormalities.

107, in this area. Sediment elutriates from these stations all produced relatively low (20.1-26.8%; see Table 9.5) abnormalities. Seven stations were "potentially toxic": 108, 110, 111, 112, 113, 128, and 129. Sediment elutriates from these stations each produced substantial abnormalities (46.7-90.6%; see Table 9.5). Six stations were "toxic," producing 100% abnormalities at 16.6% elutriate concentration or lower: 105, 109, 114, 115, 116, and 130.

The "toxic" stations were more common nearer Duwamish Head, while the "relatively non-toxic" stations tended to be nearer Alki Point. It may be that materials carried by the Duwamish River tend to accumulate in the sediments to a greater degree near Duwamish Head. Based on the biological responses, however, a great deal of patchiness is evident over the entire area. Stations in relatively close proximity show dissimilar levels of contamination and caused a broad range of biological responses. This is in contrast to an area such as the mouth of the Duwamish River/southern Elliott Bay, where sediments from almost all stations were "toxic," and there is little question of the seriousness of the contamination. Further studies are warranted in this area, so that the possible future impacts from the proposed outfall may be separated from toxicity already associated with these sediments.

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Appendix Table 9.1. Elliott Bay area sediment station locations, and cross reference identification with Subtidal Biology (Section 6.0) station designations.

Station	Depth [feet (m)]	Loran C location	Subtidal Biology (Sec. 6.0) station designation
West Beach	10-20 (3-6)	-[a]	-
Seahurst I690E	682 (208)	27910.7/42275.9	-
Duwamish S. Harbor	45 (14)	27977.0/42296.8	-
101	555 (169)	27977.4/42283.0	A600E
102	604 (184)	28009.8/42276.9	BII 600W
103	802 (244)	28007.6/42280.3	BII 800E
104	613 (187)	28009.2/42285.3	BII 600E
105	633 (193)	28014.9/42284.1	BIII 600C
106	605 (184)	28009.3/42286.9	BIV 600E
107	627 (191)	28018.9/42286.7	BIV 600N
108	630 (192)	28013.1/42286.5	BIV 600C (=34)
109	403 (123)	28003.7/42288.3	BV 400E
110	574 (175)	28011.8/42288.2	BV 600C (=24)
111	530 (162)	28008.0/42289.6	BVI 522E
112	400 (122)	28003.4/42289.8	BVI 400E
113	600 (183)	28012.9/42289.1	BVI 600E
114	400 (122)	28005.5/42291.1	BVII 400E
115	600 (183)	28012.2/42290.9	BVII 600E
116	600 (183)	28012.4/42291.0	BVII 600N
117	50 (15)	27991.9/42294.2	BIX 50E
118	300 (91)	27998.6/42294.9	BIX 300E
119	400 (122)	28002.9/42295.8	BIX 400E
120	50 (15)	27991.2/42295.5	BX 50E
121	56 (17)	27989.9/42297.6	BXI 50E
122	200 (61)	27991.7/42298.0	BXI 200E
123	330 (101)	27997.6/42299.0	BXI 300E
124	55 (17)	27988.3/42300.0	BXII 50E
125	200 (61)	27990.9/42299.8	BXII 200E
126	700 (213)	28039.4/42285.4	VIII 750
127	297 (91)	28009.5/42297.1	XI 300
128	550 (168)	28007.4/42288.2	32
129	525 (160)	28006.2/42286.9	35
130	600 (183)	28013.0/42290.7	37
134	570 (174)	28020.3/42290.2	-
135	530 (162)	28022.8/42291.0	-

Notes:

a) No Loran C reading. West Beach is in Deception Pass State Park on Whidbey Island, North of Puget Sound.

Appendix Table 9.2. Unadjusted responses of sand dollar embryos in liquid phase elutriates from sediments collected in and around Elliott Bay, Wa., in 1984.

Test No.	Station[a]	Elutriate concentration (%)	Replicate	No. Abnormal	Total No.
1 (9-26-84)	Innoculation counts	-	1	-	253
			2	-	211
			3	-	207
			4	-	204
			5	-	217
			6	-	244
	West Point control (dilution)	-	1	8	215
			2	9	223
			3	7	242
			4	9	234
			5	10	223
			6	15	223
	Friday Harbor control water		1	11	269
			2	11	243
			3	17	219
			4	21	228
			5	14	252
			6	13	232
	Kincaid Lab control water	-	1	19	231
			2	20	236
			3	15	232
			4	18	210
			5	20	234
			6	20	243
	West Beach [b]	16.6	1	11	196
			2	16	213
			3	15	222
		3.3	1	10	212
	Seahurst I690E[c]	16.6	1	78	199
			2	84	199
		3.3	1	21	232
		1.7	1	8	214
	Duwamish South[d] Harbor	16.6	1	204	205
			2	196	196
		3.3	1	74	188
		1.7	1	37	222
		0.17	1	6	248

Appendix Table 9.2 (continued).

Test No.	Station[a)]	Elutriate concentration (%)	Replicate	No. Abnormal	Total No.
1 (9-26-84)	101	16.6	1	150	150
		3.3	1	9	187
		1.7	1	5	215
	104	16.6	1	54	219
	105	16.6	1	125	125
	106	16.6	1	51	217
	107	16.6	1	67	224
	108	16.6	1	93	190
	109	16.6	1	122	122
			2	116	116
			3	144	144
	110	16.6	1	105	188
	111	16.6	1	168	188
	112	16.6	1	125	196
	113	16.6	1	166	213
	114	16.6	1	147	147
			2	155	155
			3	193	193
	115	16.6	1	179	179
	116	16.6	1	234	235
	117	16.6	1	75	75
			2	80	80
			3	84	84
	118	16.6	1	72	254
	119	16.6	1	39	236
			2	27	209
	120	16.6	1	193	193
			2	118	118
			3	148	148
	121	16.6	1	213	243
	122	16.6	1	160	160

Appendix Table 9.2 (continued).

Test No.	Station[a)]	Elutriate concentration (%)	Replicate	No. Abnormal	Total No.
1 (9-26-84)	123	16.6	1	192	205
			2	235	239
			3	219	219
	124	16.6	1	43	44
	125	16.6	1	172	215
			2	170	223
			3	167	204
	126	16.6	1	64	200
	127	16.6	1	54	190
	128	16.6	1	135	222
	129	16.6	1	181	199
	130	16.6	1	68	68
	134	16.6	1	189	193
		3.3	1	14	235
		1.7	1	9	220
	135	16.6	1	47	47
			2	48	48
			3	32	32
		3.3	1	26	228
		1.7	1	12	228
2 (10-22-84)	Innoculation counts	-	1	-	255
			2	-	244
			3	-	218
			4	-	216
			5	-	197
			6	-	202
	West Point control (dilution)	-	1	15	185
			2	14	193
			3	11	201
			4	16	179
			5	12	205
			6	17	203
	Friday Harbor control water	-	1	20	207
			2	28	230
			3	21	207

Appendix Table 9.2 (continued).

Test No.	Station[a)]	Elutriate concentration (%)	Replicate	No. Abnormal	Total No.
2 (10-22-84)	Kincaid Lab control water	-	1	21	228
			2	12	192
			3	17	208
			4	23	194
			5	18	223
			6	11	199
	West Beach [b,e)]	10.0	1	78	167
		5.0	1	56	178
		2.5	1	10	183
		1.0	1	7	212
	Duwamish S.	10.0	1	54	179
		5.0	1	46	165
		2.5	1	12	196
		1.0	1	13	186
	103[e,f)]	10.0	1	90	203
		5.0	1	110	171
		2.5	1	17	199
		1.0	1	15	212
			2	12	192
	105[e)]	10.0	1	69	203
		5.0	1	36	199
		2.5	1	23	198
		1.0	1	14	210
	109[e)]	10.0	1	42	212
		5.0	1	31	226
		2.5	1	24	213
		1.0	1	12	192
	114[e)]	10.0	1	40	189
		5.0	1	57	200
		2.5	1	18	192
		1.0	1	11	211
			2	10	185
	115[e)]	9.1	1	49	212
		5.0	1	55	232
		2.5	1	13	185
		1.0	1	15	188
	117[e)]	10.0	1	37	37
		5.0	1	180	180
		2.5	1	49	168
		1.0	1	19	202

Appendix Table 9.2 (continued).

Test No.	Station[a]	Elutriate concentration (%)	Replicate	No. Abnormal	Total No.
2 (10-22-84)	120[e]	10.0	1	19	19
		5.0	1	194	194
		2.5	1	36	188
		1.0	1	12	187
	122[e]	10.0	1	38	217
		5.0	1	25	200
		1.0	1	18	204
	123[e]	10.0	1	62	201
		5.0	1	25	179
		2.5	1	17	214
		1.0	1	8	179
	124[e]	3.3	1	16	191
		2.5	1	17	180
		1.0	1	16	199
			2	10	195
	130[e]	10.0	1	40	207
		5.0	1	57	200
		2.5	1	18	192
		1.0	1	11	211
			2	10	185
	135[e]	10.0	1	165	165
		5.0	1	27	179
		2.5	1	16	188
			2	16	182
		1.0	1	15	208
	135	10.0	1	51	179
		5.0	1	22	175
		2.5	1	19	190
		1.0	1	12	199
			2	12	188

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a) See Text and Appendix Table 12.1 for station location/descriptions.
b) Clean sand control for amphipod bioassays.
c) "Clean" fine-grained sediment control for amphipod bioassays.
d) "Toxic" control.
e) Sediment tested as "refrozen/rethawed."
f) Sediment not tested 9-26-84 (i.e., only tested as "refrozen/rethawed).

Appendix Table 9.3. Responses of the marine amphipod, *Rhepoxynius abronius*, to Elliott Bay area sediments in 10-day bioassays, 1984.

Station[a)]	Replicate	Alive No.	Alive %	No. moribund	$\overline{X}$ % survival (S.D.)
West Beach	1	19	95	0	92.5 (9.64)
	2	20	100	0	
	3	20	100	0	
	4	19	95	0	
	5	18	90	1	
	6	19	95	0	
	7	19	95	0	
	8	14	70	0	
Seahurst I690E	1	17	85	0	72.5 (11.0)
	2	16	80	0	
	3	11	55	0	
	4	14	70	0	
	5	15	75	0	
	6	17	85	0	
	7	14	70	0	
	8	12	60	0	
Duwamish South Harbor	1	17	85	1	72.5 (23.5)
	2	17	85	1	
	3	16	80	1	
	4	16	80	1	
	5	16	80	0	
	6	3	15	0	
	7	16	80	0	
	8	15	75	0	
101	1	12	60	1	68.75 (6.29)
	2	15	75	1	
	3	14	70	2	
	4	14	70	0	
102		- NOT TESTED -			
103	1	14	70	0	83.75 (12.5)
	2	20	100	0	
	3	17	85	0	
	4	16	80	0	
104	1	14	70	0	62.5 (21.8)
	2	9	45	0	
	3	9	45	0	
	4	18	90	0	

Appendix Table 9.3 (continued).

Station[a)]	Replicate	Alive No.	Alive %	No. moribund	$\overline{X}$ % survival (S.D.)
105	1	16	80	1	77.5 (6.45)
	2	17	85	0	
	3	15	75	0	
	4	14	70	0	
106	1	14	70	1	63.75 (17.5)
	2	9	45	0	
	3	11	55	0	
	4	17	85	0	
107	1	11	55	0	66.25 (11.1)
	2	14	70	1	
	3	16	80	3	
	4	12	60	0	
108	1	14	70	0	68.75 (6.29)
	2	14	70	0	
	3	15	75	0	
	4	12	60	0	
109	1	13	65	2	56.25 (8.54)
	2	12	60	0	
	3	9	45	0	
	4	11	55	0	
110	1	11	55	0	78.75 (17.0)
	2	19	95	1	
	3	16	80	1	
	4	17	85	0	
111	1	16	80	0	81.25 (6.29)
	2	16	80	1	
	3	18	90	0	
	4	15	75	0	
112	1	15	75	0	70.0 (10.0)
	2	15	75	1	
	3	15	75	1	
	4	11	55	0	
113	1	11	55	0	57.5 (14.4)
	2	12	60	0	
	3	15	75	0	
	4	8	40	1	

Appendix Table 9.3 (continued)

Station[a)]	Replicate	Alive		No. moribund	$\overline{X}$ % survival (S.D.)
		No.	%		
114	1	13	65	0	51.25 (13.8)
	2	12	60	0	
	3	7	35	1	
	4	9	45	0	
115	1	17	85	0	86.25 (9.46)
	2	20	100	0	
	3	16	80	0	
	4	16	80	1	
116	1	16	80	0	78.75 (6.29)
	2	14	70	0	
	3	16	80	0	
	4	17	85	0	
117	1	20	100	0	96.25 (7.50)
	2	20	100	1	
	3	20	100	1	
	4	17	85	1	
118	1	12	60	0	55.0 (13.5)
	2	7	35	1	
	3	13	65	0	
	4	12	60	0	
119	1	19	95	0	83.75 (16.0)
	2	12	60	1	
	3	18	90	2	
	4	18	90	0	
120	1	16	80	0	92.5 (8.66)
	2	20	100	0	
	3	19	95	0	
	4	19	95	0	
121	1	20	100	0	98.75 (2.50)
	2	20	100	0	
	3	20	100	0	
	4	19	95	0	
122	1	15	75	0	66.25 (11.8)
	2	10	50	2	
	3	15	75	0	
	4	13	65	1	

Appendix Table 9.3 (continued).

Station[a)]	Replicate	Alive		No. moribund	$\overline{X}$ % survival (S.D.)
		No.	%		
123	1	15	75	0	83.75 (11.1)
	2	16	80	0	
	3	20	100	0	
	4	16	80	0	
124	1	17	85	0	87.5 (5.00)
	2	17	85	0	
	3	17	85	0	
	4	19	95	0	
125	1	13	65	0	71.25 (4.79)
	2	14	70	0	
	3	15	75	0	
	4	15	75	0	
126	1	18	90	0	81.25 (8.54)
	2	16	80	0	
	3	17	85	0	
	4	14	70	0	
127	1	18	90	0	81.25 (19.3)
	2	20	100	0	
	3	11	55	0	
	4	16	80	0	
128	1	4	20	0	58.75 (26.3)
	2	15	75	1	
	3	13	65	0	
	4	15	75	0	
129	1	14	70	1	62.5 (11.9)
	2	9	45	0	
	3	13	65	0	
	4	14	70	0	
130	1	17	85	1	71.25 (14.9)
	2	15	75	0	
	3	15	75	0	
	4	10	50	0	
134	1	16	80	0	78.75 (14.4)
	2	16	80	0	
	3	19	95	0	
	4	12	60	0	

Appendix Table 9.3 (continued)

Station[a)]	Replicate	Alive		No. moribund	$\overline{X}$ % survival (S.D.)
		No.	%		
135	1	13	65	0	62.5 (29.6)
	2	4	20	0	
	3	16	80	0	
	4	17	85	0	

Notes:

a) See Appendix Table 12.1 for station location/descriptions.
b) Clean native sand control.
c) "Clean" fine-grained sediment control
d) "Toxic" control.

Appendix Table 9.4. Organic pollutants in Elliott Bay area sediments used in toxicity bioassays. Results are presented as ug/kg dry weight (ppb).

STATION	133	130	120	122	106	129	102	131
2-4-6-TRICHLOROPHENOL	.000	.000	.000	.000	.000	.000	.100	.000
2-4-DICHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-4-DIMETHYLPHENOL	4.000	.000	17.000	.000	.000	.000	53.000	.000
2-4-DINITROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-NITROPHENOL	.000	.000	.000	.000	.000	.000	.700	.000
4-6-DINITRO-O-CRESOL	.000	.000	.000	.000	.000	.000	.000	.000
4-CHLORO-3-METHYL PHENOL	.000	.000	.000	.000	.000	.000	2.000	.000
4-NITROPHENOL	.000	.000	.000	.000	.000	.000	1.000	.000
PENTACHLOROPHENOL	.000	.000	50.000	.000	.000	.000	1.000	.000
PHENOL	2154.000	47.000	353.000	306.000	59.000	130.200	125.000	23.000
1-2-DIPHENYLHYDRAZINE	.000	.000	.000	.000	.000	.000	.000	.000
3-3-DICHLOROBENZIDINE	.000	.000	.000	.000	.000	.000	.000	.000
BENZIDINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODI-N-PROPYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODIMETHYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODIPHENYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-4-TRICHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-DICHLOROBENZENE	2.000	.000	.000	.000	.000	.000	.000	.000
1-3-DICHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
1-4-DICHLOROBENZENE	2.000	.000	.000	.000	.000	.000	.000	.000
2-4-DINITROTOLUENE	.000	.000	.000	.000	.000	.000	.000	.000
2-6-DINITROTOLUENE	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLORONAPHTHALENE	.000	.000	.000	.000	.000	.000	.000	.000
4-BROMOPHENYL PHENYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
4-CHLOROPHENYL PHENYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
ACENAPHTHENE	20.000	3.000	1400.000	18.000	.000	.000	3.000	.000
ACENAPHTHYLENE	.000	.000	50.000	7.000	.000	.000	.000	.000
ANTHRACENE	45.000	10.000	510.000	46.000	3.000	5.900	4.000	4.000
BENZO (A) ANTHRACENE	156.000	22.000	880.000	82.000	11.000	15.100	9.000	10.000
BENZO (A) PYRENE	145.000	21.000	480.000	108.000	9.000	.000	7.000	8.000
BENZO (B) FLUORANTHENE	139.000	.000	666.000	77.000	10.000	10.500	6.500	.000
BENZO (G-H-I) PERYLENE	88.000	15.000	234.000	73.000	8.000	10.000	5.000	9.000
BENZO (K) FLUORANTHENE	96.000	.000	556.000	71.000	12.000	15.900	9.000	.000
BIS (2-CHLOROETHOXY) METHANE	.000	.000	.000	.000	.000	.000	.000	.000
BIS (2-CHLOROETHYL) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BIS (2-CHLOROISOPROPLY) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BUTYL BENZYL PHTHALATE	.000	.000	.000	.000	.000	.000	.000	.000
CHRYSENE	273.000	36.000	1090.000	232.000	24.000	24.700	19.000	24.000
DI-N-BUTYL PHTHALATE	81.000	168.000	130.000	160.000	32.000	177.900	84.000	228.000
DI-OCTYL PHTHALATES	90.000	.000	8.000	.000	.000	.000	.000	.000
DIBENZO (A-H) ANTHRACENE	20.000	6.000	121.000	16.000	.000	.000	1.000	.000
DIETHYL PHTHALATE	2.000	2.000	3.500	2.000	.000	.000	.000	.000
DIMETHYL PHTHALATE	2.000	.000	.860	.000	.000	.000	.000	.000
FLUORANTHENE	191.000	32.000	1755.000	102.000	21.000	24.400	15.000	17.000
FLUORENE	26.000	5.000	1025.000	23.000	.000	.000	4.000	.000
HEXACHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROCYCLOPENTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
INDENO (1-2-3-C-D) PYRENE	108.000	.000	400.000	97.000	7.000	9.000	6.000	8.000
ISOPHORONE	.000	.000	.000	.000	.000	.000	.000	.000
NAPHTHALENE	24.000	.000	2000.000	65.000	.000	10.300	11.000	.000
NITROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
PENTACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
PHENANTHRENE	102.000	16.000	1490.000	76.000	10.000	13.300	10.000	11.000
PYRENE	365.000	70.000	2650.000	252.000	42.000	58.400	26.000	36.000
TETRACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
TRICHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
2-3-7-8-TCDD	.000	.000	.000	.000	.000	.000	.000	.000
4-4-DDD	.000	.700	.000	.000	.000	.000	.060	.000
4-4-DDE	6.000	.000	.000	3.000	.700	.650	.500	.700
4-4-DDT	.000	.000	.000	.000	.000	.000	.000	.000

Appendix Table 9.4, continued.

STATION	133	130	120	122	106	129	102	131
A-BHC	.000	.000	.000	.000	.000	.000	.000	.000
A-ENDOSULFAN	.000	.000	.000	.000	.000	.000	.000	.000
ALDRIN	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1016	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1221	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1232	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1242	.000	8.000	20.000	13.000	5.000	6.000	3.000	6.000
AROCLOR 1248	.000	8.000	20.000	13.000	5.000	6.000	3.000	6.000
AROCLOR 1254	177.000	24.000	65.000	117.000	14.000	13.000	3.400	10.000
AROCLOR 1260	133.000	20.000	47.000	195.000	16.000	10.000	3.500	11.000
B-BHC	.000	.000	.000	.000	.000	.000	.000	.000
B-ENDOSULFAN	.000	.000	.000	.000	.000	.000	.000	.000
CAFFEINE	.000	.000	.000	.000	.000	.000	.000	.000
CARBARYL	.000	.000	.000	.000	.000	.000	.000	.000
CHLORDANE	.000	.000	.000	.000	.000	.000	.000	.000
D-BHC	.000	.000	.000	.000	.000	.000	.000	.000
DEMETON	.000	.000	.000	.000	.000	.000	.000	.000
DIAZINON	.000	.000	.000	.000	.000	.000	.000	.000
DICHLOROPHENOXYACETIC ACID	.000	.000	.000	.000	.000	.000	.000	.000
DIELDRIN	.000	.000	.000	.000	.000	.000	.000	.000
ENDOSULFAN SULFATE	.000	.000	.000	.000	.000	.000	.000	.000
ENDRIN	.000	.000	.000	.000	.000	.000	.000	.000
ENDRIN ALDEHYDE	.000	.000	.000	.000	.000	.000	.000	.000
G-BHC	.000	.000	.000	.000	.000	.000	.000	.000
GUTHION	.000	.000	.000	.000	.000	.000	.000	.000
HEPTACHLOR	.000	.000	.000	.000	.000	.000	.000	.000
HEPTACHLOR EPOXIDE	.000	.000	.000	.000	.000	.000	.000	.000
MALATHION	.000	.000	.000	.000	.000	.000	.000	.000
METHOXYCHLOR	.000	.000	.000	.000	.000	.000	.000	.000
MIREX	.000	.000	.000	.000	.000	.000	.000	.000
NICOTINE	.000	.000	.000	.000	.000	.000	.000	.000
PARATHION	.000	.000	.000	.000	.000	.000	.000	.000
SILVEX	.000	.000	.000	.000	.000	.000	.000	.000
SWEP	.000	.000	.000	.000	.000	.000	.000	.000
TOXAPHENE	.000	.000	.000	.000	.000	.000	.000	.000
G-CHLORDENE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-1-TRICHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-2-2-TETRACHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-2-TRICHLOROETHANE	.000	.000	.010	.000	.030	.000	.000	.000
1-1-DICHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-DICHLOROETHYLENE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-DICHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-DICHLOROPROPANE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-TRANS-DICHLOROETHYLENE	.000	.000	.030	.030	.000	.030	.000	.040
1-3-DICHLOROPROPENE	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLOROETHYL VINYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
ACROLEIN	.000	.000	.000	.000	.000	.000	.000	.000
ACRYLONITRILE	.000	.000	.000	.000	.000	.000	.000	.000
BENZENE	.000	.300	2.200	3.000	4.000	2.000	2.500	3.500
BIS (CHLOROMETHLY) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BROMOFORM	.000	.010	.010	.000	.010	.000	.100	.000
CARBON TETRACHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000
CHLOROBENZENE	.000	.040	.040	.500	.070	.020	.100	.000
CHLORODIBROMOMETHANE	.000	.010	.010	.020	.010	.010	.000	.700
CHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
CHLOROFORM	.000	.000	.040	.000	3.000	.050	.500	.000
DICHLOROBROMOMETHANE	.000	.000	.020	.000	.200	.020	.300	.000
DICHLORODIFLUOROMETHANE	.000	.000	.000	.000	.000	.000	.000	.000
ETHYLBENZENE	.000	.030	.300	.500	.080	.060	.200	.300
METHYL BROMIDE	.000	.000	.000	.000	.000	.000	.000	.000
METHYL CHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000
METHYLENE CHLORIDE	.000	68.500	46.000	24.000	11.000	21.000	43.600	50.000
TETRACHLOROETHYLENE	.000	.030	.090	.000	.000	.040	.000	.100
TOLUENE	.000	.040	.200	.090	.400	.200	.100	.200
TRICHLOROETHYLENE	.000	.000	.030	.000	.200	.100	.000	.000
TRICHLOROFLUOROMETHANE	.000	.000	.000	.000	.000	.000	.000	.000
VINYL CHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000

Appendix Table 9.4, continued.

STATION	107	117	119	108	112	137	114	124
2-4-6-TRICHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-4-DICHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-4-DIMETHYLPHENOL	11.000	.000	3.000	.000	.000	21.000	4.000	6.000
2-4-DINITROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLOROPHENOL	.000	.000	.000	1.000	.000	.000	.000	.000
2-NITROPHENOL	3.000	.000	.000	87.000	.000	.000	.000	.000
4-6-DINITRO-O-CRESOL	.000	.000	.000	.000	.000	.000	.000	.000
4-CHLORO-3-METHYL PHENOL	.000	.000	.000	.000	.000	.000	1.000	1.000
4-NITROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
PENTACHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	124.000
PHENOL	1209.000	.000	27.000	84.000	.000	10.000	295.000	850.000
1-2-DIPHENYLHYDRAZINE	.000	.000	.000	.000	.000	.000	.000	.000
3-3-DICHLOROBENZIDINE	.000	.000	.000	.000	.000	.000	.000	.000
BENZIDINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODI-N-PROPYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODIMETHYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODIPHENYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-4-TRICHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-DICHLOROBENZENE	2.000	.000	.000	2.000	.000	2.000	.000	.000
1-3-DICHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
1-4-DICHLOROBENZENE	1.000	.000	.000	.000	.000	1.000	.000	.000
2-4-DINITROTOLUENE	.000	.000	.000	.000	.000	12.000	.000	.000
2-6-DINITROTOLUENE	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLORONAPHTHALENE	.000	.000	.000	.000	.000	.000	.000	.000
4-BROMOPHENYL PHENYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
4-CHLOROPHENYL PHENYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
ACENAPHTHENE	2.000	145.000	.000	1.000	.000	6822.000	.000	17.000
ACENAPHTHYLENE	3.000	6.000	.000	1.000	.000	.000	.000	.000
ANTHRACENE	8.000	243.000	10.000	6.000	5.000	3625.000	12.000	238.000
BENZO (A) ANTHRACENE	17.000	460.000	24.000	12.000	13.000	1774.000	27.000	120.000
BENZO (A) PYRENE	12.000	377.000	22.000	12.000	11.000	1153.000	36.000	86.000
BENZO (B) FLUORANTHENE	14.000	463.000	22.000	10.000	13.000	1500.000	66.000	90.000
BENZO (G-H-I) PERYLENE	17.000	370.000	20.000	11.000	10.000	354.000	16.000	72.000
BENZO (K) FLUORANTHENE	21.000	393.000	31.000	20.000	16.000	812.000	48.000	94.000
BIS (2-CHLOROETHOXY) METHANE	.000	.000	.000	.000	.000	.000	.000	.000
BIS (2-CHLOROETHYL) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BIS (2-CHLOROISOPROPLY) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BUTYL BENZYL PHTHALATE	.000	.000	.000	.000	.000	.000	.000	.000
CHRYSENE	31.000	860.000	58.000	29.000	33.000	1438.000	30.000	261.000
DI-N-BUTYL PHTHALATE	50.000	81.000	50.000	40.000	51.000	86.000	53.000	173.000
DI-OCTYL PHTHALATES	.000	.000	49.000	1.000	.000	.000	.000	8.000
DIBENZO (A-H) ANTHRACENE	3.000	131.000	10.000	1.000	.000	170.000	.000	23.000
DIETHYL PHTHALATE	2.000	5.000	.000	.000	.000	.000	.000	4.000
DIMETHYL PHTHALATE	.000	9.000	1.000	.000	.000	.000	.000	1.000
FLUORANTHENE	26.000	604.000	38.000	23.000	21.000	2904.000	45.000	176.000
FLUORENE	4.000	162.000	.000	4.000	.000	5810.000	5.000	43.000
HEXACHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROCYCLOPENTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
INDENO (1-2-3-C-D) PYRENE	18.000	456.000	23.000	13.000	11.000	570.000	10.000	101.000
ISOPHORONE	.000	.000	.000	.000	.000	.000	.000	.000
NAPHTHALENE	13.000	145.000	19.000	11.000	11.000	1864.000	.000	70.000
NITROBENZENE	.000	.000	.000	.000	.000	15.000	.000	.000
PENTACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
PHENANTHRENE	16.000	348.000	22.000	13.000	12.000	5562.000	22.000	97.000
PYRENE	52.000	967.000	76.000	43.000	46.000	7867.000	109.000	271.000
TETRACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
TRICHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
2-3-7-8-TCDD	.000	.000	.000	.000	.000	.000	.000	.000
4-4-DDD	.000	.000	.000	.000	.000	.000	.000	.000
4-4-DDE	1.000	1.000	.800	1.000	.500	.000	.900	.800
4-4-DDT	.000	.000	.000	.000	.000	.000	.000	.000

Appendix Table 9.4, continued.

STATION	107	117	119	108	112	137	114	124
A-BHC	.000	.000	.000	.000	.000	.000	.000	.000
A-ENDOSULFAN	.000	.000	.000	.000	.000	.000	.000	.000
ALDRIN	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1016	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1221	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1232	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1242	12.000	32.000	8.000	7.000	3.600	.000	6.000	4.000
AROCLOR 1248	12.000	32.000	8.000	7.000	3.600	.000	6.000	4.000
AROCLOR 1254	16.000	34.000	23.000	15.000	7.800	.000	16.000	25.000
AROCLOR 1260	12.000	27.000	21.000	11.000	9.400	.000	9.000	26.000
B-BHC	.000	.000	.000	.000	.000	.000	.000	.000
B-ENDOSULFAN	.000	.000	.000	.000	.000	.000	.000	.000
CAFFEINE	.000	.000	.000	.000	.000	.000	.000	.000
CARBARYL	.000	.000	.000	.000	.000	.000	.000	.000
CHLORDANE	.000	.000	.000	.000	.000	.000	.000	.000
D-BHC	.000	.000	.000	.000	.000	.000	.000	.000
DEMETON	.000	.000	.000	.000	.000	.000	.000	.000
DIAZINON	.000	.000	.000	.000	.000	.000	.000	.000
DICHLOROPHENOXYACETIC ACID	.000	.000	.000	.000	.000	.000	.000	.000
DIELDRIN	.000	.000	.000	.000	.000	.000	.000	.000
ENDOSULFAN SULFATE	.000	.000	.000	.000	.000	.000	.000	.000
ENDRIN	.000	.000	.000	.000	.000	.000	.000	.000
ENDRIN ALDEHYDE	.000	.000	.000	.000	.000	.000	.000	.000
G-BHC	.000	.000	.000	.000	.000	.000	.000	.000
GUTHION	.000	.000	.000	.000	.000	.000	.000	.000
HEPTACHLOR	.000	.000	.000	.000	.000	.000	.000	.000
HEPTACHLOR EPOXIDE	.000	.000	.000	.000	.000	.000	.000	.000
MALATHION	.000	.000	.000	.000	.000	.000	.000	.000
METHOXYCHLOR	.000	.000	.000	.000	.000	.000	.000	.000
MIREX	.000	.000	.000	.000	.000	.000	.000	.000
NICOTINE	.000	.000	.000	.000	.000	.000	.000	.000
PARATHION	.000	.000	.000	.000	.000	.000	.000	.000
SILVEX	.000	.000	.000	.000	.000	.000	.000	.000
SWEP	.000	.000	.000	.000	.000	.000	.000	.000
TOXAPHENE	.000	.000	.000	.000	.000	.000	.000	.000
G-CHLORDENE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-1-TRICHLOROETHANE	.000	.000	.000	.000	.000	.000	.900	.020
1-1-2-2-TETRACHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-2-TRICHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.010
1-1-DICHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.050
1-1-DICHLOROETHYLENE	.000	.000	.000	.000	.000	.000	.040	.020
1-2-DICHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-DICHLOROPROPANE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-TRANS-DICHLOROETHYLENE	.000	.030	.030	.000	.400	.000	.050	.000
1-3-DICHLOROPROPENE	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLOROETHYL VINYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
ACROLEIN	.000	.000	.000	.000	.000	.000	.000	.000
ACRYLONITRILE	.000	.000	11.000	.000	.000	.000	.000	.000
BENZENE	.000	1.060	.030	.000	.100	.000	1.000	.320
BIS (CHLOROMETHLY) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BROMOFORM	.000	.000	.000	.000	.000	.000	.000	.010
CARBON TETRACHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000
CHLOROBENZENE	.000	.020	.020	.000	.010	.000	.100	.040
CHLORODIBROMOMETHANE	.000	.000	.000	.000	.400	.000	.000	.000
CHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
CHLOROFORM	.000	1.700	.000	.000	.000	.000	.000	.030
DICHLOROBROMOMETHANE	.000	.090	.000	.000	.000	.000	.060	.000
DICHLORODIFLUOROMETHANE	.000	.000	.000	.000	.000	.000	.000	.000
ETHYLBENZENE	.000	.000	.000	.000	.000	.000	.050	.130
METHYL BROMIDE	.000	.000	.000	.000	.000	.000	.000	.000
METHYL CHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000
METHYLENE CHLORIDE	.000	13.000	3.000	.000	6.000	.000	13.000	.600
TETRACHLOROETHYLENE	.000	.050	.020	.000	.500	.000	.200	.100
TOLUENE	.000	.500	.000	.000	.040	.000	.400	.100
TRICHLOROETHYLENE	.000	.040	.000	.000	.000	.000	.000	.020
TRICHLOROFLUOROMETHANE	.000	.000	.000	.000	.000	.000	.000	.000
VINYL CHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000

Appendix Table 9.4, continued.

STATION	127	126	135	125	136	105	103	109
2-4-6-TRICHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-4-DICHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-4-DIMETHYLPHENOL	.000	.000	.000	.000	559.000	.000	.000	.000
2-4-DINITROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-NITROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
4-6-DINITRO-O-CRESOL	.000	.000	.000	.000	.000	.000	.000	.000
4-CHLORO-3-METHYL PHENOL	.000	.000	.000	.000	.000	.000	.000	.000
4-NITROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
PENTACHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
PHENOL	265.000	95.000	228.000	483.000	577.000	127.000	120.000	354.000
1-2-DIPHENYLHYDRAZINE	.000	.000	.000	.000	.000	.000	.000	.000
3-3-DICHLOROBENZIDINE	.000	.000	.000	.000	.000	.000	.000	.000
BENZIDINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODI-N-PROPYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODIMETHYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODIPHENYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-4-TRICHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-DICHLOROBENZENE	.000	.000	2.000	.000	.000	.000	.000	.000
1-3-DICHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
1-4-DICHLOROBENZENE	.000	.000	8.000	3.000	.000	.000	.000	.000
2-4-DINITROTOLUENE	.000	.000	.000	.000	.000	.000	.000	.000
2-6-DINITROTOLUENE	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLORONAPHTHALENE	.000	.000	.000	.000	.000	.000	.000	.000
4-BROMOPHENYL PHENYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
4-CHLOROPHENYL PHENYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
ACENAPHTHENE	.000	.000	5.000	13.000	8542.000	.000	.000	.000
ACENAPHTHYLENE	.000	.000	.000	.000	65.000	.000	.000	.000
ANTHRACENE	10.000	3.000	5.000	31.000	1908.000	.000	4.000	9.000
BENZO (A) ANTHRACENE	24.000	10.000	64.000	62.000	1434.000	12.000	10.000	16.000
BENZO (A) PYRENE	20.000	9.000	43.000	58.000	851.000	10.000	9.000	28.000
BENZO (B) FLUORANTHENE	23.000	8.000	60.000	54.000	1444.000	9.000	9.000	31.000
BENZO (G-H-I) PERYLENE	16.000	8.000	22.000	49.000	212.000	9.500	7.000	13.000
BENZO (K) FLUORANTHENE	40.000	11.000	61.000	67.000	537.000	10.000	12.000	35.000
BIS (2-CHLOROETHOXY) METHANE	.000	.000	.000	.000	.000	.000	.000	.000
BIS (2-CHLOROETHYL) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BIS (2-CHLOROISOPROPLY) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BUTYL BENZYL PHTHALATE	.000	.000	.000	.000	.000	.000	.000	.000
CHRYSENE	58.000	22.000	179.000	136.000	1070.000	20.000	16.000	26.000
DI-N-BUTYL PHTHALATE	44.000	28.000	65.000	162.000	152.000	94.000	53.000	39.000
DI-OCTYL PHTHALATES	.000	.000	3.000	2.000	.000	.000	.000	.000
DIBENZO (A-H) ANTHRACENE	4.000	.000	6.000	.000	127.000	.000	.000	.000
DIETHYL PHTHALATE	17.000	2.000	.000	3.000	.000	.000	.000	5.000
DIMETHYL PHTHALATE	.000	.000	.000	.000	.000	.000	.000	.000
FLUORANTHENE	31.000	18.000	90.000	73.000	1861.000	20.000	15.000	37.000
FLUORENE	4.000	2.000	5.000	16.000	5168.000	.000	.000	3.000
HEXACHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROCYCLOPENTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROETHANE	.000	.000	000	.000	.000	.000	.000	.000
INDENO (1-2-3-C-D) PYRENE	19.000	9.000	43.000	62.000	399.000	8.000	8.000	.000
ISOPHORONE	.000	.000	.000	.000	.000	.000	.000	.000
NAPHTHALENE	14.000	.000	13.000	43.000	2006.000	.000	.000	1.000
NITROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
PENTACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
PHENANTHRENE	18.000	11.000	13.000	51.000	2780.000	11.000	8.000	17.000
PYRENE	56.000	35.000	134.000	174.000	10010.000	49.500	37.000	78.000
TETRACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
TRICHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
2-3-7-8-TCDD	.000	.000	.000	.000	.000	.000	.000	.000
4-4-DDD	.000	.000	.000	.000	.000	000	.000	.000
4-4-DDE	.400	10.700	1.000	1.100	.000	1.400	.500	.700
4-4-DDT	.000	.000	.000	.000	.000	.000	.000	.000

Appendix Table 9.4, continued.

STATION	127	126	135	125	136	105	103	109
A-BHC	.000	.000	.000	.000	.000	.000	.000	.000
A-ENDOSULFAN	.000	.000	.000	.000	.000	.000	.000	.000
ALDRIN	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1016	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1221	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1232	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1242	4.000	6.000	60.000	7.000	10.000	11.000	3.000	5.000
AROCLOR 1248	4.000	6.000	60.000	7.000	10.000	11.000	3.000	5.000
AROCLOR 1254	14.000	8.000	25.000	29.000	30.000	24.000	8.000	10.000
AROCLOR 1260	18.000	12.000	17.000	52.000	20.000	18.000	7.000	8.000
B-BHC	.000	.000	.000	.000	.000	.000	.000	.000
B-ENDOSULFAN	.000	.000	.000	.000	.000	.000	.000	.000
CAFFEINE	.000	.000	.000	.000	.000	.000	.000	.000
CARBARYL	.000	.000	.000	.000	.000	.000	.000	.000
CHLORDANE	.000	.000	.000	.000	.000	.000	.000	.000
D-BHC	.000	.000	.000	.000	.000	.000	.000	.000
DEMETON	.000	.000	.000	.000	.000	.000	.000	.000
DIAZINON	.000	.000	.000	.000	.000	.000	.000	.000
DICHLOROPHENOXYACETIC ACID	.000	.000	.000	.000	.000	.000	.000	.000
DIELDRIN	.000	.000	.000	.000	.000	.000	.000	.000
ENDOSULFAN SULFATE	.000	.000	.000	.000	.000	.000	.000	.000
ENDRIN	.000	.000	.000	.000	.000	.000	.000	.000
ENDRIN ALDEHYDE	.000	.000	.000	.000	.000	.000	.000	.000
G-BHC	.000	.000	.000	.000	.000	.000	.000	.000
GUTHION	.000	.000	.000	.000	.000	.000	.000	.000
HEPTACHLOR	.000	.000	.000	.000	.000	.000	.000	.000
HEPTACHLOR EPOXIDE	.000	.000	.000	.000	.000	.000	.000	.000
MALATHION	.000	.000	.000	.000	.000	.000	.000	.000
METHOXYCHLOR	.000	.000	.000	.000	.000	.000	.000	.000
MIREX	.000	.000	.000	.000	.000	.000	.000	.000
NICOTINE	.000	.000	.000	.000	.000	.000	.000	.000
PARATHION	.000	.000	.000	.000	.000	.000	.000	.000
SILVEX	.000	.000	.000	.000	.000	.000	.000	.000
SWEP	.000	.000	.000	.000	.000	.000	.000	.000
TOXAPHENE	.000	.000	.000	.000	.000	.000	.000	.000
G-CHLORDENE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-1-TRICHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	1.000
1-1-2-2-TETRACHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-2-TRICHLOROETHANE	.000	.000	.000	.000	.000	.020	1.900	.000
1-1-DICHLOROETHANE	.000	.000	.000	.000	.000	.000	.080	.000
1-1-DICHLOROETHYLENE	.000	.020	.000	.000	.020	.000	.000	.000
1-2-DICHLOROETHANE	.000	.000	.000	.000	.000	.020	.000	.000
1-2-DICHLOROPROPANE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-TRANS-DICHLOROETHYLENE	.000	.000	.000	.030	.000	.050	.070	.000
1-3-DICHLOROPROPENE	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLOROETHYL VINYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
ACROLEIN	.000	.000	.000	.000	.000	.000	.000	.000
ACRYLONITRILE	.000	.000	.000	.000	.000	.000	.000	.000
BENZENE	2.000	4.000	.090	.500	6.000	2.000	1.900	1.000
BIS (CHLOROMETHLY) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BROMOFORM	.050	.000	.000	.000	.050	.010	.020	.000
CARBON TETRACHLORIDE	.000	.000	.000	.000	.040	.000	.000	.000
CHLOROBENZENE	.010	.000	.000	.020	.010	.020	.010	.010
CHLORODIBROMOMETHANE	.000	.000	.000	.000	.000	.000	.000	.000
CHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
CHLOROFORM	.000	.000	.000	.030	.000	.000	.100	.000
DICHLOROBROMOMETHANE	.000	.000	.000	.000	.050	.000	.020	.050
DICHLORODIFLUOROMETHANE	.000	.000	.000	.000	.000	.000	.000	.000
ETHYLBENZENE	.040	.060	060	.070	6.000	.060	.010	.010
METHYL BROMIDE	.000	.000	.000	.000	.000	.000	.000	.000
METHYL CHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000
METHYLENE CHLORIDE	29.000	20.000	.000	7.700	70.000	32.000	23.000	14.000
TETRACHLOROETHYLENE	.020	.050	.000	.030	.050	.030	.000	.030
TOLUENE	.200	.300	.200	.100	.600	.140	.180	.130
TRICHLOROETHYLENE	.000	.000	.050	.020	.100	.070	.090	.000
TRICHLOROFLUOROMETHANE	.000	.000	.000	.000	.000	.000	.000	.000
VINYL CHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000

Appendix Table 9.4, continued.

STATION	121	123	110	104	111	116	101	118
2-4-6-TRICHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-4-DICHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-4-DIMETHYLPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-4-DINITROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
2-NITROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
4-6-DINITRO-O-CRESOL	.000	.000	.000	.000	.000	.000	.000	.000
4-CHLORO-3-METHYL PHENOL	.000	.000	.000	.000	.000	.000	.000	.000
4-NITROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
PENTACHLOROPHENOL	.000	.000	.000	.000	.000	.000	.000	.000
PHENOL	.000	107.000	.000	309.000	.000	388.600	555.000	266.000
1-2-DIPHENYLHYDRAZINE	.000	.000	.000	.000	.000	.000	.000	.000
3-3-DICHLOROBENZIDINE	.000	.000	.000	.000	.000	.000	.000	.000
BENZIDINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODI-N-PROPYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODIMETHYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
N-NITROSODIPHENYLAMINE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-4-TRICHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-DICHLOROBENZENE	25.300	.000	.000	.000	.000	.000	.000	.000
1-3-DICHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
1-4-DICHLOROBENZENE	.000	.000	1.000	.000	.000	.000	.000	.000
2-4-DINITROTOLUENE	.000	.000	.000	.000	.000	.000	.000	.000
2-6-DINITROTOLUENE	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLORONAPHTHALENE	.000	.000	.000	.000	.000	.000	.000	.000
4-BROMOPHENYL PHENYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
4-CHLOROPHENYL PHENYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
ACENAPHTHENE	.000	6.000	.000	.000	.000	.000	.000	.000
ACENAPHTHYLENE	7.000	3.000	.000	.000	.000	.000	.000	.000
ANTHRACENE	239.000	30.000	6.000	4.000	9.000	10.400	.000	13.000
BENZO (A) ANTHRACENE	472.000	47.000	16.000	11.500	19.000	22.400	5.500	33.000
BENZO (A) PYRENE	336.000	56.000	13.000	12.000	17.000	21.900	.000	26.000
BENZO (B) FLUORANTHENE	296.000	38.000	12.000	12.000	15.000	18.600	6.000	25.000
BENZO (G-H-I) PERYLENE	266.000	38.000	15.000	9.000	16.000	17.400	.000	16.000
BENZO (K) FLUORANTHENE	274.000	44.000	19.000	10.000	22.000	22.800	6.500	29.000
BIS (2-CHLOROETHOXY) METHANE	.000	.000	.000	.000	.000	.000	.000	.000
BIS (2-CHLOROETHYL) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BIS (2-CHLOROISOPROPLY) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BUTYL BENZYL PHTHALATE	.000	.000	.000	.000	.000	.000	.000	.000
CHRYSENE	952.000	121.000	23.000	30.000	33.000	58.600	17.500	52.000
DI-N-BUTYL PHTHALATE	88.000	103.000	83.000	49.000	519.000	12.000	88.000	178.000
DI-OCTYL PHTHALATES	.000	1.000	.000	.000	.000	.000	7.000	.000
DIBENZO (A-H) ANTHRACENE	110.000	9.000	2.000	.000	2.000	1.800	.000	.000
DIETHYL PHTHALATE	.000	.000	3.000	.000	.000	.000	.000	.000
DIMETHYL PHTHALATE	.000	.000	.000	.000	.000	.000	.000	.000
FLUORANTHENE	738.000	55.000	23.000	21.000	29.000	35.600	16.000	37.000
FLUORENE	96.000	11.000	4.000	.000	.000	.000	.000	.000
HEXACHLOROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROCYCLOPENTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
HEXACHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
INDENO (1-2-3-C-D) PYRENE	389.000	48.000	15.000	6.000	16.000	19.600	.000	18.000
ISOPHORONE	.000	.000	.000	.000	.000	.000	.000	.000
NAPHTHALENE	51.000	34.000	12.000	.000	13.000	15.100	.000	22.000
NITROBENZENE	.000	.000	.000	.000	.000	.000	.000	.000
PENTACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
PHENANTHRENE	516.000	37.000	13.000	11.500	16.000	16.900	.000	22.000
PYRENE	1252.000	114.000	53.000	46.000	73.000	66.900	32.000	96.000
TETRACHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
TRICHLOROBUTADIENE	.000	.000	.000	.000	.000	.000	.000	.000
2-3-7-8-TCDD	.000	.000	.000	.000	.000	.000	.000	.000
4-4-DDD	.000	.000	.000	.000	.000	.000	.000	.000
4-4-DDE	2.500	3.800	.400	1.700	1.300	.900	2.000	.600
4-4-DDT	.000	.000	.000	.000	.000	.000	.000	.000

Appendix Table 9.4, continued.

STATION	121	123	110	104	111	116	101	118
A-BHC	.000	.000	.000	.000	.000	.000	.000	.000
A-ENDOSULFAN	.000	.000	.000	.000	.000	.000	.000	.000
ALDRIN	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1016	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1221	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1232	.000	.000	.000	.000	.000	.000	.000	.000
AROCLOR 1242	14.000	19.000	3.000	12.000	7.000	9.000	13.000	6.000
AROCLOR 1248	14.000	19.000	3.000	12.000	7.000	9.000	13.000	6.000
AROCLOR 1254	95.000	76.000	9.500	27.000	18.000	30.000	26.000	22.000
AROCLOR 1260	75.000	83.000	8.000	21.000	13.000	17.000	23.000	16.000
B-BHC	.000	.000	.000	.000	.000	.000	.000	.000
B-ENDOSULFAN	.000	.000	.000	.000	.000	.000	.000	.000
CAFFEINE	.000	.000	.000	.000	.000	.000	.000	.000
CARBARYL	.000	.000	.000	.000	.000	.000	.000	.000
CHLORDANE	.000	.000	.000	.000	.000	.000	.000	.000
D-BHC	.000	.000	.000	.000	.000	.000	.000	.000
DEMETON	.000	.000	.000	.000	.000	.000	.000	.000
DIAZINON	.000	.000	.000	.000	.000	.000	.000	.000
DICHLOROPHENOXYACETIC ACID	.000	.000	.000	.000	.000	.000	.000	.000
DIELDRIN	.000	.000	.000	.000	.000	.000	.000	.000
ENDOSULFAN SULFATE	.000	.000	.000	.000	.000	.000	.000	.000
ENDRIN	.000	.000	.000	.000	.000	.000	.000	.000
ENDRIN ALDEHYDE	.000	.000	.000	.000	.000	.000	.000	.000
G-BHC	.000	.000	.000	.000	.000	.000	.000	.000
GUTHION	.000	.000	.000	.000	.000	.000	.000	.000
HEPTACHLOR	.000	.000	.000	.000	.000	.000	.000	.000
HEPTACHLOR EPOXIDE	.000	.000	.000	.000	.000	.000	.000	.000
MALATHION	.000	.000	.000	.000	.000	.000	.000	.000
METHOXYCHLOR	.000	.000	.000	.000	.000	.000	.000	.000
MIREX	.000	.000	.000	.000	.000	.000	.000	.000
NICOTINE	.000	.000	.000	.000	.000	.000	.000	.000
PARATHION	.000	.000	.000	.000	.000	.000	.000	.000
SILVEX	.000	.000	.000	.000	.000	.000	.000	.000
SWEP	.000	.000	.000	.000	.000	.000	.000	.000
TOXAPHENE	.000	.000	.000	.000	.000	.000	.000	.000
G-CHLORDENE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-1-TRICHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-2-2-TETRACHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-2-TRICHLOROETHANE	.030	.000	.000	.000	.400	.000	.010	.000
1-1-DICHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
1-1-DICHLOROETHYLENE	.010	.000	.000	.010	1.200	.000	.000	.000
1-2-DICHLOROETHANE	.000	.000	.000	.000	.000	.200	.000	.000
1-2-DICHLOROPROPANE	.000	.000	.000	.000	.000	.000	.000	.000
1-2-TRANS-DICHLOROETHYLENE	.030	.040	.010	.030	.000	.020	.030	.000
1-3-DICHLOROPROPENE	.000	.000	.000	.000	.000	.000	.000	.000
2-CHLOROETHYL VINYL ETHER	.000	.000	.000	.000	.000	.000	.000	.000
ACROLEIN	.000	.000	.000	.000	.000	.000	.000	.000
ACRYLONITRILE	.000	.000	.000	.000	.000	.000	.000	.000
BENZENE	2.000	.070	.220	1.400	49.000	.200	.600	.000
BIS (CHLOROMETHLY) ETHER	.000	.000	.000	.000	.000	.000	.000	.000
BROMOFORM	.040	.000	.020	.010	.000	.000	5.000	.000
CARBON TETRACHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000
CHLOROBENZENE	.250	.020	.010	.010	.400	.020	.000	.000
CHLORODIBROMOMETHANE	.000	.000	.000	.000	.000	.000	.000	.000
CHLOROETHANE	.000	.000	.000	.000	.000	.000	.000	.000
CHLOROFORM	.000	.060	.000	.250	.060	.300	.400	.000
DICHLOROBROMOMETHANE	.000	010	.000	.010	.050	.040	.050	.000
DICHLORODIFLUOROMETHANE	.000	.000	.000	.000	.000	.000	.000	.000
ETHYLBENZENE	.700	.010	.030	.070	.000	.050	.020	.000
METHYL BROMIDE	.000	.000	.000	.000	.000	.000	.000	.000
METHYL CHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000
METHYLENE CHLORIDE	41.000	13.300	2.200	.000	.000	82.000	52.000	.000
TETRACHLOROETHYLENE	.090	.020	.000	.030	.100	.030	.000	.000
TOLUENE	.400	.000	.090	.100	.000	.100	.000	.000
TRICHLOROETHYLENE	.050	.000	.020	.030	1.000	.030	.000	.000
TRICHLOROFLUOROMETHANE	.000	.000	.000	.000	.000	.000	.000	.000
VINYL CHLORIDE	.000	.000	.000	.000	.000	.000	.000	.000

Appendix Table 9.4, continued.

STATION	128	115	134	113	132
2-4-6-TRICHLOROPHENOL	.000	.000	.000		
2-4-DICHLOROPHENOL	.000	.000	.000		
2-4-DIMETHYLPHENOL	.000	.000	.000		
2-4-DINITROPHENOL	.000	.000	.000		
2-CHLOROPHENOL	.000	1.000	.000		
2-NITROPHENOL	.000	107.000	.000		
4-6-DINITRO-O-CRESOL	.000	.000	.000		
4-CHLORO-3-METHYL PHENOL	.000	.000	.000		
4-NITROPHENOL	.000	.000	.000		
PENTACHLOROPHENOL	.000	.000	.000		
PHENOL	149.000	1568.000	236.000		
1-2-DIPHENYLHYDRAZINE	.000	.000	.000		
3-3-DICHLOROBENZIDINE	.000	.000	.000		
BENZIDINE	.000	.000	.000		
N-NITROSODI-N-PROPYLAMINE	.000	.000	.000		
N-NITROSODIMETHYLAMINE	.000	.000	.000		
N-NITROSODIPHENYLAMINE	.000	.000	.000		
1-2-4-TRICHLOROBENZENE	.000	.000	.000		
1-2-DICHLOROBENZENE	.000	.000	.000		
1-3-DICHLOROBENZENE	.000	.000	.000		
1-4-DICHLOROBENZENE	.000	.000	.000		
2-4-DINITROTOLUENE	.000	.000	.000		
2-6-DINITROTOLUENE	.000	.000	.000		
2-CHLORONAPHTHALENE	.000	.000	.000		
4-BROMOPHENYL PHENYL ETHER	.000	.000	.000		
4-CHLOROPHENYL PHENYL ETHER	.000	.000	.000		
ACENAPHTHENE	.000	.000	.000		
ACENAPHTHYLENE	.000	.000	10.000		
ANTHRACENE	.000	14.000	28.000		
BENZO (A) ANTHRACENE	12.000	38.000	56.000		
BENZO (A) PYRENE	11.000	35.000	40.000		
BENZO (B) FLUORANTHENE	10.000	29.000	38.000		
BENZO (G-H-I) PERYLENE	8.000	22.000	27.000		
BENZO (K) FLUORANTHENE	13.000	39.000	58.000		
BIS (2-CHLOROETHOXY) METHANE	.000	.000	.000		
BIS (2-CHLOROETHYL) ETHER	.000	.000	.000		
BIS (2-CHLOROISOPROPLY) ETHE	.000	.000	.000		
BUTYL BENZYL PHTHALATE	.000	.000	.000		
CHRYSENE	32.000	65.000	96.000		
DI-N-BUTYL PHTHALATE	35.000	184.000	102.000		
DI-OCTYL PHTHALATES	.000	.000	3.000		
DIBENZO (A-H) ANTHRACENE	.000	.000	15.000		
DIETHYL PHTHALATE	.000	11.000	8.000		
DIMETHYL PHTHALATE	.000	.000	.000		
FLUORANTHENE	20.000	59.000	62.000		
FLUORENE	.000	.000	14.000		
HEXACHLOROBENZENE	.000	.000	.000		
HEXACHLOROBUTADIENE	.000	.000	.000		
HEXACHLOROCYCLOPENTADIENE	.000	.000	.000		
HEXACHLOROETHANE	.000	.000	.000		
INDENO (1-2-3-C-D) PYRENE	.000	18.000	36.000		
ISOPHORONE	.000	.000	.000		
NAPHTHALENE	.000	12.000	.000		
NITROBENZENE	.000	.000	.000		
PENTACHLOROBUTADIENE	.000	.000	.000		
PHENANTHRENE	11.000	26.000	31.000		
PYRENE	46.000	106.000	160.000		
TETRACHLOROBUTADIENE	.000	.000	.000		
TRICHLOROBUTADIENE	.000	.000	.000		
2-3-7-8-TCDD	.000	.000	.000		
4-4-DDD	.000	.000	.000		
4-4-DDE	1.500	.000	2.500		
4-4-DDT	.000	.000	.000		

(Data for these stations
not provided by METRO
in time for publication)

Appendix Table 9.4, continued.

STATION	128	115	134	113	132
A-BHC	.000	.000	.000	(Data for these stations not provided by METRO in time for publication)	
A-ENDOSULFAN	.000	.000	.000		
ALDRIN	.000	.000	.000		
AROCLOR 1016	.000	.000	.000		
AROCLOR 1221	.000	.000	.000		
AROCLOR 1232	.000	.000	.000		
AROCLOR 1242	11.000	.000	13.000		
AROCLOR 1248	11.000	.000	13.000		
AROCLOR 1254	32.000	.000	85.000		
AROCLOR 1260	20.000	.000	88.000		
B-BHC	.000	.000	.000		
B-ENDOSULFAN	.000	.000	.000		
CAFFEINE	.000	.000	.000		
CARBARYL	.000	.000	.000		
CHLORDANE	.000	.000	.000		
D-BHC	.000	.000	.000		
DEMETON	.000	.000	.000		
DIAZINON	.000	.000	.000		
DICHLOROPHENOXYACETIC ACID	.000	.000	.000		
DIELDRIN	.000	.000	.000		
ENDOSULFAN SULFATE	.000	.000	.000		
ENDRIN	.000	.000	.000		
ENDRIN ALDEHYDE	.000	.000	.000		
G-BHC	.000	.000	.000		
GUTHION	.000	.000	.000		
HEPTACHLOR	.000	.000	.000		
HEPTACHLOR EPOXIDE	.000	.000	.000		
MALATHION	.000	.000	.000		
METHOXYCHLOR	.000	.000	.000		
MIREX	.000	.000	.000		
NICOTINE	.000	.000	.000		
PARATHION	.000	.000	.000		
SILVEX	.000	.000	.000		
SWEP	.000	.000	.000		
TOXAPHENE	.000	.000	.000		
G-CHLORDENE	.000	.000	.000		
1-1-1-TRICHLOROETHANE	.000	.000	.000		
1-1-2-2-TETRACHLOROETHANE	.000	.000	.000		
1-1-2-TRICHLOROETHANE	.000	.000	.000		
1-1-DICHLOROETHANE	.000	.000	.000		
1-1-DICHLOROETHYLENE	.000	.000	.000		
1-2-DICHLOROETHANE	.000	.000	.000		
1-2-DICHLOROPROPANE	.000	.000	.000		
1-2-TRANS-DICHLOROETHYLENE	.200	.000	.010		
1-3-DICHLOROPROPENE	.000	.000	.000		
2-CHLOROETHYL VINYL ETHER	.000	.000	.000		
ACROLEIN	.000	.000	.000		
ACRYLONITRILE	.000	.000	.000		
BENZENE	.900	.000	.500		
BIS (CHLOROMETHLY) ETHER	.000	.000	.000		
BROMOFORM	.000	.000	.000		
CARBON TETRACHLORIDE	.000	.000	.000		
CHLOROBENZENE	.030	.000	.100		
CHLORODIBROMOMETHANE	.000	.000	.000		
CHLOROETHANE	.000	.000	.000		
CHLOROFORM	.500	.000	.150		
DICHLOROBROMOMETHANE	.020	.000	.000		
DICHLORODIFLUOROMETHANE	.000	.000	.000		
ETHYLBENZENE	.040	.000	.010		
METHYL BROMIDE	.000	.000	.000		
METHYL CHLORIDE	.000	.000	.000		
METHYLENE CHLORIDE	10.000	.000	3.700		
TETRACHLOROETHYLENE	.150	.000	.000		
TOLUENE	.300	.000	.100		
TRICHLOROETHYLENE	.060	.000	.000		
TRICHLOROFLUOROMETHANE	.000	.000	.000		
VINYL CHLORIDE	.000	.000	.000		

Appendix Table 9.5. Metals analyses of Elliott Bay sediments used in toxicity bioassays (see text for station locations). Results are mg/kg dry weight, unless otherwise noted. Be, Cr, Co, Cu, Ni, V, and Zn were analysed by plasma emission. Atomic absorption (AA) was used for Ag, Cd, and Pb. As, Al, and Mn were determined by Neutron Activation Analysis, and cold vapor AA was used for Hg.

SAMPLE	Be	Cr	Co	Cu	Ni	V	Zn	Ag	Cd	Pb	Hg (ug/kg)	As	Al (g/kg)	Mn	Wet/Dry Wt.
101	1.7	100	27.1	49.8	56.7	118	138	0.19	0.19	16.3	238	25.1	70	826	3.18
102	1.2	60.2	23.3	24.9	67.2	87.2	314	0.10	0.91	6.1	127	30.8	63	773	2.28
103	1.8	72.1	29.3	37.4	160	112	229	0.19	0.89	7.6	62	23.1	71	590	2.31
104	1.7	61.7	24.5	44.8	46.5	112	203	0.28	0.91	15.3	206	9.5	19	641	3.39
105	1.7	73.8	25.8	46.0	63.8	115	113	0.15	0.23	11.7	201	19.2	68	572	3.16
106	1.0	67.4	20.7	37.3	74.2	87.7	116	0.21	0.18	15.8	214	18.7	66	741	3.36
107	1.4	55.8	20.0	38.6	75.7	90.8	84.5	N.D.	0.35	13.8	215	17.9	59	674	3.26
108	1.6	64.0	24.0	37.3	62.5	103	334	0.15	0.19	14.9	219	15.4	65	743	3.61
109	1.7	71.1	27.7	49.1	50.7	111	225	N.D.	0.19	10.1	251	30.8	67	561	2.95
110	1.4	56.0	22.3	41.5	45.1	98.9	101	N.D.	0.17	10.6	281	28.8	72	600	3.32
111	1.9	79.3	31.0	59.0	73.5	131	241	0.14	0.37	11.7	180	27.6	68	544	3.12
112	1.4	46.7	20.1	35.6	50.3	82.0	79.4	0.24	0.23	18.5	288	27.4	66	549	3.39
113	2.4	86.7	35.6	60.2	60.2	146	828	N.D.	0.28	39.9	299	19.5	69	748	3.14
114	1.9	70.8	27.6	49.0	119	116	276	0.15	0.29	20.7	265	17.7	71	605	3.00
115	1.3	46.7	20.0	36.5	40.1	78.6	436	0.20	0.36	16.1	188	24.4	67	697	1.89
116	2.3	82.6	32.8	65.7	60.0	144	310	0.14	0.28	13.8	354	35.0	70	692	2.98
117	1.1	149	21.0	225	92.7	68.2	248	0.10	0.33	63.0	<16	30.7	64	648	1.91
118	1.6	75.2	22.4	87.4	51.8	102	137	0.24	0.18	39.6	291	37.0	76	728	2.49
119	1.6	70.6	23.7	71.5	45.4	106	227	0.24	0.28	29.2	293	32.0	75	613	2.74
120	1.4	77.0	22.2	133	36.8	85.1	691	0.24	0.62	34.4	<21	7.8	74	591	2.19
121	1.4	52.8	29.7	220	30.7	82.2	659	0.20	0.24	60.6	654	83.7	78	722	1.72
122	1.5	52.2	21.5	84.8	32.7	89.3	116	0.17	0.27	14.3	714	70.7	78	426	2.05
123	1.6	75.5	24.7	74.1	50.2	107	840	N.D.	0.28	26.3	400	28.8	74	652	2.71
124	1.3	58.1	18.9	52.7	38.7	74.5	83.0	0.32	0.20	13.6	104	29.4	67	541	1.49
125	1.6	74.2	23.9	86.3	46.3	104	285	0.19	0.44	36.0	359	42.7	75	527	2.12
126	1.6	84.0	24.2	65.9	55.9	112	179	N.D.	0.38	13.3	152	17.8	68	653	2.80
127	1.2	52.3	13.9	36.5	36.4	65.2	44.1	0.17	0.14	17.2	561	32.7	67	446	6.89
128	1.9	101	26.5	100	67.3	118	589	0.32	0.44	36.5	212	23.6	70	721	3.18
129	1.7	79.1	23.6	65.6	54.3	107	173	0.13	0.34	34.7	358	24.8	70	684	5.21
130	1.6	73.4	22.8	68.6	46.7	102	390	0.13	0.42	21.6	284	17.2	69	689	3.20
131	1.6	82.2	27.4	64.9	54.2	111	619	N.D.	0.32	3.0	185	39.4	71	878	2.89
132	1.0	57.0	14.3	15.1	36.8	64.7	100	N.D.	0.11	17.3	<11	10.0	66	538	1.27
133	1.6	59.0	25.0	150	33.8	107	573	N.D.	1.08	31.4	413	77.8	83	649	2.08
134	1.6	72.1	25.2	108	58.6	103	422	0.33	0.83	11.9	787	48.9	75	698	2.77
The following are duplicate digested samples.															
135	1.4	44.1	19.9	31.7	31.1	93.6	106	0.27	0.16	17.1	32	32.6	73	540	1.51
	1.3	51.4	20.7	38.4	31.8	103	177	<0.10	0.19						
135-N	0.6	32.9	12.0	25.5	27.9	51.0	110	<0.10	0.14	16.4					
136	1.2	66.7	12.0	65.2	39.9	84.4	359	<0.10	0.27	51.1	312	15.1	67	426	2.13
	1.3	77.5	16.4	76.3	39.4	87.3	430	<0.10	0.30						
136-N	0.7	53.8	11.8	64.0	39.3	58.1	185	0.14	0.33	40.9					
137	1.4	68.3	17.0	70.7	41.9	86.2	258	0.14	0.35	16.5	566	21.2	69	481	2.38
	1.3	72.2	17.4	103	41.7	90.5	300	0.15	0.38						

Samples 135-N and 136-N were digested with nitric acid and hydrogen peroxide. All other samples were done with hydrofluoric and nitric acids plus hydrogen peroxide. Samples 135, 136, and 137 had duplicate digestions done.

PRECISION (C.V.) %	0.55	0.74	0.86	0.72	0.63	0.57	0.56	10.00	2.30	2.50
MESS-1 STAND/ANA	1.9/1.9	71/70	11/18	25/25	29/33	72/87	191/180	N/A	0.36/0.38	34/35
MATRIX SPIKE %	98.9	98.5	98.9	96.6	98.2	100.0	107.0			
SAMPLE SPIKE %	93.4	91.9	95.3	84.0	86.4	95.2	102.0	109.00	85.00	85.0
DETECTION LIMIT ug/g	0.6	1.0	1.0	1.0	2.0	2.0	5.0	0.1	0.1	2.0

(C.V.) Coeficient of variation expressed as a percent......

MESS-1 is a standard sediment with known concentrations of these elements, except silver..
The STAND/ANA is the known value and the analysed value in ug/gr. D.W.

The MATRIX SPIKE is a solution made up of the elements: Fe, Al, Si, Ca, Mg, Na, and K in the concentrations found in the samples analysed. The elements to be tested are added in known concentrations and the result is a percent recovery.....

The SAMPLE SPIKE is also a percent recovery. Known concentrations of the elements tested for are added to a sample.....

N.D.= NONE DETECTED

Appendix Table 9.6. Other physical/chemical parameters measured for sediments used in toxicity bioassays. Elliott Bay/Duwamish Head Baseline Studies, 1984.

STATION	%GRAVEL	%SAND	%SILT	%CLAY	MEAN PHI	OIL & GREASE (ml/kg)	CARBON (g/kg)	NITROGEN (g/kg)	B.O.D. (mg/kg)	%VOLATILE SOLIDS	DRY/WET	DEPTH (FT)
101	0.00	06.88	40.57	52.56	8.08	b	18.07	2.23	b	05.13	0.383	600
103	0.34	32.11	37.88	29.66	5.99	00.17	18.67	2.43	0692	05.72	0.384	800
104	0.00	13.13	41.30	45.57	7.05	08.72	24.76	2.78	1650	08.75	0.279	600
105	0.00	04.38	46.80	48.83	7.60	02.29	23.77	2.44	1675	07.90	0.320	600
106	0.00	03.41	42.11	54.45	7.87	01.88	23.78	2.58	1691	09.12	0.296	600
107	0.00	07.45	47.61	44.95	7.40	01.97	24.90	2.68	2653	08.57	0.286	600
108	0.00	05.28	49.32	45.30	7.49	01.52	24.44	2.94	2339	08.98	0.305	600
109	0.24	24.43	35.21	40.12	6.59	09.71	18.91	2.01	1341	05.80	0.392	400
110	0.00	09.79	50.86	39.35	7.12	00.82	23.72	2.44	1573	08.41	0.338	600
111	0.02	08.42	43.54	48.01	7.48	05.33	23.39	2.64	1842	06.78	0.334	500
112	0.03	12.12	41.30	45.44	7.17	01.13	22.33	2.45	1546	07.76	0.319	400
113	0.07	10.49	52.24	37.20	7.00	03.23	24.31	2.56	1969	08.67	0.324	600
114	0.07	18.56	37.37	43.99	6.93	04.95	23.58	2.34	1595	07.36	0.360	400
115	0.00	11.96	52.50	35.54	6.94	01.56	25.47	2.64	2575	08.47	0.336	600
116	0.00	11.25	51.86	36.89	6.90	01.71	24.39	3.98	2077	08.60	0.307	600
117	0.98	63.58	25.80	09.62	3.92	05.38	14.92	0.95	1220	04.02	0.583	050
118	0.00	29.18	36.85	32.98	6.15	00.94	18.91	1.60	1195	05.75	0.413	300
119	0.00	16.83	42.59	39.59	6.77	06.88	19.99	1.90	1075	06.97	0.377	400
120	3.59	42.36	36.01	18.04	4.64	04.35	45.67	1.21	1369	13.00	0.465	050
121	0.09	70.20	19.84	09.86	3.66	01.42	08.50	0.57	0760	03.17	0.622	050
122	0.40	31.17	41.58	26.84	5.76	11.72	18.28	1.11	1068	07.41	0.501	200
123	0.00	05.79	48.17	45.88	7.44	04.44	19.99	1.81	1499	06.50	0.387	300
124	2.15	68.27	17.90	11.67	3.82	05.61	07.98	0.48	0818	03.75	0.609	050
125	0.25	25.69	36.20	37.86	6.44	05.34	24.59	1.36	1397	09.70	0.475	200
126	0.00	03.38	52.34	44.28	7.47	00.26	22.62	4.29	1246	06.42	0.323	750
127	0.00	29.28	32.80	37.92	6.33	00.49	20.02	1.73	0544	04.27	0.430	300
128	0.00	03.50	42.08	49.90	7.54	18.18	24.46	2.61	1260	06.90	0.295	550
129	0.00	12.21	42.61	45.19	7.28	07.48	21.20	2.05	1825	08.82	0.313	500
130	0.00	13.02	51.33	35.65	6.83	03.09	24.66	3.85	1722	08.39	0.333	600
131(a)	0.00	15.14	33.04	51.82	7.64	b	10.40	1.21	b	10.80	0.469	700
132(a)	0.00	98.17	00.46	00.83	2.23	b	00.51	1.27	b	01.08	0.790	000
133(a)	1.12	33.96	46.29	18.63	5.45	b	15.40	1.25	b	08.46	0.480	050
134	b	b	b	b	b	b	12.40	1.70	b	07.02	0.522	600
135	b	b	b	b	b	b	06.81	1.29	b	05.87	0.694	500
136	b	b	b	b	b	b	b	b	b	b	b	050
137	b	b	b	b	b	b	22.50	4.15	b	09.03	0.465	050

a) Measurements from the Seahurst Baseline Studies, 1983.

b) Not measured.

Appendix Table 9.7A. Sand dollar embryo abnormalities in sediment elutriates compared against "Other Sediment Parameters" given in Appendix Table 9.6.

Parameter[a)]	Correlation coefficient (r)	r^2	Probability of r
% Gravel	.30074	.09044	0.59970
% Sand	.19054	.03639	0.16572
% Silt	-.03361	.00113	0.43258
% Clay	-.28282	.07999	0.07238
Mean Phi Size	-.24110	.05813	0.10824
Oil & Grease	.19342	.03741	0.16202
Carbon	.06417	.00412	0.37281
Nitrogen	-.10550	.01113	0.29657
B.O.D.[b)]	.16542	.02736	0.20011
% Volatile Solids	.06237	.00389	0.37628
Dry/Wet Wt.	.28842	.08319	0.06831
Depth	-.36972	.13670	0.02641 *
Summed Organics[c)]	.684	.468	<0.01 **

a) Regressed against arcsine transformed percent abnormality in 16.6% elutriate, by volume.

b) Biochemical oxygen demand.

c) Sumnation of organic priority pollutants present in the sediment, in PPB dry wt.

* Significant at a = 0.05

** Significant at a = 0.01

Appendix Table 9.7B. Survival of amphipods compared against "Other sediment parameters" given in Appendix Table 9.6.

Parameter[a]	Correlation coeff. (r)	r^2	Probability of r
% gravel	.41947	.17595	0.01314*
% sand	.60057	.36069	0.00036**
% silt	-.39245	.15401	0.01943*
% clay	-.66721	.44516	0.00005**
Mean Phi size	-.64180	.41191	0.00012**
Oil & grease	-.30573	.09347	0.05680
Carbon	-.18176	.03304	0.17730
Nitrogen	-.36289	.13169	0.02885*
B.O.D.[b]	-.32181	.10356	0.04746*
% volatile solids	-.31492	.09918	0.05131
Dry/wet wt.	.61213	.37470	0.00027**
Depth	-.42994	.18485	0.01120*
Summed organics[c]	.49216	.24222	<0.01**

a) Regressed against arcsine transformed percent amphipod survival.

b) Biochemical oxygen demand.

c) Summation of organic priority pollutants present in the sediment, in PPB dry wt.

* Significant at a = 0.05.

** Significant at a = 0.01.