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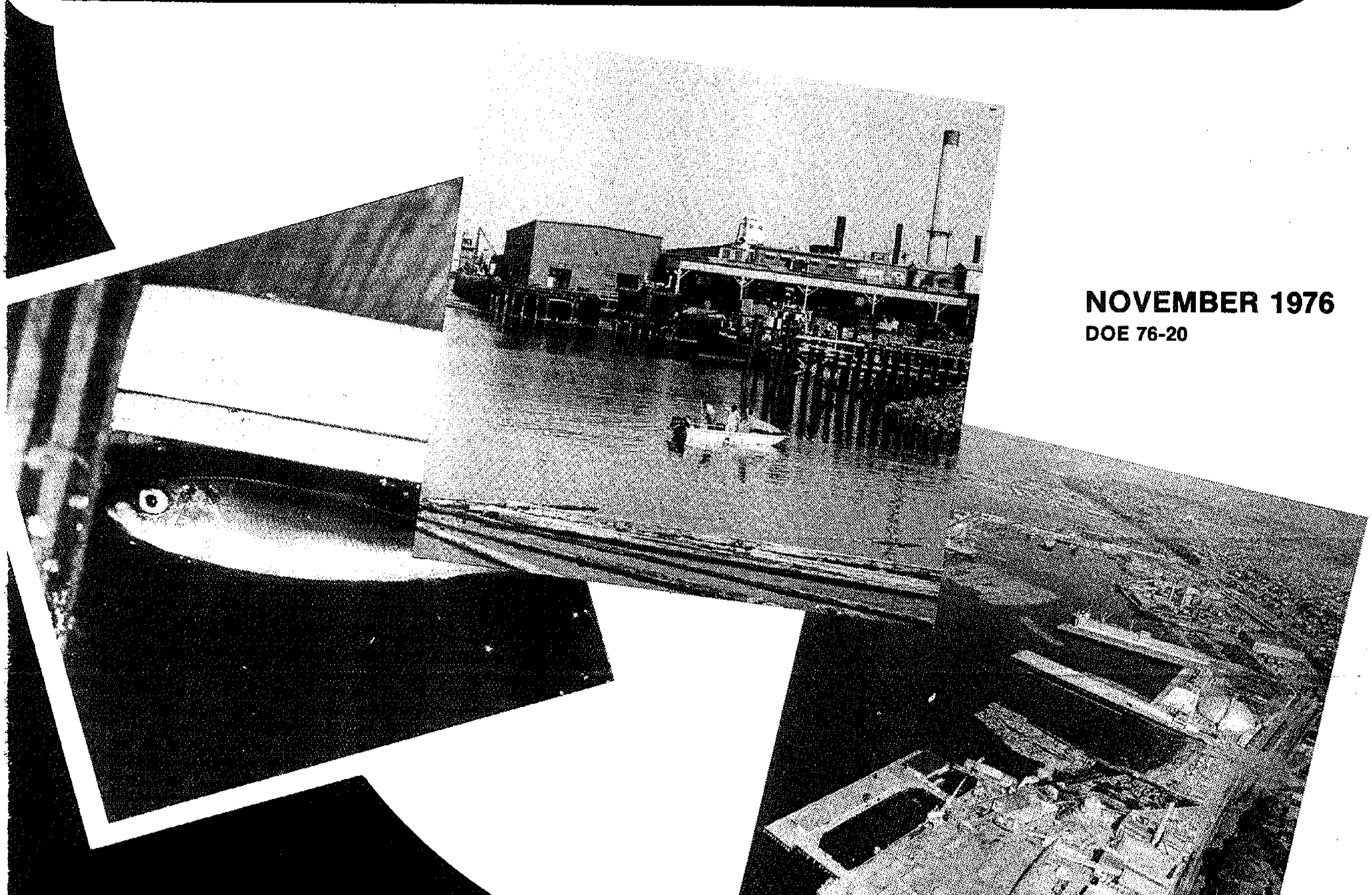
ECOLOGICAL BASELINE AND MONITORING STUDY FOR PORT GARDNER AND ADJACENT WATERS

A SUMMARY REPORT FOR THE YEARS 1972 THROUGH 1975



NOVEMBER 1976
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STATE OF WASHINGTON
DANIEL J. EVANS
GOVERNOR

ECOLOGICAL BASELINE AND MONITORING STUDY

FOR

PORT GARDNER AND ADJACENT WATERS

A Summary Report for the Years 1972 through 1975

Participating Agencies

Washington Department of Ecology
Washington Department of Fisheries
University of Washington
U.S. Environmental Protection Agency
Scott Paper Company
Weyerhaeuser Company

November 1976

State of Washington
Department of Ecology
Olympia, Washington
98504

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EXECUTIVE SUMMARY

ECOLOGICAL BASELINE AND MONITORING STUDY FOR PORT GARDNER AND ADJACENT WATERS

The Ecological Baseline and Monitoring (ECOBAM) Study began in 1972 in response to a request by Governor Evans to examine relationships between reductions in pulp mill waste discharges and biological changes in Port Gardner. The objective of the study is to develop baseline descriptions and to monitor expected changes in the saltwater environment and possible changes in populations of marine plants and animals.

The two sulfite pulp mills discharging into Port Gardner have begun a stepwise reduction of their waste process water discharged through inshore and deepwater diffuser outfalls. Scott Paper Company completed and began operating their stage 1 recovery system in 1974, which reduced the sulfite waste liquor discharged through the deepwater diffuser by more than 80% from one-half of its operation. Weyerhaeuser Company shut down their sulfite pulping operation in May 1975 and began using a new thermomechanical pulping process in October 1975. As a result, the waste discharged through the deepwater diffuser and the inshore discharges has been reduced by about 80 percent and 50 percent respectively.

Early indications of improvements in water quality have been noted as a result of these waste reductions. Sulfite waste liquor concentrations near the deepwater diffuser have decreased about 50 percent and dissolved oxygen concentrations at depth have increased as much as 30 percent. The area of toxic water, as indicated by Pacific oyster larvae bioassays from 1972 to 1975 appears to have decreased substantially.

Changes in populations of biological organisms are not yet apparent since major waste discharges have only recently occurred. Environmental monitoring should continue, however, in the Port Gardner and adjacent water areas for several years as waste reductions continue so that biological changes can be detected with confidence. The biological monitoring of ECOBAM will continue to observe: plankton populations; research catches of fishes, shrimps, and crabs; sport and commercial catch statistics; intertidal and subtidal plants and animals; growth plates; and fish and oyster bioassays. The accumulating body of data appears to provide adequate baseline descriptions against which future monitoring data can be compared as a basis for evaluating the magnitude of benefits from waste load reductions.

INTRODUCTION

In early 1972, the pulp and paper mills in Everett, Washington announced cutbacks in production and one mill indicated a closure of operations. Some citizens considered the threatened loss of jobs to be a result of proposed actions by the Washington State Department of Ecology and the United States Environmental Protection Agency.

The Mayor of Everett called a public hearing on 27 March 1972 at the Everett Yacht Club to consider the controversy surrounding effluent limitations required for the two sulfite pulp mills on the city waterfront. As a result of the hearing, and other meetings involving the Governor's Office, the regulatory agencies and mill representatives, Governor Evans instructed the Department of Ecology to initiate a study in Port Gardner and adjacent waters to document changes in the marine environment associated with waste load reductions resulting from the effluent limitations imposed upon the mills.

The Department of Ecology began observations for this study of Port Gardner in the spring of 1972. The work included toxicity studies of juvenile salmon and Pacific oyster larvae, observations on distributions of young salmon, and three cruises by the University of Washington to collect oceanographic and water quality data. In the spring of

1973, the Ecological Baseline and Monitoring (ECOBAM) Study for Port Gardner and Adjacent Waters was developed, a Coordinating Council was formed, and the study objective established.

Coordinating Council

The ECOBAM Coordinating Council has representatives from the Department of Ecology (DOE), the Environmental Protection Agency (EPA), and the University of Washington, Department of Oceanography (UW). The Council meets approximately bimonthly for the purposes of 1) describing and defining study phases, 2) identifying gaps in the data and establish priorities for further data collection, 3) reviewing study phases, 4) describing study results, and 5) inviting contributions from other sources. Participants at council meetings have the opportunity to comment on and criticize all aspects of the study.

Study Objective

The objective of ECOBAM is to develop the best practicable baseline descriptions and monitor changes in the saltwater environment and populations of marine organisms in Port Gardner and adjacent waters. The study began shortly before the construction and installation of new pollution control facilities at the mills which would result in a stepwise decrease of sulfite waste liquor discharges. This cooperative study is continuing as a lengthening baseline and is evolving into a monitoring program designed to detect biological changes in the Port Gardner marine ecosystem. The results of the ECOBAM study will ultimately provide a basis for quantifying any biological benefits from waste treatment.

The ECOBAM Study was designed to obtain a variety of continuing series of measurements of water quality parameters and marine populations in Port Gardner and adjacent waters. Aspects of major interest include:

1. Decreases in sulfite waste liquor concentrations.
2. Changes in dissolved oxygen concentrations.
3. Changes in plankton populations.
4. Changes in research catches of fishes, shrimps, and crabs.
5. Changes in sport and commercial catch statistics.
6. Changes in species and abundance of intertidal and subtidal plants and animals.
7. Changes in species and abundance on experimental growth plates.
8. Changes in toxicity indicated by fish and oyster larva bioassays.

Waste Load Reductions

The waste load discharged into Port Gardner by the Scott Paper and Weyerhaeuser Company sulfite pulp mills has been measured by the total solids contained in the effluent since reporting began in the mid1950's. Substantial reductions in total solids began in 1974 (Figure 1).

The waste load discharged through the deep water diffuser routinely exceeded 2.5 million pounds per day of total solids from 1966 through 1971. The decreased waste load in 1972 is attributed to market conditions which caused a decrease in average pulp production of about 200 tons per day below the roughly 1040 tons per day produced in 1970 and 1971. The average production returned to about 975 tons per day in 1973. The Scott Paper Company completed and began operating the stage 1 recovery system in 1974, which reduced the sulfite waste liquor discharged through the diffuser in excess of 80% in one-half of its operation. This process change reduced the total solids load to less than 2 million pounds per day. The Weyerhaeuser Company shut down their sulfite pulping operation on May 15, 1975, in preparation for conversion to a thermomechanical process, further reducing the total solids load through the deep water diffuser outfall to about 0.5 million pounds per day. Start up of the new process was initiated in October 1975.

The total solids load discharged by the two mills into the inshore waters of Port Gardner remained nearly the same from 1966 through the first quarter of 1975. After Weyerhaeuser shut down its sulfite pulping operation in May 1975, the

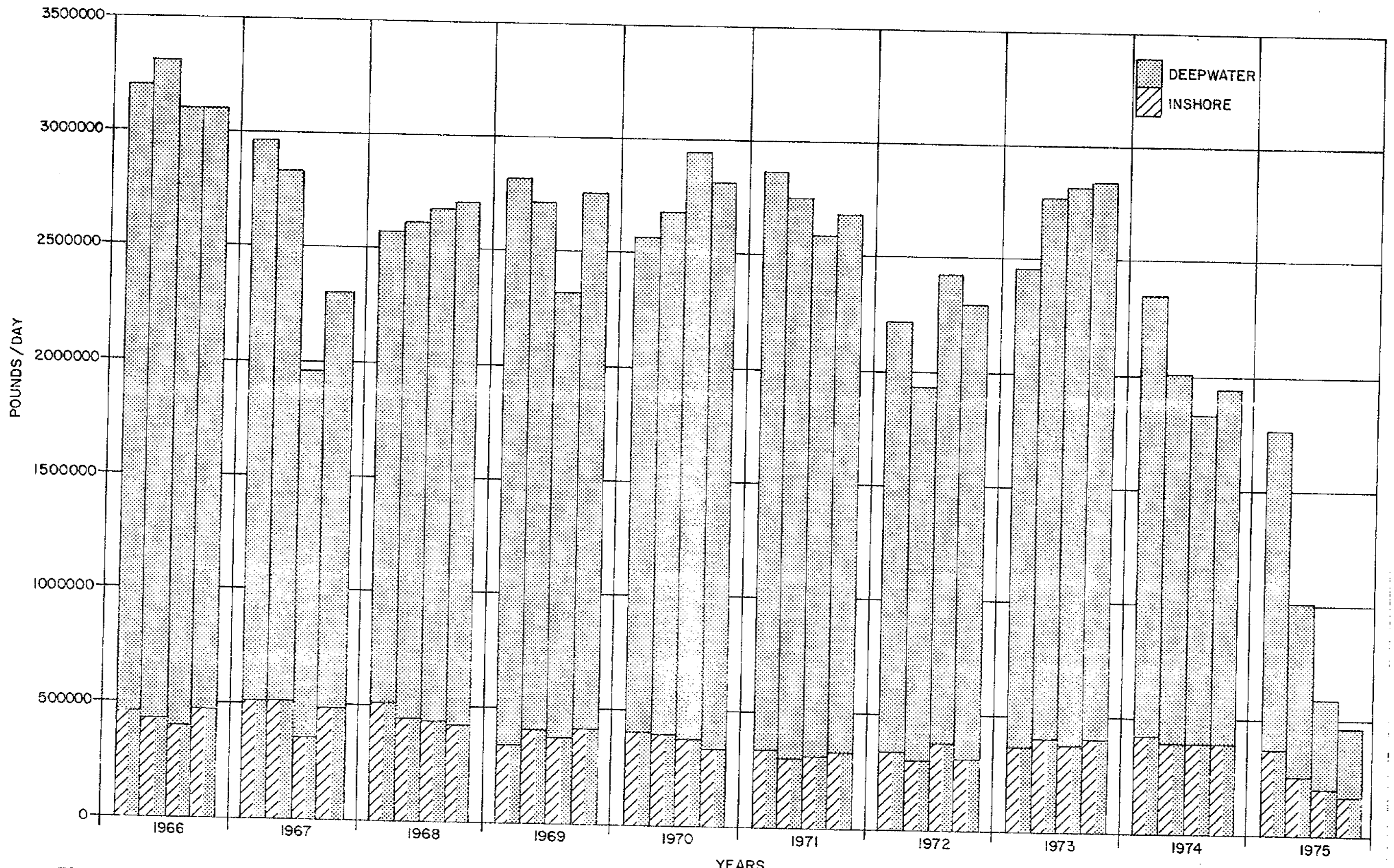

Figure 1. TOTAL SOLIDS DISCHARGED INTO PORT GARDNER AND ADJACENT WATERS BY SCOTT PAPER COMPANY AND WEYERHAEUSER THROUGH THE DEEP WATER DIFFUSER AND INSHORE OUTFALLS FROM 1966 THROUGH 1975.

inshore waste load was reduced from approximately 0.4 million pounds per day of total solids to less than 0.2 million pounds per day.

Additional reductions in waste loads discharged into Port Gardner will occur when the Scott Paper Company installs the second recovery system designed to recover 80% of the pulping liquor from the remaining onehalf of its operation. However, the installation of the stage 2 recovery system, scheduled for 1978, has been delayed pending the outcome of legal appeals regarding additional treatment requirements set forth in the waste discharge permit issued to Scott Paper Co. by DOE on 14 March 1975.

Summary of Conclusions

1. Benthos Setting and Growth DOE

Analysis of ash free dry weight data shows a steady increase in biomass production at all stations from 1972 through 1974 with the greatest increase occurring in 1974. The variation in biomass production between stations and from year to year, however, cannot totally be explained by the reduction in waste loads since biomass production decreased slightly from 1974 to 1975 with a significant decrease in waste load. However, some of these annual changes may be a function of natural conditions affecting the setting and survival of benthic larvae.

2. Juvenile Salmon and Indigenous Fish Distributions and Toxicity Studies DOE

There has been a decrease in sulfite waste liquor concentrations and a corresponding increase in dissolved oxygen values found in the inshore areas of Port Gardner since Weyerhaeuser Company discontinued their sulfite pulping process on May 15, 1975. There has also been an increase in pH values and water clarity.

Mortalities of juvenile salmon held in liveboxes in the inshore areas of Everett Harbor have decreased slightly with the reduction in waste load. Hydrogen sulfide gas appears to be the cause of a portion of the observed mortalities; however, mortalities have also been observed at the south piers of both Scott Paper Company and Weyerhaeuser Company when hydrogen sulfide was not measured.

The numbers of flatfish (starry flounder, English sole, etc.) collected in beach seine samples has remained constant except for seasonal highs in July and August. The occurrence of English sole was higher in 1975 than in 1974 and the numbers of juvenile Pacific salmon species was also higher in 1975. Biological changes, however, generally lag behind improvements in water quality and are more difficult to document. As these studies continue we should be better able to determine whether the changes in fish density are due to reductions in waste loads or if they are caused by fluctuations in natural production.

3, Toxicity of Marine Waters near Everett and Port Angeles, to Larval Pacific Oysters 1972 through 1975 - Washington Department of Fisheries

The 1972-1975 evaluations of the quality of the receiving waters near Everett have shown a decline in the extent and scope of toxicity to larval Pacific oysters. Statistical analysis of these data has also revealed that the Pearl Bensen Index (PBI) of sulfite waste liquor accounts for only a portion of pulp mill wastewater toxicity, and that the relationship between PBI and the responses of larval oysters has changed each year since the inception of these studies. There appear to be differences in receiving water toxicity as a function of depth, in that deeper waters (36-73m) were considerably more toxic than surface (0-18 m) waters from 1972 to 1974, but not in 1975.

4. Water Quality and Oceanographic Observations - UW

Distributions with depth and seasonal cycles of temperature, salinity, dissolved oxygen, chlorophyll a, nitrate, phosphate, silicate and sulfite waste liquor have been documented for Port Gardner and adjacent waters. The location of highest concentrations of sulfite waste liquor, and the lowest concentrations of dissolved oxygen, in Port Gardner is in the vicinity of the deepwater diffuser outfall shared by the two sulfite pulp mills. Sulfite waste liquor has also been found in high concentrations near the inshore outfalls of each mill. The observed decrease in concentrations of sulfite waste liquor and increases in dissolved oxygen appeared to correspond to waste load reductions.

5. Trawling Observations - UW

A series of research beam trawl samples has documented the distribution and abundance of populations of fishes, shrimps and crabs over time at several depths in Port Gardner and at two control locations, Tulalip and Mukilteo. Catches of English sole and crab were greater in Port Gardner than at Tulalip and Mukilteo. Some other bottom fishes and some shrimps were more abundant at the control locations.

6. Sonic Observations - UW

Distributions of fishes and concentrations of zooplankton targets have been observed with a high-frequency echosounder in the water column of Port Gardner and Puget Sound. The survey identified a water volume near the deepwater diffuser outfall which was almost devoid of sonic targets observed at similar depths in other areas of Port Gardner and Puget Sound. The location of that water volume corresponds to the highest concentrations of sulfite waste liquor and the lower concentrations of dissolved oxygen, as well as to high toxicity indicated by the oyster larva bioassay.

7. Benthic Observations - EPA and UW

The numbers of animal groups and specimens in the subtidal benthos were found to increase generally with distance from the deepwater diffuser outfall. Sediment size distributions and the concentrations of volatile solids in the study area have been described; differences with depth and with distance from the outfall were found. The distribution and abundance of plants and animals in the intertidal benthos have been documented in springtime surveys in 1973, 1974, and 1975. There have been no apparent major changes in the distribution and abundance of the organisms, establishing, in effect, a 3-year baseline.

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SECTION II

Benthos Setting and Growth in Port Gardner and Adjacent Waters

BENTHOS SETTING AND GROWTH IN PORT GARDNER AND ADJACENT WATERS 1972 THROUGH 1975

BY

GROVER SCOTT JEANE II

November 1976

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INTRODUCTION

A consortium of involved parties was formed to characterize ecological, physical, and chemical changes in Port Gardner Bay as pollution loadings were decreased. The Ecological Baseline and Monitoring Study of Port Gardner and Adjacent Waters Coordination Committee (ECOBAM) evolved to guide the consortium studies and facilitate exchange of data between the study participants.

The objective of the study is to describe and measure changes in biomass and species diversity which will reflect positive or negative changes in the aquatic ecosystem as waste load reductions decrease the concentration of sulfite waste liquor. The method chosen uses artificial substrate plates attached to piling at two depths.

METHODOLOGY

Setting plates were cut from a sheet of asbestos cement "transite" boards 0.6 cm (0.25 inches) thick. The plates measured 20 cm (8 inches) by 15 cm (6 inches). Galvanized lag screws with rubber washers were used to attach the plates to existing pier pilings at the selected depths. For the 1975 replicate study, the plate size was reduced by 25 percent, with four replicates at each depth and station. The four replicate plates were attached by iron nails to a two-foot-long, 2- by 4-inch board which was placed parallel to the bottom using the same piling during later studies whenever possible.

A shallow intertidal depth (+2-feet MLLW) and a deep near maximum low tide depth (-5-foot MLLW) were evaluated at each station. A third shallower depth (+6-foot MLLW) was evaluated in 1975. At the latter depth the growth plates were exposed frequently to allow a maximum diversity of organisms to develop.

The length of time which the plate remains at the study sites was decreased from seven months tin 1972 to three months in 1975 (Figure 1). The plates were photographed monthly in 1972 using SCUBA and underwater techniques. It became evident by late summer and early fall that local preditors (crabs and fish) were utilizing the plates to supplement their food sources as the abundance of their natural summer foods diminished. Thus the optimum time period for satisfactory diversified setting in the biomass production is believed to be the three months from April to July. Use of the three month period prevents excess predation on plate communities and enhances biomass accumulation in a minimum time frame; however, as experienced in 1975, a late or poor growing season may reduce the total biomass.

Each plate was visited monthly during the 1972 study to visually assess changes and make a photographic record of the plate's condition. The photographic record was to be used to evaluate month to month changes. Weinmann, 1972, during his benthic setting study near Cherry Point concluded that the biomass and species diversity at the end of his nine week study was sufficient to characterize each station and that intensive weekly sampling did not significantly increase the information obtained.

Prior to installation in the field, the cut and drilled plates were cured in a brine solution for several days, well rinsed, and sun-dried to age the plates and remove any toxic compounds. Attachment of all plates to commercially treated piling exposed the rear side to creosote leaching from the piling. When the plates were removed for sampling, a creosote odor was evident. The effect of the low-level leaching of creosote to the outer or test surface of the plates is considered insignificant or consistent between plates in its affect on growth due to its presence at all stations and depths. Local piling communities also did not appear to be affected.

The number of stations increased over the duration of the study (Figure 2). Stations 1-4 were initially chosen and Stations 5 through 8 were added for the 1973 growth season. Station 8 was located on a dolphin at the Columbia Beach ferry landing and was subsequently lost during the growth season, resulting in loss of biomass information. Station 8 was reestablished in 1975 at a piling south of Station 3.

Biomass, barnacle growth, and species diversity data were collected when the plates were removed and carried through the analysis process described in Figure 3. The two subsamples were collected from the plates at each station and depth, one for biomass determination and the other for species and growth information. Only the exposed face (untextured) side of the plates was sampled. The area near the edge or screw hole was not sampled due to uneven growth rates. At all times, techniques were incorporated to remove sample bias. The plates were protected from physical damage between field collection and laboratory analysis. Only macroscopic organisms were considered during diversity evaluations.

RESULTS

The results of the biomass sampling for years 1972, 1973, 1974, and 1975 are presented in Tables 1 and 2. The ash weight of each sample may be obtained by subtracting the ash-free dry weight from the dry weight. The replicate biomass analysis differences are plotted in Figure 4. It is readily discernable that the deep depth replicates were the most consistent of the replicates in biomass accumulation. This replicate value which skewed Station 4 into its abnormal percent difference was discarded and not used to compute the station biomass average in Tables 1 and 2. The percent difference between ash-free dry weight and dry weight replicates was found to be very similar. While the shallow depth stations are not as consistent between replicated in biomass accumulation, the depths should continue being evaluated to gather species diversity data.

The ash-free dry weight (Figure 5) and dry weight (Figure 6) yield very similar plots. The ash-free dry weights have been increasing each year, except for 1975. The 1975 growth year is believed to have been below normal due to hydrologic and atmospheric conditions. Station 8 is felt to be unrepresentative of the area. Retesting Station 8 during the 1976 growth year should clarify the actual conditions at that station.

The presence and general abundance levels of most of the animal types found inhabiting the growth plates are presented in Table 3. If one sums up the number of different types of animals (excluding barnacles) found at each station, it becomes evident that Station 8 has the greatest diversity with Stations 1, 2, 3, and 5 being just below Station 4. The station with the least diversity was Station 7. Station 6 was not considered due to missing data. Using a similar method of summation, one realizes that the deep stations have a greater diversity than the shallow stations.

The volume of 10 cm^2 (1.5 in^2) sample of biomass (mainly barnacles) from the 1975 deep depth growth plates was measured (Table 3 and Figure 7). Station 3 exhibited the largest volume (8.1 ml). Station 6 was next largest with 6.8 ml. Interharbor Stations 1 and 5 were below all other stations except 4 and 7. Station 4 was low in volume due to a lack of a barnacle population. Early covering of the artificial substrate plate by algae and hydroids may have limited the amount of suitable free substrate available for barnacle attachment.

Early in the study it became evident that two species (ulva and hydroids) were very restricted in zonation (Station 4 only). By 1975, algae and hydroids were sampled at stations (1,2, and 5) within the harbor. Station 4 still remains dominant in biomass of these two sensitive species, but they are returning to the inner harbor. Station 7 was the least diversified, with only stunted barnacles and some red worms present.

DISCUSSION

Major reductions in waste loading, discharged through the various outfalls of the Weyerhaeuser Company and Scott Paper Company pulp mills, into Port

Gardner and Inner Everett Harbor, have occurred since 1974 (Table 4). Analysis of the ash free dry weight data (Figure 5) shows a steady increase in biomass production at all stations from 1972 through 1975 with the greatest increase occurring in 1974. The variations in biomass production between stations and from year to year, however, cannot be totally explained by the reduction in waste loads, since biomass production decreased slightly from 1974 to 1975 with a significant decrease in waste load. Natural conditions affecting the setting and survival of benthic larvae is also a factor with these kinds of observations.

ACKNOWLEDGEMENTS

The positive suggestions gathered during the interim progress report presentations were of great assistance in making improvements in study methodology.

Eva Enlow provided the typing for the report.

Mr. David Anderson of Battelle Pacific Northwest Laboratories provided a critical review of the draft which was of assistance in completion of the final report.

Shirley Prescott is responsible for all creative graphic work.

LITERATURE CITED

Weinmann, F. 1972. Pilot Study for Research Proposals. University of Washington, College of Engineering, Department of Civil Engineering. Unpublished mimeo.

APPENDIX I

Tables

Table 1. Dry Weight (gm/10 cm^2) Analysis of Biomass Samples Collected in Port Gardner

Station	1972		1973		1974		1975	
	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep
4	6.93	--	7.728	4.288	7.27	3.98	0.0854	2.7211
8	--	--	--	--	--	--	0.1555	5.3293
3	3.22	.50	3.032	3.752	2.71	4.06	0.6933	3.5601
2	3.11	.87	2.852	3.920	3.56	4.98	0.1952	3.0196
1	1.36	.73	2.820	2.072	3.81	5.16	0.0391	2.3180
7	--	--	0.404	0.036	0.29	0.24	0.0095	0.0574
6	--	--	2.996	3.004	--	--	--	3.2326
5	--	--	2.288	2.632	3.62	3.66	0.1820	1.3440

Table 2. Ash-Free Dry Weight (gm/10 cm^2) of Biomass from Port Gardner

Station	1972		1973		1974		1975	
	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep
4	0.481	--	0.492	0.328	0.99	0.47	0.0537	0.4108
8	--	--	--	--	--	--	0.0287	1.8731
3	0.302	0.08	0.208	0.248	0.22	0.38	0.1264	0.4652
2	0.243	0.07	0.180	0.228	0.35	0.56	0.0343	0.3747
1	0.130	0.22	0.210	0.164	0.37	0.57	0.0110	0.4621
7	--	--	0.124	0.008	0.06	0.05	0.0033	0.0115
6	--	--	0.348	0.196	--	--	--	0.4182
5	--	--	0.232	0.184	0.36	0.37	0.0282	0.1525

le 3. Species Diversity of 1975 Port Gardner Growth Plates

ation	Barnacle Volume in ml/10 cm^2	Algae			Hydroids	Mussel spate	Isopods	Amphi-pods	Worms			Nudibranch
		Ulva	Other Green	Brown					Seg-mented	Green	Red	
S D	.1 .2	Yes	Yes	Yes	Yes + Yes ++	Yes			Yes++		Yes Yes	
S D	.1 5.6	Yes	Yes Yes	Yes		Yes Yes	Yes	Yes	Yes	Yes Yes	Yes Yes	
S D	2.9 8.1				Yes	Yes +	Yes	Yes Yes		Yes	Yes	Yes
S D	.3 6.1		Yes		Yes	Yes	Yes	Yes Yes	Yes	Yes		
S D	.1 4.9	Yes	Yes Yes	Yes		Yes Yes		Yes	Yes			
S D	.1 .1										Yes++	
S D	6.6						Yes	Yes		Yes		Yes
S D	.1 4.4			Yes		Yes Yes		Yes Yes	Yes	Yes		

Yes = Present
+ = <10
++ = Numerous

Table 4. Average Tons of Pulp Produced, and Loadings of BOD and Total Solids Discharged to Everett Harbor and Port Gardner by Scott Paper Company and Weyerhaeuser for the Dates Indicated

Date	Tons of Pulp Produced/Day	Lbs of BOD Discharged/Day	Lbs. of Total Solids Discharged/Day
Scott Paper Co.			
Prior to 1972	722	563,000 (T) 527,000 (D)	1,900,000 (T) 1,650,000 (D)
(Start-up of first recovery furnace February 1974)			
April-June 1974	642	430,000 (T) 315,000 (D)	1,212,000 (T) 985,000 (D)
March-June 1975	609	215,000 (T) * 189,000 (D)	170,000 (T)
Weyerhaeuser Co.			
March-May 1974		347,000 (T) 329,650 (D)	1,147,667 (T) 1,100,000 (D)
March-May 15, 1975	260	233,000 (T) 221,000 (D)	
(Closed sulfite May 15, 1975)			
Oct.-Nov. 1975	126	8,950 (T)(D)	6,450 (T)(D)

(T) Total from all discharges
(D) Amount discharged through deep water diffuser
* Estimated from March 1974 Mill Reports

Figure 2. Station locations in Everett Harbor and Port Gardner Bay (Station 4 located on NMFS dock at Mukilteo).

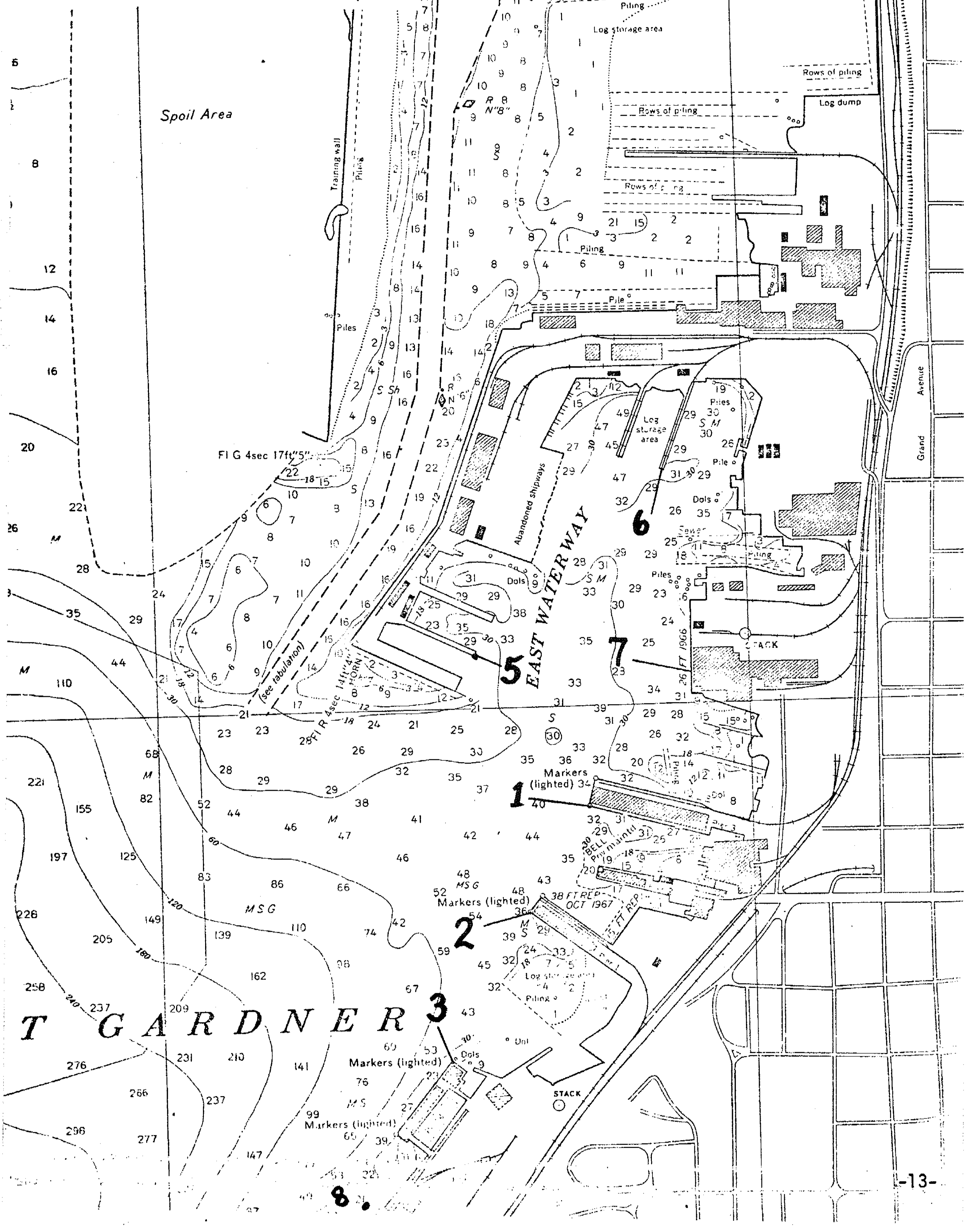
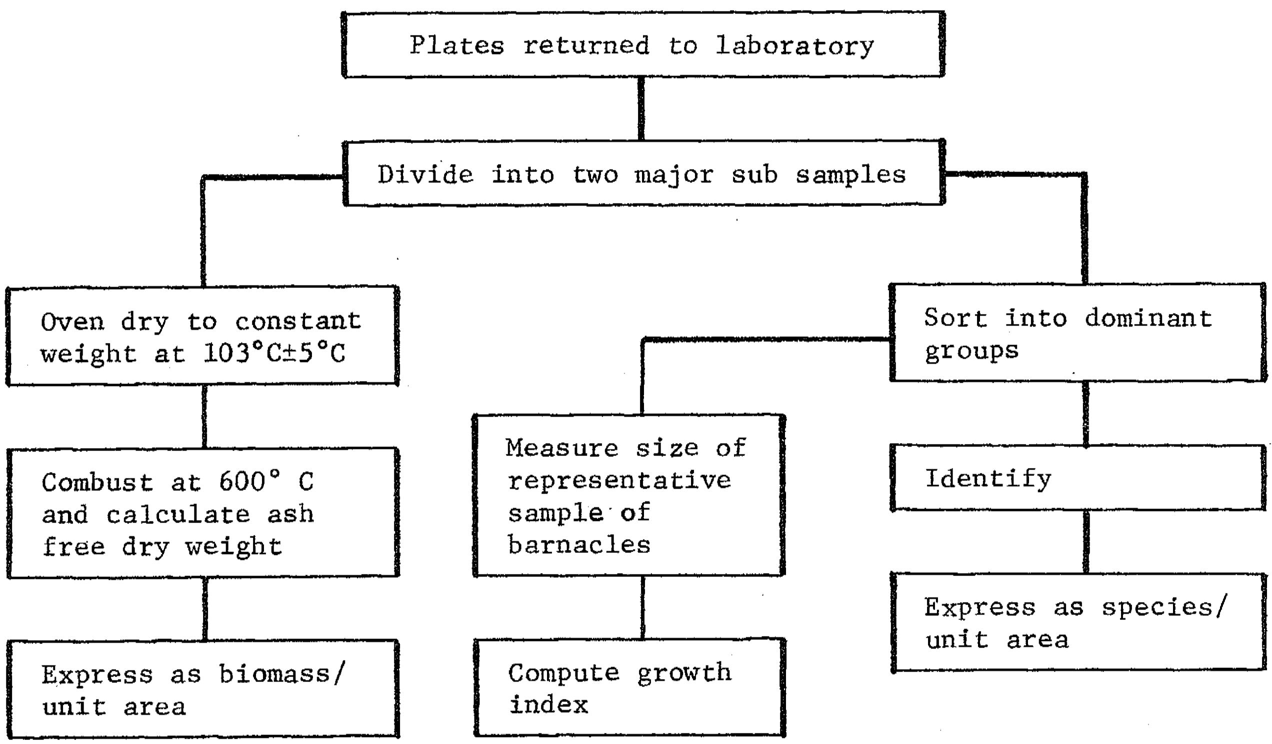


Figure 3. Flow scheme for analysis of biota from setting plates in Port Gardner, Everett, Washington.



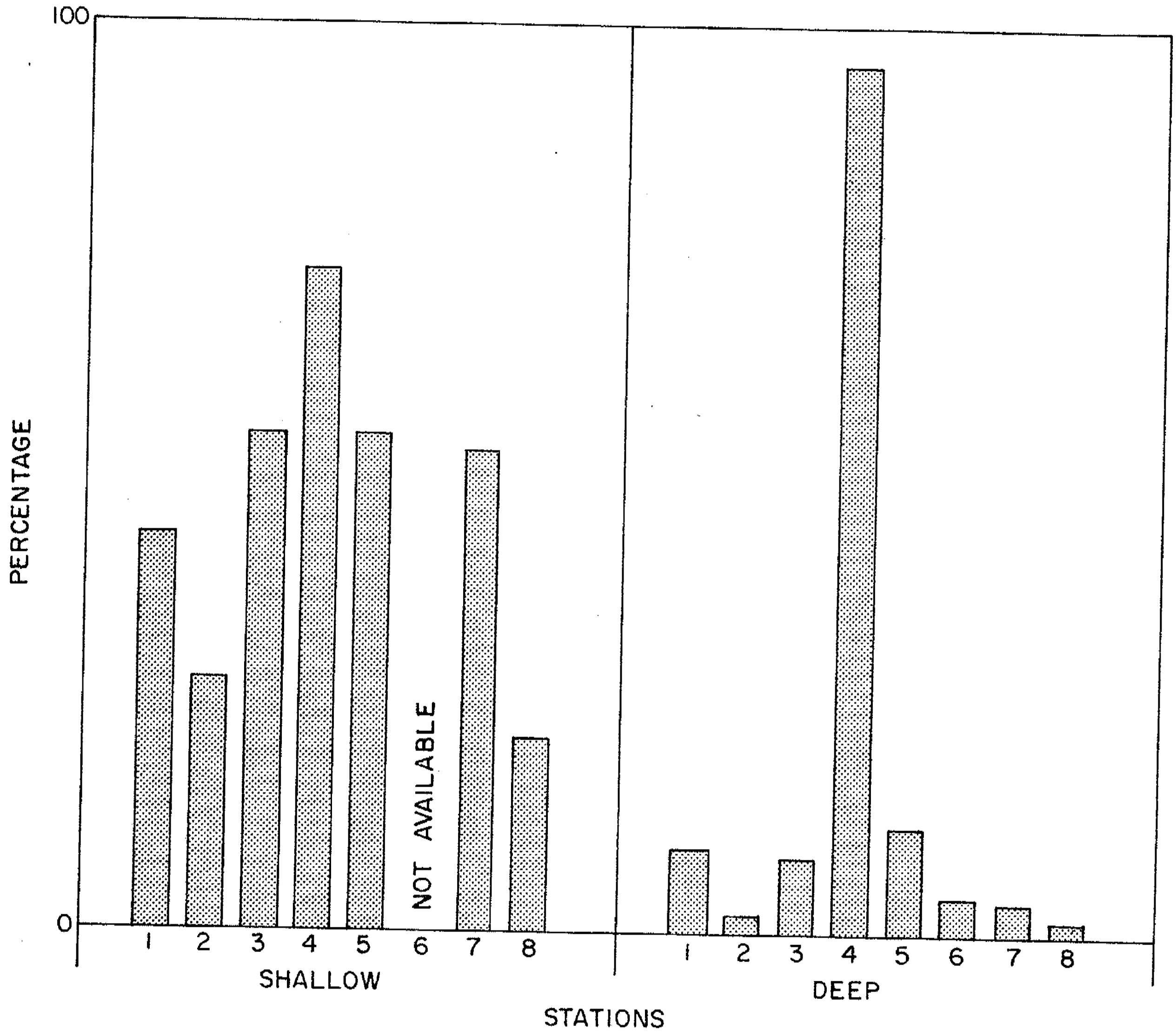


Figure 4. PERCENT DIFFERENCE BETWEEN REPLICATES A & B FOR ASH-FREE DRY WEIGHT, PORT GARDNER, 1975.

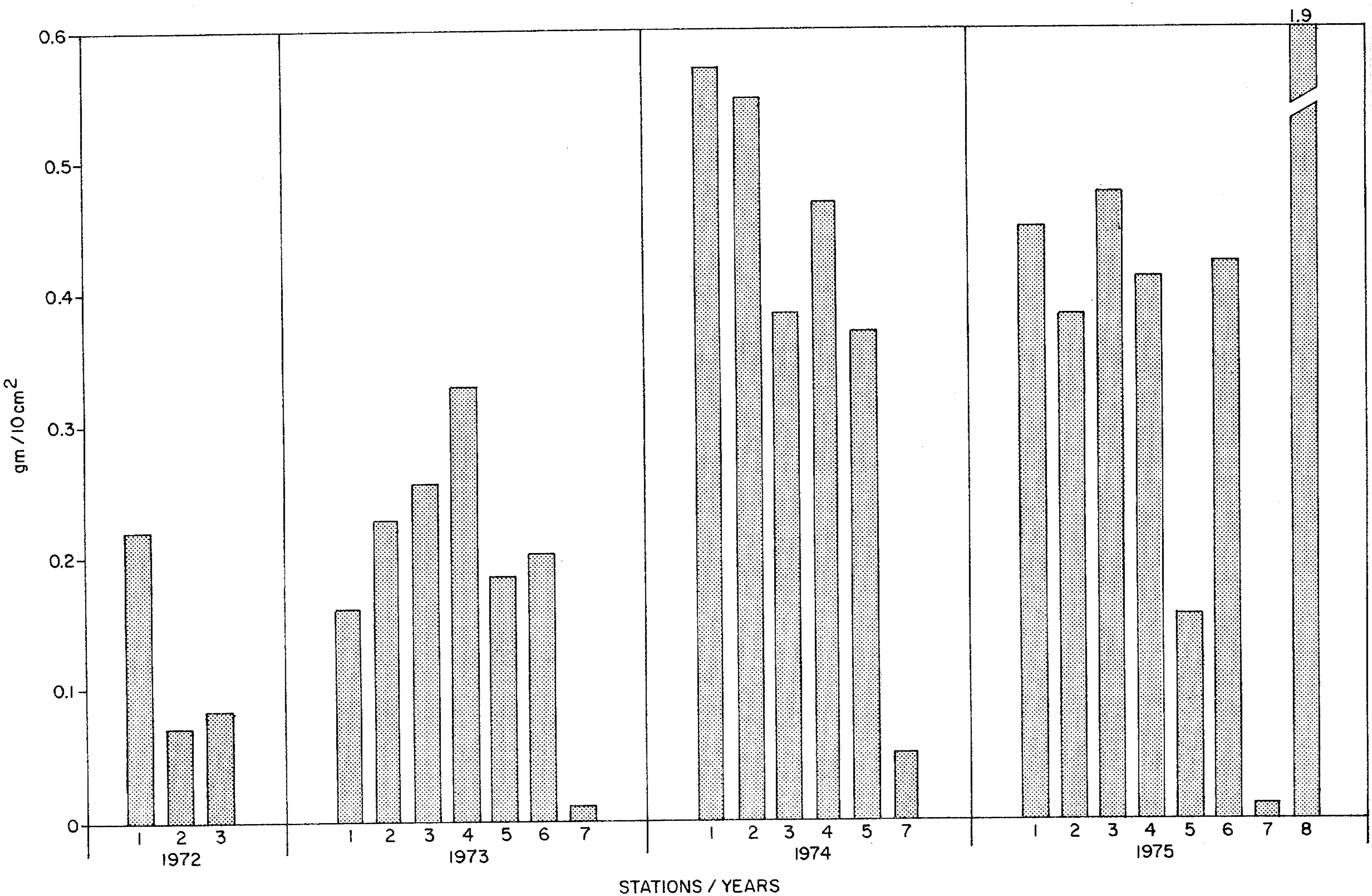


Figure 5. ASH-FREE DRY WEIGHT AT DEEP DEPTH, PORT GARDNER, 1972-1975.

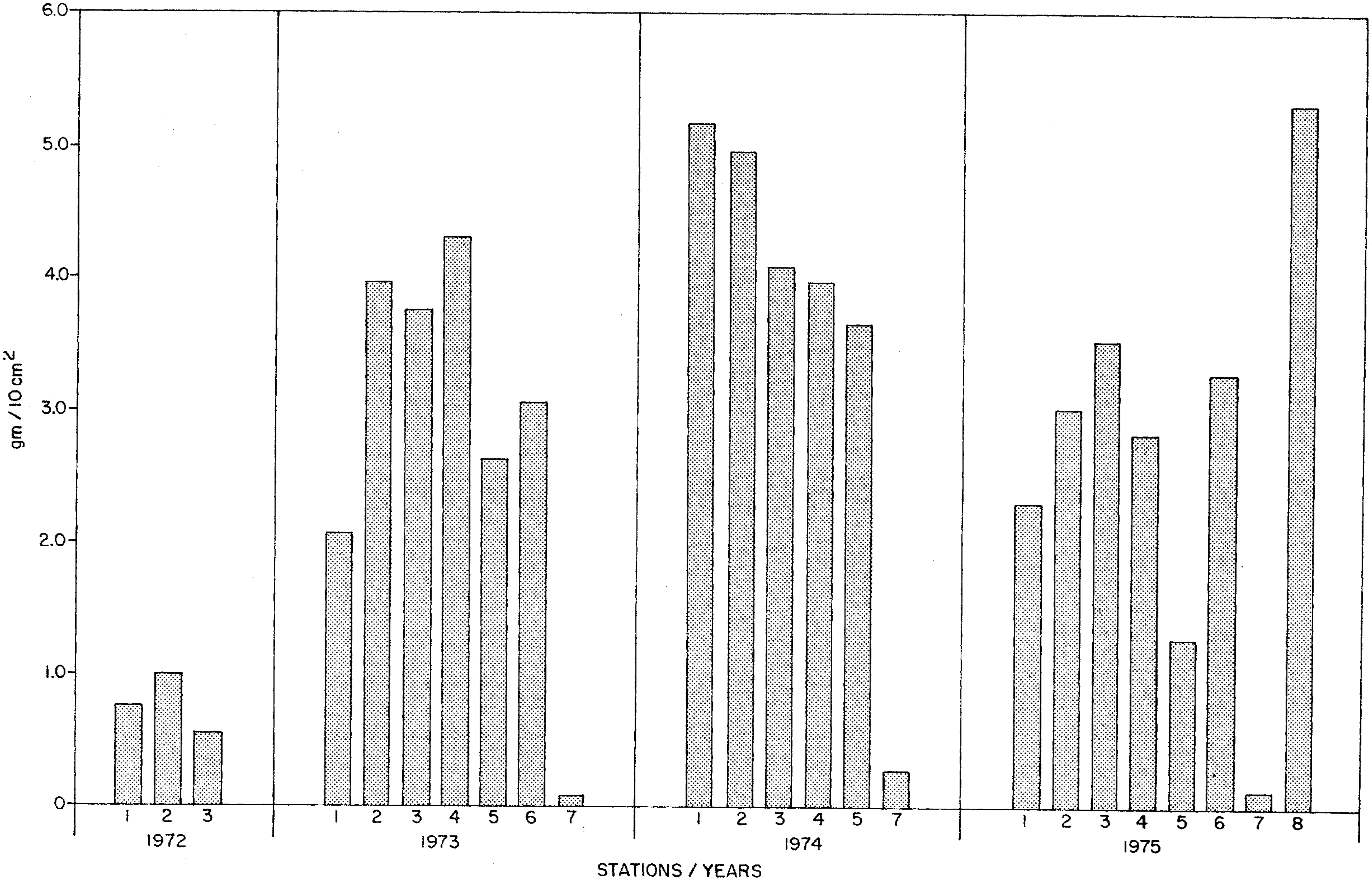


Figure 6. DRY WEIGHT AT DEEP DEPTH, PORT GARDNER, 1972-1975

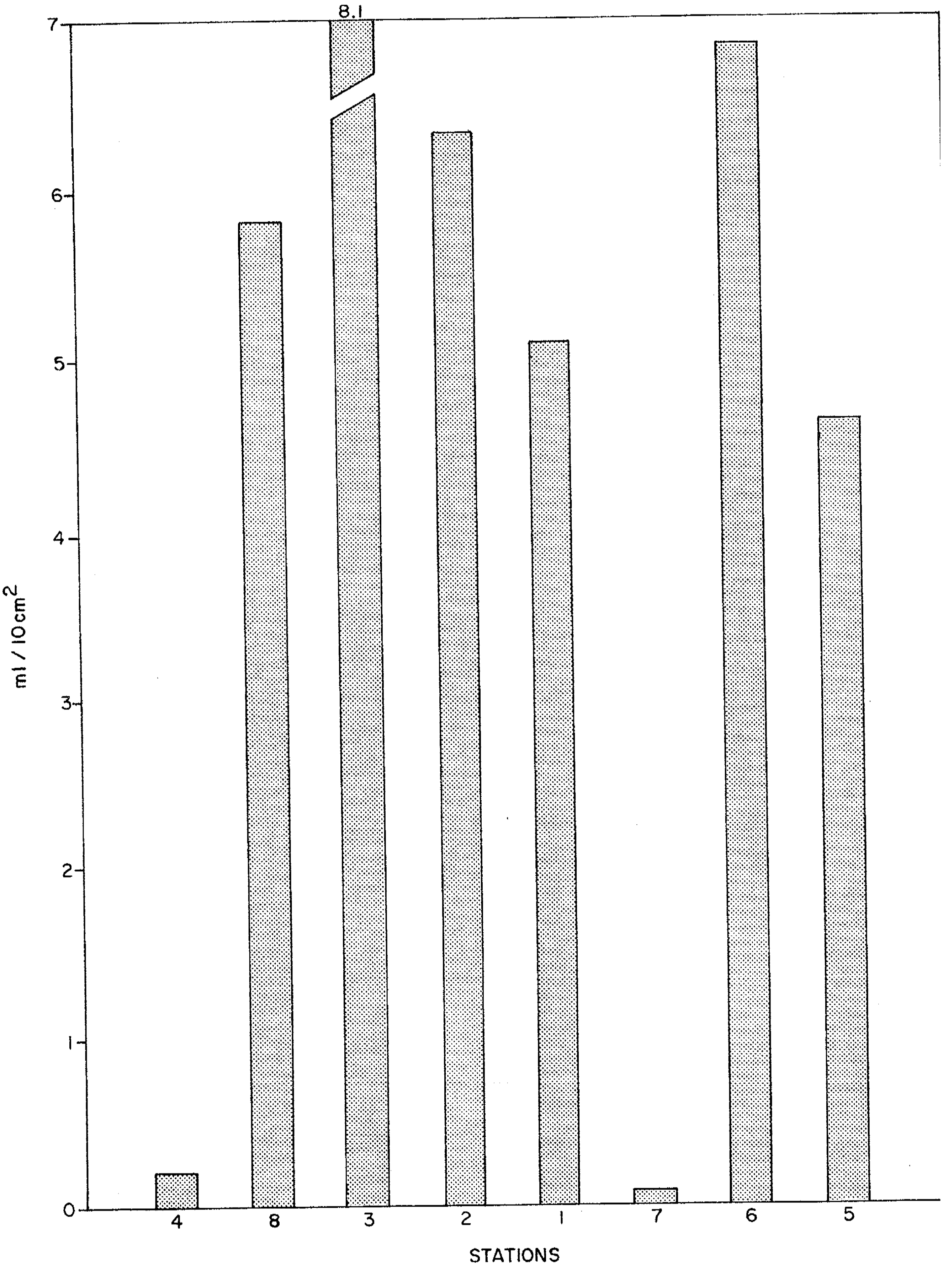


Figure 7. DEEP DEPTH BIOMASS VOLUME, PORT GARDNER, 1975.

SECTION III

Juvenile Salmon, Indigenous Fishes and Livebox Toxicity Studies, Port Gardner and Adjacent Waters

ECOLOGICAL BASELINE AND MONITORING STUDY

JUVENILE SALMON, INDIGENOUS FISHES AND LIVEBOX TOXICITY STUDIES

PORT GARDNER AND ADJACENT WATERS

by

Allen Moore

State of Washington

Department of Ecology

November 1976

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INTRODUCTION

Starting in the spring of 1974 and continuing through the present, a study is being conducted of the fish in the Inner Harbor at Everett, Washington and the fish and invertebrates collected along the beaches extending for several miles to the south from Everett Harbor.

The waters of the Inner Harbor have been receiving the industrial wastes of two large sulfite pulp mills for a number of years. As the production at the Scott Pulp and Paper Mill and the Weyerhaeuser Pulp Mill was increased, the local residents began complaining of decreasing numbers of herring in the area, particularly in the Everett Yacht Basin. With the advent of Public Law 92-500 and the U. S. Environmental Agency and the subsequent formation of the Washington State Department of Ecology, it became evident that the pulp mills would have to spend millions of dollars to improve the quality of the waste-waters which they discharge to Everett Harbor.

The ECOBAM study was implemented so that research could be carried out before, during and after the period when waste recovery would improve the quality of the receiving water.

During the spring of 1974, Scott began the operation of a waste recovery system which would substantially reduce the BOD load from 50% of the sulfite waste liquor (SWL) which goes out the deep diffuser line. This became fully operational during early summer of 1974. Also during early summer, the effluent from Scott's main dockside diffuser was seen to change from a brownish-orange color to a relatively clear effluent containing many light colored particles. Also the heavy foaming and odor which occurred at low tides was eliminated. Only the dockside diffuser effluent from the clarifier-chlorination washer remained as before. At low tide especially, the 'boil' from the diffuser is characteristically bright orange-brown and smells of chlorine.

Early in 1974, the Weyerhaeuser Pulp Mill asked for and received a variance to continue operating as before until they shut down in late spring of 1975. At that time they changed from their present sulfite process to a mechanical process. This meant there would be no more sulfite waste liquor (SWL) from the Weyerhaeuser plant. Their BOD load was reduced from the past 300,000 pounds per day to 3,000 pounds per day. Startup of this new plant was in September 1975.

The research carried out during spring 1974 should give data prior to any substantial change of effluent discharges to the waterway. After that time through the spring survey of 1975 the changes were at the main dockside diffuser and deep diffuser because of changes at Scott. A further change occurred after the spring survey of 1975 when Weyerhaeuser shut down its plant for changeover.

MATERIALS AND METHODS

This project primarily centers around the study of the economically important, newly hatched, out-migrant pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) from the Snohomish River basin which tend to gather in the Everett, East Waterway, and along the beaches to the south of Everett. All the net apparatuses used have mesh diameters small enough to prevent escape of the very smallest salmon fry.

The work done in the East Waterway breaks down into three separate phases: deep seines, visual surveys and livebox toxicity tests.

During the springtime of each year when the salmon fry are outmigrating from the Snohomish River, the fieldwork is a constant five days a week effort. After the fry begin to disappear in mid-June the program reverts to an abbreviated two days a month field study.

A seventeen foot Boston Whaler powered with a sixty-five horsepower motor is the work boat. A special platform is mounted on the bow from which the seines are deployed.

Deep Seining - The deep seine is 280 feet long, tapering from 6 feet deep at the ends to 12 feet deep at the middle where a large bag is built-in. The panels are colored ranging from bright colors at the ends to a dark green at the bag to encourage the fish to swim to the bag. Five stations, 1, 2A, 3, 4 and 16 shown in Figure 1, are used for the deep seining sites. During the spring they are regularly seined with duplicated sets at each site. During the rest of the year they are seined once a month. Any fish captured are identified, counted and measured. Surface temperature, salinity, dissolved oxygens, pH, and water transparency by Secchi disc are measured. Samples are taken for laboratory analysis of SWL and turbidity. The dissolved oxygen values are determined by either the Winkler-azide method or by an IBC Dissolved Oxygen Meter. Salinities are determined by a Beckman portable Electrodless Induction

Salinometer. The pH values are determined with an Analytical Measurements portable pH meter.

Visual Survey - Pink and chum salmon fry school along shorelines just below the surface where they can easily be seen. In the East Waterway, they remain in these areas until reaching a length of about 6 cm which includes the time between late March through the middle of June for chum salmon and late April through the middle of May on even-numbered years for pink salmon.

The methods to count, identify and measure the fry are the same techniques used by the State of Washington, Department of Fisheries for estimation of chum and pink adult salmon runs. An estimation of numbers of each school in the water is recorded. Then a number of the fry are captured with a dip net. The size and species of each captured salmon is recorded. If both pink and chum fry are present in the dip net, the fraction of occurrence is multiplied by the total number of fry estimated in that school to achieve an estimation of total numbers of chum and pink fry. Figure 1 shows the sites where schools of fry are commonly seen.

Toxicity Testing - *In situ* live boxes are placed in areas where toxic conditions are expected to occur in the East Waterway. Each live box is a piece of fiberglass pipe 12 inches in diameter and 18 inches in length. The ends are covered with a fine mesh net which is held in place by heavy rubber bands. Each live box contains 10 salmon fry.

The fry have been previously collected in the area and held in a holding box for at least 48 hours before being used in toxicity testing. The live box is either held in position by floats and anchors or by attaching them to log booms or pilings. Generally, about 5 live boxes are positioned throughout the area to be studied. Each live box is checked at least once every 30 minutes during the low tide cycle. During this time, dissolved oxygen, temperature, pH, salinity and total sulfide values are determined. Also, samples are taken for SWL and turbidity. After the initial low tide survey, the live boxes are left out for 24 to 48 hours and checked once or twice daily. Condition of the fish is reported as normal, distressed or dead. Mortalities are expressed as percentages. The toxicity testing is done only during the spring intensive survey. Stations tested are 1, 2, 3 and 4 shown on Figure 2.

Beach Seining - A beach seine 100 feet long and 6 feet deep at its center is used on the beaches to the south of Everett. The net is operated by two persons - one on the shore and one wading offshore. The net is towed parallel to shore for 100 feet and then brought in. Four stations, A, B, C and E as illustrated on Figure 3 are each seined in duplicate sets. All fish and invertebrates are identified, counted and measured. These stations are seined regularly during the spring and once a month for the rest of the year. Temperature, dissolved oxygen, pH and salinity values are recorded. Samples are taken for lab analysis of SWL and turbidity.

RESULTS

The following discussion covers data collected from April 1974 to as late as February 1976.

Deep Seining - Below is a list of names and sizes of fish commonly captured in the deep seine.

Common Name	Scientific Name	Size Range
Pink Salmon	Oncorhynchus gorbuscha	3.5 to 6.0 cm
Chum Salmon	O. keta	3.5 to 6.0 cm
King Salmon	O. tshawytscha	8 to 15 cm
Silver Salmon	O. kisutch	8 to 15 cm
Surf Smelt	Hypomesus pretiosus pretiosus	3 to 15 cm
Pacific Herring	Clupea harengus pallasi	3 to 15 cm
Pacific Sand Lance	Ammodytes hexapterus	3 to 15 cm
Threespine Stickleback	Gasterosteus aculeatus	2.5 to 6 cm

At all deep seine stations there were higher total numbers of chum fingerlings in the spring of 1975 than the spring of 1974 (Figure 4). Department of Fisheries data (personal conversation with Charles Morrill, Department of Fisheries) also shows that higher numbers of chum fingerlings normally occur in the odd-numbered years.

Pink salmon fingerlings, which occur in large numbers only on even-numbered years will be discussed in later reports after the spring 1976 data can be worked up to be compared with 1974 data.

Silver salmon were found at Stations 2 and 16 in 1974 and at Stations 2, 3 and 4 in 1975. Station 2 had more silvers in 1975 than 1974 (Figure 5).

King salmon numbers increased at all stations except Station 16 from 1974 to 1975 with numbers of increase ranging from 2 at Station 2 to 60 at Station 3 (Figure 6).

Herring larvae (3 to 5 cm) were present at all stations in 1974 and only Stations 1 and 2 in 1975 (Figure 7). The highest total number in spring 1974 was 675 at Station 16. The highest total number in spring 1975 was 21 at Station 1. A preliminary look at the spring 1976 data shows more herring larvae than in 1975.

Beach Seining - Fish which are economically important and which are captured by the beach seine in abundant numbers during the spring are chum and pink salmon fingerlings (3 to 6 cm), silver and king salmon yearlings (8 to 15 cm) and flatfish. Most of the flatfish are Starry Flounder (*Platichthys stellatus*) and English or Lemon Sole (*Parophrys vetulus*). Very few pink salmon fingerlings were found in 1975 due to the run cycle. Therefore pinks will not be discussed until later reports where the 1976 data can be compared with the 1974 data.

King salmon were much more abundant at all stations (A, B, C and E) in 1975 than in 1974 (Figure 8). Percentage increases ranged from 188% at Station B to 2533% at Station A.

Silver salmon were also more abundant in 1975 than in 1974 except at Station A (Figure 9). The decrease at Station A was 47.5%. The increases at Stations B, C, and E were 186%, 141% and 260% respectively.

Chum salmon were also much more abundant in 1975 than 1974 (Figure 10) which corresponds to past cycles of more young in the odd-numbered years. Percentages of increase for Stations A, B, C and E were 313%, 104%, 232% and 194% respectively.

The total numbers of flatfish at each station were also compared (Figure 11). Station A showed a decrease from 1974 to 1975 of 23%. Stations B, C and E had increases of 167%, 190% and 108% respectively. Total numbers of flatfish at Stations A and B were compared graphically by month from April 1974 through February 1976 (Figure 13). On the whole, increases and decreases by month, in numbers over this period correspond between the two stations. The greatest numbers of English sole were found during the periods of July through March of the following year for both 1974-75 and 1975-76. Using totals of all stations, Figure 12 shows greater numbers and higher peaks of English sole for the 1975-76 period.

Water Quality Parameters

A comparison of dissolved oxygen and sulfite waste liquor (PBI) at Station 1 shows a highly correlated, inverse relationship (Figure 14). The implementation of Scott's waste recovery and shutdown of Weyerhaeuser's sulfite plant show up very clearly in the water quality at about June-July 1975. Sulfite waste liquor values dropped off dramatically to a low steady concentration approaching the suggested limit of 10 ppm. Concentrations above 10 ppm are toxic to oyster larvae and juvenile salmon according to EPA suggested standards. At the same time of the SWL dropoff, the dissolved oxygen values continued to remain high. The late summer 'turnover' which regularly occurs every year throughout Puget Sound showed only a slight dip in dissolved oxygen. The minimum values remained above the Class B standard of 6 mg/l. The relationship of SWL and DO is not apparent at Station E (Figure 15). However, after July 1975, the SWL values taper off to values averaging less than 10 ppm.

A comparison of pH values at Stations 1, A and E show all stations have increases toward the normal expected values of 7.5 to 8.5 (Figure 16). Station 1, which was near the low pH outfall of Weyerhaeuser showed numerous Class B standard violations. After the effluent ceased in June 1975, the pH values rose dramatically. A single, unexplained violation occurred in October 1975.

Secchi disc readings taken in 1976 have been compared with readings obtained during the Puget Sound Pollution Study of the early 1960's. An average of these readings shows 4.75 feet in 1963 and 6.6 feet in 1976 - an improvement of 39%.

Livebox Mortalities

Four areas were selected as being important sites for toxicity tests. Areas 2 and 4 are areas where effluents may become concentrated enough to cause toxicities. Areas 1 and 3 are sites of hydrogen sulfide toxicity due to decomposing sludge or wood chip materials. Table 1 summarizes the live box results.

Area 1 showed nearly 100% mortalities in 1974 and 100% mortalities in 1975.

Area 2 had essentially the same high mortalities both years as expected since no change had been done yet in the manner of effluent discharge. Shortly after the test the outfall was discontinued.

Area 3 had some mortalities in 1974 but none in 1975 which was somewhat unexpected. Because the 1975 testing was done towards the end of a series of low tides, the hydrogen sulfide probably had been released on the earlier low tides.

Area 4 had significant mortalities due to effluents in 1974 and insignificant mortalities in 1975. This was expected because the diffuser was apparently not operating during the test period in 1974.

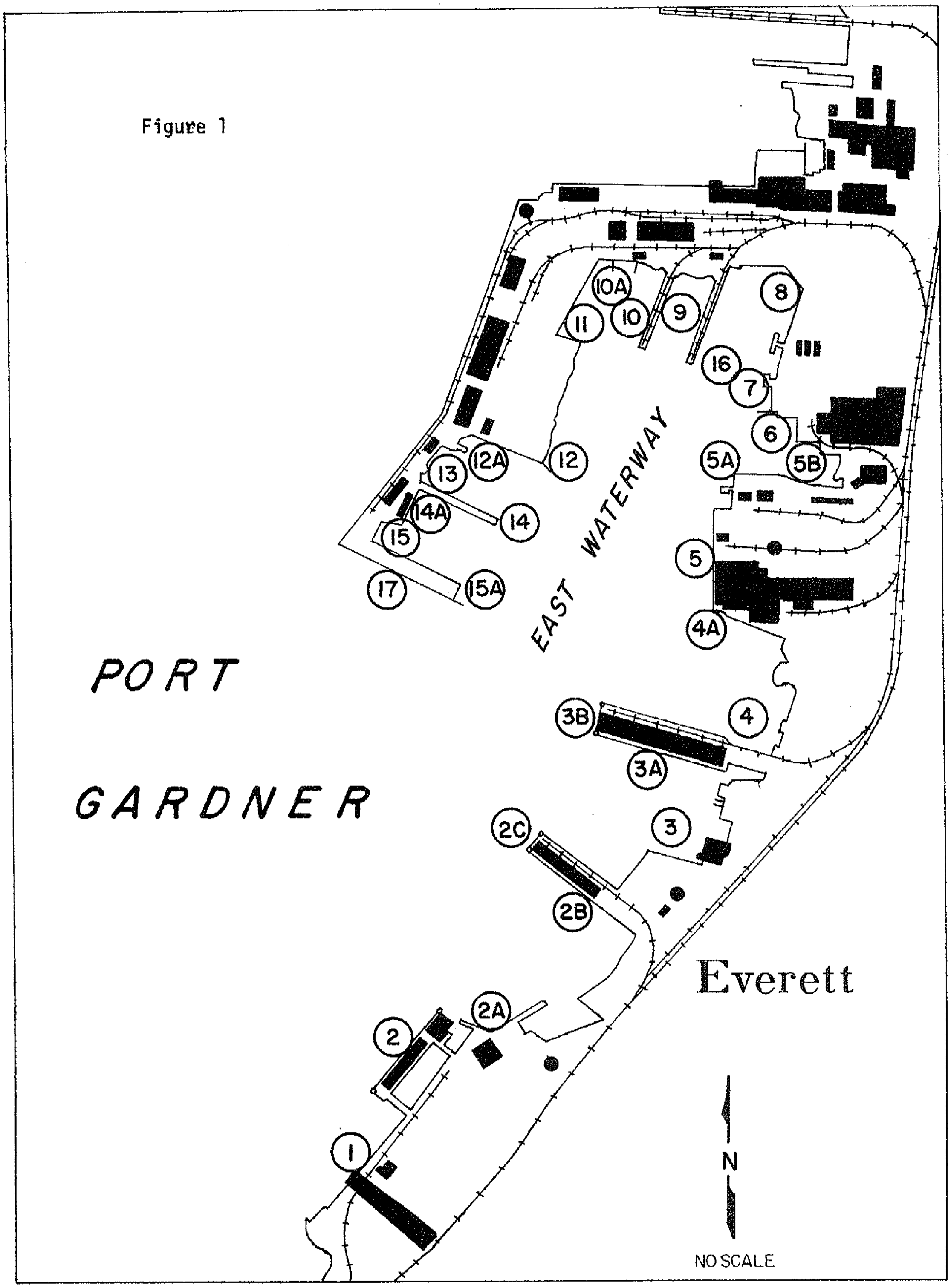
DISCUSSION

Several changes in water quality have been documented so far by this ECOBAM study. Sulfite Waste Liquor concentrations in the East Waterway have decreased dramatically to near acceptable limits. Dissolved oxygen and pH have also shown dramatic improvements. The changeover of the Weyerhaeuser plant also resulted in a clearer water as reported by Secchi disc readings.

The biological phase of this study also shows what may be improving trends in such things as larger numbers of king and silver salmon in the East Waterway and along the beaches. Biological changes, however, generally lag behind improved water quality and are harder to document.

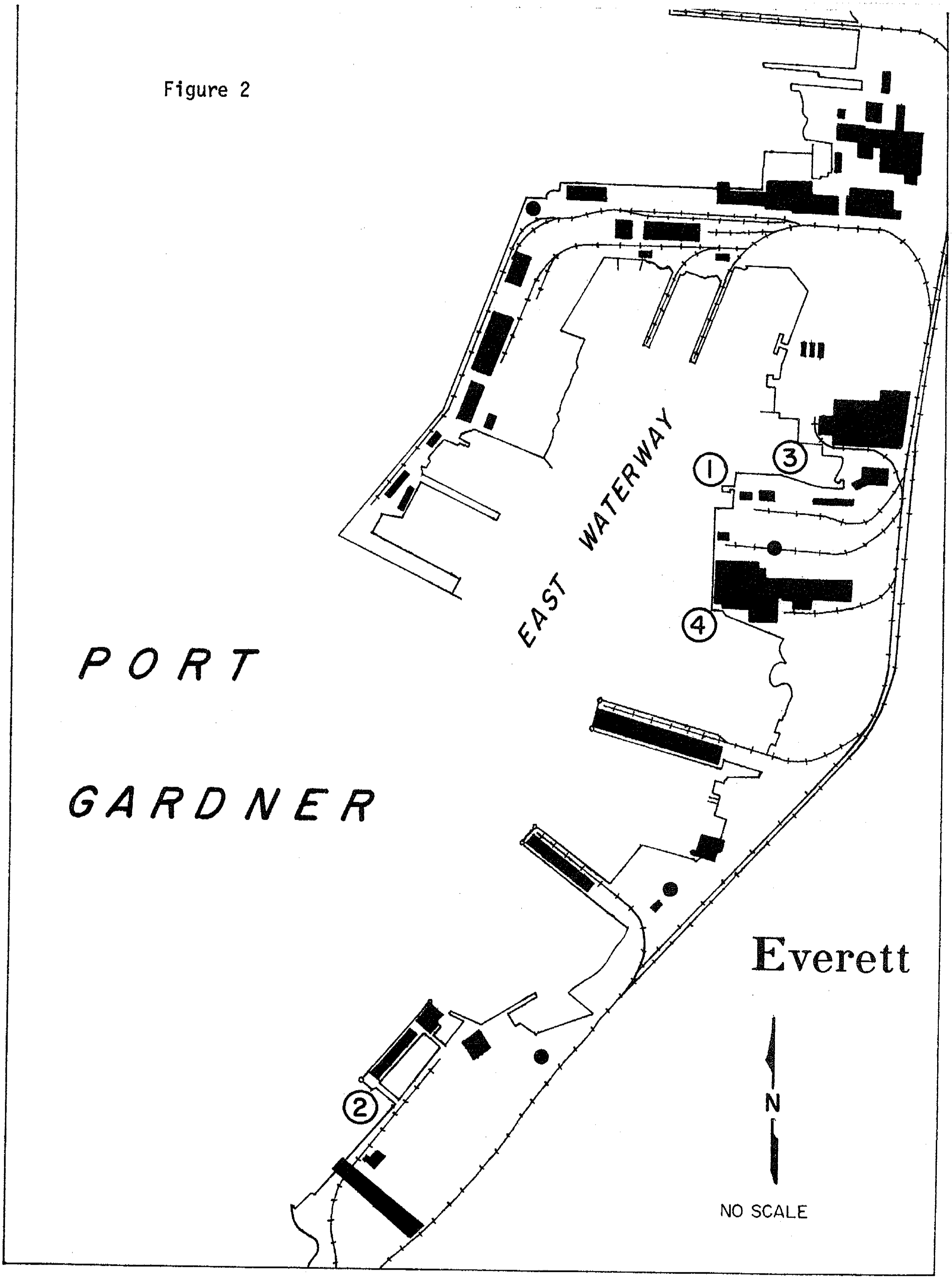
Mortalities of juvenile salmon held in liveboxes in the inshore areas of Everett Harbor have decreased slightly with the reduction in waste load. Hydrogen sulfide gas appears to be the cause of a portion of the observed mortalities; however, mortalities have also been observed at the south piers of both Scott Paper Company and Weyerhaeuser Company when hydrogen sulfide was not measured.

Figure 1

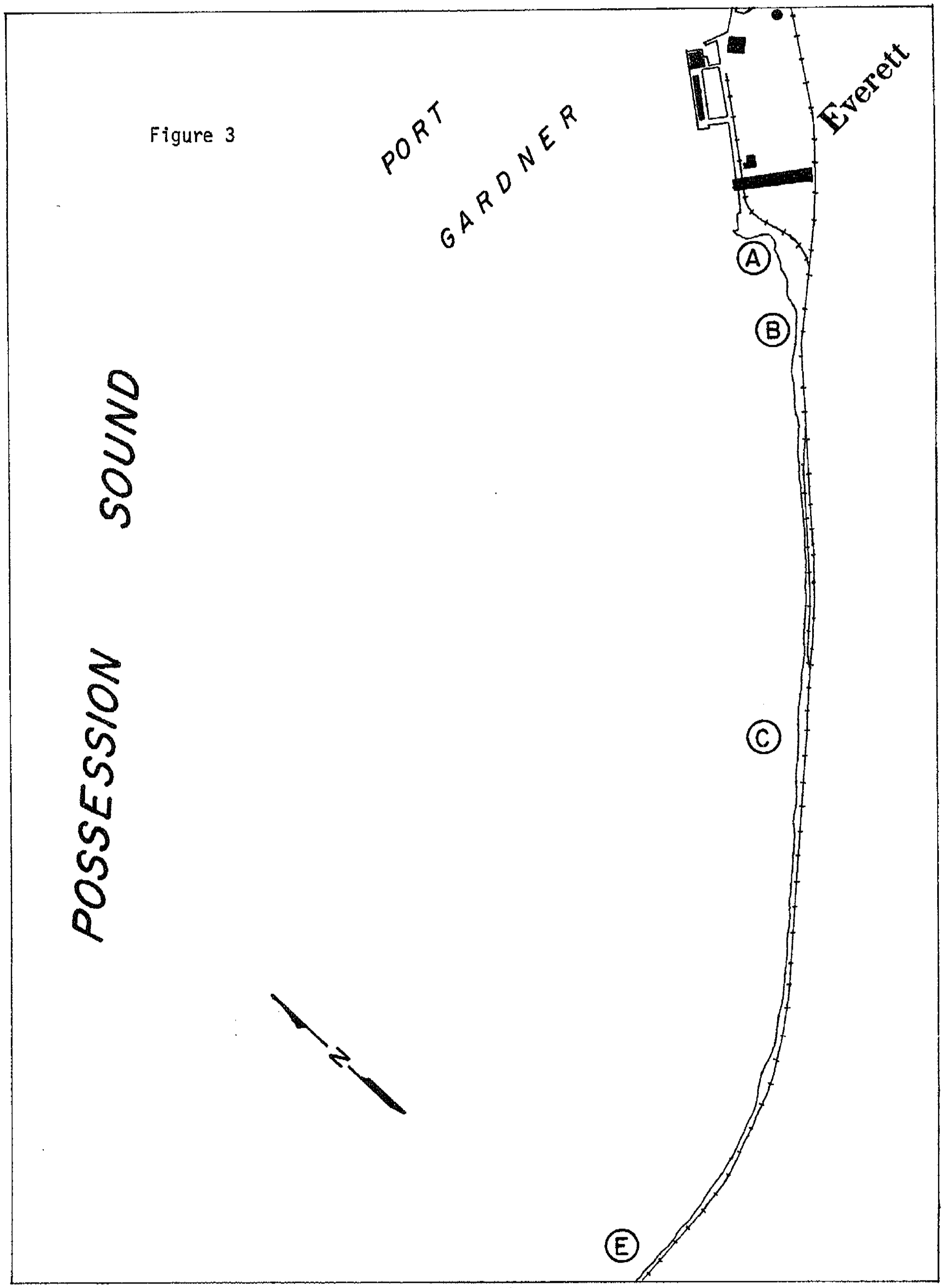


MAP SHOWING ECOBAM VISUAL SURVEY AND DEEP SEINE STATIONS.

Figure 2

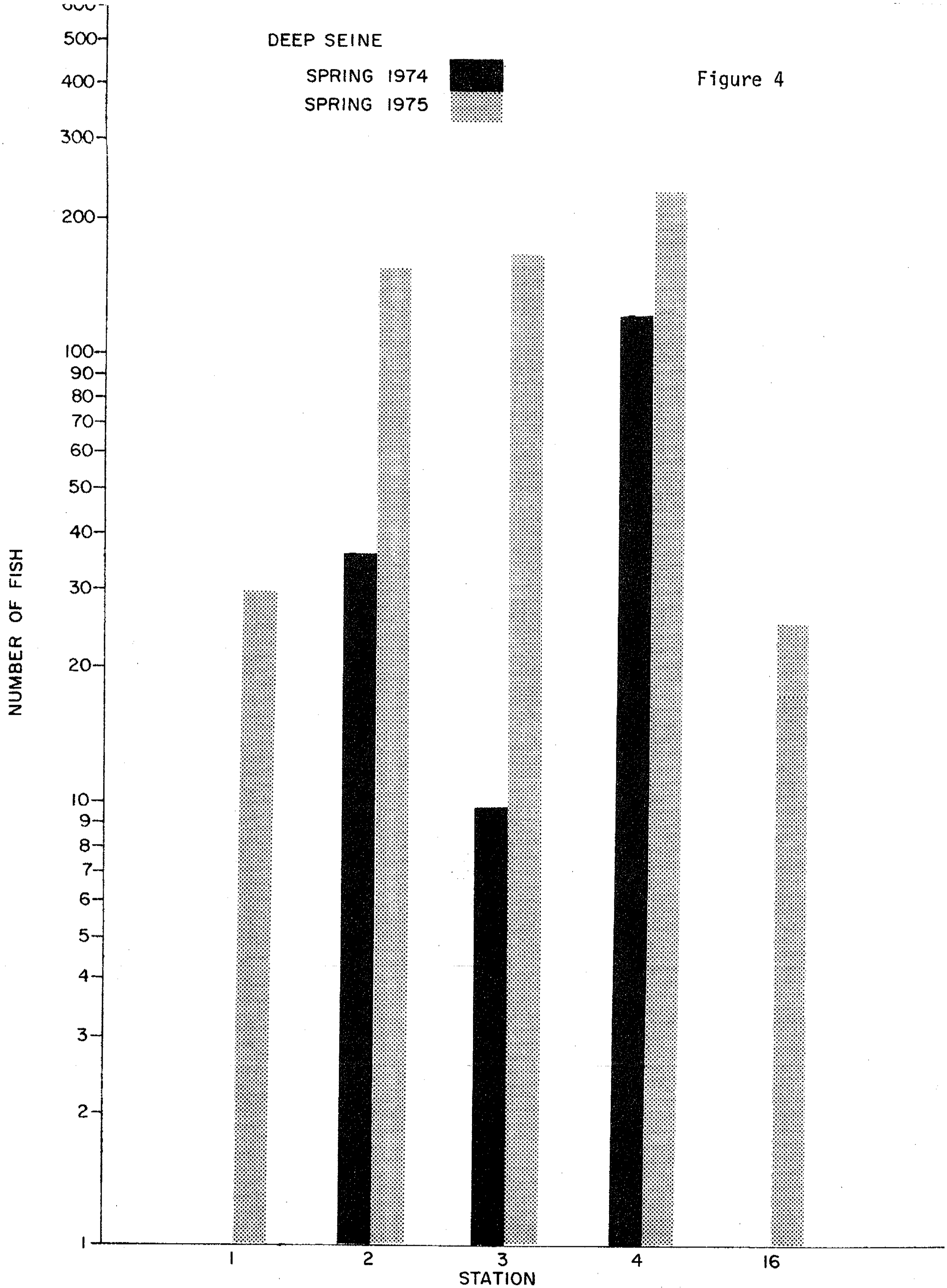


MAP SHOWING ECOBAM LIVE BOX AREAS

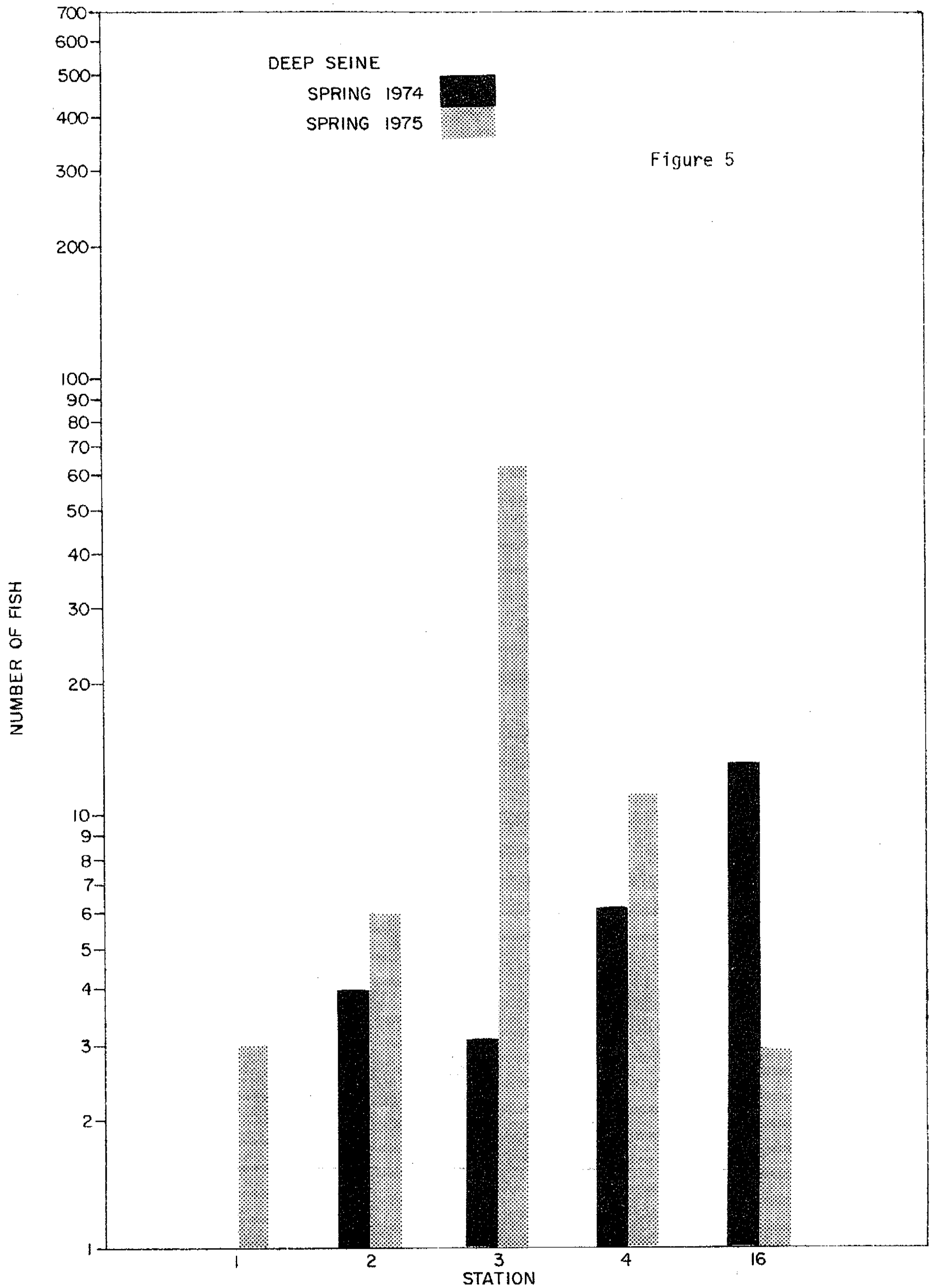


MAP SHOWING ECOBAM BEACH SEINE STATIONS

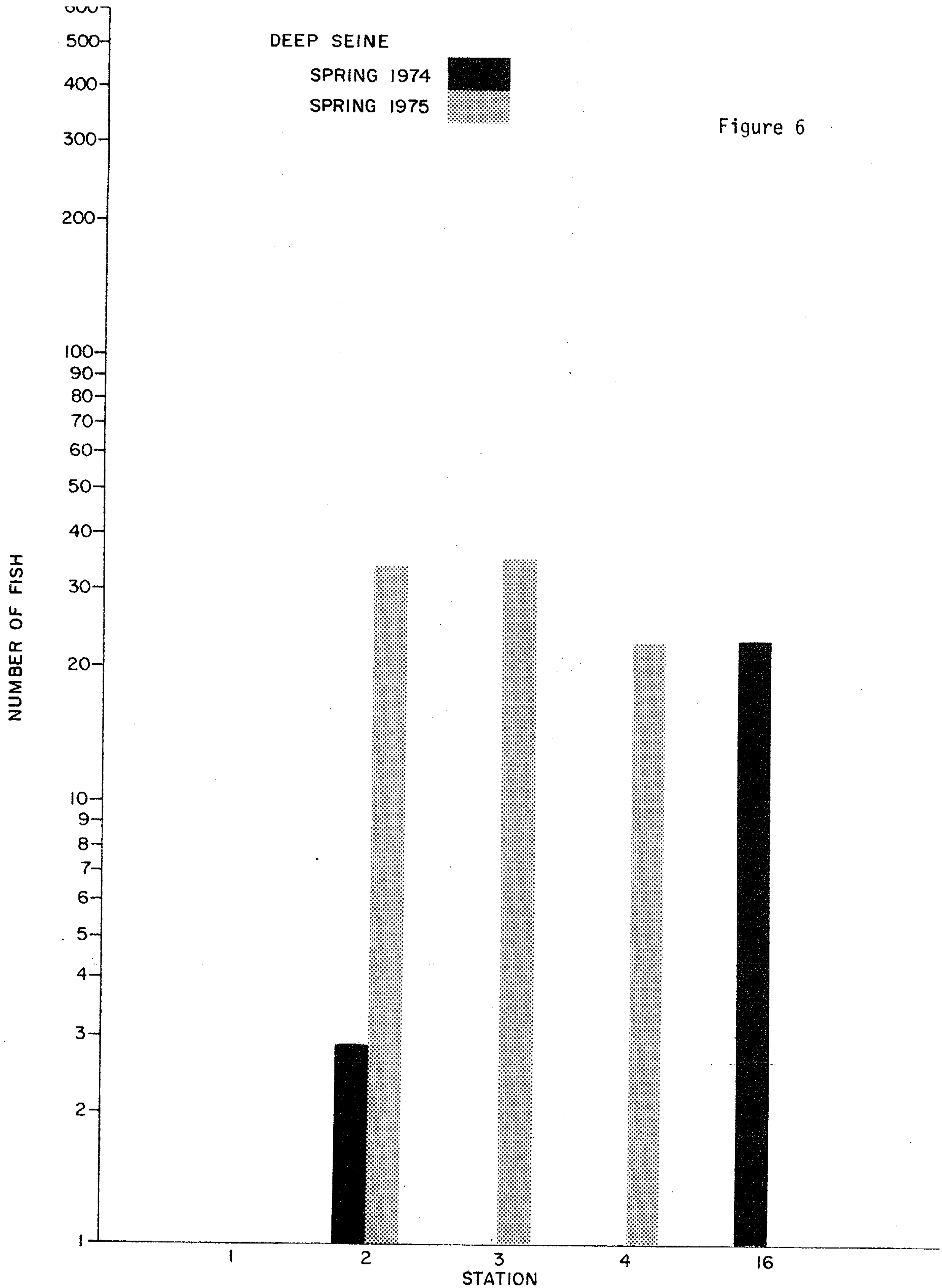
Figure 4



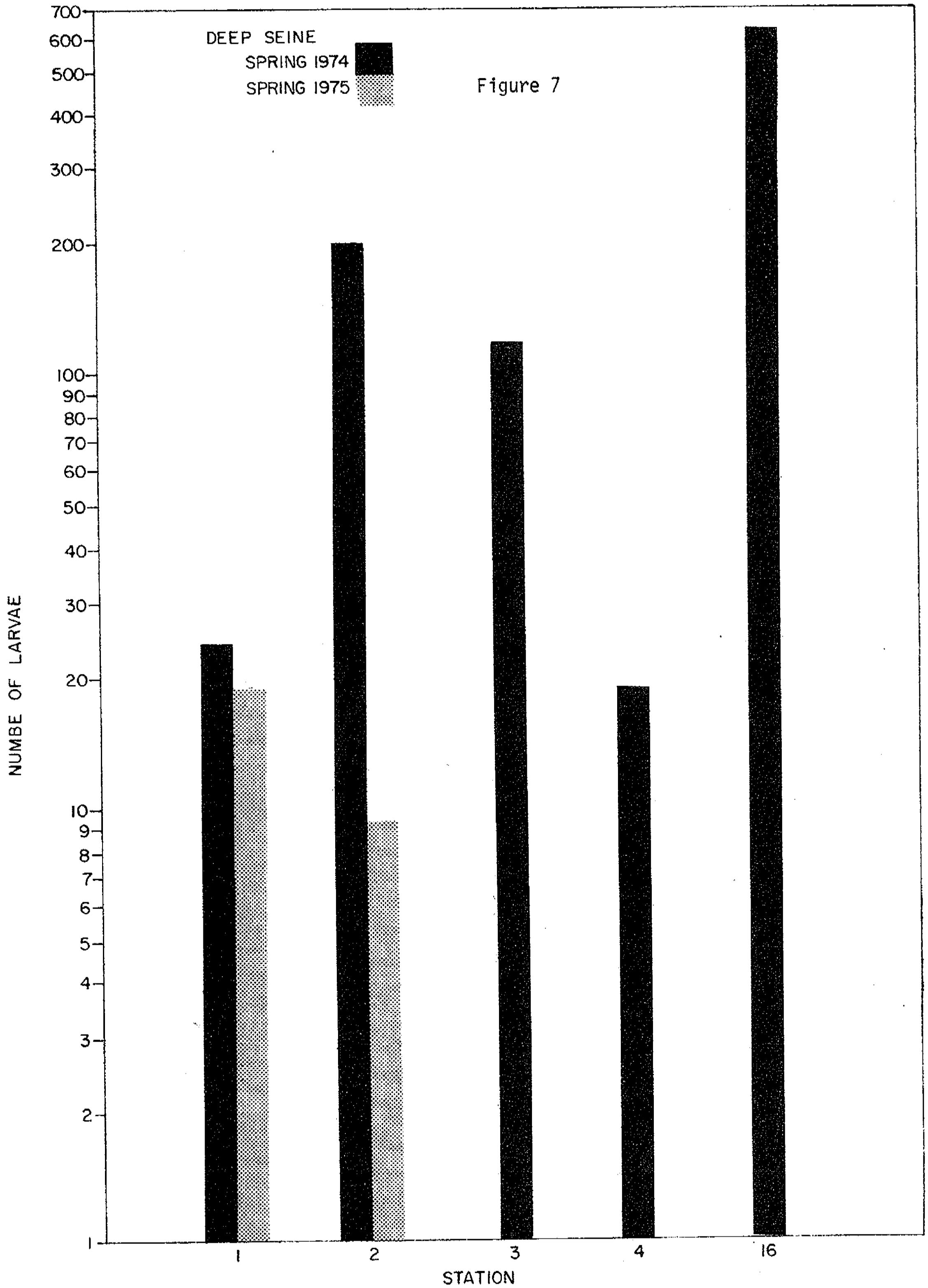
ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY, CHUM SALMON FINGERLINGS (ONCORHYNCHUS KETA).



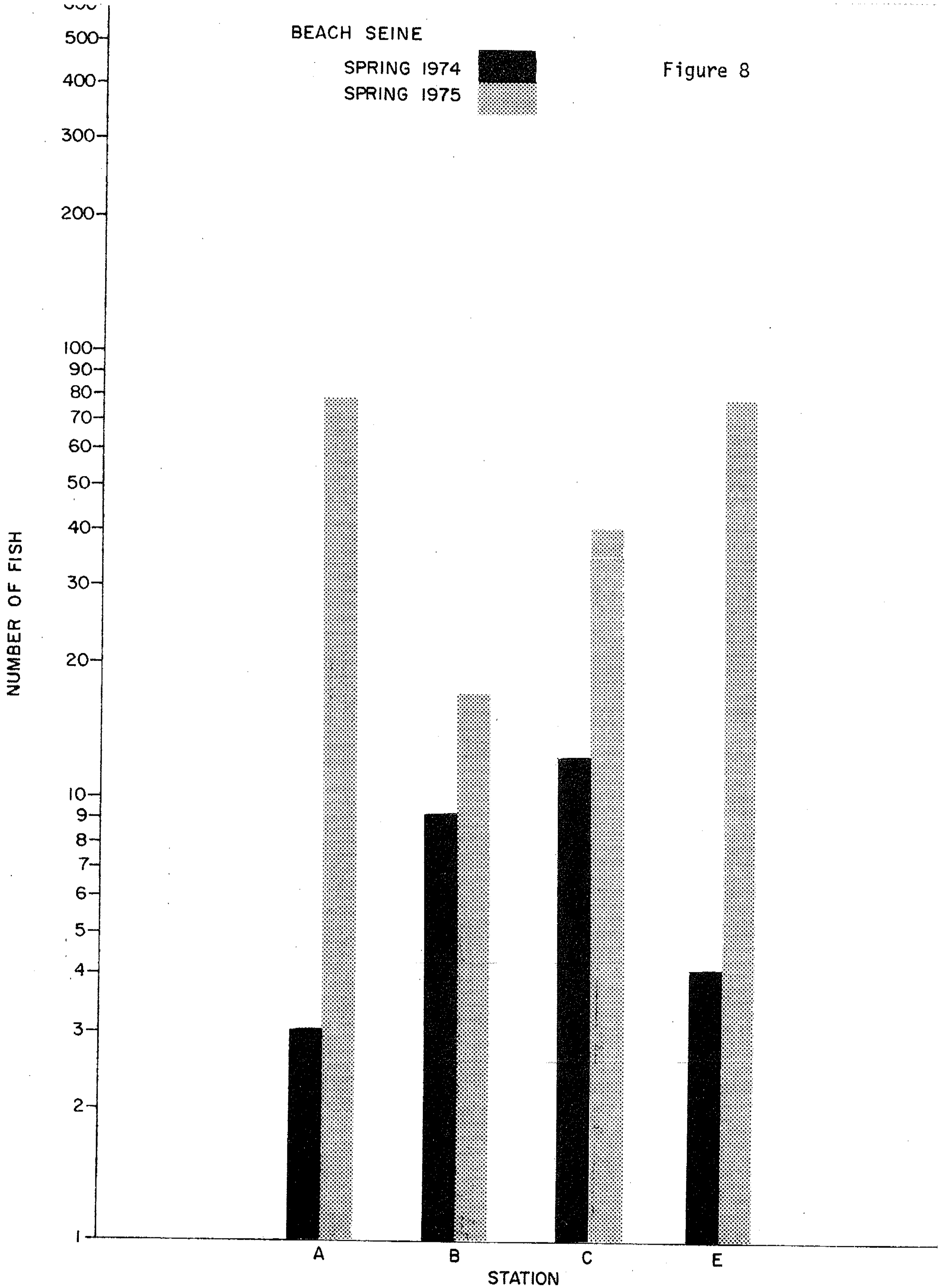
ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY, KING SALMON JUVENILES (ONCORHYNCHUS TSHAWYTSCHA).



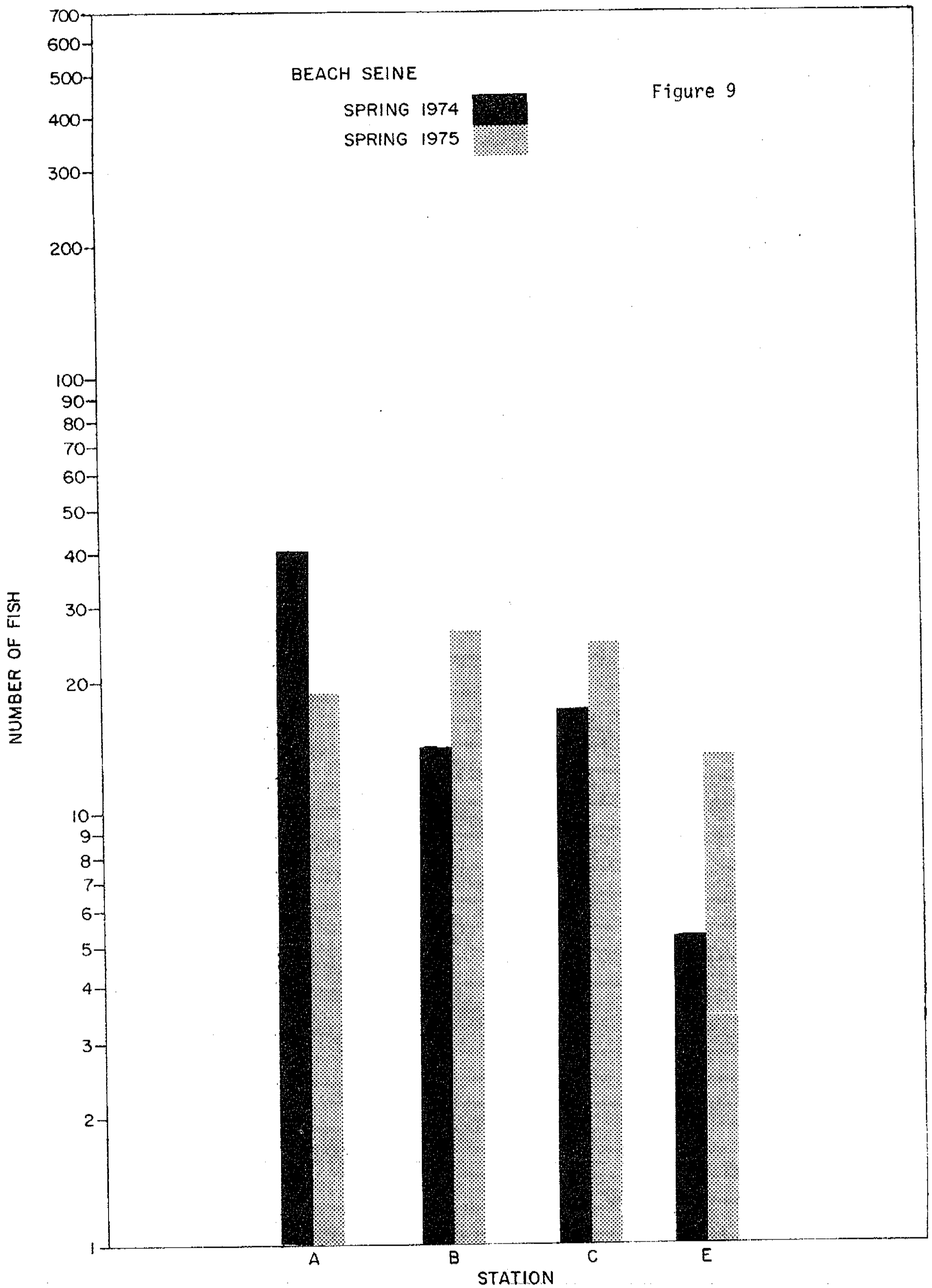
ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY, SILVER SALMON JUVENILES (ONCORHYNCHUS KISUTCH).



ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY, HERRING LARVAE
(CLUPEA PALLASI)



ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY, KING SALMON JUVENILES (ONCORHYACHUS TSHAWYTSCHA).



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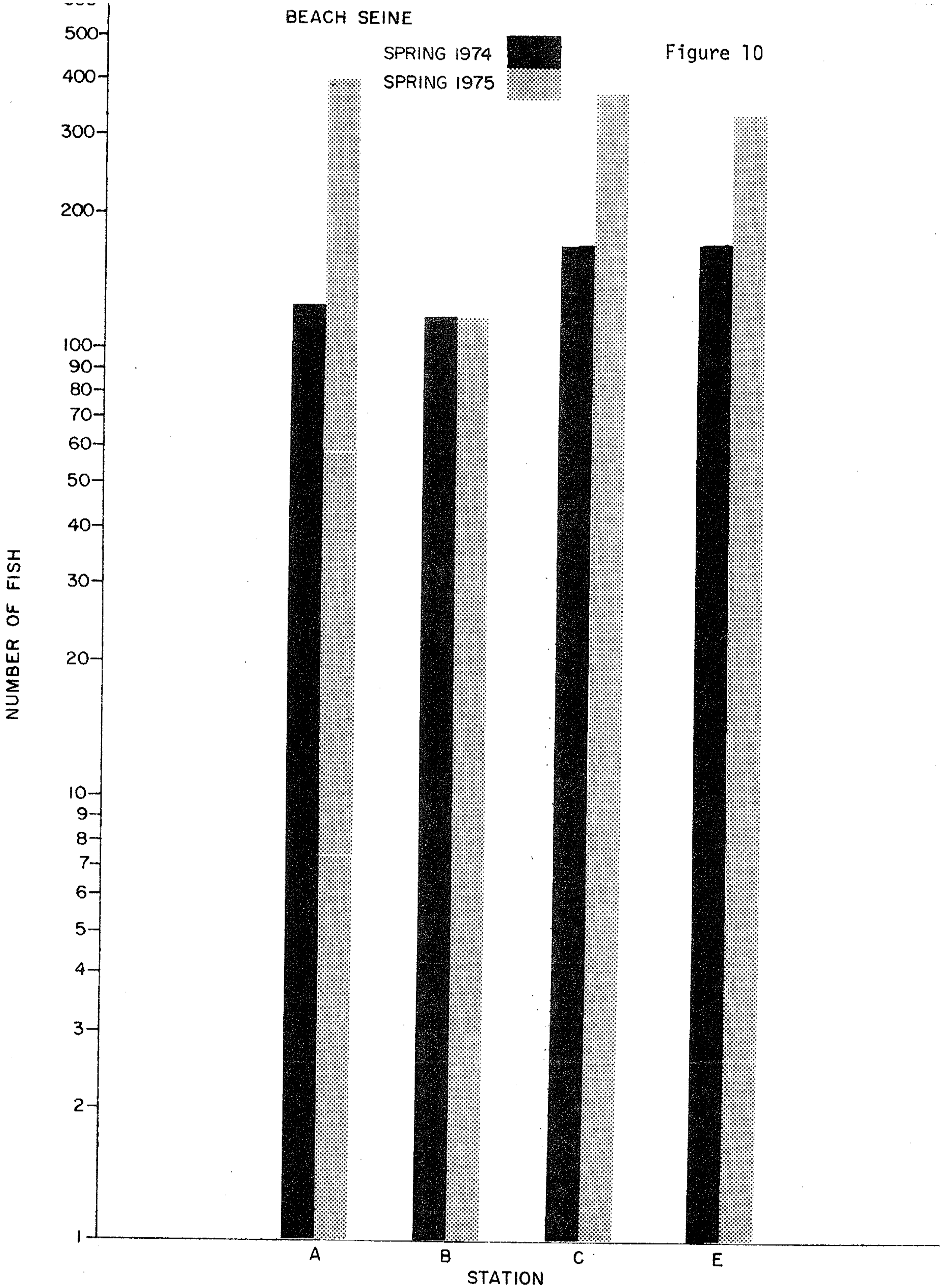
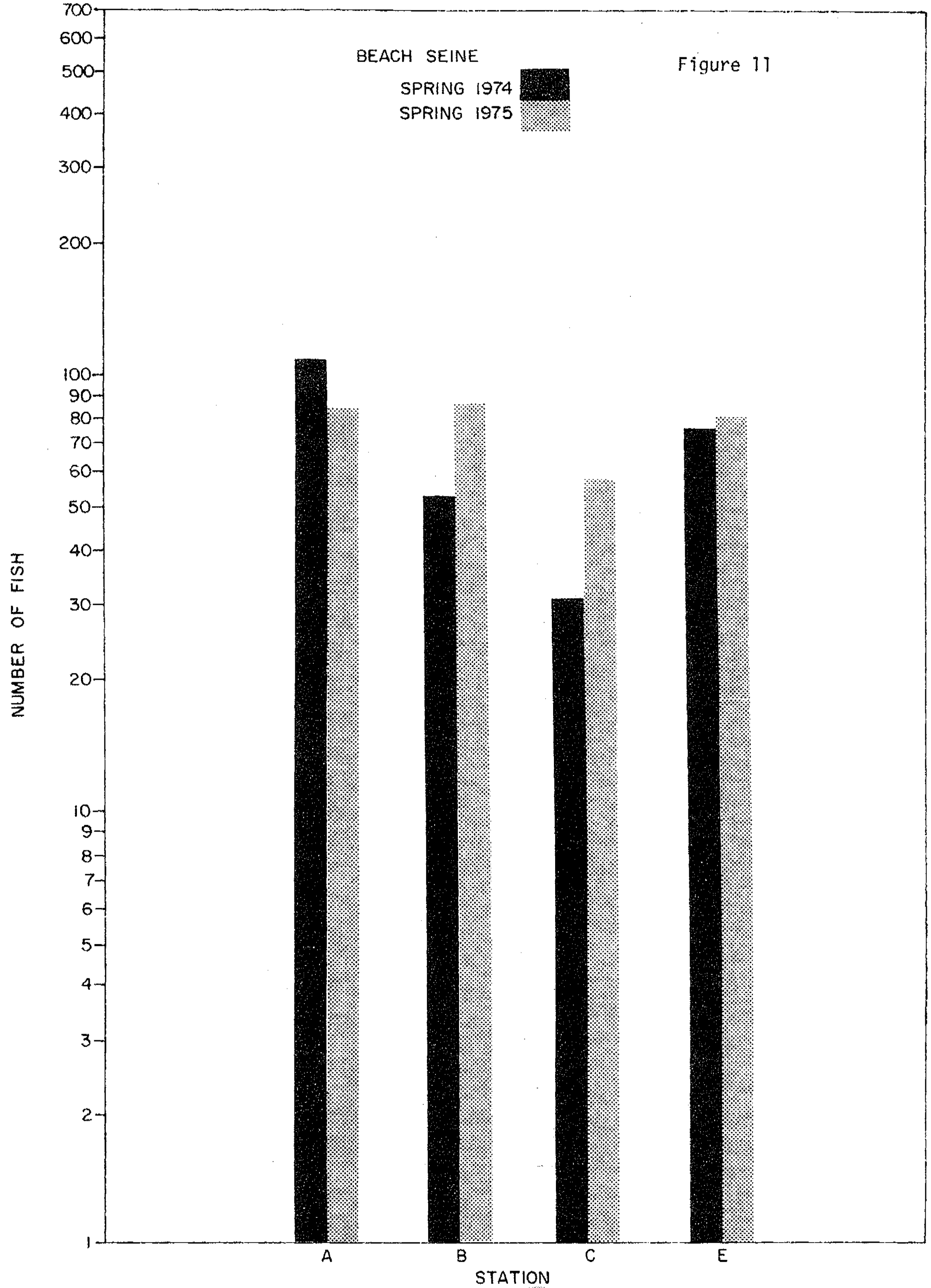
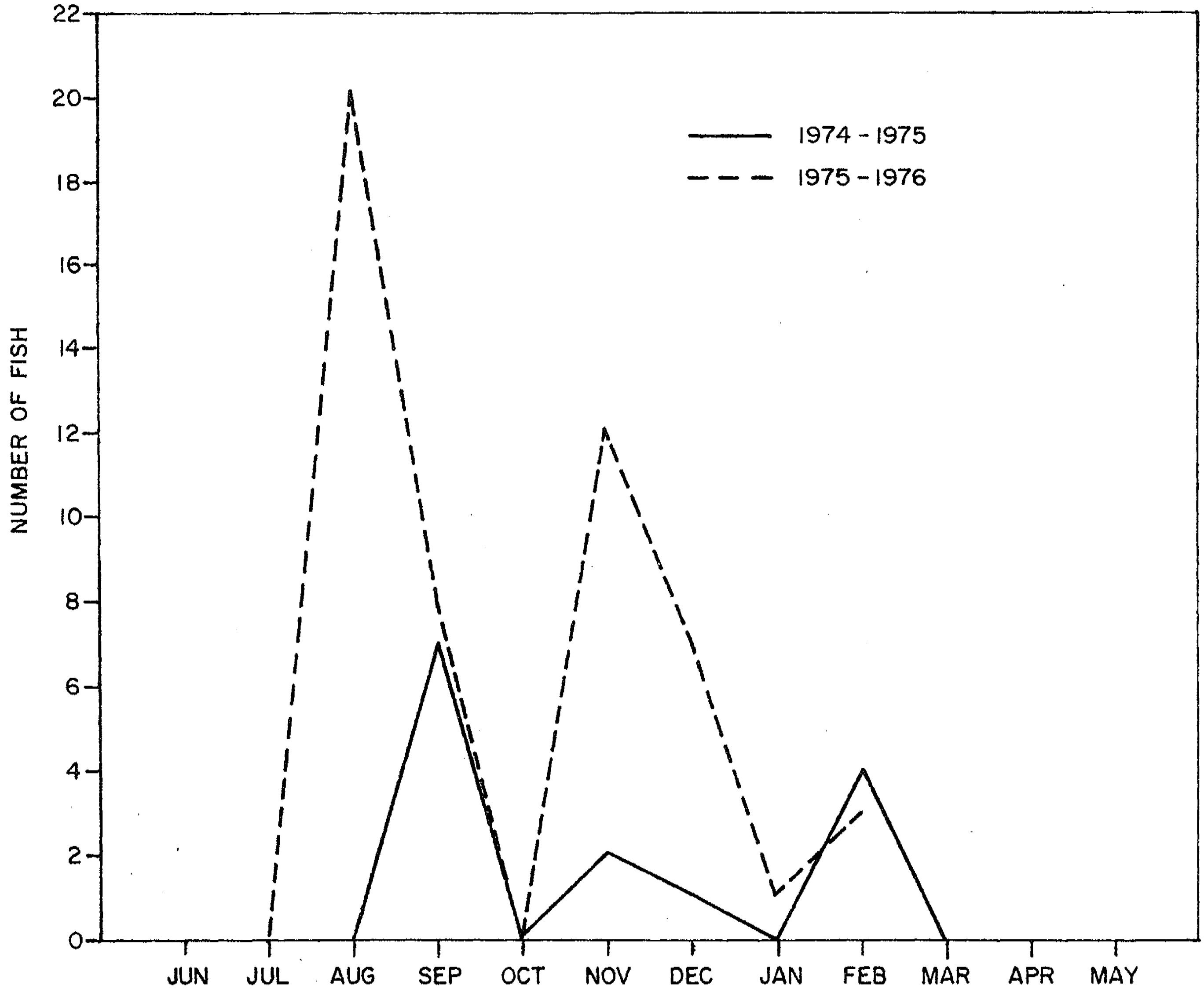


ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY, CHUM SALMON FINGERLINGS (ONCORHYNCHUS KETA).

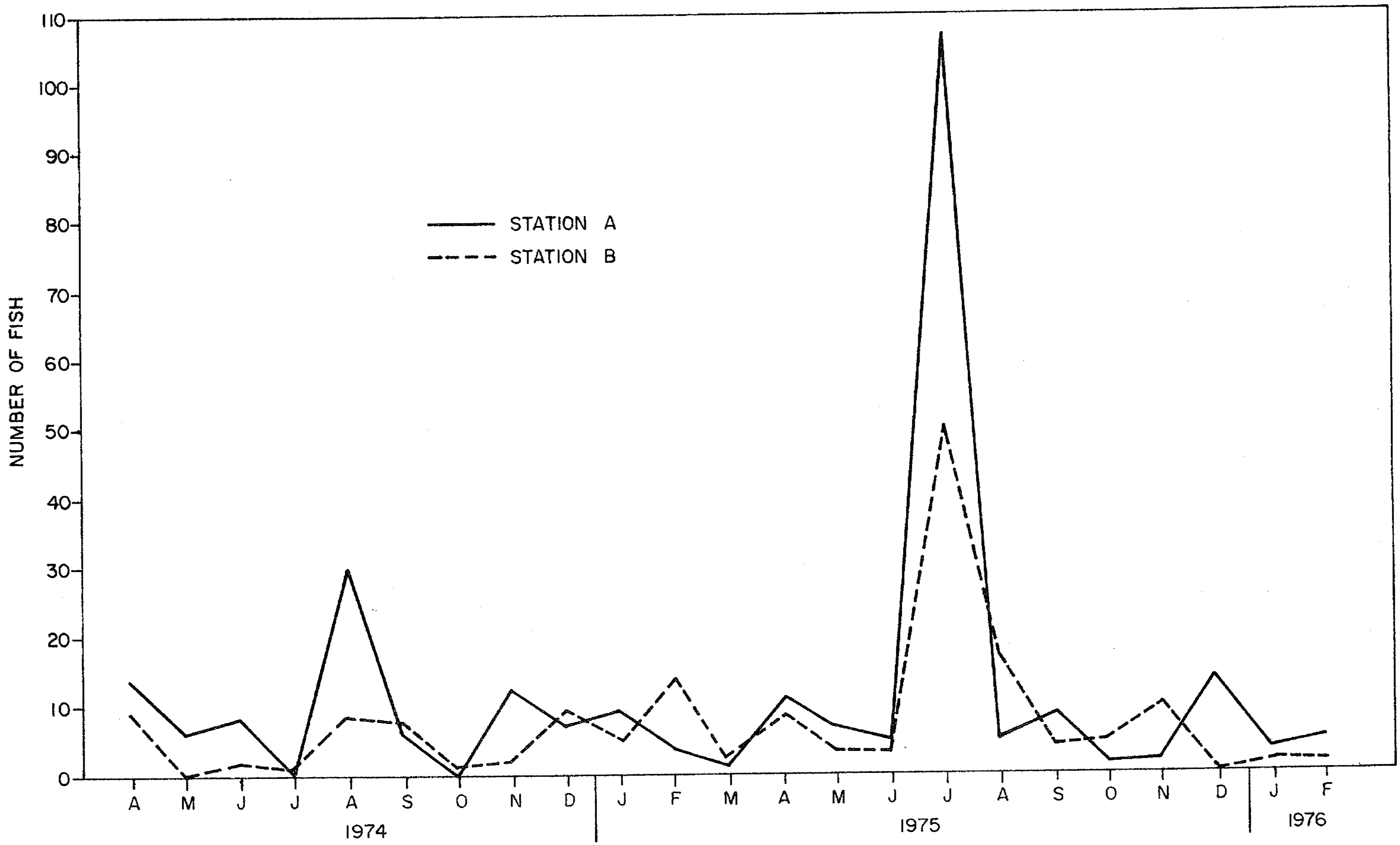


ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY, FLATFISH.



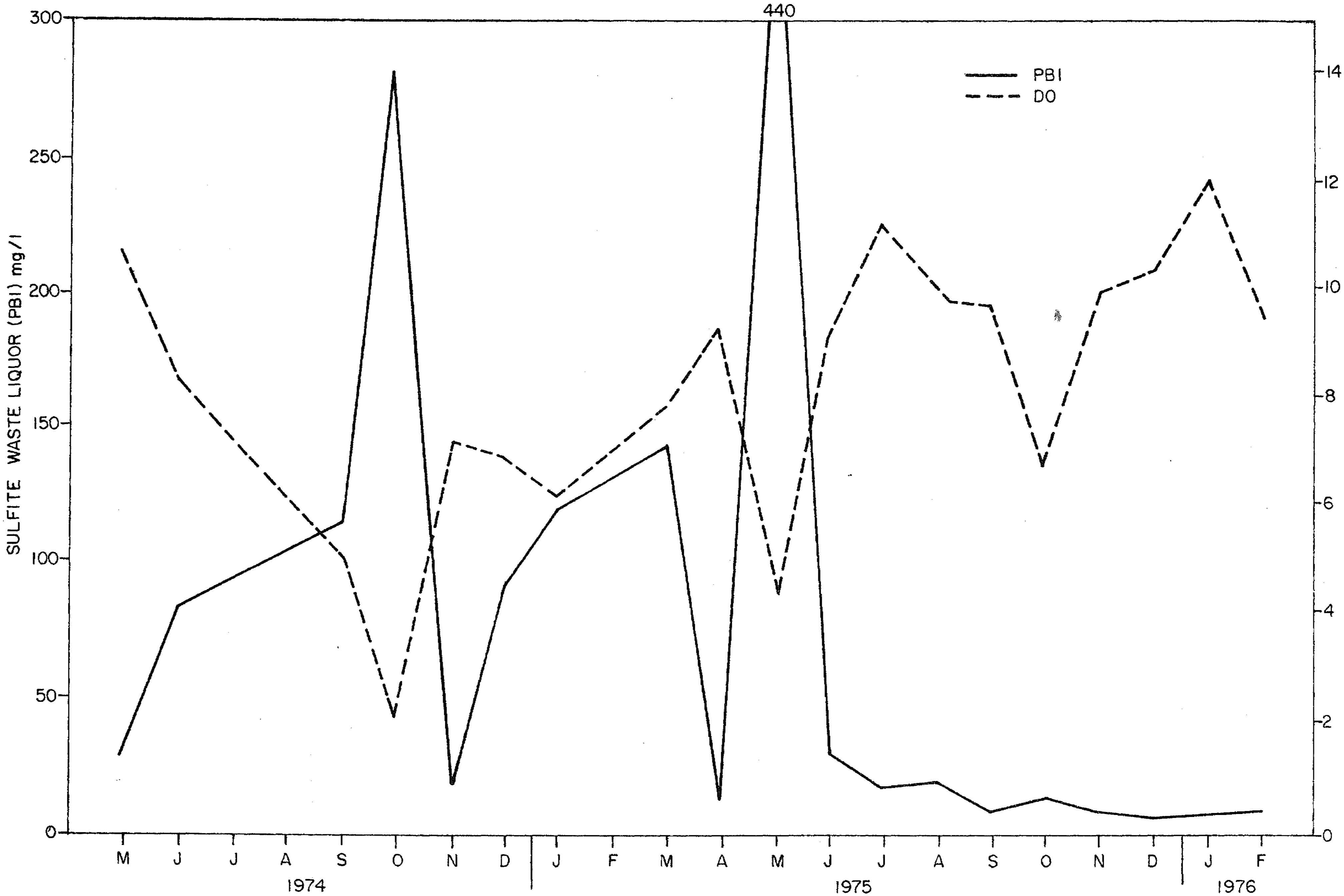
ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY, BEACH SEINE, ENGLISH SOLE (PAROPHRYS VETULUS).

Figure 13



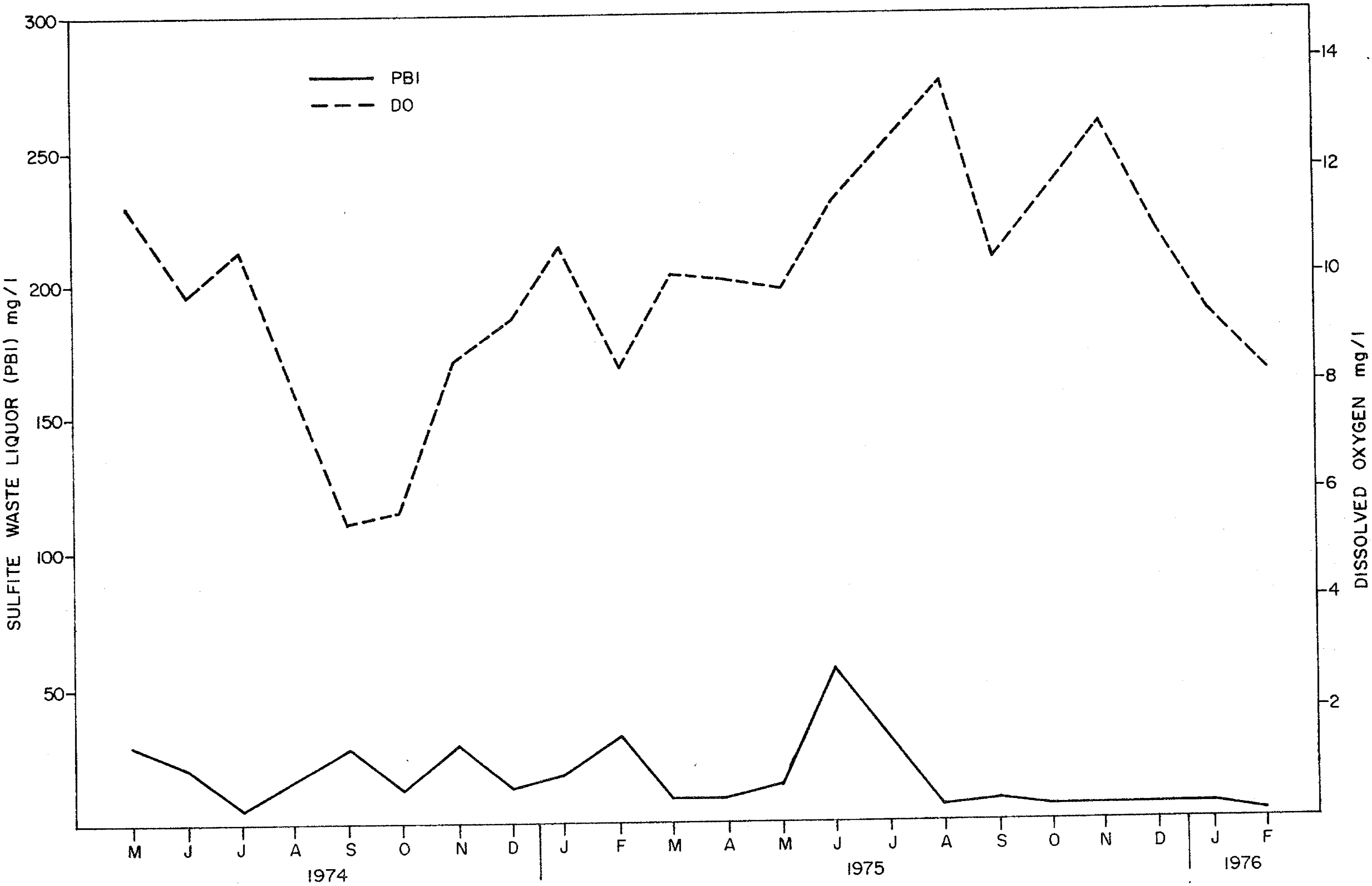
PORT GARDNER FISH DISTRIBUTION STUDY BEACH SEINE TOTAL FLATFISH

Figure 14



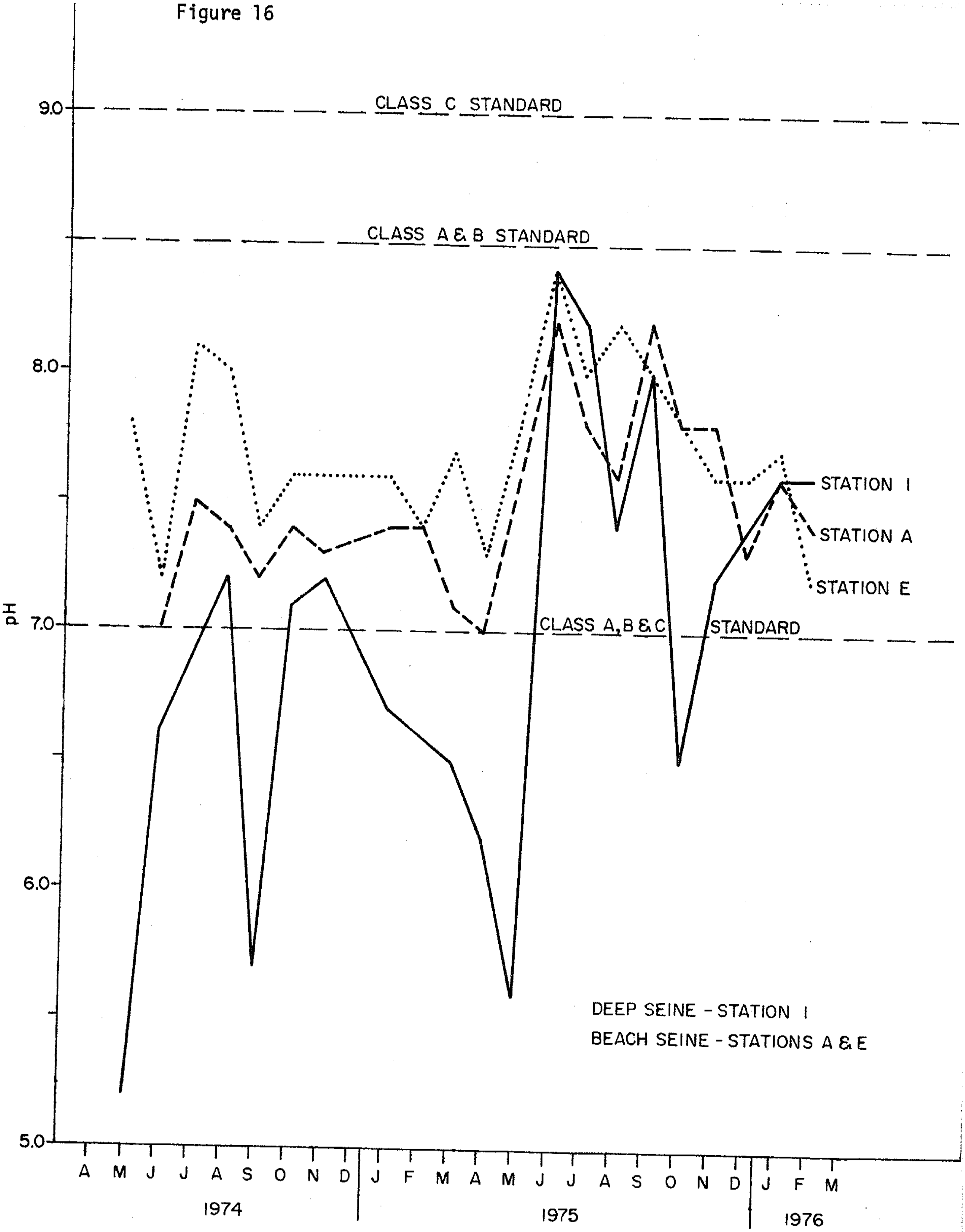
DISSOLVED OXYGEN AND SULFITE LIQUOR CONCENTRATIONS (PBI) AT ECOBAM STATION I, MAY 1974-FEB 197

Figure 15



MAY 1974-FEB 1976

Figure 16



ECOBAM - FISH DISTRIBUTION STUDY, MINIMUM pH VALUES 1974-1976.

TABLE 1 ECOBAM PORT GARDNER LIVE BOX STUDIES

Live Box Mortalities (percentages)

Live Box Area 1 (Scott Chip Off Loading)

Box	8 May 1974	Maximum Sulfides (ppm)	10 June 1975		Maximum Sulfides (ppm)
A	100%	1.2	A	100%	Unable to test for sulfides. Profuse gas bubbling and hydrogen sulfide odor present.
B	100%	2.9	B	100%	
C	100%	5.8	C	100%	
D	80%	2.5	D	100%	
E	0	0.0	E	100%	

Live Box Area 2 (South Pier Weyco Sulfite Mill)

Box	9 May 1974		29 April 1975		
A	100%	0.0	A	100%	0.0
B	100%	0.0	B	100%	0.0
C	0	0.0	C	20%	0.0
D	100%	0.0	D	10%	0.0
E	0	0.0			

Live Box Area 3 (Scott Pulp Mill)

Box	22-23 May 1974		11 June 1975		
A	0	0.0	A	0	0.2
B	0	0.0	B	0	--
C	10%	0.0	C	0	--
D	0	0.0	D	0	--
E	100%	0.6	E	0	--

Live Box Area 4 (South Pier Scott Pulp & Paper)

Box	4-6 June 1974		14-15 May 1975		No 'boil' from diffuser even at minus 2.0 tide
A	100%	0.0	A	0	0.0
B	20%	0.0	B	0	0.0
C	10%	0.0	C	0	0.0
D	20%	0.0	D	10%	0.0
E	0	0.0	E	0	0.0

ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY

Table 2 Deep Seine - 1974

Chum Salmon Fingerlings (*Oncorhynchus keta*)

Station	25 Apr.	29 Apr.	14 May	15 May	5 June	12 June	Totals
1	0	1	0	0	0	0	1
2	0	0	0	0	33	3	36
3	0	0	0	0	0	10	10
4	3	3	0	0	113	1	120
16	0	0	0	0	1	0	1

Deep Seine - 1975

	23 Apr.	30 Apr.	13 May	15 May	4 June	11 June	Totals
1	0	0	23	0	6	0	29
2	0	0	19	0	106	27	152
3	1	1	116	0	0	43	161
4	0	78	16	0	131	3	228
16	0	0	11	0	4	9	24

ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY

Table 3 Deep Seine - 1974

Silver Salmon Juveniles (*Oncorhynchus kisutch*)

Station	25 Apr.	29 Apr.	14 May	15 May	5 June	12 June	Totals
1	0	0	0	0	0	0	0
2	0	0	0	0	3	0	3
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
16	0	0	0	7	17	0	24

Deep Seine - 1975

	23 Apr.	30 Apr.	13 May	15 May	4 June	11 June	Totals
1	0	0	0	0	0	0	0
2	0	0	33	0	1	1	35
3	0	0	0	32	0	4	36
4	0	0	22	0	1	0	23
16	0	0	0	0	1	0	1

APPENDIX II

Figures

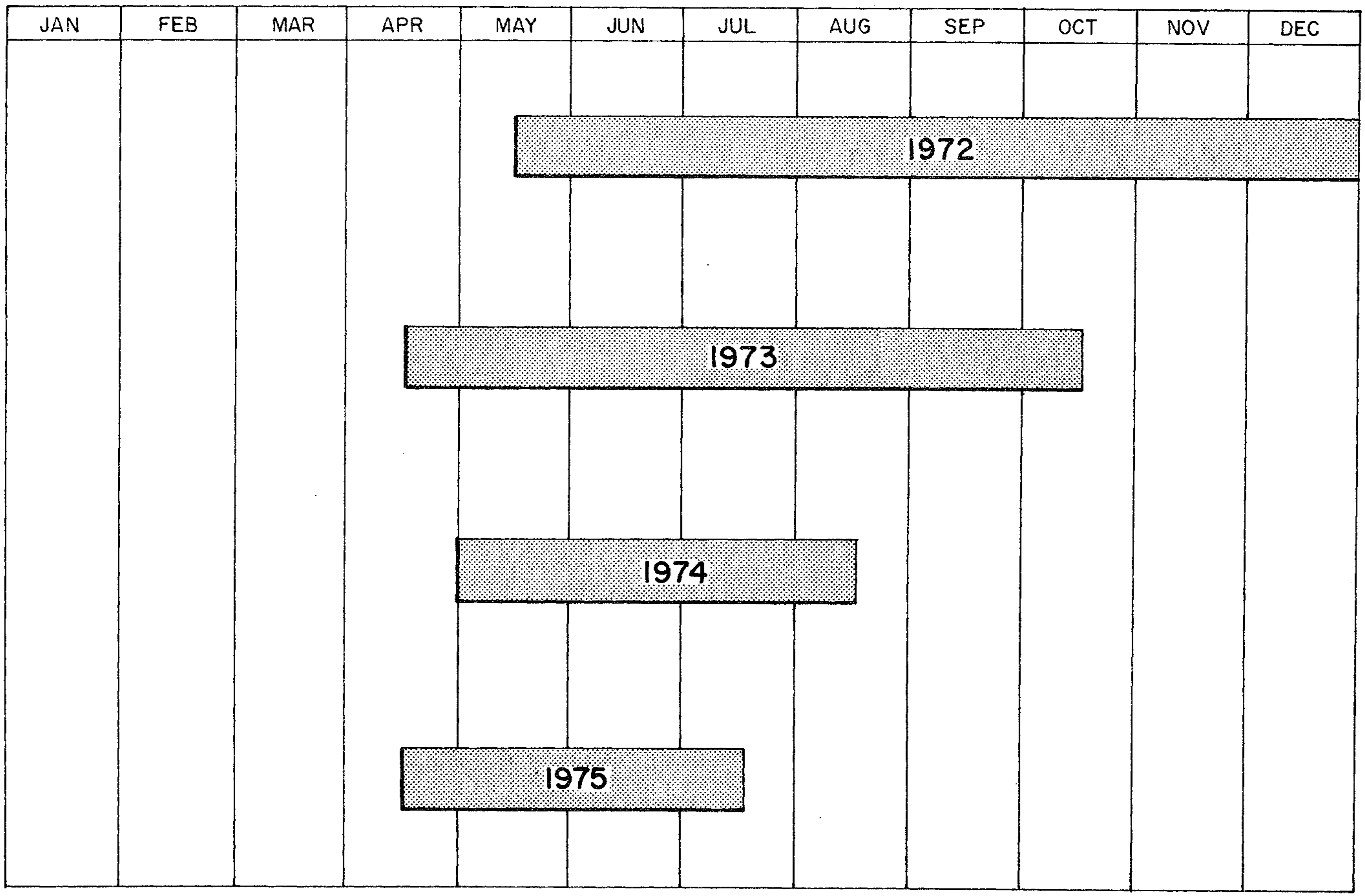


Figure 1. TIME INTERVAL FOR ARTIFICAL SUBSTRATE PLACEMENT, PORT GARDNER, 1972-1975.

ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY

Table 4 Deep Seine - 1974

King Salmon Juveniles (<u>Oncorhynchus</u> <u>tshawytsc</u>

Station	25 Apr.	29 Apr.	14 May	15 May	5 June	12 June	Totals
1	0	0	0	0	0	0	0
2	0	0	0	0	3	1	4
3	0	0	0	0	1	2	3
4	0	0	0	0	0	6	6
16	0	0	0	0	13	0	13

Deep Seine - 1975

	23 Apr.	30 Apr.	13 May	15 May	4 June	11 June	Totals
1	0	0	0	0	3	0	3
2	0	0	5	1	0	0	6
3	0	0	0	54	8	1	63
4	0	0	9	0	2	0	11
16	0	0	3	0	0	0	3

ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY

Table 5 Deep Seine - 1974

Herring Larvaé (Clupea pallasi)

Station	25 Apr.	29 Apr.	14 May	15 May	5 June	12 June	Totals
1	1	0	0	0	15	10	26
2	1	11	0	0	200	10	222
3	0	0	0	0	125	0	125
4	0	0	0	0	20	0	20
16	0	0	600	0	75	0	675

Deep Seine - 1975

	23 Apr.	30 Apr.	13 May	15 May	4 June	11 June	Totals
1	0	0	0	1	20	0	21
2	0	0	0	10	0	0	10
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0

ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY

Table 6 Beach Seine

King Salmon Juveniles (Oncorhynchus tshawytscha)

Spring 1974

Station	24 Apr.	25 Apr.	30 Apr.	14 May	4 June	12 June	Totals
A	0	0	1	2	0	0	3
B	0	0	0	0	4	5	9
C	0	3	1	1	6	1	12
E	0	0	0	0	0	4	4

Spring 1975

	22 Apr.	24 Apr.	30 Apr.	13 May	4 June	12 June	Totals
A	65	2	0	0	9	0	76
B	8	4	0	0	3	2	17
C	14	25	0	1	0	0	40
E	32	44	2	2	0	0	80

ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY

Table 7 Beach Seine

Silver Salmon Juveniles (Oncorhynchus kisutch)

Spring 1974

Station	24 Apr.	25 Apr.	30 Apr.	14 May	4 June	12 June	Totals
A	0	0	1	36	2	1	40
B	0	3	0	11	0	0	14
C	0	0	0	2	15	0	17
E	0	2	0	1	0	2	5

Spring 1975

Station	22 Apr.	24 Apr.	30 Apr.	13 May	4 June	12 June	Totals
A	0	0	0	1	18	0	19
B	1	0	1	0	23	1	26
C	0	0	0	8	16	0	24
E	0	0	0	10	3	0	13

ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY

Table 8 Beach Seine

Chum Salmon Fingerlings (*Oncorhynchus keta*)

Spring 1974

Station	24 Apr.	25 Apr.	30 Apr.	14 May	4 June	12 June	Totals
A	15	31	12	13	1	53	125
B	2	12	27	53	4	16	114
C	1	27	99	14	8	15	164
E	26	6	83	24	0	32	171

Spring 1975

	22 Apr.	24 Apr.	30 Apr.	13 May	4 June	12 June	Totals
A	0	1	299	92	14	8	414
B	0	0	25	50	34	9	118
C	1	0	52	320	3	5	381
E	22	3	38	262	5	1	331

ECOBAM - PORT GARDNER FISH DISTRIBUTION STUDY

Table 9 Beach Seine

Flatfish

Spring 1974

Station	24 Apr.	25 Apr.	30 Apr.	14 May	4 June	12 June	Totals
A	7	36	18	7	3	37	108
B	13	15	3	4	1	13	49
C	8	6	8	4	2	1	29
E	9	1	41	16	2	2	71

Spring 1975

	22 Apr.	24 Apr.	30 Apr.	13 May	4 June	12 June	Totals
A	22	20	7	12	5	17	83
B	1	14	18	4	2	43	82
C	2	4	0	28	2	19	55
E	7	0	21	28	8	13	77

Table 10

ECOBAM - Fish Distribution Study

Minimum pH Values

Date		Deep Seine		Beach Seine	
		Station #1	Station #16	Station A	Station E
1974	May	5.2	7.2	7.0	7.8
	June	6.6	6.8	7.0	7.2
	July	--	--	7.5	8.1
	Aug.	7.2	7.0	7.4	8.0
	Sept.	5.7	6.8	7.2	7.4
	Oct.	7.1	7.2	7.4	7.6
	Nov.	7.2	6.9	7.3	7.6
	Dec.	--	--	--	--
1975	Jan.	6.7	7.3	7.4	7.6
	Feb.	--	7.3	7.4	7.4
	Mar.	6.5	7.3	7.1	7.7
	Apr.	6.2	7.0	7.0	7.3
	May	5.6	6.9	7.6	7.8
	June	8.4	7.4	8.2	8.4
	July	8.2	8.0	7.8	8.0
	Aug.	7.4	7.4	7.6	8.2
	Sept.	8.0	8.0	8.2	8.0
	Oct.	6.5	7.3	7.8	7.8
	Nov.	7.2	8.2	7.8	7.6
	Dec.	7.4	7.5	7.3	7.6
1976	Jan.	7.6	7.4	7.6	7.7
	Feb.	7.6	7.7	7.4	7.2

SECTION IV

Toxicity of Marine Waters near Everett and Port Angeles, Washington to Larval Pacific Oysters 1972 through 1975

TOXICITY OF MARINE WATERS NEAR EVERETT AND PORT ANGELES, WASHINGTON, TO LARVAL PACIFIC OYSTERS IN 1975

by

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November 1976

ABSTRACT

The acute effects of marine waters near Everett and Port Angeles on the early embryonic development of Pacific oysters (*Crassostrea gigas*) were determined with reference to the toxicity of sulfite pulp mill effluents discharged into these waters. The status of receiving water toxicity in 1975 was compared to that in previous years.

In the Everett region, receiving water acute toxicity diminished progressively from 1972 to 1975. The changes corresponded largely to improvements in pulp mill wastewater treatment. Receiving water toxicity in the Port Angeles region increased somewhat between 1972 and 1974, but essentially disappeared in late 1975 when the ITT Rayonier pulp mill instituted incineration of its sulfite waste liquor.

Less than half of the receiving water toxicity in both regions could be explained by Pearl-Benson Index concentrations, even though correlations between PBI and toxicity were usually significant. The Pearl-Benson Index should not be used as the sole chemical parameter to assess the toxicity of receiving waters impacted by sulfite pulp mill wastes, particularly of those which reflect a treatment such as sulfite waste liquor incineration.

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INTRODUCTION

Over the past 15 years the Washington Department of Fisheries has annually monitored the quality of the surface marine waters of Washington state using the early development (fertilized egg to veliger stage) of Pacific oysters (*Crassostrea gigas*) as an indicator. Marine waters receiving effluents from pulp mills, particularly those utilizing one of the sulfite processes, have been investigated more extensively for the following reasons: pulp mill effluents constitute the largest source of industrial effluents being discharged into the fjord-like, marine waters of Washington state; pulp mill effluents are highly toxic to the larvae of several species of native and exotic bivalve molluscs (Woelke, 1960; Woelke et al., unpublished); marine waters from areas near pulp mills have frequently been found to be acutely toxic to Pacific oyster larvae; and effluents from sulfite process mills are both more toxic and chemically contaminated because process chemicals are not recovered to the extent practiced by kraft (sulfate) process mills.

In 1972 intensive investigations of marine water quality in Everett and Port Angeles were begun. Selection of these two areas was based upon a variety of considerations: sulfite pulp mills in both areas had scheduled major changes in process design or wastewater treatment or both to meet more stringent requirements for effluent quality; substantial receiving water acute toxicity existed prior to institution of these changes; there were marked differences in each area's oceanography which would be reflected in differences in the mixing, dilution, and flushing of discharged wastes. These investigations sought to document the efficacy of pulp mill wastewater treatment in improving each area's respective receiving water quality as indicated by the responses of larval oysters.

In 1975, exploratory research was also directed toward defining the toxicity and chemical composition of pulp mill effluents and determining whether receiving water toxicity was being caused in part by such basic water quality parameters as low dissolved oxygen and pH or by elevated concentrations of ammonia and hydrogen sulfide. Finally, the receiving water quality data collected from the two areas in the summers of 1972, 1973 and 1974 were statistically analyzed and summarized in an effort to determine whether there had been any demonstrable improvements in receiving water quality and the extent to which variation in receiving water toxicity was explained by Pearl-Benson Index concentrations.

MATERIALS AND METHODS

Sample Collection and Handling

Water samples were collected in and adjacent to Everett (i.e., Everett Harbor, Port Gardner, Saratoga Passage, Port Susan [Figs. 1 and 2; Appendix Table 1]) and Port Angeles (Freshwater Bay east to Dungeness Spit [Figs. 3 and 4; Appendix Table 2]) on 18-19 August 1975 and 25 August 1975, respectively. Samples were collected at the surface and at various depths with plastic Van Dorn bottles and transported by air to the Department's Pt. Whitney Shellfish Laboratory where they were tested the same day for toxicity to Pacific oyster larvae.

Because the study focused on the responses of larval oysters to marine waters containing in many cases detectable quantities of sulfite waste liquor (SWL, expressed in terms of Pearl-Benson Index-sensitive substances or PBI), we also sought to relate the *in situ* PBI-organism response data to those of pulp mill wastewaters which had been discharged within the 24-hr period preceding the field phase of the study.

Of the two pulp mills of concern in Everett, the Scott Paper Company's ammonia-base, sulfite process pulp and paper mill was the only one discharging during the period of the study. Although chips from Western hemlock (*Tsuga heterophylla*) are the primary source of pulp, small proportions (2-5%) of white fir (*Abies concolor*), Pacific silver fir (*A. amabilis*)

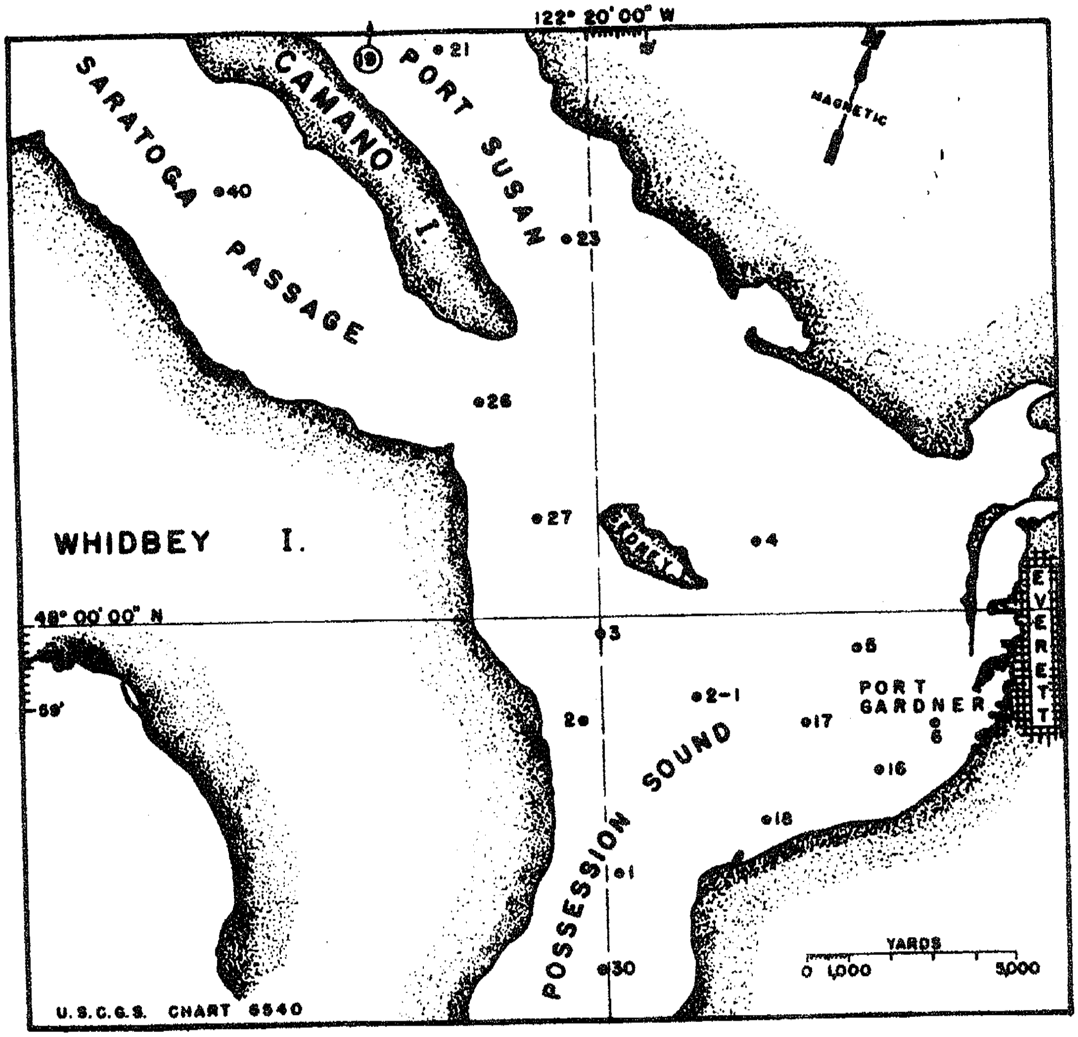

Fig. 1. Sampling stations in Everett region peripheral to inner Port Gardner and East Waterway

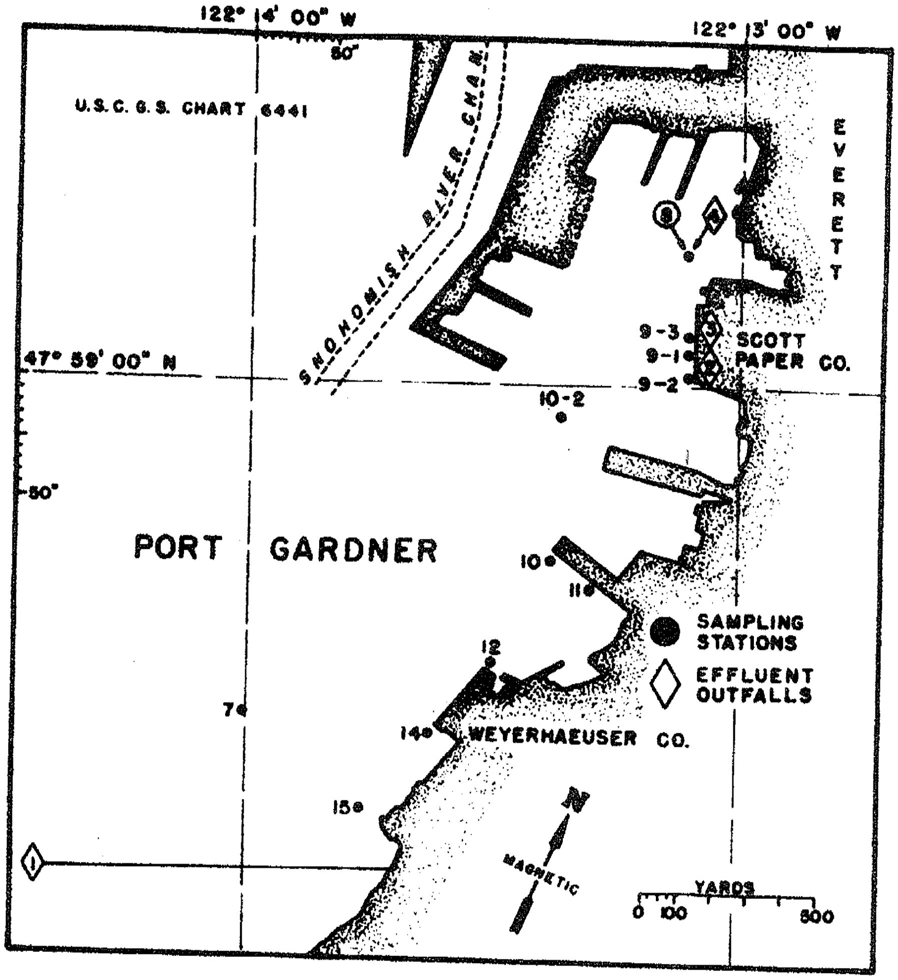

Fig. 2. Sampling stations in inner Port Gardner and East Waterway

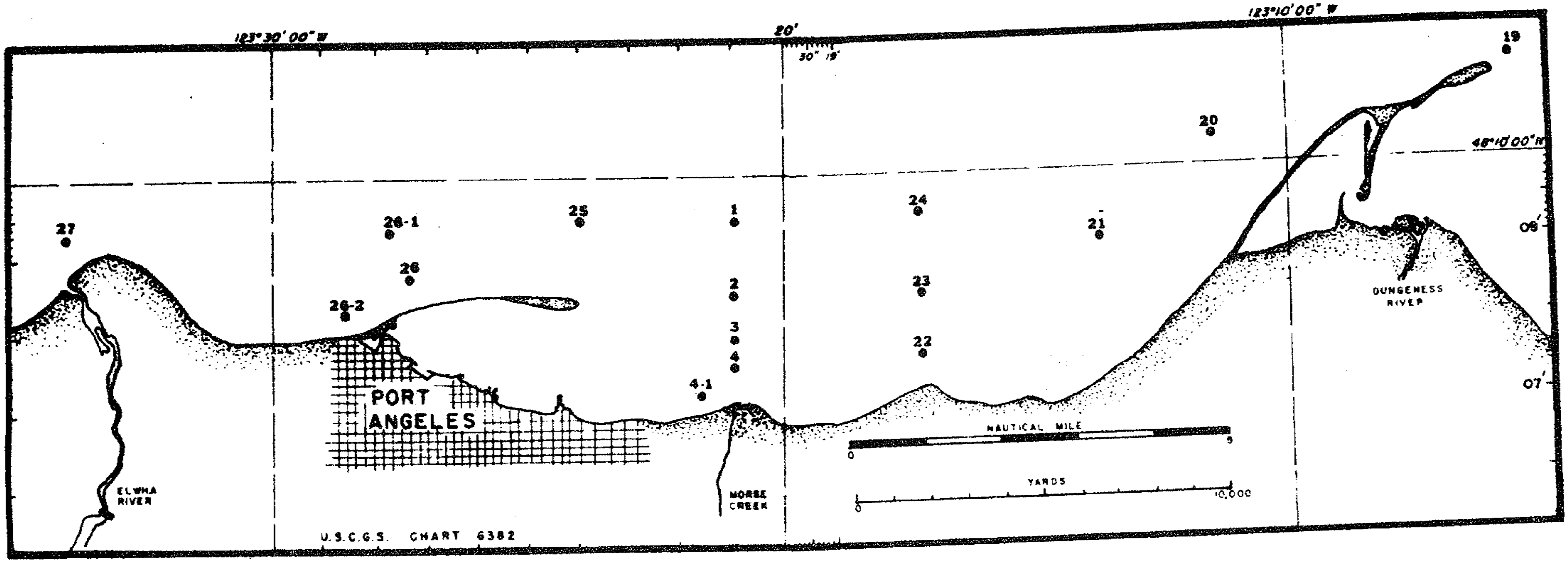

Fig. 3. Sampling stations in general Port Angeles region

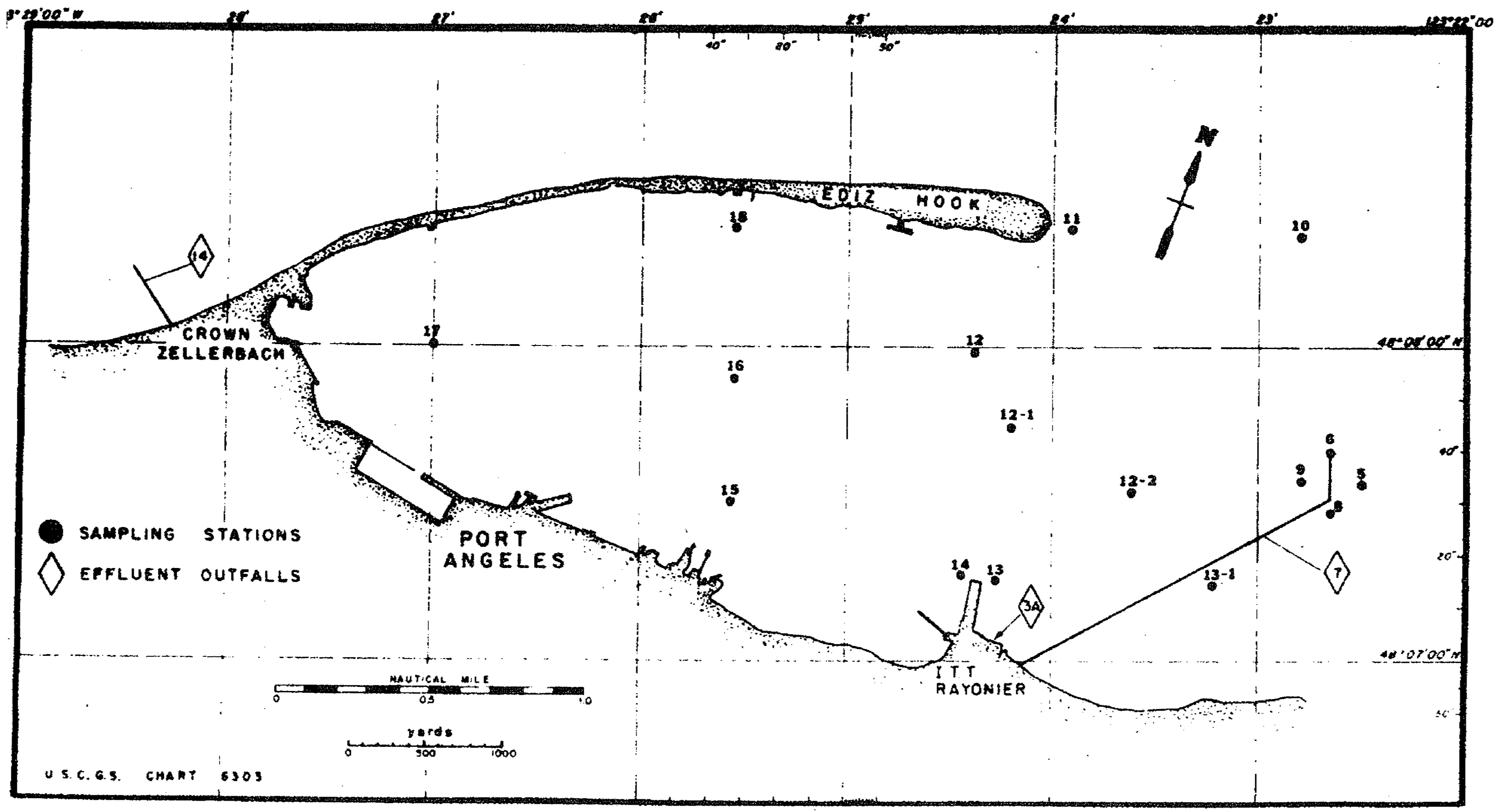

Fig. 4. Sampling stations near Port Angeles harbor

and Douglas fir (*Pseudotsuga menziesii*) are also processed. Weyerhaeuser Company has historically operated a calcium-base, sulfite-process pulp mill at Everett, but as of May 1975 the mill temporarily ceased operation pending conversion to a thermal-mechanical pulping process. Therefore, only effluents from the Scott facility were tested. These included a composite of wastes from the chlorinated washer (outfall 002), main pulp mill sewer (outfall 003), and paper mill (outfall 004); and wastes from the pulp digesters which exit via a deepwater diffuser (outfall 001)(Table 1 and Figs. 1 and 2). Outfall 001 also normally carries all wastewaters from the Weyerhaeuser mill when that facility is operating. According to Scott Paper Co. (Cecil Baldwin, personal communication), mill production was about 70% of capacity at the time of these studies and sulfite liquor from six of the twelve digester units was being incinerated. Since the collection and incineration system removes about 95% of the digester liquor solids (C. Baldwin, personal communication), approximately half the solids were being removed.

There are two pulp mills operating in Port Angeles, Washington (Figs. 3 and 4). Only ITT Rayonier's dissolving pulp, sulfite-process mill was the object of effluent sampling because this mill's effluents have been readily detected in the outer harbor and are believed to be largely responsible for the toxicity of these waters to larval Pacific oysters. Crown

Table 1. Location and character of major waste streams of Scott Paper Co. (Everett) and ITT Rayonier (Port Angeles) pulp mills

Pulp mill	Process stream			
	No.	Location	Approximate depth of discharge[a]	Description
Scott Paper Co., Everett Washington	001	47° 58' 19" N 122° 14' 24" W	101 m or 330 ft	Digester liquor (treated and untreated) from Scott Paper Co. and all wastewaters from Weyerhaeuser pulp mill
	002	47° 59' 01" N 122° 13' 06" W	8.8 m or 29 ft	Wastewaters from the bleaching of pulp
	003	47° 59' 03" N 122° 13' 06" W	7.5 m or 24.5 ft	Main pulp mill sewer, e.g. pulp wash waters, primary treated (clarified) wastes
	004	47° 59' 11" N 122° 13' 07" W	9.1 m or 30 ft	Paper mill wastes
ITT Rayonier, Inc., Port Angeles	003A	48° 07' 04" N 123° 24' 18" W	0 m (on beach)	Sulfite waste liquor from digesters and washings from the blow pits-dissolving pulp sulfite process
	007	48° 07' 33" N 123° 22' 22" W	16.8 m or 55 ft	Overflow from primary treatment (to remove settleable solids) system, woodroom effluent, and bleach plant wastes

[a] Below mean lower low water.

Zellerbach operates a mechanical (groundwood) bleached pulp and paper mill, the wastewaters from which are considered to be less deleterious to *in situ* water quality than the chemical sulfite pulping process. This mill discharges most of its wastewaters at 9.1 m (30 ft) below mean lower low water (MLLW) via a diffuser (outfall 014) into the well-mixed Strait of Juan de Fuca (Fig. 4). Consequently, detection of receiving water toxicity which can be attributed to the Crown Zellerbach facility has been limited historically and effects of these wastewaters are of only limited concern at present.

Two series of tests were conducted using effluents from the ITT Rayonier mill. The first, a preliminary evaluation conducted on 18 August 1975, tested grab samples of treated (after SWL incineration) and untreated wastes from the digester (outfall 003A) and those mixed wastewaters which exit at 12 m from an extended outfall (007) (Fig. 4 and Table 1). On 25 August 1975, 24-hr composites of effluents from outfalls 003A and 007 were obtained from ITT Rayonier biologists. These samples reflected largely the SWL incineration treatment, although during the 24-hr period in which the two samples were collected, the SWL incineration process had been "off-line" for an estimated 10% of the time and at least 75% rather than the normal 85% of the liquor was being burned. Therefore, the toxicity of the latter samples may not have been entirely representative.

Toxicity Testing Procedures

Receiving Waters.--Upon arrival at the laboratory, each receiving water sample was distributed among two 1-liter disposable polyethylene beakers and the remainder analyzed for selected chemical parameters. Samples from stations which have historically possessed low salinities were analyzed upon receipt at the laboratory. Samples less than 20 g/kg were adjusted to this concentration with high-salinity seawater (concentrated by freezing in the preceding 24-hr period) for two reasons: salinities less than approximately 20 g/kg are inimical to the normal development of Pacific oyster larvae obtained from adults acclimatized to high-salinity seawater[1] (Woelke, 1972); in the past, there has been limited use of toxicity data for low salinity receiving waters since elucidation of the relationship between PBI and larval shell development has been the primary relationship of concern. Pending use of more sophisticated statistical techniques to assess the joint effects of PBI, salinity, and other stressers, salinity adjustments were intended to enhance interpretation of results in the present study by eliminating this stress as a variable. In 1975, however, the marine waters near Everett and Port Angeles reflected little freshwater influence at the time of sampling. The only low salinity sample was collected at Everett from the surface

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[1] In this case, adults acclimatized to salinities greater than approximately 25 g/kg. Salinity tolerance of larval oysters varies considerably, depending upon the salinity at which the adults were acclimatized during gametogenesis.

at station 9-3, near the discharge from a 0.6 m (2 ft) diameter pipe at the base of one of the Scott Paper Co. docks (Fig. 2). This outfall, formerly designated as No. 005, presently carries overflow from one of the City of Everett's raw sewage collector lines and small amounts of surface water from within the Scott Paper Company facility (C. Baldwin, personal communication). To determine whether the salinity-adjusted seawater was toxic, larvae were exposed to water which had been adjusted to both 20 and 28 g/kg. No deleterious effects were observed with this manipulation.

The method for testing the toxicity of the receiving water samples to larval Pacific oysters was developed by Woelke (1968, 1972) and is similar with one exception to the methods used in earlier investigations (Woelke et al., 1972; Carr et al., 1974, 1975). It has recently been found that the filtration step recommended by Woelke (1972) to concentrate the larvae from the test container prior to sampling at the end of the test may result in the loss of some larvae through the "Nitex" 37 μ filter, particularly in tests of toxicants which retard growth (Cardwell et al., 1976). Accordingly, filtration was abandoned and the larvae in the test containers subsampled directly with a pipet. To determine whether the filtration step may have biased the results of the previous water quality surveys conducted by Woelke et al. (1972) and by Carr et al. (1974, 1975), and if so, the direction of the effect, water samples from selected stations were subsampled with both techniques. Selected stations comprised waters peripheral to and those directly impacted by pulp mill effluents at both surface and depth.

Differences in larval response (transformed to the $\sqrt{\ }$ arcsin) as a function of subsampling technique were examined with analysis of variance having a factorial design. The results did not unequivocally indicate significant differences between subsampling techniques (Appendix Table 3), but whether such a conclusion is valid is complicated by the absence of appreciable toxicity in many of the samples. In general, differences between subsampling techniques followed patterns observed by Cardwell et al. (1976) in that filtration had no effect on the percentages of abnormally developed larvae and increased the mortality percentages.

Several methods were used to define the quality of the oyster larvae used in all receiving water and effluent evaluations. At Everett, one station (No. 4) was sampled at three depths on both days, and the water samples tested for toxicity and chemically analyzed. On the day of any given test, larvae were also exposed to an anionic surfactant, dodecyl sodium sulfate (Aldrich Chemical Company, Lot. No. 111447), which has been recommended as a standard for appraising test specimen quality (LaRoche et al., 1970). Finally, larval shell development and survival of controls were also determined. Control survival was calculated by dividing observed survival by expected survival. The difference from unity, i.e. 100%, was considered natural mortality.

Effluents.--All pulp mill effluents were treated according to the following procedure. Prior to testing, each effluent was aerated for approximately 16-20 hr at (two) 2 C with oil-free compressed air from an aquarium diaphram pump, and the effluents neutralized to a pH of 7.6 to 7.8 with 1.0 N reagent sodium hydroxide. After aeration, but before neutralization, a composite of effluents 002 (36.96%), 003 (55.56%), and 004 (7.48%) was prepared on the basis of each effluent's respective volumetric contribution to the total surface Scott Paper Co. discharge at the time of sampling. In a preliminary toxicity test, residual chlorine in effluents 002 and 004 was removed with reagent sodium thiosulfate prior to compositing because 1 and 39 mg/l of residual chlorine were measured, respectively. None of the effluents used in the definitive tests possessed detectable quantities of residual chlorine. The rationale for these manipulations was to remove those variables and sources of error which could only further obscure the relationship between PBI and larval response. Removal of the volatile and readily oxidizable components was believed necessary for the following reasons: the toxicities of some were known, although interactions had not been defined; means were unavailable for their measurement (even if all variables were known); their concentrations would be unstable during the course of toxicant solution preparation and testing; and they probably did not contribute to the toxicity observed *in situ*. Thus, attempts were made to drive off volatile constituents (e.g. sulfur dioxide, chlorine), preclude low pH as a variable since we already know that larvae incur impaired development and diminished survival at levels less than approximately 7.0; and to remove residual chlorine as a factor in toxicity since it is known to be highly toxic at low concentrations (i.e. less than 100 μg/l; Brungs, 1973; Becker and Thatcher, 1973) to many aquatic organisms.

Following manipulation of the effluents, various concentrations were prepared in duplicate by diluting with Pt. Whitney Laboratory seawater and tested at approximately 20 C in 1-liter polyethylene beakers. Subsequent conduct of the tests followed that described for the samples collected *in situ*.

Statistical Analysis

Responses of the larval oysters to receiving waters containing known concentrations of PBI-sensitive substances were analyzed with a modified version of logarithmic-probability analysis on a programmable calculator. Since the program did not include the iterative subroutine, the results were approximate rather than maximum likelihood estimates and identical to weighted linear regression. However, comparison of the program with that of Litchfield and Wilcoxon (1949) showed good agreement.

The results of the effluent tests were analyzed with the graphical method of Litchfield and Wilcoxon (1949) or the computer program or both. Insufficient intermediate percentage responses for the abnormal shell development data precluded valid estimates of the effluent EC50's using the computer program and even hampered use of the graphical method.

Chemical Analysis

Receiving water temperatures were recorded at the time of sample collection. Upon arrival at the laboratory, selected samples were analyzed for pH, dissolved oxygen (D.O.), ammonia, and total sulfides to determine whether these variables were toxicologically important. Dissolved oxygen and pH were also determined at the end of the test, but ammonia and total sulfides were not because they were found to have occurred at low concentrations initially, and it was expected that they would have largely volatilized or oxidized during the course of the test. The salinities and concentrations of PBI-sensitive substances in all samples were meausured at the end of the test. Electrometric methods of analysis were used for D.O., pH and salinity, while wet chemical methods were used to determine ammonia (by the phenate method, Strickland and Parsons, 1968), total sulfides (American Public Health Association, 1971), and PBI-sensitive substances (Barnes et al., 1963).

Effluent samples were analyzed upon receipt at the laboratory for ammonia, residual chlorine (selected effluents), PBI substances, D.O., and pH, whereas PBI was redetermined after the manipulation and at the end of the toxicity tests on all toxicant concentrations used. Residual chlorine was measured with an iodometric method (APHA, 1971).

RESULTS

Everett Studies

Test Specimen Quality.--Although oyster larvae used for the Everett studies were from the same lot--but from different male-female spawnings--those used for the 18 August tests were believed to be of slightly poorer quality than the 19 August lot because greater proportions were abnormally developed, fewer survived, and they were more sensitive to the standard stressing agent, dodecyl sodium sulfate (Appendix Table 4). Furthermore, larvae incubated in water taken at different depths from station No. 4 on 18 August were somewhat more sensitive than those incubated in similar samples collected on 19 August (Appendix Table 5). Assuming little variation in water quality characteristics between days at this station, it appears that the several laboratory methods of assessing stock quality were verified in the field trials.

Receiving Water Toxicity and Chemical Composition.--In August 1975 waters from the East Waterway of Everett Harbor, portions of Port Gardner, the inshore waters of Everett to Mukilteo, and upper Possession Sound were inimical in varying degrees to the early development of Pacific oysters. On the other hand, there was little toxicity associated with waters collected from 0 to 73 m (240 ft) in Saratoga Passage and Port Susan (Appendix

Table 5). Waters causing increased mortality at one or more depths extended from the East Waterway-Port Gardner region north to Gedney Island and approximately southwest into Possession Sound (Appendix Table 5).

Receiving water toxicity was greatest in the regions where pulp mill wastewaters were being discharged. The high toxicity noted in surface waters of the East Waterway was probably caused by Scott effluents 002, 003, and 004. Although these fresh-water effluents are discharged at least 7 m below MLLW, they evidently are carried to the surface as a result of their lower specific gravities. Subsequent dispersal of these wastes appeared to be largely inshore and southwestward toward Mukilteo and Possession Sound.

Treated and untreated spent sulfite liquor from the Scott facility is discharged via a diffuser at a depth of 101 m (330 ft) near station 6. This waste was apparently detected at stations 6 and 16 at depths of 55 m (180 ft) and 73 m (240 ft) since elevated PBI levels and increased abnormal shell development and mortality percentages were encountered. At both stations, however, considerable dispersion of the effluent must have occurred, for increased abnormality and mortality were noted throughout the deeper water column. Subsequent dilution of this effluent was substantial since increased larval responses to the deeper waters were only noted in upper Possession Sound

(Station 1) and between Gedney Island and Possession Sound (station 2-1).

In an effort to provide a general characterization of the toxicity of the marine waters near Everett, those from 0 to 18 m (60 ft) in depth and those from 37 (120 ft) to 73 m (240 ft) were separately analyzed by log-probit analysis to determine the _in situ_ PBI concentrations causing 50% abnormal shell development (median effective concentration or EC50) and 50% mortality (median lethal concentration or LC50) in Pacific oyster larvae within 48 hr. The rationale for this segregation by depth was based on the finding of the Washington State Enforcement Project (1967) that wastewaters discharged at 101 m (330 ft) depth by outfall 001 usually do not rise above 46 m (150 ft) during the summer.[2] The EC50 and LC50 estimates for the surface (0 to 18 m) waters were 44 and 3,690 mg/l, respectively. The relationship between PBI and mortality was very poor; only 9% of the variation in mortality about the regression line could be assigned to PBI and the correlation coefficient of 0.27 was not statistically significant ($p > 0.05$) (Appendix Table 6). With respect to the deeper waters (37 to 73 m), the correlation between PBI and mortality was significant

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[2] From monitoring studies conducted in previous years by the Department of Fisheries, the data suggest that toxicity associated with the deeper waters (> 37 m) may sometimes be detected at the 37 m level. Hence, the scheme of depth segregation may not be entirely valid for all locations.

and the LC50 was lower (795 mg/l PBI), but the regression line between the two parameters still accounted for only 38% of the variation in mortality. As observed for the surface waters, the EC50 was substantially lower (69 mg/l PBI) than the LC50, but the regression equation still explained only 43% of the variation in abnormality (Appendix Table 6).

The slopes of the concentration-response curves also suggested that the factors influencing abnormal shell development and mortality differed between the upper (0-18 m) and lower water column (Fig. 5). This was also indicated by the R^2 values (Appendix Table 6).

Measurements of dissolved oxygen, ammonia, total sulfides, and pH in selected receiving water samples indicated that most of the concentrations fell within ranges considered suitable for the early embryonic development of Pacific oysters and within the ranges normally encountered in our laboratory seawater supply. Exceptions were station 9-1 (0 m) and station 4 (37 m), which possessed total sulfide concentrations of 0.18 mg S^{-2}/l (Appendix Table 7).

Scott Paper Company Effluent Toxicity.--Acute toxicity tests of effluent 001 and of a composite of effluents 002, 003, and 004 indicated that abnormality was affected at far lower concentrations than mortality, the relationship between PBI and abnormality was different from that between PBI and mortality, and the correlation between PBI and percent larval response was stronger than that observed *in situ*. As shown below, the EC50 and LC50 estimates for effluent 001, based on PBI, were only 16 and 46% of those found for the composite of effluents 002, 003, and 004. Effluent 001 was also much more toxic on a unit volume basis than the composite.

Response criterion	Toxicity estimate	
	PBI, mg/l	% effluent
Effluent 001		
Abnormality, EC50	25[a] (9 - 67)	0.029 (0.009 - 0.095)
Mortality, LC50	355 - 2360[b]	0.96 - 2.4[b]
Effluents 002, 003 & 004		
Abnormality, EC50	150 -[c]	1.58 (0.28 - 8.79)
Mortality, LC50	1480 (834 - 2625)	12.1 (6.2 - 23.8)

[a] EC50 with 95% confidence limits.

[b] Approximate range between which LC50 falls.

[c] Could not be estimated because of insufficient number of intermediate percentage responses.

Comparison of the shapes and positions of the concentration-percent response curves for the effluents with those generated from the *in situ* data shows that the effluents affected abnormality over a much more limited range of PBI levels than did the receiving waters (Fig. 5). The EC50 for effluent 001 was also 63% lower than that for the deeper receiving waters. On the other hand, abnormal shell development occurred in surface receiving waters at PBI concentrations which would not have been predicted to be toxicologically effective on the basis of the PBI-abnormality curve for the composited effluent. Relative to the PBI-larval response curves for the receiving waters, both effluents caused mortality, not only over a more limited range of PBI concentrations, but also at higher concentrations. In other words, acute lethal thresholds for the effluents were higher than would have been predicted on the basis of the receiving water results.

Upon receipt at the laboratory, the Scott Paper Company effluents ranged in pH from 2.50 (effluent 001) to 4.70 (effluent 004), in D.O. concentrations from 2.0 mg/l (effluent 004) to 7.75 mg/l (effluent 002), and in specific conductance from 570 umhos/cm (effluent 004) to 4420 umhos/cm (effluent 001). Just prior to testing, effluent 001 contained 217 mg/l total ammonia (both ionized and unionized) and the composite of effluents 002, 003, and 004, 4.3 mg/l. Residual chlorine was

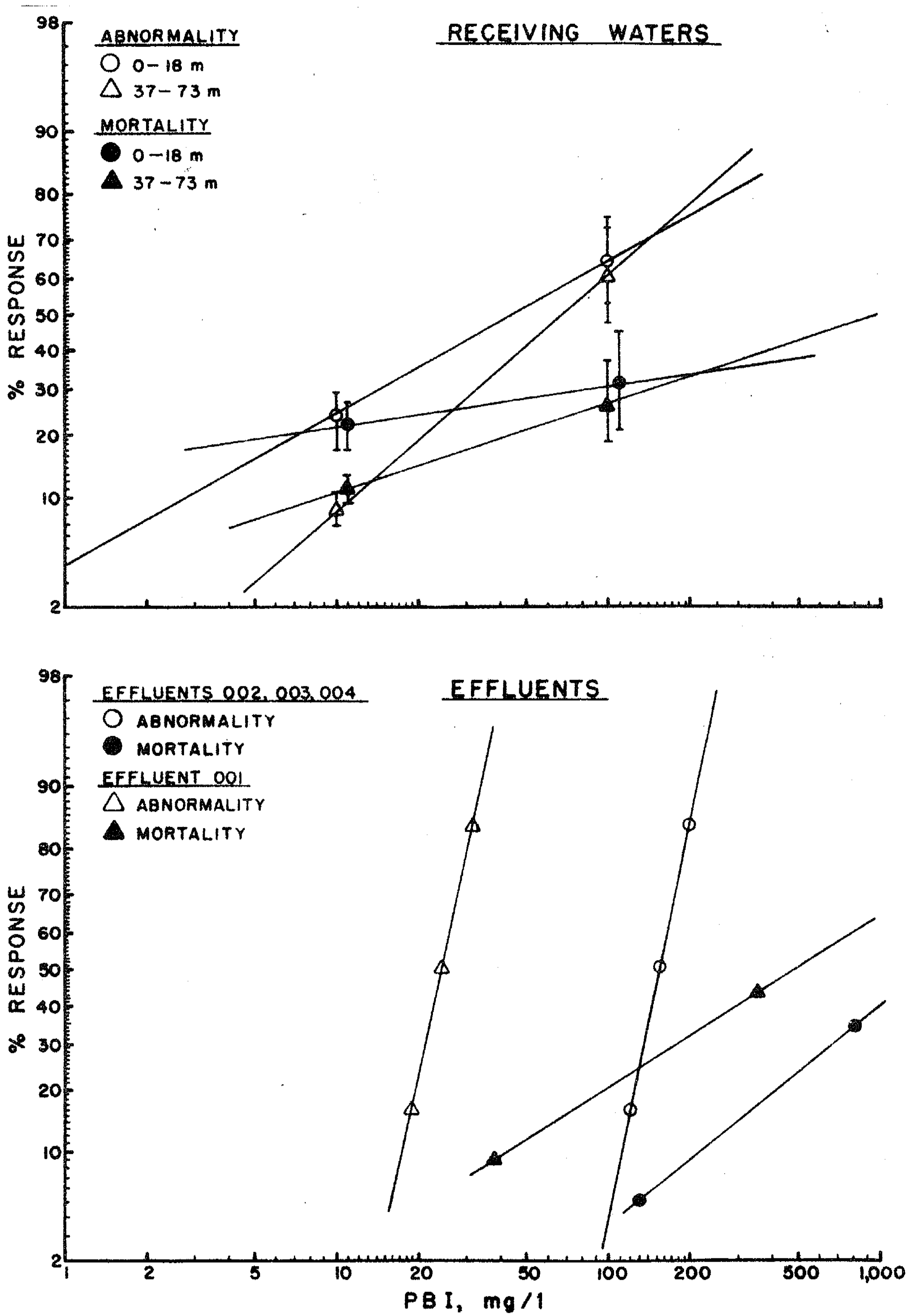

Fig. 5. Relationship between the PBI concentrations of Everett receiving waters and Scott Paper Co. effluents and the responses of larval Pacific oysters

not detected, but in an earlier preliminary test it had been found in effluent 002 at a concentration less than 1 mg/l and in effluent 004 at a concentration of 39 mg/l. At the end of the tests, D.O. and pH were recorded from every treatment and found to be above 2.5 mg/l and 7.0, respectively, in all treatments used for calculation of EC50-LC50 estimates. However, D.O. levels even hypoxic to oyster larvae did exist in the highest effluent concentrations tested. For example, concentrations of effluent 001 greater than 10,000 mg/l PBI possessed D.O. levels as low as 0.2 mg/l.

Port Angeles Studies

Test Specimen Quality.--Oyster larvae used for evaluating receiving water qualityin the Port Angeles region and for testing effluents from the ITT Rayonier pulp mill were similar in quality to those used on 19 August 1975 in the Everett studies. Larvae used on 25 and 26 August 1975 differed somewhat in terms of the proportions which developed abnormally, but were very similar with respect to survival and sensitivity to the standard toxicant (Appendix Table 4).

Receiving Water.--With only a few exceptions, marine waters from the Elwha River east to Dungeness Spit had only slight toxicity to oyster larvae and possessed either low or undetectable concentrations of PBI (Appendix Table 8). Elevated concentrations of PBI and high percentages of abnormally developed larvae were only encountered at three locations: a short distance east of the ITT Rayonier pulp mill (station 13); at the ITT Rayonier's extended outfall (station 9); and at the most inshore station adjacent to Morse Creek (station 4). Significant increases in both abnormality and mortality occurred at a depth of 60 ft (18 m) in the inner harbor (station 17), but were not associated with high PBI. Mortality also occurred in other areas, mainly at the surface and 20 ft (6 m) depths, but the cause was probably not due to pulp mill effluents since PBI was not detected and the more PBI-sensitive abnormality criterion was unaffected.

For the marine waters of the Port Angeles region, there was no statistical relationship between PBI and percent mortality and only a limited relationship between PBI and percent abnormality (Appendix Table 9). The linear relationship between abnormality and PBI was significant (i.e. $r > 0$ at $p = 0.05$), but the R^2 value of 17% indicated that little of the variation in toxicity could be ascribed solely to PBI.

Marine waters of the Port Angeles region were uniform in quality with respect to D.O., pH, total ammonia, and total sulfides, and there was no evidence of significant effluent effect on these parameters *in situ*. Dissolved oxygen ranged from 6.2 to 7.5 mg/l and averaged 6.8 ± 0.4 mg/l, while pH ranged from 7.81 to 7.94 and averaged 7.86 ± 0.04. Apparently none of the samples possessed appreciable biochemical oxygen demands since D.O. concentrations of 6.2 ± 0.5 mg/l and pH values of 7.98 ± 0.02, measured at the end of the toxicity tests, were homogeneous and apparently in air equilibreum. Appendix Table 10 summarizes the water quality data with respect to those samples where ammonia or sulfides or both were measured.

ITT Rayonier Effluents.--The toxicity of effluents from the ITT Rayonier pulp mill varied according to whether the wastewaters were being treated, the time and duration of sample collection, and the biological response criterion used to measure effect. In the preliminary tests, untreated wastes were usually more toxic than treated wastes and wastes from outfall 003A were considerably more toxic than those from outfall 007. Treatment of 003A wastes resulted in a 300% decrease in effects on abnormal shell development and an 81% decrease in effects on mortality. Treated effluent from outfall 007 actually was slightly more (20%) toxic in terms of abnormality, but 88% less toxic in terms of the LC50. Even with incineration of at least 85% of the solids from the digester liquor, wastes from 003A were 3- to 5-times more toxic than those from outfall 007. Although greater concentrations of treated wastes were required to adversely affect oyster larvae, waste toxicity calculated as a function of PBI was essentially equivalent to that of untreated wastes. The preliminary tests also demonstrated the great differential effects of these effluents on shell development and mortality. The amount of effluent required to kill larvae was from 17- to more than 200-times greater than that causing abnormal development.

	Pacific oyster larvae[a]				Fingerling rainbow trout[a,b]
	EC50		LC50		LC50,
Effluent	as PBI, mg/l	as % effluent	as PBI, mg/l	as % effluent	% effluent
19 August 1975					
003A untreated	31	0.015	7,500	3.5	7
003A treated	28	0.062	2,300	5.5	>9
007 untreated	92	0.38	3,850	10.0	25
007 treated	75	0.31	4,250	17.5	<18
25 August 1975					
003A treated	23	<0.0222	1,430	1.25	9
007 treated	50	0.31	1,130	5.25	36

a 95% confidence limits have not been calculated since median response estimates are considered only approximations.

b Static tests in soft freshwater conducted by Folsom and Denison (1976).

The definitive tests of 25 August essentially confirmed the results of the preliminary tests, except that the 24-hr composites of both wastes were considerably more toxic to oyster larvae than those collected by grab 1 week earlier. The EC50 for effluent 003A was at least 14-times lower than that for effluent 007, while the LC50 was 4-times lower. Although LC50 values based on PBI were comparable between wastes, the EC50 for 003A was less than half (< 23 mg/l PBI) that for 007 (50 mg/l PBI).

Static toxicity tests of subsamples of the same effluents were also conducted by Folsom and Denison (1976) using a soft freshwater and fingerling (< 50 mm total length) rainbow trout. Relative to the abnormality criterion for larval oysters, the juvenile trout were considerably more tolerant (58- to 467-times) of the effluents; but with respect to the mortality criterion, trout were only slightly more tolerant (0- to 7-times). Patterns of effluent toxicity to trout were comparable to those observed with oysters in that effluent 003A was more toxic than 007 and treated effluent was usually less toxic than untreated.

The preliminary evaluation of 18 August 1975 using effluents from ITT Rayonier's pulp mill indicated considerable variation in chemical content between treated and untreated wastes (Appendix Table 11). Untreated effluent 003A possessed greater organic content than untreated wastes from effluent 007. Treatment of 003A resulted in an approximate 79% reduction in total solids and PBI, an 81% reduction in furfural content, and 86-88% reductions in total ammonia and biochemical (B.O.D.) and chemical (C.O.D.) oxygen demands. However, there was no appreciable change in the highly acid character of this waste stream. Sulfite waste liquor incineration had relatively little effect on the composition of outfall 007, basically because some liquor was being discharged in this effluent at the time of sampling. Both wastes possessed essentially the same total solids, D.O., pH, ammonia, and furfural contents, although treated wastes had somewhat higher concentrations of B.O.D. and C.O.D. and of formic and acetic acids.

The 24-hr composites of treated wastes obtained on 25 August were considerably different from the treated wastes obtained earlier. This was particularly evident for effluent 003A, which possessed over 3-times as much total solids, 4-times higher concentrations of ammonia, and over 2-times more B.O.D. than its treated equivalent sampled 1 week earlier. In contrast, treated waste from effluent 007 was remarkably similar to treated effluent collected the week before (Appendix Table 11).

DISCUSSION

Everett

The 1972-1975 evaluations of the quality of the receiving waters near Everett have shown a dramatic overall decline in the extent and scope of toxicity to larval Pacific oysters. Statistical analysis of these data has also revealed that PBI accounts for only a portion of pulp mill wastewater toxicity, and that the relationship between PBI and the responses of larval oysters has changed each year since the inception of these studies. There appear to be discrete differences in receiving water toxicity as a function of depth in that deeper waters (36-73 m) were considerably more toxic than surface (0-18 m) waters from 1972 to 1974, but not in 1975.

Changes in receiving water toxicity in the Everett region from 1972 to 1975 are presented in Figs. 6-9 for the upper water column ($\leq$ 37 m or 120 ft) and in Figs. 10-13 for the deeper water column (> 37 m). When the region was first studied extensively in June 1972, a sizable area encompassing Port Gardner, Port Susan and waters between upper Possession Sound and Saratoga Passage was highly toxic throughout the water column (Figs. 6 and 10). In July 1973 there was a slight diminution in the degree--but not extent--of upper water column toxicity (Fig. 7). Surveys conducted in August of 1974 and 1975 revealed progressive, dramatic diminutions in both the degree

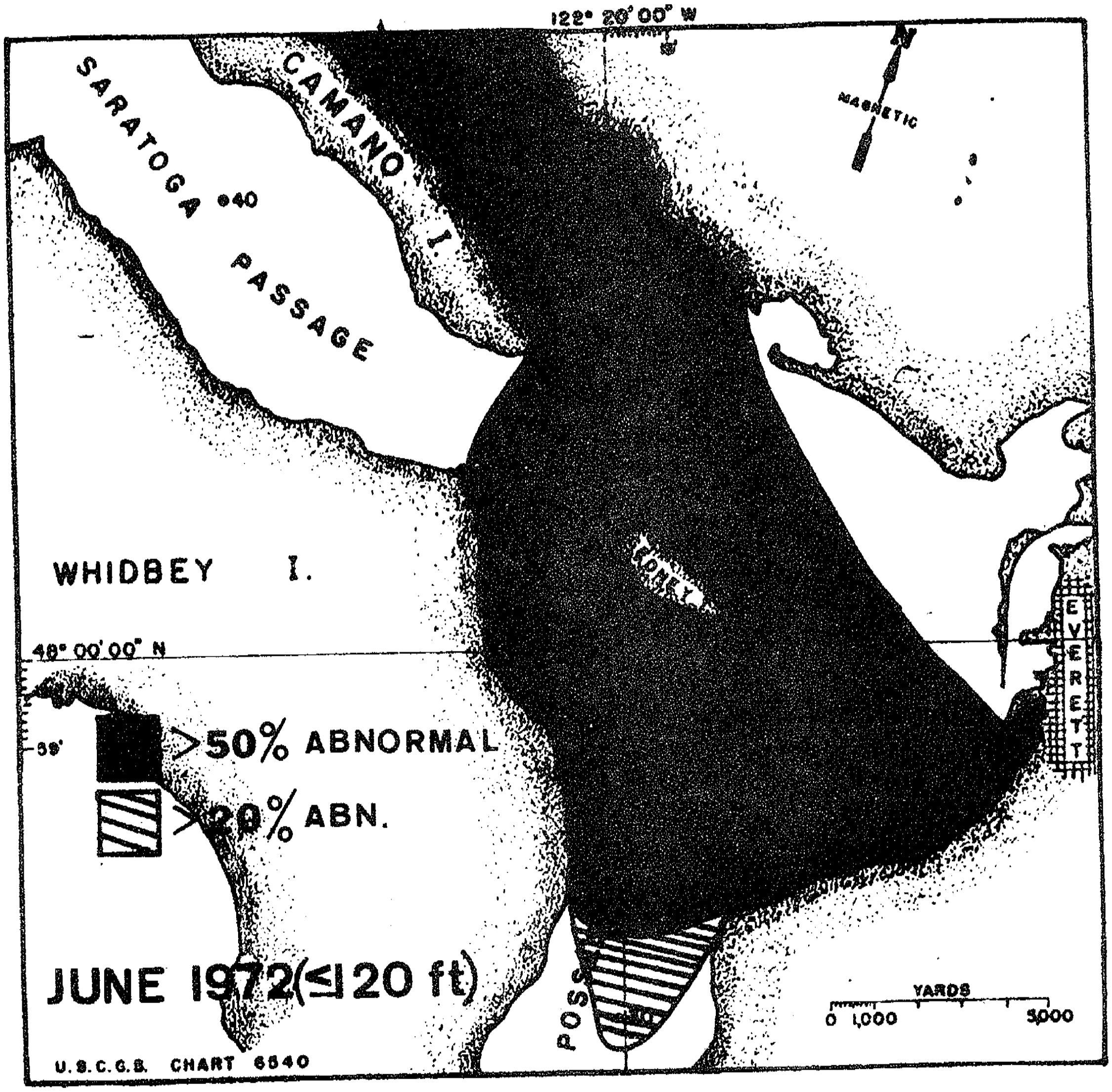

Fig. 6. Areas causing appreciable toxicity to larval Pacific oysters in the upper water column on 13-14 June 1972 in the Everett region

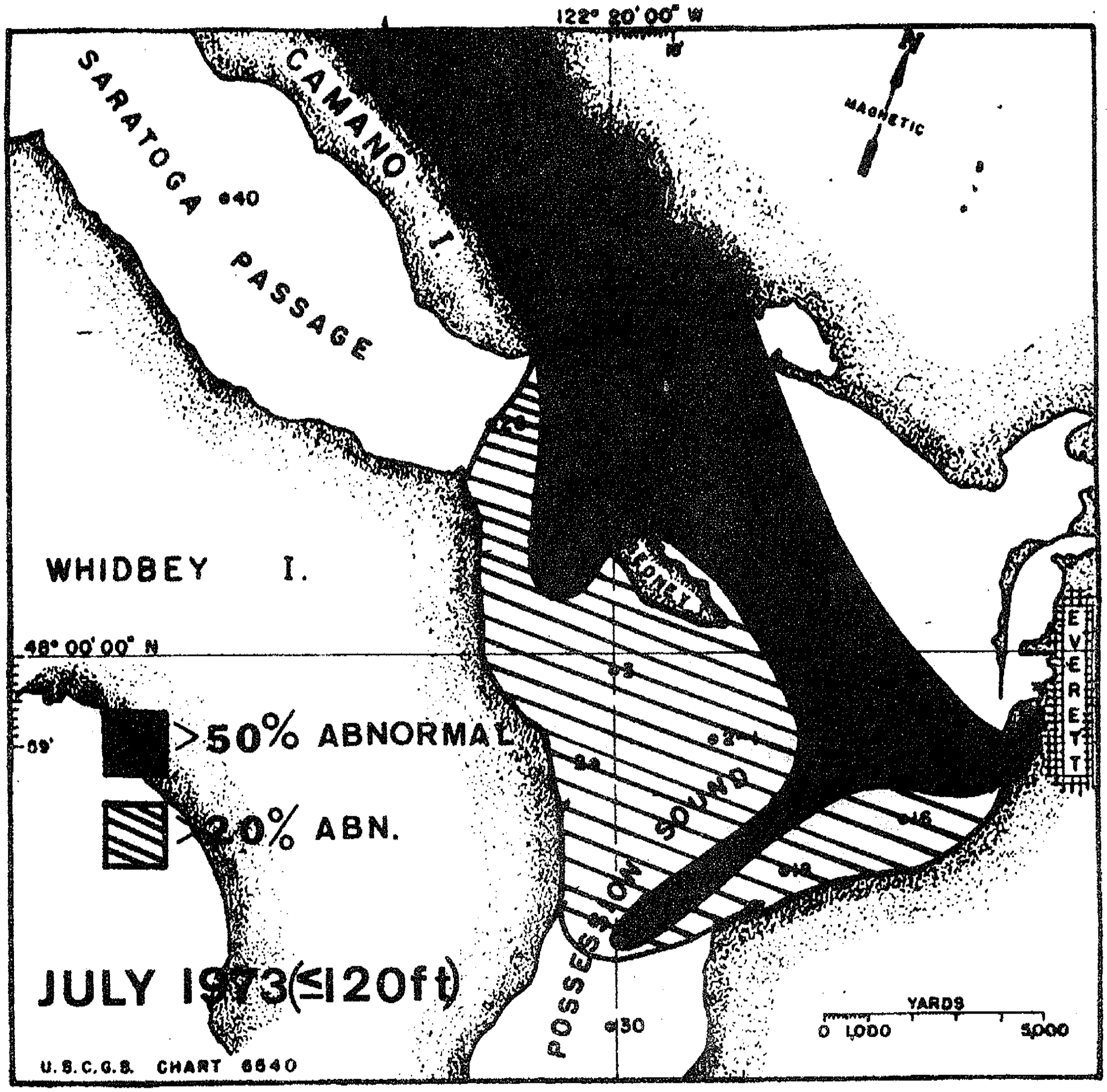

Fig. 7. Areas causing appreciable toxicity to larval Pacific oysters in the upper water column on 17-18 July 1973 in the Everett region

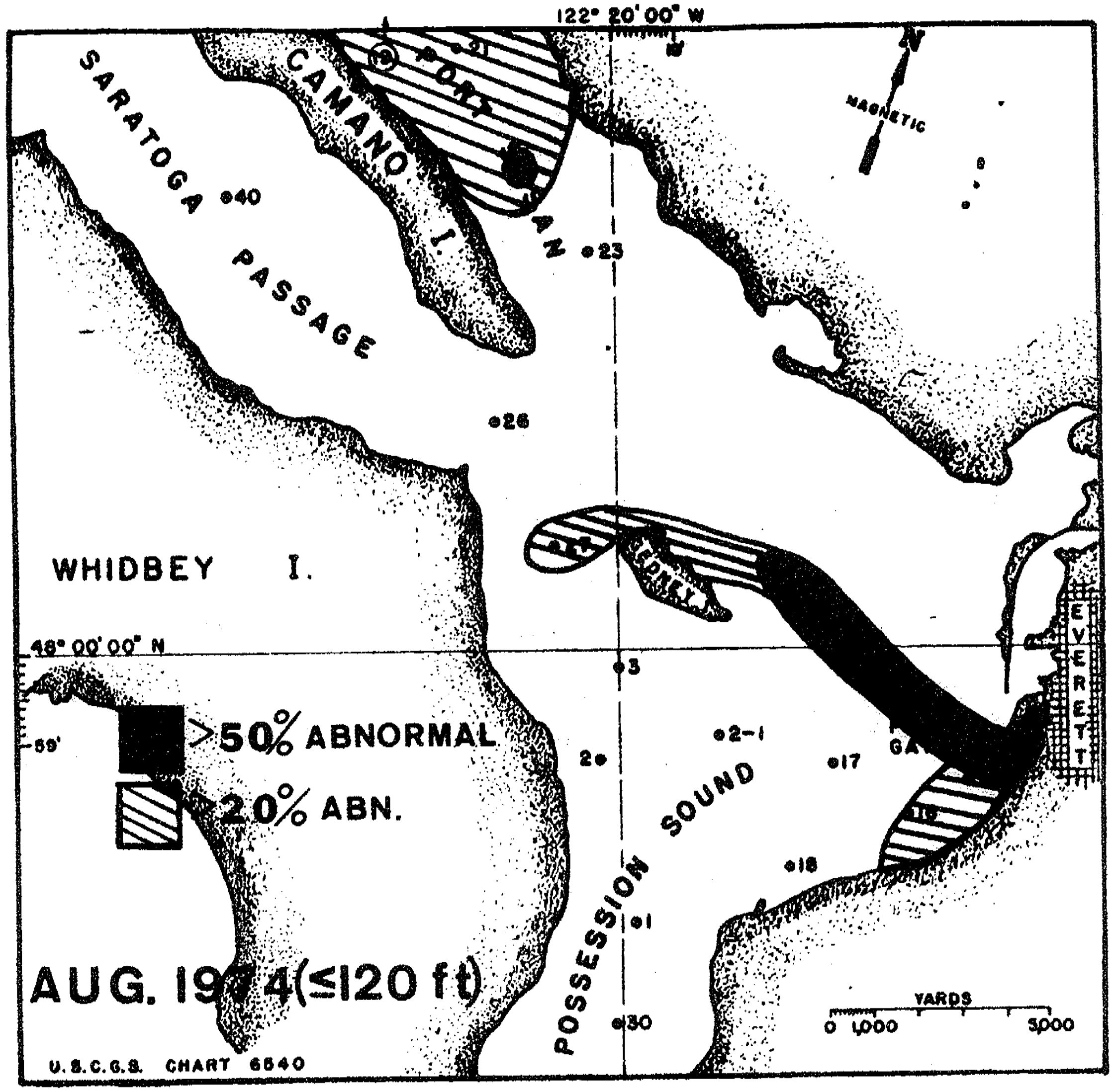

Fig. 8. Areas causing appreciable toxicity to larval Pacific oysters in the upper water column on 20-21 August 1974 in the Everett region

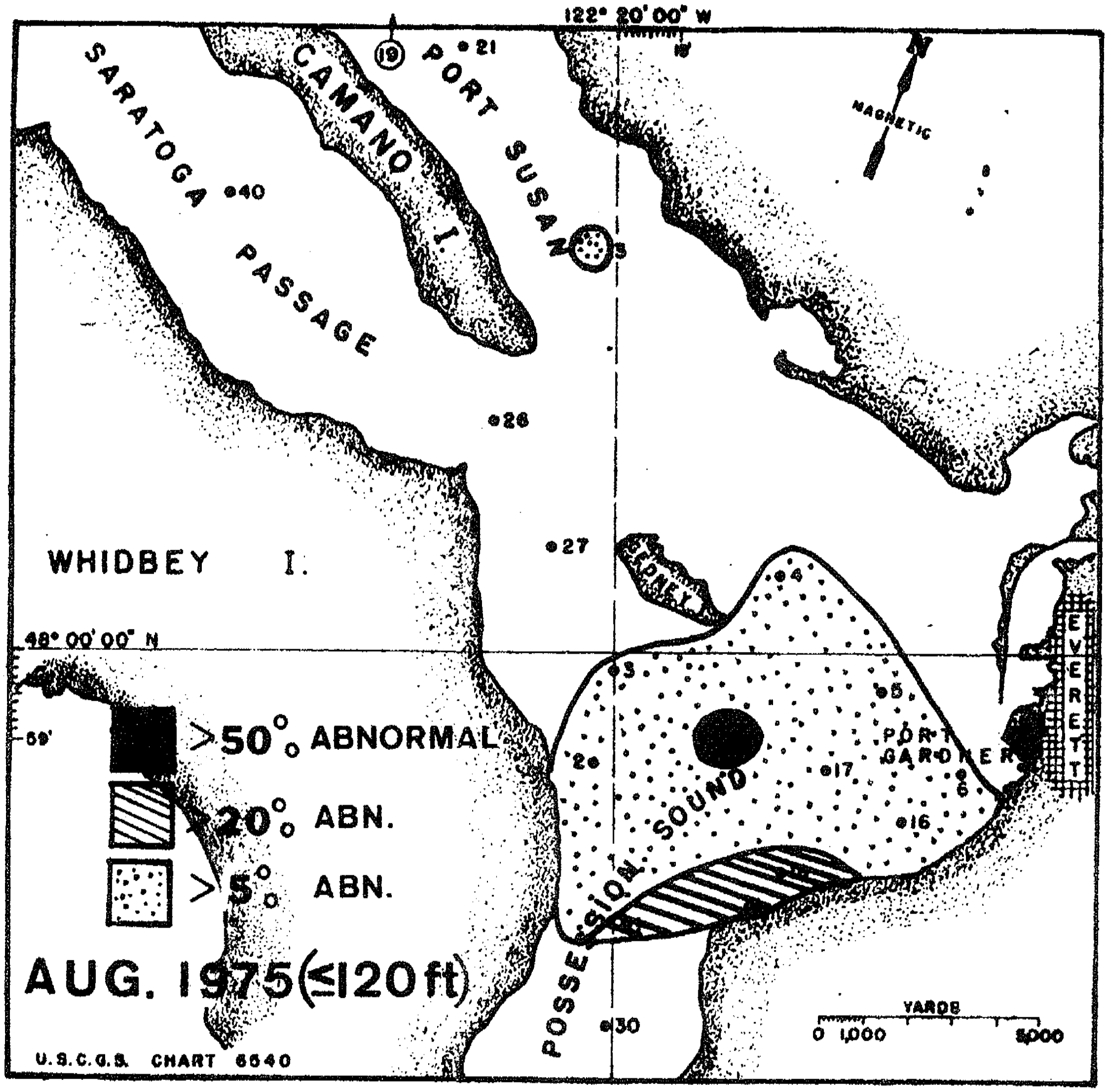

Fig. 9. Areas causing appreciable toxicity to larval Pacific oysters in the upper water column on 18-19 August 1975 in the Everett region

and extent of toxicity (Figs. 8 and 9). With respect to the deeper water column there was no difference in toxicity between the summer of 1972 and 1973 (Figs. 10 and 11). Slight mitigation in toxicity was observed in 1974 (Fig. 12), but it was not until 1975 that major reductions in deeper water column toxicity occurred (Fig. 13).

The progressive diminution in upper water column toxicity from 1972 to 1975 cannot be assigned entirely to reductions in waste loading or to improvements in effluent quality. Waste loading (and pulp production) by the two mills via their inshore outfalls actually increased from 1972 to 1974 (Fig. 14), and there were no major improvements in effluent treatment prior to 1974. However, several prominent changes did occur in 1974: Scott Paper Co. instituted incineration--intermittent at first--of sulfite waste liquor from half of its twelve digester units in the spring of 1974 and improved primary treatment of its shallow water discharges through better handling of sludges; also, Weyerhaeuser Co. shifted to production of paper-grade rather than dissolving-grade pulp. These changes evidently reduced waste loading to the deeper waters and appeared to have little effect on loading via the inshore outfalls. Changes which could have affected our 1975 results include the temporary closure in May 1975 of the Weyerhaeuser mill as it converted to a thermomechanical form of pulping and better

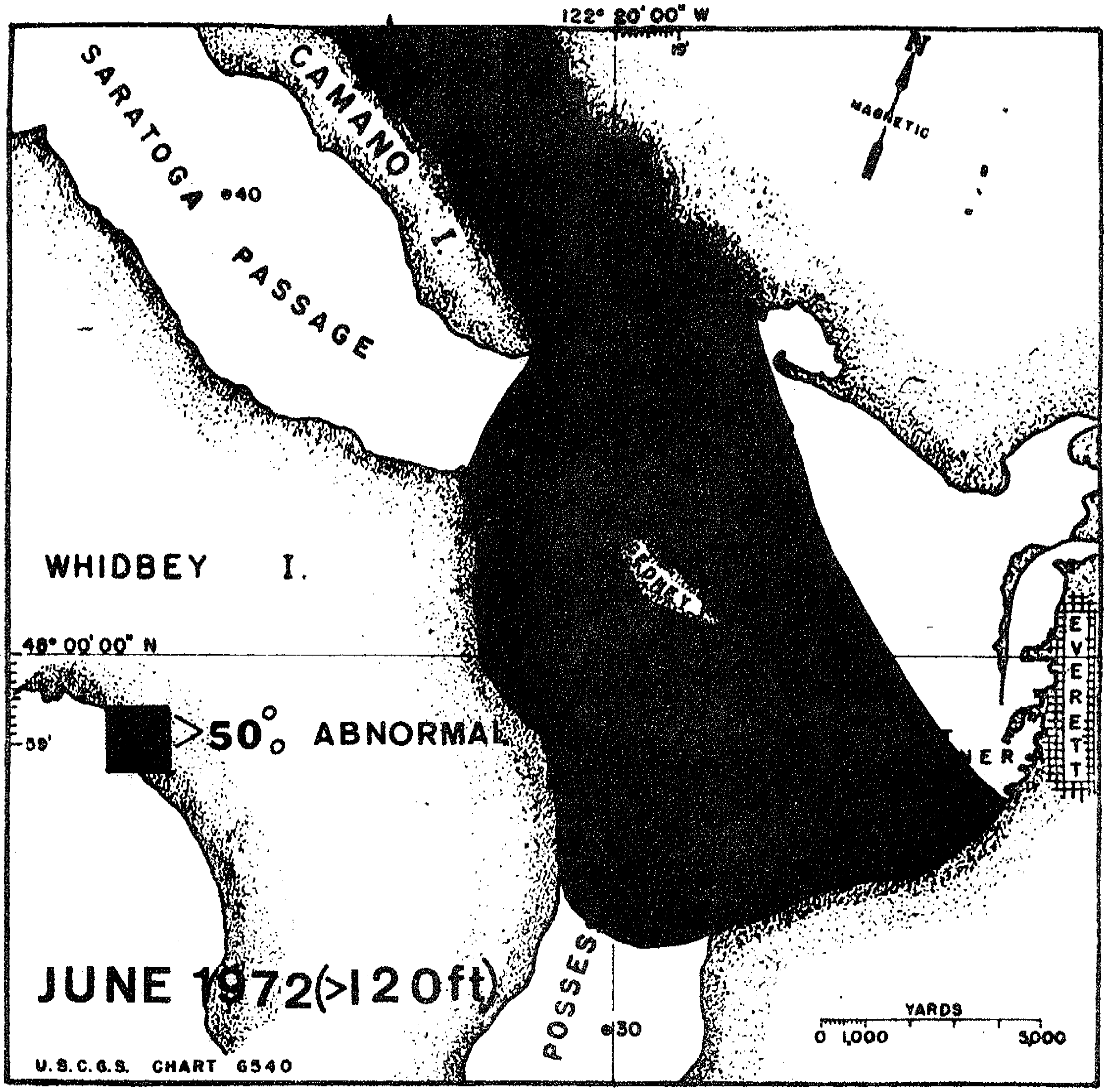

Fig. 10. Area causing appreciable toxicity to larval Pacific oysters in the deeper water column on 13-14 June 1972

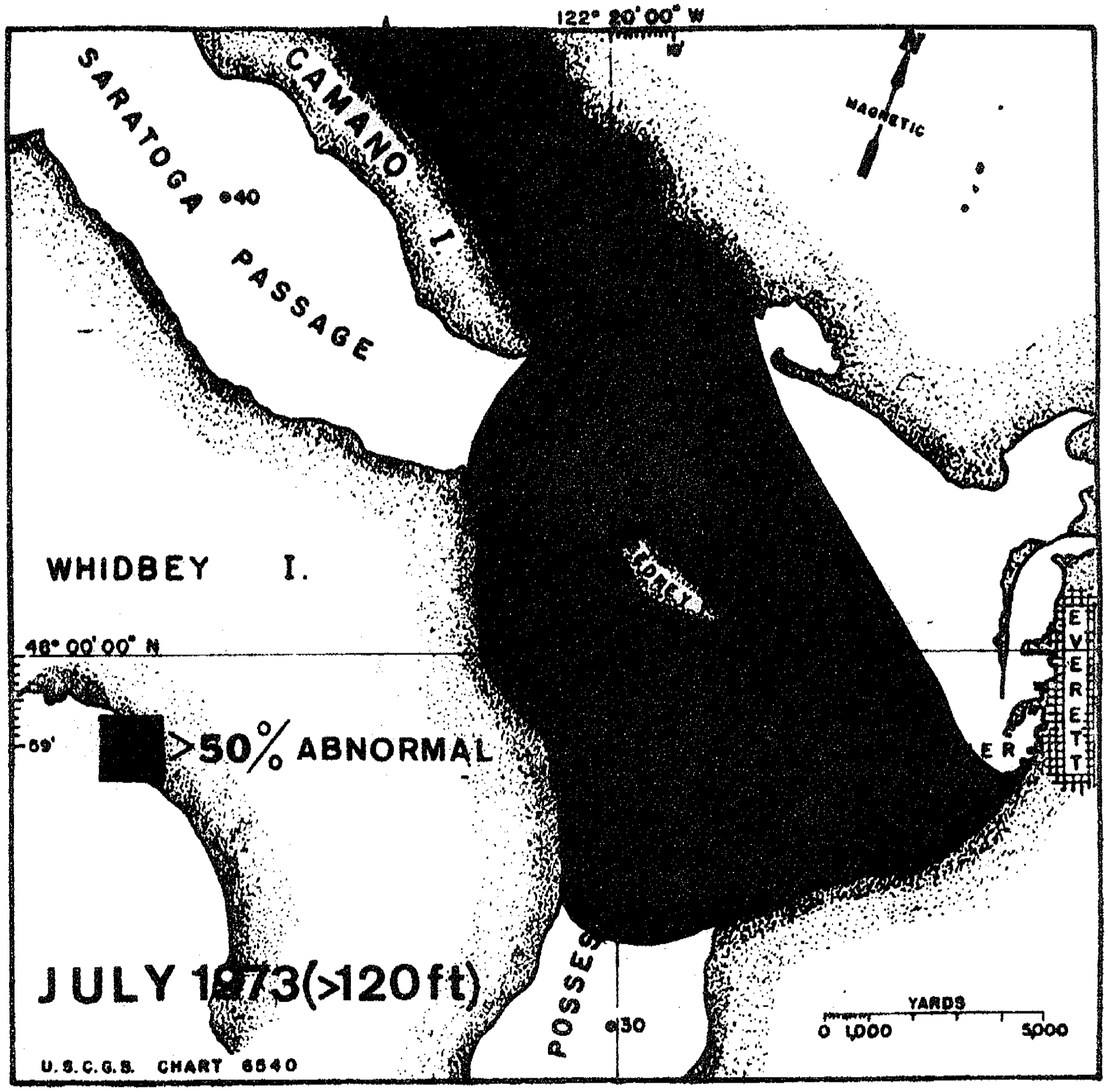

Fig. 11. Area causing appreciable toxicity to larval Pacific oysters in the deeper water column on 17-18 July 1973

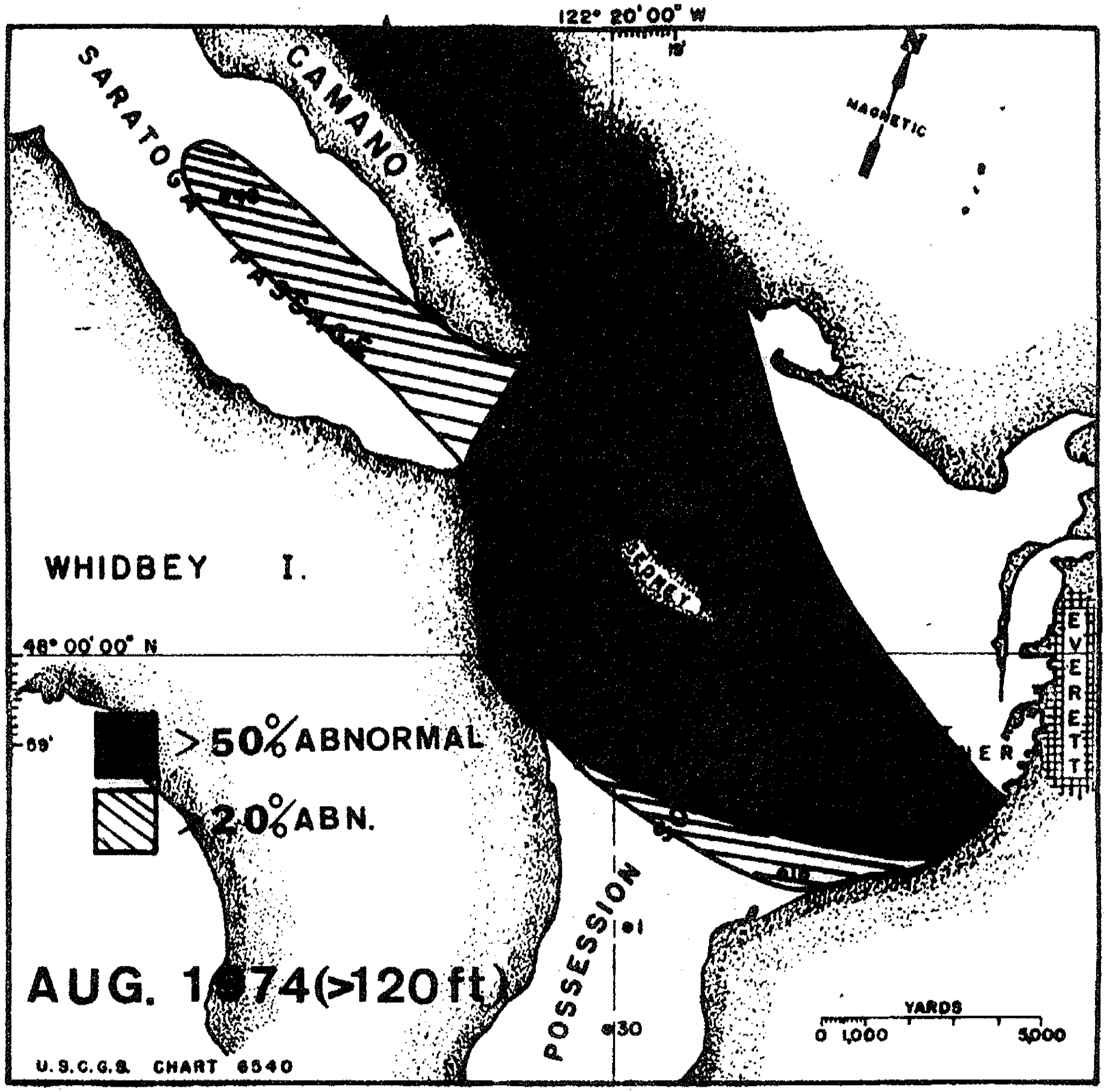

Fig. 12. Areas causing appreciable toxicity to larval Pacific oysters in the deeper water column on 20-21 August 1974

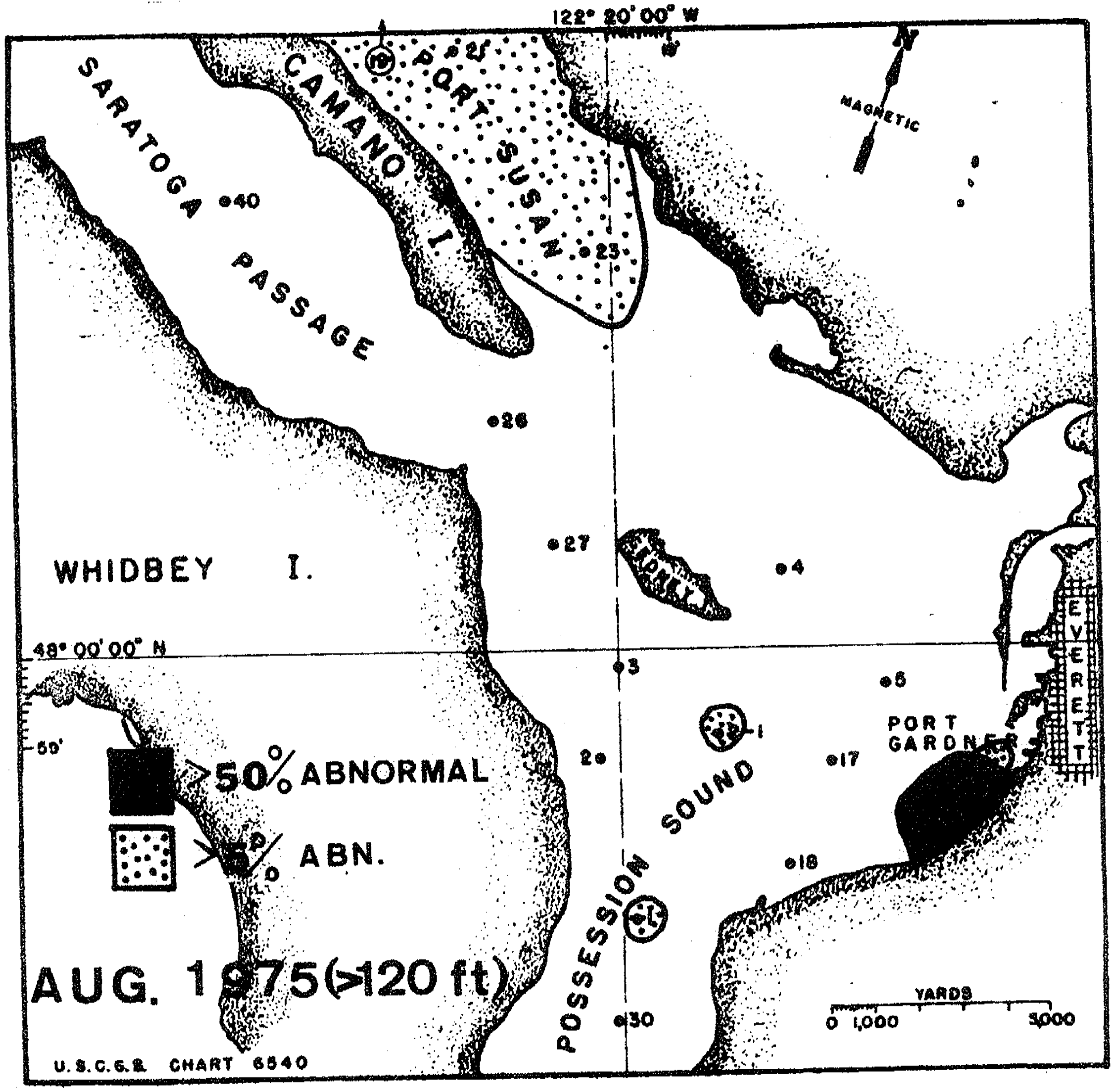

Fig. 13. Areas causing appreciable toxicity to larval Pacific oysters in the deeper water column on 18-19 August 1975

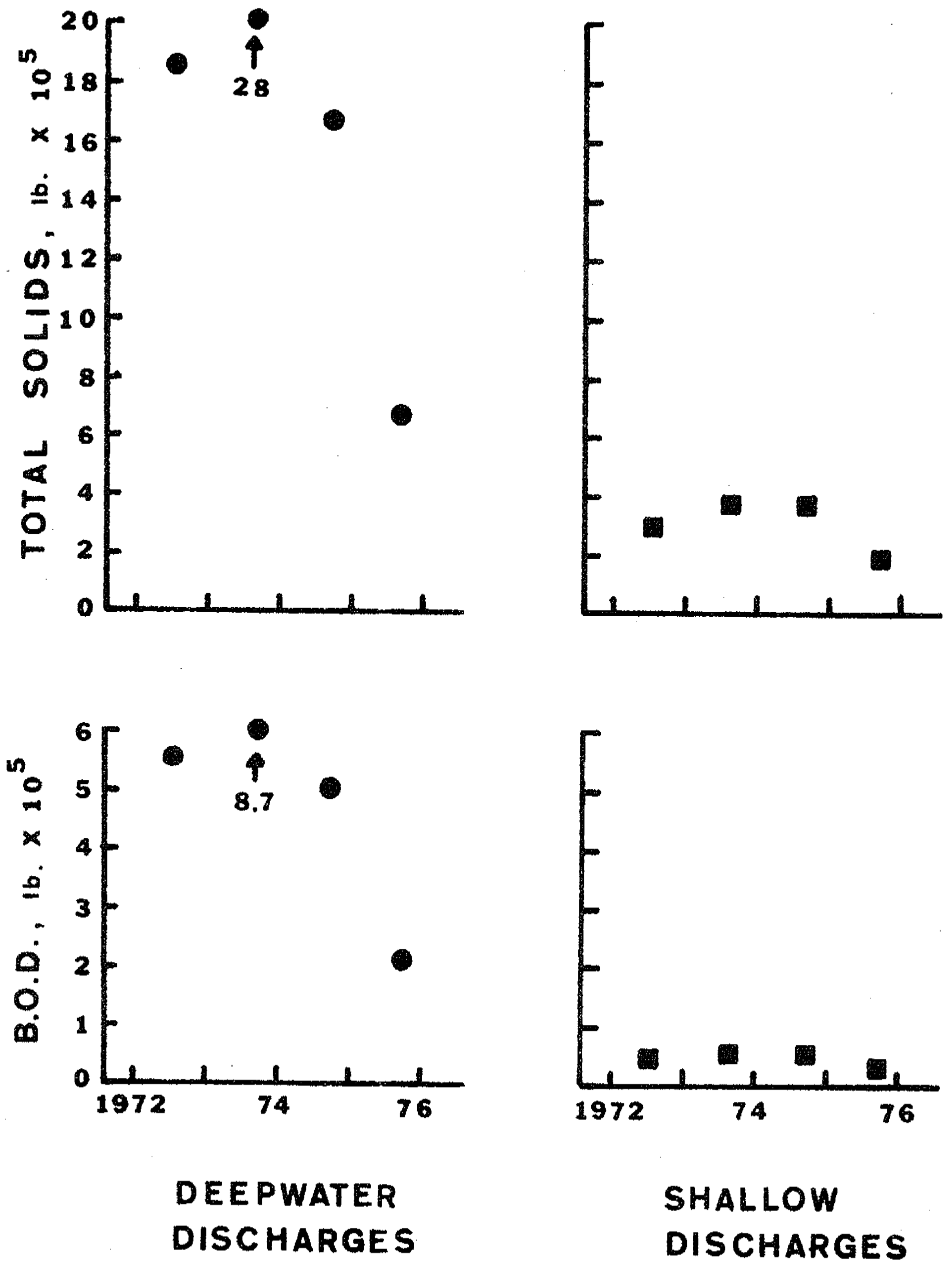

Fig. 14. Average combined wastewater loading by the Scott Paper Co. and Weyerhaeuser Corp. sulfite mills in Everett over the 2-week period preceding each receiving water evaluation

efficiency in SWL incineration by the Scott facility. These changes lowered total B.O.D. and total solids contents of the inshore outfalls by about half.

Among the other factors which could have influenced the toxicity results for the upper water column are qualitative changes in both effluent chemical composition and toxicity as a function of waste treatment, the effects of currents which could cause variations in flushing and waste dilution, and the presence of other toxic materials.

Changes in the toxic constituents of the pulp mill effluents explain some of the variation. These changes could be a function of waste treatment or to the nature and efficacy of biodegradation *in situ*. This hypothesis is supported by the following findings:

1. The amount of PBI-sensitive substances, i.e., those compounds detected by the PBI analytical method, required to cause abnormal shell development in 50% of the larvae became progressively greater between 1972 and 1975 (Fig. 15). This indicates either that compounds not measured specifically by the PBI tests contributed significantly to toxicity or that highly toxic PBI-sensitive (or insensitive) compounds were removed.
2. Analysis by weighted linear regression indicated that

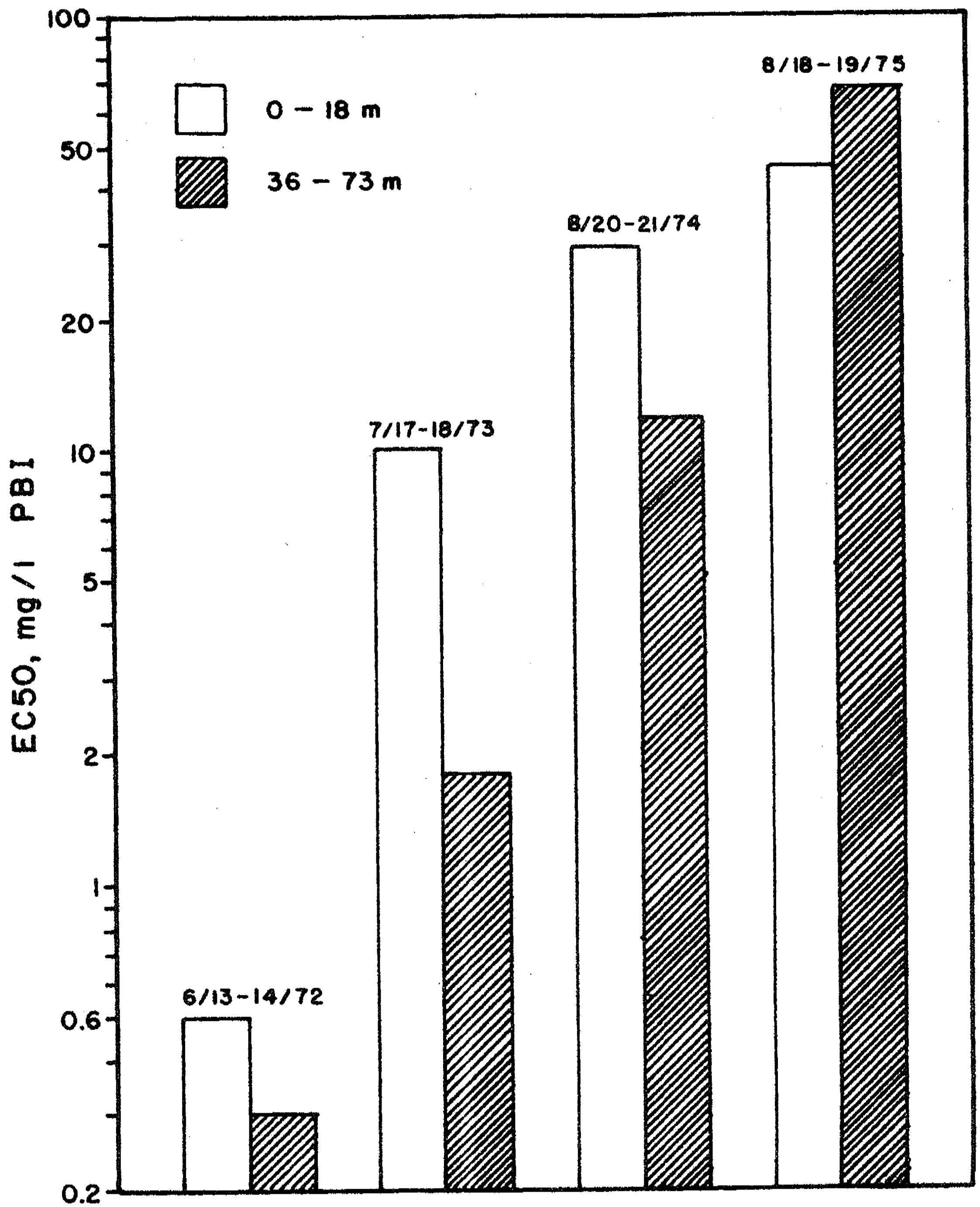

Fig. 15. Variation in toxicity to larval Pacific oysters of marine waters near Everett from 1972 to 1975

less than half of the toxicity could be explained solely by PBI concentration, and that the toxicity curve describing the relationship between PBI concentration and percent larval response changed every year (Appendix Table 6). Changes in the character of such curves imply different mechanisms of toxicity (Finney, 1952; Jensen, 1972; Sprague, 1969).

The analytical limitations of the PBI method are well known. Barnes et al. (1963) states that the method suffers from non-specificity, and McCarthy (1967) indicated that the method measures only "...certain ortho-, meta-, and para-substituted phenols and other substances..."

In an obscure publication, Woelke (1965) arrived at a conclusion similar to ours more than 10 years ago. Woelke compared the toxicity of various industrial effluents to larval Pacific oysters in terms of each sample's PBI, B.O.D., C.O.D., total suspended solids, and sulfur content. Using stepwise linear regression, a form of multiple regression, Woelke found that sulfur ($r = 0.914$), total solids ($r = 0.916$), PBI ($r = 0.914$), B.O.D. ($r = 0.894$), and C.O.D. ($r = 0.888$) possessed high individual linear correlations with toxicity and accounted for 95% in the aggregate of the variation in sample toxicity, expressed as the $\log_{10}$ waste dilution causing 20% larval abnormal shell development. On the other hand, sulfur, total solids, suspended solids, B.O.D., and C.O.D. accounted for only 34% of the variation in toxicity expressed in terms of PBI concentration causing 20% abnormality. Woelke concluded that the most toxic constituents of pulp mill wastes appeared to be associated with the pulp cooking, i.e. digestion process, that the strong multiple correlation between sample sulfur content and toxicity implied that the toxic constituents possessed relatively high proportions of this element, and that PBI was unsatisfactory as the sole chemical indicator of effluent toxicity.

The question of whether other toxic constituents were present and contributing to receiving water toxicity was explored only superficially by measuring ammonia, sulfides, pH, and dissolved oxygen at selected locations and depths. In general, none of these parameters appeared to figure prominently in toxicity.

Variation in waste flushing as a function of currents was suggested earlier as a factor having an influence on toxicity results for the upper water column, at least during the summer when the system is not overturning. According to the Washington State Enforcement Project (1967), pulp mill effluents discharged near the surface are transported toward Mukilteo as a function of the freshwater discharges from the Snohomish and Stillaguamish

River systems. Discharge data collected for the two river systems by the U.S. Geological Survey (1973, 1974) were examined to determine whether flows were higher in 1973 than 1972, which could be taken as presumptive evidence of greater waste flushing. However, fluvial discharges were greater in June 1972 (mean discharge of 23,100 cubic feet/sec [cfs] or 14,900 mgd) than in July 1973 (mean discharge of 4,900 cfs or 3,150 mgd).

Port Angeles

Water quality in the Port Angeles region remained relatively constant during the summers of 1972, 1973, and 1974 in that the inshore waters from Ediz Hook to the base of Dungeness Spit were largely deleterious to larval Pacific oysters at one or more depths (Figs. 16, 17, 18). Although there was a two-fold increase during this period in receiving water toxicity as a function of PBI (Fig. 19), the cause and effect relationship between PBI and abnormal larval shell development remained relatively constant, as indicated by similar regression coefficients for the three years (Appendix Table 9). In 1975 a dramatic increase in receiving water toxicity was observed at the same time ITT Rayonier was incinerating 85% of its SWL (Fig. 20).

The relationship between receiving water toxicity and waste loading by the ITT Rayonier pulp mill appeared to be very good. Between 1972 and 1974 there were only small variations

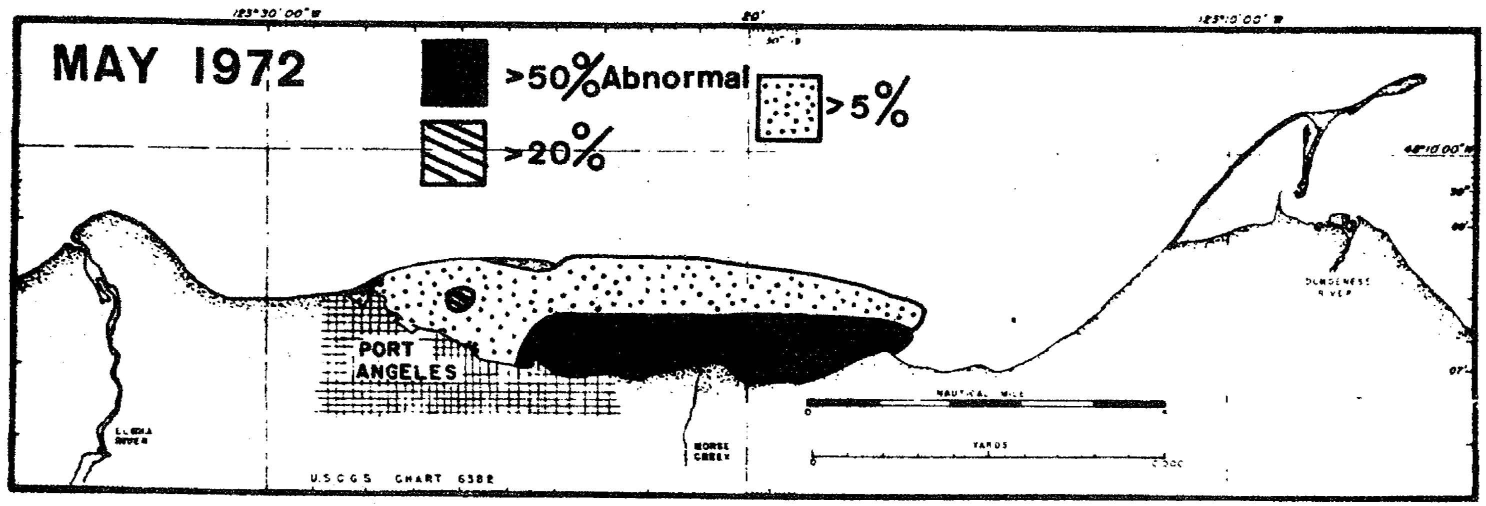

Fig. 16. Areas causing appreciable toxicity to larval Pacific oysters on 10 May 1972 in the Port Angeles region

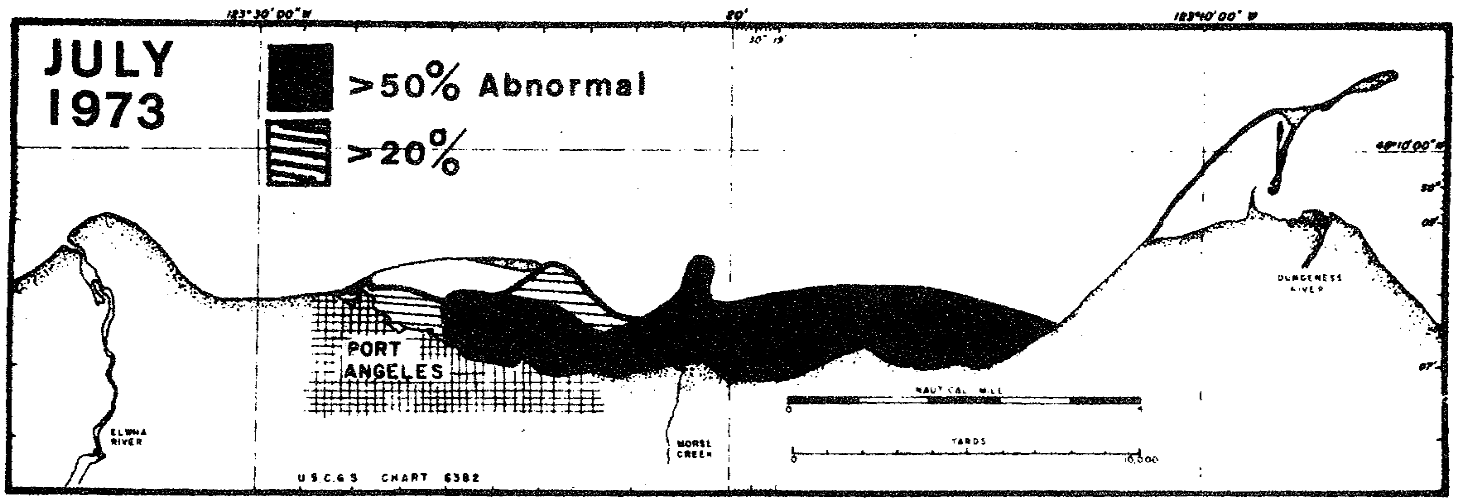

Fig. 17. Areas causing appreciable toxicity to larval Pacific oysters on 24 July 1973 in the Port Angeles region

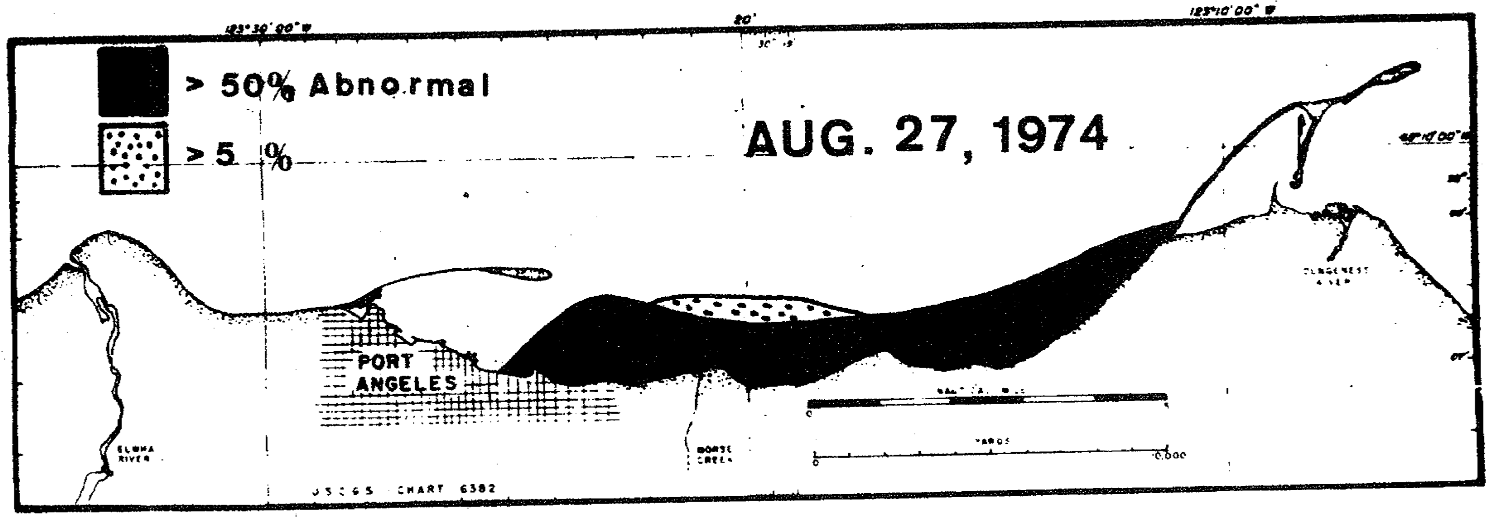

Fig. 18. Areas causing appreciable toxicity to larval Pacific oysters on 27 August 1974 in the Port Angeles region

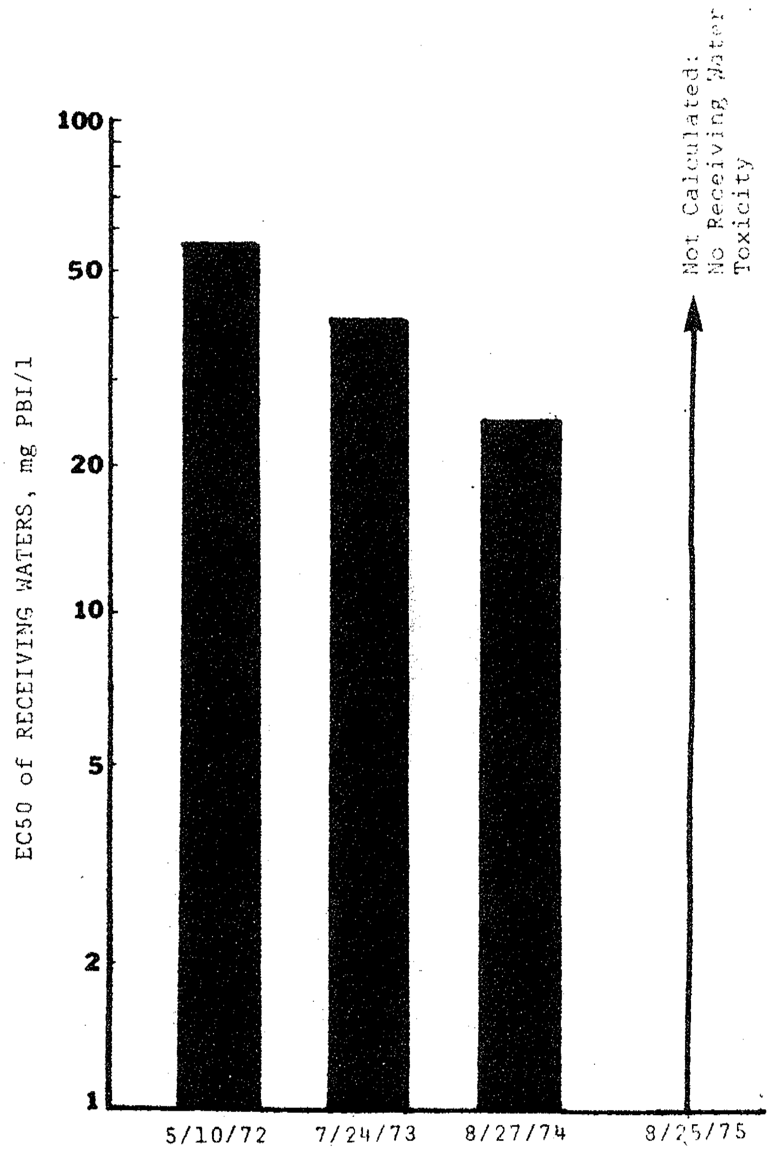

Fig. 19. Variation in receiving water toxicity to larval Pacific oysters of marine waters near Port Angeles during the summers of 1972 to 1975

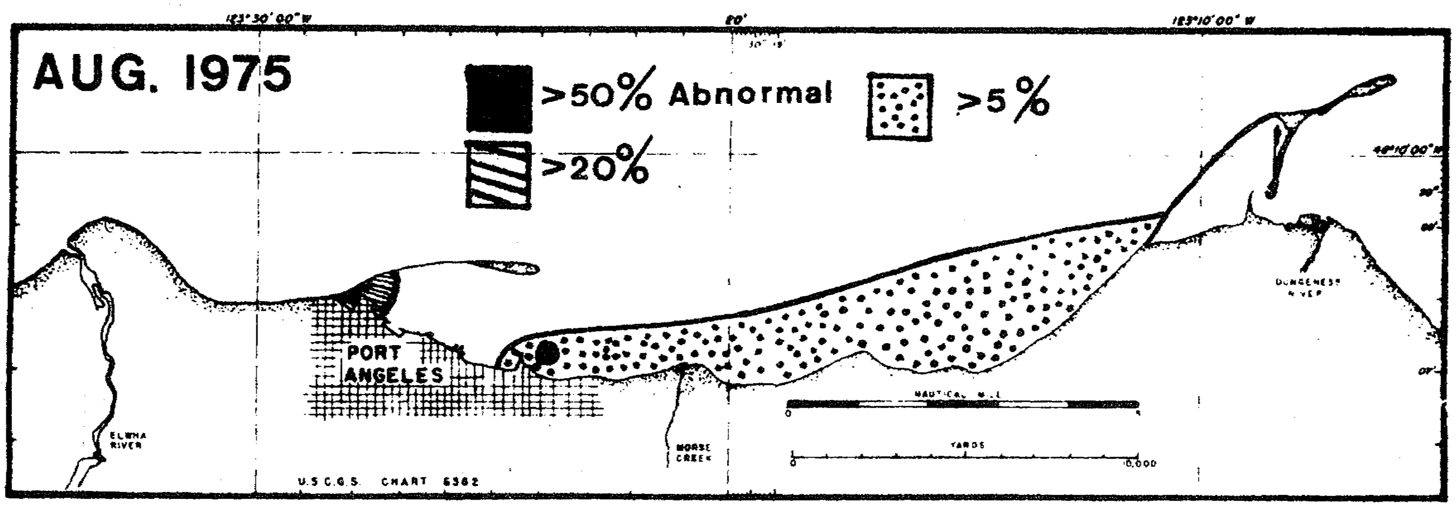

Fig. 20. Areas causing appreciable toxicity to larval Pacific oysters on 25 August 1975 in the Port Angeles region

in pulp production and B.O.D. contents of the effluents. The major reduction occurred in August 1975 concomitant with the SWL incineration (Fig. 21).

In the Port Angeles region there are strong tidal currents, and some variation in the extent and degree of receiving water toxicity occurs, depending upon the direction and strength of the tide. Other sources of variation relate to the qualitative and quantitative changes in effluent chemical composition as a function of the grade of dissolving pulp being produced and the type of wastewater treatment being applied.

Statistical analysis of the receiving water quality data from 1972 through 1975 produced conclusions which were similar to those reached upon analysis of the Everett data: the strength of the cause and effect relationship between PBI and larval response was generally poor even though linear correlations were good; PBI accounted for more of the variation in abnormal larval development than larval mortality; and improved wastewater treatment changed the slopes of the PBI-larval response curves and further diminished the adequacy of PBI as an indicator of sulfite waste liquor concentration and toxicity *in situ* (Appendix Table 9). Larval mortality was not even positively correlated with PBI in the 1975 studies.

The data suggest that as the Port Angeles and Everett pulp mills attain prescribed levels of wastewater treatment, receiving water acute toxicity will largely disappear. Absence

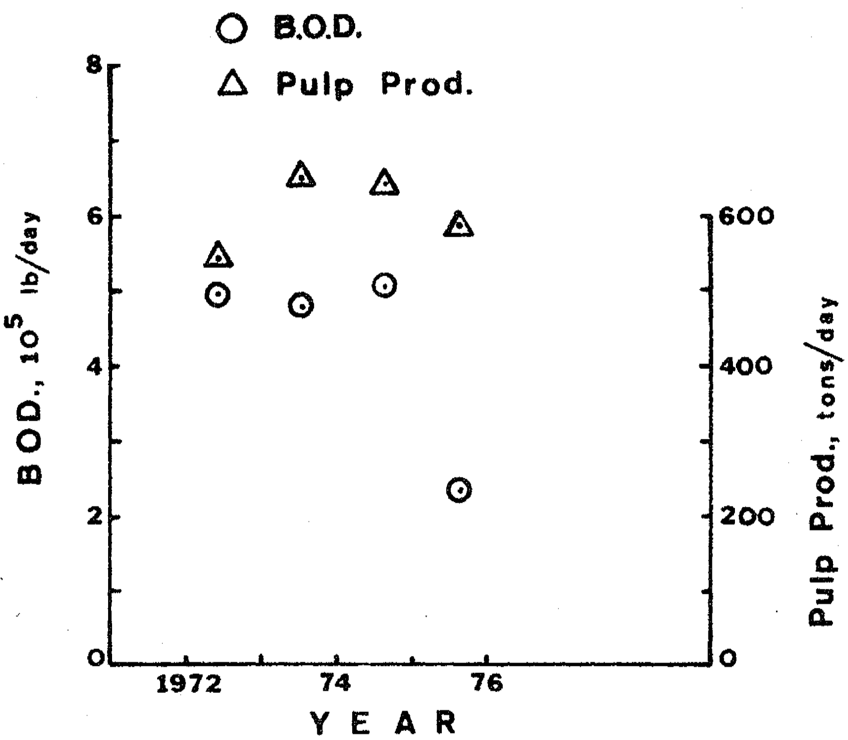

Fig. 21. Total waste loading and pulp production from ITT Rayonier mill in Port Angeles for 7-day periods preceding each receiving water investigation

of acute effects on larval oysters does not necessarily imply that other marine organisms will be unaffected, however. Although Pacific oyster larvae develop abnormally in dilutions of pulp mill effluents greatly below those lethal to juvenile salmonids (Holland et al., 1960; Wilson, 1972; Folsom and Denison, 1976), little data on their sensitivity relative to other species and life stages have been published in the formal literature. When it can be demonstrated that pulp mill effluents are not acutely toxic in situ, the question of chronic effects on the life cycles of marine organisms will remain. Of the toxicants tested to date, the concentrations producing deleterious chronic effects on growth, survival or reproduction of organisms have generally ranged from 10 to 20% (e.g. surfactants, Pickering and Thatcher, 1970) down to at least 0.5% (e.g. cadmium, Pickering and Gast, 1972) of the levels causing acute lethal effects. Determination of the chemicals responsible for life cycle effects should rely on more sophisticated analytical methodology, such as that reported by Leach and Thakore (1973, 1975) and Hrutfiord et al. (1975), because of the limitations of the PBI test, and the practical advantage of eliminating specific toxic chemicals, if possible, rather than treating entire effluents.

Setting environmentally "safe" levels for pulp mill effluents or their toxic constituents on the basis of effluent tests in the laboratory may not be valid since our results suggest that receiving water toxicity may be different in character from that of effluent toxicity. Wilson (1972) has also cautioned about making this application since sulfite waste liquor toxicity does not necessarily reach a threshold within 96 hr; hence toxicity *in situ* may occur at much lower concentrations than predicted by a 96-hr exposure. The disparity between effluent and receiving water toxicity is particularly evident with respect to the marine waters near Everett, and may be a function of the limited waste assimilation capacity of these waters prior to the autumnal overturn and flushing of the system Effluent toxicity should prove to be a better indicator of receiving water quality in the Port Angeles region because this system has much better flushing. However, a more elaborate regimen of effluent toxicity testing needs to be used to gain better estimates of effects (i.e. EC50, LC50) than accomplished in our exploratory experiments and to account for the daily variations in effluent composition.

ACKNOWLEDGMENTS

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LIST OF APPENDIX TABLES

Appendix Table 1. Locations of sampling stations near Everett[a]

Station	Latitude	Longitude	Station	Latitude	Longitude
1	47° 57' 00"[b]	122° 19' 38"[b]	10-1	47° 58' 54"	122° 13' 17"
2	47° 58' 32"	122° 20' 20"	10-2	47° 58' 57.5"	122° 13' 22"
2-1	47° 58' 59"	122° 18' 32"	11	47° 58' 43"	122° 13' 18"
3	47° 59' 48"	122° 20' 00"	11-1	47° 58' 44"	122° 13' 20"
4	48° 1' 00"	122° 17' 17"	12	47° 58' 36"	122° 13' 30"
5	47° 59' 35"	122° 15' 38"	13	47° 58' 34"	122° 13' 36"
6	47° 58' 42"	122° 14' 42"	14	47° 58' 30"	122° 13' 37"
7	47° 58' 32"	122° 14' 00"	14-1	47° 58' 28"	122° 13' 38"
8	47° 59' 11.5"	122° 13' 07"	15	47° 58' 24"	122° 13' 46"
9	47° 59' 00"	122° 13' 13"	16	47° 58' 6"	122° 15' 18"
9-1	47° 59' 3"	122° 13' 6"	17	47° 58' 32"	122° 16' 28"
9-2	47° 59' 1"	122° 13' 6"	18	47° 57' 30"	122° 17' 18"
9-3	47° 59' 4.5"	122° 13' 6"	19	48° 8' 52"	122° 25' 12"
10	47° 58' 45.5"	122° 13' 23"	20	48° 7' 42"	122° 23' 30"

Appendix Table 1. Locations of sampling stations near Everett--continued

Station	Latitude	Longitude	Station	Latitude	Longitude
21	48° 6' 42"	122° 22' 30"	34	47° 51'	122° 20' 12"
22	48° 5' 38"	122° 21' 30"	35	47° 53' 30"	122° 21' 18"
23	48° 4' 32"	122° 20' 27"	36	47° 57' 37"	122° 15' 48"
24	48° 3' 37"	122° 19' 20"	37	47° 58' 6"	122° 14' 12.5"
25	48° 2' 30"	122° 18' 28"	38	47° 58' 35"	122° 13' 37"
26	48° 2' 38"	122° 22' 00"	39	48° 3' 24"	122° 23' 52"
27	48° 1' 15"	122° 21' 00"	40	48° 5' 2"	122° 26' 14"
28	48° 1' 00"	122° 17' 17"	008[c]	47° 58.3'	122° 14.4'
29	47° 55' 42"	122° 21' 48"	825[c]	47° 58.5'	122° 14.7'
30	47° 56' 00"	122° 20' 00"	850[c]	47° 58.7'	122° 15.0'
31	47° 56' 30"	122° 18' 48"	875[c]	47° 59.0'	122° 15.3'
32	47° 57' 7"	122° 18' 17"	009[c]	47° 59.3'	122° 15.6'
33	47° 48' 54"	122° 23' 18"			

[a] Includes all stations sampled from 1972 to 1975.
[b] Latitude north and longitude west.
[c] University of Washington (T.S. English) stations.

Appendix Table 2. Locations of sampling stations near Port Angeles (1972-1975)

Station	Latitude	Longitude	Station	Latitude	Longitude
1	48° 9' 24"[a]	123° 21'[a]	12-2	48° 7' 33"	123° 23' 37"
2	48° 8' 23"	123° 21'	13	48' 7' 14.5"	123° 24' 17"
3	48° 7' 50"	123° 21'	13-1	48° 7' 15"	123° 23' 13"
4	48° 7' 30"	123° 21'	14	48° 7' 15.5"	123° 24' 27"
4-1	48° 7' 6"	123° 21' 36"	15	48° 7' 30"	123° 25' 33"
5	48° 7' 35.5"	123° 22' 30"	16	48° 7' 54"	123° 25' 33"
6	48° 7' 42"	123° 22' 38.5"	17	48° 8'	123° 27'
7	48° 7' 35.5"	123° 22' 38.5"	18	48° 8' 23"	123° 25' 33"
8	48° 7' 29.5"	123° 22' 38.5"	19	48° 11' 18"	123° 5' 24"
9	48° 7' 35.5"	123° 22' 47.5"	20	48° 10' 24"	123° 11' 24"
10	48° 8' 23"	123° 22' 47.5"	21	48° 9' 6"	123° 13' 42"
11	48° 8' 23"	123° 23' 54"	22	48° 7' 36"	123° 17' 18"
12	48° 7' 59"	123° 24' 23"	23	48° 8' 23"	123° 17' 18"
12-1	48° 7' 45"	123° 24' 12"	24	48° 9' 24"	123° 17' 18"

Appendix Table 2. Locations of sampling stations near Port Angeles (1972-1975)--continued

Station	Latitude	Longitude	Station	Latitude	Longitude
25	48° 9' 24"	123° 24'	26-2	48° 8' 12"	123° 28' 35"
26	48° 9' 15"	123° 27' 42"	27	48° 9' 12"	123° 34'
26-1	48° 8' 42"	123° 27' 20"			

[a] Latitude north and longitude west.

Appendix Table 3. Differences in responses of larval oysters as a function of subsampling technique

Source	d.f.	SS	MS	F
Everett studies				
Abnormal shell development criterion				
Between treatments	33	86,024.03	2,606.79	113.26[a]
Between factors	1	134.05	134.05	5.82[a]
Error	68	1,565.11	23.02	
Total	102	87,723.19		
Mortality criterion				
Between treatments	33	65,638.68	1,989.05	43.00[a]
Between factors	1	4,157.01	4,157.01	89.87[a]
Error	68	3,145.39	46.26	
Total	102	72,941.08		
Port Angeles studies				
Abnormal shell development criterion				
Between treatments	16	5,749.18	359.32	2.33[a]
Between factors	1	22.95	22.95	0.14[b]
Error	34	5,246.59	154.31	
Total	51	11,018.72		

Appendix Table 3. Differences in responses of larval oysters as a function of subsampling technique--continued

Source	d.f.	SS	MS	F
Port Angeles studies				
Mortality criterion				
Between treatments	15	5,728.51	381.90	3.28[a]
Between factors	1	219.78	219.78	1.89[b]
Error	32	3,729.44	116.55	
Total	48	9,677.73		

[a] Significant at $p \leq 0.05$.

[b] Not significant ($p = 0.05$).

Appendix Table 4. Quality of oyster larvae used for testing as defined by several indices

Date	Adult conditioning period, days	Control responses		Sensitivity to DSS	
		Abnormality, %	Survival,[a] %	EC50, mg/l	LC50, mg/l
Everett studies					
8/18/75	68	1.0[b] (0.8 - 1.2)	74.9[b] (73.0 - 76.7)	0.78[c] (0.71 - 0.86)	0.88[c] (0.79 - 0.97)
8/19/75	69	0.6 (0.3 - 0.8)	96.9 (93.9 - 99.9)	1.02 (0.49 - 2.14)	1.03 (0.56 - 1.91)
Port Angeles studies					
8/25/75	59	4.0 (0.9 - 7.4)	87.6 (77.1 - 99.6)	1.03 [d] ...	~1.0 ...
8/26/75	60	1.2 (0 - 5.6)	87.7 (80.0 - 94.7)	1.00 (0.77 - 1.30)	1.08 (1.06 - 1.11)

[a] Calculated relative to expected control survival (i.e. number of individuals introduced).
[b] Mean with range in parentheses.
[c] Median response estimate with 95% confidence limits in parentheses.
[d] Could not be calculated due to insufficient number of intermediate percentage responses.

Appendix Table 5. Water quality and toxicity of marine waters near Everett, Washington

Depth,		Controls		Station No.									
ft	m	Laboratory	Carry-along	30	1	2	3	4	2-1	18	17	5	16
Abnormal larval shell development, %													
0	0	0.8	0.7	1.2	5.5	2.7	3.5	6.1	16.4	3.8	13.4	7.3	3.5
60	18				45.0	8.6	2.8		100	23.1	3.2	2.2	0.9
120	37			2.9	13.5	0.7	9.7	1.9	3.2	1.5	3.0	1.5	5.1
180	55				12.3	2.9	2.4		7.6	2.7	2.6	1.7	92.9
240	73			20.6	18.0	2.1	2.0	6.3	0.8	4.0	2.3	1.5	2.0
Larval mortality, %													
0	0	0[b]	0	54.2	34.6	16.7	23.0	6.1	28.3	16.0	12.2	12.0	3.0
60	18				96.2	24.9	5.3		78.9	23.6	0	0	0
120	37			3.2	21.1	13.9	7.6	0	11.8	8.6	0	0	15.0
180	55				21.5	7.2	0		12.7	1.5	0	0	19.8
240	73			25.3	27.2	2.3	3.6	12.4	2.7	6.1	1.3	0	6.2

Appendix Table 5. Water quality and toxicity of marine waters near Everett, Washington--continued

Depth, ft	Depth, m	Controls: Laboratory	Controls: Carry-along	Station No. 30	1	2	3	4	2-1	18	17	5	16
PBI, mg/l													
0	0	0	0	1	2	2	0	5	0	3	2	4	1
60	18				1	1	0		0	4	1	3	1
120	37			0	3	0	0	0	0	6	4	2	12
180	55				11	2	3		2	5	6	6	24
240	73			10	0	8	2	13	2	4	3	6	12
Salinity, g/l													
0	0	30	30	25.3	24.7	22.5	24.9	21.8	24.9	23.0	20.1	20.5	23.5
60	18				29.0	29.0	29.7		29.1	28.3	28.7	28.3	27.7
120	37			29.0	29.1	29.0	29.0	29.8	29.0	29.0	28.8	28.7	26.3
180	55				28.8	29.3	29.0		29.1	28.0	28.5	28.0	28.4
240	73			29.1	29.5	29.3	29.3	28.0	28.8	29.8	29.0	26.5	26.2

Appendix Table 5. Water quality and toxicity of marine waters near Everett, Washington--continued

Depth, ft	Depth, m	Controls: Laboratory	Controls: Carry-along	Station No. 6	7	8	9-1	9-2	9-3	10-2	10	11	12
Abnormal larval shell development, %													
0	0	0.8	0.7	0.8	2.0	82.4	100	98.9	100	40.2	100	85.8	2.8
60	18			2.3		9.0[a]	25.5[a]	26.3[a]		100[a]	0.9	4.1	1.6
120	37			11.8	6.4								
180	55			25.9									
240	73			80.5	6.0								
Larval mortality, %													
0	0	0[b]	0	6.8	6.1	65.4	62.7	10.5	100	24.3	37.3	39.7	13.1
60	18			7.6		21.5[a]	19.6[a]	29.1[a]		38.8[a]	0	12.7	1.9
120	37			22.4	17.1								
180	55			25.9									
240	73			26.0	18.3								

Appendix Table 5. Water quality and toxicity of marine waters near Everett, Washington--continued

Depth,		Controls		Station No.									
ft	m	Laboratory	Carry-along	6	7	8	9-1	9-2	9-3	10-2	10	11	12
PBI, mg/l													
0	0	0	0	0	2	17	195	49	460	15	18	65	6
60	18			1		6[a]	34[a]	37[a]	...	15[a]	6[a]	8[a]	3[a]
120	37			15	17								
180	55			20									
240	73			35	21								
Salinity, g/l													
0	0	30	30	22.8	22.5	23.2	22.1	24.0	17.0	23.5	23.4	24.8	25.0
60	18			26.9		26.5[a]	26.3[a]	24.0[a]		25.1[a]	26.1[a]	26.0[a]	26.4[a]
120	37			28.1	24.8								
180	55			27.7									
240	73			26.0	29.0								

Appendix Table 5. Water quality and toxicity of marine waters near Everett, Washington--continued

Depth,		Controls		Station No.								
ft	m	Laboratory	Carry-along	14	15	40	26	27	19	21	23	4
Abnormal larval shell development, %												
0	0	0.8	0.7	17.6	4.5	1.8	1.8	2.6	0.2	1.0	0.7	4.1
60	18			1.1	2.6	1.9	0.4	1.6	2.4	0.8	1.5	0.6
120	37					1.2	0.4	0.9	1.2	1.9	6.4	1.2
180	55					0.8	0.8	1.9	1.6	1.6	1.2	0.9
240	73					0.9	0	1.0	13.5	5.0	1.0	0.7
Larval mortality, %												
0	0	0	0	51.5	28.7	21.3	19.6	37.2	9.9	0	0	1.2
60	18			0	5.3	0	0	0	0	0	19.8	1.6
120	37					2.6	0.2	0	0	0	8.9	1.4
180	55					0	2.8	4.9	1.8	0	0	0
240	73					0	0	0	0	0	3.2	0

Appendix Table 5. Water quality and toxicity of marine waters near Everett, Washington--continued

Depth,		Controls		Station No.								
ft	m	Laboratory	Carry-along	14	15	40	26	27	19	21	23	4
PBI, mg/l												
0	0	0	0	7	5	0	0	0	0	2	2	4
60	18			2[a]	5[a]	1	0	0	1	2	1	1
120	37					1	0	0	4	2	7	5
180	55					2	2	0	7	9	9	12
240	73					4	3	4	10	12	7	3
Salinity, g/l												
0	0	30	30	24.3	23.1	25.2	25.8	25.4	23.9	24.6	24.5	20.9
60	18			26.9[a]	28.4[a]	29.5	29.8	29.7	29.6	27.2	28.9	28.4
120	37					29.9	29.9	29.8	29.4	28.8	28.5	28.5
180	55					29.9	29.8	29.8	29.4	27.8	28.1	28.2
240	73					29.9	29.8	29.8	28.5	28.9	28.9	25.0

[a] 20 ft (6.1 m).

[b] To determine relative mortality, control mortality was set at 0%.

Appendix Table 6. Relationship between PBI and responses of larval oysters to receiving waters collected near Everett

Date	Depth, m	Log-probit regression equation[a]	EC50, mg/l PBI	R^2, %	Corr. coeff., r	Analysis of variance table: Source	d.f.	SS	MS	F
PBI and % abnormal development										
6/13-14/72	0-18	5.78 + 2.25	0.5	43	0.48	Regression	1	2.42	2.42	22.1[b]
						Residual	29	3.18	0.11	
						Total	30	5.60		
	37-73	5.97 + 1.63	0.3	35	0.50	Regression	1	1.56	1.56	31.0[b]
						Residual	58	2.92	0.05	
						Total	59	4.47		
7/17-18/73	0-18	2.58 + 2.41	10.1	35	0.80	Regression	1	6.11	6.11	38.0[b]
						Residual	72	11.59	0.16	
						Total	73	17.70		
	37-73	4.37 + 2.44	1.8	45	0.65	Regression	1	3.41	3.41	50.4[b]
						Residual	61	4.13	0.07	
						Total	62	7.54		
8/20-21/74	0-18	2.74 + 1.53	29.5	18	0.67	Regression	1	2.55	2.55	11.3[b]
						Residual	53	11.96	0.23	
						Total	54	14.51		
	37-73	0.06 + 4.60	11.9	49	0.79	Regression	1	9.70	9.70	63.2[b]
						Residual	65	9.98	0.15	
						Total	66	19.68		

Appendix Table 6. Relationship between PBI and responses of larval oysters to receiving waters collected near Everett--continued

Date	Depth, m	Log-probit regression equation[a]	EC50, mg/l PBI	R^2, %	Corr. coeff., r	Analysis of variance table: Source	d.f.	SS	MS	F
PBI and % abnormal development										
8/18-19/75	0-18	3.25 + 1.06	44.3	37	0.74	Regression	1	3.17	3.17	23.92[b]
						Residual	41	5.44	0.13	
						Total	42	8.62		
	37-73	1.47 + 1.65	68.8	43	0.61	Regression	1	3.00	3.00	32.35[b]
						Residual	43	3.99	0.09	
						Total	44	7.00		
PBI and % mortality										
8/18-19/75	0-18	3.89 + 0.31	3,690[d]	9	0.27	Regression	1	0.53	0.53	3.33[c]
						Residual	32	5.10	0.16	
						Total	33	5.63		
	37-73	2.99 + 0.69	795[d]	37	0.57	Regression	1	0.61	0.61	14.97[b]
						Residual	25	1.02	0.04	
						Total	26	1.63		

[a] Probit $\hat{Y}_i = a + b\ (\text{Log}\ X_i)$.
[b] Significant ($p < 0.05$).
[c] Not significant.
[d] Median lethal concentrations.

Appendix Table 7. Chemical characteristics of selected receiving water samples collected near Everett in August 1975

Station	D.O., mg/l	pH	PBI, mg/l	Total NH_3, mg/l	Total sulfides, mg S/l
Surface					
30	8.1	8.12	1	...[a]	N.D.[b]
4	7.3	8.00	5	...	N.D.
7	7.8	8.05	2	...	N.D.
9-1	4.2	7.20	195	7.31	0.18
9-2	6.5	7.86	49	0.38	...
10-2	6.5	7.86	15	...	N.D.
23	7.9	8.04	2	...	...
37 m depth					
30	7.0	8.12	0	...	N.D.
4	6.6	8.00	0	...	0.18
7	6.7	7.98	17	0.03	N.D.
19	6.8	7.68	4	...	N.D.
23	6.3	7.65	7	...	...
73 m depth					
30	6.4	7.94	10	0.05	N.D.
4	6.3	8.00	13	0.03	N.D.
7	6.5	7.94	21	0.06	N.D.
19	6.2	7.58	10	0.03	N.D.
23	6.3	7.66	7	0.03	N.D.

Appendix Table 7. Chemical characteristics of selected receiving water samples collected near Everett in August 1975--continued

Station	D.O., mg/l	pH	PBI, mg/l	Total NH_3, mg/l	Total sulfides, mg S/l
Pt. Whitney control					
	4.4	7.92	0	0.03	N.D.

[a] No observation.

[b] Not detected.

Appendix Table 8. Water quality and toxicity to larval oysters of marine waters near Port Angeles, Washington

Depth, ft	Depth, m	Controls: Laboratory	Controls: Carry along	Station 19	20	21	22	23	24	8	7	6	9
Abnormal shell development, %													
0	0	4.0 ±1.5	2.8	2.5	1.6	4.9	4.6	3.0	5.0	8.4	6.7	5.2	23.3
20	6.1		...	3.4	3.2	4.1	3.4	2.4	4.1	5.2	4.5	6.8	4.0
40	12.2	...	...	2.9	6.7	3.0	5.4	5.1	3.5	3.5	6.4	5.7	3.7
60	18.3	...	...	3.2	4.5[a]	8.0[b]	...	7.5	2.3	6.7[a]	5.2[a]	4.9	6.6
100	30.5	...	...	...	...	...	...	...	...	...	...	...	...
160	48.8	...	...	...	...	...	...	...	...	...	...	...	...
Mortality[d], %													
0	0	0[d]	0.3	0	0.2	0	0	7.4	1.6	6.0	2.6	2.1	0.2
20	6.1			3.5	0	0	4.9	21.2	0	0	0	0	0
40	12.2			0	6.7	5.6	0.9	4.2	0.7	0	0	0	0
60	18.3			0	1.2[a]	0[b]	...	6.5	0	0[a]	0[a]	0	0.9
100	30.5			...	...	...	...	...	...	...	...	...	...
160	48.8								...	...	...	...	...

Appendix Table 8. Water quality and toxicity to larval oysters of marine waters near Port Angeles, Washington--continued

Depth, ft	Depth, m	Controls: Laboratory	Controls: Carry along	Station 19	20	21	22	23	24	8	7	6	9
PBI, mg/l													
0	0	0	0	0	0	0	2	0	0	4	5	5	21
20	6.1			0	0	0	0	0	0	0	0	0	11
40	12.2			0	1	3	1	1	0	0	0	0	0
60	18.3			0	0[a]	3[b]	...	0	0	0[a]	0[a]	0	5
100	30.5			...	...	...	...	...	...	...	...	...	...
160	48.8			...	...	...	...	...	...	...	...	...	...
Salinity, g/kg													
0	0	29.9	29.9	30.7	30.2	31.2	31.1	30.8	31.0	31.5	30.4	31.8	31.5
20	6.1			31.0	30.1	31.4	31.5	31.0	31.1	31.8	30.4	31.9	28.2
40	12.2			30.0	31.0	31.8	32.0	31.0	31.4	31.9	31.9	32.0	31.7
60	18.3			31.5	31.5[a]	31.0[b]	...	31.4	31.9	31.3[a]	31.6[a]	32.5	31.0
100	30.5			...	...	...	...	...	...	...	...	...	...
160	48.8			...	...	...	...	...	...	...	...	...	...

Appendix Table 8. Water quality and toxicity to larval oysters of marine waters near Port Angeles, Washington--continued

Depth,		Controls		Station									
ft	m	Laboratory	Carry along	5	13	14	27	26	26-2	25	11	10	4
Abnormal shell development, %													
0	0	4.0 ±1.5	2.8	7.0	6.2	3.3	7.3	3.1	1.1	3.5	3.4	3.0	7.6
20	6.1			6.8	6.2	5.5	...	17.2	3.3	4.2	3.3	1.8	4.3
40	12.2			6.7	100[c]	4.9[c]	...	3.7	0	3.8	3.1	3.7	...
60	18.3			4.2	...	...	...	1.5	2.6	1.5	4.7	2.8	...
100	30.5			...	...	...	...	0.7	...	0	2.0	2.0	...
160	48.8			...	...	...	...	1.7	...	3.3	6.6	4.8	...
Mortality,[d] %													
0	0	0	0.3	0	0	0.5	0	9.1	14.7	5.8	0	8.1	2.1
20	6.1			7.2	0	0	...	24.2	14.9	0.9	1.9	0	0
40	12.2			0	5.8[c]	0.2[c]	...	0	7.7	0	1.6	0	...
60	18.3			0	...	...	...	7.9	2.8	7.7	1.4	0.9	...
100	30.5			...	...	...	...	5.6	...	9.5	0	6.3	...
160	48.8							2.6		2.3	0	0	...

Appendix Table 8. Water quality and toxicity to larval oysters of marine waters near Port Angeles, Washington--continued

Depth,		Controls		Station									
ft	m	Laboratory	Carry along	5	13	14	27	26	26-2	25	11	10	4
PBI, mg/l													
0	0	0	0	0	13	2	0	0	0	0	0	0	19
20	6.1			1	5	2	...	0	0	0	0	0	2
40	12.2			3	81[c]	0[c]	...	0	0	0	0	0	...
60	18.3			4	...	...	...	0	0	0	0	0	...
100	30.5			...	...	...	...	0	...	0	0	0	...
160	48.8			...	...	...	...	0	...	0	0	0	...
Salinity, g/kg													
0	0	29.9	29.9	31.7	31.4	29.9	32.0	30.8	29.6	30.6	31.2	28.3	30.2
20	6.1			30.2	30.8	29.8	...	31.9	28.9	29.8	31.2	30.2	32.1
40	12.2			30.9	31.6[c]	30.7[c]	...	30.9	28.9	31.7	31.2	31.7	...
60	18.3			30.0	...	...	...	32.0	32.9	32.2	28.0	31.9	...
100	30.5			...	...	...	...	31.3	...	32.9	29.6	32.0	...
160	48.8			...	...	...	...	31.4	...	33.0	29.5	33.3	...

Appendix Table 8. Water quality and toxicity to larval oysters of marine waters near Port Angeles, Washington--continued

Depth, ft	Depth, m	Controls: Laboratory	Controls: Carry along	Station 3	Station 2	Station 1	Station 13-1	Station 12-2	Station 12	Station 18	Station 16	Station 15	Station 17
<u>Abnormal shell development, %</u>													
0	0	4.0 ±1.5	2.8	3.3	2.4	4.3	5.6	1.2	2.6	3.0	4.9	3.2	2.6
20	6.1			2.9	4.2	3.1	2.5	2.2	3.0	1.9	2.8	1.0	2.8
40	12.2			2.5	1.2	0.7	...	2.6	1.6	4.9	1.9	2.3	3.1
60	18.3			...	2.6	2.9	...	4.0	2.9	3.5	3.6	...	28.5
100	30.5			...	...	1.7	...	...	...	4.0	...	...	...
160	48.8			...	...	1.7	...	...	...	2.8	...	...	...
<u>Mortality,[d] %</u>													
0	0	0	0.3	8.8	4.9	3.7	3.7	2.1	0.7	15.1	10.7	11.6	0
20	6.1			3.5	0	4.0	0	5.3	0	4.2	7.2	7.2	0.5
40	12.2			6.5	0.9	0	...	1.9	1.2	9.8	4.0	7.0	3.7
60	18.3			...	2.3	10.9	...	1.9	2.1	0	3.7	...	28.3
100	30.5			...	...	5.3	...	...	...	6.7	...	...	...
160	48.8			...	...	5.1	...	...	...	9.3	...	...	...

Appendix Table 8. Water quality and toxicity to larval oysters of marine waters near Port Angeles, Washington--continued

Depth,		Controls		Station									
ft	m	Laboratory	Carry along	3	2	1	13-1	12-2	12	18	16	15	17
PBI, mg/l													
0	0	0	0	3	0	0	20	5	0	0	2	5	2
20	6.1			2	0	0	0	7	2	0	4	3	3
40	12.2			0	0	0	...	8	5	0	4	2	0
60	18.3			...	0	0	...	0	2	0	0	...	0
100	30.5			...	...	0	...	...	...	0	...	...	...
160	48.8			...	...	0	...	...	...	0	...	...	...
Salinity, g/kg													
0	0	29.9	29.9	30.7	31.5	29.8	30.9	31.5	31.0	31.0	31.0	29.8	29.9
20	6.1			31.8	31.9	32.0	31.8	31.2	31.5	31.1	30.9	30.4	30.9
40	12.2			31.9	32.1	32.0	...	31.1	30.9	31.2	31.0	31.0	31.5
60	18.3			...	31.3	31.2	...	31.8	31.7	31.4	31.4	...	31.0
100	30.5			...	...	32.1	...	...	...	31.0	...	...	...
160	48.8			...	...	32.7	...	...	...	32.0	...	...	...

Appendix Table 8. Water quality and toxicity to larval oysters of marine waters near Port Angeles, Washington--continued

[a] Sample collected at 55 ft (16.8 m), the bottom.
[b] Sample collected at 50 ft (15.2 m), the bottom.
[c] Sample collected at 30 ft (15.2 m), the bottom.
[d] Mortality relative to controls (not natural mortality).

Appendix Table 9. Relationship between PBI and responses of larval oysters to marine waters near Port Angeles

Date	Depth, m	Log-probit regression equation[a]	EC50, mg/l PBI	Corr. coeff.	R^2[b], %	Analysis of variance table: Source	d.f.	SS	MS	F
Abnormal shell development										
5/10/72	All depths	2.88 + 1.21	55.9	0.57	46	Regression	1	5.05	5.05	55.2[c]
						Residual	66	6.04	0.09	
						Total	67	11.09		
7/24/73	All depths	2.97 + 1.27	39.3	0.58	28	Regression	1	4.53	4.53	32.7[c]
						Residual	83	11.50	0.14	
						Total	84	16.03		
8/27/74	All depths	2.14 + 2.05	24.8	0.80	58	Regression	1	8.32	8.32	104.5[c]
						Residual	75	5.97	0.08	
						Total	76	14.29		
8/25/75	All depths	3.21 + 0.34	>1000	0.57	17	Regression	1	0.14	0.14	7.40[c]
						Residual	35	0.66	0.02	
						Total	36	0.81		
Mortality										
8/25/75	All depths	2.70 - 0.13	...[e]	-0.03	4	Regression	1	0.02	0.02	1.2[d]
						Residual	35	0.51	0.02	
						Total	36	0.53		

[a] Probit $Y_i = a + b\ (\text{Log}\ X_i)$.

[b] Percent of variation in larval response explained by PBI-sensitive substances.

[c] Significant, $p < 0.05$.

[d] Not significant.

[e] Not calculated because of truncated concentration - % response data and lack of correlation.

Appendix Table 10. Chemical characteristics of selected receiving water samples collected near Port Angeles

Station	D.O., mg/l	pH	PBI, mg/l	Total NH_3, mg/l	Total sulfides, mg/l
Surface					
7	6.60	7.84	5	0.042	N.D.[a]
11	7.50	7.91	0	0.051	N.D.
12-2	7.40	7.90	5	0.060	...[b]
12	6.90	7.92	0	...	N.D.
16	7.00	7.89	2	0.060	...
17	7.00	7.87	2	0.060	N.D.
Bottom					
7 (16.8 m)[c]	6.20	7.84	0	0.051	...
11 (18.3 m)	6.90	7.88	0	0.034	...
12-2 (18.3 m)	7.10	7.84	0	0.051	...
12 (18.3 m)	7.10	7.88	2	...	N.D.
16 (18.3 m)	6.80	7.84	0	0.042	...
17 (18.3 m)	6.70	7.81	0	0.085	N.D.

[a] Not detected.

[b] No observation.

[c] Actual depths at which samples collected.

Appendix Table 11. Chemical composition of ITT Rayonier pulp mill effluents

Chemical parameters	8/19/75 tests				8/26/75 tests	
	003A untreated	003A treated	007 untreated	007 treated	003A treated	007 treated
Total solids, %	2.15	0.46	0.24	0.24	1.40	0.26
PBI, mg/l	215,000	46,000	24,000	24,000	140,000	26,000
D.O., mg/l	3.4	6.4	5.6	6.1	7.5	7.6
pH	2.52	2.68	2.90	2.64	2.35	4.08
Specific conductance, umhos/cm	6,000	2,600	2,000	1,600	4,700	1,400
Ammonia, mg/l	748	94	15	15	361	31
Residual chlorine, mg/l	N.D.[b]	N.D.	N.D.	N.D.	...[a]	...
B.O.D, mg/l [c]	5,925	819	152	280	10,170	492
C.O.D., mg/l [c]	27,727	3,204	838	1,293	17,888	1,636
Furfural, mg/l [c]	125	24	3	4	108	N.D.
5-methyl furfural, mg/l [c]	10	N.D.	N.D.	N.D.	N.D.	N.D.
Formic acid, mg/l [c]	208	129	32	71	390	264
Acetic acid, mg/l [c]	483	135	39	75	377	252

Appendix Table 11. Chemical composition of ITT Rayonier pulp mill effluents--continued

Chemical parameters	8/19/75 tests				8/26/75 tests	
	003A untreated	003A treated	007 untreated	007 treated	003A treated	007 treated
Total mercury, mg/l	...	...	...	...	0.010 - 0.011[d]	
Organic mercury, mg/l	...	...	...	...	0.01	
Total chromium	...	...	...	...	0.014 - 0.023	
Hexavalent chromium	...	...	...	...	ND.	
Zinc	...	...	...	...	0.084 - 0.15	
Copper	...	...	...	...	0.007 - 0.025	
Lead	...	...	...	...	0.044 - 0.062	
Cadmium	...	...	...	...	0.004 - 0.007	
Nickel	...	...	...	...	N.D. - 0.006	

[a] Not measured.
[b] Not detected.
[c] Folsom and Denison (1976).
[d] Ranges for the two effluents. Single values represent identical readings.

SECTION V

Water Quality and Oceanographic Observations in Port Gardner, Washington 1973, 1974 and 1975

WATER QUALITY AND OCEANOGRAPHIC OBSERVATIONS IN PORT GARDNER, WASHINGTON

1973, 1974 and 1975

by

T. Saunders English

Department of Oceanography
University of Washington
1976

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Introduction

A baseline description of the saltwater environment in Port Gardner, Washington, was sought so that the effect of reductions in pulp mill waste discharges could be documented and evaluated. Concentrations of sulfite waste liquor were expected to decrease and concentrations of dissolved oxygen were expected to increase. It was considered possible that related changes in concentrations of inorganic nutrient ions and phytoplankton populations might be detected in later monitoring.

The baseline observations were planned to cover a geographic area larger than Port Gardner in order to document environmental changes not likely to be related to changes in mill waste discharges. The plan was to try to sample at least monthly during the first year and bimonthly or quarterly thereafter.

Materials and Methods

The sampling stations for water quality and oceanographic observations were chosen to extend from the main basin of Puget Sound, through Port Gardner, and into Port Susan and Saratoga Passage (Figure 1). Periodic hydrographic cruises were made to measure chemical water properties at 22 locations. Standard hydrographic casts to 100 meters and greater depths sampled salinity, temperature, dissolved oxygen, sulfite waste liquor (SWL), chlorophyll *a*, and the inorganic nutrient ions of phosphate, silicate, nitrate, nitrite, and ammonia.

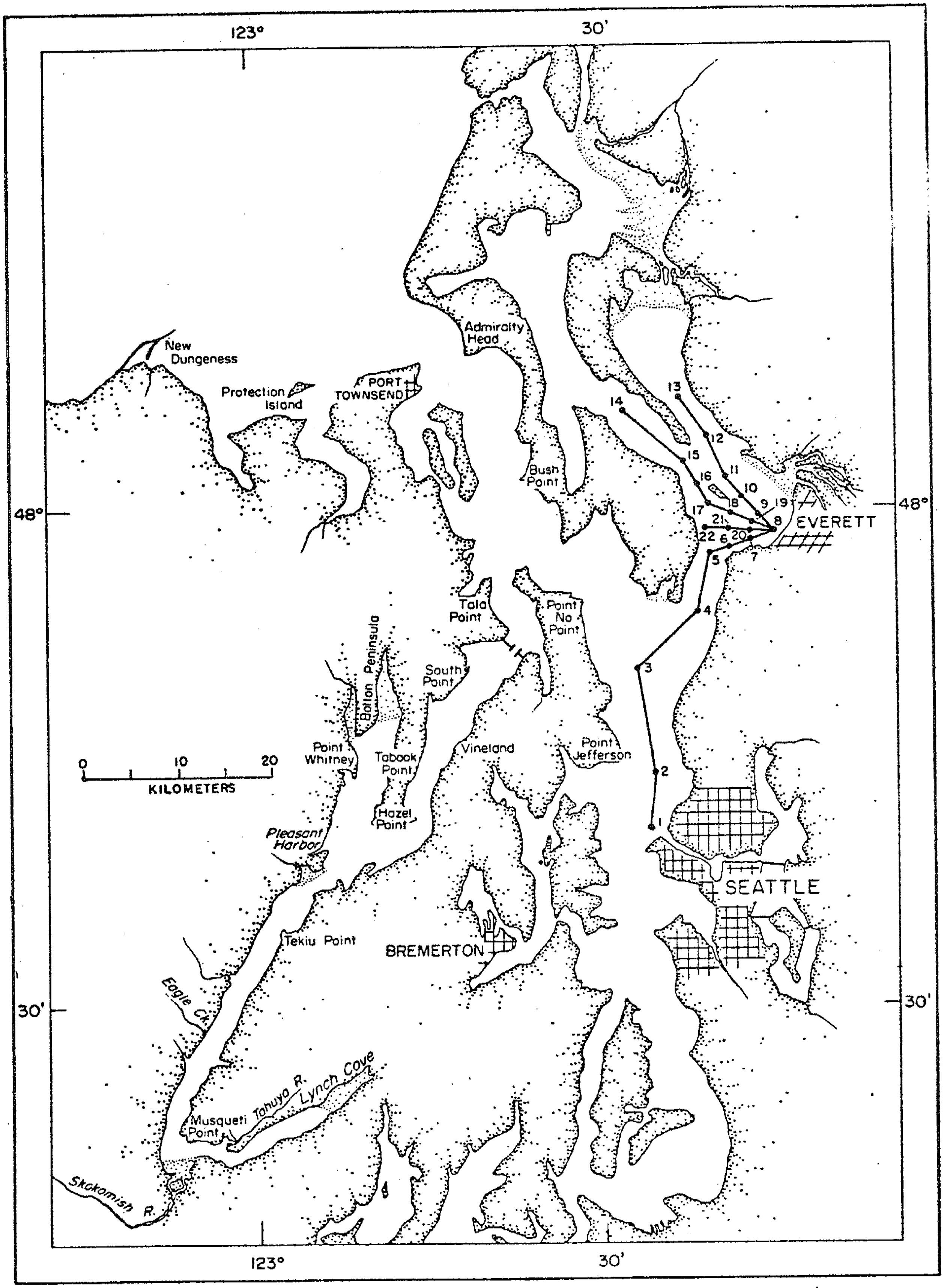

Figure 1. Station locations.

The analyses of salinity, dissolved oxygen, and the inorganic nutrient ions, and chlorophyll *a* were done by standard methods in the Department of Oceanography, University of Washington. The concentrations of sulfite waste liquor were determined as Pearl Benson Index in the analytical laboratory of the Washington State Department of Ecology.

The data have been processed by Department of Oceanography computer programs. The results are prepared for dissemination by xerographic reduction and reproduction to a format of 8½ by 11 inch page size.

The data for descriptions of mill operations were obtained from the files of the Department of Ecology and by the cooperation of the Scott Paper Company and the Weyerhaeuser Company.

Results

The discharge of total solids is considered to be a good index of waste loading to the environment from 1966 through 1975 (Figure 2). The reduction of wastes discharged through the deepwater diffuser outfall by Scott in 1974 was a result of operation of the stage 1 recovery system. The total waste load was reduced to levels of 1972 caused by poor market conditions. The reduction of waste loads by Weyerhaeuser in 1975 was reflected in both the deepwater and inshore waste outfalls.

The effect of SWL discharges into the environment can be seen by examination of a series of representations of concentrations against depth at stations 1 to 13 on a transect line from the main basin off

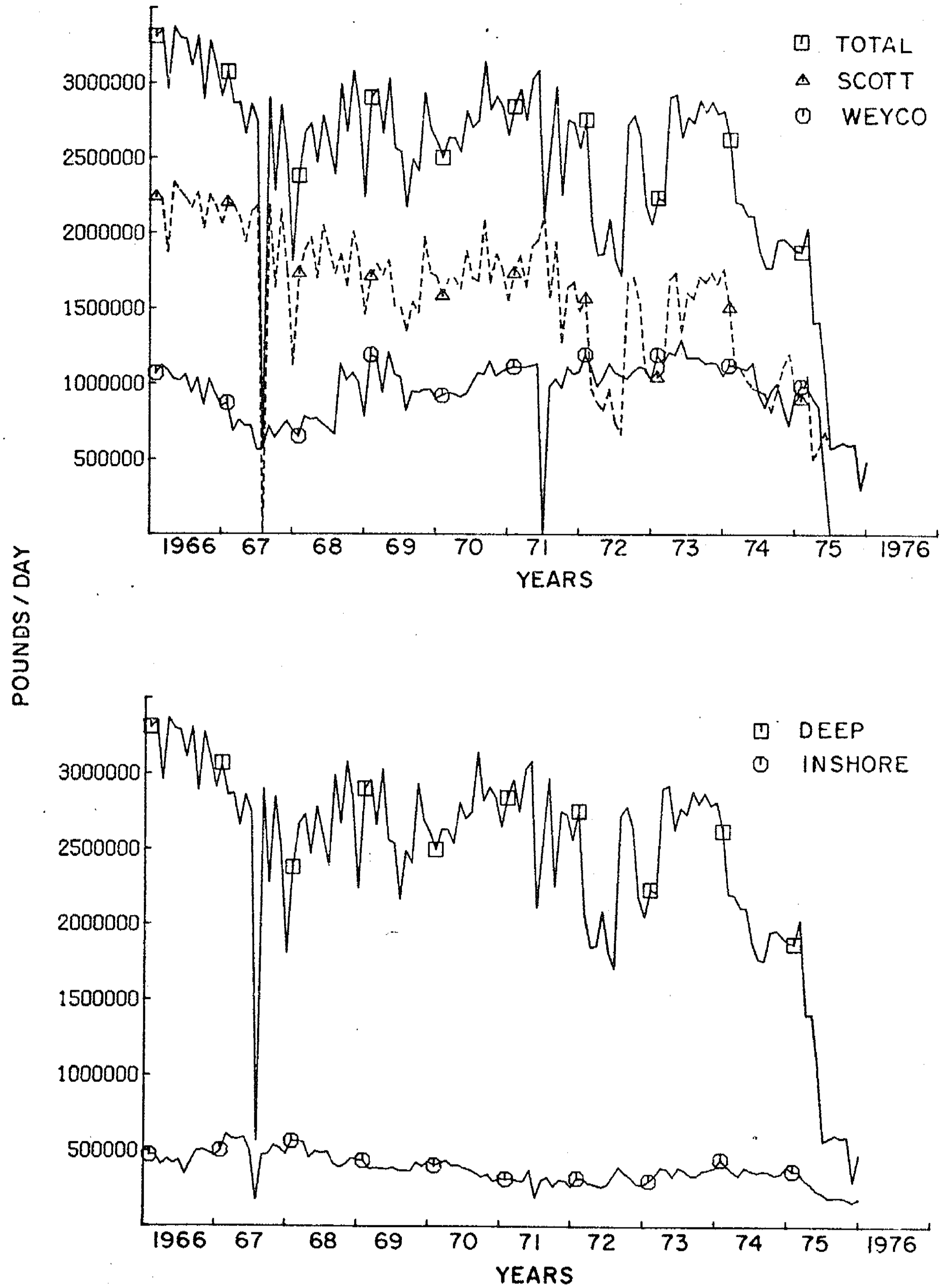

Figure 2. Mill operations as total solids from Scott and Weyerhaeuser and the total of both mills through the deepwater diffuser outfall; total inshore outfalls compared to the deepwater diffuser outfall.

Seattle, through Port Gardner, and into Port Susan (Figures 3 and 4). The highest concentrations of SWL are at depth at station 8; concentrations tend to be higher to the north into Port Susan than to the south into the main basin of Puget Sound. The differences in SWL concentrations between four 6-month periods are suggestive, but not striking.

The corresponding concentrations of dissolved oxygen reveal occasional evidence of decreases at depth near station 8 (Figures 3 and 4). The level of concentration of dissolved oxygen shows a strong seasonal change, higher in winter-spring and lower in late summer-fall. The concentrations of dissolved oxygen tend to be lower in Port Susan than in the main basin of Puget Sound.

Concentrations of dissolved oxygen and sulfite waste liquor can also be represented by contours on a transect from the main basin near Seattle, through Port Gardner, and into Port Susan (Figures 5 and 6). The source of sulfite waste liquor at the deepwater diffuser outfall can be located repeatedly; a corresponding area of decreased concentrations of dissolved oxygen can be found occasionally. The differences between the four 6-month periods are not clear.

Relative concentrations of sulfite waste liquor under unit area of sea surface are highest at and near the location of the deepwater diffuser outfall at station 8 (Figures 7 and 8). Concentrations tend to be higher toward Port Susan than in the main basin of Puget Sound to the south. The extreme variability in concentrations between times at station 8 is considered to be caused by the variable location of the subsurface plume from the outfall.

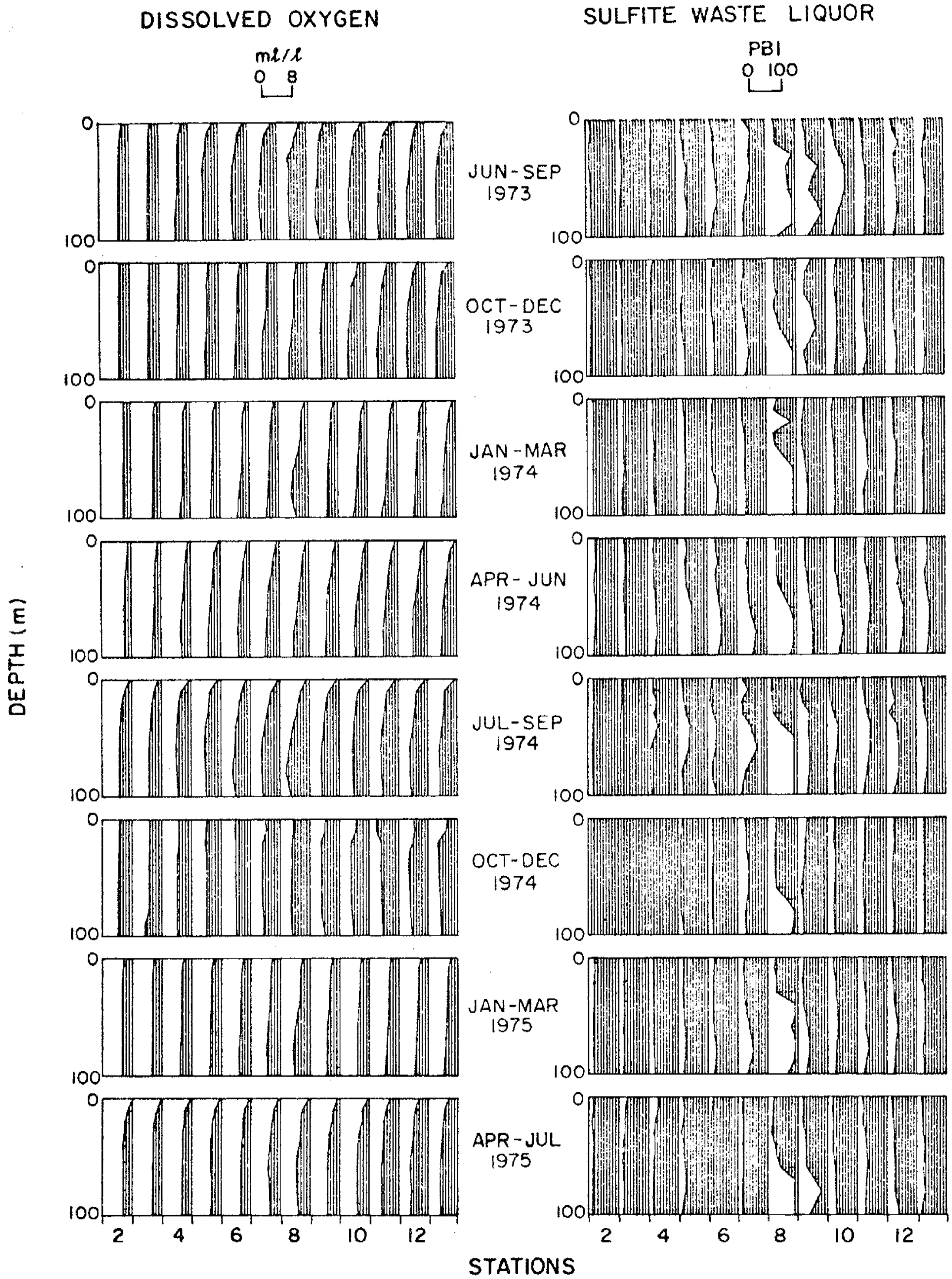

Figure. 3. Vertical distributions of dissolved oxygen and sulfite waste liquor concentrations at 13 stations, 1973-1975.

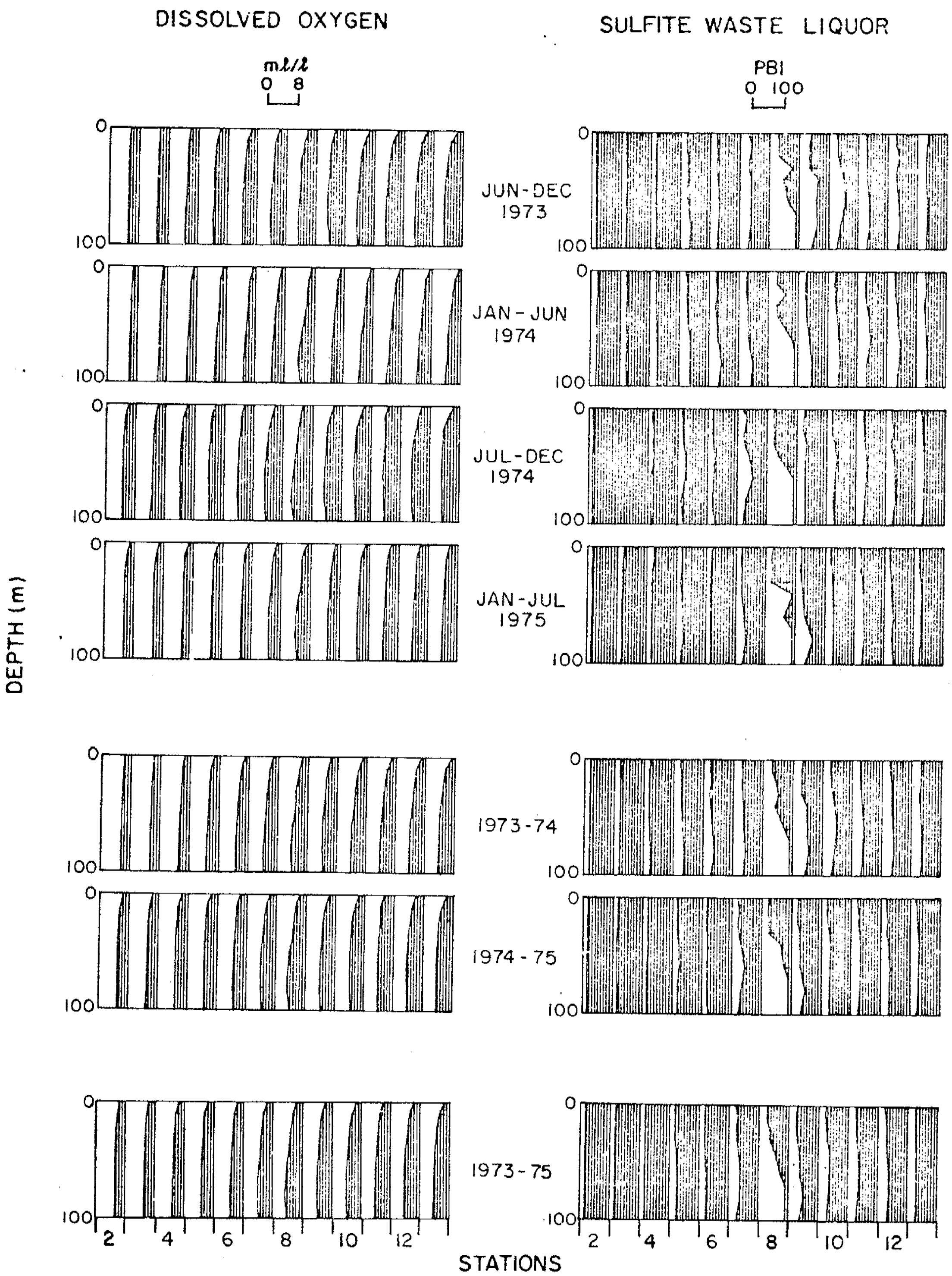

Figure 4. Vertical distributions of dissolved oxygen and sulfite waste liquor concentrations at 13 stations, 1973-1975.

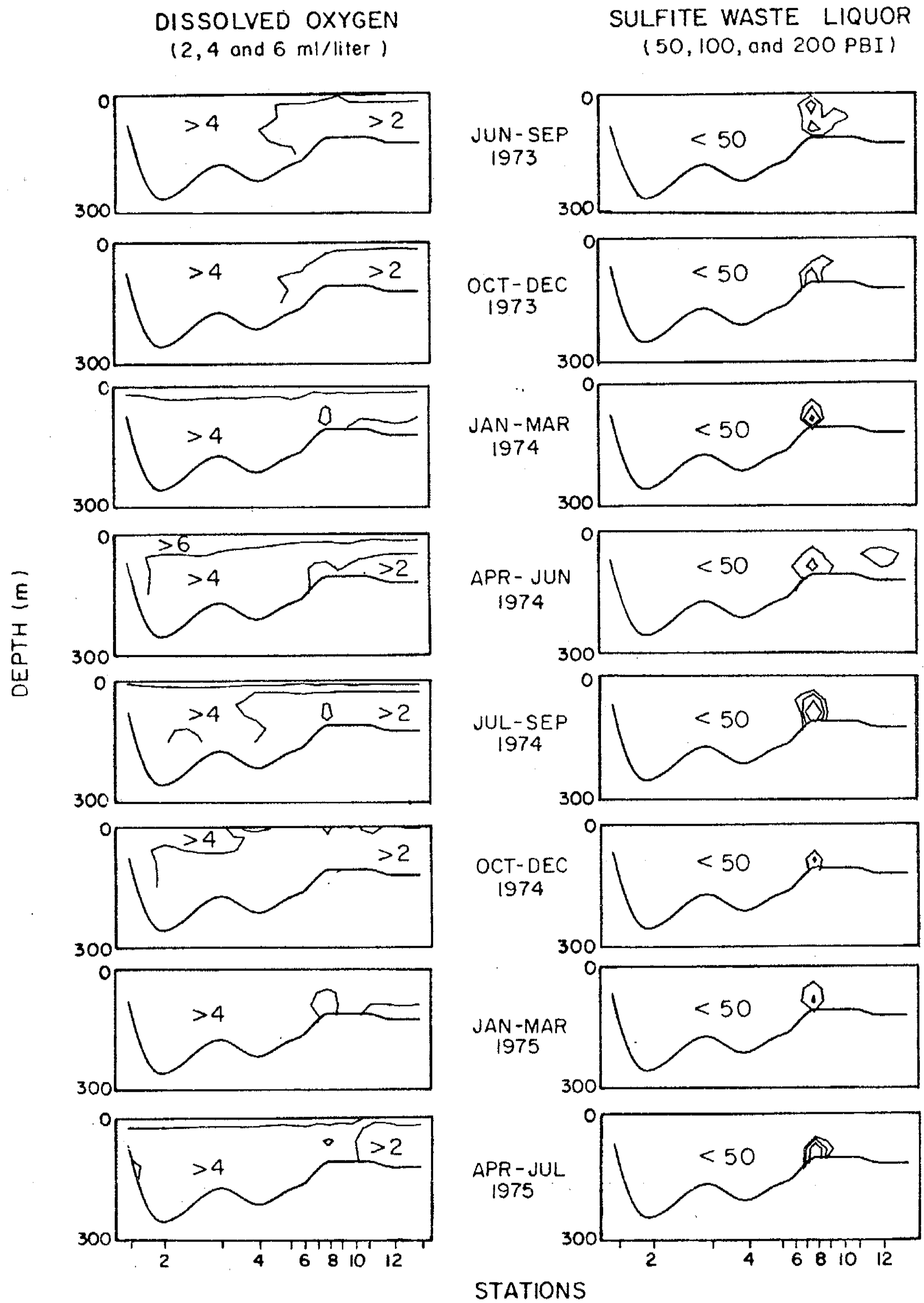

Figure 5. Vertical distributions of dissolved oxygen and sulfite waste liquor concentrations at 13 stations, 1973–1975.

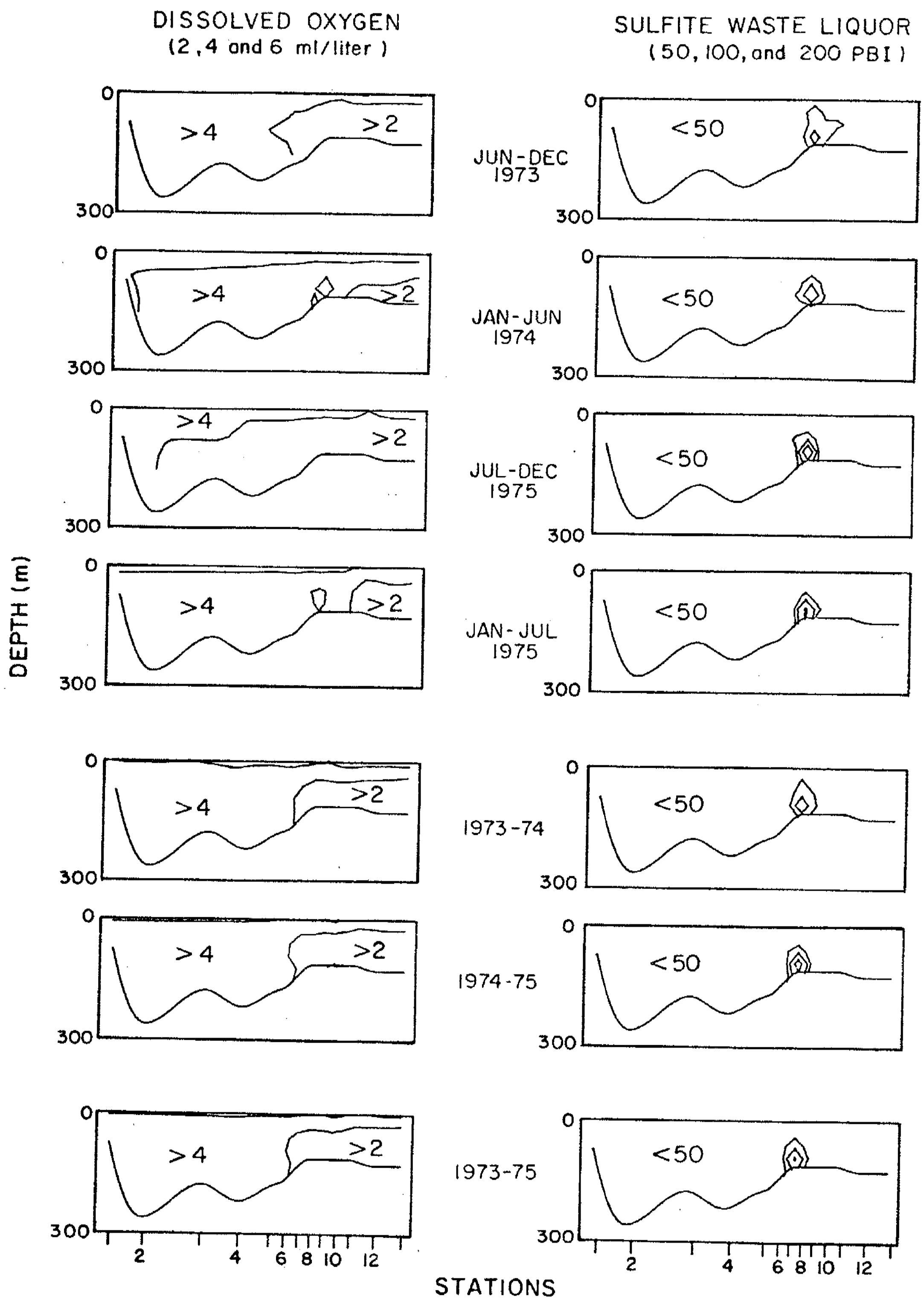

Figure 6. Vertical distributions of dissolved oxygen and sulfite waste liquor concentrations at 13 stations, 1973-1975.

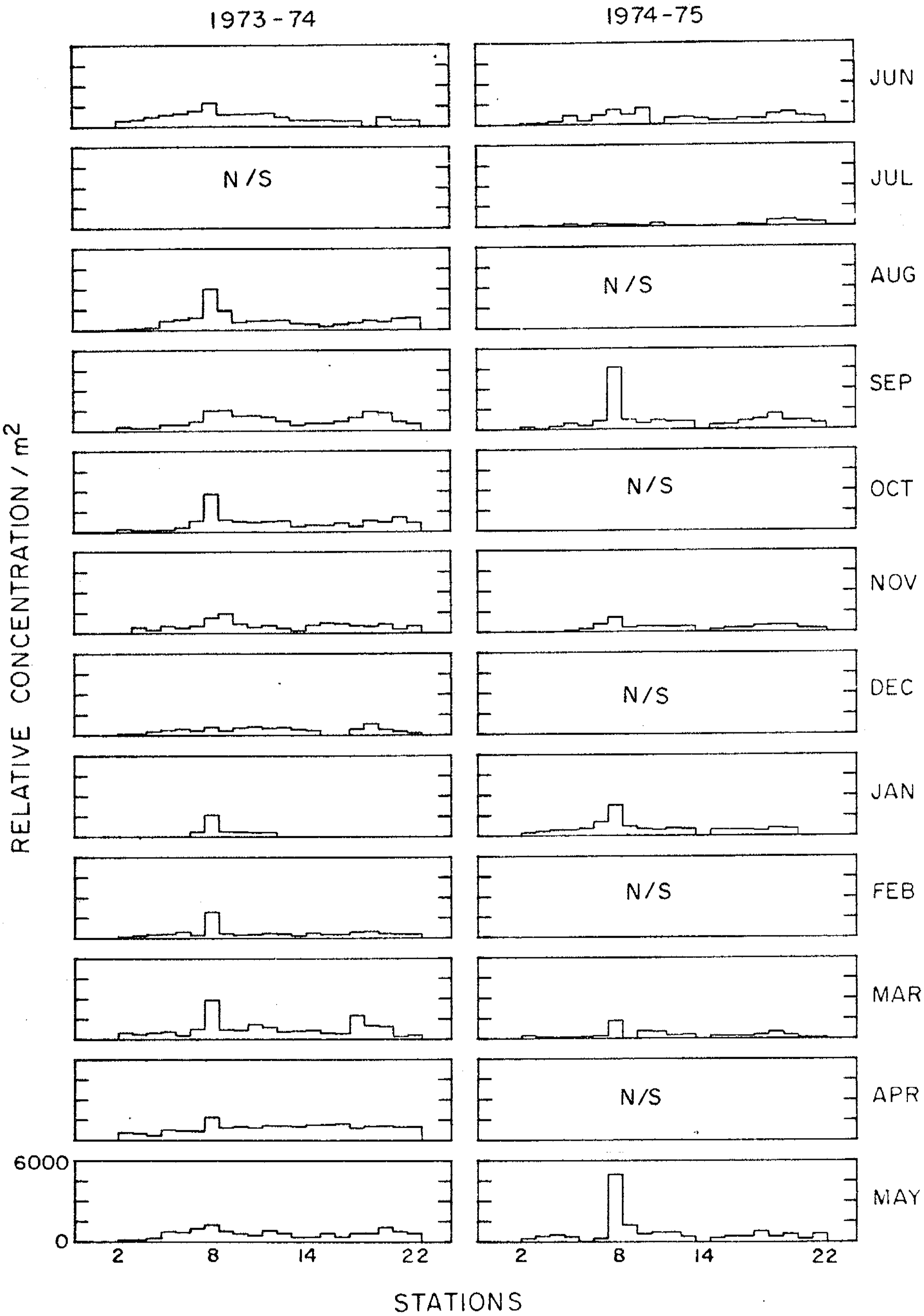

Figure 7. Relative concentrations of sulfite waste liquor to 100 meters at all locations, 1973-1975.

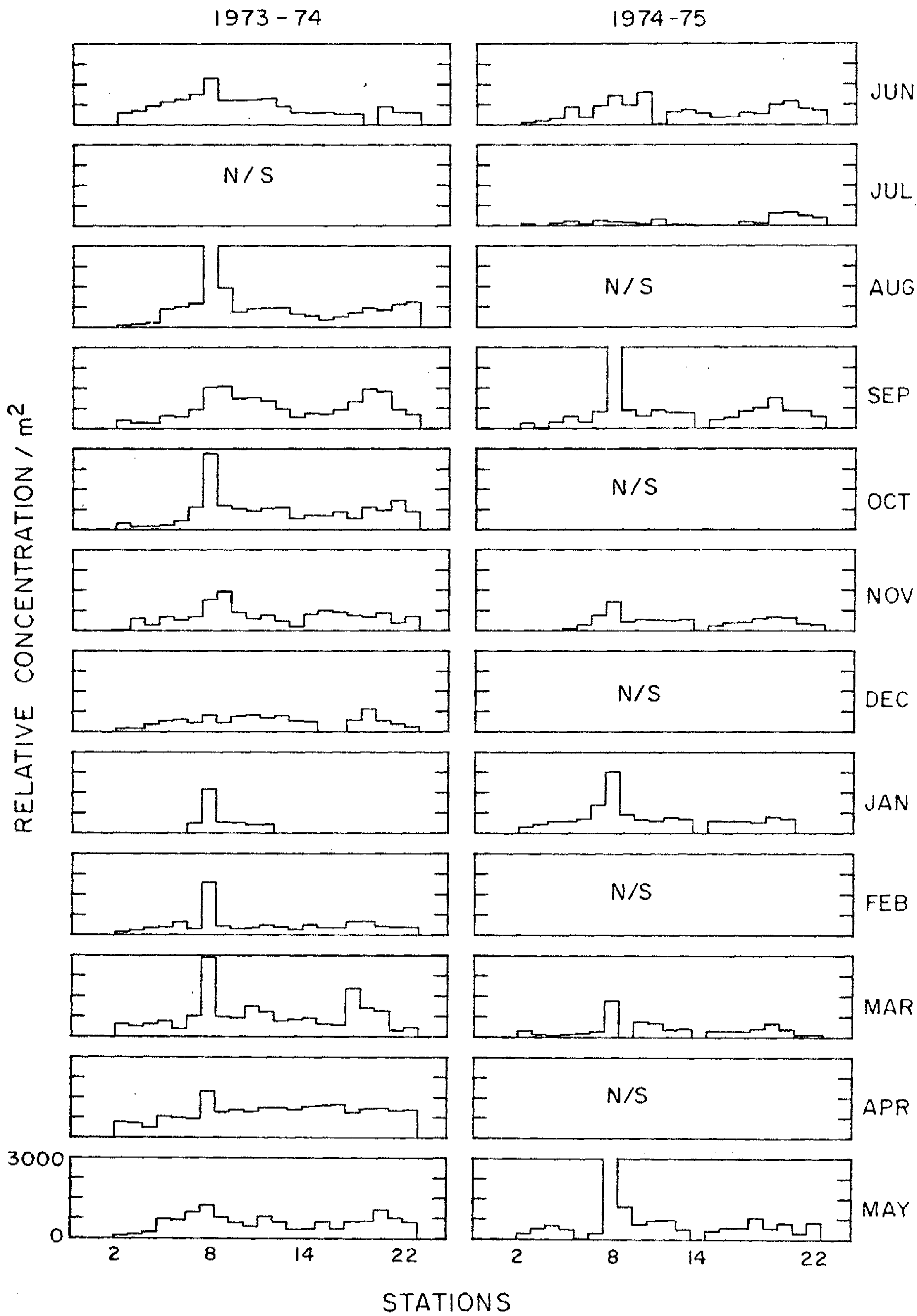

Figure 8. Relative concentrations of sulfite waste liquor to 100 meters at all locations, 1973-1975.

The seasonal changes in water properties at a station location can be seen by examination of a series of representations of concentrations against depth (Figures 9, 10 and 11). An alternative representation of the same data can be made by contouring concentrations over time (Figures 12, 13, and 14). The seasonal changes are most obvious in the surface water. Density, as sigma-t, is controlled by salinity. The relationship between high chlorophyll *a* and low inorganic nutrients is clear in the main basin of Puget Sound (station 2), but less striking in Port Gardner (stations 20 and 8).

The distributions of relative concentrations of chlorophyll *a* show differences between the main basin of Puget Sound, Port Gardner, and Port Susan (Figure 15). The seasonal cycle of relative concentration of chlorophyll *a* show similar timing between stations, but differences in the peak concentrations between locations (Figure 16).

Discussion

The water quality and oceanographic observations which have been taken in Port Gardner provide a baseline against which further changes can be compared. The effect of mill discharges can be seen in concentrations of sulfite waste liquor and dissolved oxygen in Port Gardner near the deepwater diffuser outfall. The changes through mid-1975 were relatively slight, but were in the expected directions.

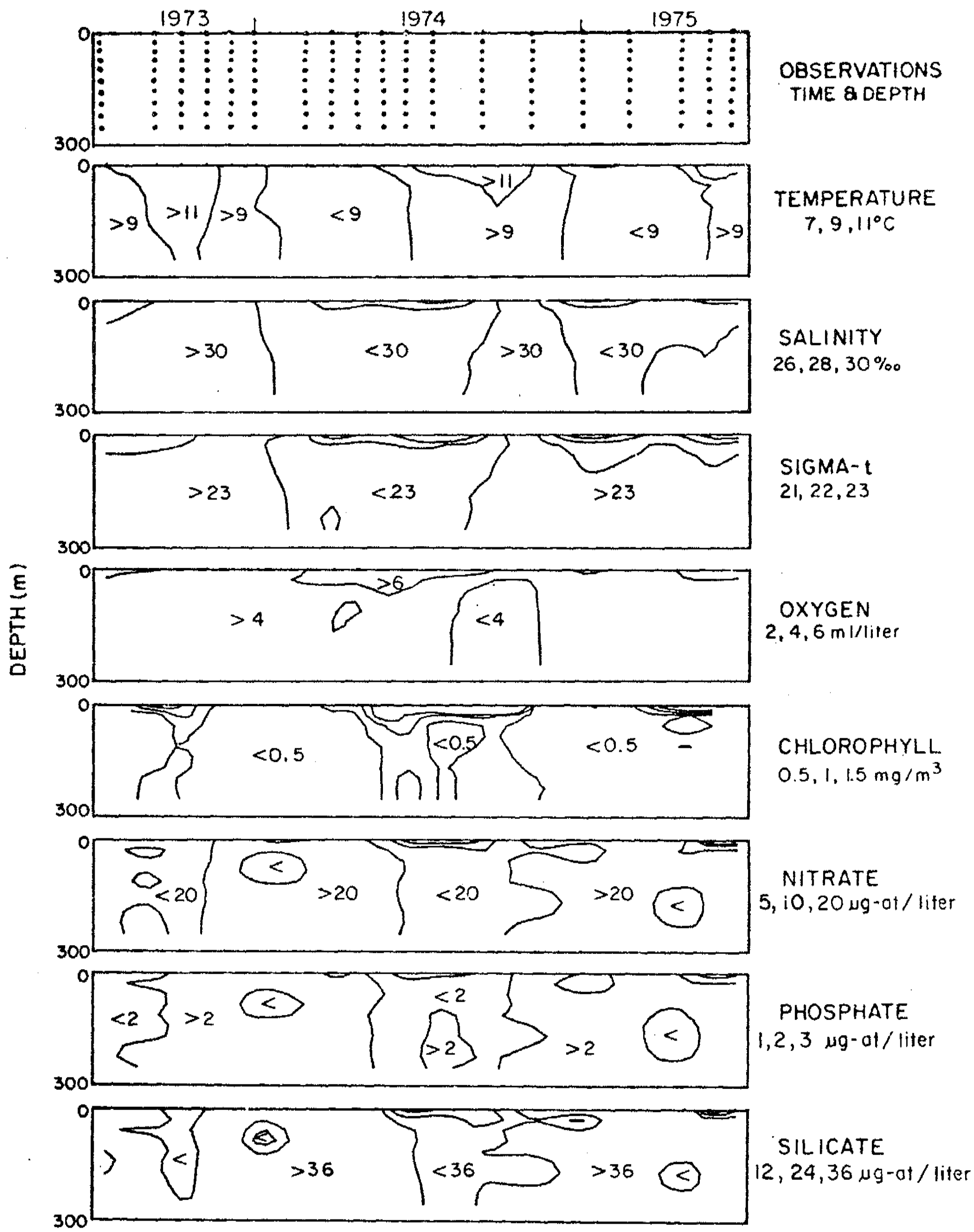

Figure 9. Time series observations of water properties at station 2, 1973-1975.

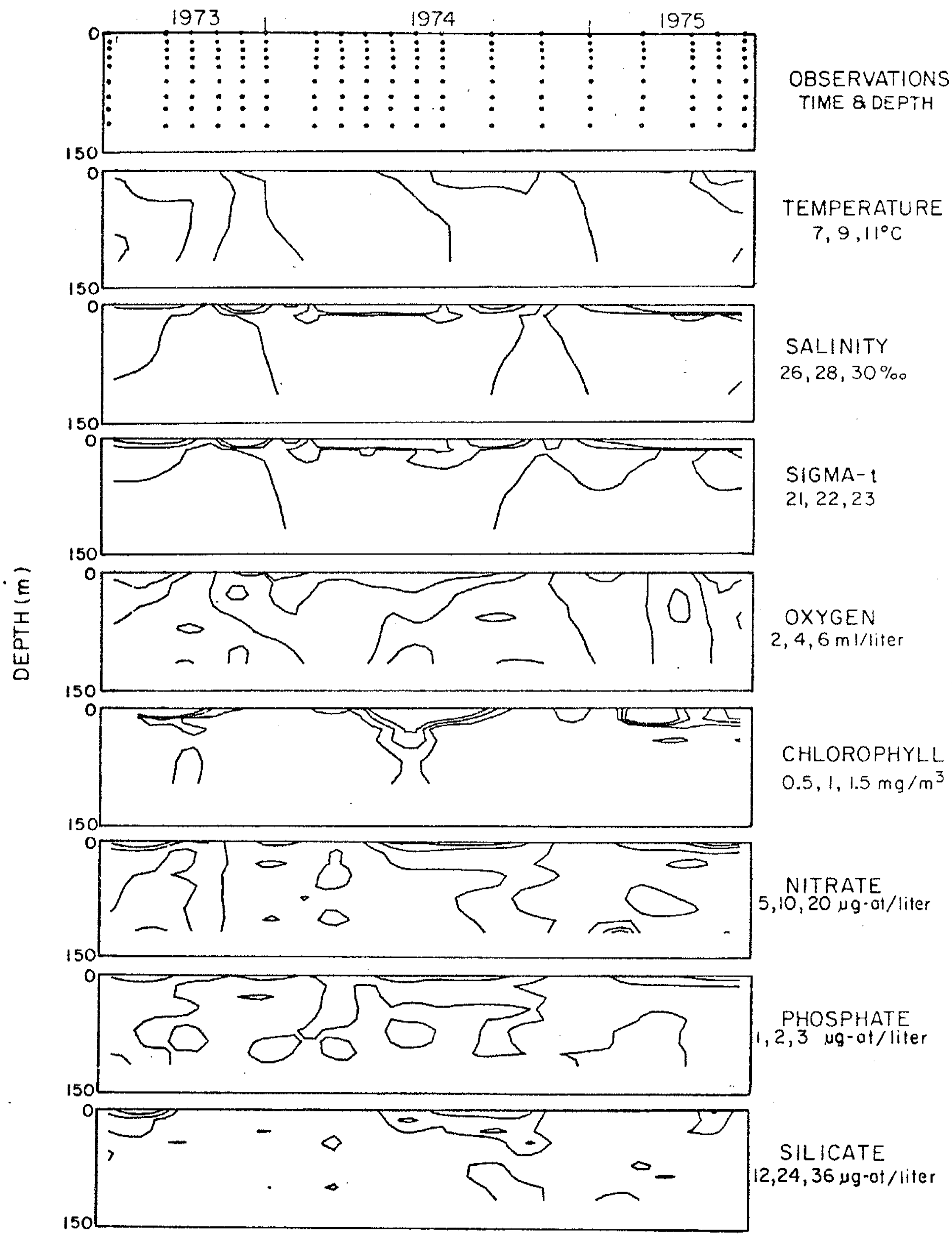

Figure 10. Time series observations of water properties at station 29, 1973-1975.

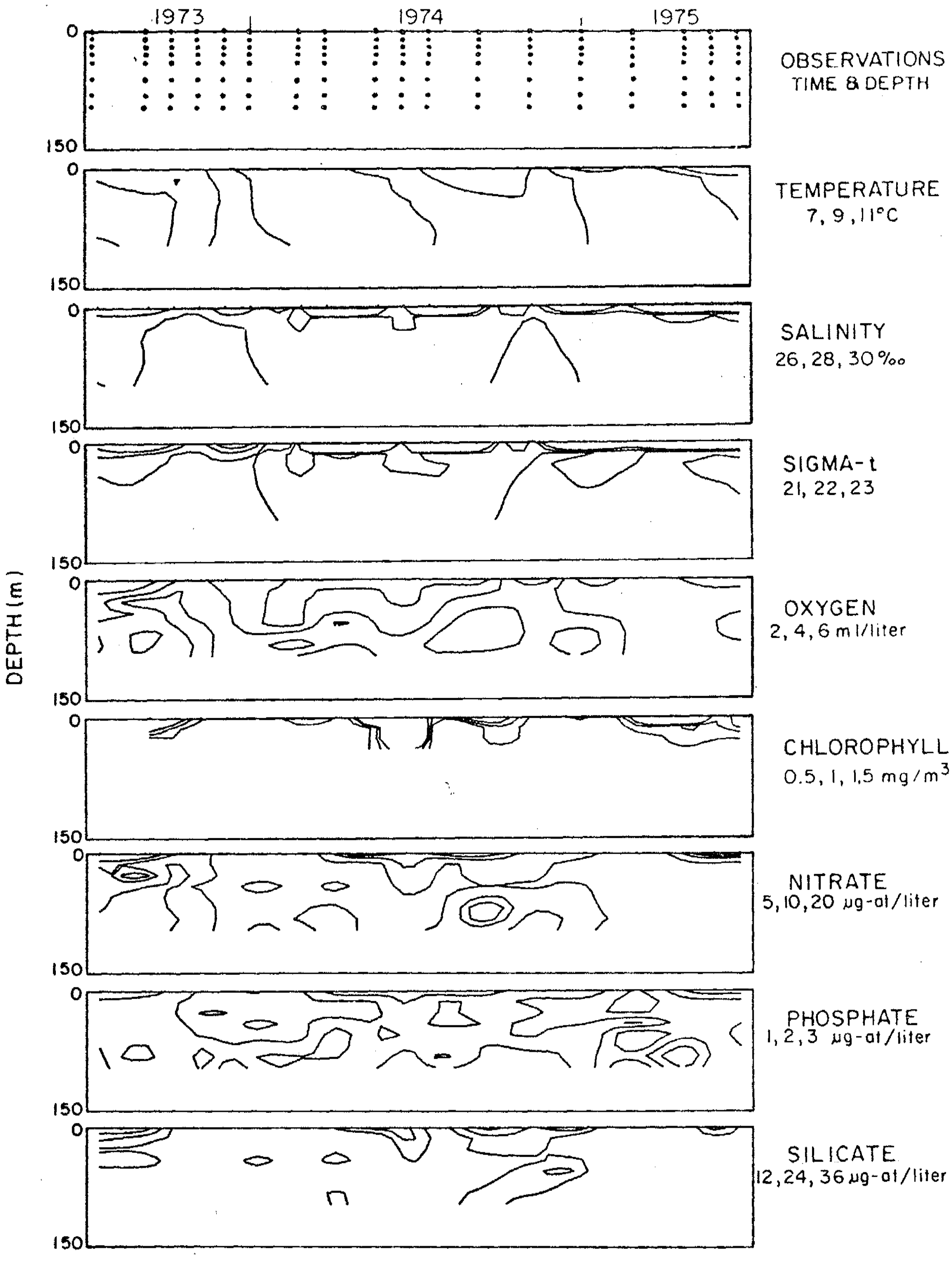

Figure 11. Time series observations of water properties at station 8, 1973-1975.

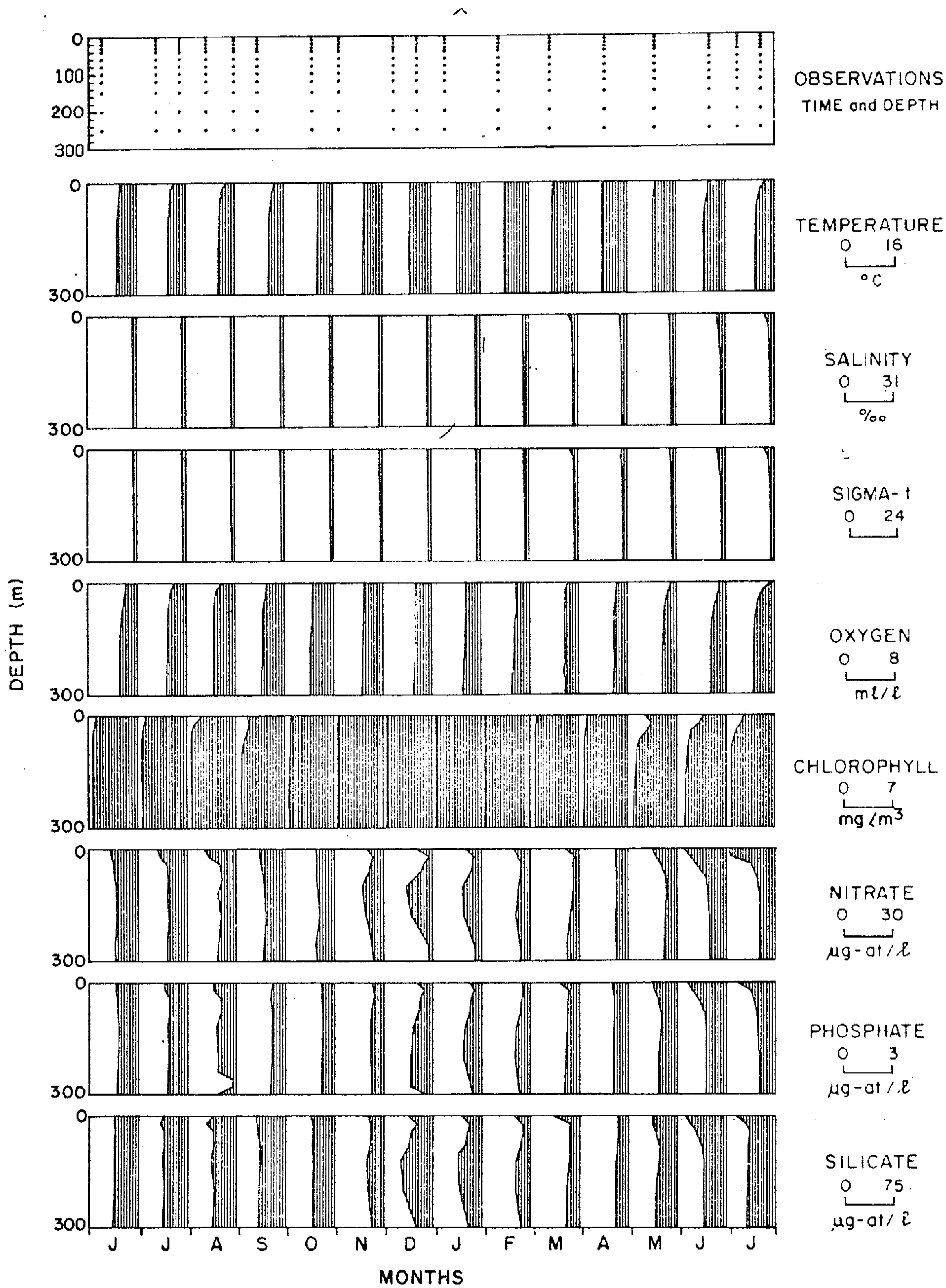

Figure 12. Time series observations of water properties at station 2, 1973-1975.

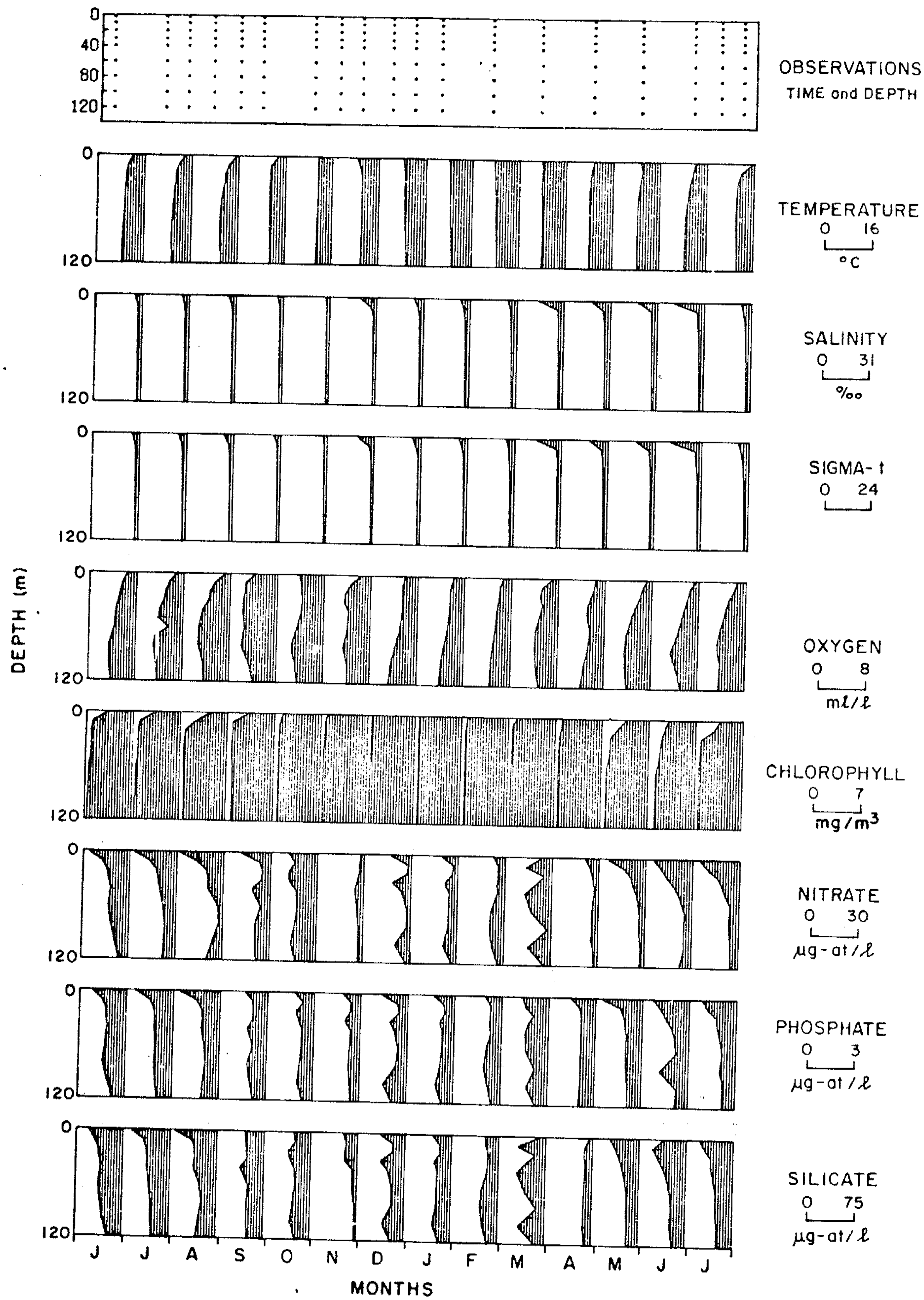

Figure 13. Time series observations of water properties at station 20, 1973-1975.

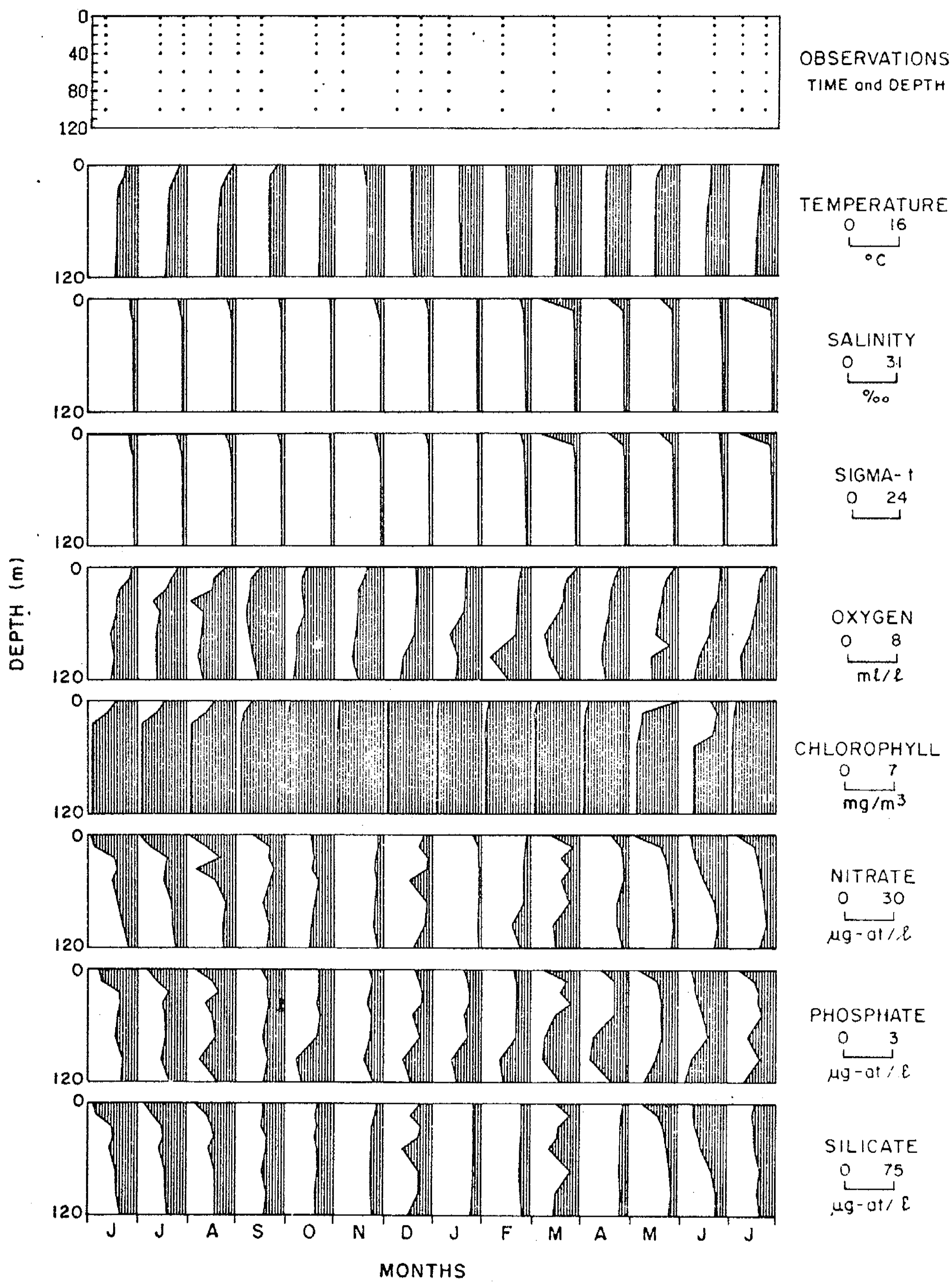

Figure 14. Time series observations of water properties at station 8, 1973-1975.

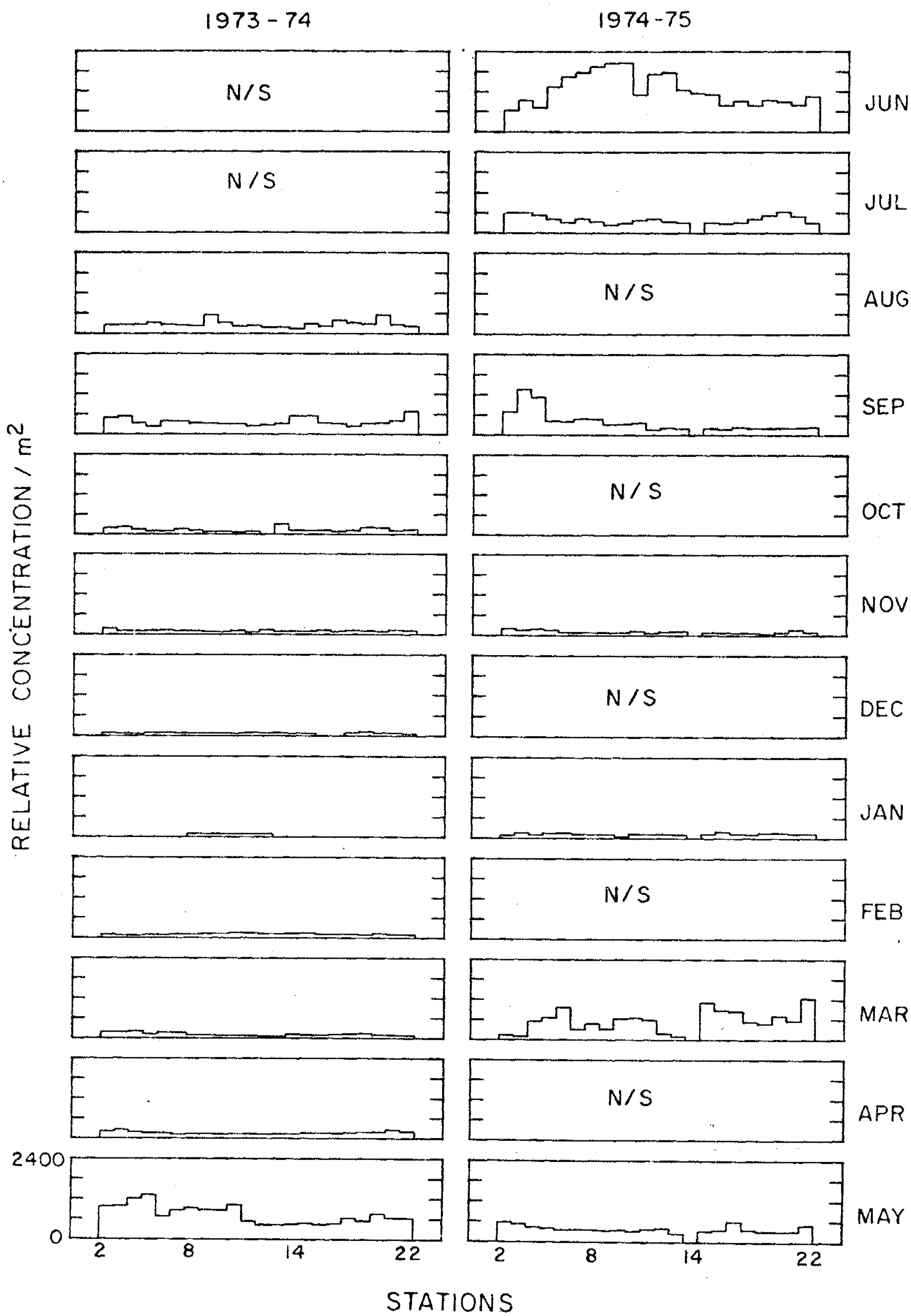

Figure 15. Relative concentrations of chlorophyll *a* to 40 meters at all stations, 1973-1975.

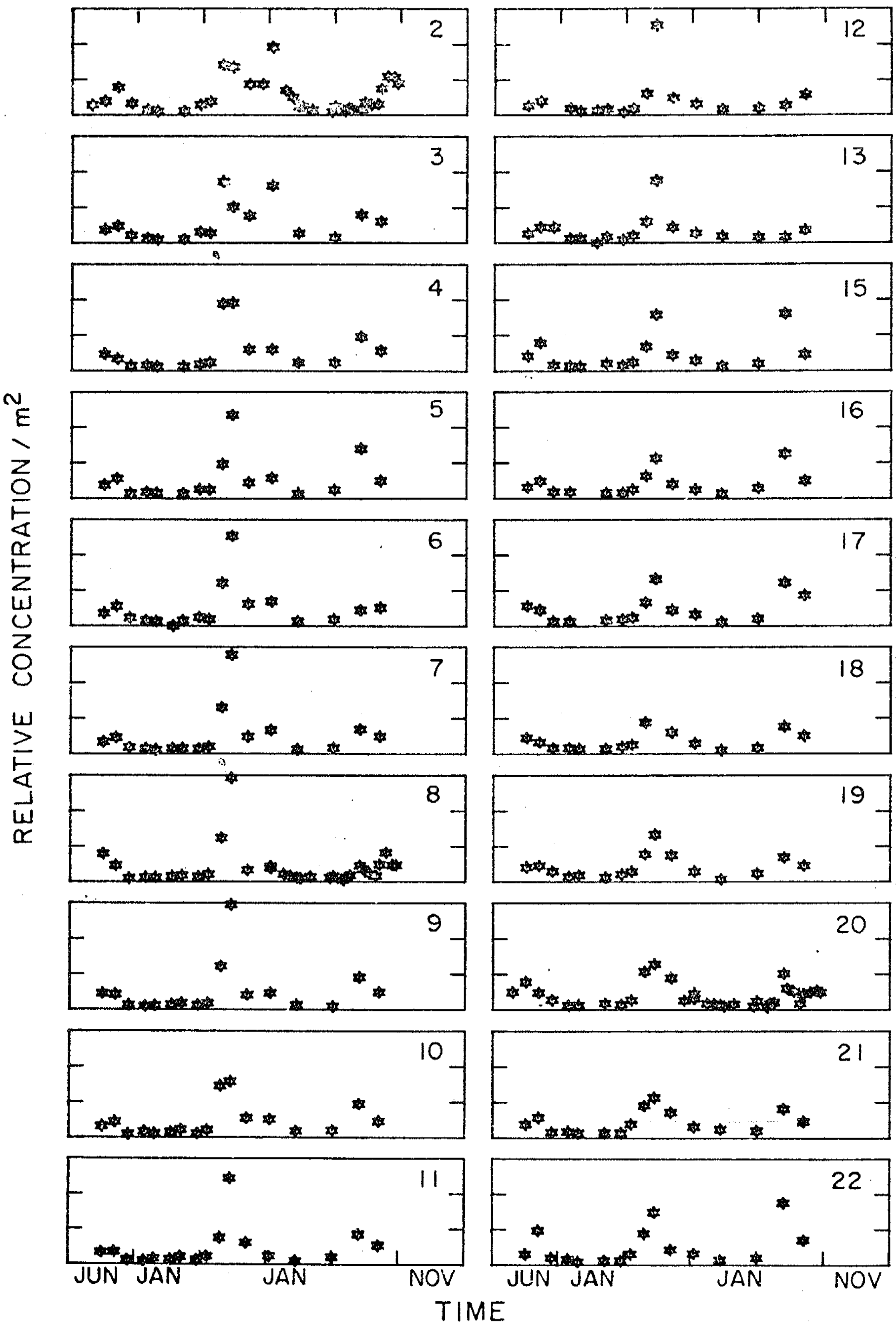

Figure 16. Relative concentrations of chlorophyll *a* to 40 meters at individual stations, 1973–1975.

SECTION VI

Trawling Observations in Port Gardner, Washington

1973, 1974, 1975

TRAWLING OBSERVATIONS IN PORT GARDNER, WASHINGTON

1973, 1974, AND 1975

by

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1976

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Introduction

A series of samples taken with a research beam trawl was sought to provide a baseline description of populations of fishes, crabs, and shrimps in Port Gardner so that the beneficial biological changes caused by reductions in pulp mill waste discharges might be assessed. There had been no statement of precisely what biological changes might occur, so information was sought over a range of species, depths, areas, and seasons.

The time available to obtain a biological baseline by trawling before changes in mill waste discharges began was recognized to be undesirably short. However, biological changes in populations might be expected to occur more slowly than chemical changes in the environment, increasing the time for baseline observations.

Materials and Methods

The research trawl selected for use was a 3-meter beam trawl. The trawl frame consisted of two steel skids attached to a 3-m aluminum beam. A 16-ft semi-balloon otter trawl net of 1¼-in mesh (cod-end of 1-in mesh; cod-end liner of ¼-in mesh) was attached to the frame. A weak link of 3/8-in polypropylene line was interposed between the terminal end of the winch cable and the beam trawl's towing bridle. This weak link allowed the trawl to be separated from the cable if underwater obstacles were encountered which would otherwise damage the trawl frame or the net. A float and a safety line of 3/8-in braided polypropylene were attached to the cod-end of the net to permit retrieval of the beam trawl and net when they were torn from the towing cable. Two pacer wheels attached to the skids with Veeder-Root counters, provided an estimate of the distance the trawl travelled along the bottom. Duplicate beam trawl hauls were made at 5, 10, 20, 40, 60, 80, 100, 120, and 150 meters. The net was trawled along the bottom for 5 min. Processing commenced as soon as the net was retrieved. All fishes and crabs were determined to species and measured to the nearest 5 millimeters. Sex was determined whenever possible. Similar processing was accorded to the Pandalid shrimps, which were measured to the nearest millimeter.

Trawling locations were selected in Port Gardner (near station 8), at Tulalip, near station 12, at Mukilteo, near station 6, and at Clinton, near station 22 (Figure 1). The location at Clinton was not used after early results seemed poor.

The sampling design was more balanced for the first year, 1973-74, than for the second year, 1974-75 (Table 1). In the second year, more hauls were made at Port Gardner than at Mukilteo and Tulalip. The shrimp were not analyzed for all trawl hauls.

Results

The results of the trawling observations have been analyzed by species, length, depth, and month, and in some cases by sex. The results are given as length-frequency diagrams, uncorrected for the different numbers of trawl hauls (see Table 1).

Ten species, or sexes within species, have been analyzed and depicted: male *Parophrys vetulus*, female *P. vetulus*, male *Cancer magister*, female *C. magister*, *Panadopsis dispar*, *Pandalus borealis*, *P. danae*, *P. hypsinatus*, *P. jordani*, and *P. platyceros*. Each of the

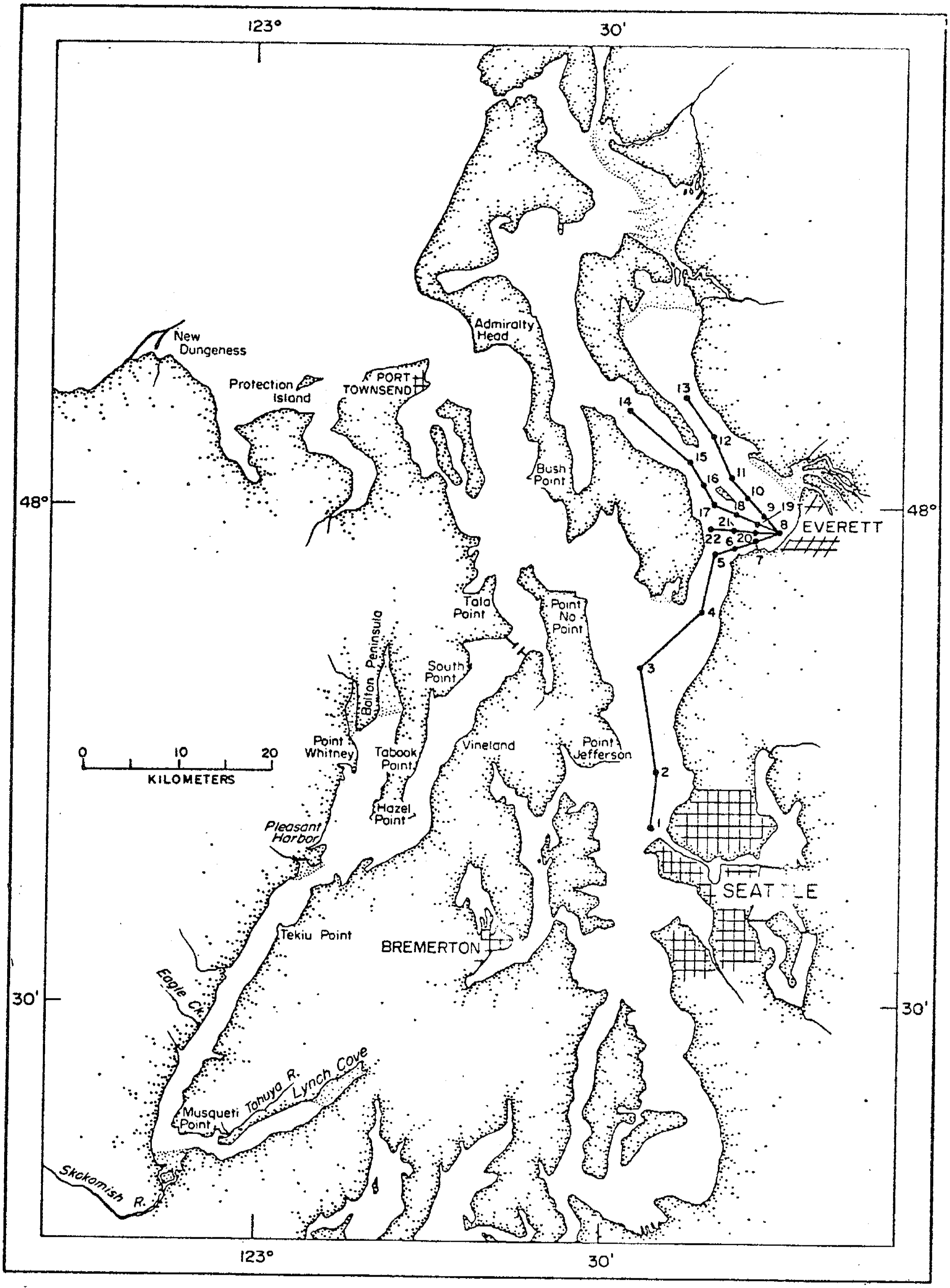

Figure 1. Station locations.

Table 1. Sampling pattern with the research beam trawl, by depth and by cruise, in 1973-74 and 1974-75, for *Parophrys* and *Cancer* and for shrimp, at Mukilteo, Port Gardner, and Tulalip

DEPTH (m)	73-74 PAR & CAN			73-74 SHRIMP			74-75 PAR & CAN			74-75 SHRIMP		
	M	P	T	M	P	T	M	P	T	M	P	T
5	18	17	18	9	9	9	14	23	14	14	23	14
10	18	18	20	9	9	10	14	23	14	14	23	14
20	18	20	20	9	10	10	14	22	14	14	21	14
30	18	20	20	9	10	10	12	24	14	12	24	14
40	18	19	20	9	10	10	14	24	14	14	24	14
60	18	20	20	9	10	10	14	24	14	14	24	14
80	18	20	20	9	10	10	13	24	14	13	24	14
120		20	20		10	10		23	13		23	13
150		18			9			24			24	

DATE	73-74 PAR & CAN			73-74 SHRIMP			74-75 PAR & CAN			74-75 SHRIMP		
	M	P	T	M	P	T	M	P	T	M	P	T
JUN	14	16	16				14	18	16			
JUL	4	16	16	2	8	8	14	18	16	14	18	16
AUG	14	14	16	7	7	8	14	18	16	14	18	16
SEP	14	18	16	7	9	8		18			18	
OCT	14	18	16	7	9	8	14	18	16	14	18	16
NOV	14	18	16	7	9	8		15			15	
DEC							13	18	16	13	18	16
JAN	10	18	16	5	9	8		16			16	
FEB	14	18	14	7	9	7	12	18	15	12	18	15
MAR								18			18	
APR	14	18	16	7	9	8	14	18	16	14	18	16
MAY	14	18	16	7	9	8		18			18	
JUN				7	9	8				14	17	16

ten categories has been depicted for Mukilteo, Port Gardner, and Tulalip, by depth in 1973-74, by depth in 1974-75, by month in 1973-74, and by month in 1974-75.

The male English sole, *Parophrys vetulus*, is taken mostly at 100 meters and shallower (Figures 2 and 3). They are relatively most abundant in Port Gardner, and more abundant at Tulalip in the second year. The smaller individuals tend to occur at shallower depths. The smaller mode, presumably young-of-the-year, become abundant in late fall and early winter (Figures 4 and 5). The female English sole are sexually dimorphic, growing to a larger ultimate size than the males. In these research catches, the results for the females are very similar to those for the males (Figures 6, 7, 8, and 9). The commercial catch is almost all females.

The Dungeness crab, *Cancer magister*, fishery is restricted by law to males. Most males were taken by the beam trawl at 60 meters and shallower (Figures 10 and 11). Most were taken in Port Gardner and least at Tulalip. The seasonal distributions show no striking patterns (Figures 12 and 13). The females are most abundant in Port Gardner, but more evenly distributed between Mukilteo and Tulalip. The females appear least abundant in late fall and early winter (Figures 16 and 17).

The large shrimp *Panalopsis dispar* prefers the deeper depths in all three areas (Figures 18 and 19). No valid comparisons between areas can be made since 120 and 150 meters do not occur at Mukilteo and 150 meters was not sampled at Tulalip. Seasonal changes in length distributions reveal a small mode entering the catch in November 1973 (Figures 20 and 21).

The shrimp *Pandalus borealis* is most abundant at Tulalip and least abundant at Mukilteo (Figures 22 and 23). They are caught mostly at the deepest several depths at each location. Several modes of length grow through the year (Figures 24 and 25).

The small shrimp *Pandalus danae* occurs at shallower depths than the other species (Figures 26 and 27). The species is least abundant in Port Gardner. The scattered catches present no clear seasonal pattern (Figures 28 and 29).

The shrimp *Pandalus hypsinotus* is most abundant between 40 and 80 meters and at Tulalip (Figures 30 and 31). The scattered catches present no clear seasonal pattern (Figures 32 and 33).

The most abundant shrimp in these catches was *Pandalus jordani* (Figures 34 and 35). This shrimp was most abundant at Tulalip and much more abundant in the first year. The numerous individuals show the progression of two modes over the seasons (Figures 36 and 37).

The shrimp *Pandalus platyceros* was most abundant from 60 to 100 meters at Tulalip (Figures 38 and 39). This species is least abundant in Port Gardner. There is a suggestion of several modes and some change with seasons (Figures 40 and 41).

Discussion

The research beam trawl observations from Port Gardner and two control areas, Mukilteo and Tulalip, provide a detailed biological baseline against which to monitor future biological changes. The English sole and Dungeness crab were more abundant in Port Gardner than at Mukilteo and Tulalip. The shrimp were generally most abundant at Tulalip. The animals showed differences between depths, areas, and seasons, any or all of which might change in response to environmental changes in Port Gardner.

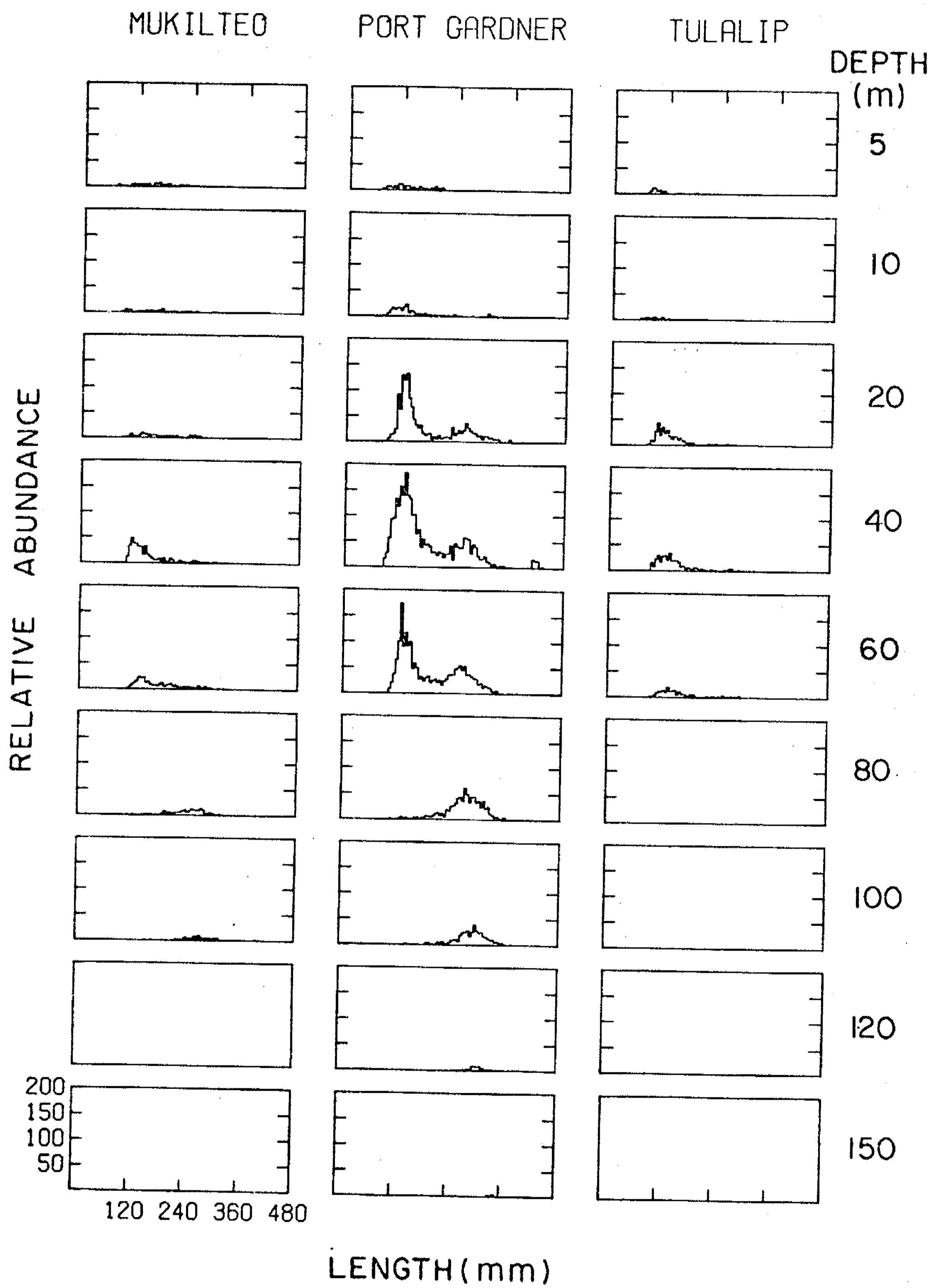

Figure 2. Length frequency distributions for male English sole at three locations over 9 depths, 1973-1974.

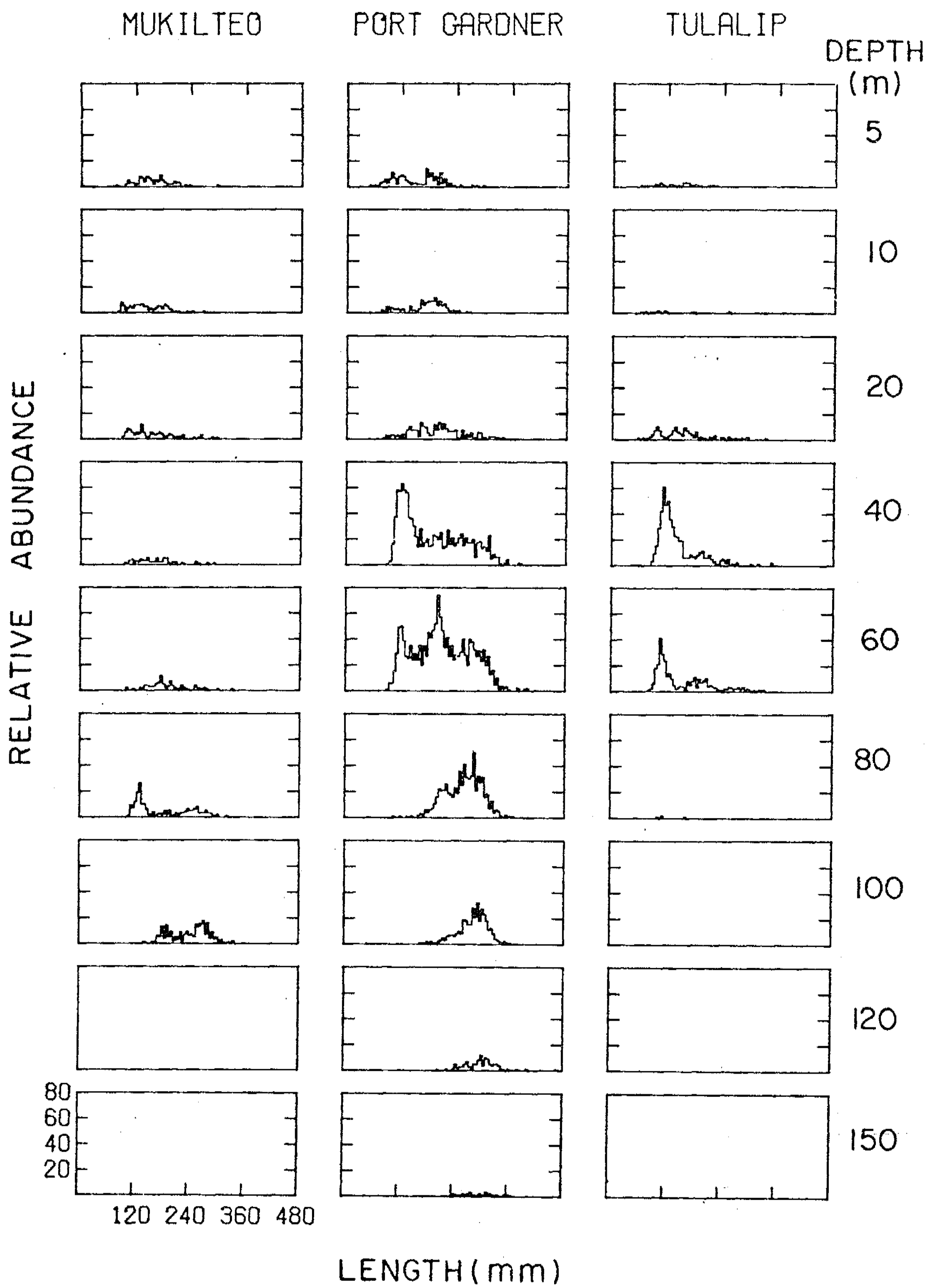

Figure 3. Length frequency distributions for male English sole at three locations over 9 depths, 1974-1975.

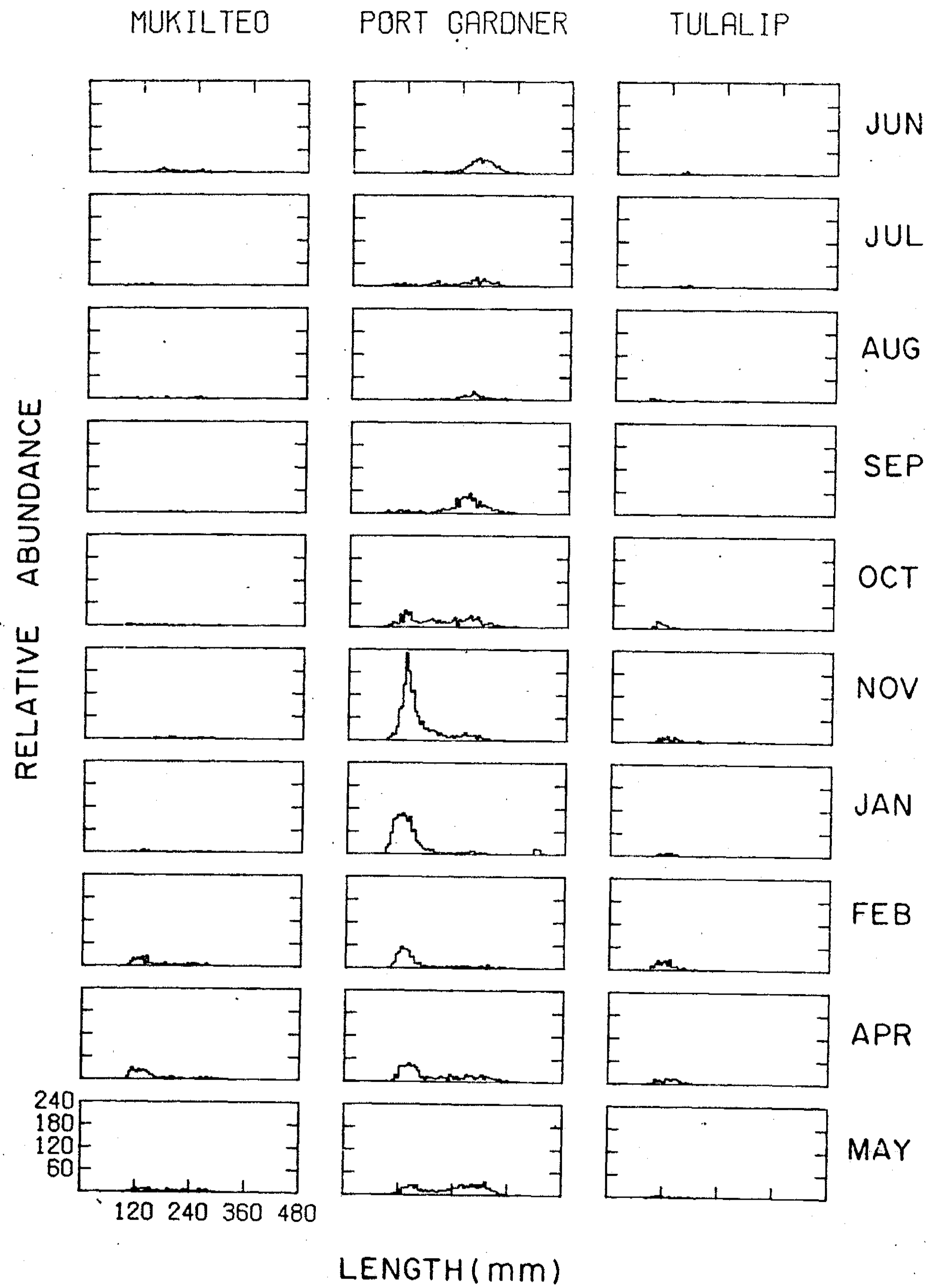

Figure 4. Length frequency distributions for male English sole at three locations over 10 months, 1973-1974.

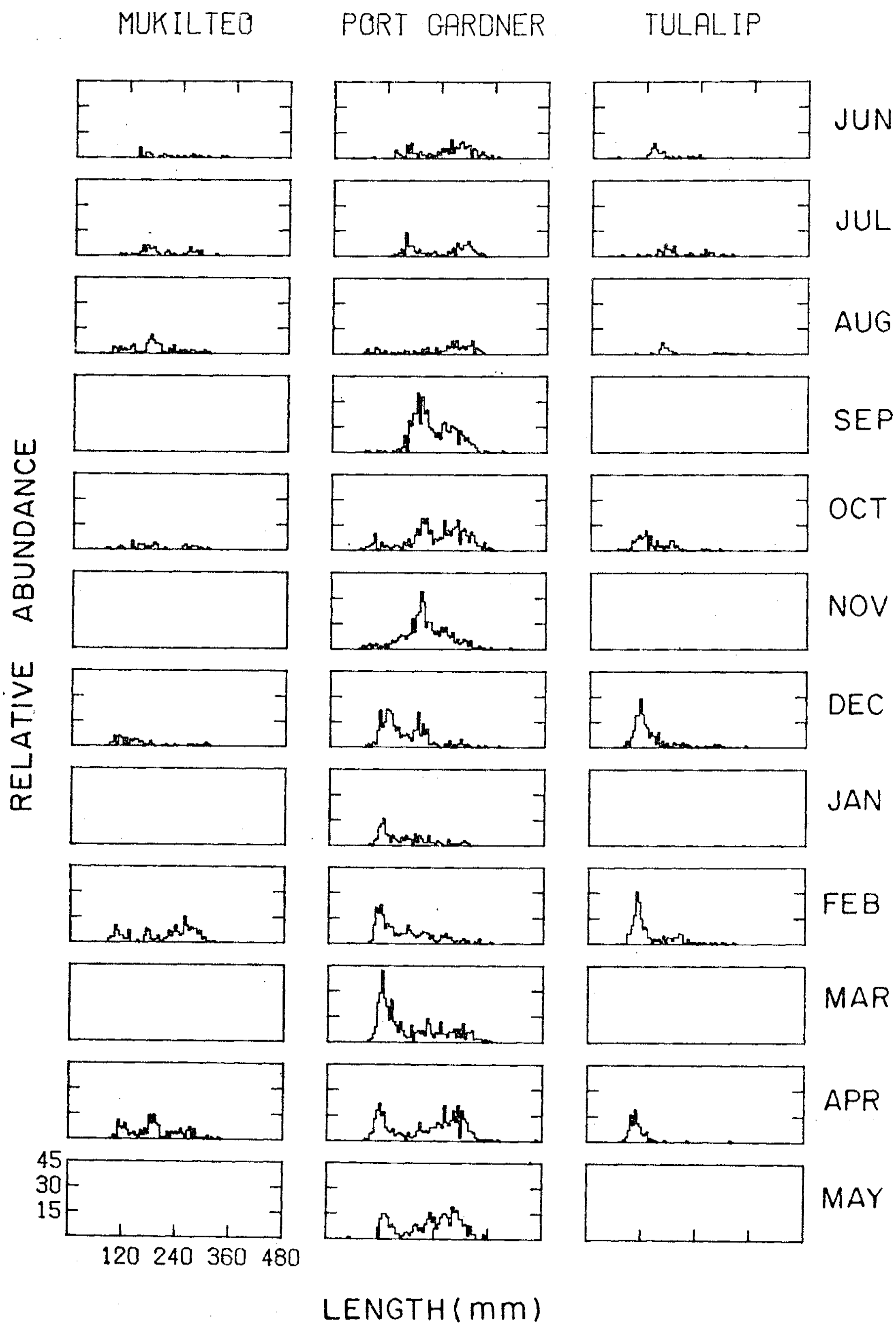

Figure 5. Length frequency distributions for male English sole at three locations over 12 months, 1974-1975.

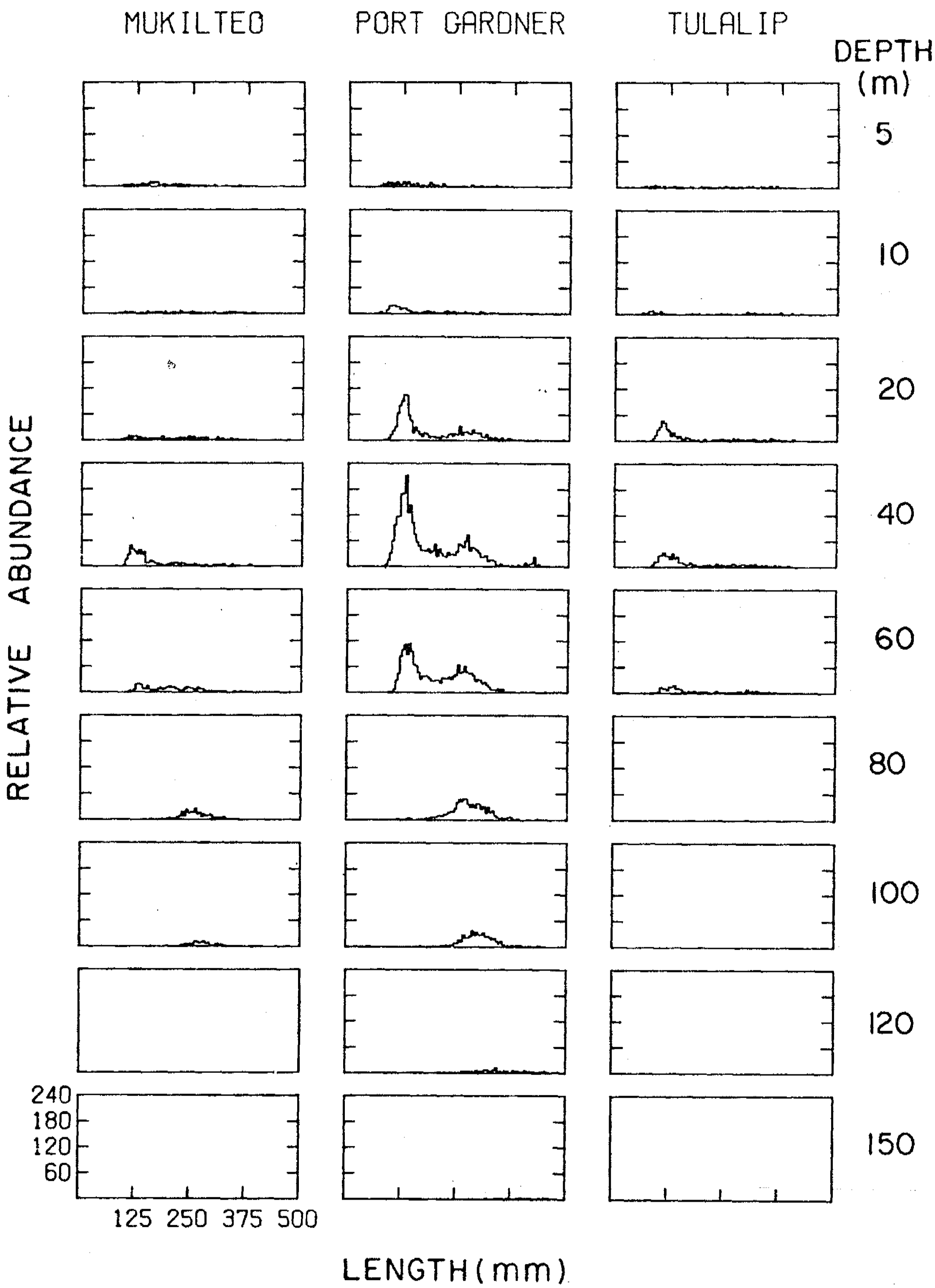

Figure 6. Length frequency distributions for female English sole at three locations over 9 depths, 1973-1974.

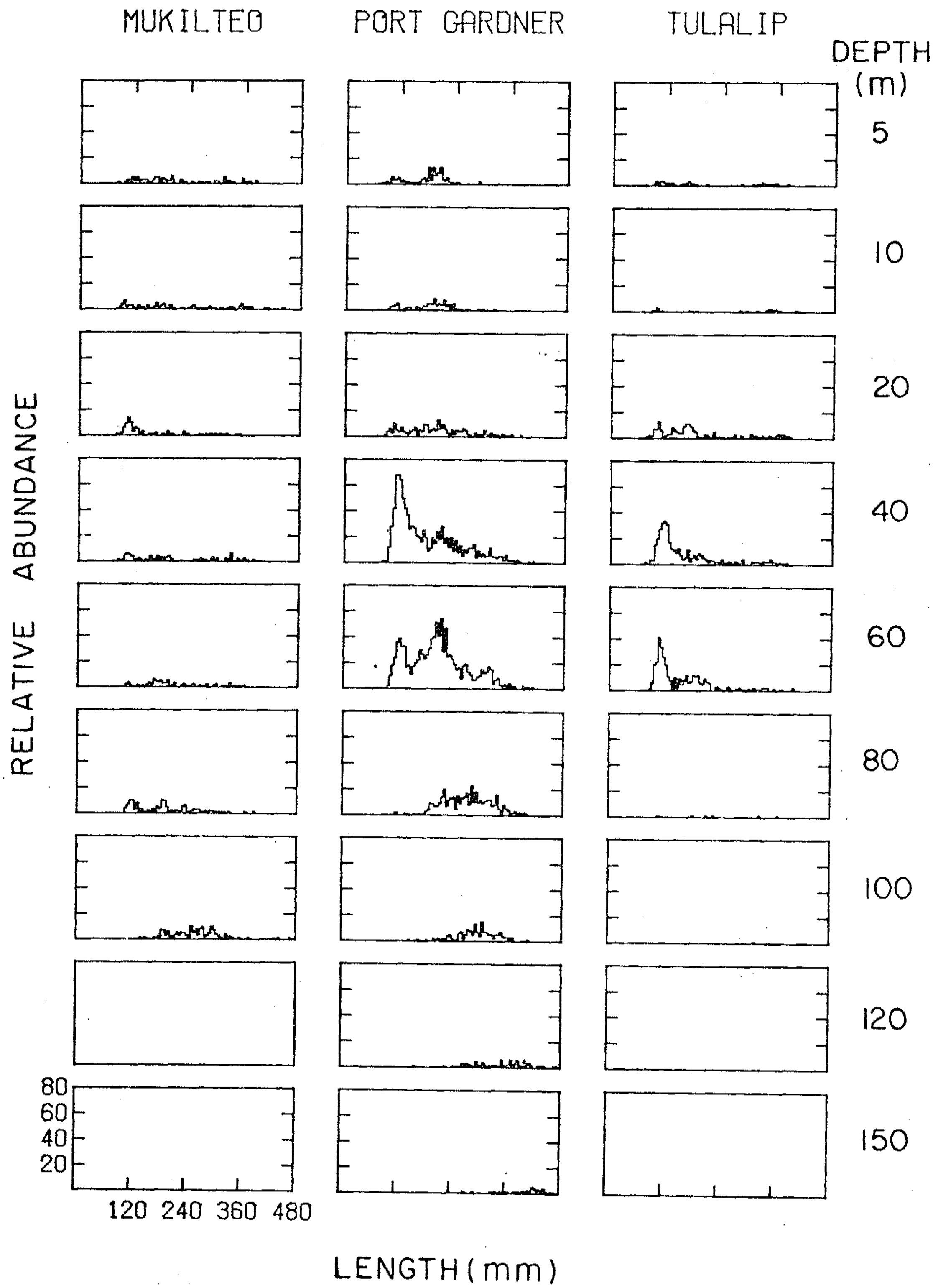

Figure 7. Length frequency distributions for female English sole at three locations over 9 depths, 1974-1975.

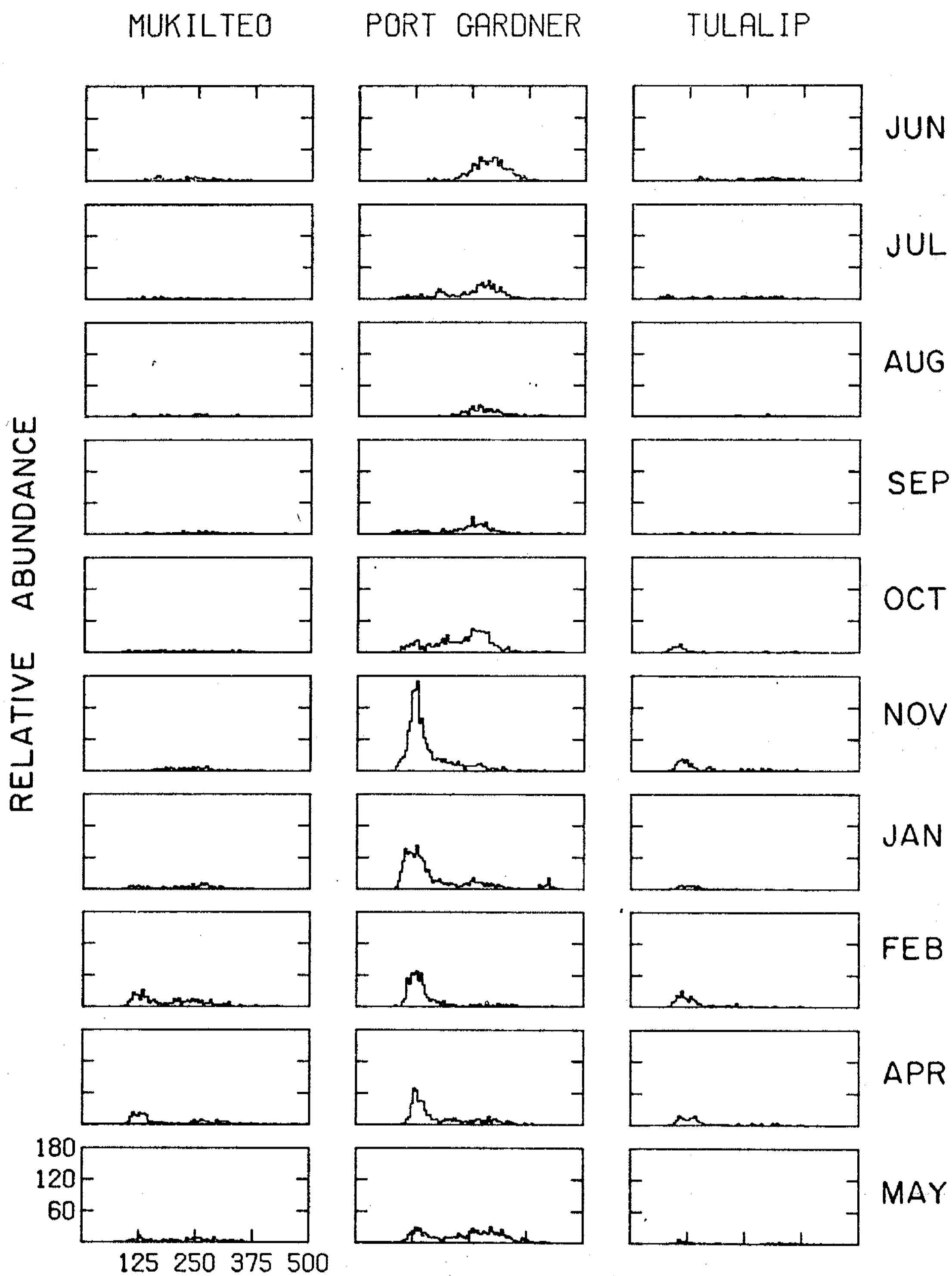

Figure 8. Length frequency distributions for female English sole at three locations over 10 months, 1973-1974.

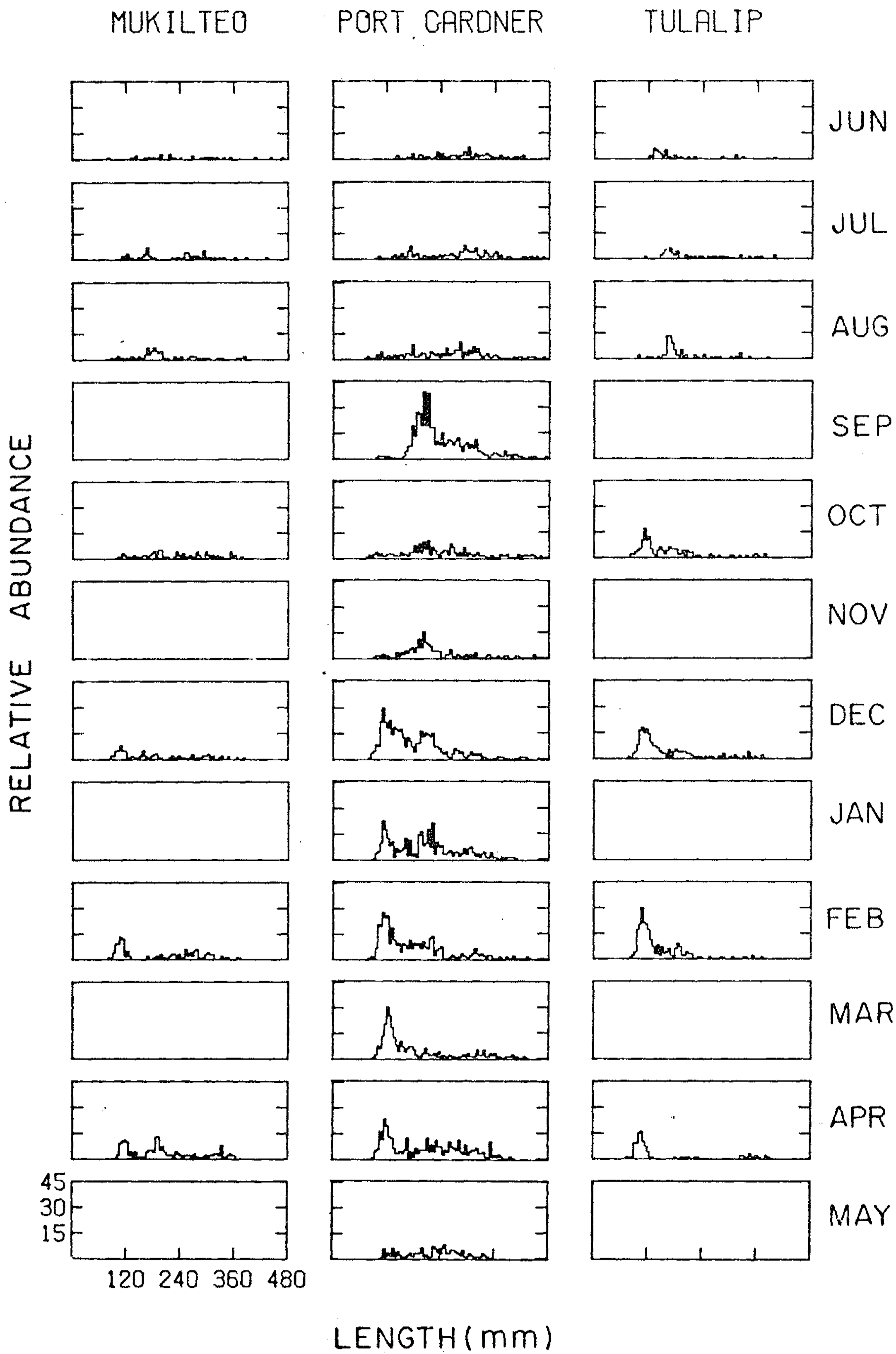

Figure 9. Length frequency distributions for female English sole at three locations over 12 months, 1974-1975.

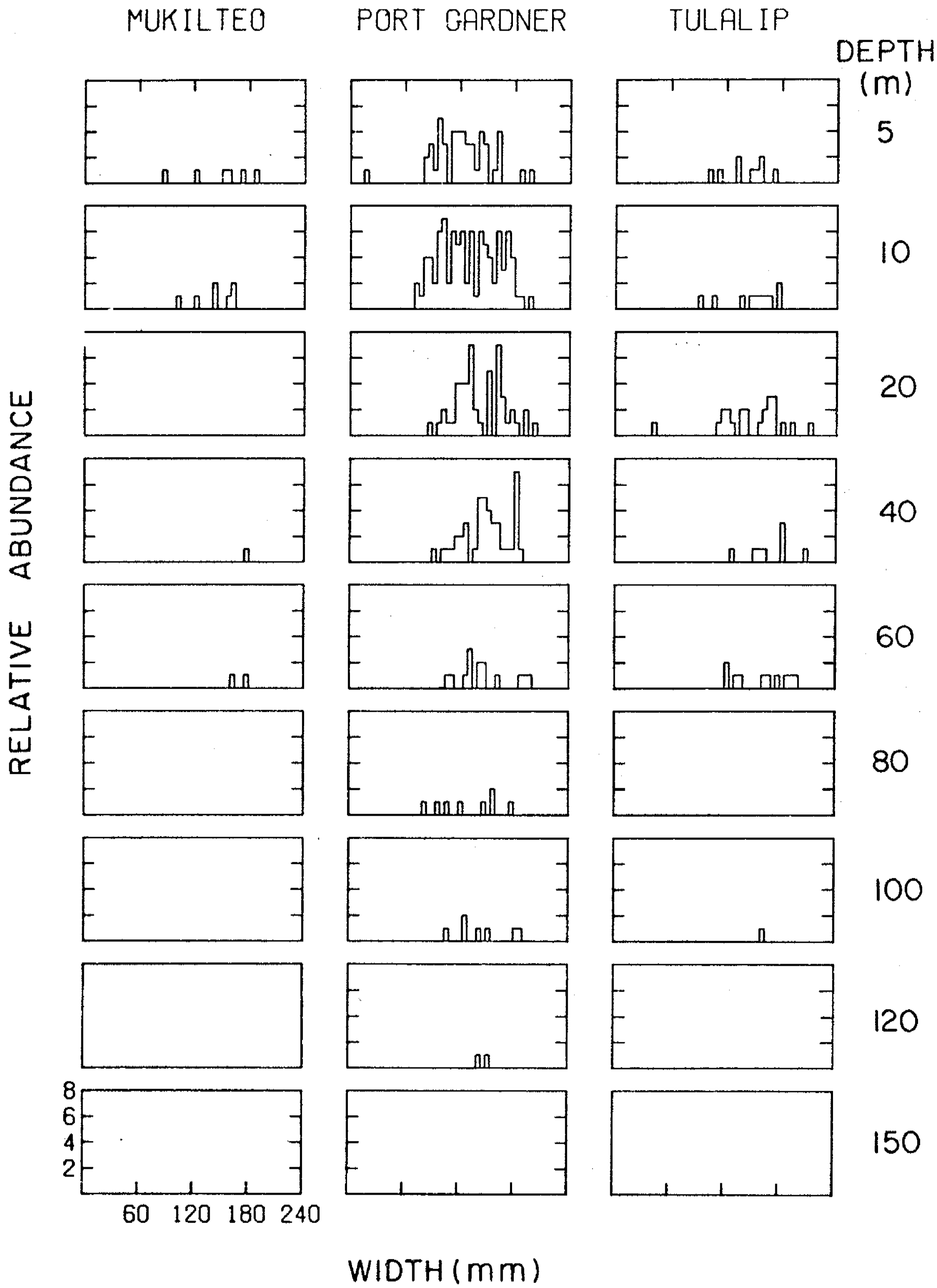

Figure 10. Length frequency distributions for male Dungeness crab at three locations over 9 depths, 1973-1974.

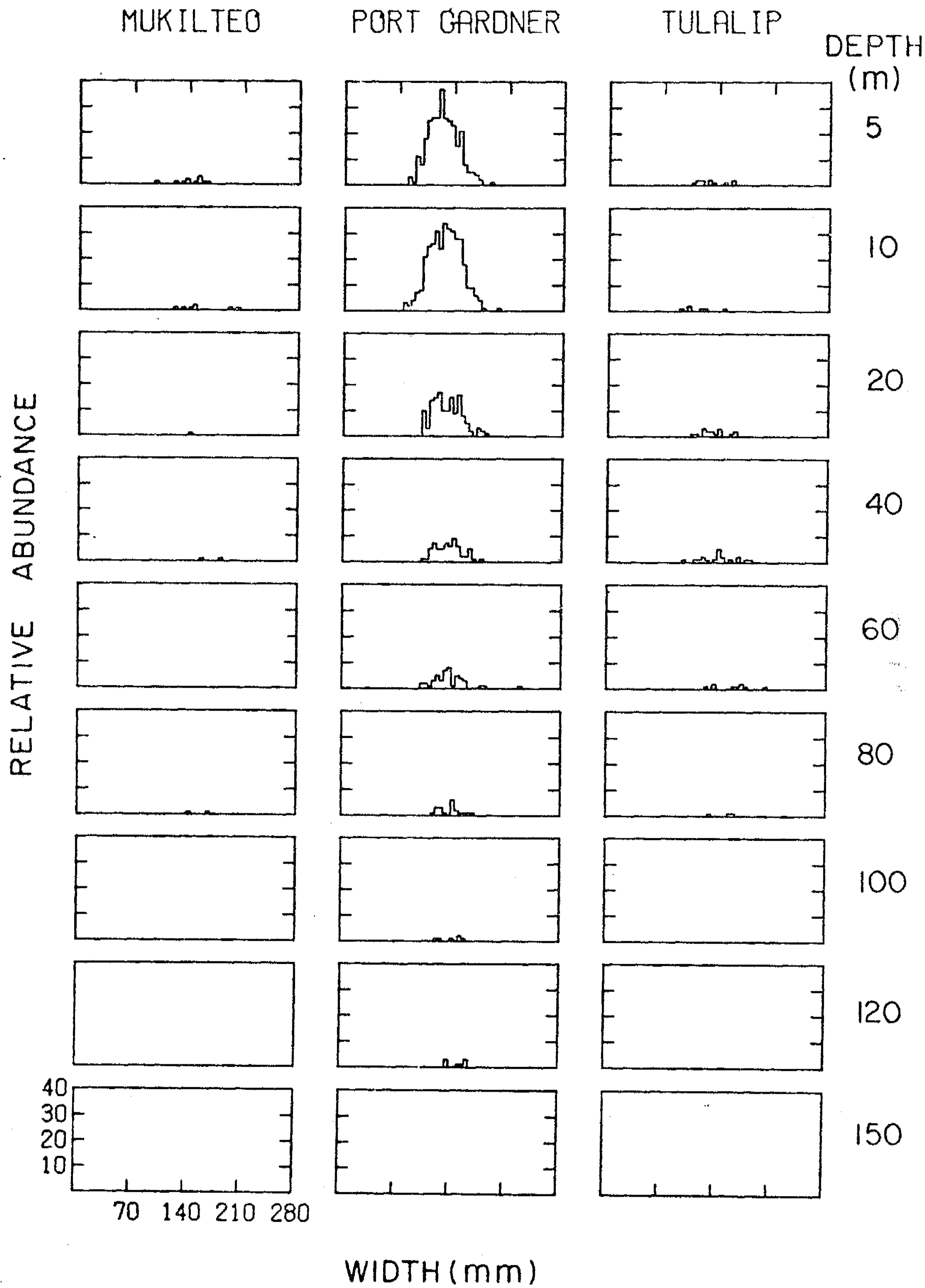

Figure 11. Length frequency distributions for male Dungeness crab at three locations over 9 depths, 1974-1975.

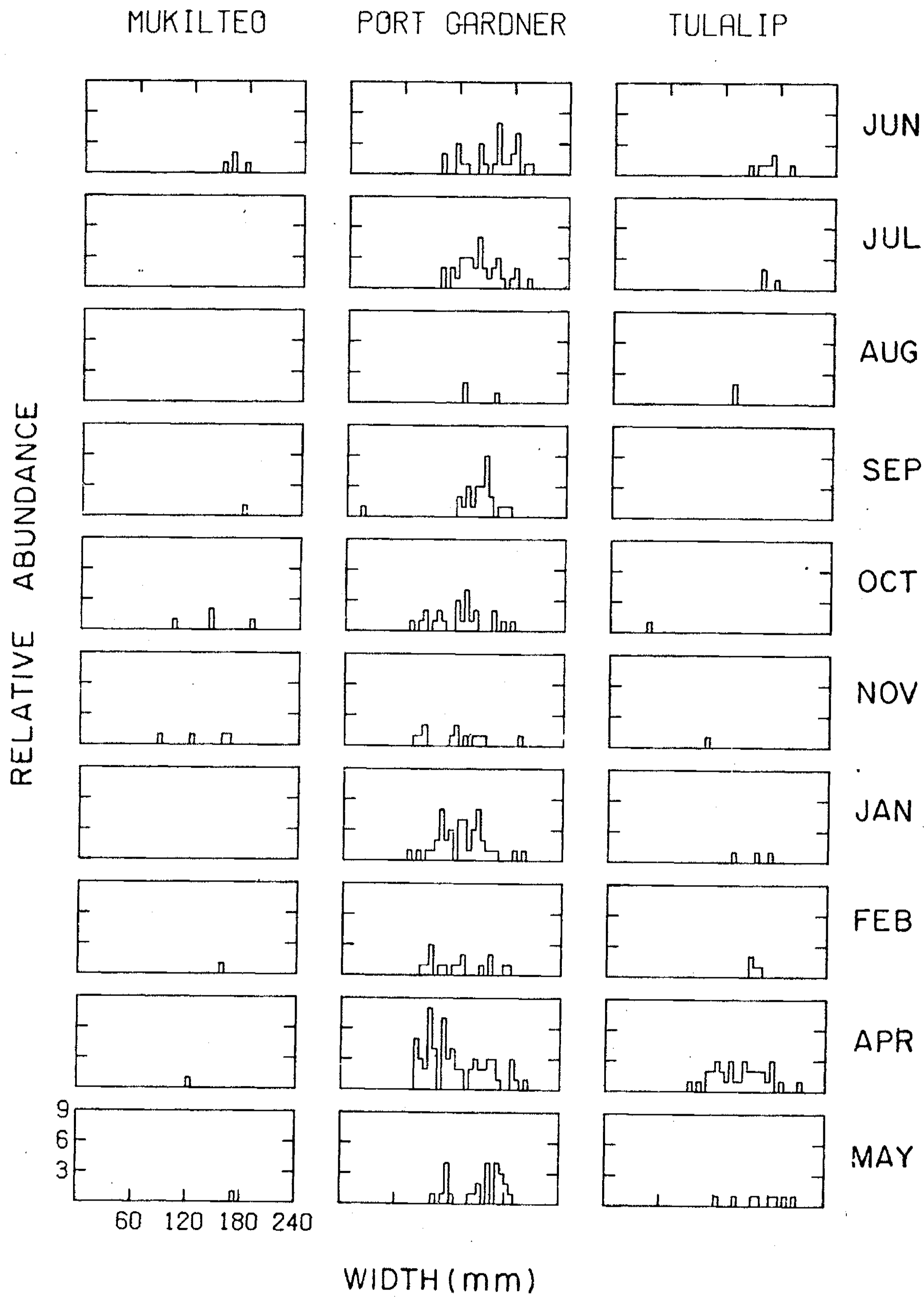

Figure 12. Length frequency distributions for male Dungeness crab at three locations over 10 months, 1973-1974.

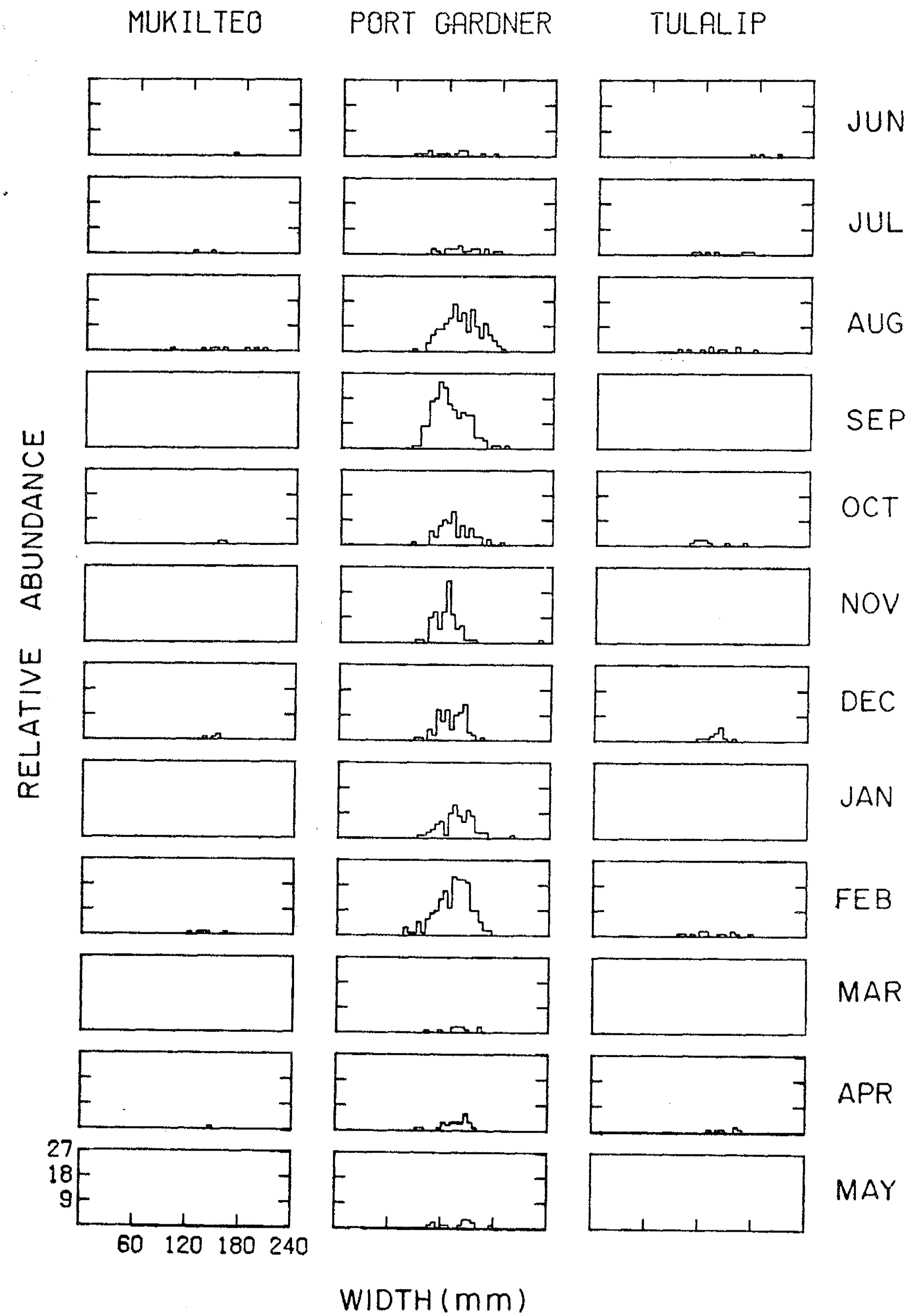

Figure 13. Length frequency distributions for male Dungeness crab at three locations over 12 months, 1974-1975.

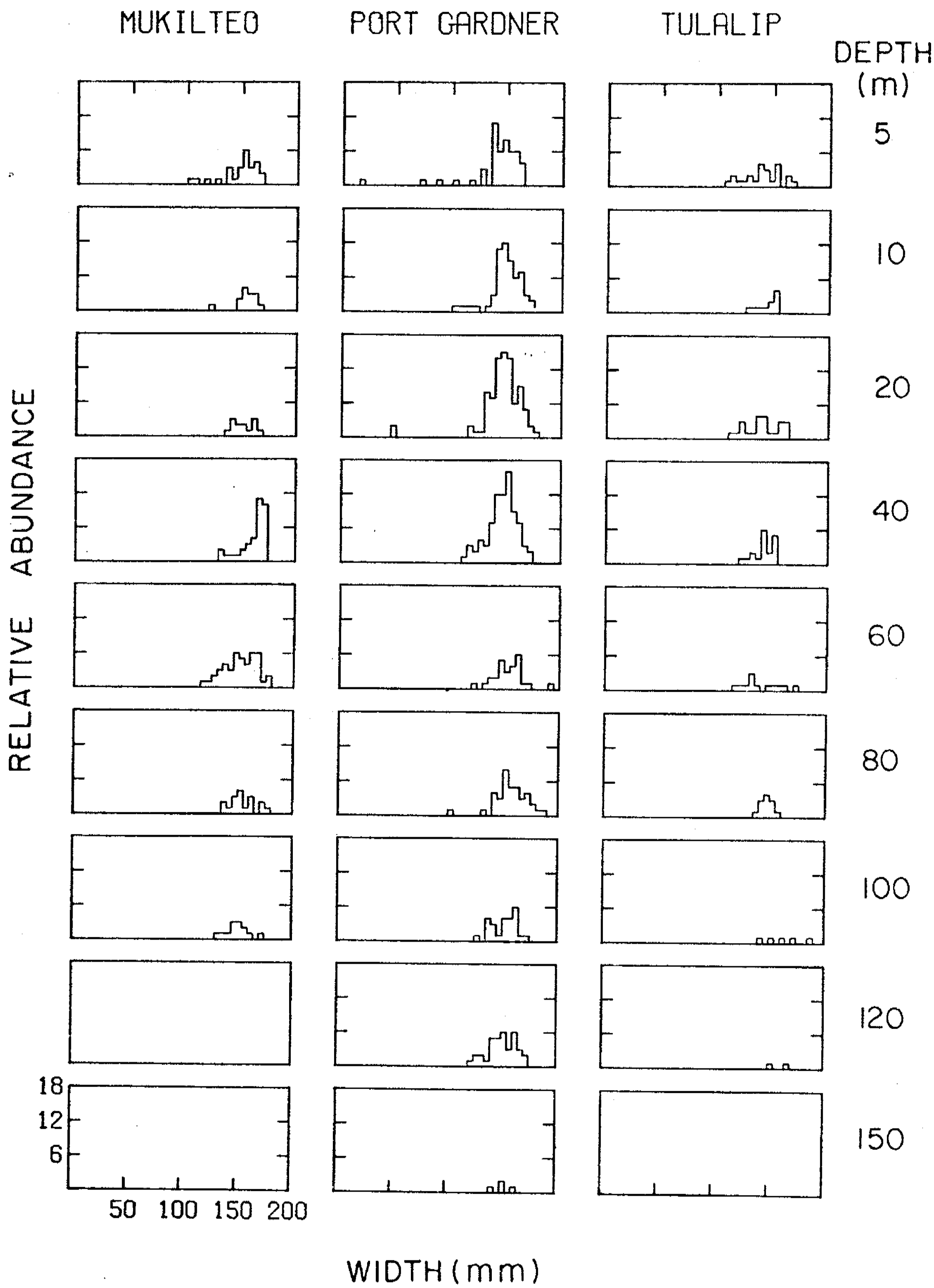

Figure 14. Length frequency distributions for female Dungeness crab at three locations over 9 depths, 1973-1974.

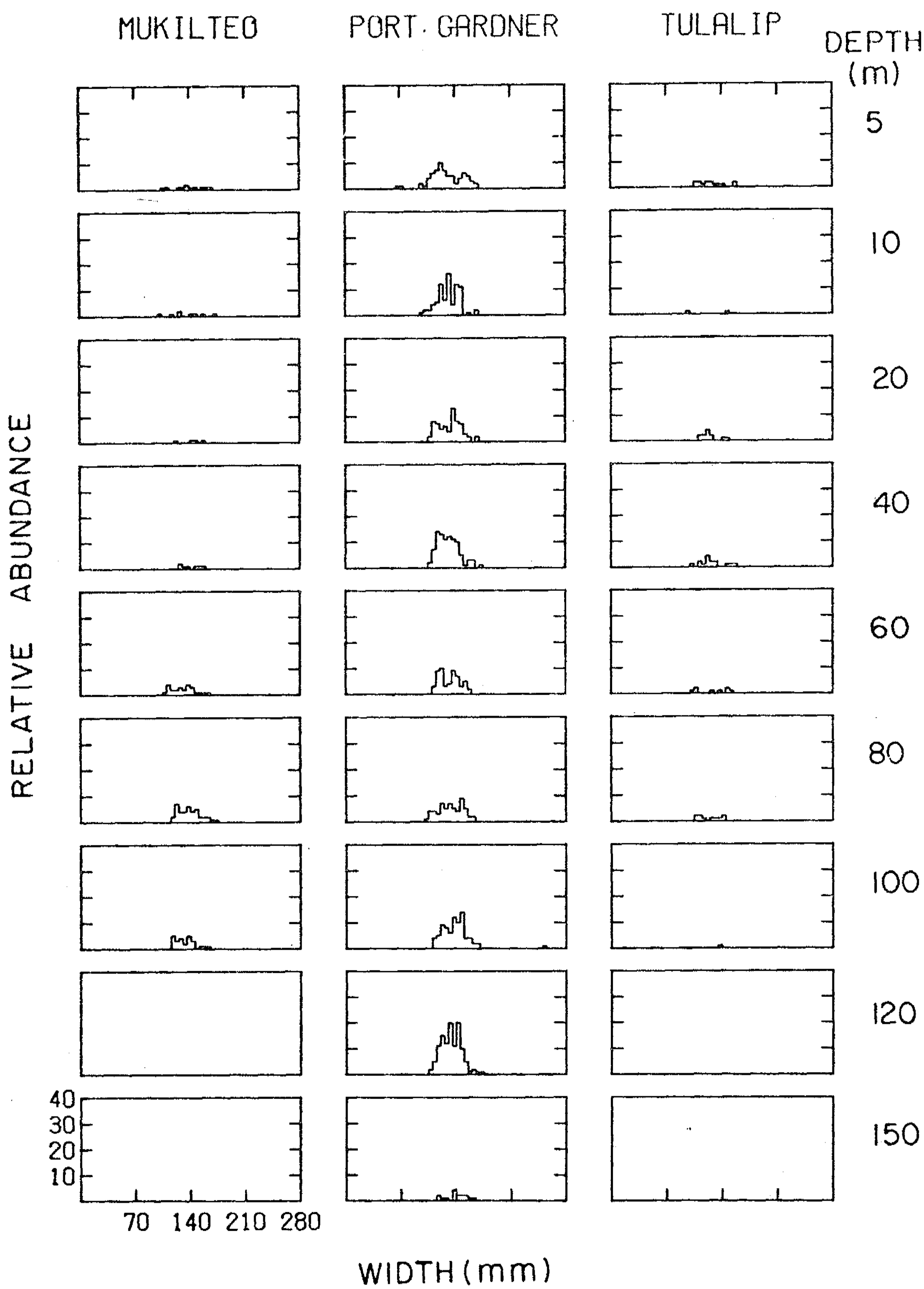

Figure 15. Length frequency distributions for female Dungeness crab at three locations over 9 depths, 1974-1975.

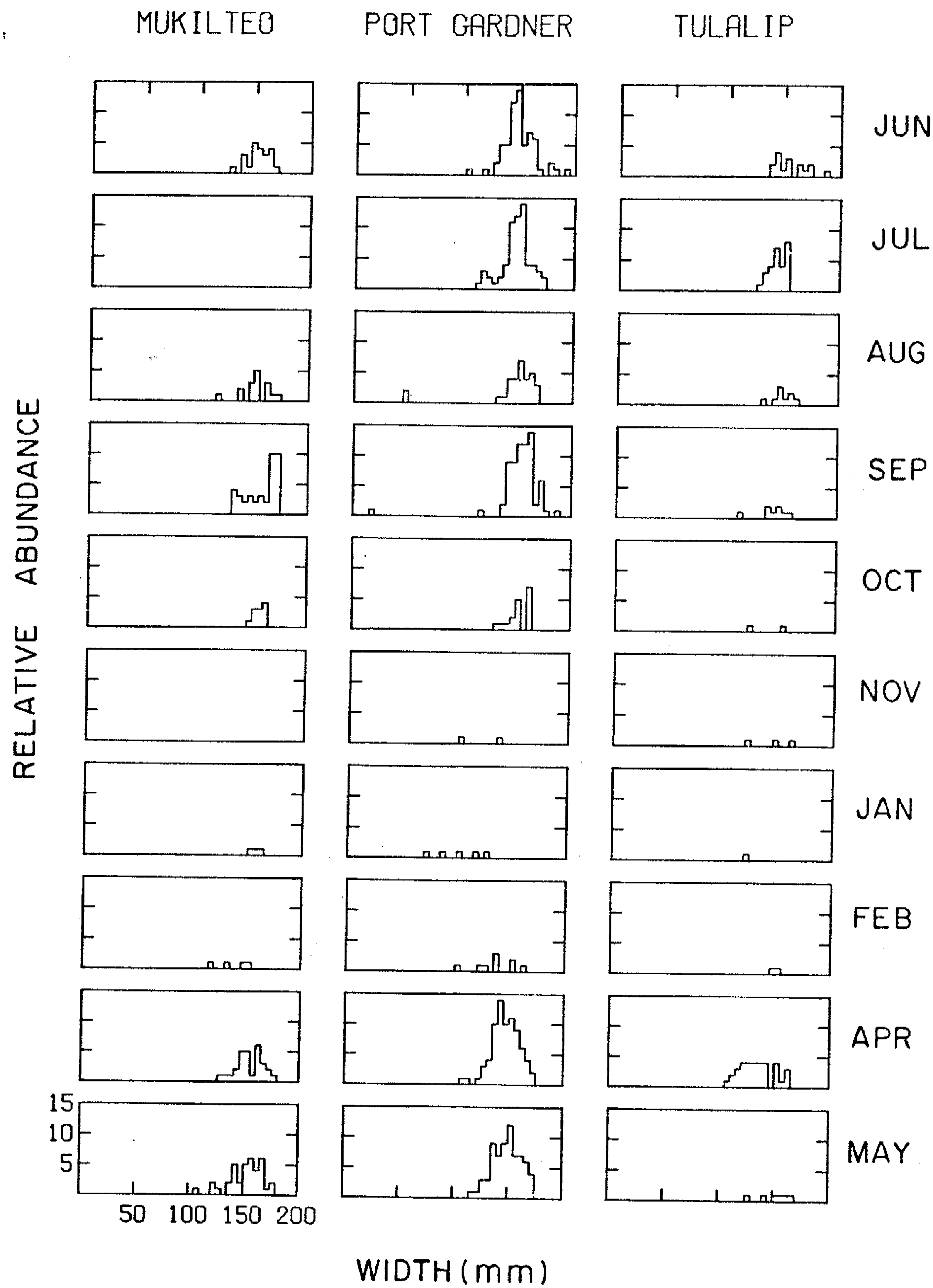

Figure 16. Length frequency distributions for female Dungeness crab at three locations over 10 months, 1973-1974.

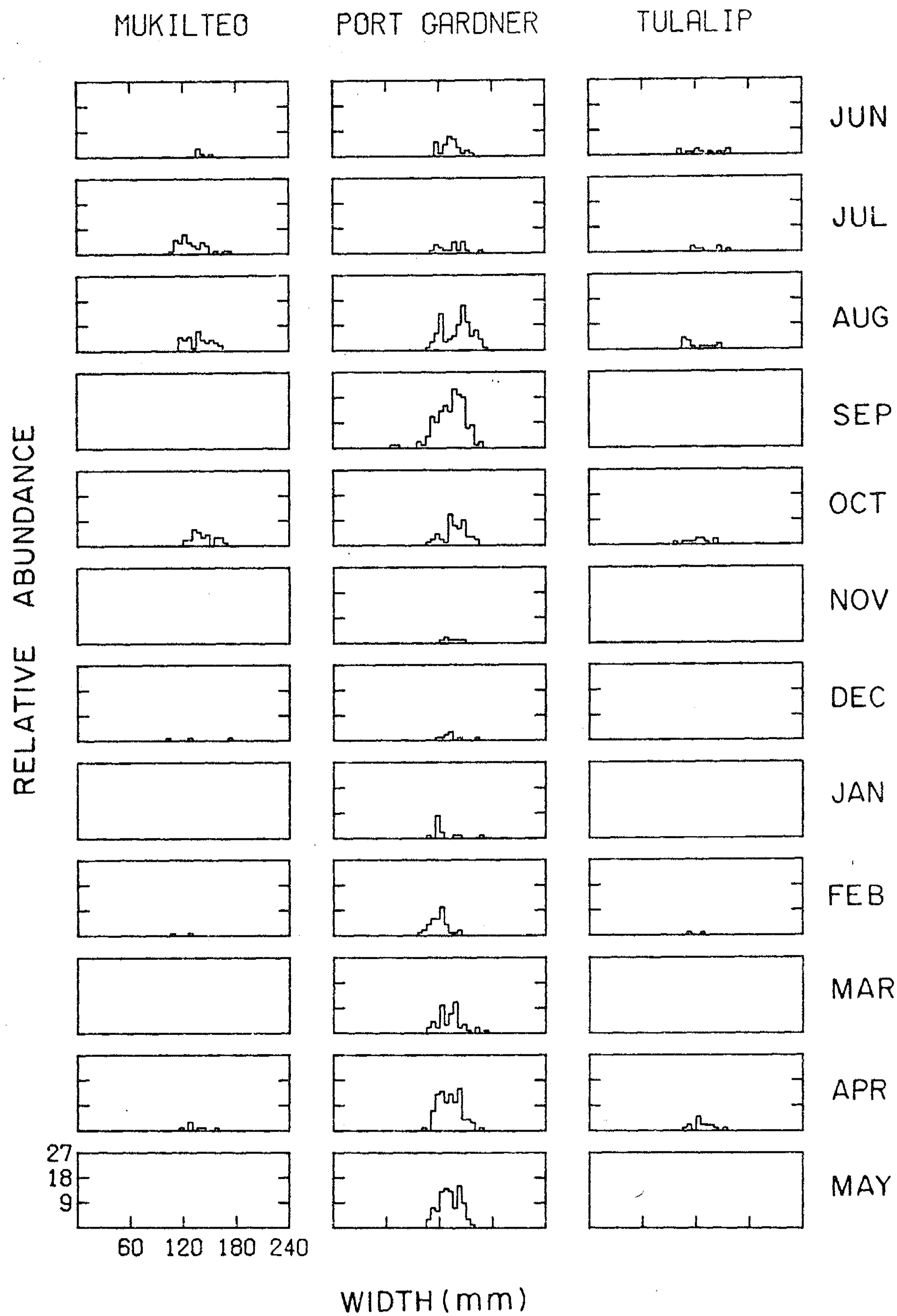

Figure 17. Length frequency distributions for female Dungeness crab at three locations over 12 months, 1974-1975.

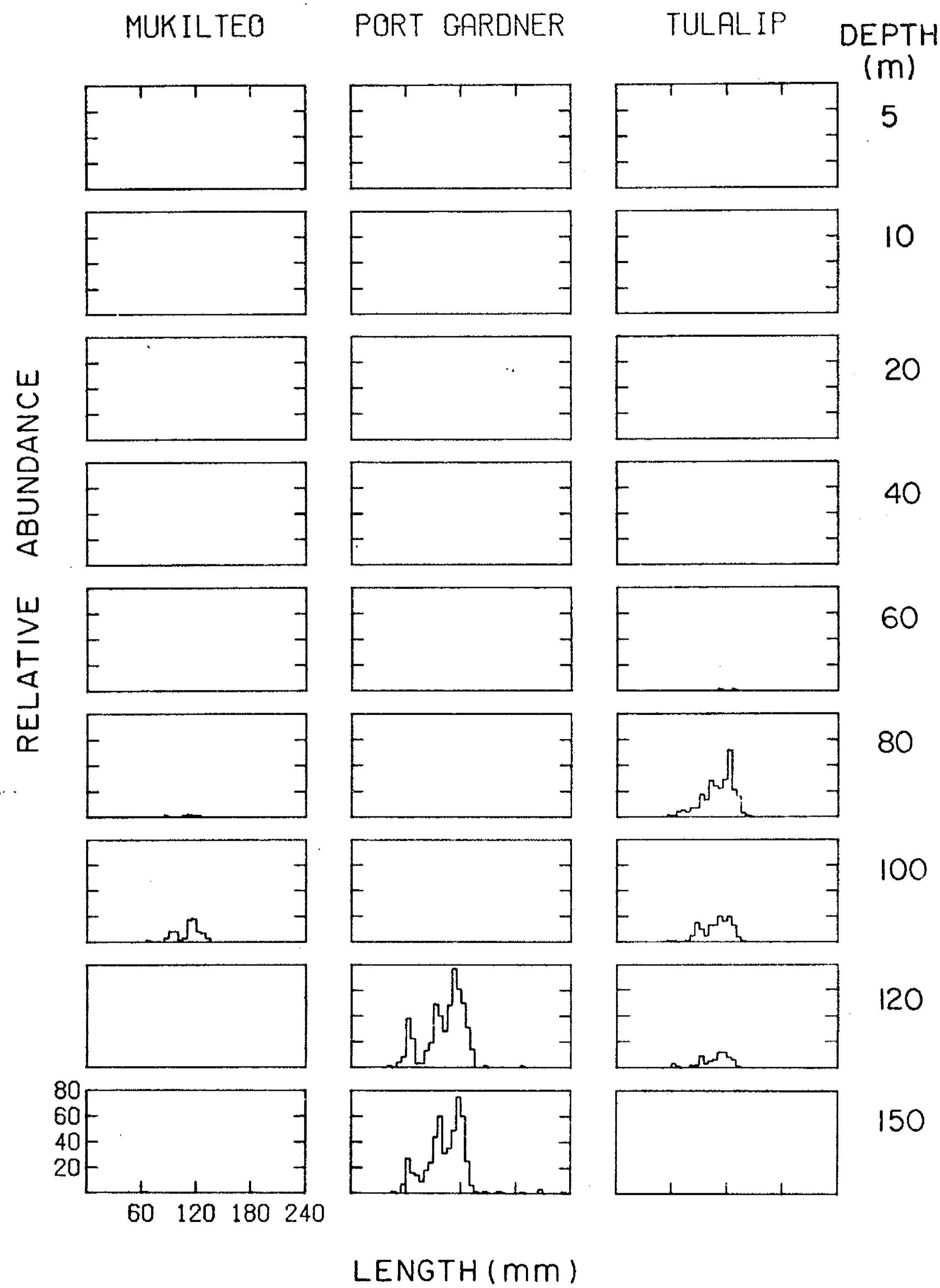

Figure 18. Length frequency distributions for the shrimp *Pandalopsis dispar* at three locations over 9 depths, 1973-1974.

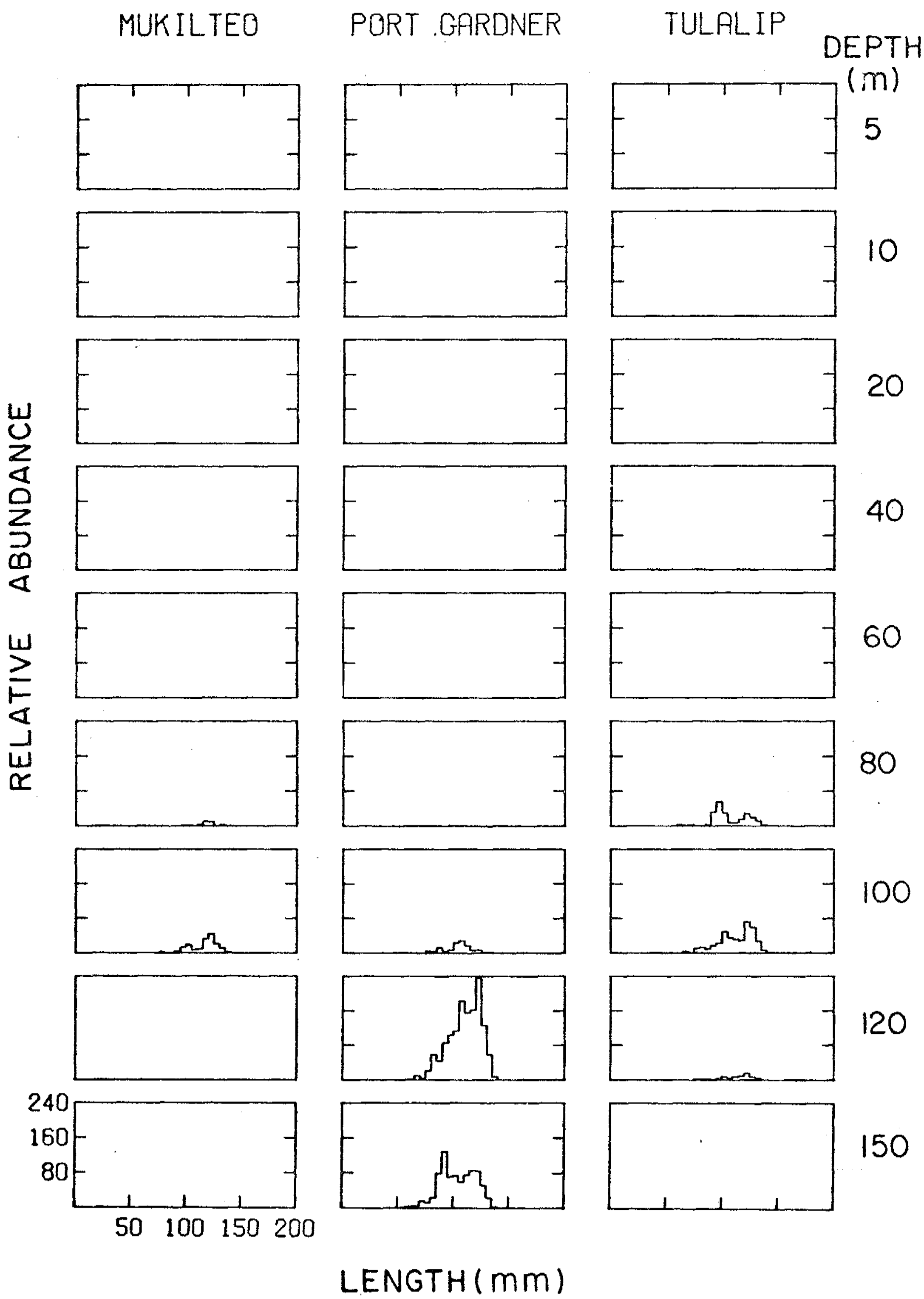

Figure 19. Length frequency distributions for the shrimp *Pandalopsis dispar* at three locations over 9 depths, 1974-1975.

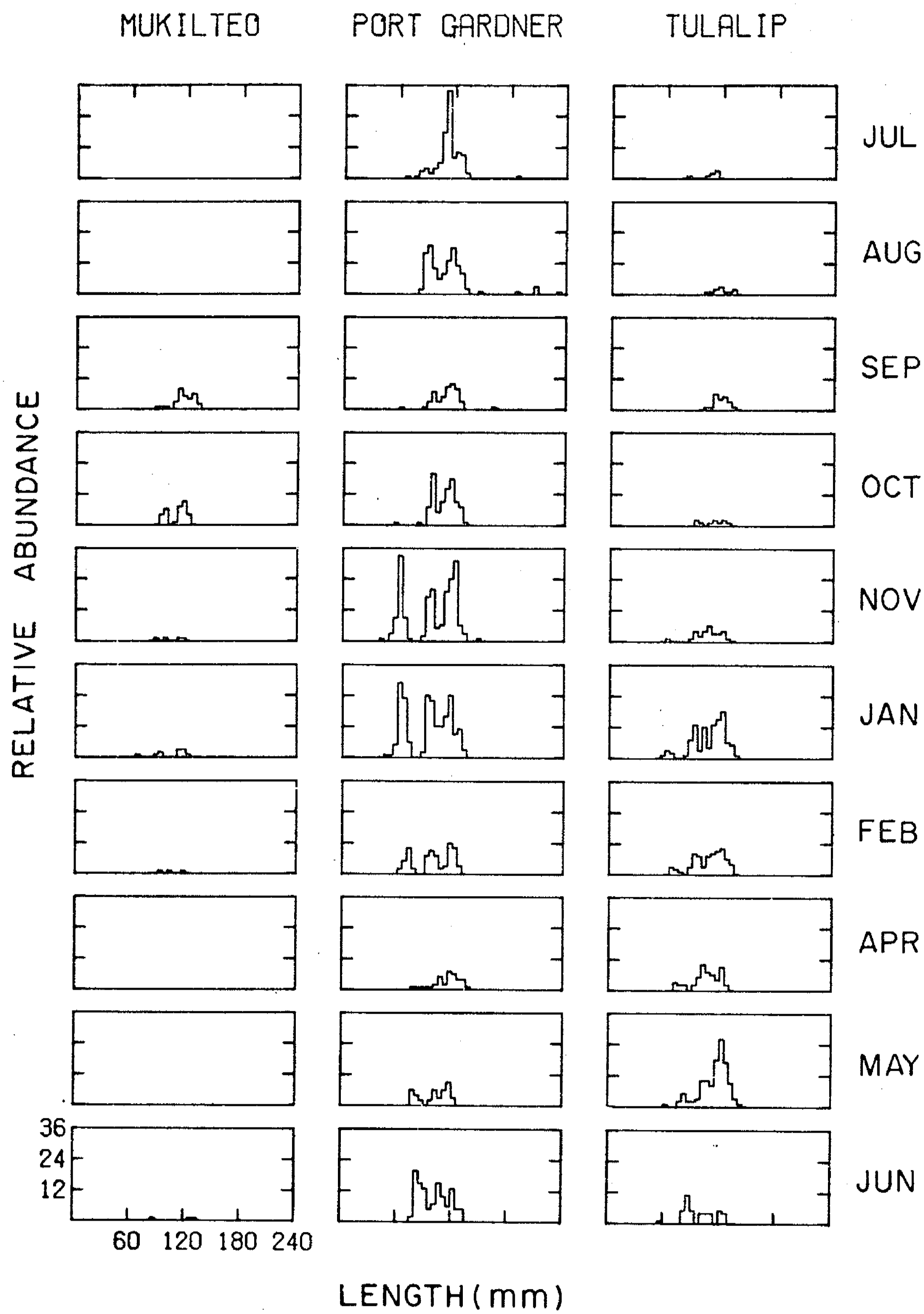

Figure 20. Length frequency distributions for the shrimp *Pandalopsis dispar* at three locations over 10 months, 1973-1974.

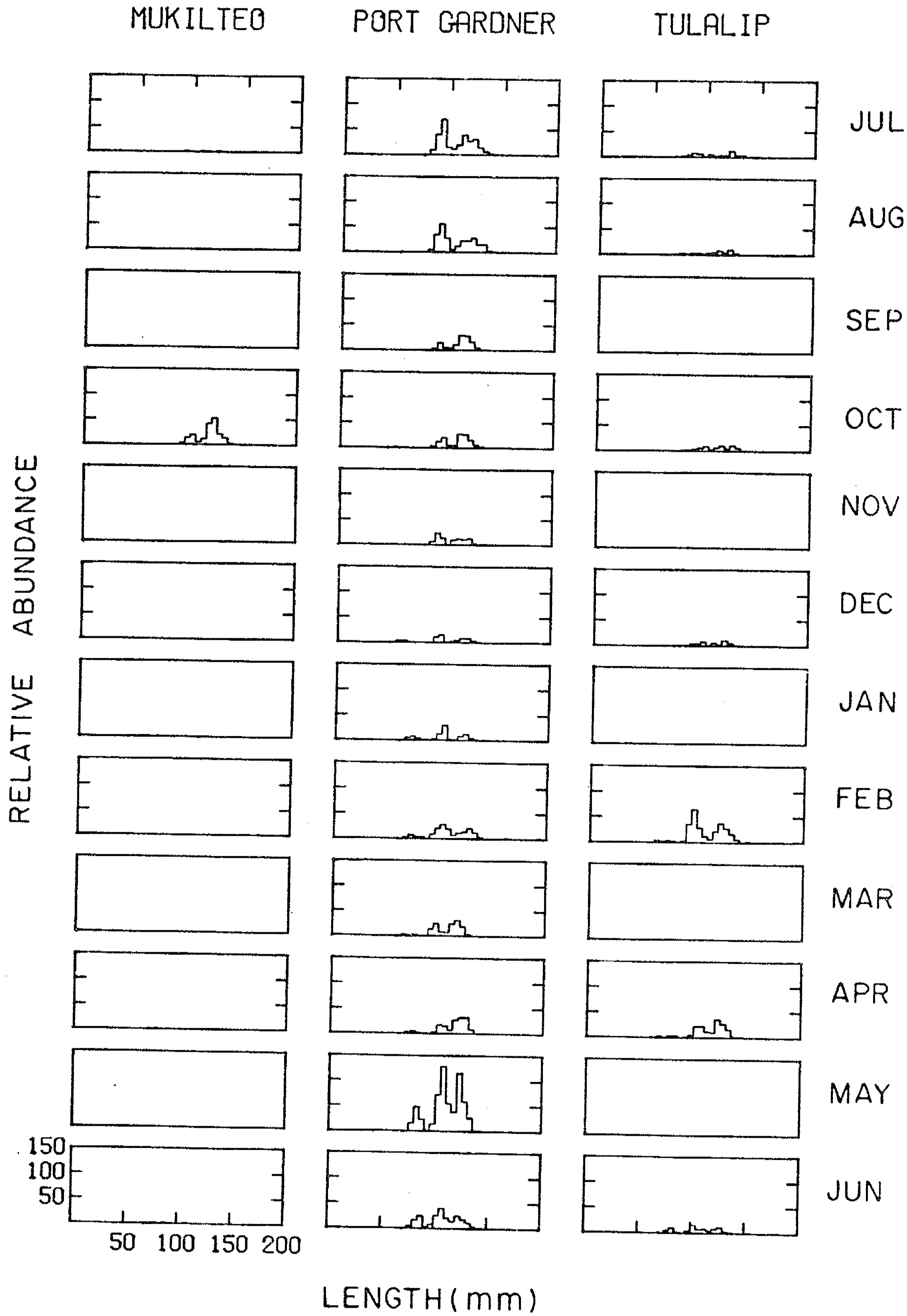

Figure 21. Length frequency distributions for the shrimp *Pandalopsis dispar* at three locations over 12 months, 1974-1975.

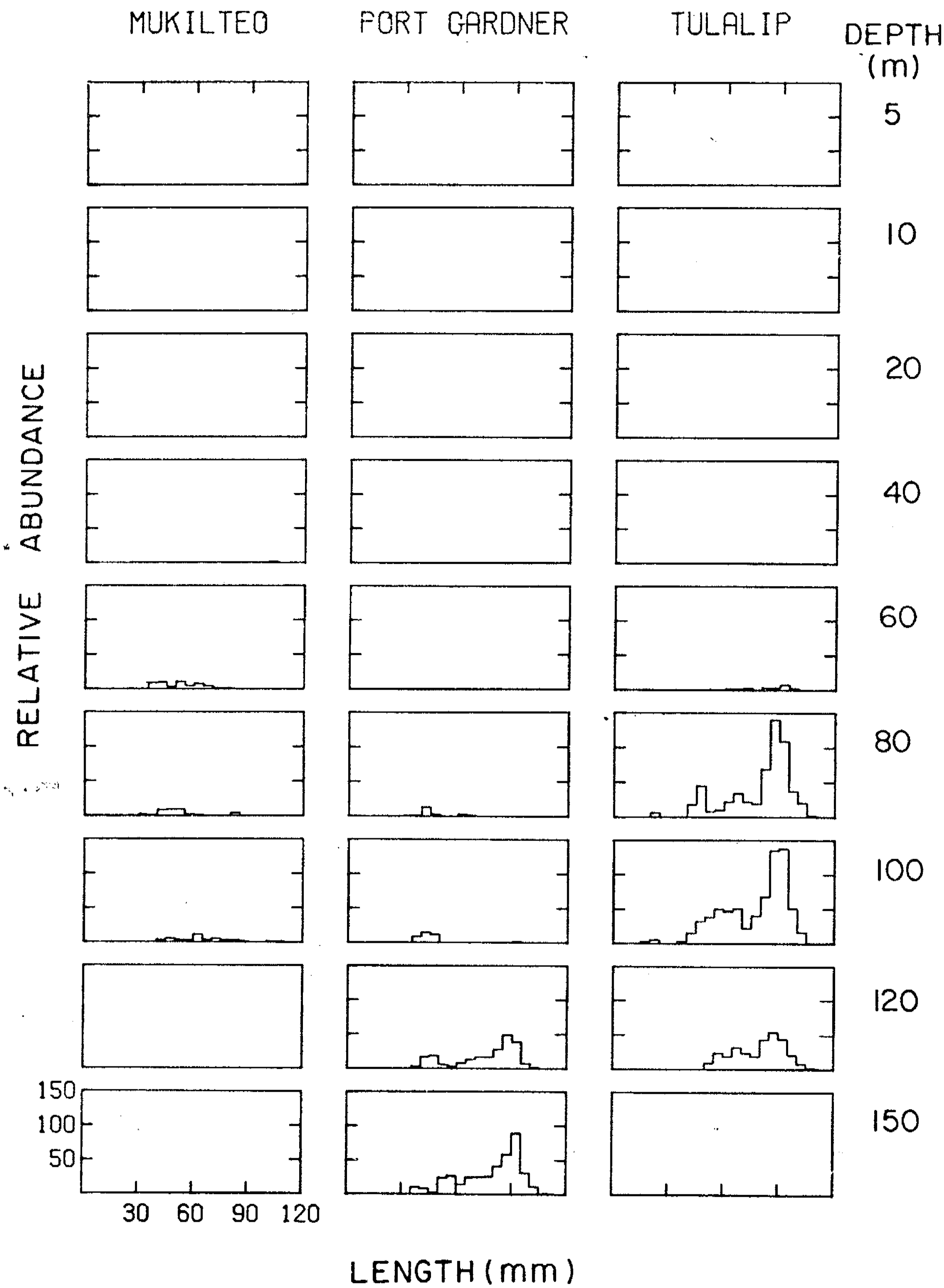

Figure 22. Length frequency distributions for the shrimp *Pandalus borealis* at three locations over 9 depths, 1973-1974.

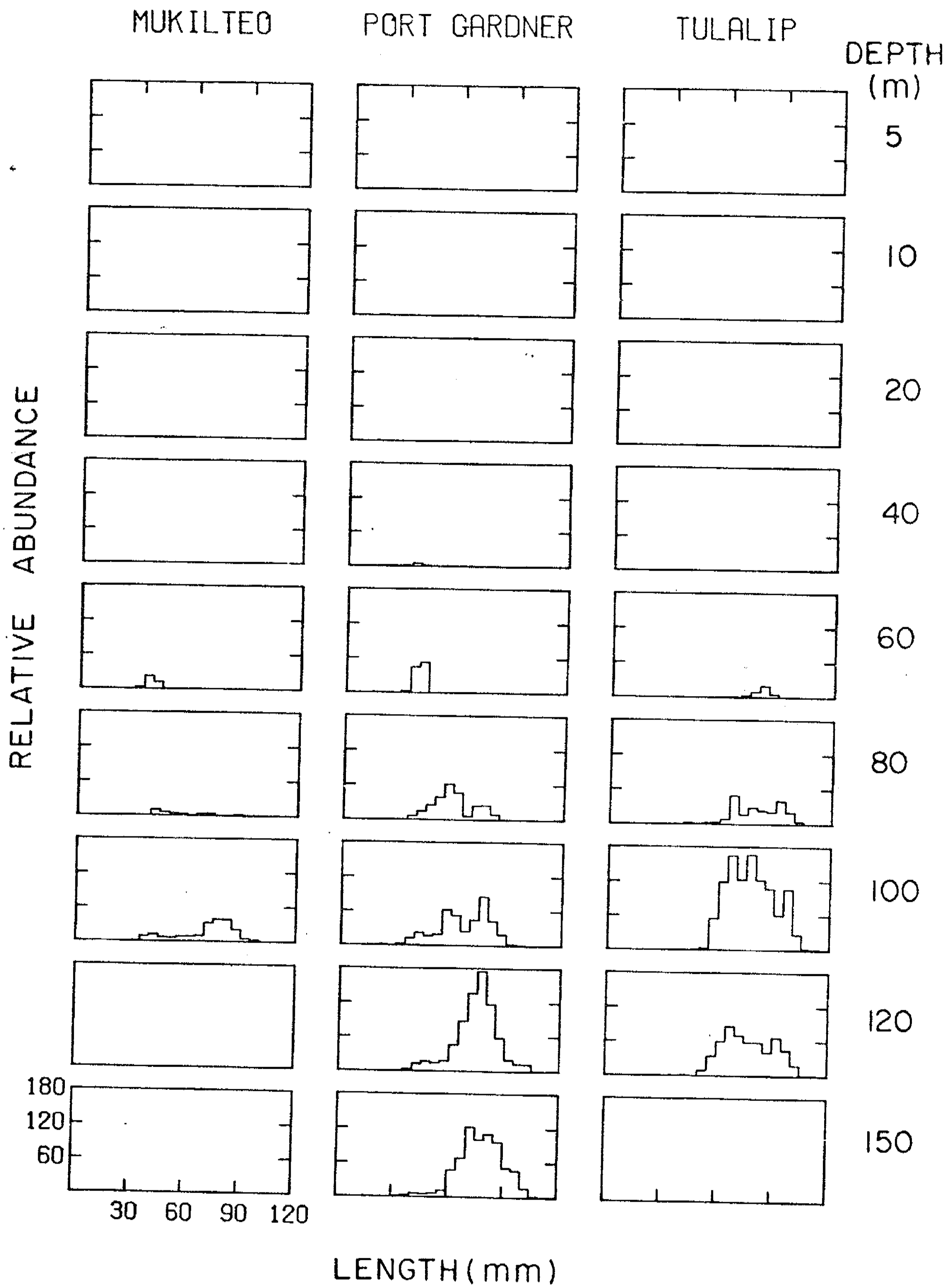

Figure 23. Length frequency distributions for the shrimp *Pandalus borealis* at three locations over 9 depths, 1974-1975.

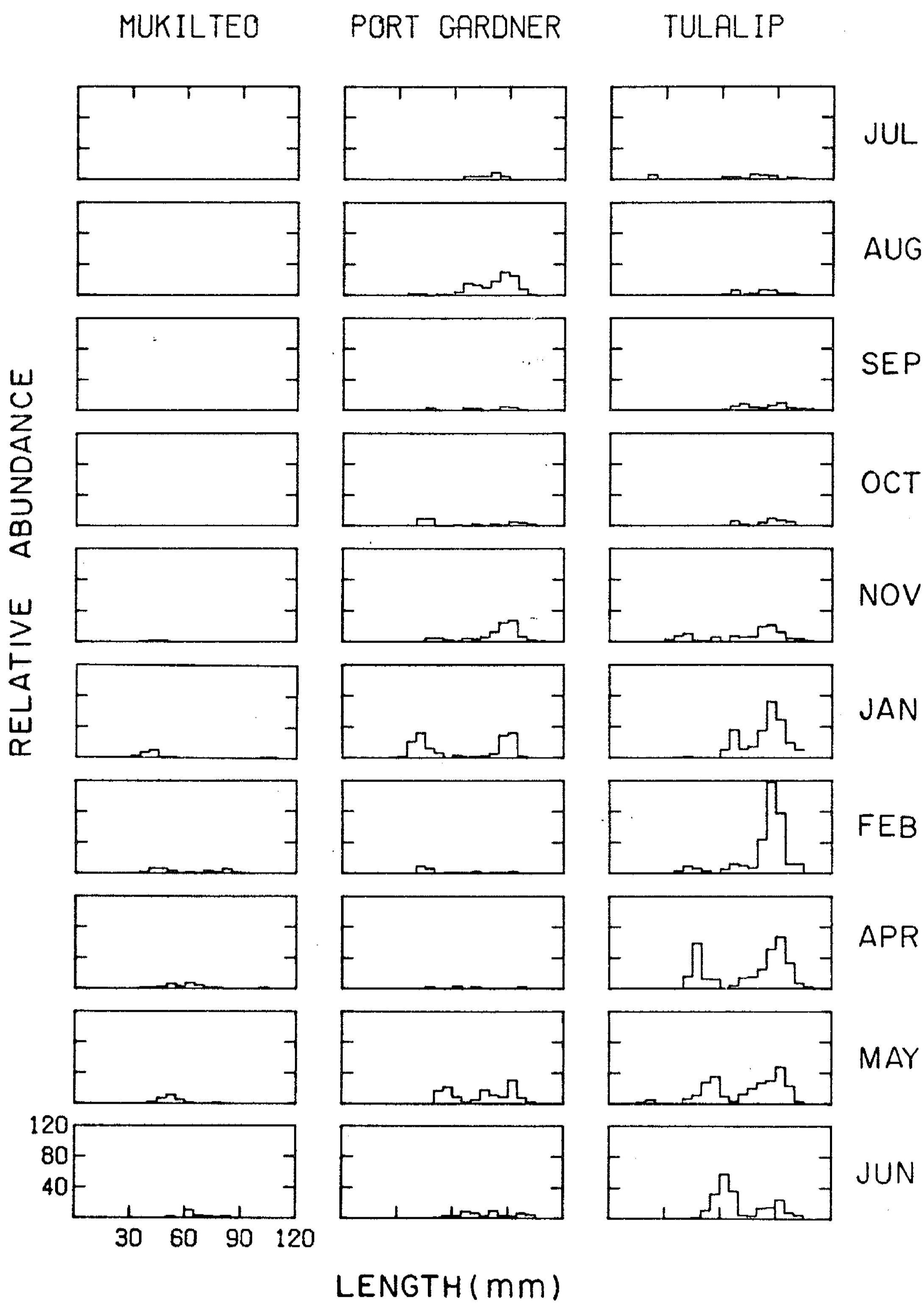

Figure 24. Length frequency distributions for the shrimp *Pandalus borealis* at three locations over 10 months, 1973-1974.

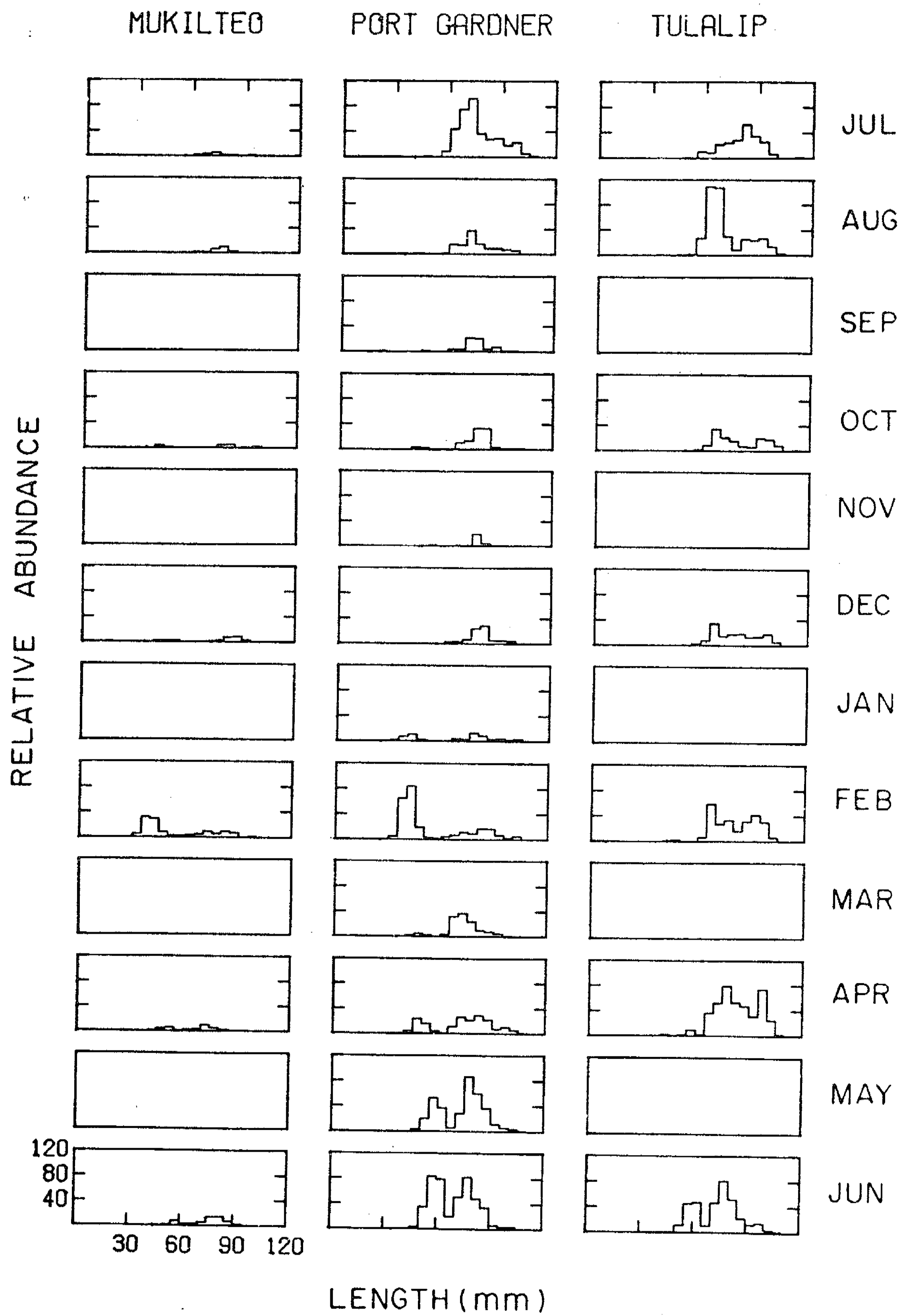

Figure 25. Length frequency distributions for the shrimp *Pandalus borealis* at three locations over 12 months, 1974-1975.

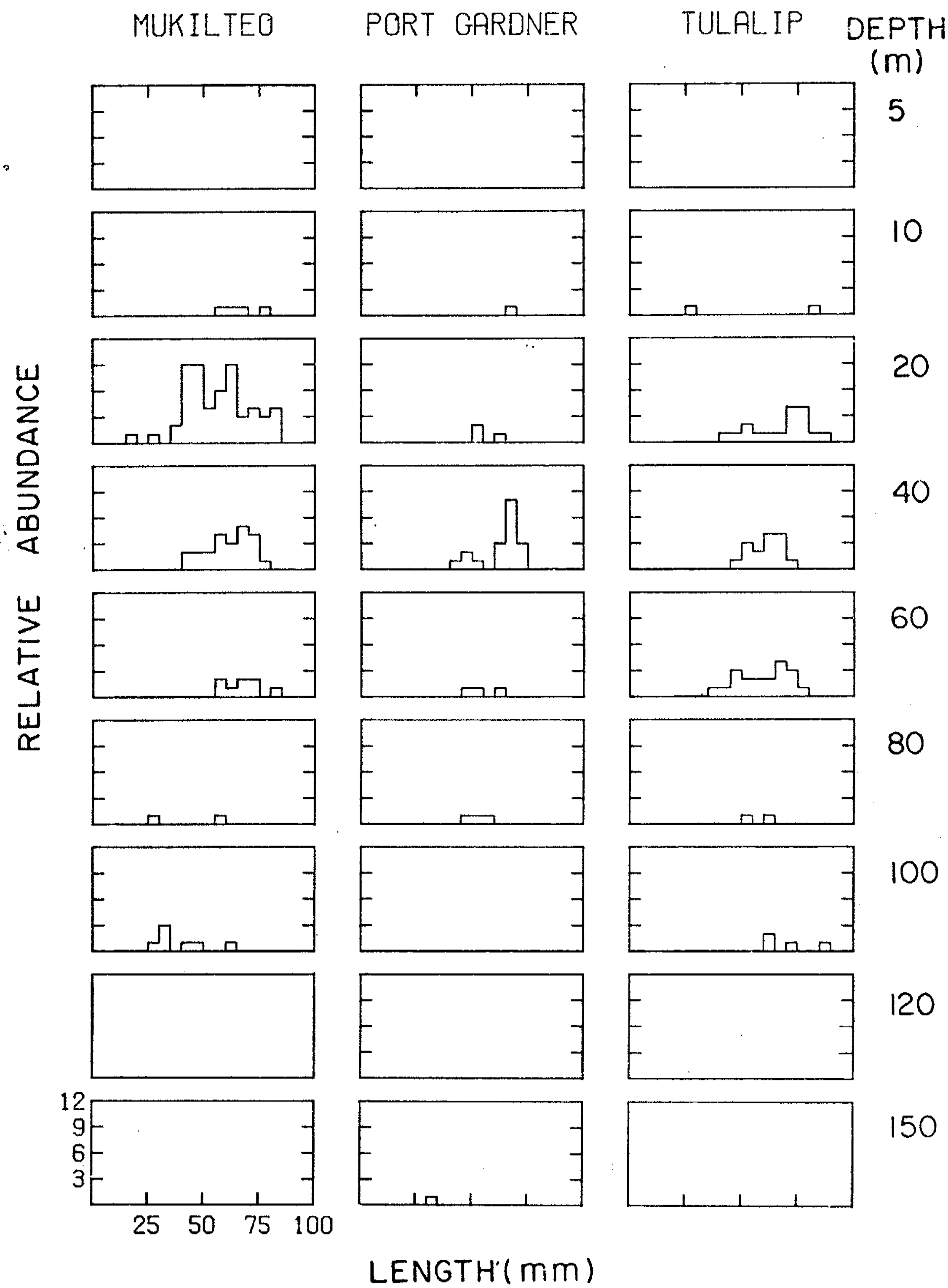

Figure 26. Length frequency distributions for the shrimp *Pandalus danae* at three locations over 9 depths, 1973-1974.

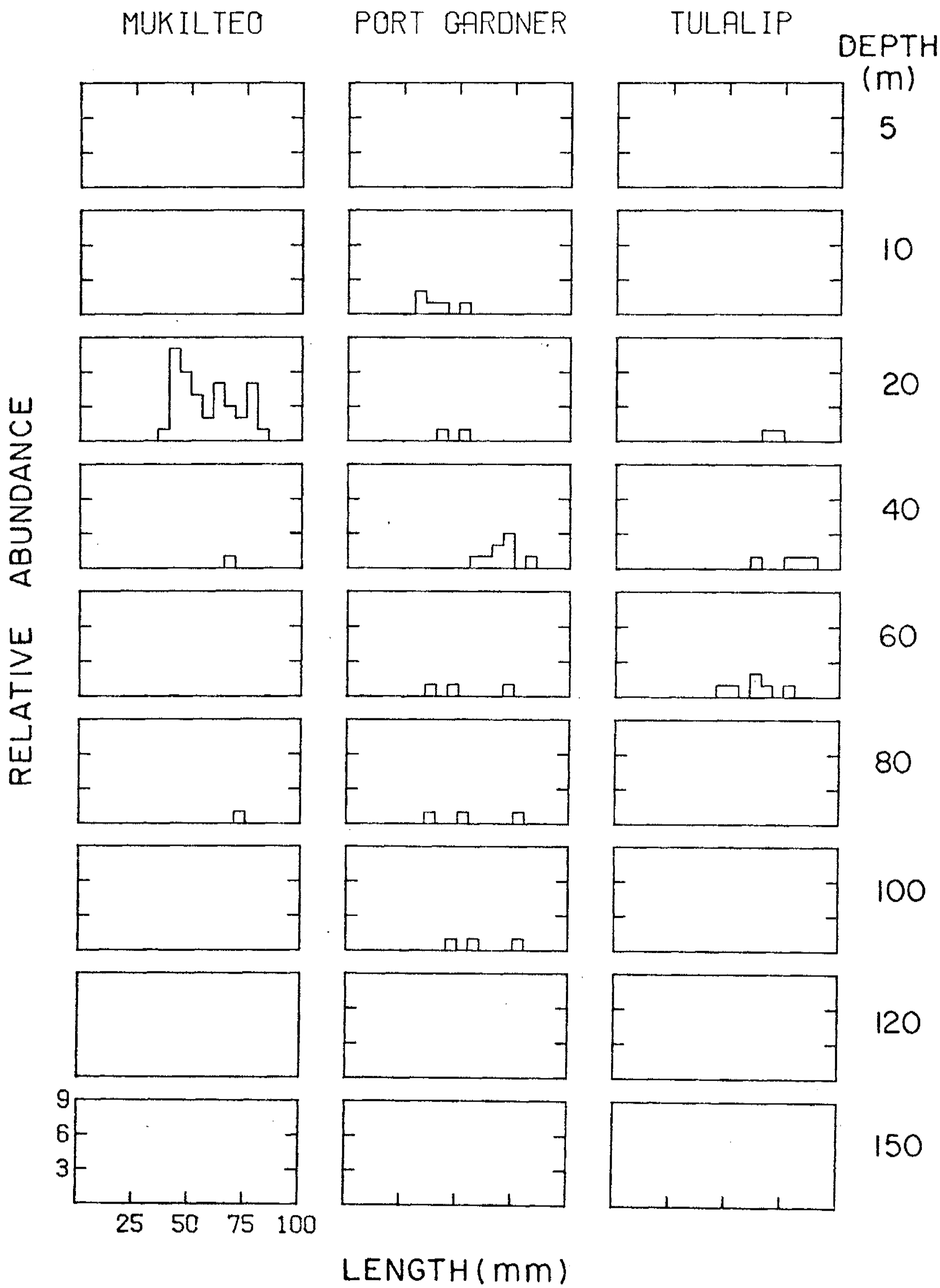

Figure 27. Length frequency distributions for the shrimp *Pandalus danae* at three locations over 9 depths, 1974-1975.

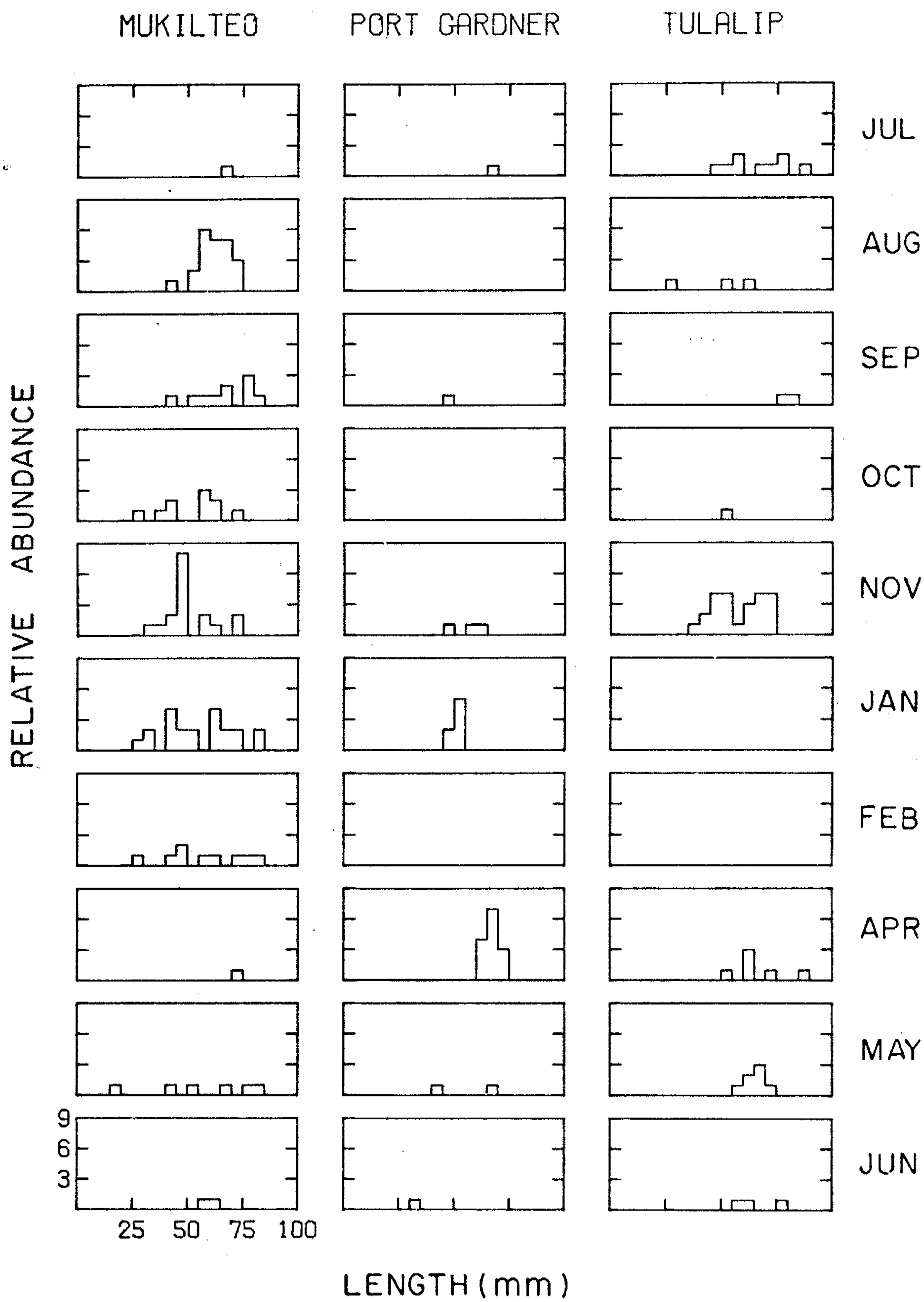

Figure 28. Length frequency distributions for the shrimp *Pandalus danae* at three locations over 10 months, 1973-1974.

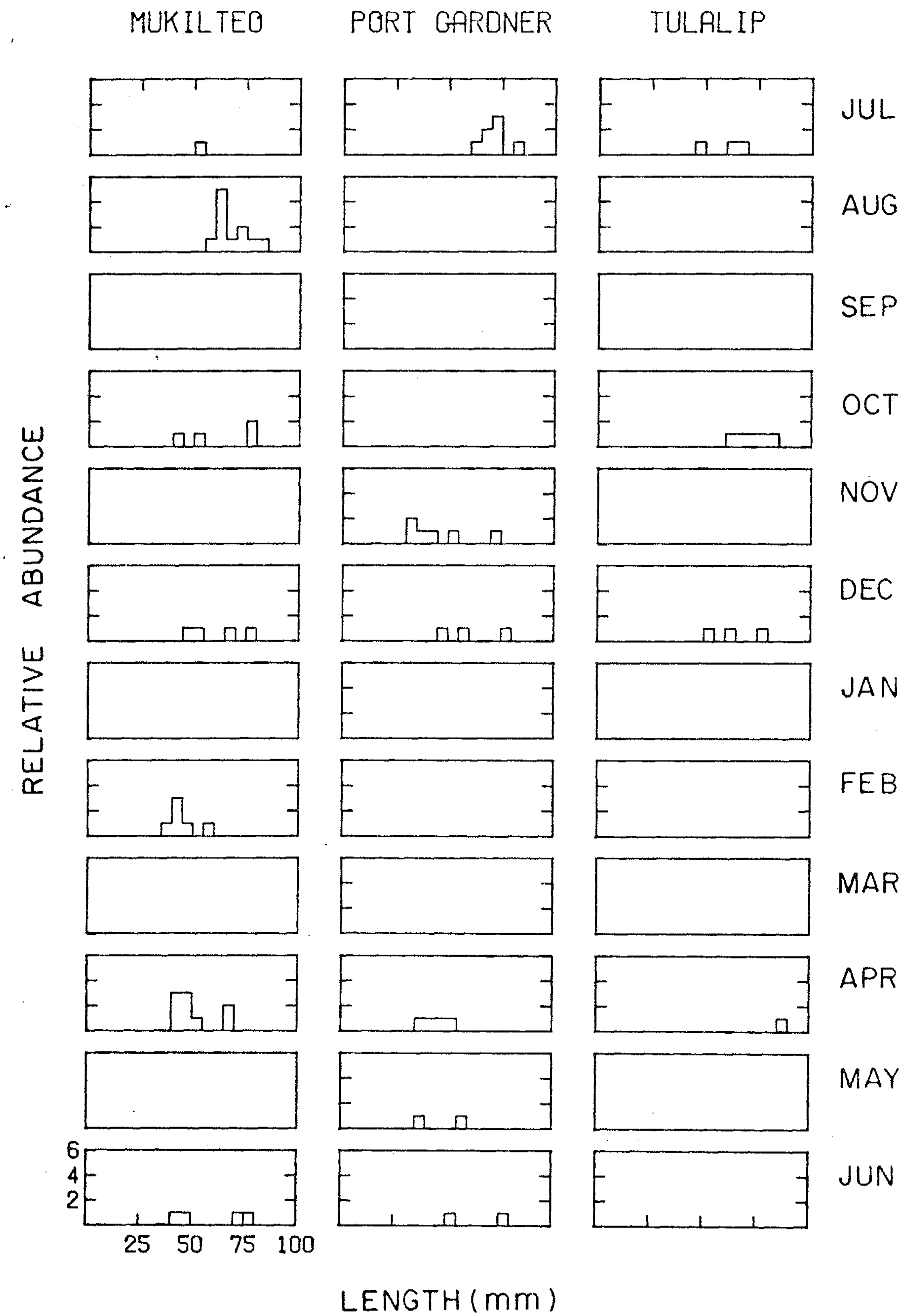

Figure 29. Length frequency distributions for the shrimp *Pandalus danae* at three locations over 12 months, 1974-1975.

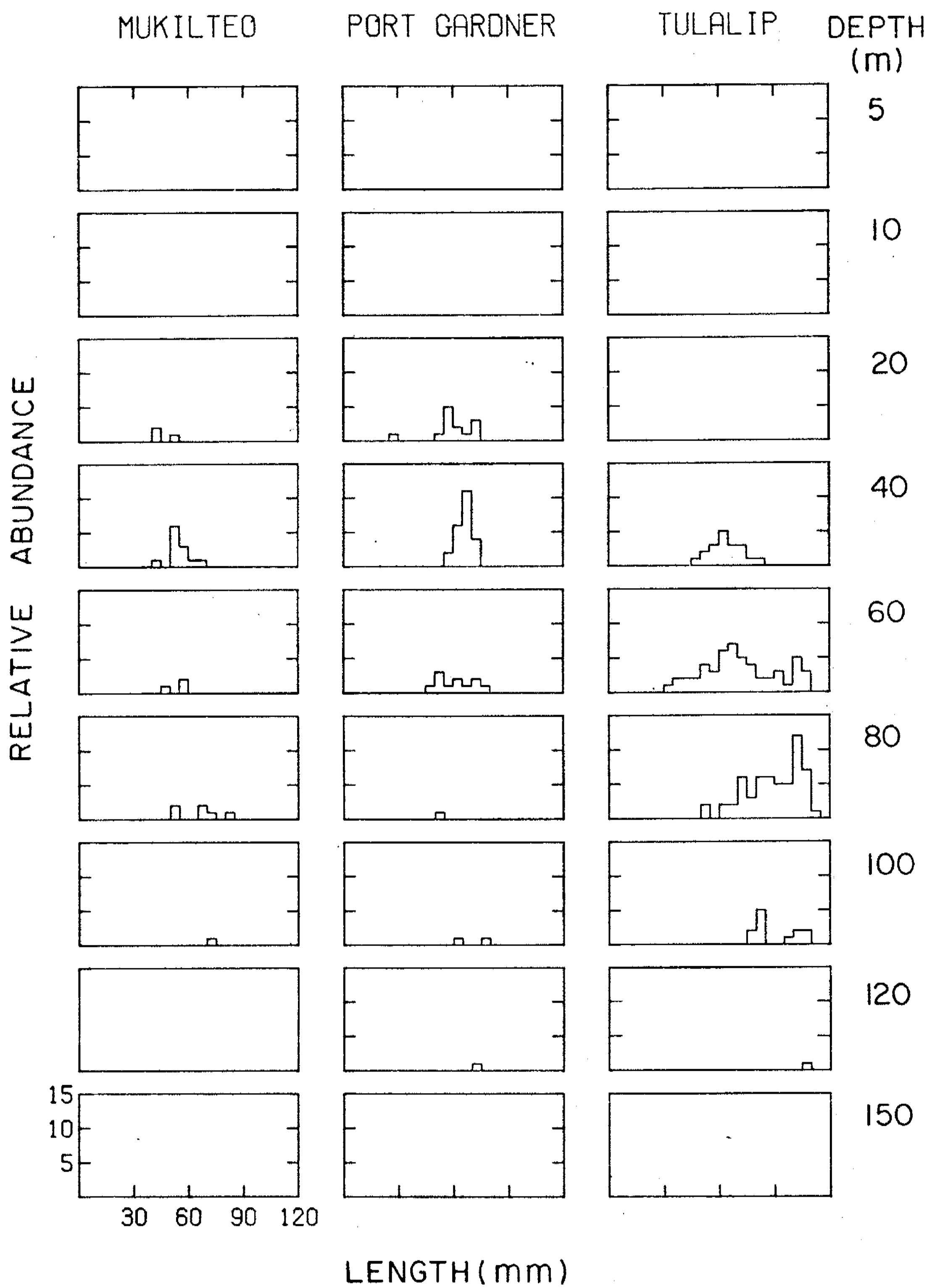

Figure 30. Length frequency distributions for the shrimp *Pandalus hypsinotus* at three locations over 9 depths, 1973-1974.

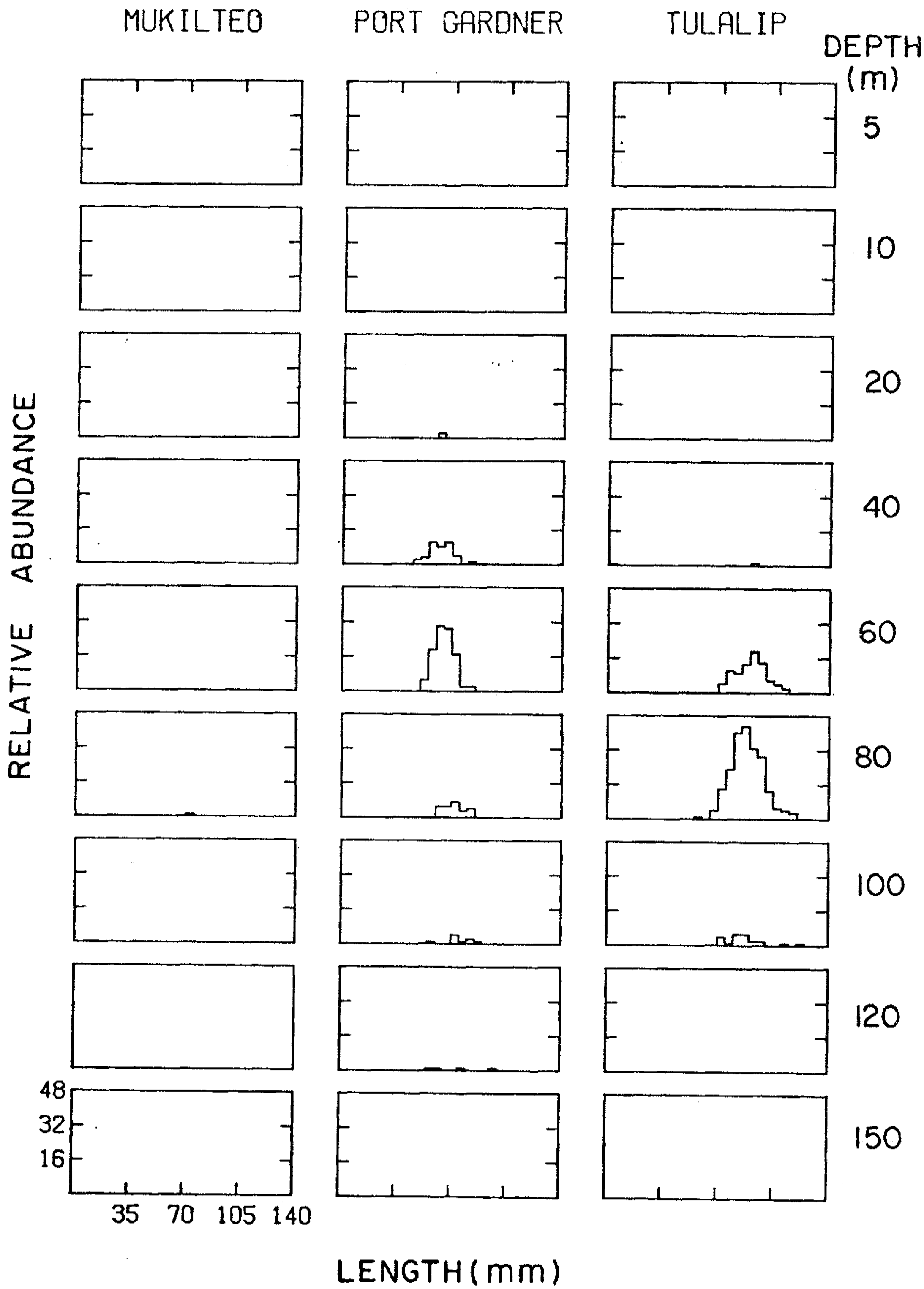

Figure 31. Length frequency distributions for the shrimp *Pandalus hypsinotus* at three locations over 9 depths, 1974-1975.

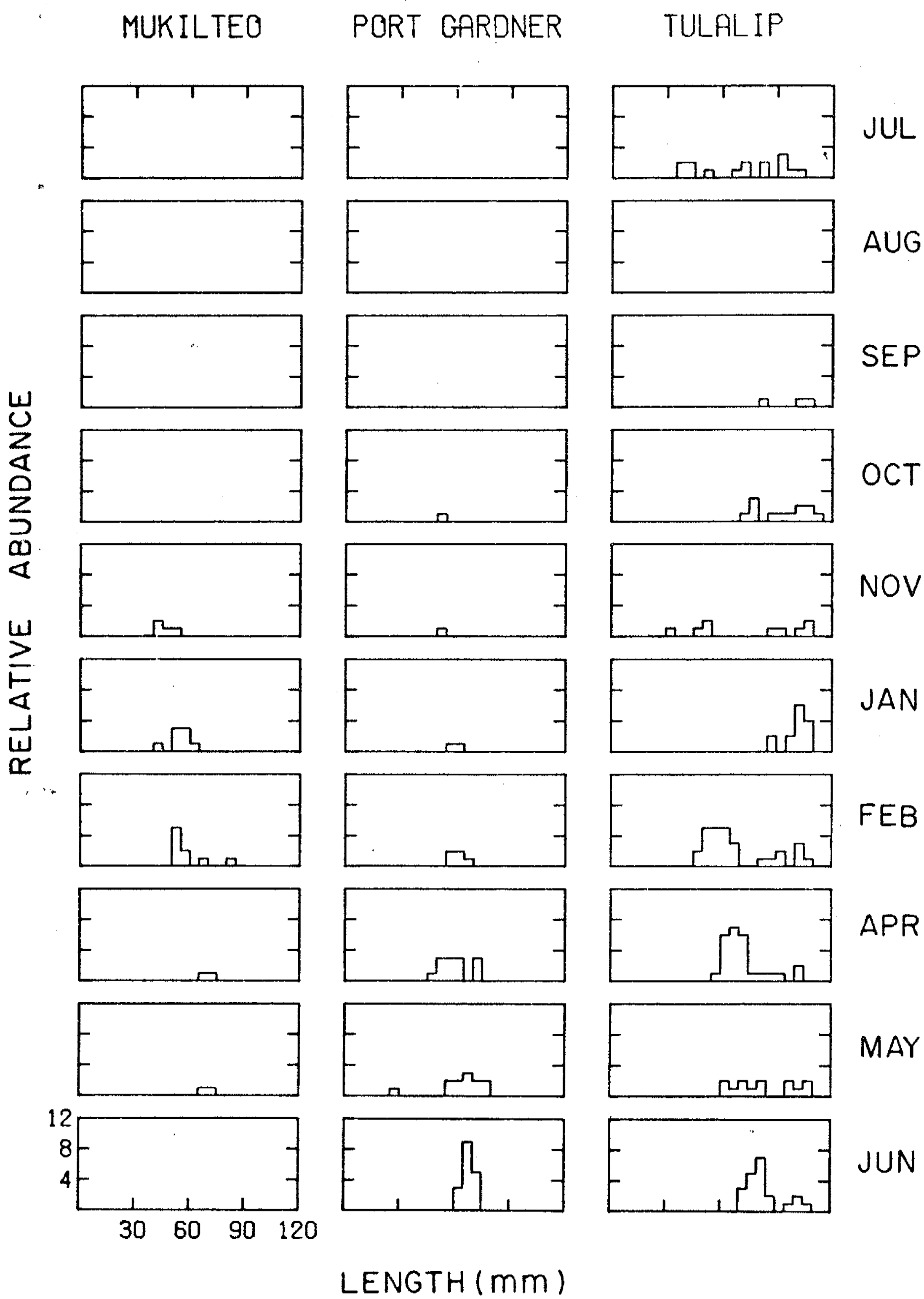

Figure 32. Length frequency distributions for the shrimp *Pandalus hypsinotus* at three locations over 10 months, 1973-1974.

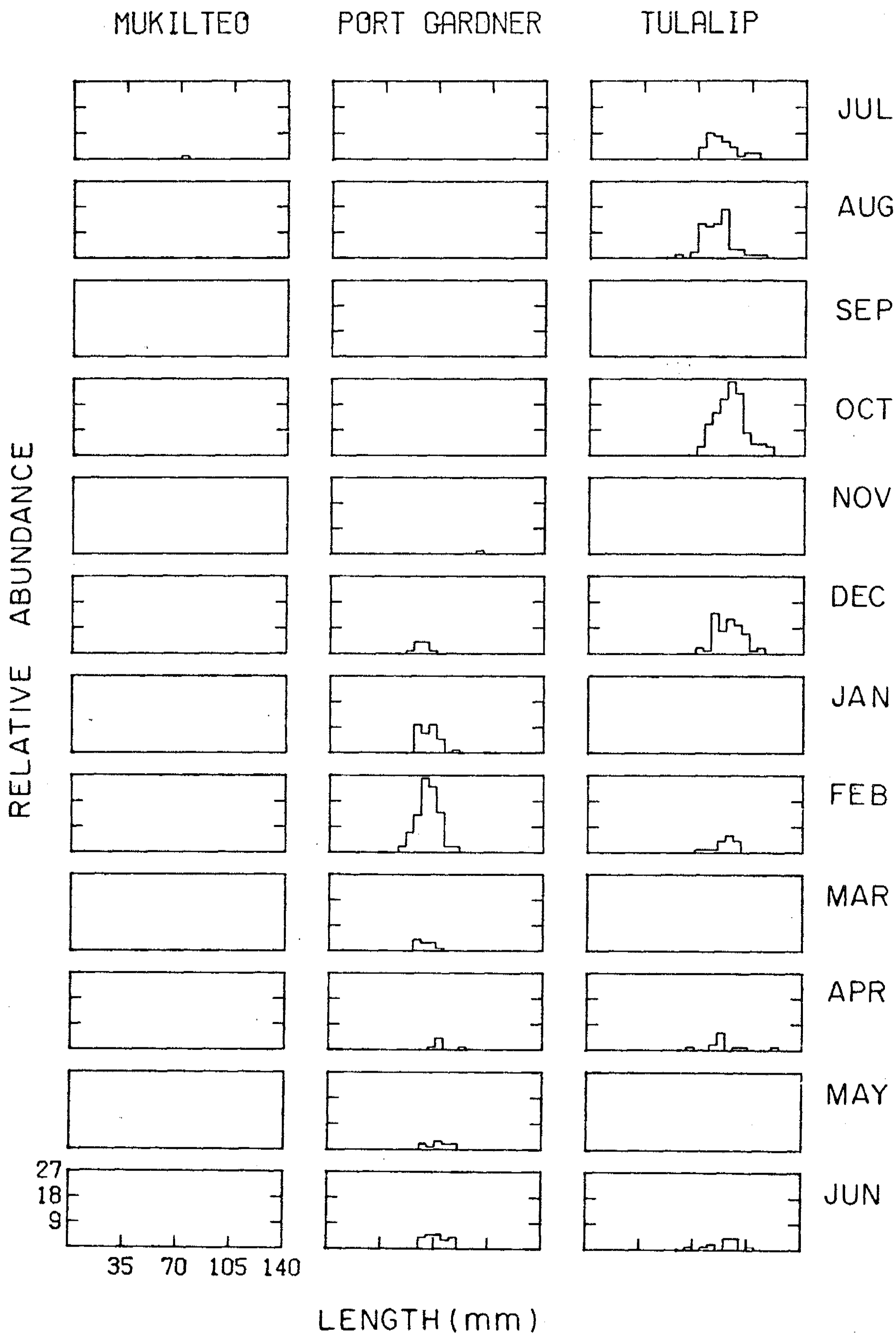

Figure 33. Length frequency distributions for the shrimp *Pandalus hypsinotus* at three locations over 12 months, 1974-1975.

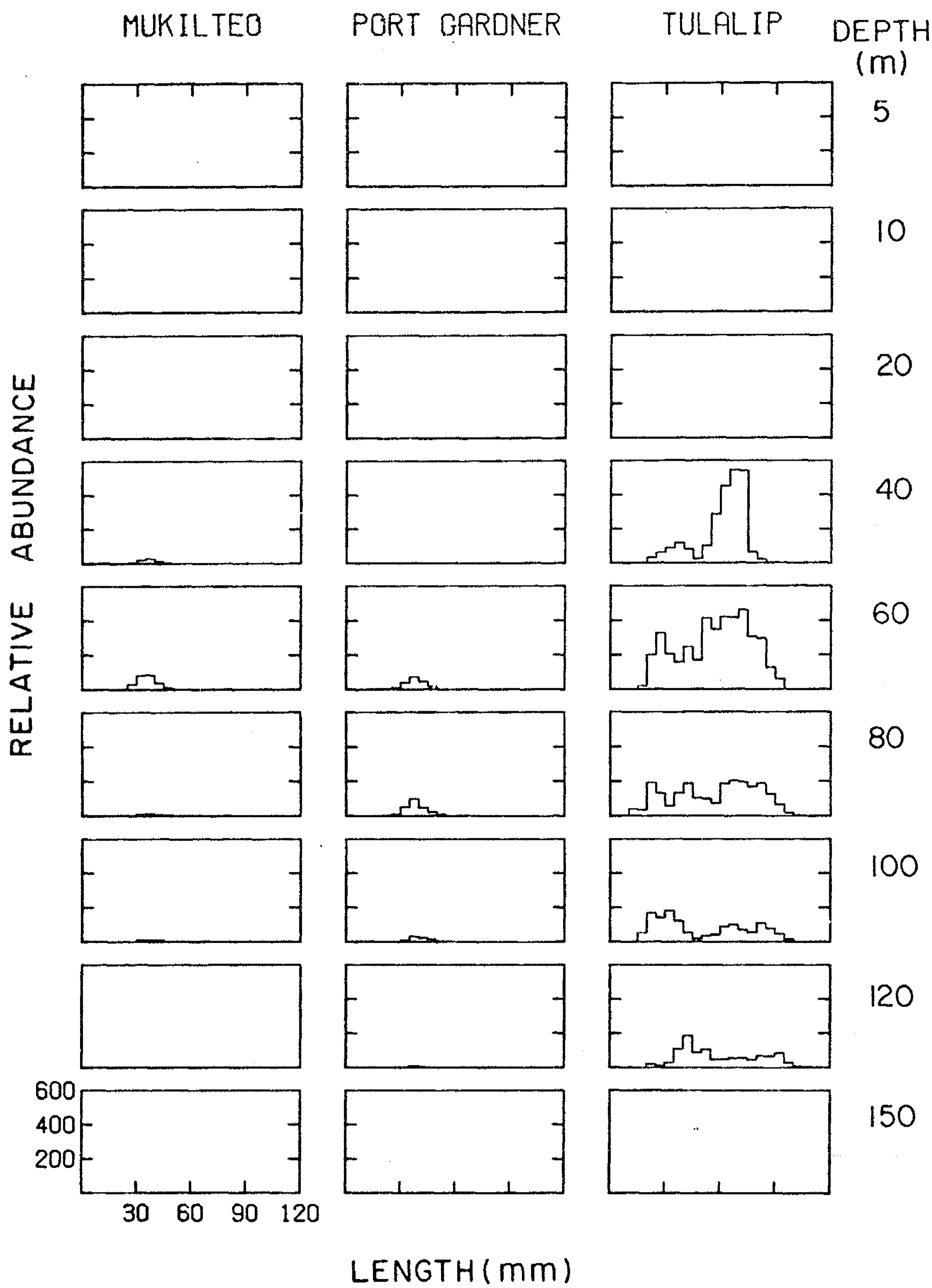

Figure 34. Length frequency distributions for the shrimp *Pandalus jordani* at three locations over 9 depths, 1973-1974.

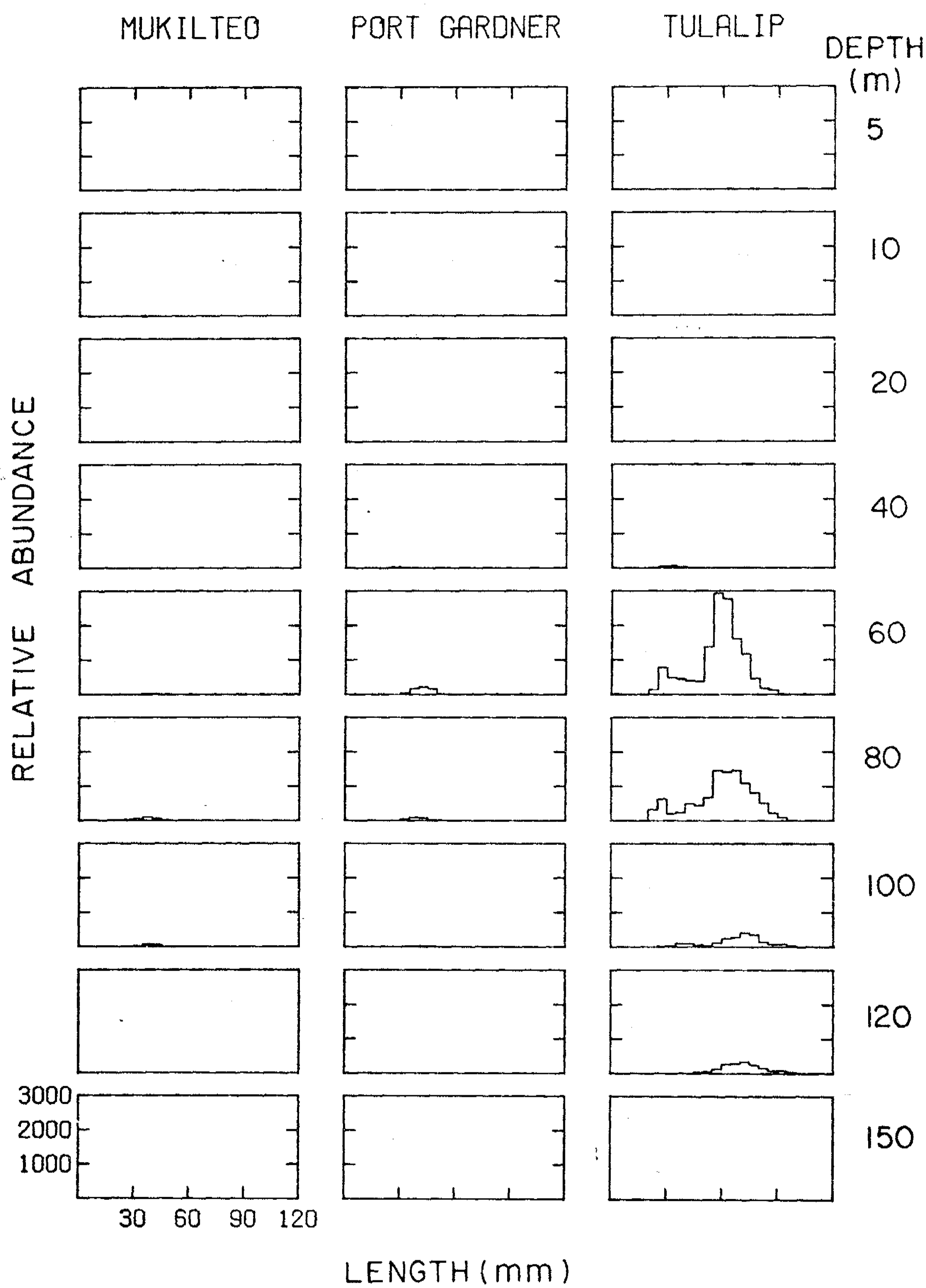

Figure 35. Length frequency distributions for the shrimp *Pandalus jordani* at three locations over 9 depths, 1974-1975.

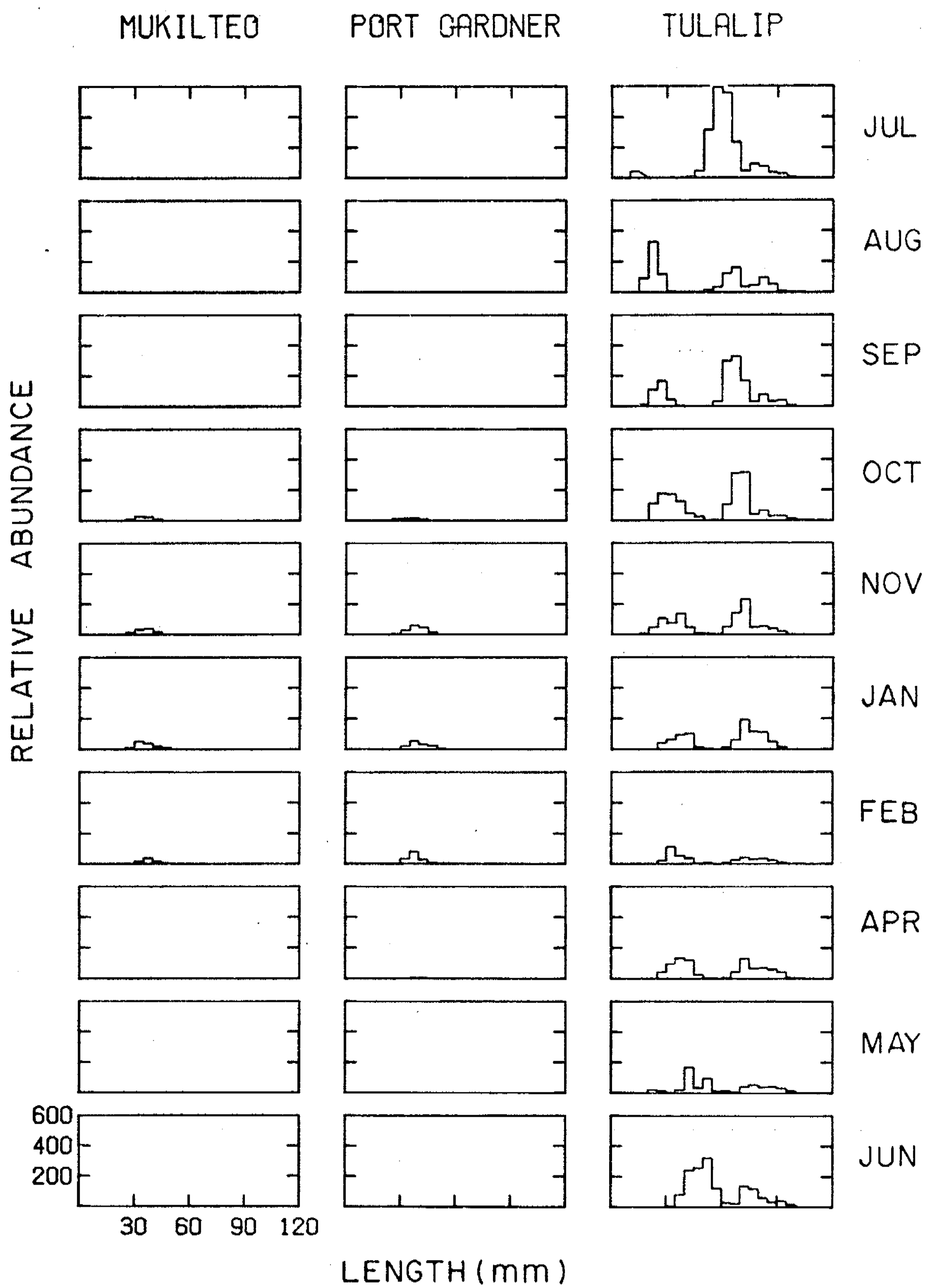

Figure 36. Length frequency distributions for the shrimp *Pandalus jordani* at three locations over 10 months, 1973-1974.

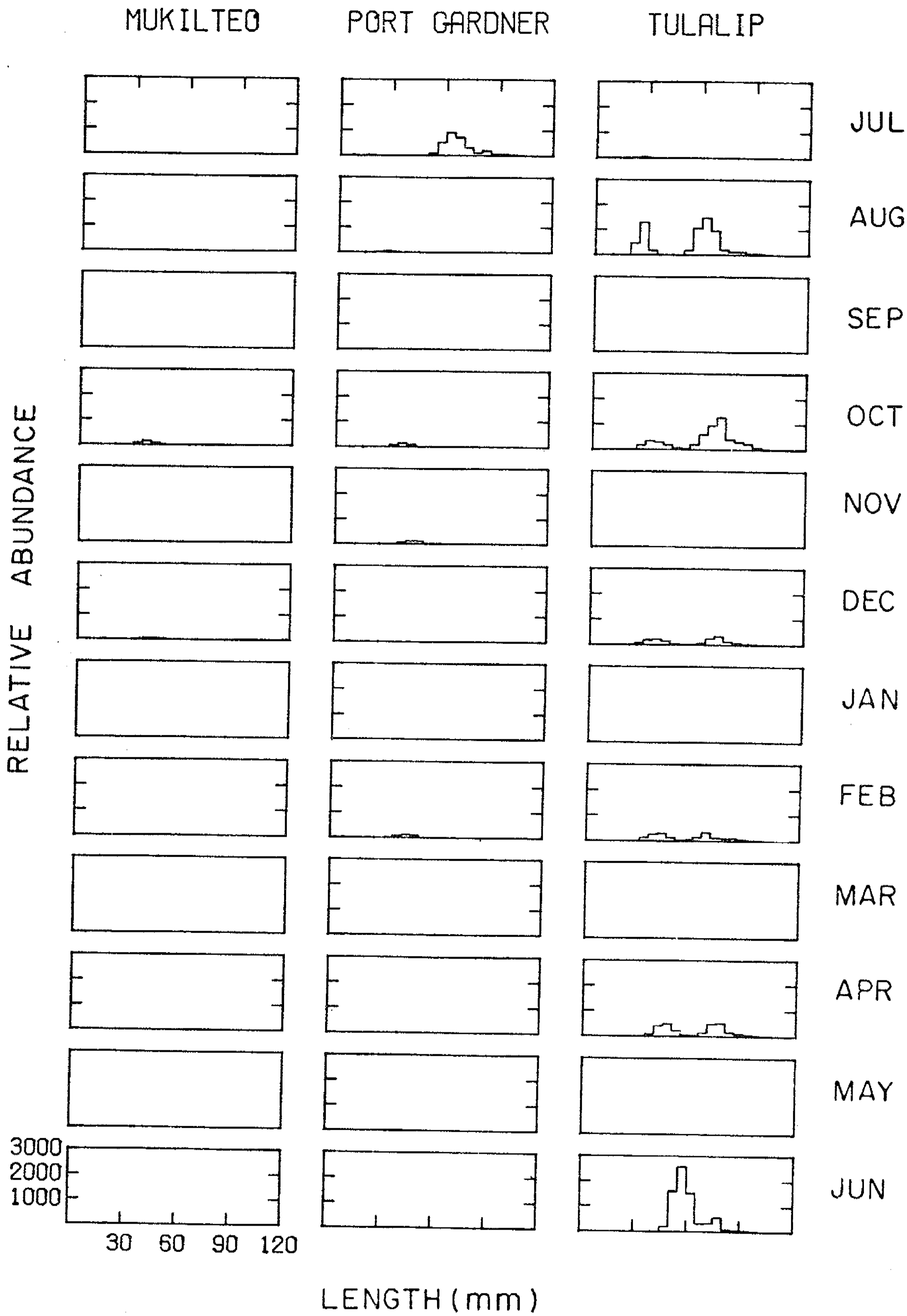

Figure 37. Length frequency distributions for the shrimp *Pandalus jordani* at three locations over 12 months, 1974-1975.

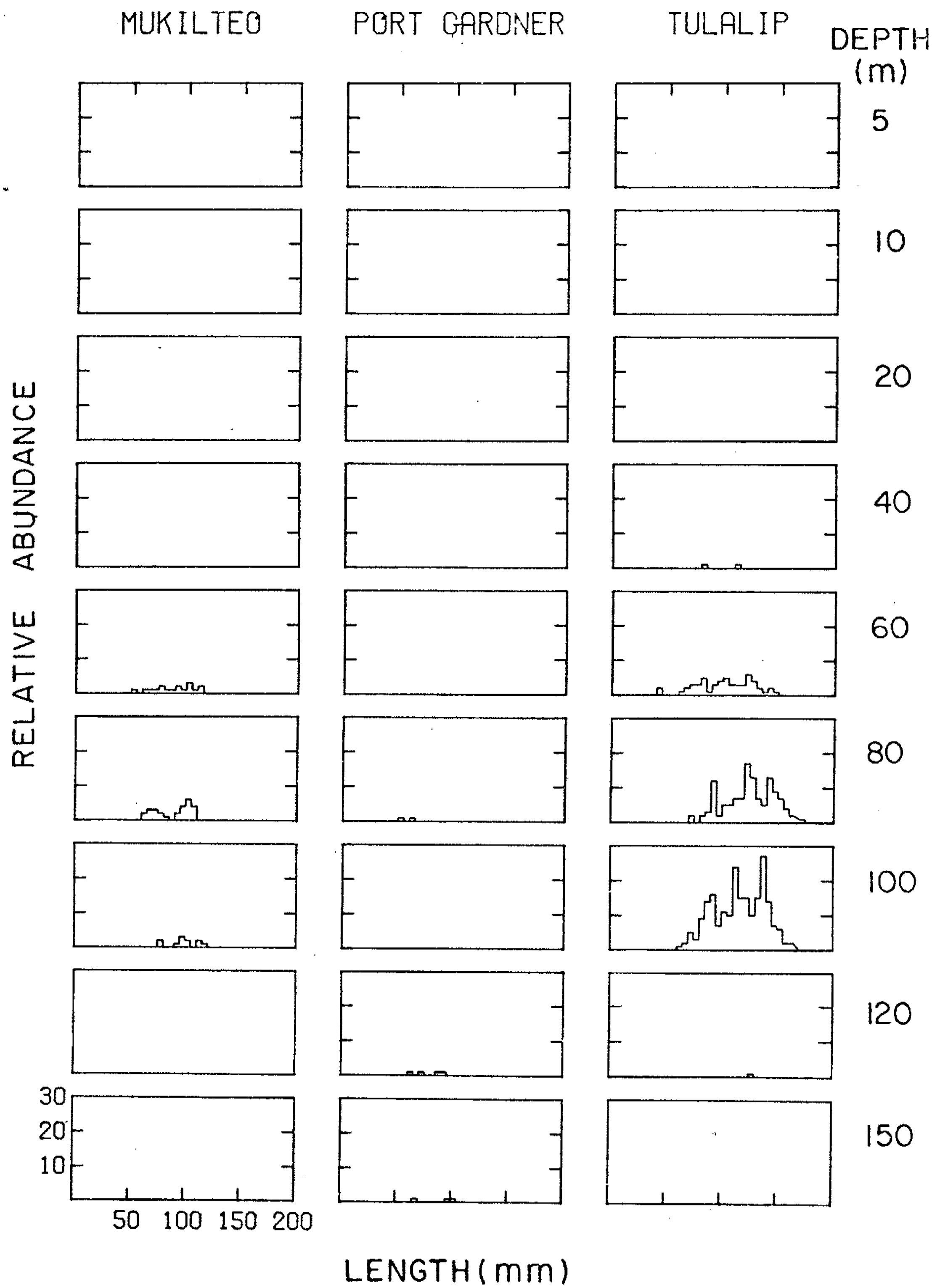

Figure 38. Length frequency distributions for the shrimp *Pandalus platyceros* at three locations over 9 depths, 1973-1974.

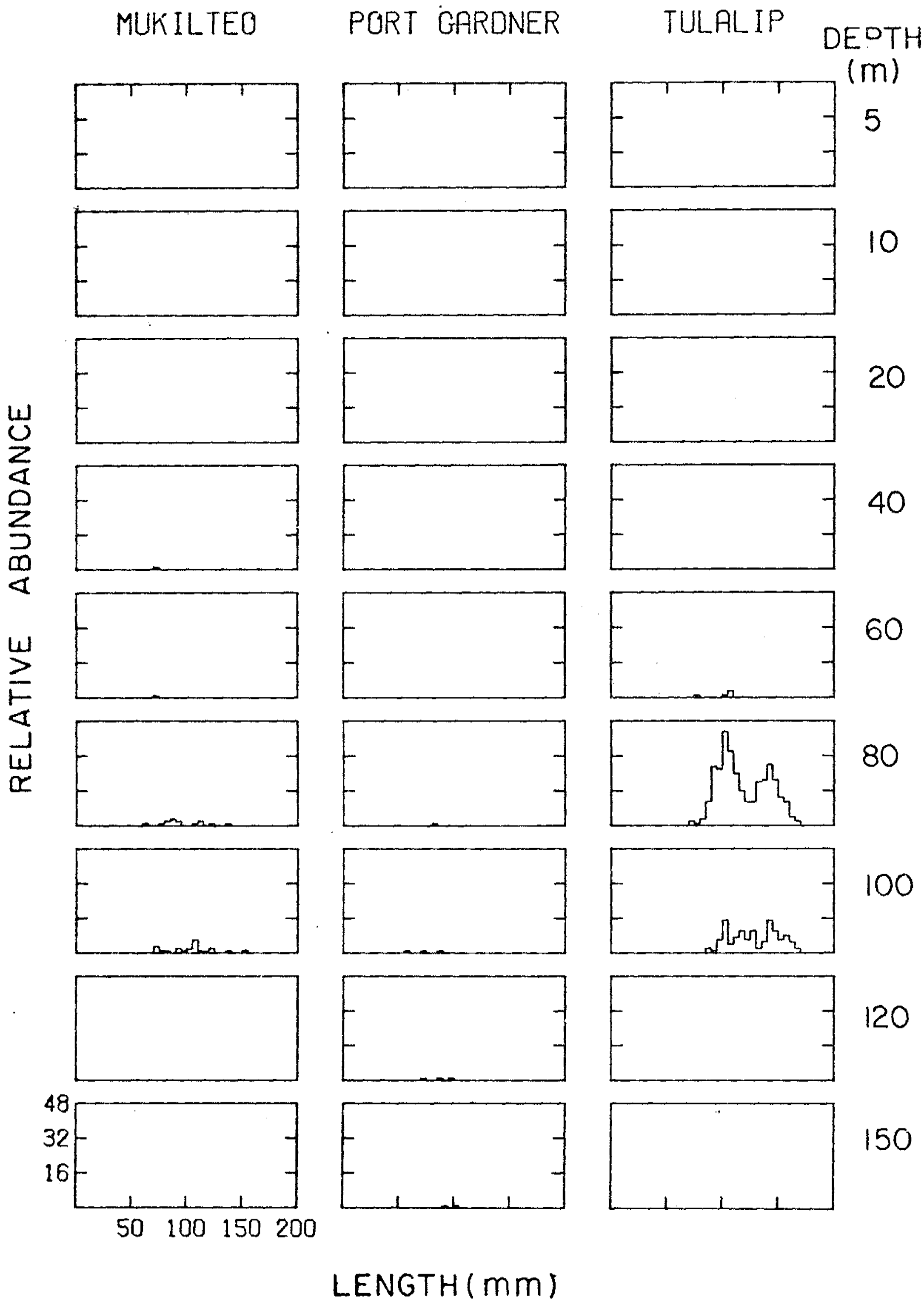

Figure 39. Length frequency distributions for the shrimp *Pandalus platyceros* at three locations over 9 depths, 1974-1975.

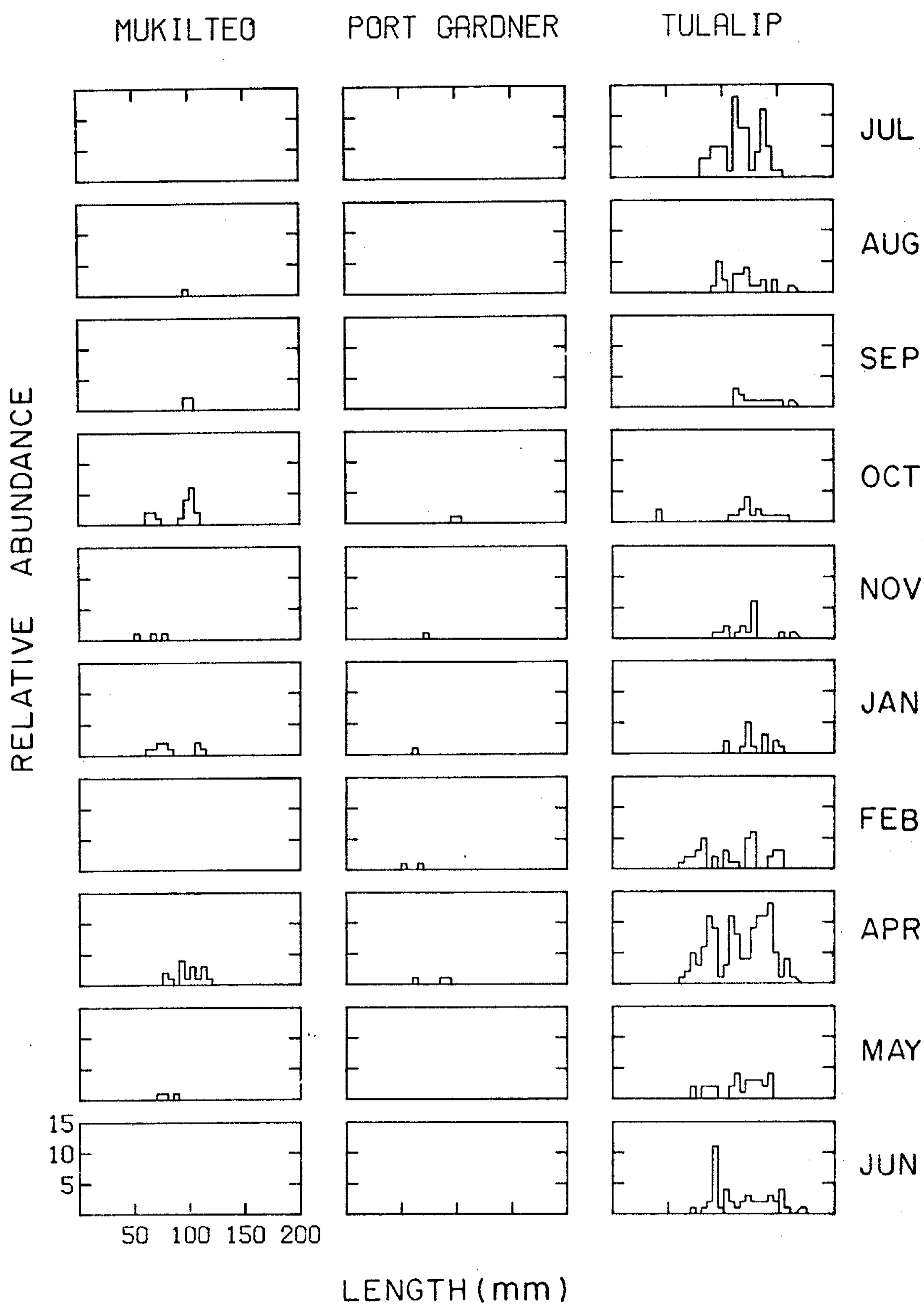

Figure 40. Length frequency distributions for the shrimp *Pandalus platyceros* at three locations over 10 months, 1973-1974.

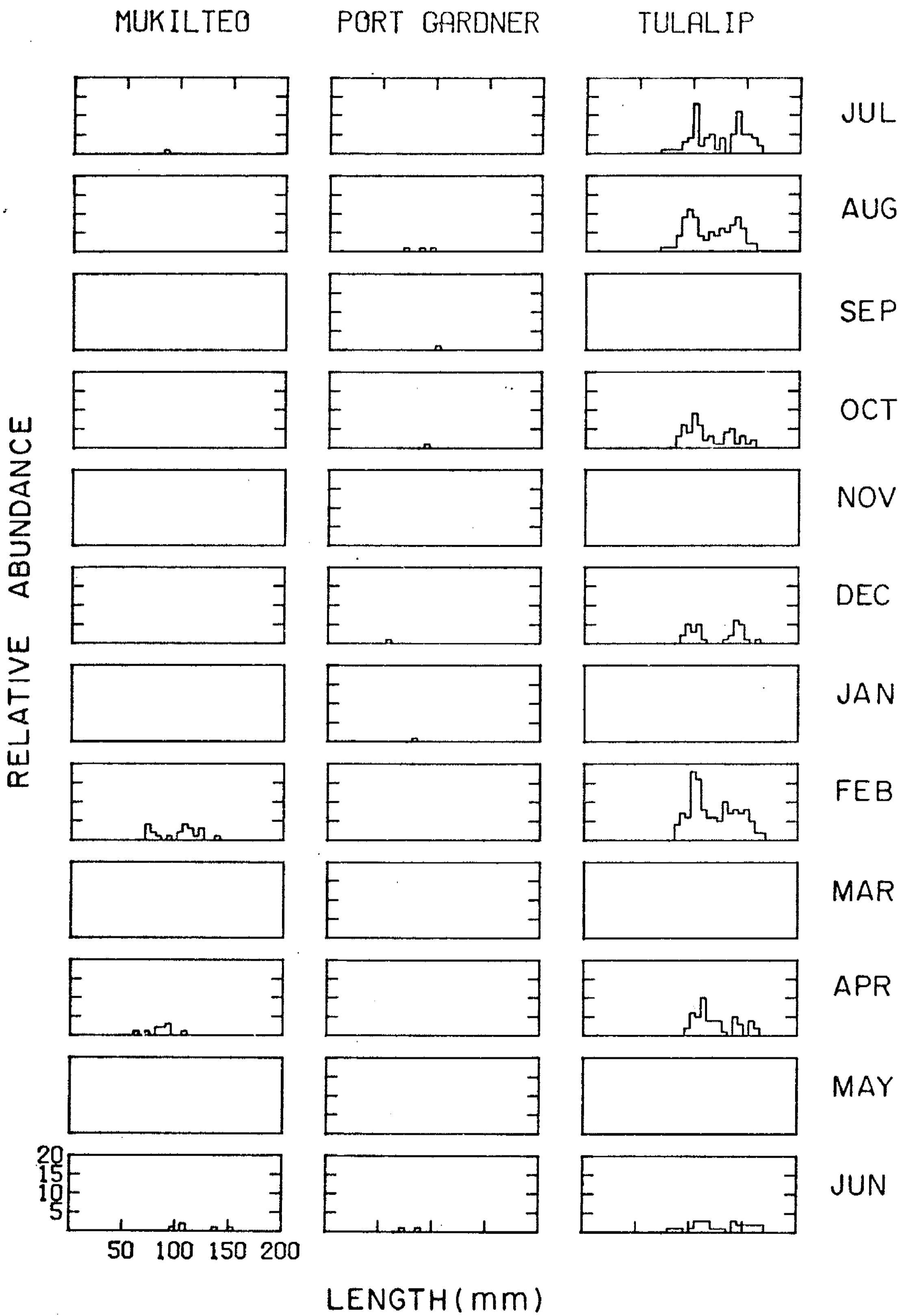

Figure 41. Length frequency distributions for the shrimp *Pandalus platyceros* at three locations over 12 months, 1974-1975.

SECTION VII

Sonic Observations in Port Gardner, Washington

1973, 1974 and 1975

SONIC OBSERVATIONS IN PORT GARDNER, WASHINGTON

1973, 1974, AND 1975

by

T. Saunders English

Department of Oceanography
University of Washington
1976

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Introduction

The sonic observations were designed to obtain biological baseline descriptions of acoustic targets in their relationship to the saltwater environment in Port Gardner. An echosounder could be operated on cruise tracks in Port Gardner and adjacent waters to document zooplankton and fishes in the water column which might reveal relationships more complex than routine net sampling could describe. Net samples were needed, however, to confirm the idendity of some acoustic targets and to provide baseline history observations.

During the first year of sonic observations, a subsurface volume of special interest was located which appeared to correspond to the plume from the deepwater diffuser outfall. Chemical observations and special samples for oyster larvae bioassay were added to the observations in the sonic study.

The results of the sonic observations are expected to relate to reductions in pulp mill waste discharges and possible resultant beneficial biological changes in Port Gardner.

Materials and Methods

Sonic observations are made with a high frequency (105 kHz) echosounder. The echosounder is a Ross model 200A modified for quantitative observations. A 10° beam transducer is mounted in the hull of the research vessel *HOH*. An isolation transformer was used to minimize noise from the vessel's electrical system. The echosounder was operated continuously while the vessel was underway, usually observing the 0-50 fathom depth range. The survey was planned to follow a track crossing 22 sampling stations (Figure 1).

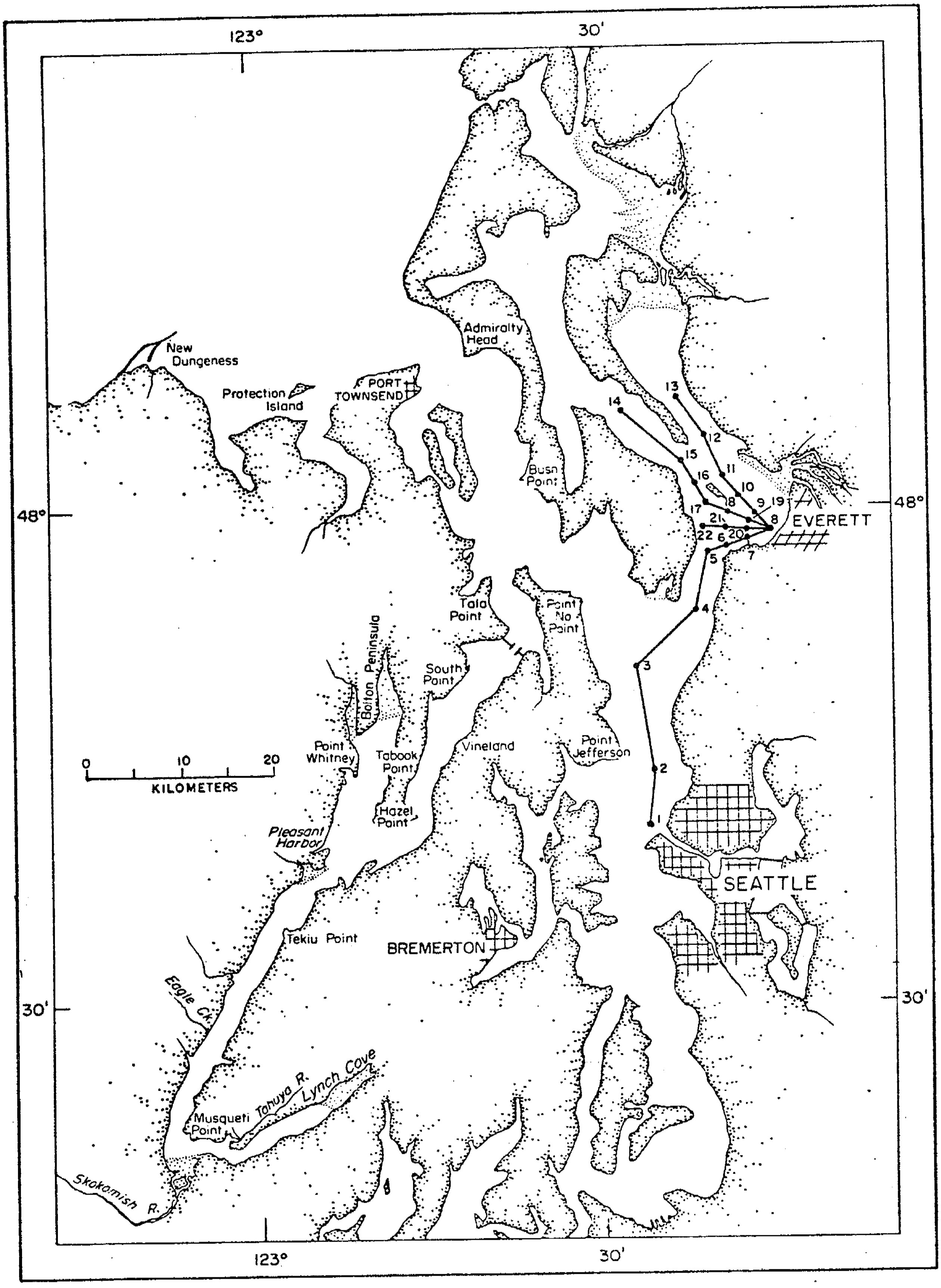

Figure 1. Station locations.

A Sony model TC-560D stereo tape recorder and an interface amplifier were used to record the incoming acoustic signal from the echosounder on magnetic tape. Taping was done, usually for 5 minutes, between successive stations and also in conjunction with net hauls to sample the zooplankton. Chart records and tapes were returned to the University of Washington for storage and analysis.

Zooplankton samples were collected with a 1-m NIO net of 561-μm mesh. This net consists of upper and lower weight bars and two identical nets. The nets are fastened to the net-bars, with the bottom of one net and the top of the next net attached to a single net-bar so that when the net-bar is released, the lower net is closed and the upper net is simultaneously opened. The lower net, without a collecting cup, acts as a drogue to stabilize the depth of the net in the water column before sampling with the upper net. An instrument package attached to the upper weight bar, together with an Amergraph conducting cable and a deck unit, provide continuous telemetry of the depth and speed of the net. Deck-actuated solenoids allowed the net to be opened at a selected depth, fished in the horizontal mode, and then closed before retrieval. This precludes contamination of the sample during lowering and retrieval. At each sampling location net hauls were made through the sonic scattering layer, except at Station 20 where replicate hauls were made at 0, 10, 20, layer depth, 60 and 100 m. The samples were preserved in 5% buffered formaldehyde and stored in glass jars for later analysis.

In the laboratory, zooplankton samples were split and individual euphausids were counted, measured, and examined for sexual maturity. The samples were split to about 100 euphausids with a modified sand splitter.

The euphausids were measured in 1-mm increments; the distance measured was from the tip of the rostrum, just behind the eyes, to the tip of the telson. Sexual maturity of female euphausids was determined by examining the unfertilized eggs within the ovaries. Individual females to be examined were cleaned by soaking about 0.5 hour in a solution of 15% water, 35% ethanol, and 50% lactic acid. Individuals were measured and inspected using a microscope with a magnification of 40 times. In some cases it was necessary to dissect the female and remove the ovary to determine the maturity of the eggs. The euphausids were classified as juvenile, male, or one of five female sexual maturity stages (Table 1).

Results

The primary results of the program of sonic observations in Port Gardner are the chart records of acoustic target returns to the high frequency echosounder (Figure 2). The chart records allowed realtime location of the diffuse midwater sonic scattering layer so that opening-closing net hauls could be made in the layer and above and below the layer when desired.

The diffuse midwater sonic scattering layer was found to correspond in depth and concentration to zooplankton crustaceans called euphausids (Figure 3). The layer changed with season as the overwintering adult population spawned to produce a large young-of-the-year population. The growth of the juveniles, males, and five sexual maturity stages of females can be examined by length frequency distributions (Figure 4).

In the summer of 1973, when the euphausids were abundant and formed a well-defined sound-scattering layer, a water volume almost devoid of

Table 1. Sexual maturity stages of female euphausids

I. The ovary is small and flat and lies just behind and above the hepatopancreas; contains small yellow, transparent, round eggs.

II. The ovary has increased in size and the closely packed polygonal eggs are uniform in size.

III. The polygonal eggs are of many sizes. Most of the eggs have lost their transparency, but the nuclei are still visible.

IV. The ovary has expanded to fill completely the thoracic cavity, pushing aside the other organs. Several sizes of eggs are present. The larger eggs contain enough yolk to obscure the nuclei. When the ovary is removed, the larger opaque eggs separate easily from the rest of the egg mass.

V. Spawning has occurred. The ovary is shrunken and sometimes contains a few large opaque mature eggs.

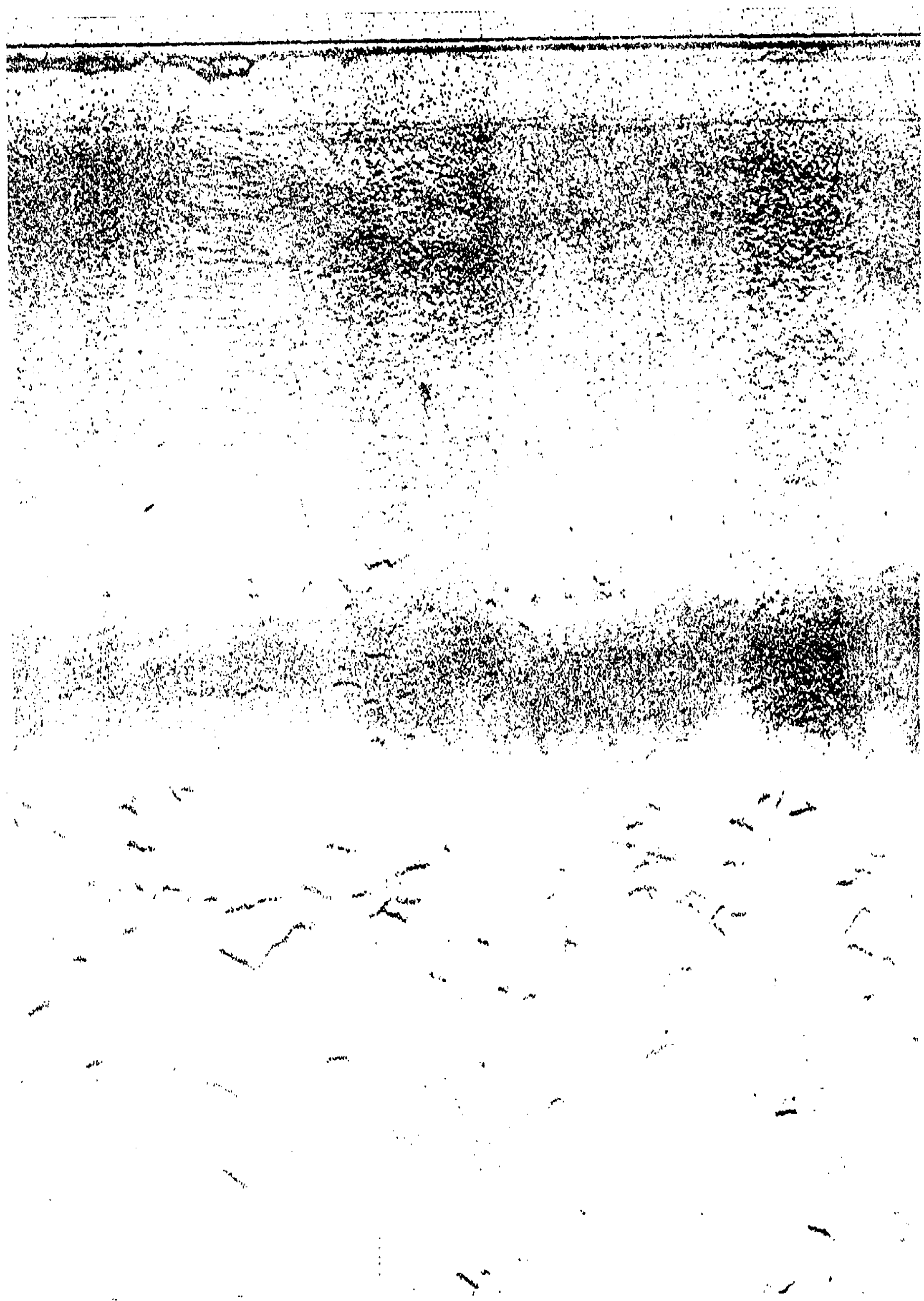

Figure 2. Chart record from Port Gardner from the surface at the top to about 110 meters at the bottom. The midwater diffuse scattering layer is about 55 meters deep.

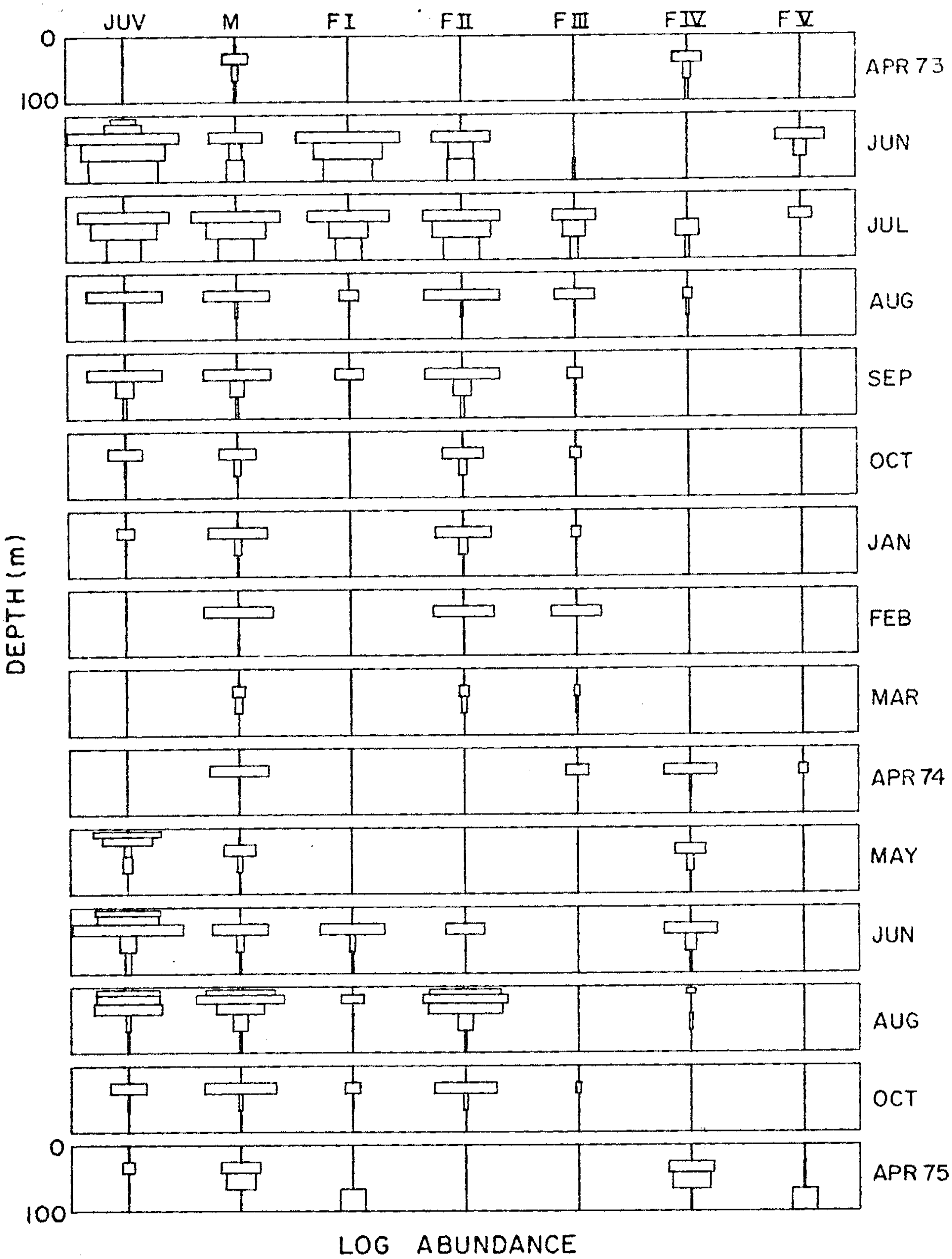

Figure 3. Vertical distributions of juvenile, male and five sexual maturity stages of female euphausids between stations 8 and 20, 1973-1975.

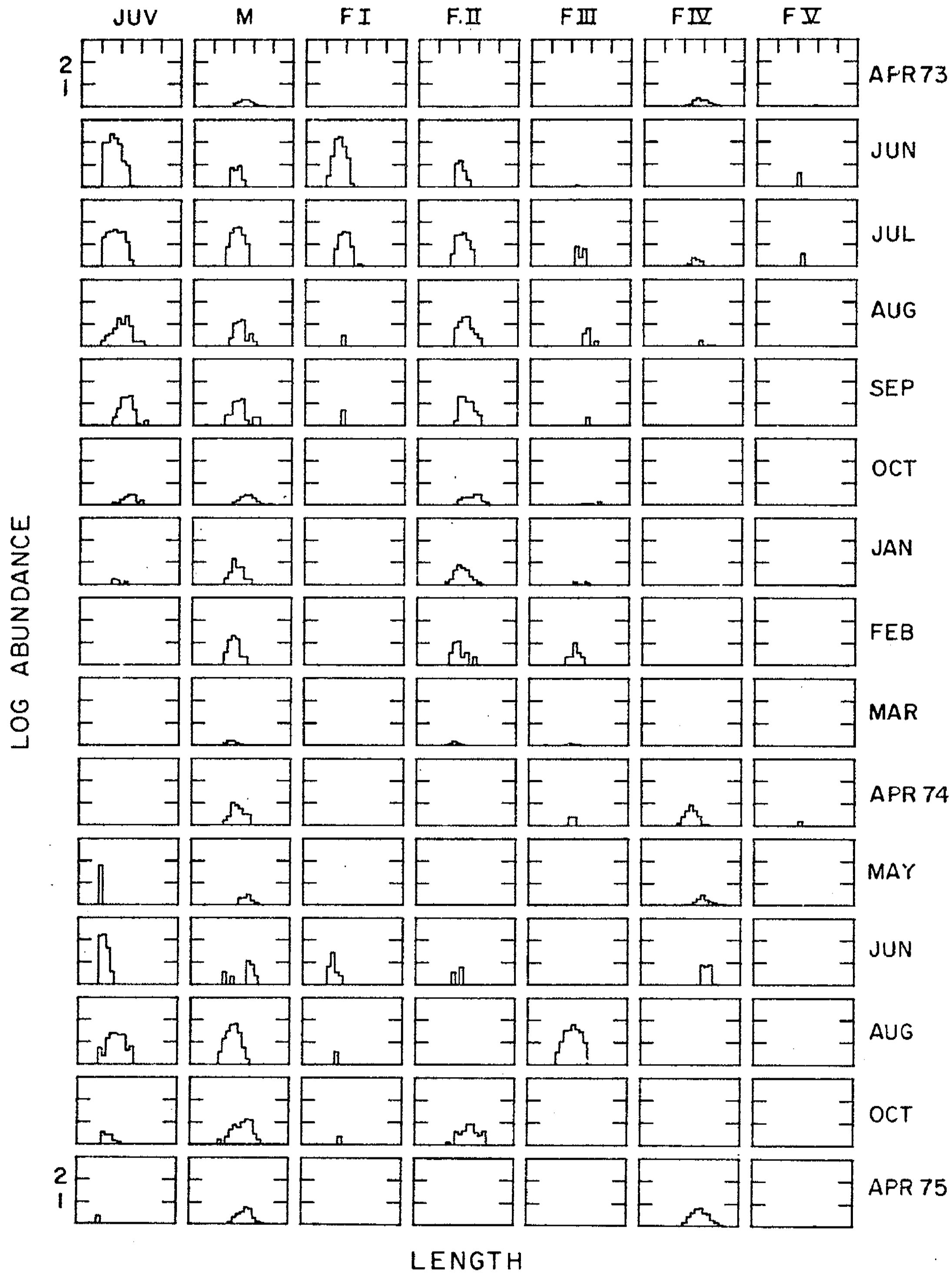

Figure 4. Length-frequency distributions of juvenile, male and five sexual maturity stages of female euphausids between stations 8 and 20, 1973-1975.

sonic targets was observed between stations 8 and 9, a transect running about 1 mile from above the deepwater diffuser outfall along the river delta to the northwest (Figure 5). Samples for sulfite waste liquor (SWL) over a range of depth from 15 to 90 meters along the transect confirmed that the absence of acoustic targets was associated with high SWL concentrations (Table 2).

The discovery of the water volume devoid of sonic targets, and the associated high concentrations of SWL, led to a more intensive study of the transect between stations 8 and 9. The chart records sometimes suggested a volume devoid of sonic targets and sometimes no void was evident (Figures 6, 7, 8, and 9). The SWL concentrations observed appear to correspond somewhat, but not completely to the evidence of the chart record (Table 3).

The water volume on the transect from stations 8 to 9 was sampled frequently for sulfite waste liquor and dissolved oxygen concentrations (Figures 10, 11, and 12). Although there is considerable variability evident, the SWL concentrations appear to have decreased over the period of observations and the concentrations of dissolved oxygen show some evidence of increasing in 1975.

The most obvious measure of the reduction of sulfite waste liquor time over time in the environment is the integrated total concentration for a series of transects between stations 8 and 9 (Figure 13). The relationship between relatively high SWL concentrations and low dissolved oxygen is striking (Figure 14). Therefore, a decrease in areas of relatively high SWL in the environment, as in the middle depths between stations 8 and 9, can be expected to lead to increased concentrations of dissolved oxygen.

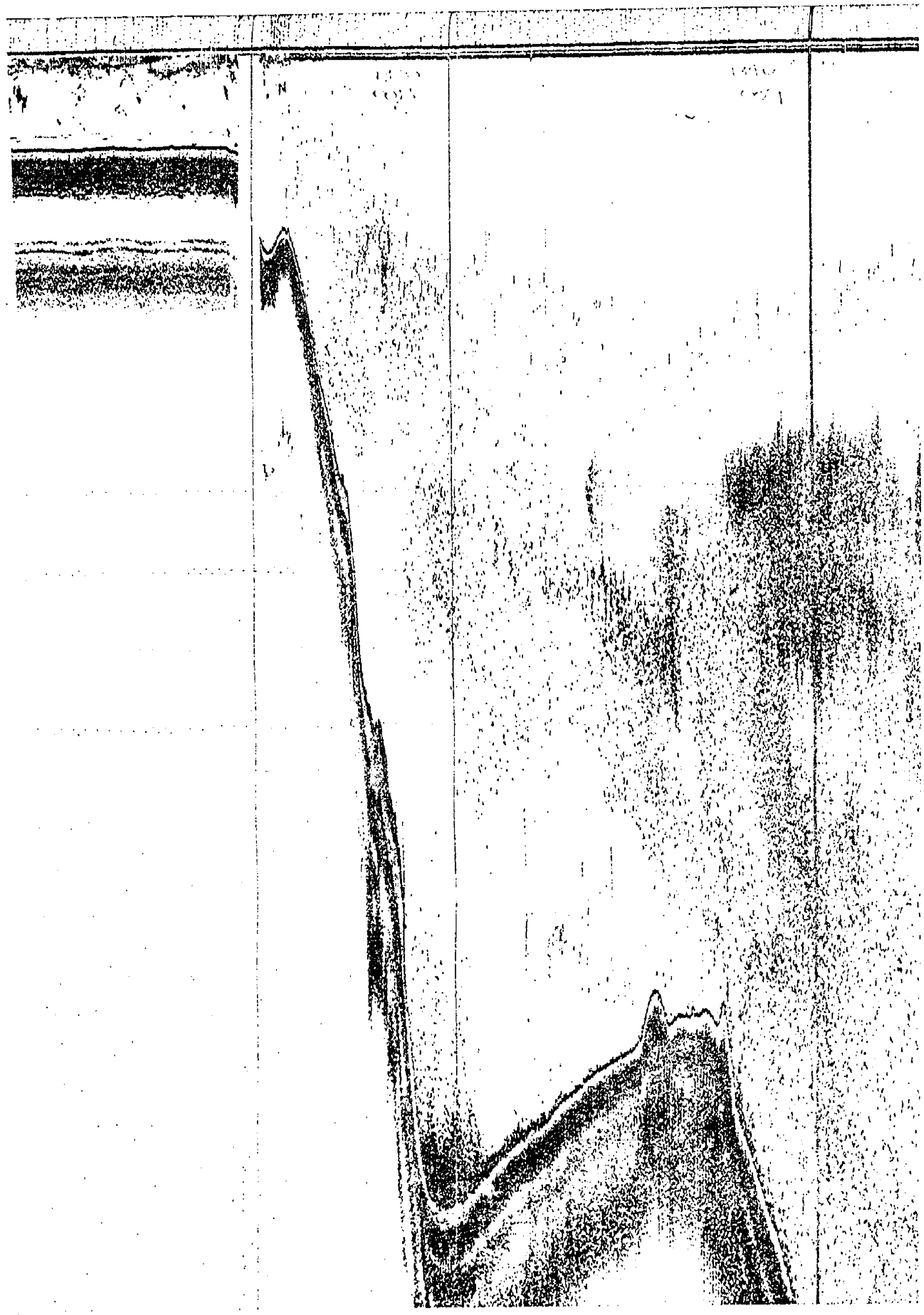

Figure 5. Chart record from Port Gardner including the transect between stations 8 and 9, 26 August 1973.

Table 2. Sulfite waste liquor concentrations with depth on the transect between stations 8 and 9, 26 August 1973

Depth (m)	Station 8.25	8.50	8.75	9
15	45	36	28	9
30	77	113	59	36
45	68	122	50	63
60	140	127	54	41
75	425	420	28	41
90	450	260	122	50

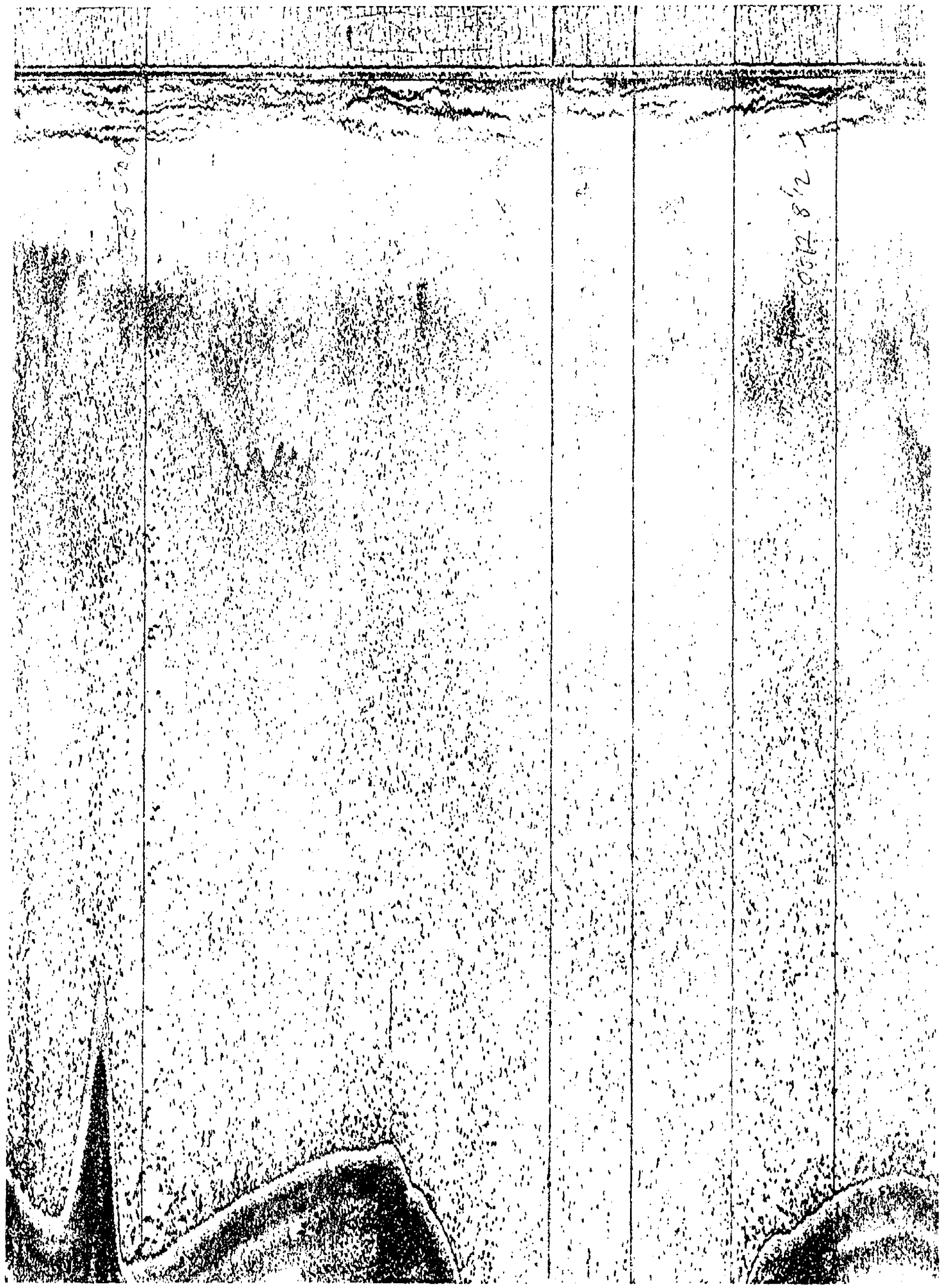

Figure 6. Chart record from Port Gardner including the transect between stations 8 and 9, 19 December 1973.

Figure 7. Chart record from Port Gardner including the transect between stations 8 and 9, 2 May 1974.

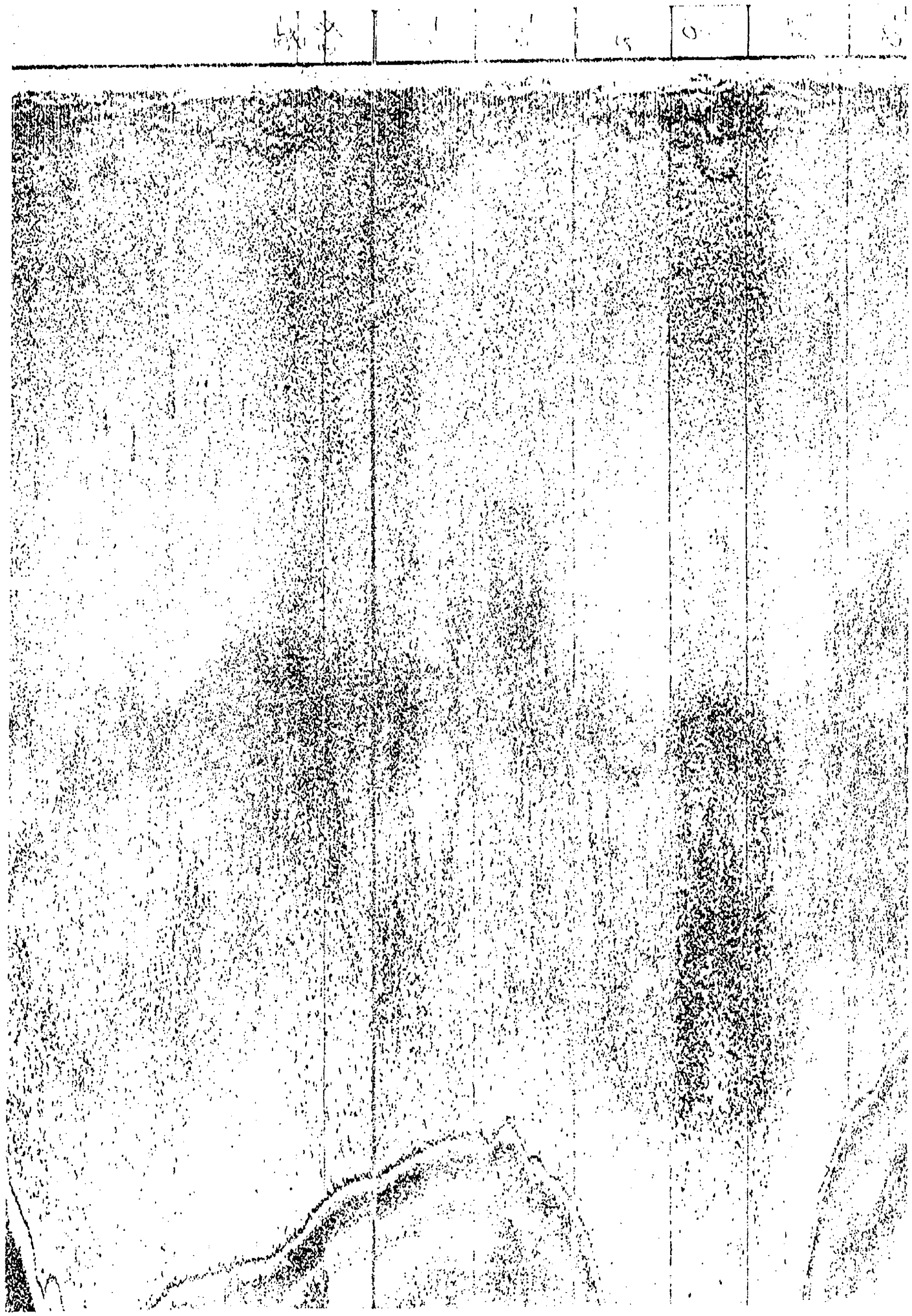

Figure 8. Chart record from Port Gardner including the transect between stations 8 and 9, 27 February 1975.

Figure 9. Chart record from Port Gardner including the transect between stations 8 and 9, 23 June 1975.

Table 3. Sulfite waste liquor concentrations with depth on the transect between stations 8 and 9, on four dates

19 DEC 73

Depth (m)	8	8.25	8.50	8.75	9
15	25	25	48	20	33
30	30	40	40	13	15
45	80	265	20	5	13
60	5	15	15	5	10
75	5	33	13	13	18
90	15	55	15	15	25

2 MAY 73

Depth (m)	8	8.25	8.50	8.75	9
15	0	0	48	35	8
30	5	0	7	15	8
45	13	0	8	7	12
60	115	35	20	40	23
75	550	25	25	85	28
90	60	95	60	38	23

27 FEB 75

Depth (m)	8	8.25	8.50	8.75	9
15	9	5	5	5	23
30	0	5	5	18	18
45	45	9	18	18	18
60	180	23	23	36	23
75	205	28	32	36	28
90	104	28	41	36	32

23 JUN 75

Depth (m)	8	8.25	8.50	8.75	9
15	3	5	0	0	0
30	4	10	7	3	0
45	25	10	8	7	7
60	25	10	8	20	13
75	27	8	12	13	27
90	13	10	7	6	7

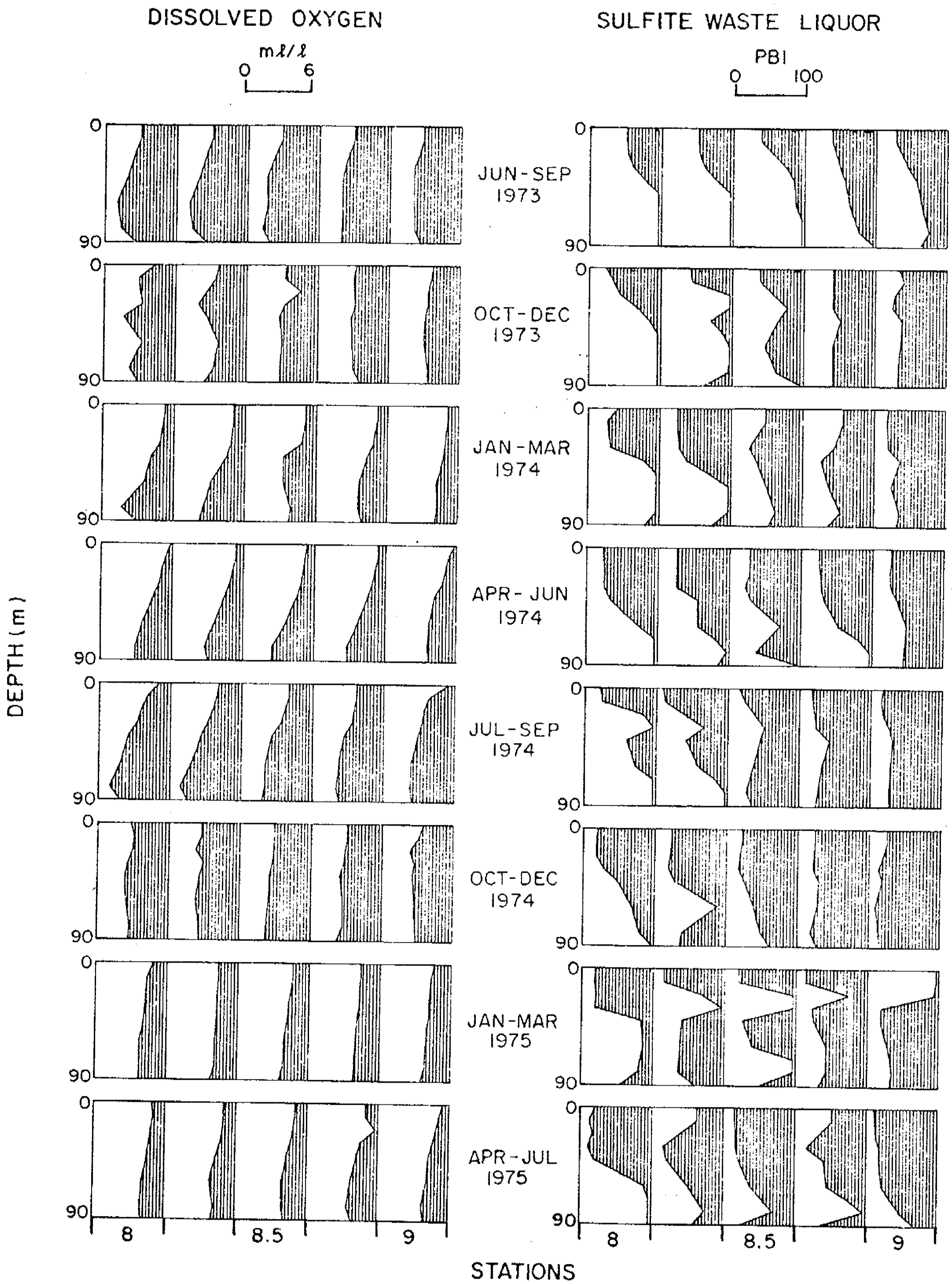

Figure 10. Dissolved oxygen and sulfite waste liquor concentrations at five locations between stations 8 and 9, 1973-1975.

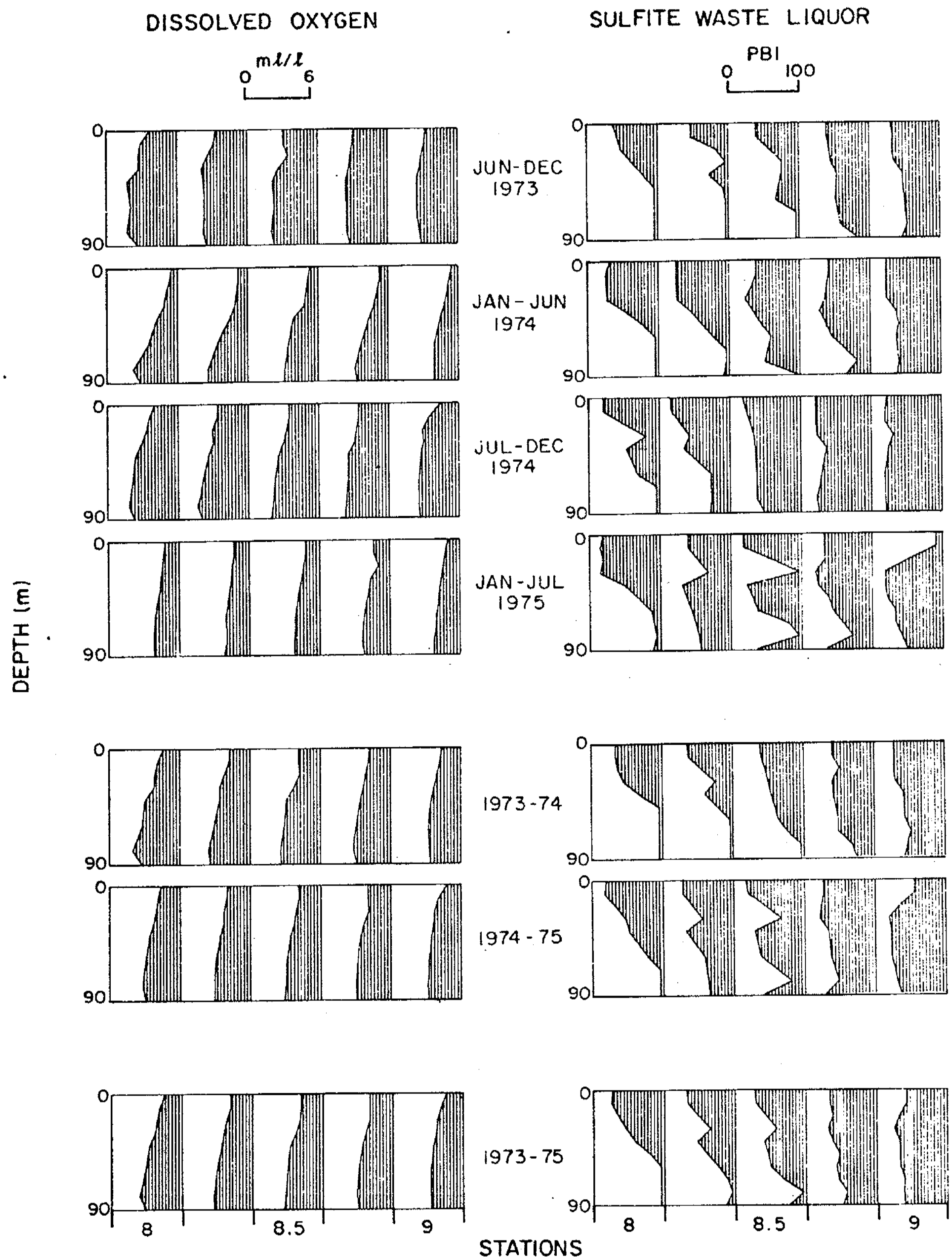

Figure 11. Dissolved oxygen and sulfite waste liquor concentrations at five locations between stations 8 and 9, 1973-1975.

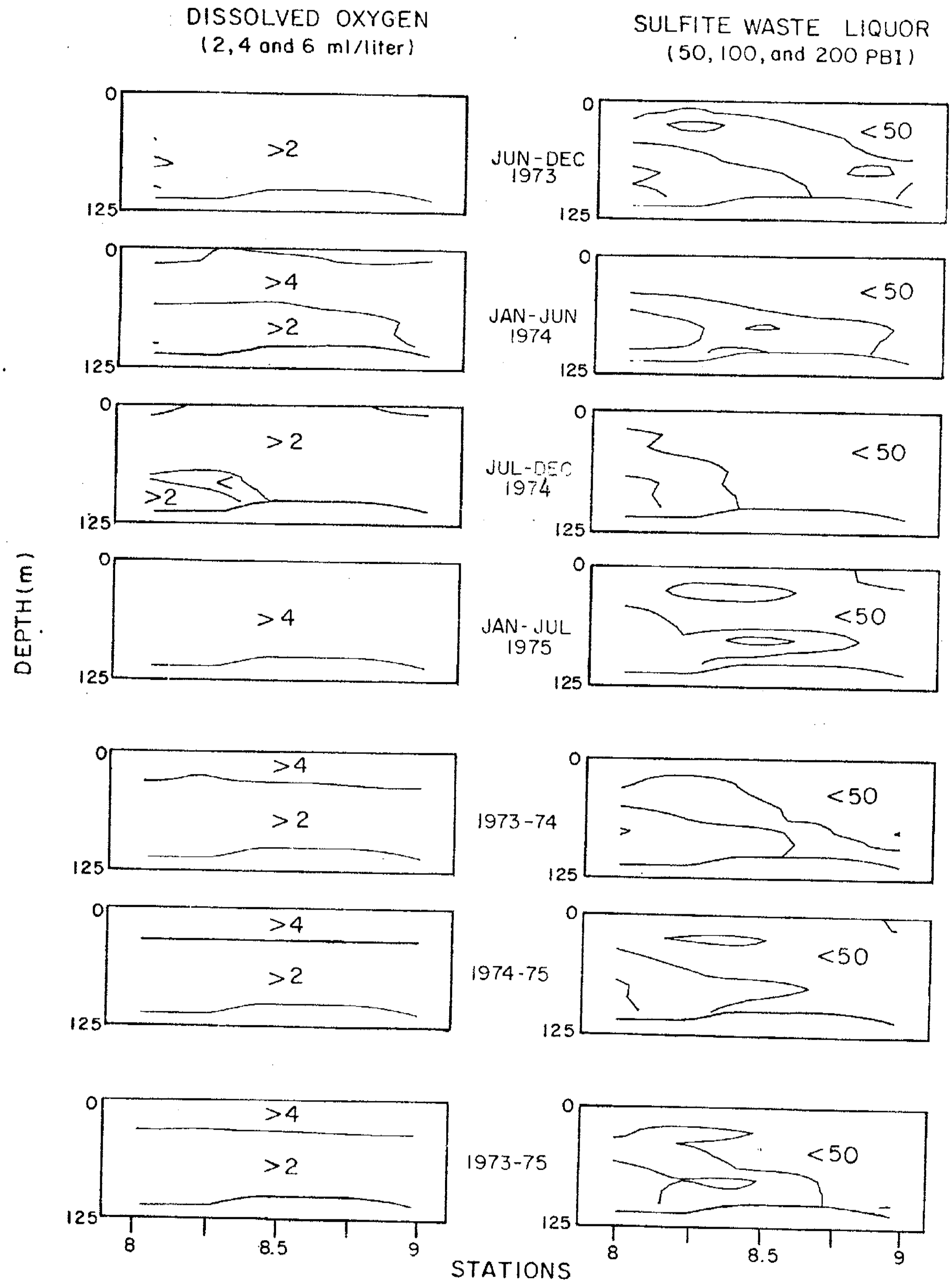

Figure 12. Dissolved oxygen and sulfite waste liquor concentrations at five locations between stations 8 and 9, 1973-1975.

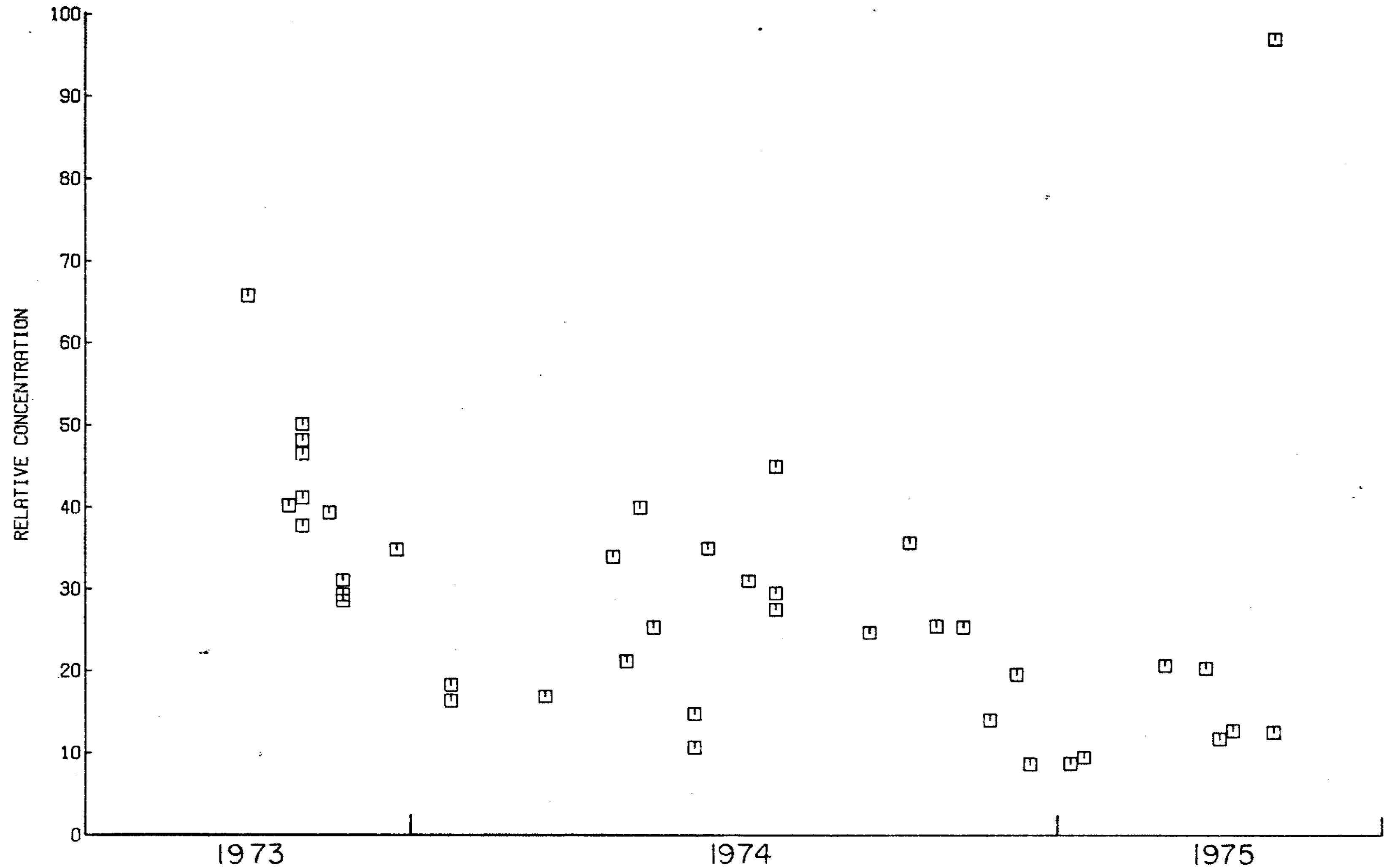

Figure 13. Relative concentrations of sulfite waste liquor integrated in the area between stations 8 and 9, 1973–1975.

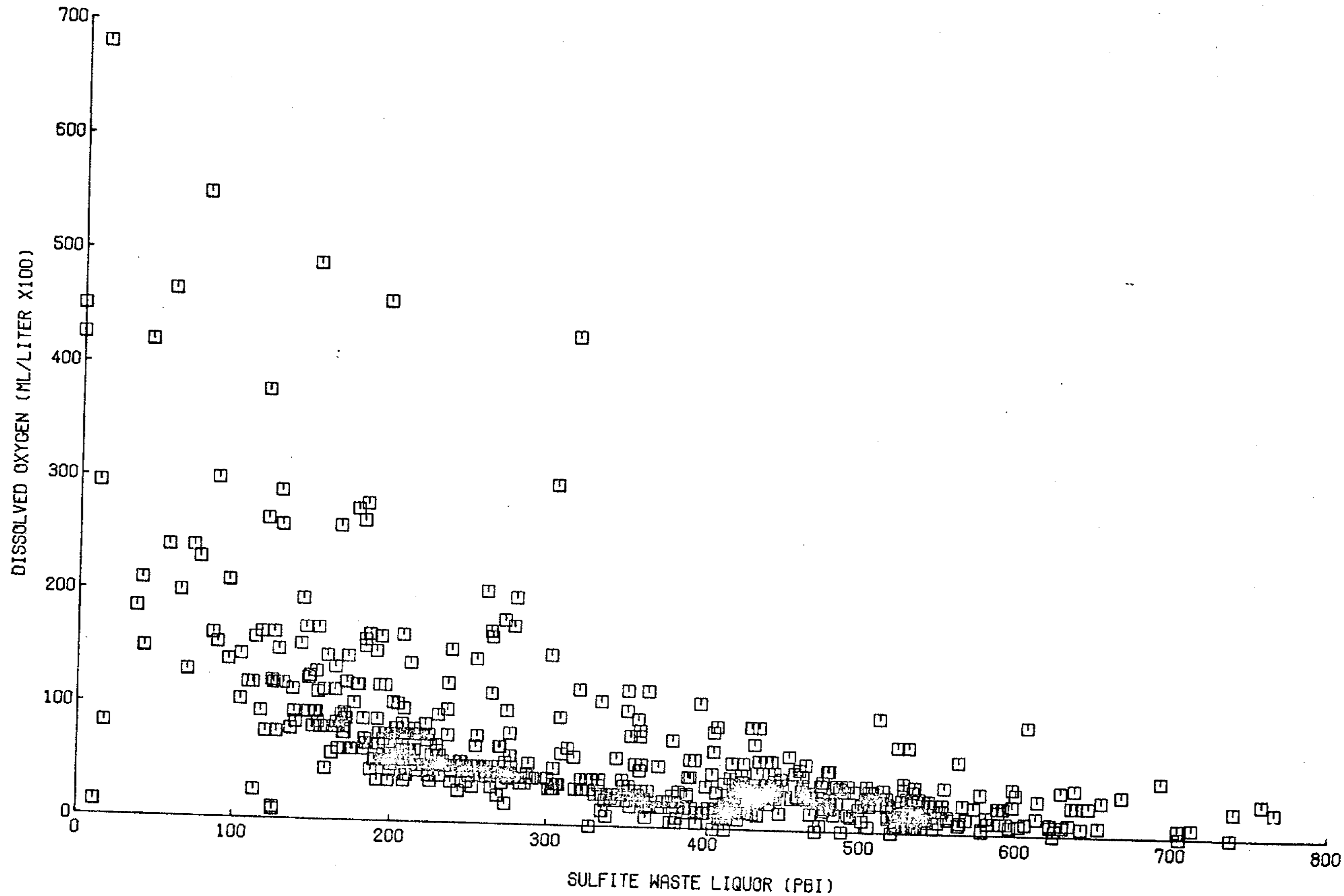

Figure 14. Relationship between dissolved oxygen and sulfite waste liquor concentrations in Port Gardner, 1973-1975.

The discovery of the water volume devoid of sonic targets led to the ability to sample water of relatively high SWL concentration. The use of some high SWL samples in the oyster larva bioassay program was suggested. The initial samples from 4 April 1974 showed an obvious relationship between experimental response and SWL concentration (Figure 15). All of the Washington State Fisheries data from Port Gardner in 1973 and 1974 show a similar relationship between response and SWL concentration (Figure 16).

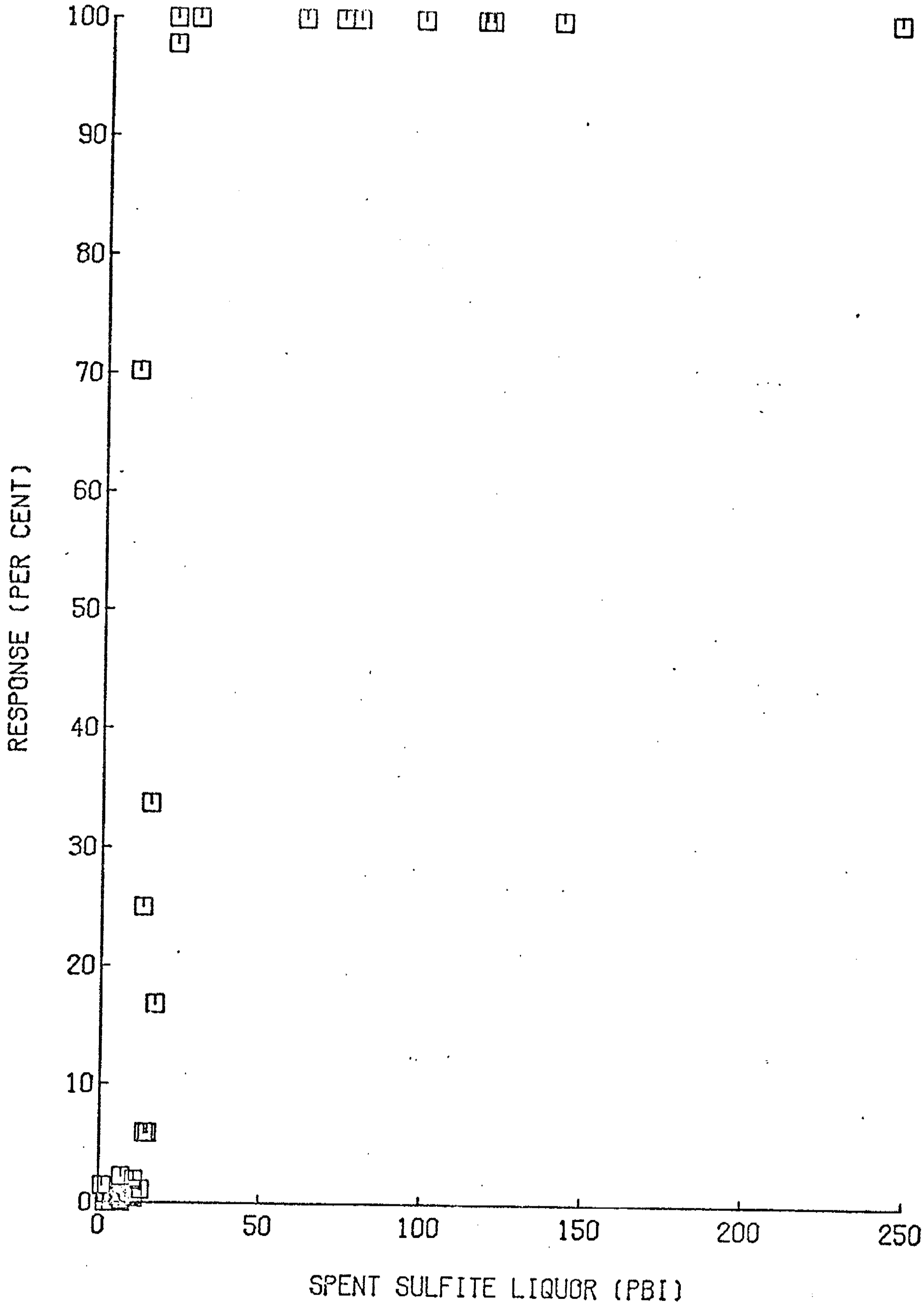

Figure 15. Response of abnormal oyster larvae to sulfite waste liquor concentrations in the area between stations 8 and 9, 4 April 1974.

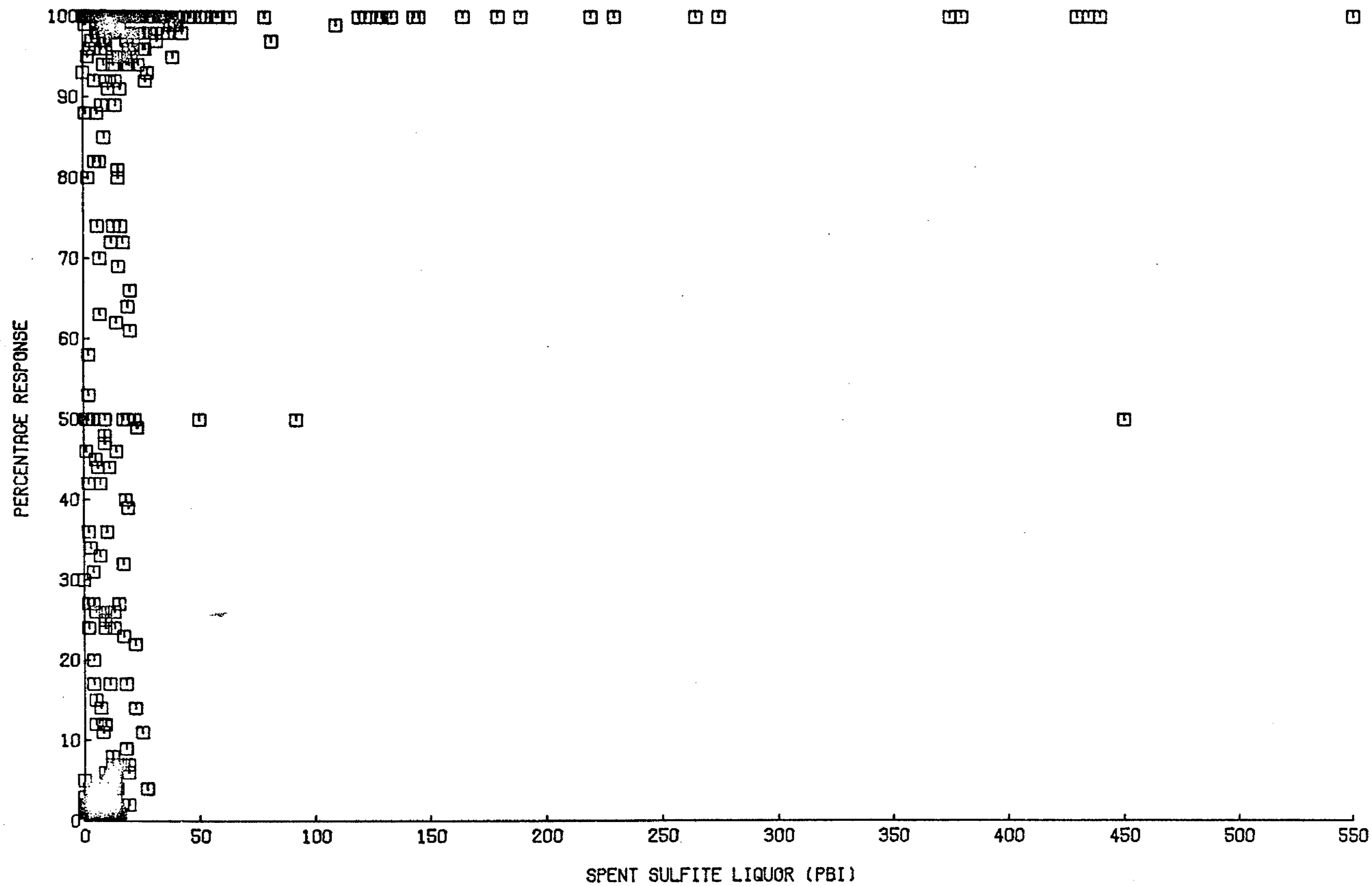

Figure 16. Response of abnormal oyster larvae to sulfite waste liquor concentrations in Port Gardner, 1973-1974.

SECTION VIII

The Relationship of Sulfite Waste Liquor to Marine Infauna in Port Angeles, Washington

1973

THE RELATIONSHIP OF SULPHITE WASTE LIQUOR TO MARINE INFAUNA IN PORT GARDNER, WASHINGTON

1973

by

Melvyn Irwin Malkoff

University of Washington

1976

This work was conducted under
U.S. Environmental Protection Agency
Contract Number 68-01-3109

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ABSTRACT

Environmental parameters and benthic infauna from 33 stations in Puget Sound off Everett, Washington, collected during 1973 indicate large physical and biological gradients along 2.5 nautical miles from the mouth of the Snohomish River and Everett Harbor. Patterns of overlapping faunal distributions indicate a highly complex environment. A general association was observed between high concentrations of SWL and low numbers of benthic infauna; other environmental parameters also may have contributed to this observation. Everett Harbor has few benthic species and few individuals per species. Suggestions are made for forthcoming monitoring studies.

INTRODUCTION

This study follows an initial assessment of benthic conditions in Everett Harbor and the adjacent southeastern shoreline of Port Gardner begun by John Sainsbury of the Environmental Protection Agency (Malkoff, 1974). A diver-controlled suction dredge was used in an unsuccessful attempt to gather quantitative benthic samples. However, the resultant qualitative samples provided a useful reference collection and starting place for the present study.

A report prepared by the U. S. Department of the Interior Federal Water Pollution Control Administration, Northwest Regional Office, Portland, Oregon, and the Washington State Pollution Control Commission, Olympia, Washington (WSPCC) in 1967 was the major source of historical and background data. Studies reported included many parts of the environment, but the benthic studies were inadequate for a biological baseline in Port Gardner. Sampling did not provide sufficient coverage of Port Gardner, several bottom samplers were used, and faunal lists were not well detailed.

Port Gardner has been intensively studied since 1973 through cooperative studies by the University of Washington's Department of Oceanography, the Environmental Protection Agency, and the Washington State Department of Ecology. Some data from this comprehensive program of study, Ecological Baseline and Monitoring Study (ECOBAM), were incorporated in the present study.

The purpose of this study is to describe quantitatively some of the marine benthic infaunal invertebrates in an area of Port Gardner, Washington, and to examine possible relationships between infauna and the distribution of sulphite waste liquor. In addition, baseline geological, chemical, and biological data have been gathered in the Everett Harbor area of Port Gardner; they are reviewed separately (Appendix I). A reference collection was another goal of this work. Finally, using the data for existing benthic conditions thus acquired, an attempt has been made to outline a method for monitoring to assess the environmental impact of future reductions of industrial waste loads presently discharged in Port Gardner.

A pilot survey was conducted to provide general qualitative information on the distribution, abundance, and variability of the benthic infauna along the southeastern shore of Port Gardner. The data gathered allowed a more informed selection of sampling stations by depth and by increasing distance away from the deep-water diffuser outfall. The pilot survey permitted refinement of shipboard procedures prior to the major sampling effort.

Port Gardner is situated adjacent to Possession Sound, off the central basin of Puget Sound (Fig. 1). Depths reach over 150 m; areas less than 10 m are confined to the delta of the Snohomish River, Everett Harbor, and the eastern shore of Port Gardner (Fig. 2). Water circulation is controlled principally by tidal exchange and the influence of the river's discharge plume (Lincoln and Lam, 1975). Currents in the area are weak and variable; consequently, wind stress can have a marked effect on circulation (Townsend, Eriksen and Cheyne, 1941). The ocean circulation of the area has been characterized as a three-layered system: a general southward flow at the surface; a northward flow at intermediate depths; and a southerly flow in the deepest portions (WSPCC,

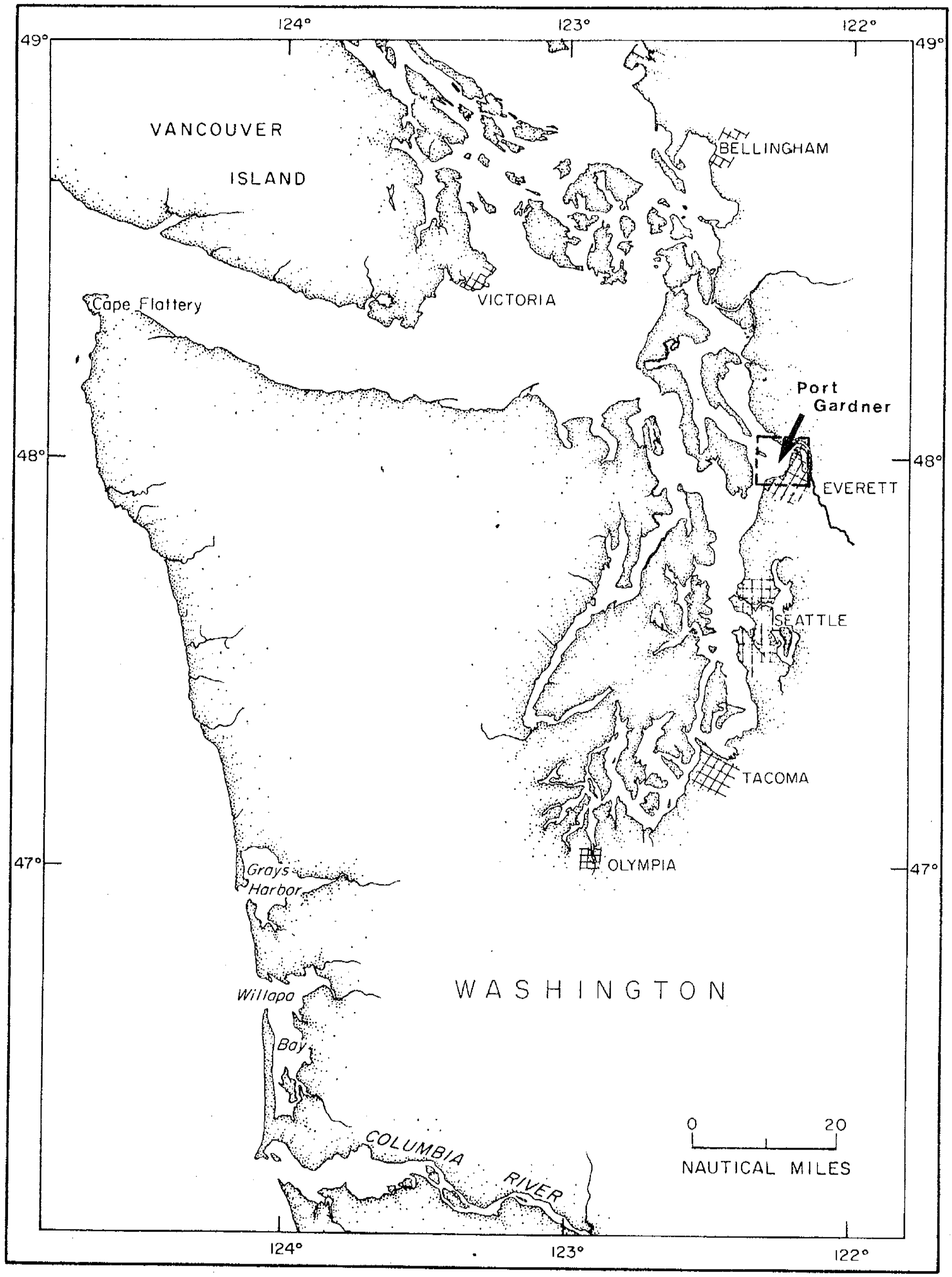

Fig. 1. Puget Sound and adjacent waters.

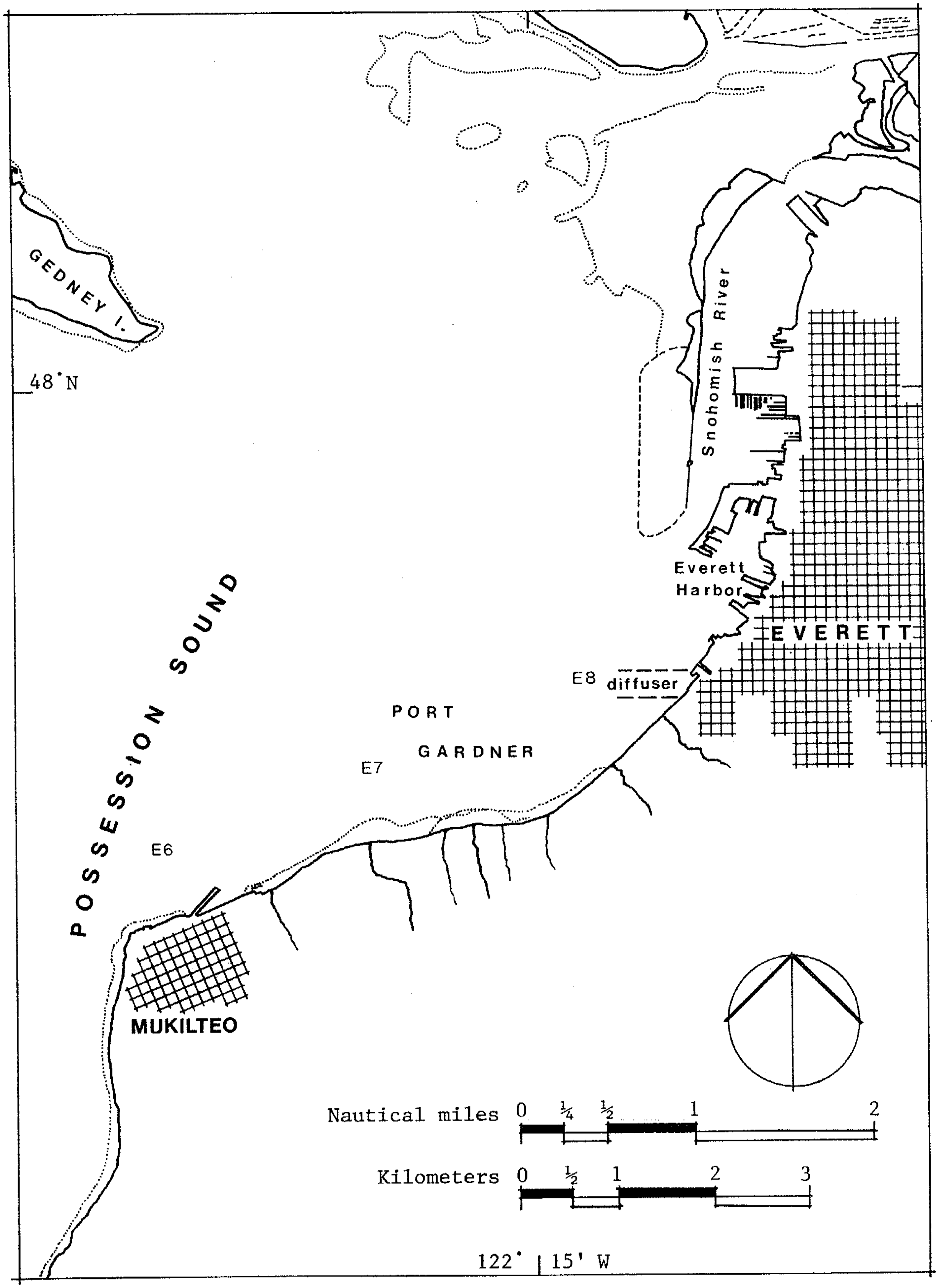

Fig. 2. Port Gardner and surroundings.

1967). Sources of fresh water are the Snohomish River and streams draining into the study area along the eastern shore (Fig. 2).

Industrial wastes, principally sulphite waste liquor (SWL) originating from the Scott Paper Company and the Weyerhaeuser Company sulphite pulp mills, were discharged into Port Gardner just south of the Everett Harbor through a deep-water diffuser outfall (Fig. 2). The pipeline terminates about 900 m offshore; about the last 300 m is a multiport diffuser releasing SWL at a depth of about 100-110 m. Concurrent ECOBAM data indicated that differences in the density of the SWL and the receiving waters result in a layer of maximum SWL concentration often observed at about 60 m. Other wastes from these mills, and other sources, are discharged within Everett Harbor.

Review of Literature

Studies relating to reduced harbor, river estuary, and coastal pollution (McNulty 1970; Dean and Haskins 1964; Beyer 1968; Tulkki 1968) have shown that repopulation of fauna-poor areas occurs fairly rapidly; within 1 yr and before more stable, long-term populations become established, pioneer species are observed. Comparable results were found in areas of dredge spoil disposal (Leathem et al. 1973). Olsson (1973) observed differences in species composition from areas of harbor pollution, mostly sewage and industrial wastes, to areas affected by sulphite pulp mill wastes.

Several studies were conducted prior to, during, and after closure of a sulphite pulp mill whose effluents, mainly SWL, drained into Saltkallefjord, Sweden. Leppakoski (1968) described the fjord environment with special reference to the bottom substrates; extensive characterization of the fauna was done prior to and during the closure of the mill (Bagge 1969a, 1969b). Long-term environmental and faunal changes were assessed by Rosenberg (1971, 1972, 1973) and these investigations were related to other pollution studies in adjacent areas (Swedmark 1970). Most of these studies approached the description of benthic fauna in terms of community description (Thorson 1957); Pearson (1970), in his studies of pulp mill pollution in Scotland, used this approach. However, upon finding the community approach inadequately described his results, Pearson (1971a, 1971b) examined the data in light of feeding strategies.

The same few species frequently are mentioned closest to the sources of pollution. Indicator species have been discussed (Hartman 1960; Reish 1960; Henriksson 1969); localization of these species into recognizable zones at increasing distances away from the pollution sources has been reported by Bellan-Santini (1968), Theede et al. (1969), and Reish (1971). However, the distribution of benthic fauna is affected by sediment characteristics, which tends to confuse the interpretation of distributional patterns related to pollution. Attempts to relate sediment parameters to benthos (Buchanan 1963; Phelps 1964; Carey 1965) have been only partially successful.

The present study area is located in Puget Sound, an area investigated by Wennekens (1959), Lie (1968, 1969a, 1969b), Lie and Evans (1973), Nichols (1970), Dawson (1971), and Lincoln and Lam (1975). Taxonomic keys to the fauna of this region are well-developed (Kozloff 1974). Pollution in Everett Harbor was described by Townsend et al. in 1941; pollution has been reported from other areas of Puget Sound (WSPCC 1967). Student-originated research on the impacts of sulphite pulp mill wastes in Port

Gardner (EROS 1974) provided concurrent environmental data. A comparison of the fauna from the Everett Harbor environment and the adjacent southeastern shore of Port Gardner (Malkoff 1974) indicated that the harbor contained only a small amount of benthos and that the variety and numbers of benthic fauna increased with increasing distance away from Everett Harbor.

MATERIALS AND METHODS

The Pilot Survey

Three techniques for locating sampling stations were tried: using a pelorus after picking the approximate spot; shooting sites with a sextant; and using radar ranging. The first two methods were time consuming and highly dependent on visibility. Radar proved to be the fastest method and was not dependent on visibility. The range off an object at a selected station location was determined from a nautical chart; the vessel was run shoreward until the proper, tide-corrected, depth was indicated on a fathometer. Beginning at the pipeline, 10 stations were selected southward along the 50-m isobath, spaced at intervals of 275 m (Fig. 3).

A so-called 0.1 m^2 van Veen grab, with a capacity of 17.7 liters and an access hatch in the top, was used to obtain duplicate samples at each station (Appendix II). Each sample was washed through a nest of stainless steel wire sieves with square openings of 4, 2, and 1 mm. The 4-mm screen prevented large amounts of bark from clogging the smaller screens during washing. Often only the two finer screens were needed. The material from the screens, primarily animals and wood debris, was collected separately for each duplicate sample and placed in 500-ml jars of 5% unbuffered formalin.

Shipboard Procedures

Radar positioning and a depth sounder* were used to find a station

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* SIMRAD[R] Model EM Super Sounder, Simonsen Radio A.S, Oslo, Norway.

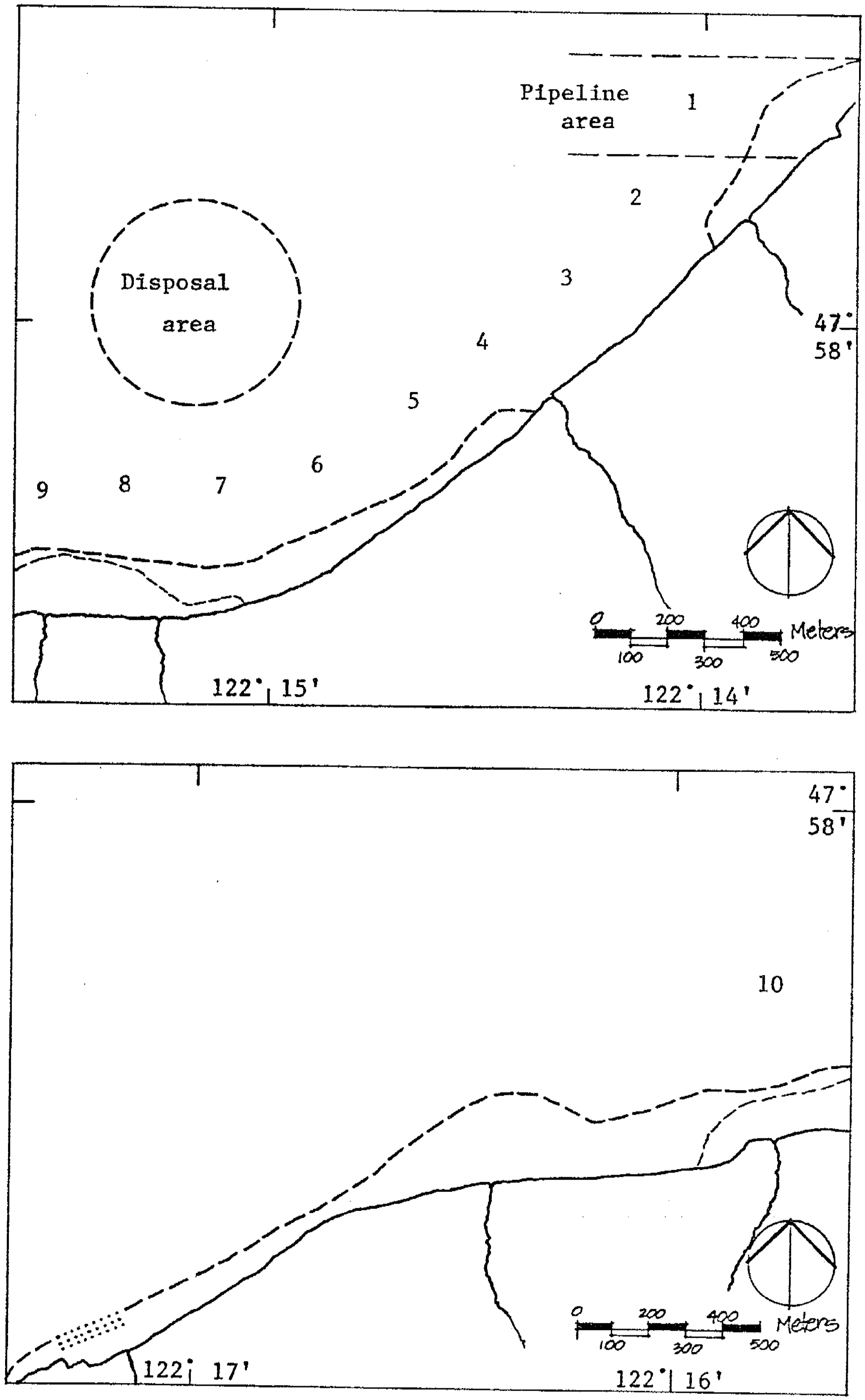
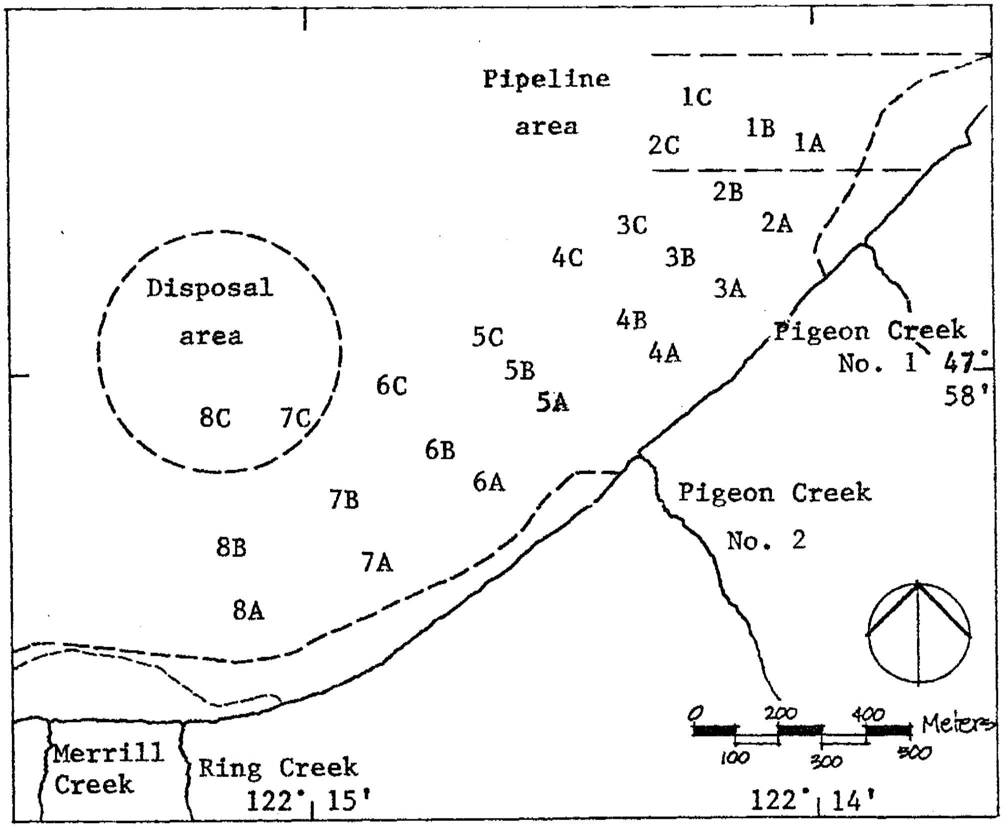


Fig. 3. Pilot survey station locations.

and maintain the vessel there. The selection of sampling locations was based upon the pilot survey and concurrent ECOBAM SWL studies. Eleven transects perpendicular to the shoreline, beginning at the pipeline and continuing to the south, were chosen along the 60-m isobath: transects 1 through 4 were spaced about 180 m apart; transects 5 through 8 were spaced about 275 m apart; and transects 9 through 11 were spaced approximately 915 m apart (Fig. 4). Three sampling depths were selected along each transect at 30(A), 60(B), and 90(C) m, presumably located above, within, and below the core of the SWL layer. Of the 33 stations, 9 stations were sampled after a delay of approximately 2 months.

After each successful cast: 1) a qualitative estimate of the amount of hydrogen sulphide (H_2S) on a scale of 0-4 was recorded; 2) the depth to the surface of the sediment within the grab from the inside edge of the access hatch was measured for conversion to sample volume; 3) a sediment sample was withdrawn from the grab using a 50-mm diameter core liner tube, labeled, and stored for granulometric analysis; and 4) the remaining sample was washed through 2-mm and 1-mm sieves. Wood debris and other biological material was collected from the screens by washing the contents of each screen into labeled 500-ml jars. Larger pieces of wood debris were measured but not retained. Forceps were occasionally required to remove worms wrapped around the wire mesh. A combination of 5% formalin buffered with sodium borate and with Rose Bengal stain added was used to preserve the samples. The Rose Bengal was expected to aid in sorting. Duplicate samples were obtained at every station except 9B, where 10 replicate samples were taken. When necessary, repeated casts were made to obtain the desired number of samples.



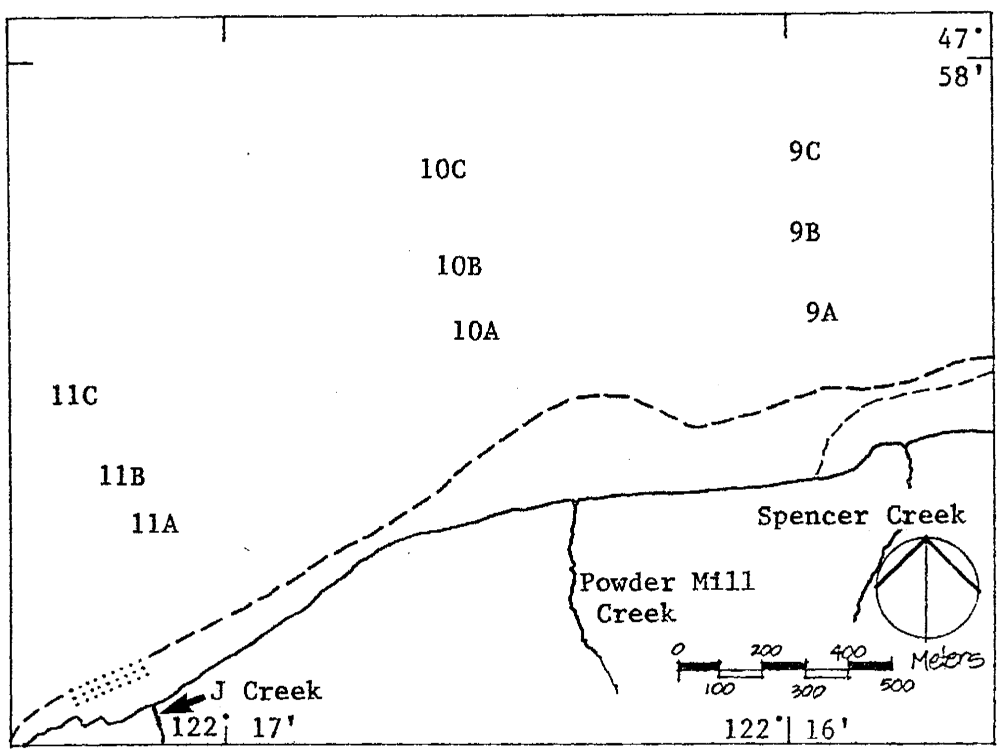


Fig. 4. Port Gardner station locations.

Laboratory Procedures

Samples for sediment size distribution were quartered, dried, weighed, and wet-sieved through a 4-phi* (62 micron) screen (APHA, 1965). The fraction retained on the screen was dried, dry-sieved into whole-phi fractions, weighed, and recorded. The other fraction was dried, weighed, and the combined silts and clays recorded as mud. The mean, standard deviation, skewness, kurtosis, and sand/mud ratio for every duplicate sample was calculated (Creager, McManus, and Collias, 1962).

Sediment samples were quartered, dried, and weighed, then treated with 20 ml of 30% H_2O_2, until the bubbling stopped. The samples were reweighed after drying and the calculated percentage weight losses taken as the total volatile organic matter.

The initial sorting of fauna from wood debris and sediment into a few main groups was accomplished with the help of student sorters. Thoroughness of the sorting was monitored by checking for missed specimens in some sample jars. Samples were sorted individually by station, screen, and duplicate in white photo trays, often with the aid of magnifying lamps.

The settled volume of the wood debris preserved in the sample jars was added to estimates of discarded-wood volume. This total was expressed as a percentage of the total sample volume.

Identification of animals was done to the lowest taxon that time would allow. In the case of polychaetes, only whole specimens or the identifiable anterior portions were considered. The enumeration of specimens discounted empty clam shells or worm tubes. A reference collection was established.

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* Appendix III contains a table for sediment size classification.

Sulphite waste liquor data collected at ECOBAM stations 6, 7, and 8 for the period March, 1973 through February, 1974 were used to calculate a SWL mean annual concentration at each station (Fig. 2). Polynomial equations, using a least-squares estimate, were used to describe the curves fitted through the means.

RESULTS

Pilot Survey

The duplicate samples appeared more similar to each other than to samples from other stations. Visual inspection of the samples collected on July 20, 1973, revealed two breaks in the distribution of fauna (Fig. 5). Three levels of total faunal numbers were found with transitions occurring between pilot stations 2 and 3, and also between stations 6 and 7. The new grid of sampling stations was then developed to reflect these transitions.

Performance of the van Veen Grab

The average catch was 7.35 liters (n = 66, S.D. = 3.7); sample volumes ranged from 1.4 to 17.7 liters (Table 1). The range of volumes reflects the variety of substrates sampled. Samples with greater than 7% wood content and blue clay on transects 10 and 11 were difficult for the grab to penetrate. For 10 replicates at station 9B, the mean catch was 3.92 liters (S.D. = 0.9) with a range of 1.7 to 4.9 liters.

Several grab failures were recorded near stream mouths, necessitating repeated tries to get duplicate samples, where the grab tended to tip over on gravelly or steeply sloping substrates, particularly on transects 5 and 6. A further complication to sampling was the presence of the disposal area in the vicinity of stations 7C and 8C (Fig. 4). A number of unsuccessful grabs came up with steel bands, rope, or cables between gaping jaws, allowing the sample to wash out.

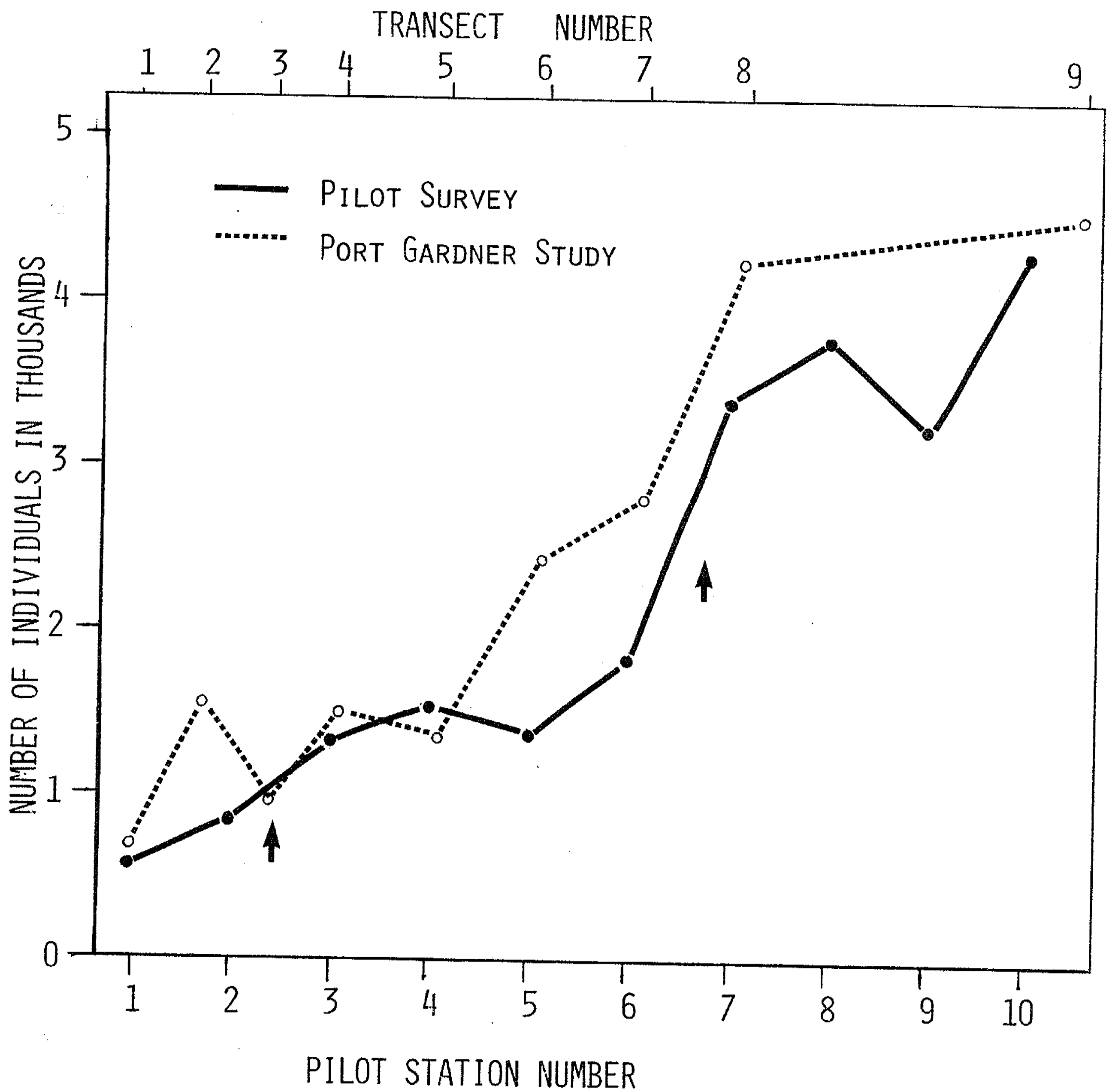


Fig. 5. Estimated numbers of individuals taken during the pilot survey. Arrows indicate possible transitions; total numbers of specimens taken from the Port Gardner study are shown.

TABLE 1. Port Gardner station locations, sampling dates and times, catch and sediment core volumes. Depths are meter-wheel readings.

Station	Latitude 47°N	Longitude 122°W	Date	Sample	Time PDT	Depth m	Catch Volume liters	Core Volume ml
1A	58' 16"	14' 03"	Oct 14	1	1408	27	14.1	232.7
				2	1419	28	14.5	224.4
1B	58' 17"	14' 07"	Aug 4	1	0843	58	9.1	194.4
				2	0855	62	9.6	176.2
1C	58' 20"	14' 15"	Oct 14	1	1336	98	17.7	232.7
				2	1350	98	14.1	191.1
2A	58' 10"	14' 09"	Aug 4	1	1052	33	6.0	108.0
				2	1107	26	4.5	66.5
2B	58' 12"	14' 12"	Aug 4	1	1025	60	9.8	147.9
				2	1042	59	8.5	118.0
2C	58' 16"	14' 18"	Aug 4	1	0940	103	10.8	141.3
				2	0948	100	8.2	171.2
3A	58' 04"	14' 13"	Aug 5	1	1554	29	6.6	133.0
				2	1602	32	11.5	124.6
3B	58' 06"	14' 17"	Aug 4	1	1125	41	3.8	74.8
				2	1148	45	6.9	104.7
3C	58' 10"	14' 21"	Aug 5	1	1525	101	5.8	99.7
				2	1542	100	17.7	216.0
4A	58' 01"	14' 20"	Aug 4	1	1329	30	6.9	108.0
				2	1342	32	7.5	98.0
4B	58' 03"	14' 23"	Aug 4	1	1308	56	6.4	134.6
				2	1318	57	3.4	79.8
4C	58' 07"	14' 29"	Aug 4	1	1207	106	8.8	137.9
				2	1211	107	11.1	146.2
5A	57' 56"	14' 31"	Oct 14	1	1320	31	5.5	141.3
				2	1327	31	5.5	66.5
5B	57' 58"	14' 34"	Aug 4	1	1410	65	6.0	111.3
				2	1438	73	5.5	114.7
5C	58' 01"	14' 37"	Oct 14	1	1255	106	9.1	191.1
				2	1307	104	8.1	157.9
6A	57' 50"	14' 41"	Aug 4	1	1554	30	3.8	91.4
				2	1603	25	6.1	118.0
6B	57' 52"	14' 43"	Aug 4	1	1528	60	7.8	84.8
				2	1538	60	6.4	103.0
6C	57' 57"	14' 50"	Aug 4	1	1453	102	11.5	211.1
				2	1506	104	8.8	103.0
7A	57' 44"	14' 52"	Oct 14	1	1152	28	5.5	99.7
				2	1201	28	3.8	91.4
7B	57' 48"	14' 55"	Aug 4	1	1612	58	3.4	74.8
				2	1620	61	3.8	149.6
7C	57' 55"	14' 59"	Oct 14	1	1117	104	8.1	149.6
				2	1126	105	14.1	199.4
8A	57' 41"	15' 07"	Aug 5	1	0921	34	3.4	108.0
				2	0928	31	5.0	91.4

TABLE 1. (continued)

Station	Latitude 47°N	Longitude 122°W	Date	Sample	Time PDT	Depth m	Catch Volume liters	Core Volume ml
8B	57' 45"	15' 07"	Aug 5	1	0857	60	7.6	116.3
				2	0906	58	5.5	83.1
8C	57' 56"	15' 08"	Oct 14	1	1053	102	4.5	207.7
				2	1105	105	10.1	108.0
9A	57' 41"	15' 50"	Aug 5	1	1208	28	4.3	91.4
				2	1214	29	5.8	116.3
9B	57' 47"	15' 51"	Aug 5	1	1010	59	3.8	116.3
				2	1017	61	1.7	99.7
				3	1028	64	3.8	----
				4	1051	63	3.8	----
				5	1057	64	5.0	----
				6	1103	63	3.4	----
				7	1118	61	5.0	----
				8	1132	64	3.8	----
				9	1140	60	4.3	----
				10	1146	65	4.5	----
9C	57' 54"	15' 52"	Aug 5	1	0945	99	5.0	99.7
				2	0954	98	5.0	124.6
10A	57' 39"	16' 33"	Oct 14	1	0959	31	5.8	164.5
				2	1030	35	10.9	108.0
10B	57' 42"	16' 34"	Aug 5	1	1303	62	5.0	116.3
				2	1310	63	5.0	124.6
10C	57' 53"	16' 37"	Oct 14	1	0919	87	9.1	114.7
				2	0924	98	1.5	124.6
11A	57' 24"	17' 13"	Aug 5	1	1448	31	2.3	83.1
				2	1459	27	5.0	116.3
11B	57' 27"	17' 15"	Aug 5	1	1417	60	4.3	108.0
				2	1432	62	7.6	99.7
11C	57' 33"	17' 20"	Aug 5	1	1320	98	14.0	207.7
				2	1336	98	9.5	199.4

Substrate Characterization

The parameters of mean sediment size and sand/mud ratios generally decreased with increasing depth (Table 2). No clear along-shore trend from the pipeline southward is evident for the sand/mud ratios. Finer sediments were typically found closer to the pipeline than a greater distance away from it. Areas of high sand/mud ratios and coarse sediments occurred at stream deltas; the distributions of these parameters reflect the proximity of transects to stream mouths (Fig. 6 and 7).

The highest wood content was found near the pipeline (Table 3). Transects 1 through 8 were statistically significantly (a = 0.05) higher in wood content than transects 9-11 (Fig. 8). The percentage total volatile organic matter generally increased with depth (Table 4). The strongest H_2S odors were found nearest the pipeline (Fig. 9).

Sulphite Waste Liquor

For the period March, 1973 to February, 1974, the greatest range in SWL concentrations occurred at ECOBAM station 8, followed by stations 7 and 6 with progressively smaller annual ranges (Table 5a). Resolution of these data into three depth ranges indicated that the highest annual mean concentrations were at 60 m, but the lowest concentrations were at 90 m at stations 6 and 7 and 30 m at station 8 (Fig. 10). When considering the shorter period of March, 1973 to October, 1973, the 8-month ranges again decreased from ECOBAM station 8 to station 6, and the maximum concentrations were found at 60 m (Table 5b).

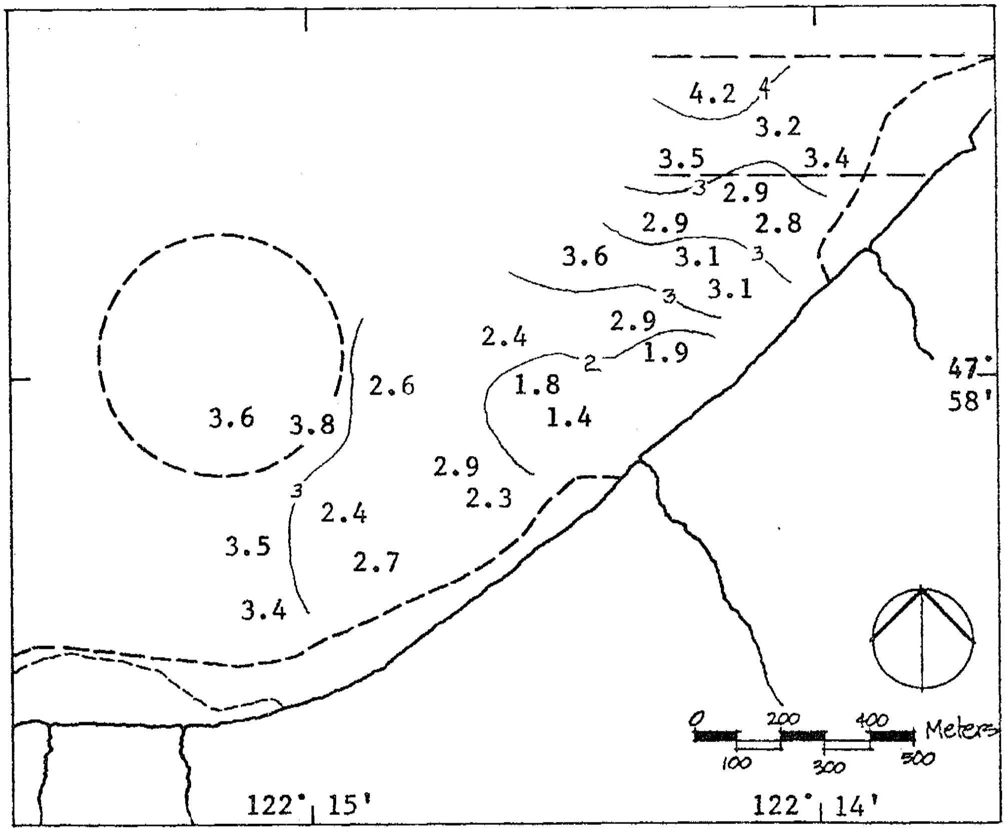
The fitted curves of the distribution of SWL concentration allow the estimation of intermediate values. Concentrations for the 11 transects sampled were estimated from mean annual values (Table 6).

TABLE 2. Sediment size-fraction parameters by transect, station, and duplicate number in Port Gardner

Sample	Mean	Standard Deviation	Skewness	Kurtosis	Sand/Mud Ratio
1A-1	3.56	1.17	-0.97	3.17	0.85
-2	3.34	1.17	-0.62	2.44	1.41
1B-1	3.12	1.39	-0.96	3.96	1.66
-2	3.30	1.45	-1.13	3.68	1.10
1C-1	4.22	0.76	-3.08	12.68	0.18
-2	4.12	0.87	-2.95	10.22	0.24
2A-1	2.81	0.91	0.00	3.87	6.88
-2	2.88	0.96	0.07	3.31	5.02
2B-1	3.45	1.22	-1.09	3.81	1.18
-2	2.50	1.87	-0.72	2.84	2.22
2C-1	2.83	1.70	-0.57	2.21	1.43
-2	4.22	0.76	-3.41	15.67	0.19
3A-1	3.29	1.13	-0.36	2.24	1.51
-2	2.61	0.92	0.30	3.14	9.26
3B-1	2.88	1.11	0.01	2.65	3.20
-2	3.33	1.08	-0.66	3.04	1.91
3C-1	2.48	1.70	-0.27	2.17	2.21
-2	3.82	1.24	-1.72	4.79	0.39
4A-1	1.65	1.28	0.45	3.85	12.11
-2	2.09	1.35	0.43	2.20	6.67
4B-1	3.10	1.17	-0.48	2.45	2.68
-2	2.85	1.19	-0.34	2.46	4.40
4C-1	3.39	1.50	-1.09	3.06	0.78
-2	3.76	1.33	-1.77	5.36	0.44
5A-1	1.57	1.23	0.58	3.75	12.80
-2	1.31	2.35	0.01	1.74	3.15
5B-1	1.82	1.26	0.52	2.69	12.17
-2	1.69	1.23	0.59	3.07	15.12
5C-1	2.10	1.38	0.45	2.43	4.75
-2	2.78	1.41	-0.05	1.80	2.08
6A-1	2.07	1.87	-1.40	4.36	11.81
-2	2.57	1.00	0.21	2.73	8.93
6B-1	2.94	1.30	-0.93	4.17	3.53
-2	2.88	1.25	-0.85	4.19	4.32
6C-1	2.78	1.74	-0.68	2.72	1.52
-2	2.34	1.54	-0.23	2.77	3.84
7A-1	2.94	1.24	-0.23	1.86	2.87
-2	2.37	1.40	0.26	1.90	3.84
7B-1	2.44	1.45	0.16	1.96	3.08
-2	2.39	1.60	-0.19	2.08	3.39
7C-1	4.15	0.84	-3.31	16.56	0.27
-2	3.55	1.33	-1.43	4.68	0.80

TABLE 2. (continued)

Sample	Mean	Standard Deviation	Skewness	Kurtosis	Sand/Mud Ratio
8A-1	3.36	0.90	-0.51	2.89	2.92
-2	3.46	0.78	-0.47	3.23	3.00
8B-1	3.62	0.84	-1.42	7.25	1.96
-2	3.39	0.93	-0.95	5.03	2.69
8C-1	3.39	1.37	-1.10	3.38	1.04
-2	3.89	1.22	-3.02	13.54	0.48
9A-1	2.83	0.88	0.02	3.24	8.89
-2	2.63	0.91	0.13	3.10	11.57
9B-1	2.97	0.97	-0.69	5.42	6.30
-2	2.96	1.02	-0.41	3.19	5.30
9C-1	3.24	1.23	-1.28	5.85	2.01
-2	3.19	1.52	-1.48	5.08	1.66
10A-1	1.29	1.33	-0.93	5.07	43.55
-2	1.29	1.30	0.11	4.04	19.43
10B-1	1.68	1.53	0.06	2.92	8.72
-2	1.53	2.15	-0.43	2.23	6.15
10C-1	3.34	1.27	-1.29	4.41	1.69
-2	3.41	1.27	-1.11	3.57	1.23
11A-1	2.75	0.86	0.00	3.03	12.89
-2	2.83	0.90	0.17	3.05	7.03
11B-1	2.87	1.36	-1.29	5.16	4.64
-2	3.22	1.39	-1.14	4.10	1.56
11C-1	2.69	1.73	-0.99	3.59	2.47
-2	2.74	1.71	-1.14	4.10	2.58



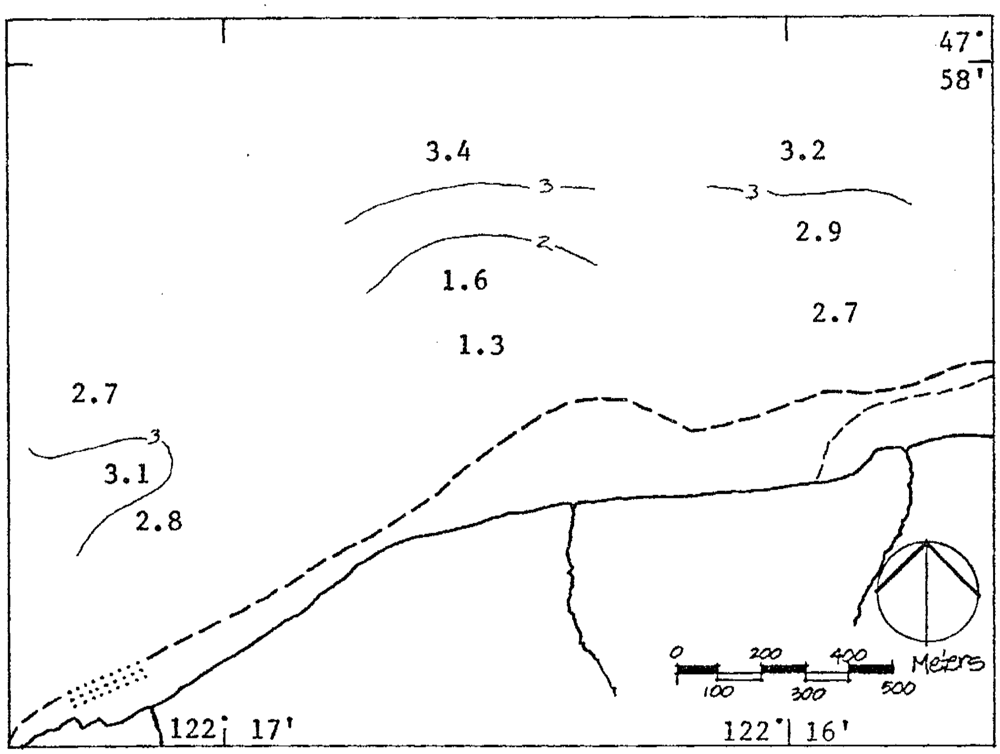
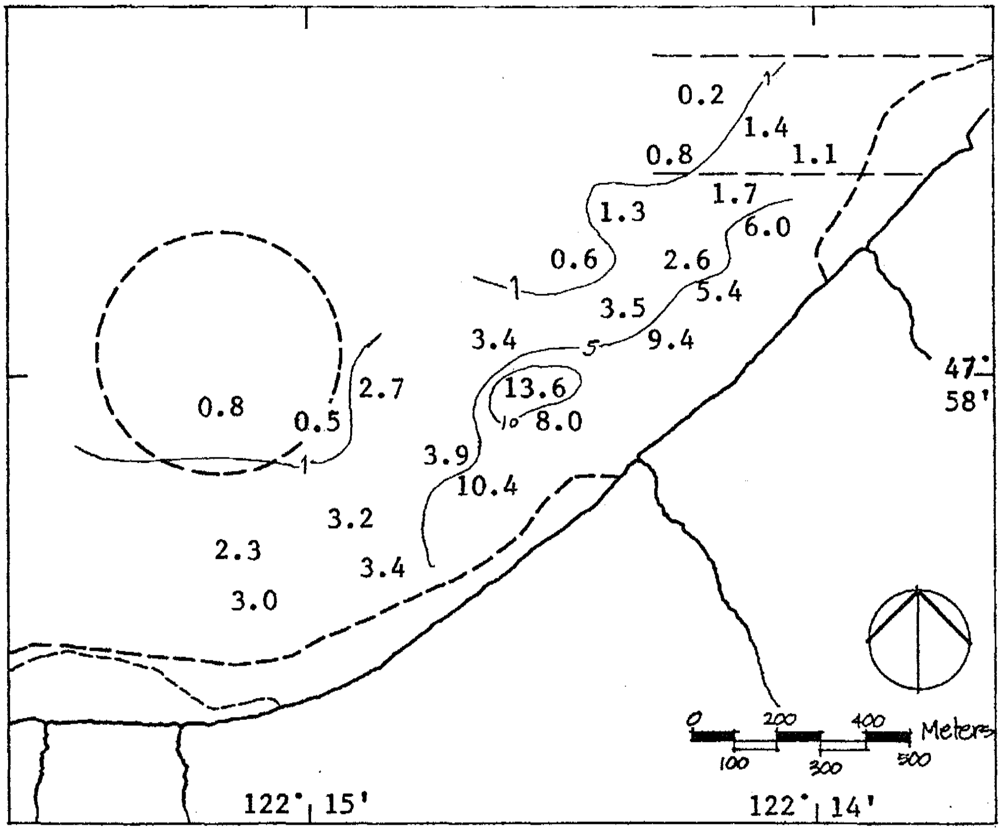


Fig. 6. Distribution of mean phi size in Port Gardner.

Numbers are in phi units (Appendix III).



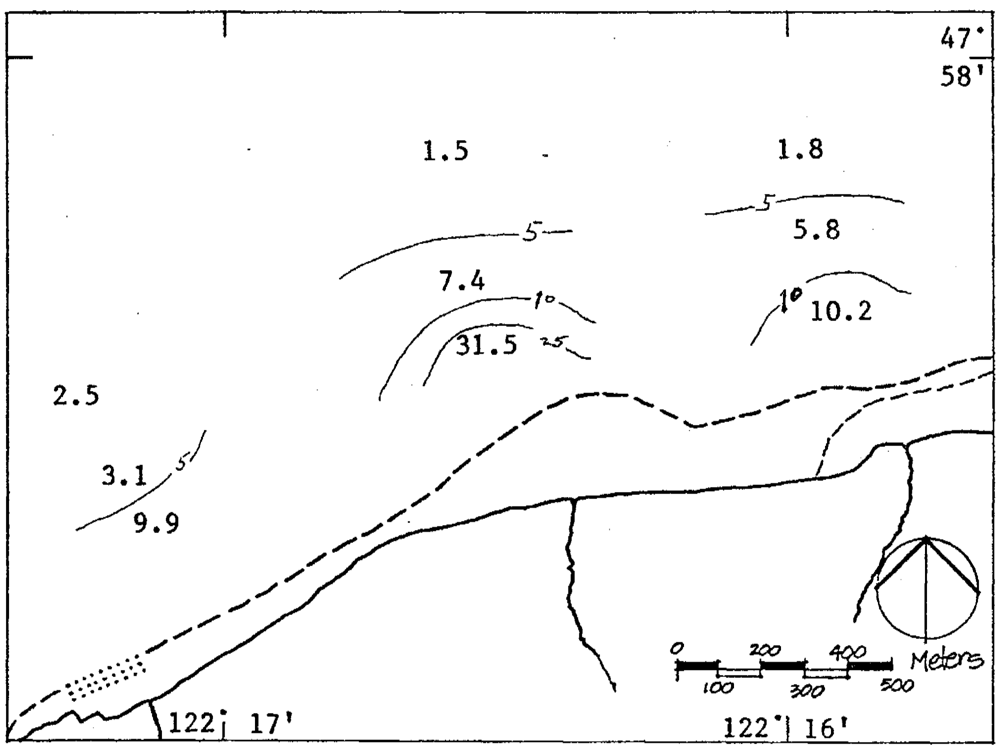


Fig. 7. Sand/mud ratios in Port Gardner.

TABLE 3. Wood content by transect, station, and duplicate number in Port Gardner. Percentages are based on sample catch volumes.

Sample	Volume (ml) 1-mm Screen	Volume (ml) 2-mm Screen	Percentage
1A-1	84	28	0.81
-2	171	42	1.49
1B-1	178	278	4.11
-2	381	693	11.45
1C-1	24	17	0.24
-2	27	6	0.24
2A-1	14	19	0.56
-2	29	21	1.12
2B-1	145	364	5.25
-2	715	419	13.59
2C-1	461	616	10.13
-2	118	91	2.62
3A-1	31	28	0.90
-2	81	83	1.44
3B-1	26	24	1.33
-2	179	183	5.30
3C-1	266	466	12.85
-2	773	430	6.89
4A-1	34	69	1.52
-2	56	146	2.72
4B-1	102	185	4.60
-2	121	395	15.50
4C-1	607	290	10.39
-2	415	1242	15.06
5A-1	8	1	0.17
-2	319	120	8.10
5B-1	41	49	1.52
-2	355	345	13.03
5C-1	20	1	0.24
-2	14	0	0.18
6A-1	16	47	1.68
-2	32	16	0.81
6B-1	246	259	6.53
-2	192	288	7.66
6C-1	420	284	6.22
-2	377	321	8.02

TABLE 3. (continued)

Sample	Volume (ml) 1-mm Screen	Volume (ml) 2-mm Screen	Percentage
7A-1	41	31	1.34
-2	17	2	0.51
7B-1	298	279	17.30
-2	237	256	13.48
7C-1	0	39	0.49
-2	481	296	5.59
8A-1	75	53	3.87
-2	25	9	0.69
8B-1	97	66	2.19
-2	89	75	3.03
8C-1	346	104	10.43
-2	86	30	1.16
9A-1	18	39	1.37
-2	13	50	1.11
9B-1	24	52	2.05
-2	29	27	3.44
9B-3	19	42	1.67
-4	26	94	3.14
-5	34	45	1.58
-6	21	51	2.11
-7	22	49	1.42
-8	23	32	1.44
-9	22	62	1.97
-10	34	66	2.21
9C-1	52	91	2.92
-2	27	69	1.97
10A-1	5	0	0.09
-2	18	1	0.18
10B-1	26	44	1.43
-2	27	73	2.05
10C-1	16	10	0.29
-2	22	1	1.68
11A-1	12	57	3.10
-2	16	40	1.15
11B-1	17	36	1.28
-2	68	100	2.25
11C-1	44	26	0.47
-2	48	90	1.49

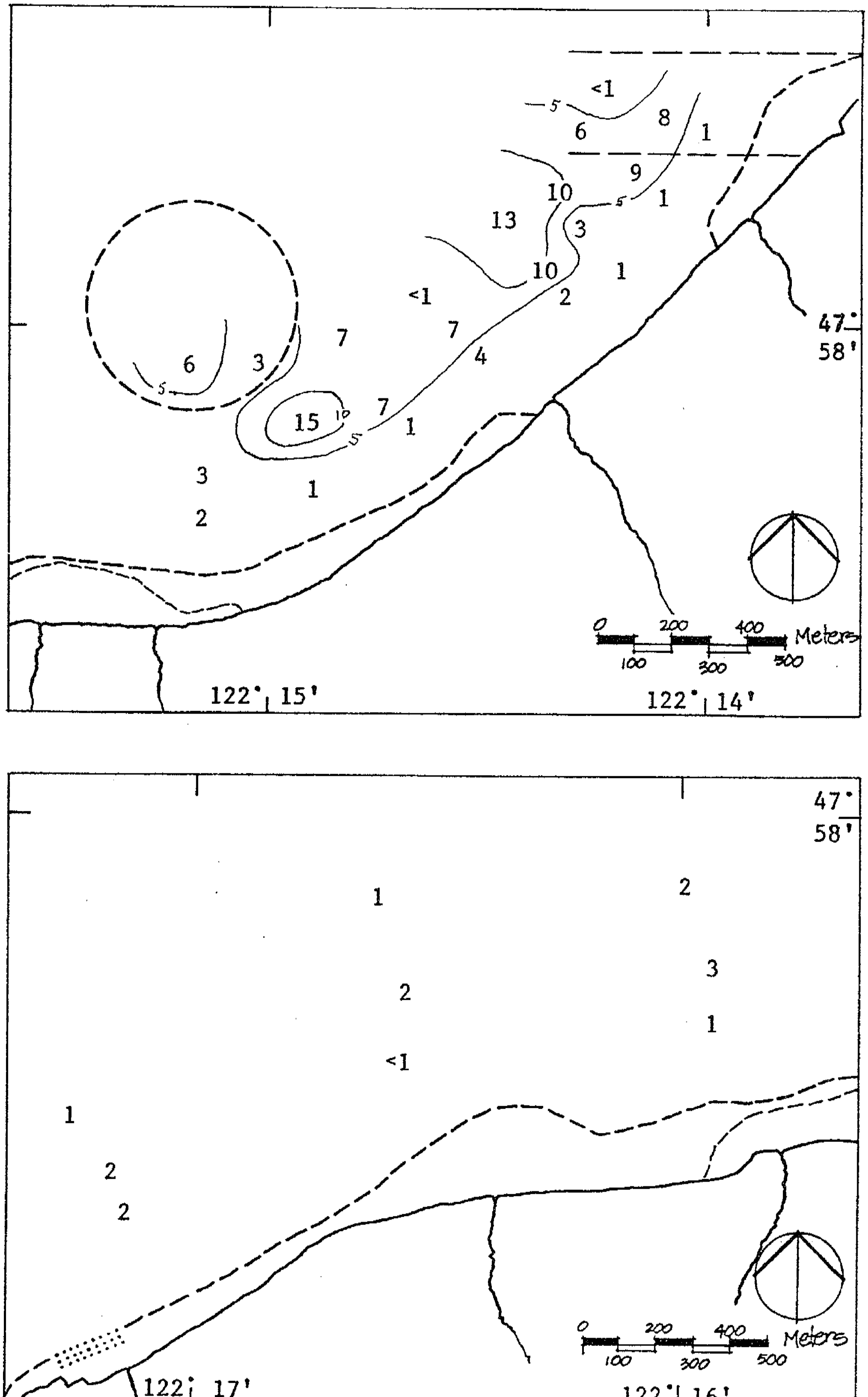
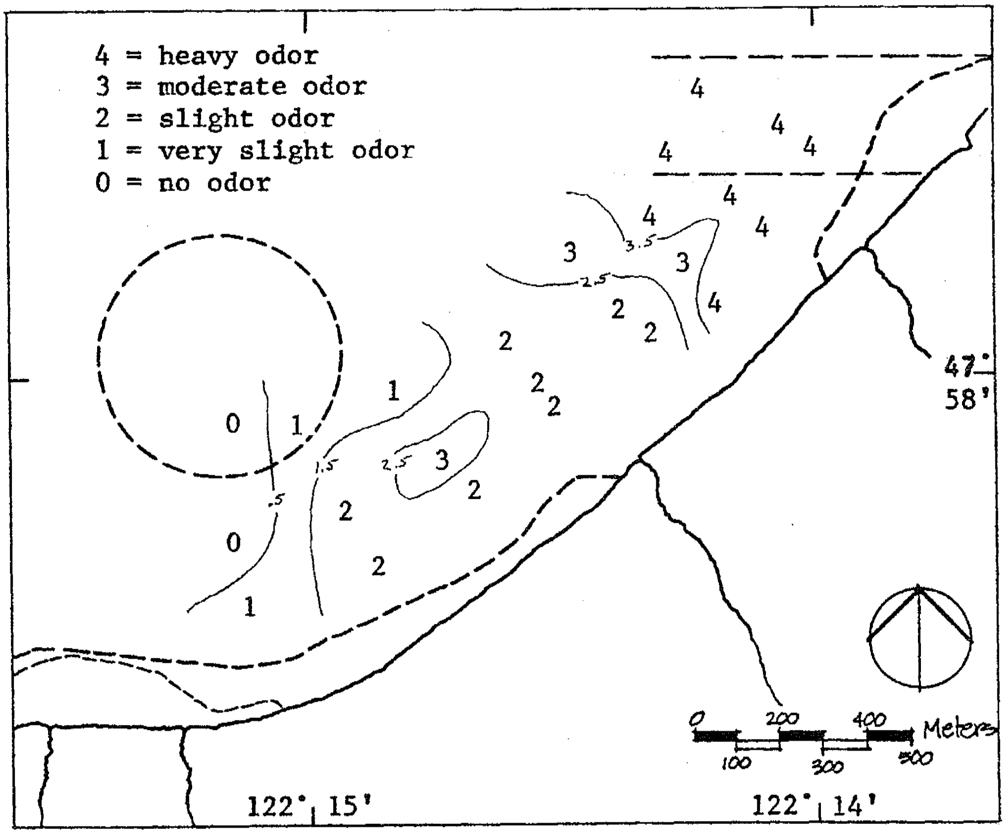


Fig. 8. Distribution of wood on the bottom in Port Gardner. Numbers are percentage of catch volume.

TABLE 4. Total volatile organic matter by transect, station, and duplicate number in Port Gardner

Sample	Weight Loss grams	Weight Loss percentage	Sample	Weight Loss grams	Weight Loss percentage
1A-1	1.5642	5.79	7A-1	0.3010	1.20
-2	0.5647	2.21	-2	0.9372	3.82
1B-1	0.2358	0.95	7B-1	0.2836	1.16
-2	0.3762	1.62	-2	0.2142	0.73
1C-1	0.7795	2.26	7C-1	0.1432	0.52
-2	0.7023	2.35	-2	0.9740	4.09
2A-1	0.1882	0.70	8A-1	0.2584	0.80
-2	0.2320	0.73	-2	0.2744	0.82
2B-1	0.2700	0.92	8B-1	0.3667	1.22
-2	0.4683	1.28	-2	0.2882	1.00
2C-1	0.3063	1.12	8C-1	1.9551	7.44
-2	0.6867	2.21	-2	2.0824	8.64
3A-1	0.2735	0.99	9A-1	0.2188	0.62
-2	0.1913	0.57	-2	0.1824	0.59
3B-1	0.3141	1.01	9B-1	0.1901	0.68
-2	0.4549	1.56	-2	0.1995	0.73
3C-1	0.6066	2.27	9C-1	0.3104	1.05
-2	0.7208	2.80	-2	0.4682	1.58
4A-1	0.1428	0.53	10A-1	0.3826	1.06
-2	0.2266	0.69	-2	0.1299	0.47
4B-1	0.3731	1.19	10B-1	0.1802	0.74
-2	0.2748	1.14	-2	0.1793	0.71
4C-1	0.5144	1.99	10C-1	0.8612	3.39
-2	0.5524	1.96	-2	3.4003	11.13
5A-1	1.1036	4.47	11A-1	0.1374	0.44
-2	0.4276	1.74	-2	0.2364	0.73
5B-1	0.0993	0.33	11B-1	1.1759	4.00
-2	0.1045	0.36	-2	0.5066	1.67
5C-1	0.2515	1.01	11C-1	0.1872	0.54
-2	0.3532	1.13	-2	2.3969	7.20
6A-1	0.1217	0.46			
-2	0.1689	0.60			
6B-1	0.3409	1.09			
-2	0.3027	0.99			
6C-1	0.3623	1.40			
-2	0.2711	0.89			



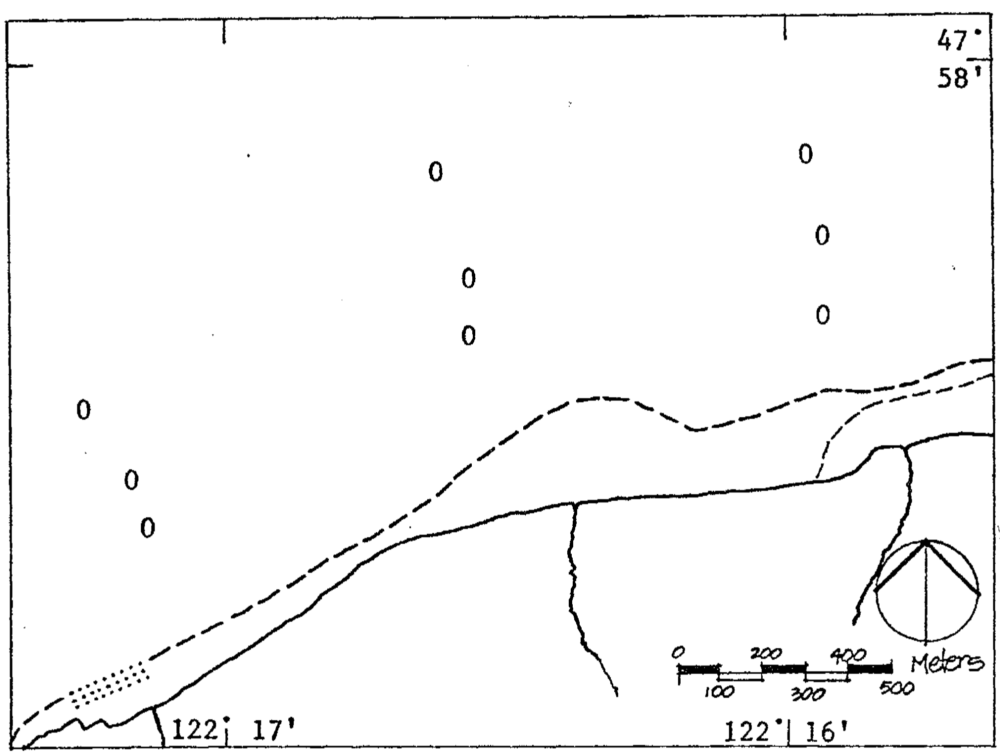


Fig. 9. Distribution of H_2S odor at Port Gardner stations.

TABLE 5. ECOBAM sulphite waste liquor concentrations for Port Gardner, 1973-1974. N is the number of observations.

a. 14 MAR 73 - 14 FEB 74

Station	Depth m	N	Mean ppm	Std Dev	Minimum	Maximum
6	30	7	13.28	7.93	5	23
	60	7	25.71	18.78	8	60
	90	7	20.57	13.65	5	45
7	30	9	28.67	26.10	5	82
	60	9	33.00	23.41	5	63
	90	9	21.67	13.58	5	41
8	30	14	52.86	82.59	5	320
	60	14	111.14	133.07	0	458
	90	12	77.17	95.46	9	360

b. 14 MAR 73 to 12 OCT 73

Station	Depth m	N	Mean ppm	Std Dev	Minimum	Maximum
E6	30	4	15.00	9.38	5	23
	60	4	35.75	19.57	14	60
	90	4	12.75	7.76	5	23
E7	30	5	42.80	28.01	5	82
	60	5	49.80	14.58	32	63
	90	5	16.40	14.55	5	41
E8	30	7	67.86	113.42	5	320
	60	7	69.71	41.04	0	127
	90	6	97.00	131.94	9	360

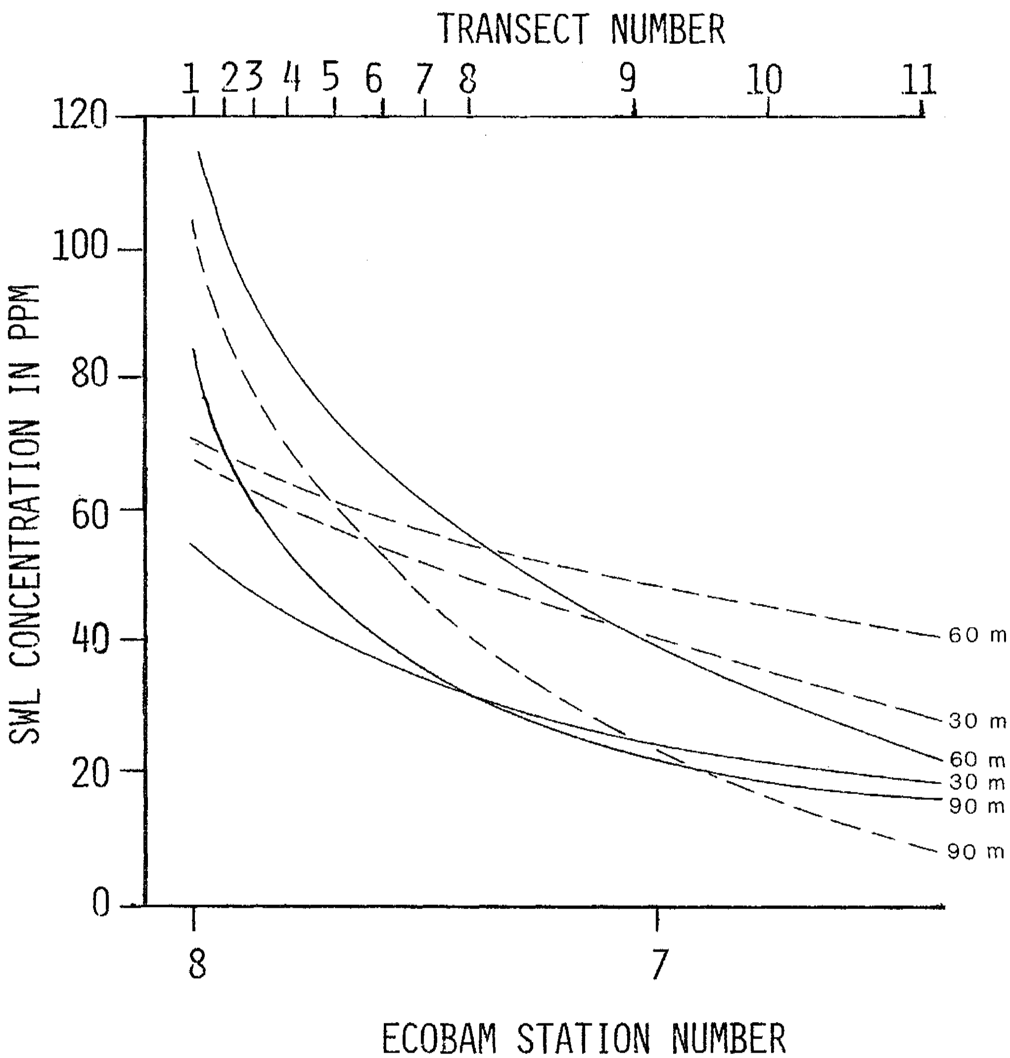


Fig. 10. Distribution of SWL with increasing depth and distance from the pipeline. ECOBAM mean annual SWL concentrations (solid lines) and 8-month mean values (dashed lines) are compared; distances are to scale.

TABLE 6. Sulphite waste liquor concentrations for Port Gardner stations. Concentrations, in ppm, are taken from Fig. 10.

Transect	Station A 30 m	Station B 60 m	Station C 90 m
1	54	116	81
2	50	104	74
3	49	100	69
4	47	94	64
5	45	85	58
6	42	76	51
7	40	68	45
8	38	60	40
9	32	42	24
10	25	27	17
11	19	22	16

The Infauna

The check on student sorters found few missed specimens. The use of Rose Bengal facilitated sorting to a large, if inconsistent, degree. Only some of the polychaetes were stained; within families staining was uneven. Crustacea were consistently the most stained and lamellibranchs the least.

Polychaeta Of the 25 polychaete families found, 16 belonged to the subclass Sedentaria and 9 to the subclass Errantia (Appendix IV, Table 19). Among the Sedentaria, Oweniidae, Capitellidae, and Maldanidae were 82.8% of the total enumerated specimens, and the addition of Terebellidae, Sabellidae and Spionidae took the total to 91.7%. The Errantiate families, Glyceridae and Phyllodocidae, represented 68.5% of the errant polychaetes; adding Goniadids, Nephtyids, and Lumbrinerids accounted for another 23.3%. Averaged over all transects, Sedentaria comprised the majority of polychaetes at each depth: 65.5% at 30 m, 71.3% at 60 m, and 75.6% at 90 m.

The Oweniidae were concentrated in transects 9-11 (89.8%) while the Capitellidae were largely confined to transects 1-4 (91.1%). The most numerous of the Errantia was the family Glyceridae, with a distribution spread broadly across all transects, although 56.5% of all individuals were recorded from transects 5-8.

The distributions of the various families were spread across many transects, but the distributions tended to be localized away from the pipeline (Fig. 11). The total number of families found at each transect indicated a continual increase through transect 7 before finally leveling off (Fig. 12).

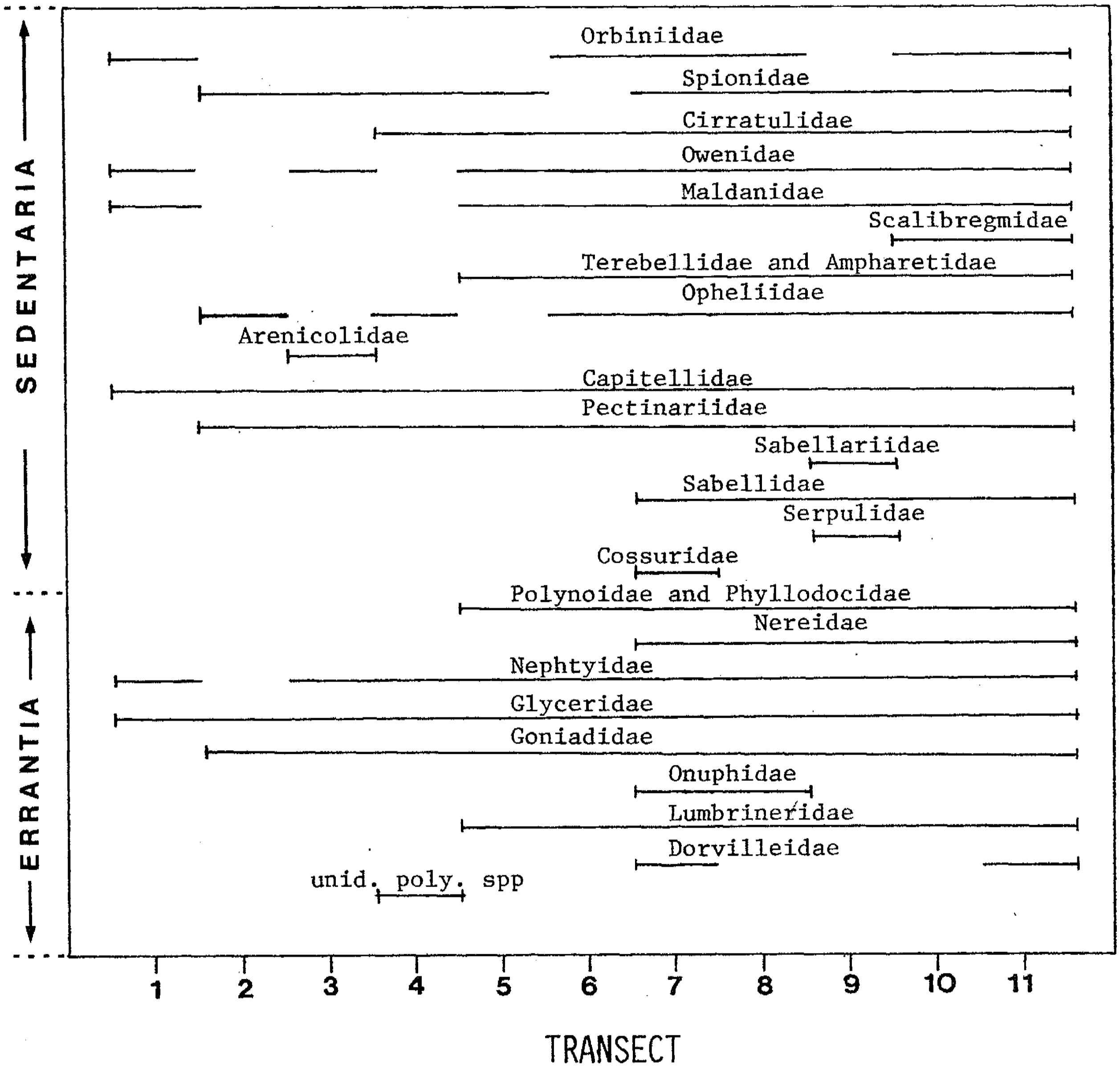


Fig. 11. Distribution of polychaete families with increasing distance from the pipeline.

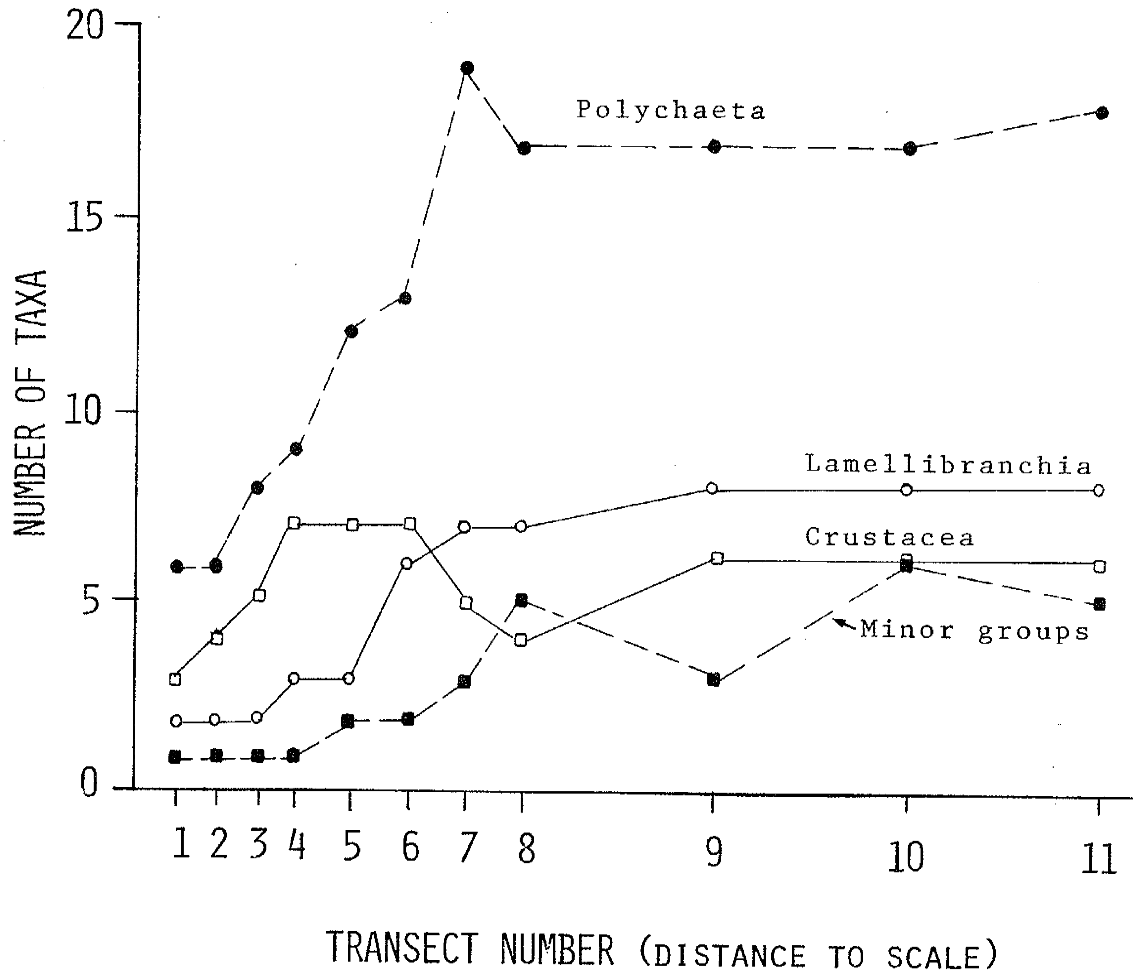


Fig. 12. Number of taxa found vs. distance away from the pipeline. Taxa are given in Appendix IV.

TABLE 7. Comparison of duplicate and 10-replicate sampling at Port Gardner station 9B. Means, standard deviations, and confidence interval estimates are computed for duplicates and 10 replicates; normality is assumed.

	Replicate	Counts	Mean	Std Dev	Confidence Limits Lower	Confidence Limits Upper	No. taxa taken per Replicate	Accumulation of new taxa in order tak
Polychaeta	1	37	44.0	9.90	30.2	57.8	10	10
	2	51					13	13
	3	49					6	13
	4	81					12	15
	5	44	78.7	33.35	58.0	99.4	8	16
	6	120					11	18
	7	101					12	18
	8	134					12	19
	9	79					11	19
	10	91					13	19
Lamellibranchia	1	674	619.0	77.78	510.9	727.1	4	4
	2	564					5	5
	3	566					4	5
	4	625					4	5
	5	680	591.9	120.73	517.0	666.8	4	5
	6	472					4	5
	7	607					4	5
	8	792					5	6
	9	591					4	7
	10	348					6	7
Crustacea	1	97	108.5	16.26	85.9	131.1	3	3
	2	120					3	3
	3	94					5	5
	4	101					5	6
	5	108	96.0	13.99	87.3	104.7	6	6
	6	97					5	6
	7	97					2	6
	8	83					6	7
	9	96					4	7
	10	67					4	7

TABLE 8. Species composition of Port Gardner Mollusca, 1973

LAMELLEBRANCHIA:

Acila castrensis
Nucula tenuis
Nuculana minuta
Megacrenella columbiana
Astarte compacta
Cyclocardia ventricosa
Axinopsida serricata
Clinocardium nuttalli
Nemocardium centifilosum
Psephidia lordi
Protothaca staminea
Macoma spp.
Solen sicarius
Hiatella arctica
Pandora filosa

GASTROPODA

Tachyrynchus lacteolus
Polinices sp.
Mitrella gouldii

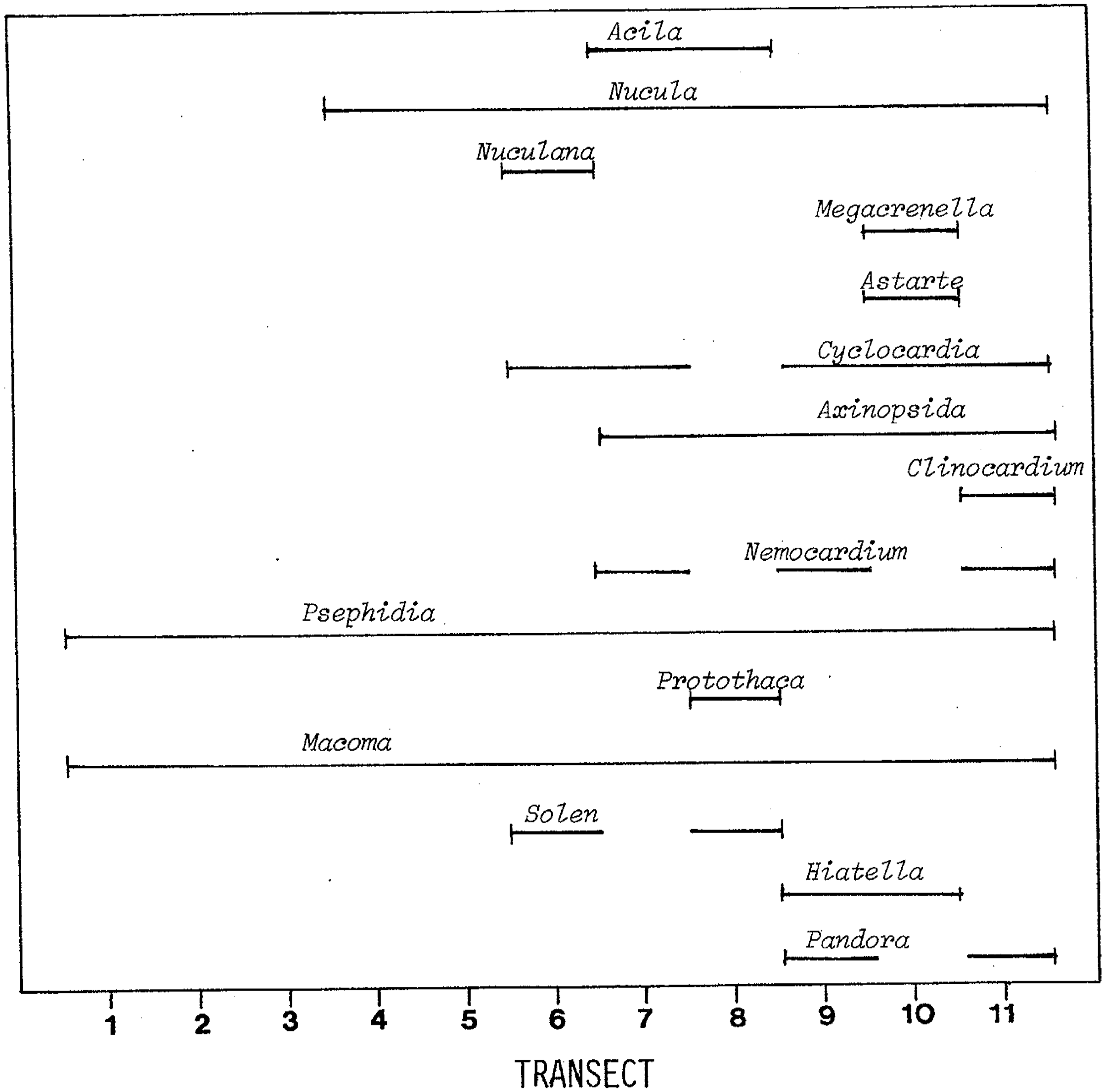


Fig. 13. Distribution of lamellibranch genera in Port Gardner.

The intensive sampling at station 9B took 19 families in 10 replicates (Appendix IV, Table 20). However, the first two samples yielded only 13 (53%) of those found. Further, the average total number of polychaetes enumerated (Table 7) for the first two replicates differed markedly from the average for ten samples (44 versus 78.7). The confidence interval estimates, under the assumption of normality, for the comparison of 2 and 10 replicates are non-overlapping (Table 7).

Lamellibranchia An unforeseen problem affected the success of identification of lamellibranchs. Despite buffering of the preserved, unsorted samples, dissolution of the clam shells occurred rapidly and differentially in the stored samples. The amount of wood debris, in particular, seemed to have an effect. Nevertheless, in most samples the majority of lamellibranchs could be identified; some were relegated to an unidentified category (Appendix IV, Table 21). The lamellibranchs were identified to species except for *Macoma*; the genera found were predominantly monospecific in the study area (Table 8). The species of *Macoma* have small differences in internal and external shell characteristics, so shell dissolution precluded identification to species.

The number of lamellibranch species tended to increase with increasing distance away from the pipeline (Fig. 13). Further in a manner similar to the polychaetes, the number of lamellibranch taxa increased gradually to transect 7 before leveling off (Fig. 12).

The proportion of lamellibranch species collected in the first two samples at 9B, 57% of the total number of taxa found, is comparable to the case for polychaetes (Appendix IV, Table 22). The average total number of lamellibranchs enumerated for these first two replicates are in close agreement with the average total counts for 10 replicates, unlike the polychaete results. The confidence interval estimates are similar for 2 and for 10 replicates (Table 7).

Crustacea Crustacea from 15 taxa were recognized (Appendix IV, Table 23). The samples include a few non-benthic individuals, e.g., Euphausiacea, and these have been ignored (Figs. 12 and 14). Ostracods (68.8%) and gammarid amphipods (23.8%) accounted for the majority of all Crustacea. Averaged across transects, ostracods become less numerous with increasing depth: 82.9% at 30 m; 74.6% at 60 m; and 37.6% at 90 m. The addition of Cumacea (3.8%), Leptostraca (1.3%), and Brachyura (0.8%) yields a total of 98.5% of all enumerated crustaceans.

The intensive replicate series at station 9E indicated that only 43% of the total number of taxa found at that station were collected in the first two samples (Appendix IV, Table 24). The confidence interval estimates and average total number of specimens for 2 and 10 replicates are similar (Table 7).

Miscellaneous Groups Four numerically minor groups comprise the balance of the fauna sampled in Port Gardner (Table 9).

The gastropods *Mitrella gouldii*, *Tachyrhynchus lacteolus*, and *Polinices* sp. were taken in the study area. Only one unidentified gastropod and one *Mitrella gouldii* were found before reaching transect 7 (stations 3C and 5E). Dissolved shells occurred in some cases (note the unidentified category in Appendix IV, Table 21). Several subtidal species of *Polinices* occur in Puget Sound, but the condition of the shells precluded differentiation.

Nemerteans were the most numerous of the minor groups with a total of 568 specimens. There appeared to be three or four species, the most numerous of which was identified as *Cerebratulus* sp. At least four

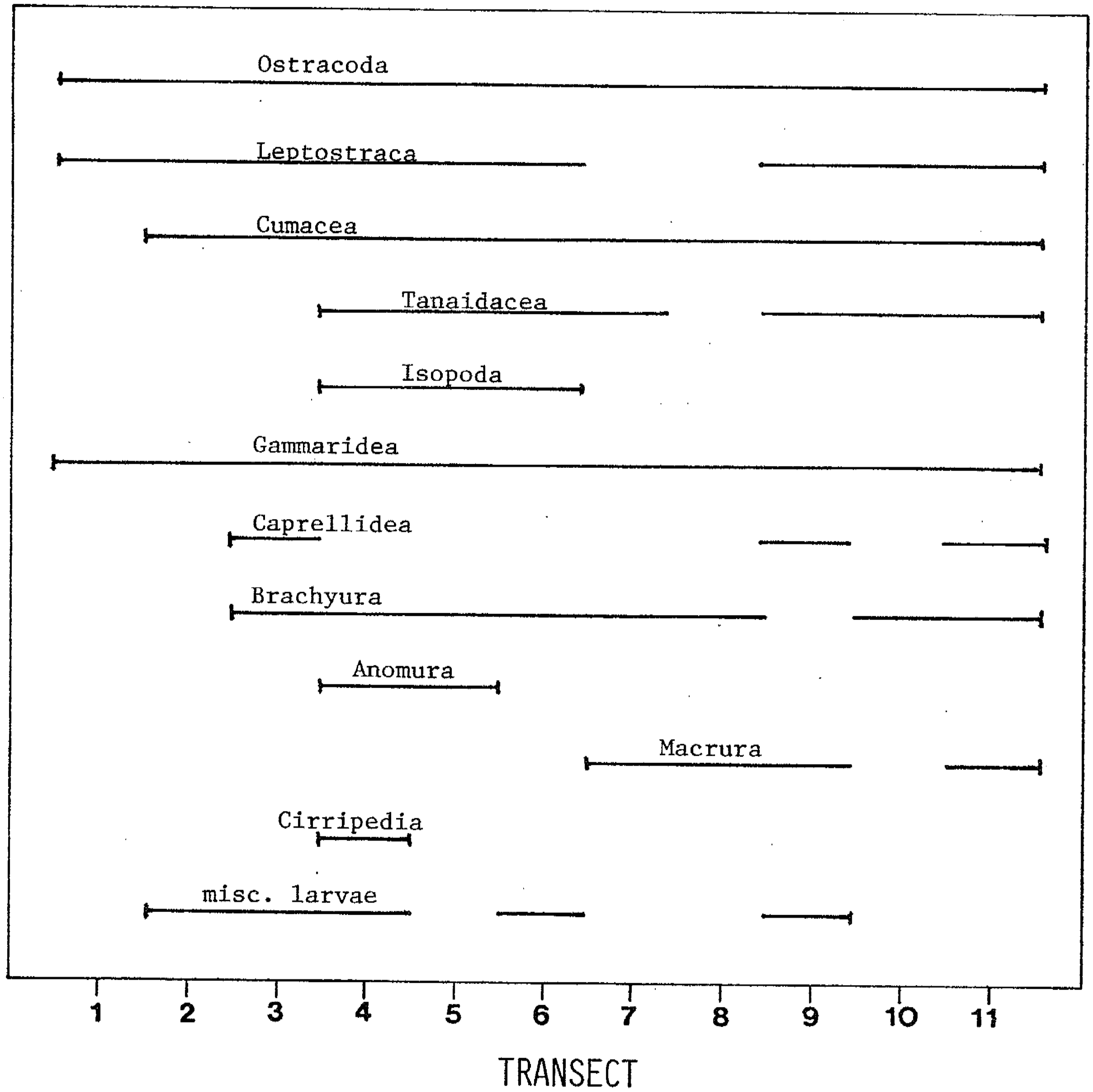


Fig. 14. Distribution of crustacean taxa in Port Gardner.

TABLE 9. Minor groups taken from Port Gardner. Occurrence is given by transect, station, and replicate number; screen 1 = 2 mm and screen 2 = 1 mm mesh.

a. Nemertea:

Sample	Screen	Numbers
1A-2	1	7
1A-2	2	27
1B-1	1	5
1B-1	2	2
1B-2	1	6
1B-2	2	22
1C-1	2	56
1C-2	2	1
2B-1	2	43
2B-2	1	43
2B-2	2	238
2C-1	1	1
2C-1	2	17
2C-2	2	3
3A-1	1	1
3A-2	2	4
3B-1	1	4
3B-1	2	1
3B-2	1	3
3B-2	2	18
3C-1	1	14
3C-1	2	14
3C-2	2	11
4B-1	2	3
4B-2	1	1
4C-1	1	2
4C-1	2	10
4C-2	2	1
5B-2	1	2
6C-2	2	1
7B-1	1	1
7C-2	2	1
8B-1	2	1
8C-1	2	1
10B-1	1	1
11C-1	1	2
11C-2	1	1

b. Echinodermata; ** denotes *Amphiopolis squamata*:

Sample	Screen	Ophiuroidea	Asteroidea
8C-1	1	1	--
9A-2	2	1	--
9B-3	2	1	--
9B-8	1	1	--
9C-2	1	2	--
9C-2	2	1	--
10B-1	2	1	--
11B-1	2	1**	4
11C-1	1	1**	--
11C-1	2	1	--
11C-1	1	14	--
11C-2	2	6	--

TABLE 9. (continued)

c. Unsegmented worms

Sample	Screen	Numbers
6C-1	1	5
6C-2	1	4
8A-1	1	1
8A-1	2	2
8A-2	2	1
8B-2	2	1
8C-1	1	1
8C-1	2	3
9B-6	1	1
10B-2	1	1
11B-2	1	1
11C-1	1	2

species from this genus are known from this area (Kozloff 1974) and specific differences are based, in part, on coloration. Thus, the use of Rose Bengal stain made such distinctions unreliable. The distribution of nemerteans was concentrated near the pipeline area so that 95% of the specimens were collected in the first three transects; adding transect 4 brought the total to 98% with the remaining 11 specimens spread across transects 5 to 11.

Ophiuroids were collected furthest away from the pipeline; the majority were found at stations 11C (71%) and 11B (3%). The balance were obtained from transects 8, 9, and 10. All but two were smaller than 8 mm and, because the keys are based in part on coloration, identification of the smallest individuals was not attempted. The two largest specimens were both *Amphiopolis squamata*.

Lastly, four very small (perhaps juvenile) asteriods were found at Station 11B. Identification could not be done.

Distribution of Taxonomic Groups

The distribution of taxonomic groups was determined by examining interrelationships between the three major groups, worms, lamellibranchs and crustaceans. Worms here include polychaetes, nemerteans, and the unidentified unsegmented worms. It was generally found that an inverse relationship existed between worms and lamellibranchs; this observation is in agreement with other reports in the literature (Lie 1968; Carey 1965). Simplifying the faunal data by progressively combining taxa did not change the relative importance of either worms or lamellibranchs (Table 10).

TABLE 10. Relative composition of Port Gardner fauna

a. All faunal groups; numbers are based on mean counts per station:

<table>
<tr><th>Transect</th><th></th><th>Poly-chaetes</th><th>Clams</th><th>Crusta-ceans</th><th>Nemer-teans</th><th>Ophi-uroidea</th><th>Gastro-poda</th><th>Other Worms</th><th>Total</th></tr>
<tr><td>1</td><td>#</td><td>508</td><td>17</td><td>28</td><td>126</td><td>0</td><td>0</td><td>0</td><td>679</td></tr>
<tr><td></td><td>%</td><td>75</td><td>3</td><td>4</td><td colspan="4">18</td><td></td></tr>
<tr><td>2</td><td>#</td><td>581</td><td>187</td><td>450</td><td>345</td><td>0</td><td>0</td><td>0</td><td>1563</td></tr>
<tr><td></td><td>%</td><td>37</td><td>12</td><td>29</td><td colspan="4">22</td><td></td></tr>
<tr><td>3</td><td>#</td><td>293</td><td>204</td><td>374</td><td>70</td><td>0</td><td>0</td><td>0</td><td>941</td></tr>
<tr><td></td><td>%</td><td>31</td><td>22</td><td>40</td><td colspan="4">7</td><td></td></tr>
<tr><td>4</td><td>#</td><td>267</td><td>472</td><td>774</td><td>16</td><td>0</td><td>0</td><td>0</td><td>1529</td></tr>
<tr><td></td><td>%</td><td>17</td><td>31</td><td>51</td><td colspan="4">1</td><td></td></tr>
<tr><td>5</td><td>#</td><td>151</td><td>585</td><td>660</td><td>2</td><td>0</td><td>1</td><td>0</td><td>1399</td></tr>
<tr><td></td><td>%</td><td>11</td><td>42</td><td>47</td><td colspan="4">< 1</td><td></td></tr>
<tr><td>6</td><td>#</td><td>148</td><td>1196</td><td>1079</td><td>1</td><td>0</td><td>0</td><td>9</td><td>2433</td></tr>
<tr><td></td><td>%</td><td>6</td><td>49</td><td>44</td><td colspan="4">1</td><td></td></tr>
<tr><td>7</td><td>#</td><td>350</td><td>1683</td><td>762</td><td>2</td><td>0</td><td>4</td><td>0</td><td>2802</td></tr>
<tr><td></td><td>%</td><td>13</td><td>60</td><td>27</td><td colspan="4">< 1</td><td></td></tr>
<tr><td>8</td><td>#</td><td>356</td><td>2563</td><td>1335</td><td>2</td><td>1</td><td>4</td><td>9</td><td>4270</td></tr>
<tr><td></td><td>%</td><td>8</td><td>60</td><td>31</td><td colspan="4">1</td><td></td></tr>
<tr><td>9</td><td>#</td><td>659</td><td>2942</td><td>918</td><td>0</td><td>4</td><td>3</td><td>0</td><td>4526</td></tr>
<tr><td></td><td>%</td><td>15</td><td>65</td><td>20</td><td colspan="4">< 1</td><td></td></tr>
<tr><td>10</td><td>#</td><td>744</td><td>2568</td><td>496</td><td>1</td><td>1</td><td>18</td><td>1</td><td>3829</td></tr>
<tr><td></td><td>%</td><td>19</td><td>67</td><td>13</td><td colspan="4">1</td><td></td></tr>
<tr><td>11</td><td>#</td><td>1664</td><td>1216</td><td>608</td><td>3</td><td>27</td><td>29</td><td>3</td><td>3550</td></tr>
<tr><td></td><td>%</td><td>47</td><td>34</td><td>17</td><td colspan="4">2</td><td></td></tr>
</table>

TABLE 10. (continued)

b. Minor taxa deleted; numbers are based on revised transect totals:

Transect	Worms	Clams	Crustaceans
1	93	3	4
2	59	12	29
3	38	22	40
4	18	31	51
5	11	42	47
6	7	49	44
7	13	60	27
8	9	60	31
9	15	65	20
10	20	67	13
11	48	35	17

c. Crustaceans and minor taxa deleted; numbers are based on revised transect totals:

Transect	Worms	Clams
1	97	3
2	83	17
3	64	36
4	37	63
5	21	79
6	12	88
7	17	83
8	13	87
9	18	82
10	23	77
11	58	42

DISCUSSION

The Port Gardner Environment

In Port Gardner, many factors affect the fauna and considerations of relationships between benthic infauna and SWL. The Snohomish River flow has a significant influence, particularly during high winter and spring runoffs, on the water circulation, water quality, and sediment and wood input to this area. The streams along the shore of Port Gardner are also important sources of freshwater inflow, as well as sediment during the winter and spring. The influx of sediment from the streams is clearly seen from the distribution of sediment size and deltas along the shore. Sampling difficulties arose near the stream deltas and environmental parameters at stations 5A, 7A, and occasionally 6A and 10A, seemed anomalous when compared with general, along-shore trends.

The distribution of sediment size was expected to reflect, through decreasing particle size, increasing distance from the river mouth. However, the mean phi size data were also affected by increasing depth offshore and proximity to streambeds. Sediment size has an effect on organic matter content in the bottom substrates.

There is generally an inverse relationship found between sediment size and the amount of organic matter present (Dawson 1971; Lie 1968). This is in part a reflection of the increased amount of bacterial flora and related microfauna in fine sediments of high clay content. This relationship was found to hold very well ($p<0.01$)* in the present study;

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* See Appendix V for statistical computations.

station 5A appears anomalous until one considers its proximity to one of the larger streams, Pigeon Creek No. 2, draining into Port Gardner (Fig. 15). Although sediment samples were stored for 9 months before analysis, organic contents were only slightly (less than 1%) diminished from those analyzed within a few days (EROS 1974). One factor contributing to the observed percentages of total volatile organic matter measured was the presence of sludge beds extending into the study area from the river mouth and adjacent Everett Harbor. Although such sludge beds are common in Puget Sound, according to Wennekens (1959), near the mouths of rivers, the magnitude of the beds in Port Gardner are enhanced by the pulp and paper mill activities in and around Everett, Washington. Log and woodchip transferring operations in the harbor contribute to the amount of wood present.

Wood debris collected by the van Veen grab ranged widely in size and composition. The largest pieces were usually chunks of bark, from 50-150 mm in length. The 13-50 mm size range was found to be mostly woodchips, which are commonly barged to the mills in the harbor. The most troublesome wood size fraction, in terms of washing and sorting of the samples, was that wood less than 13 mm in length; this included wood fibers and what are often referred to as knots, minute (1 mm) feathery pieces of wood. Besides clogging the 1 mm sieve during washing of the grab's catch, the wood fibers occasionally resembled crustaceans, thus increasing sorting time.

All of the above environmental parameters could have direct and indirect impacts on the distributions of the fauna collected. During high runoff, the river and streams transport large amounts of sediment which may adversely affect filter and suspension feeders, and the

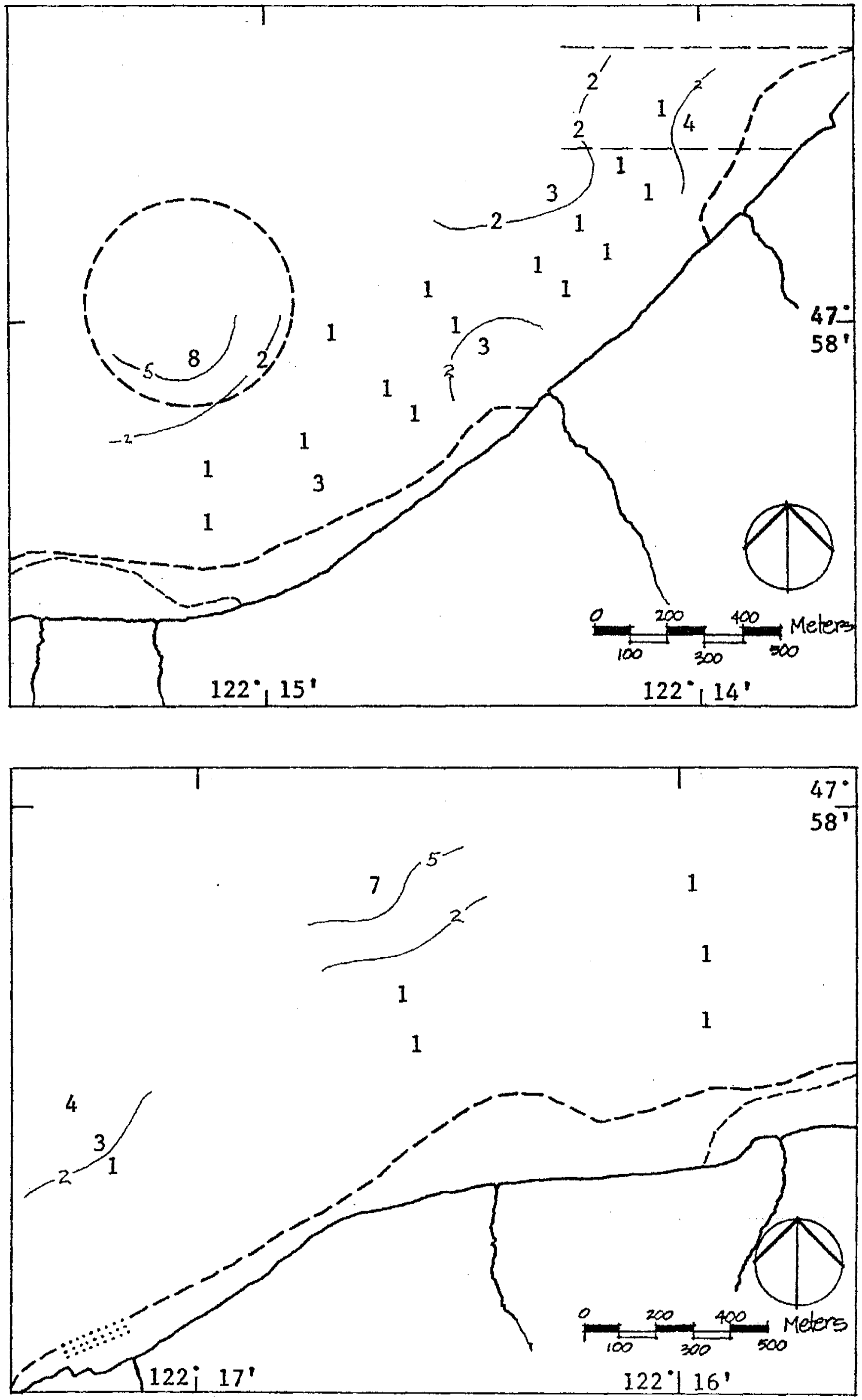

Fig. 15. Distribution of total volatile organic matter in Port Gardner. Numbers are percentage weight loss.

transported sediment may indirectly affect the composition of the fauna, particularly observed ratios of deposit to suspension feeders. The changes observed in the proportions of errant to sedentary polychaetes corresponded to changes in the mean sediment size. The presence of sludge beds and high percentages of wood on the bottom tended to exclude many organisms; the few that were found in these areas were from a limited number of taxa. Several workers (Leppakoski 1968; Henriksson 1969; Rosenberg 1972) have examined the sediment from areas influenced by pulp mill effluent. It was generally found that the sediments had low pH, high toxicity, elevated salinities, large amounts of wood, high organic content, H_2S present, and the sediments were generally incompact, attributed to high volumes of interstitial water. Also, bacterial or fungal slimes formed on the sediments, nourished by the sugars in SWL (Rosenberg 1972).

During the field sampling for the present work, SWL was discharged mostly through the deep-water diffuser; however, overflows in the mills' drains occasionally released SWL near the surface, within Everett Harbor. The report issued in 1967 (WSPCC) found that SWL from the pipeline tended to form a layer of maximum concentration at about 75 m while ECOBAM data for 1973 indicated highest concentrations closer to 60 m depth. The differences in these 2 levels may be either from different methodological determinations of SWL or may reflect slight changes in the composition of the strong mill wastes being discharged. Dispersion of the SWL from the diffuser was influenced by the general circulation; while a three-layered system is fairly well developed in Possession Sound, that system breaks down, becoming weak and variable in Port Gardner (WSPCC 1967). Consequently, SWL in the surface layers tended to move southward out of Port Gardner, while SWL released from the diffuser initially dispersed in all directions. For the present study, the assumption was made that the layer of maximum SWL concentration would encounter the bottom substrate at the same depth at which it was found elsewhere in the area. Although seemingly simplistic, by ignoring boundary conditions and possible up or downwelling, it provided a first-guess approximation which could be later elaborated upon.

In attempting to assess the relationships between SWL and the distribution of benthic invertebrates, all of the factors mentioned needed to be considered. However, the relationship between SWL and observed dissolved oxygen must also be considered. ECOBAM data indicate that there is a general inverse relationship between these two parameters. No hydrographic data were collected for the present study, and hence possible affects of the SWL-dissolved oxygen relationship on the benthos cannot be accounted for. A further complication has been reported (FWPCA 1968):

> ". . . the toxic components of SWL also reside in the biodegradable fraction and are also degradable. The composition of SWL in receiving waters at different distances from the point of discharge would therefore differ even though similar PBI (Pearl Benson Index--a measure of the lignin content of pulp wastes) values may occur. The toxicity of fresh SWL at a PBI concentration of 50 mg/l would be much greater than of biologically stabilized SWL at the same PBI concentration."

With the above constraints placed on this study, an analysis was attempted relating SWL to infauna. SWL concentrations for the period just prior to field sampling would represent the degree to which benthic fauna were exposed. However, reliable data were not available for more than 6 months prior to sampling. The range of concentrations during this time would not reflect the extreme concentrations likely to occur during a year. Consequently, SWL data were examined for an additional 6 months after initial sampling. Justification for this comes from the fact that, for the stations Lie (1968) sampled, benthic populations are fairly stable through time, on the order of 2-3 yr in Puget Sound: data gathered over a 6 yr span suggested that the mean annual abundance of organisms is rather constant (Lie and Evans 1973). Also, mill production was fairly stable during the few years centered around this study (C. Baldwin, personal communication). It was anticipated that in areas of high SWL concentration, few species would be found and that in areas of more dilute concentrations of SWL, more species and individuals per species would be found. This generalized association of SWL and benthic fauna was observed in the present study (Figs. 16 and 17). The possibility that the results indicated in Figs. 16 and 17 were an artifact of sampling bias (Christie 1975) was tested and discounted (Appendix V, Table 25). The few organisms that were found in the substrate closest to the diffuser outfall were predominantly nemerteans and the polychaete, *Capitella* cf. *capitata*.

After a 5-yr survey of the benthic fauna, Pearson (1971b) commented that the magnitude of the observed changes in benthic populations, possibly attributable to effects of pulp mill effluent on successful larval settlement, were nevertheless within the expected range of benthic population fluctuations. He concluded there was no discernible positive or negative effect of mill effluent on the benthos, to that point in time. However, the new pulp mill in his study area used a different process than in other areas, yielding an effluent composed mostly of a dilute suspension of pulped fibers; thus the discharge was low in lignins and digestion chemicals, unlike that from sulphite

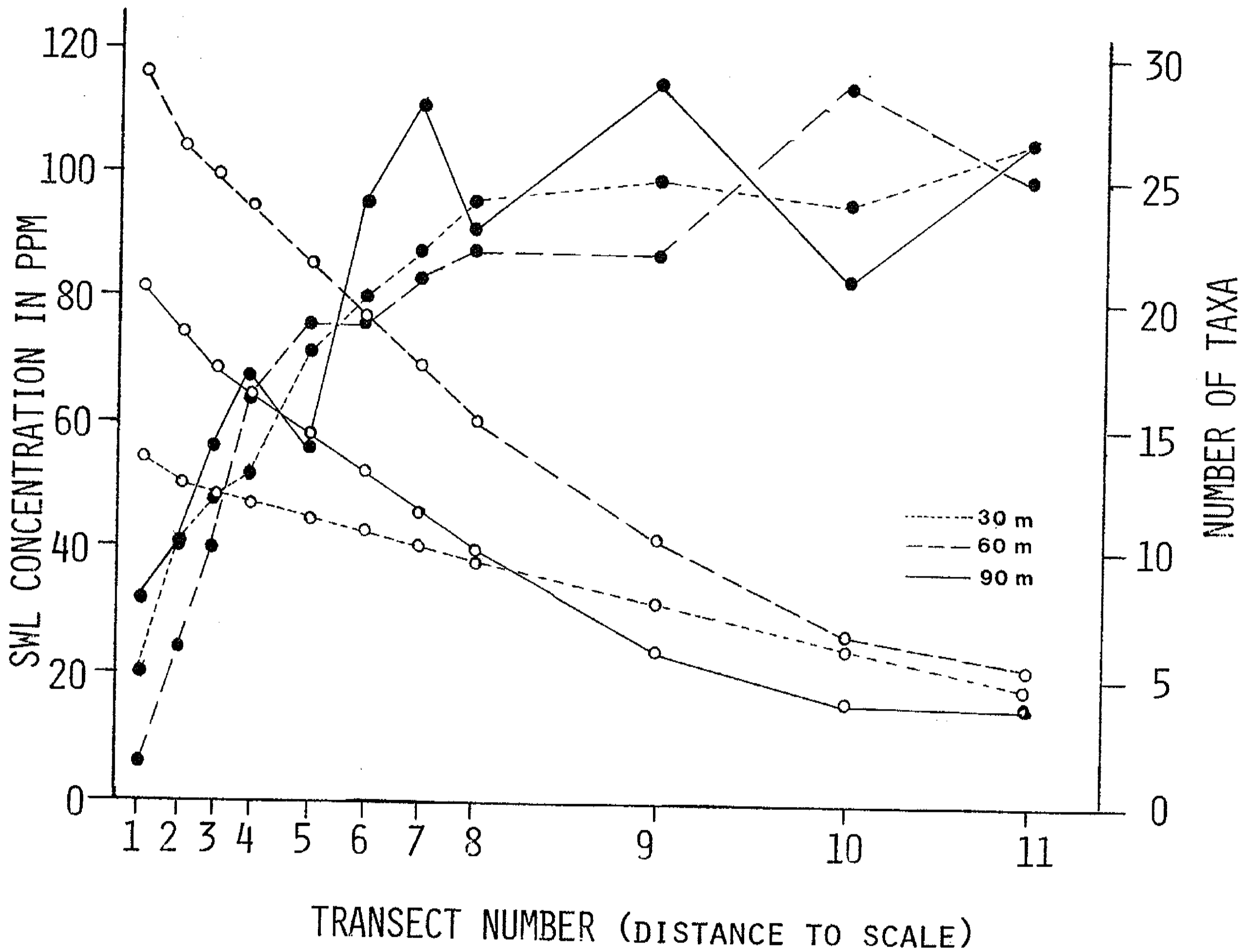

Fig. 16. Relationship between mean annual SWL concentration and the number of taxa per 0.1 m^2 of bottom with increasing depth and distance from the pipeline in Port Gardner. SWL concentrations are the open circles.

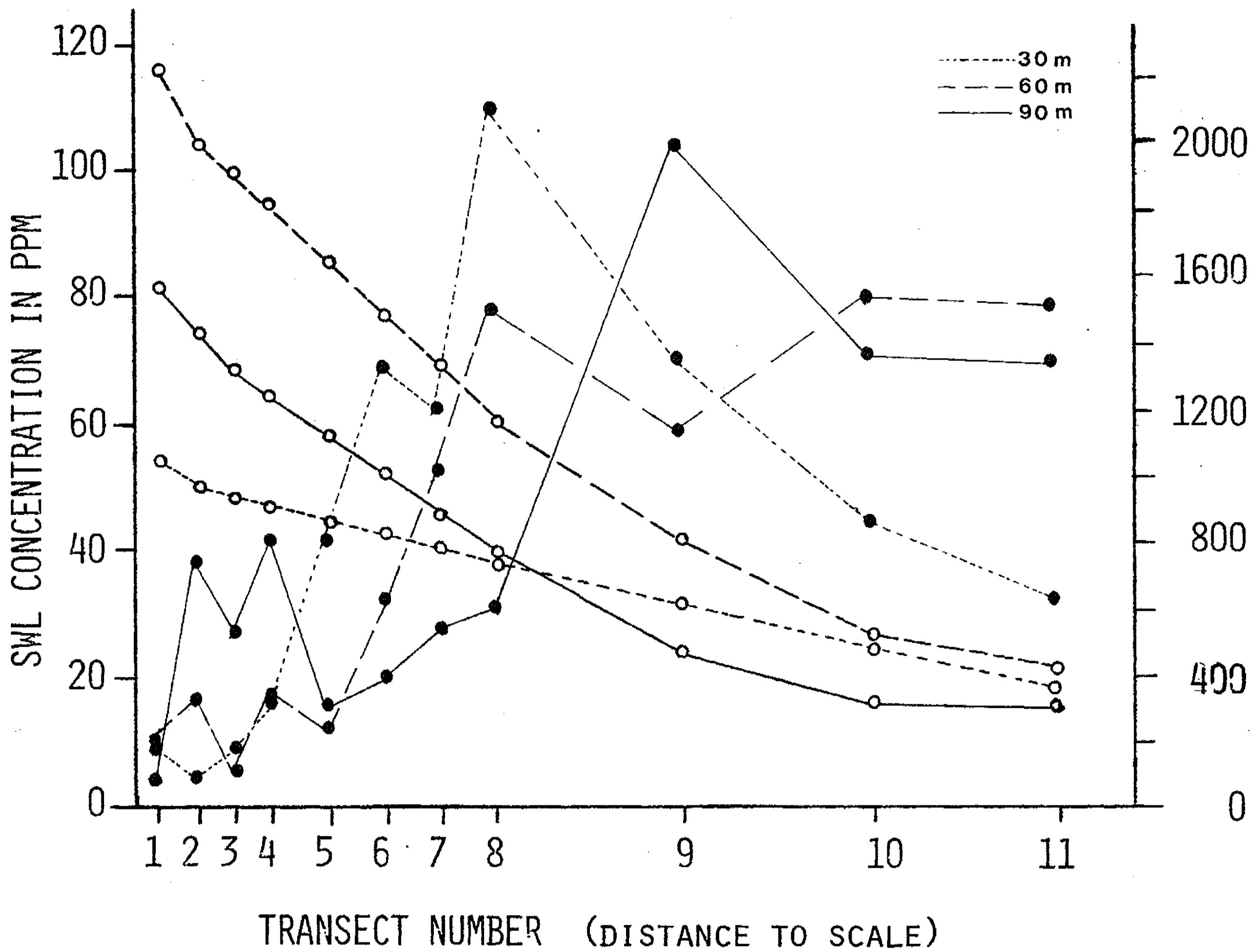

Fig. 17. Relationship between mean annual SWL concentration and the number of individuals per 0.1 m^2 of bottom with increasing depth and distance from the pipeline in Port Gardner. SWL concentrations are the open circles.

processes. In contrast, Rosenberg (1971; 1973) attributed changes in benthic populations to the marked reduction of SWL effluent, pointing out that the faunal composition in 1972 resembled that of 40 yr earlier. He suggested that recovery of the benthic populations occurred initially in the littoral community, later extending to the sublittoral areas of the fjord. After mill closure in 1966, the succession in benthic fauna appeared to follow a logistic pattern, similar to population growth curves, with initially few species and few individuals per species; later, the numbers of species as well as the number of specimens per species increased, leveling off in 1972. McNulty (1970) had reported a similar pattern of benthic faunal changes, only over increased distance from an outfall, and not over time; he also noted less influence of pollution in the soft-bottom areas than on hard substrates, possibly due to the generally higher amounts of organic matter typically found in the soft-bottom environment.

Sampling with the van Veen Grab

While the total numbers of individuals may be less reliable, the species composition for the 9 stations sampled in October, 2 months after the rest of the field sampling, is expected to be, and was, found to be the same. This is due, presumably to the stability of the Puget Sound benthos.

No minimum sample volume had been defined prior to field sampling. Lie (1968) found that only 4 liters were required to get 90-95% of the infauna present at a station; this assumed that a cut of 1 cm depth by the van Veen yielded 1 liter of volume and that the bulk of the fauna were found within the upper 4 cm of the bottom. When repeated casts had to be made, and with little sampling experience, the inclination was to accept smaller catches than desirable; however, the catch volume was a function, to a large extent, of the hardness of the bottom. The sandy bottoms were most difficult to penetrate; in the case of bottoms with more than 7% wood, the grab tended to tip slightly and take an angular, smaller, bite of the substrate. The differences in bottom hardness may account for the results of the intensive sampling at station 9B, such that the confidence interval estimate for the first 2 casts was non-overlapping with the interval estimate computed on 10 replicates; the twofold difference in catch volumes between the first and second replicates suggests differences in the substrates sampled.

The results from station 9B suggest that investigations of individual species will involve different numbers of requisite replications. Consideration must be given to whether one is interested in collecting biomass data, the greatest variety of species, or the most specimens possible. In attempting to assess the relationship of SWL to benthic infauna, it would be most useful to sample the greatest number of species; Hartman (1960) pointed out that fewer species occurred in areas affected by various forms of pollution. This would require, however, the greatest number of replicates as well as the deepest penetration into the sediment by the grab (Lie 1968; Christie 1975).

The Fauna

While the composition varies, the total number of different taxa was found to increase with distance ($p<0.01$) from the deep-water diffuser. The lamellibranch data reflect this clearly ($p<0.01$) and, while polychaetes were only identified to family, it is equally likely ($p<0.01$)

that the specific composition of polychaetes changes as distance from the pipeline increases. Lamellibranchs also show an increase in total numbers of individuals ($p<0.01$) with increasing distance as does the total number of specimens collected ($p<0.01$). For crustaceans, although the taxonomic composition changes, the numbers of individuals do not show any trend toward increasing numbers with distance from the diffuser. Complicating the picture, however, are the differences in composition due to depth, best illustrated by the change in proportions of errant and sedentary polychaetes with depth. The minor taxa identified are all fairly well localized ($p<0.01$) away from the diffuser (Fig. 18). The major problem that overshadows statements like those above is that increasing distance away from the diffuser is also increasing distance away from the Snohomish River mouth, the Everett Harbor and its thick sludge beds, and the major sources of wood debris. Further, difficulties in interpreting faunal distributions arise when attempting to account for either mean sediment size, or silt and clay content, or both. Buchanan (1963) found dissimilar faunal assemblages in sediments with identical parameters.

The discussion of taxa, and depth and distance away from the diffuser outfall, has been from a community approach, that is, a group of co-occuring species grading into a different group of co-occuring species. Where inconsistencies arise, an alternative explanation, based on functional relationships, might be in order (Pearson 1971a). Pearson identified 5 feeding types: a) motile predators, b) scrapers, c) surface deposit feeders, d) suspension feeders, and e) deposit swallowers. Given sediment size-fraction, hydrographic, and total sediment organic content data, he attempted to correlate the observed

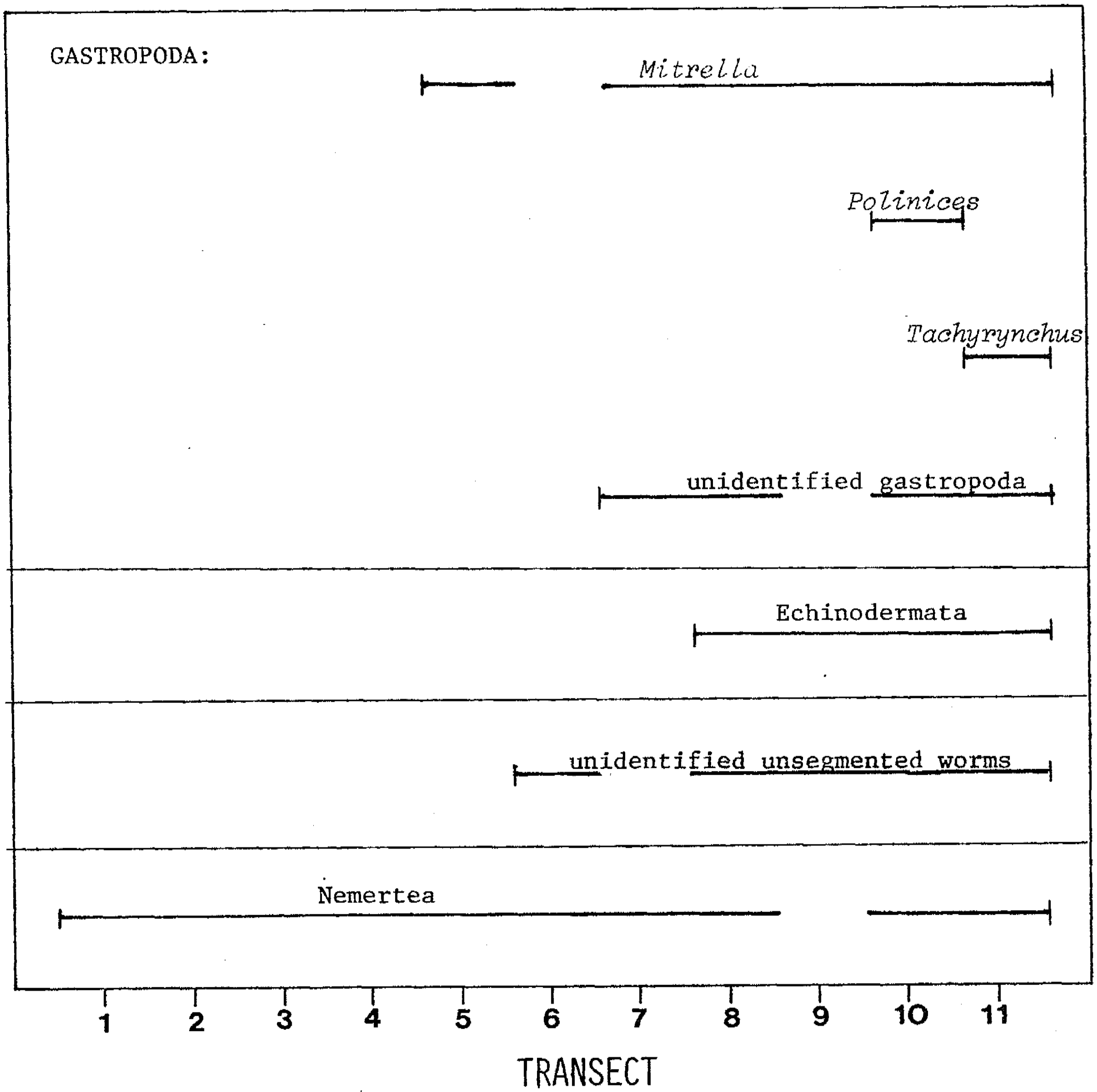

Fig. 18. Distribution of minor faunal groups from Port Gardner.

distribution of each feeding type to these environmental parameters. Groups a and b were found to be positively correlated with coarser sediments, while the opposite held for c. No clear results were obtained for d and e; however, Pearson suggested that d may be more sensitive to hydrodynamics, viz., tidal currents, and that total sediment organic content might be useful in considering the distribution of group e. Viewing the Port Gardner area from a feeding strategy point-of-view might yield a more consistent interpretation of the observed polychaete distributions, assuming the polychaetes were identified to species (P. Jumars, personal communication).

An inverse relationship in the number of polychaete taxa to lamellibranch taxa was found ($p < 0.01$); this is in agreement with other reports in the literature (Nichols 1970; Lie 1968; Rosenberg 1971). The changes in lamellibranch and polychaete taxa observed are also a function of sediment size composition (Carey 1965; Phelps 1964).

The specific makeup of the fauna closest to the diffuser outfall was found to be very similar to that reported from other disturbed environments (Reish 1960; Rosenberg 1973; Tulkki 1968; Bellan-Santini 1968); *Capitella* cf. *capitata* was commonly found closest to the outfalls of industrial wastes. However, because polychaete data to species were lacking, it was not possible in the present study to identify the zones of pollution as described by Reish (1971) and Bellan-Santini (1968).

The problem of shell dissolution that occurred made discussion of screen efficiencies for lamellibranchs, here, impossible. Crustacea were found to have been collected from screens of different sizes in an inconsistent manner. Differences here can be attributed to some degree to the amount of wood at a station. Simply, the more wood, the higher the probability that ostracods would be taken in greater numbers from the 2-mm screen as opposed to a 1-mm screen, the wood acting to eliminate available open mesh space through which the ostracods might otherwise have been washed. For polychaetes, screen efficiency seems to have even less meaning; similarly-sized polychaetes were often collected simultaneously from different mesh screens.

Inconsistencies in screen efficiency suggest that future monitoring in Port Gardner using similar methods will allow fauna to be collected from a single 1-mm screen, there being no point in attempting to separate that which is not reliably separable. The exception is if young-of-the-year clams are looked at; but then an even finer screen may be required, perhaps 0.5-mm square mesh, in addition to the 1-mm screen. However, the fewer screens used, in general, the better the condition of specimens.

Monitoring Considerations

Assuming the same stations were chosen for future monitoring in Port Gardner, the following recommendations could be made: 1) only use a 1-mm screen, to minimize damage to specimens; 2) use a 2- or 4-mm screen only where samples appear to contain large amounts of wood; 3) use 70% alcohol to preserve specimens; 4) continue to use a stain to speed up sorting, since the major taxa are not often identified by coloration; and 5) at least 2 targets should be used in radar positioning of the vessel. While some Puget Sound benthos is noted for having long-term stability, Lie (1969b) found considerable changes in species composition during the year 1963-1964; however, these changes affected only the very rare species that were present with 1 or 2 specimens each.

Changes in laboratory procedures from the present work should include doing pipette analysis, for studying animal/sediment relationships; standardizing total volatile organic matter determinations by using a muffle furnace for burning of samples at 600 degrees C; and analyzing sediment samples for volatile organic content within approximately 1 month from collection. If formalin is still used for preservation, unsorted, and perhaps even sorted samples will have to be supplemented with additional buffer periodically; this may have to be on the order of weekly intervals for unsorted samples with high wood content (D. Kisker, personal communication). Monitoring, if done on an annual basis, should fall within the same season each year.

SUMMARY

The following observations about Port Gardner can be made: 1) Port Gardner is a complex area of physical and hydrographic gradients, influenced by the Snohomish River and the industrial activities in Everett Harbor; 2) the mean annual values of SWL examined decreased one order of magnitude each of the first 2 nautical miles south of the diffuser pipeline; 3) general inverse relationships were observed for both sediment size vs. organic matter content and the number of polychaetes vs. the number of lamellibranchs; 4) the number of taxa as well as the number of specimens per taxon were found generally to increase with increasing distance from the deep-water diffuser pipeline; 5) ostracods and errant polychaetes were found to be numerically dominant compared to other crustaceans and sedentary polychaetes in the shallowest stations and diminished in importance with increasing depth, giving way to increased numbers of gammarid amphipods and sedentary polychaetes; and 6) specimens from numerically minor faunal groups, including Nemertea, Echinodermata, and Gastropoda, were found furthest from the pipeline.

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APPENDIX I

Everett Harbor Baseline Studies

The studies conducted within the Everett Harbor and the waters immediately adjacent to and south of it were confined to a baseline sampling and descriptive effort. The harbor is a complex, highly-modified environment. Sited within the harbor area are the Scott Paper Company and Weyerhaeuser Company sulphite pulp mills, along with other heavy industry (Fig. 19). Areas of the harbor are also used for log storage (WSPCC, 1967). Although the bulk of the sulphite pulp mill wastes entered Port Gardner via the deep-water diffuser, there existed several smaller discharges of assorted other materials into the harbor. Because of its proximity to the mouth of the Snohomish River, the harbor was not thought to be an appropriate place to answer the questions posed in the present study. While no pilot survey was conducted in the harbor, familiarity with the area had been obtained in an earlier study (Malkoff, 1974).

MATERIALS AND METHODS

With the exception that only a single grab sample was obtained for each station, the materials and methods employed in the Everett Harbor area were similar to those used along Port Gardner's southeastern shore. For complete coverage of the harbor area, an extensive grid of stations was chosen; this would allow for selection of some of these stations to be used in subsequent sampling or in a monitoring program.

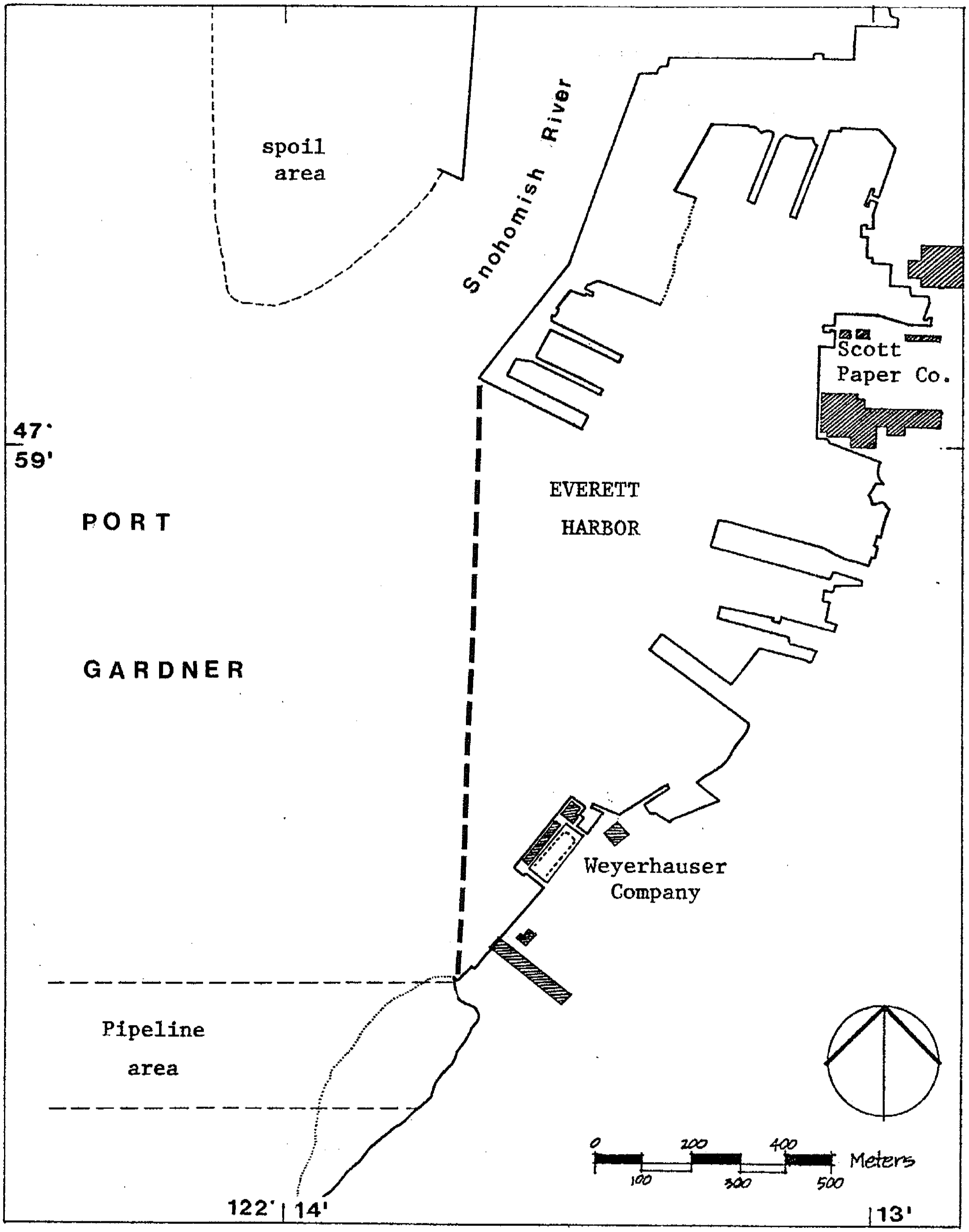


Fig. 19. Everett Harbor vicinity map.

Positioning of the vessel was simplified in the inner harbor by the number of easily-identified landmarks. Because of the large amounts of wood debris, mostly pieces of bark arising from the log-rafting activities, a 4-mm screen was used as the top nesting sieve box; this reduced the amount of time required for screening of the grab samples.

Laboratory procedures for the harbor studies were the same as those used for the Port Gardner samples. Where new specimens were identified, the reference collection was expanded. Initial sorting of fauna into the major groups of worms, clams, crustaceans, and miscellaneous was accomplished with the help of student sorters. Further taxonomic identification and enumeration was done only for the Crustacea.

RESULTS

The sponginess of the harbor bottom, due to the presence of pulp and other mill wastes, wood debris, and sludge beds, often led to a tipping over of the grab with a resultant failure to secure sufficient, if any, benthic material. Of the 19 grab failures recorded, 7 were at station 10 (Fig. 20). Further complications to sampling included the presence of sunken logs, and an abundance of discarded rope lines, cables, and metal bands from the log rafts; such impediments to sampling led to the abandoning of station 13. Log rafting activities in the inner harbor during both the November 25 and December 2 cruises precluded any sampling at station 4. Catch volumes ranged from 2.6 to 17.7 liters ($\bar{X}$ = 14.4; S.D. = 4.7); of the 23 samples taken, 15 were approximately 90% of capacity or more (Table 11).

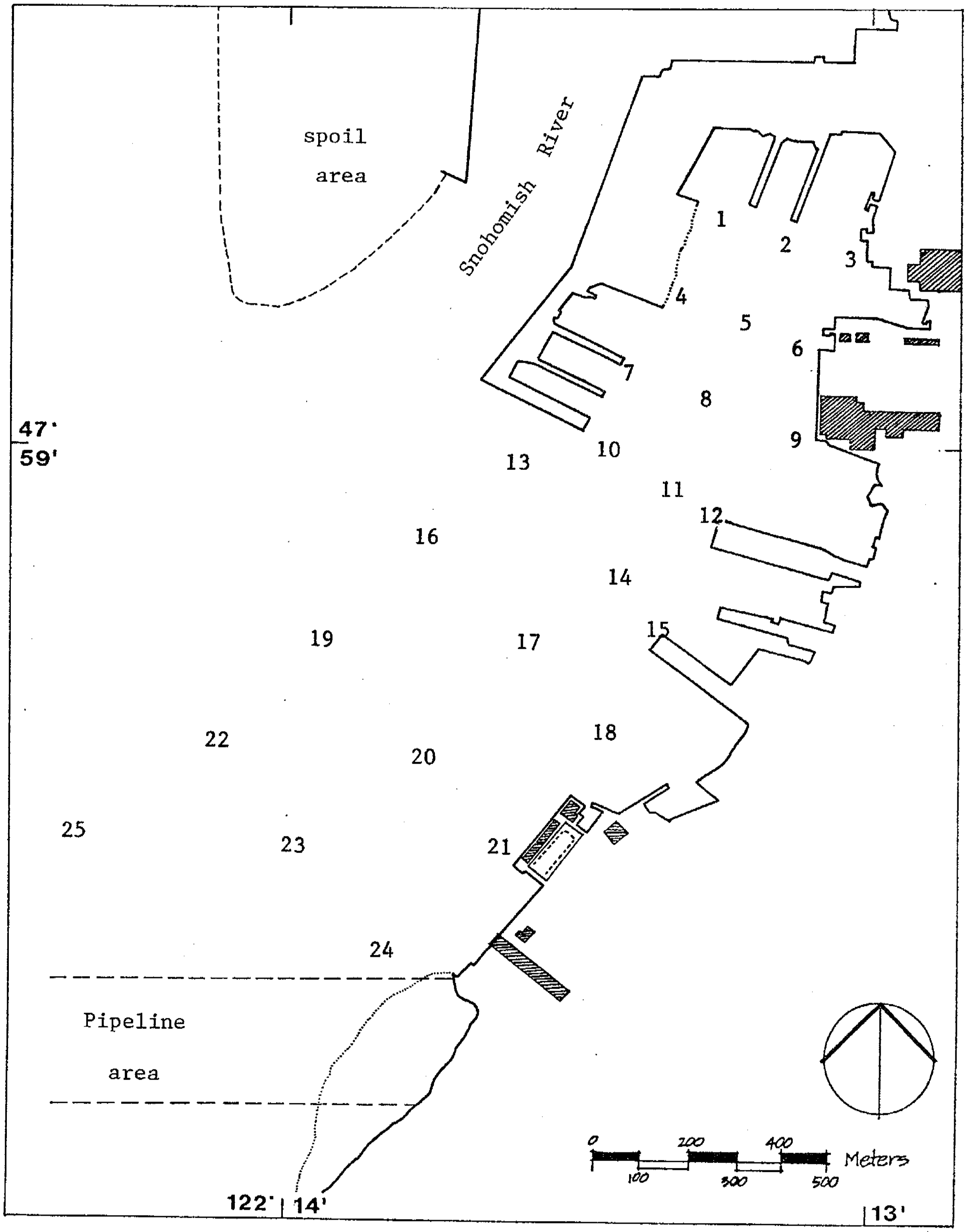


Fig. 20. Station locations for Everett Harbor study.

TABLE 11. Everett Harbor station locations, sampling dates and times, catch and sediment core volumes. Depths are meter-wheel readings.

Station	Latitude 47°N	Longitude 122°W	Date	Time PST	Depth m	Catch Volume liters	Core Volume ml
1	59' 15"	13' 17"	Nov 25	0853	6	8.5	133.0
2	59' 14'	13' 09"	Nov 25	0904	12	17.7	216.0
3	59' 13"	13' 03"	Nov 25	0910	7	17.7	265.9
4	59' 11"	13' 20"	-- Blocked by log rafts --				
5	59' 09"	13' 13"	Nov 25	0937	8	10.1	166.2
6	59' 07"	13' 07"	Nov 25	0949	5	17.7	274.2
7	59' 06"	13' 25"	Nov 25	1031	13	17.7	224.4
8	59' 03"	13' 17"	Nov 25	1055	11	5.0	166.2
9	59' 01"	13' 07"	Nov 25	1130	11	17.7	232.7
10	59' 00"	13' 27"	Nov 25	1152	4	8.5	99.7
11	58' 57"	13' 22"	Nov 25	1205	9	2.6	116.3
12	58' 55"	13' 16"	Nov 25	1255	5	17.7	191.1
13	58' 59"	13' 37"	-- No successful casts --				
14	58' 52"	13' 26"	Nov 25	1305	10	10.5	149.6
15	58' 47"	13' 22"	Dec 2	0831	10	17.3	305.8
16	58' 53"	13' 46"	Dec 2	0932	10	12.3	214.4
17	58' 46"	13' 35"	Dec 2	0914	10	17.7	212.7
18	58' 40"	13' 27"	Dec 2	0851	8	15.8	222.7
19	58' 46"	13' 57"	Dec 2	0947	34	17.7	226.0
20	58' 38"	13' 47"	Dec 2	1018	44	17.7	264.2
21	58' 32"	13' 37"	Dec 2	1025	15	17.7	222.7
22	58' 40"	14' 08"	Dec 2	1132	71	17.7	249.3
23	58' 32	14' 00"	Dec 2	1118	72	17.7	250.9
24	58' 24"	13' 51"	Dec 2	1043	8	11.5	159.5
25	58' 33"	14' 23"	Dec 2	1156	94	17.7	257.6

The harbor area was fairly uniform, very fine sand (Fig. 21). Except at station 24, sand/mud ratios were all less than 1.00 (Table 12). Omission of station 24 reduced the variability of the observed ratios by 36%; this station appeared not to be part of, but to delimit the southern extent of the harbor environment (Fig. 7 and 22).

The amount of total volatile organic matter was, on the average, much higher in the harbor than along the southeastern shore of Port Gardner (Table 13). Station 24 seemed to be more similar to areas south of it than to the harbor environment. Volatile organic matter greater than 25% was found in the immediate vicinities of Scott Paper Company's pulp and paper and Weyerhaeuser Company's pulp mills (Fig. 23). No estimates of H_2S odor were made; harbor samples all had a strong odor.

With few exceptions, wood volumes in excess of 2% were confined to the harbor (Table 14). Percentage wood content was highest in the log-rafting and woodchip-handling areas (Fig. 24).

The Everett Harbor benthos was numerically dominated by polychaetes (Table 15). Leptostracans comprised 87.9% and gammarid amphipods 8.6% of all crustacea found (Table 16). Sources of error in Crustacea counts arose from the presence of non-benthic individuals, in addition to possible underestimation of the Tanaidacea. Only 2 clams appearing to be alive at the time of collection were found in the Everett Harbor area. Miscellaneous groups were retained but not identified further.

DISCUSSION

Everett Harbor is a highly-modified area subject to many natural and human influences. Consequently, it is likely that observed changes

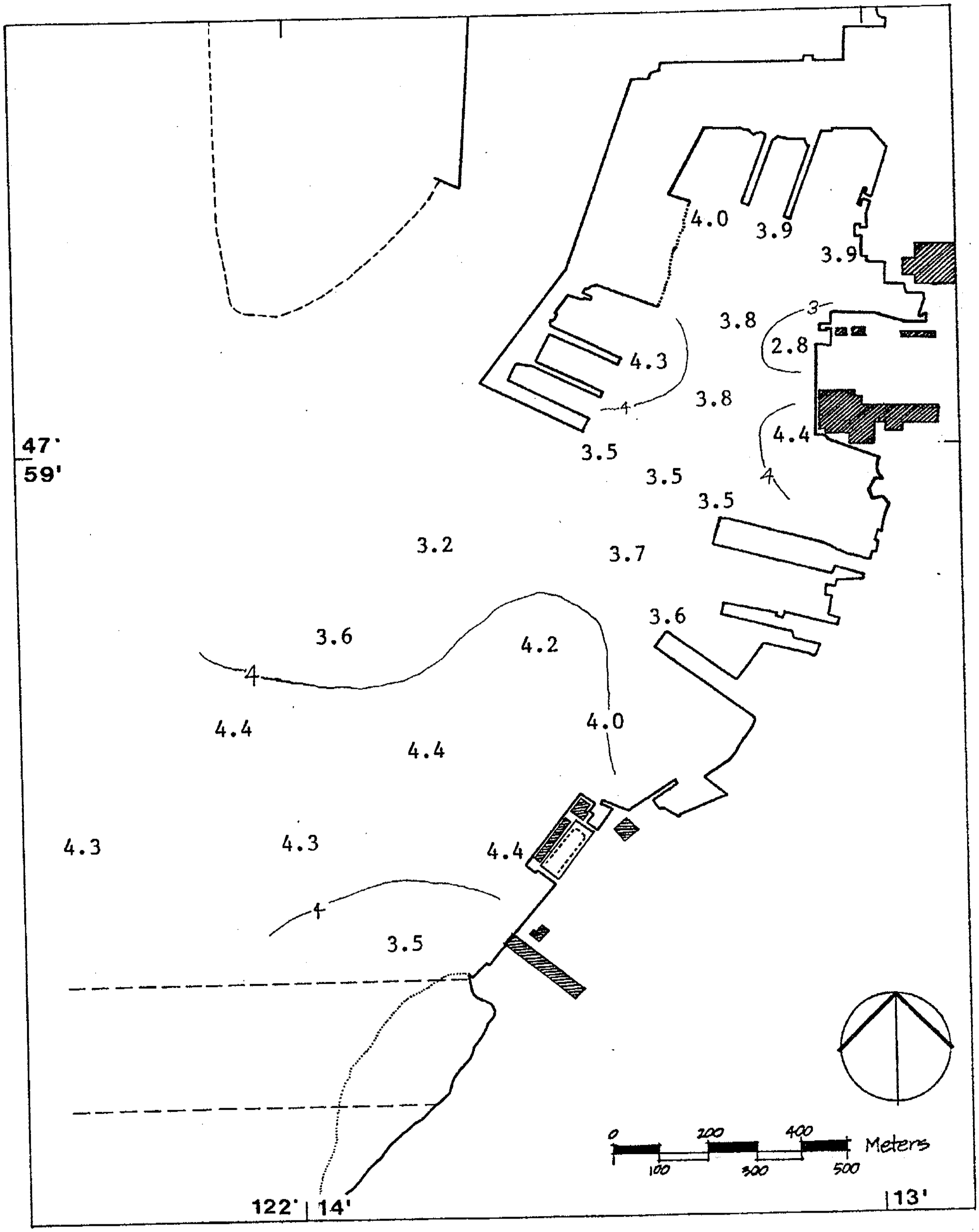


Fig. 21. Distribution of mean phi size in Everett Harbor. Numbers are in phi units (Appendix III).

TABLE 12. Sediment size-fraction parameters, Everett Harbor

Station	Mean	Standard Deviation	Skewness	Kurtosis	Sand/Mud Ratio
1	4.07	1.45	-3.67	15.60	0.12
2	3.86	1.13	-2.66	12.12	0.58
3	3.94	1.40	-3.05	12.01	0.27
5	3.75	1.90	-2.55	8,08	0.21
6	2.80	2.32	-1.03	2.64	0.74
7	4.30	0.56	-4.00	25.09	0.18
8	3.85	1.57	-2.60	8.89	0.24
9	4.43	0.44	-8.08	78.62	0.04
10	3.54	1.40	-1.82	6.43	0.84
11	3.48	2.03	-1.87	5.12	0.33
12	3.49	1.42	-0.97	2.42	0.64
14	3.66	1.71	-2.15	6.68	0.37
15	3.60	1.61	-1.89	5.91	0.46
16	3.15	1.83	-1.03	2.79	0.74
17	4.19	0.86	-3.44	15.89	0.18
18	3.95	1.21	-2.45	8.75	0.29
19	3.65	1.71	-1.89	5.35	0.32
20	4.43	0.40	-9.62	126.87	0.05
21	4.28	0.59	-3.45	17.58	0.18
22	4.35	0.50	-4.50	29.59	0.12
23	4.27	0.66	-3.17	13.55	0.15
24	3.47	1.24	-1.70	7.68	1.23
25	4.26	0.85	-3.71	16.36	0.10

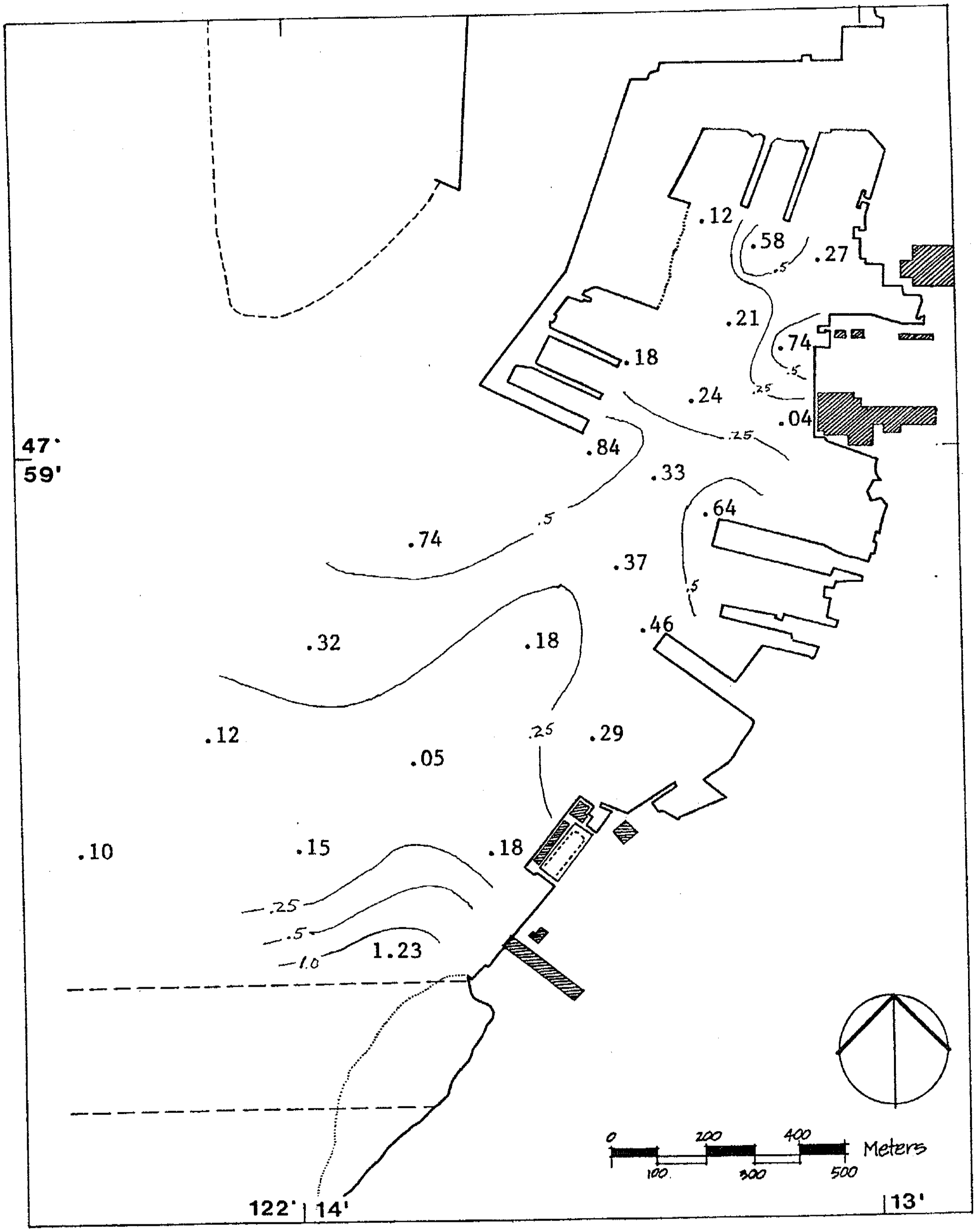


Fig. 22. Distribution of sand/mud ratios in Everett Harbor.

TABLE 13. Total volatile organic matter, Everett Harbor

	Weight Loss	
Station	grams	percentage
1	2.1415	8.89
2	3.3961	11.39
3	6.4503	25.83
5	2.8101	10.15
6	4.1305	16.87
7	1.2693	4.17
8	1.9032	7.50
9	7.6346	27.95
10	5.8505	20.37
11	5.3500	14.00
12	3.7693	15.33
14	1.3749	5.08
15	5.1747	20.00
16	2.5232	8.56
17	4.2361	15.77
18	6.8721	27.62
19	5.6260	20.77
20	3.9910	14.04
21	4.6300	17.05
22	2.9711	10.84
23	5.9863	23.65
24	1.2501	4.09
25	6.5471	24.76

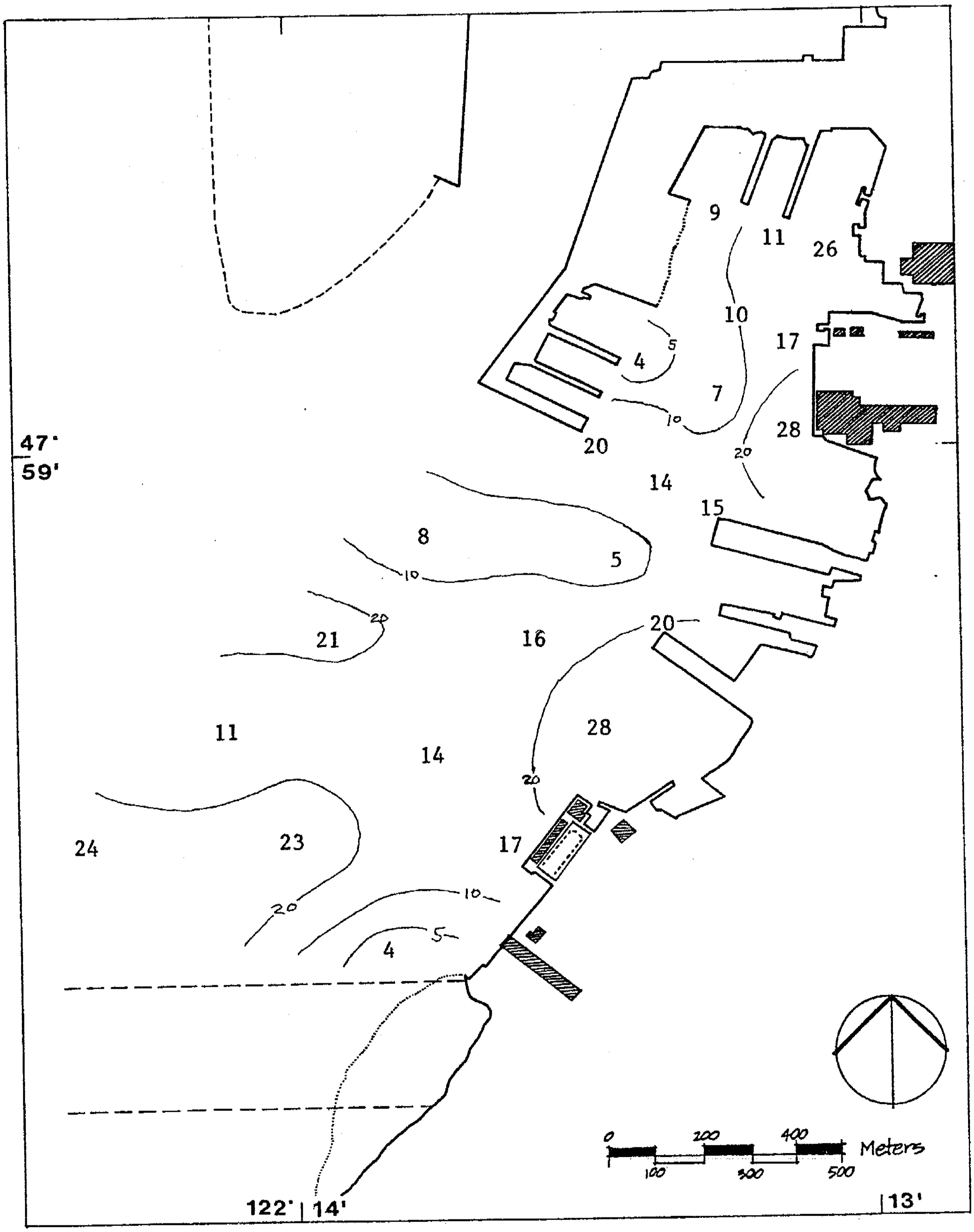


Fig. 23. Distribution of total volatile organic matter in Everett Harbor. Numbers are percentage weight loss.

TABLE 14. Wood content, expressed as a percentage of sample catch volume, Everett Harbor

Station	Volume (ml)			Percentage
	4-mm Screen	2-mm Screen	1-mm Screen	
1	651	71	134	10.23
2	500	275	535	7.51
3	617	193	369	6.78
5	1076	213	372	16.76
6	2276	648	1627	26.16
7	122	13	49	1.05
8	932	110	202	25.75
9	64	87	227	2.17
10	936	443	1063	29.08
11	1548	450	340	92.30
12	920	340	670	11.03
14	890	120	300	12.67
15	520	160	240	5.40
16	307	62	115	4.01
17	200	110	255	3.24
18	719	621	964	14.84
19	37	6	17	0.34
20	26	9	25	0.34
21	43	14	116	0.99
22	54	9	38	0.58
23	78	27	71	1.01
24	171	41	154	3.22
25	87	31	50	0.96

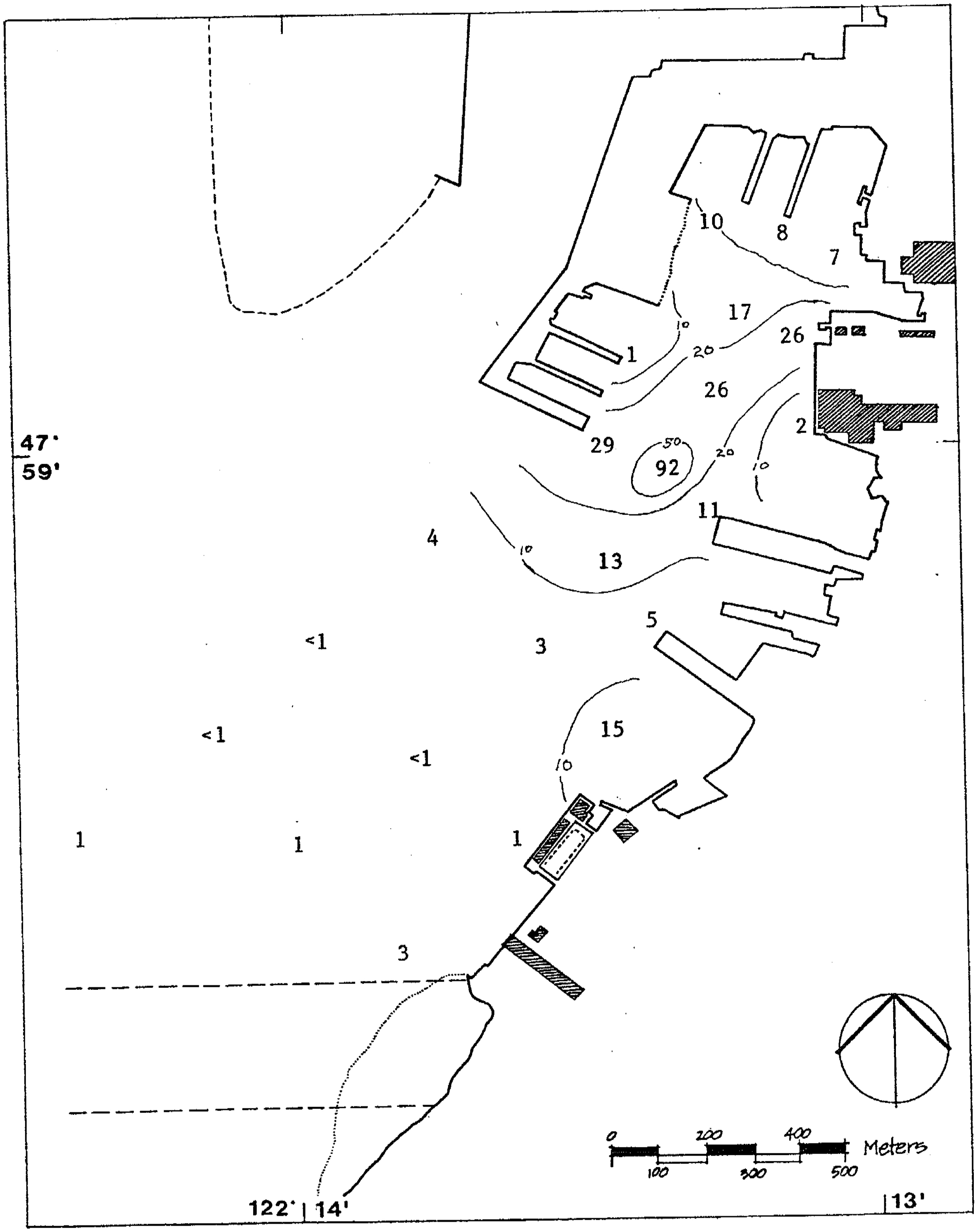


Fig. 24. Distribution of wood on the bottom in Everett Harbor. Numbers are percentage of catch volume.

TABLE 15. Benthic fauna collected from Everett Harbor. Screen 1 = 4 mm, screen 2 = 2 mm, and screen 3 = 1 mm mesh.

Station	Group:	Worms			Clams			Crustacea			Miscellaneous		
	Screen No. :	1	2	3	1	2	3	1	2	3	1	2	3
1		4	2	4	-	-	-	-	-	1	4	1	3
2		-	1	25	-	-	-	-	-	1	3	9	8
3		22	17	24	-	-	1	-	5	7	7	2	1
5		182	141	448	-	-	-	6	12	122	2	8	10
6		51	33	63	-	-	-	-	-	-	-	-	-
7		-	5	2	-	-	-	-	-	2	2	11	3
8		160	84	96	-	-	-	-	2	9	-	-	7
9		2	48	89	-	-	-	-	17	128	-	-	6
10		169	112	297	-	-	-	36	10	72	21	8	17
11		237	58	109	-	-	-	11	-	232	8	-	10
12		60	63	189	-	-	-	1	-	-	3	-	-
14		308	81	709	1	-	-	-	-	-	-	-	-
15		21	7	33	-	-	-	-	-	-	-	-	-
16		71	32	197	-	-	-	-	1	1	7	6	12
17		8	38	230	-	-	-	-	1	4	3	15	8
18		816	488	1010	-	-	-	105	55	166	9	6	21
19		6	20	86	-	-	-	1	-	-	-	-	4
20		2	1	86	-	-	-	-	-	1	-	-	-
21		4	30	332	-	-	-	-	1	4	-	1	9
22		165	1	27	-	-	-	1	-	-	-	2	7
23		122	8	85	-	-	-	-	-	-	2	1	4
24		367	6	342	-	-	-	1	-	1	1	1	7
25		12	1	21	-	-	-	-	-	-	-	-	2

TABLE 16. Crustacea taken from Everett Harbor.
Screen 1 = 4 mm, screen 2 = 2 mm, and screen 3 = 1 mm mesh.

Station	Screen	Leptostraca	Tanaidacea	Gammarid Amphipoda	Macrura	Miscel-laneous
2	3	--	--	1	--	--
3	2	5	--	--	--	--
	3	7	--	--	--	--
5	1	6	--	--	--	--
	2	12	--	--	--	--
	3	122	--	--	--	--
7	3	2	--	--	--	--
8	2	2	--	--	--	--
	3	9	--	--	--	--
9	2	17	--	--	--	--
	3	127	--	1	--	--
10	1	27	--	9	--	--
	2	8	--	2	--	--
	3	51	--	21	--	--
11	1	9	--	2	--	--
	3	220	2	10	--	--
12	1	1	--	--	--	--
16	2	1	--	--	--	--
	3	1	--	--	--	--
17	2	1	--	--	--	--
	3	4	--	--	--	--
18	1	79	--	15	--	11
	2	39	--	7	--	9
	3	137	--	19	--	10
19	1	--	--	--	1	--
20	3	--	--	--	--	1
21	2	--	--	--	--	1
	3	4	--	--	--	--
22	1	--	--	--	--	1
24	1	--	--	--	--	1
	3	--	--	--	--	1

in the physical characteristics or faunal composition of the area will not be easily attributable to any particular action or set of circumstances in or around Everett Harbor.

The sediment size-fraction data suggest that the river's effect of decreasing mean phi size and increasing sand/mud ratios is most pronounced at stations 10-16 and station 19. At station 24, the values for sediment parameters as well as total volatile organic matter begin to more nearly resemble the mean phi sizes, sand/mud ratios, and total organic contents found along the southeastern shore of Port Gardner than those in the rest of the harbor.

The presence of sludge beds, and pulping and mill wastes in large quantities on the bottom, may make the observation of improvement in the bottom environment and its associated fauna difficult. As sludge beds are common in river estuary regions in Puget Sound, reduction of industrial waste loads may have a minimal impact on the bottom fauna in the inner harbor (Wennekens, 1959). At best, one can hope to observe, over a long time, the general trend toward more variety of taxa and more individuals per taxon, as has been reported for other areas (McNulty, 1970; Rosenberg, 1973).

In the present study, the faunal data gathered, with the exception of some of the crustacean data, have been left at a taxonomic level directly comparable to the WSPCC (1967) report. The findings of the present study suggest a general, if slight, improvement both in variety and number of organisms found. Also an overall reduction in the observed total volatile organic content is suggested.

Sampling problems within the Everett Harbor were a major source of variability. The sponginess of the bottom and the resultant sampling problems may be attributable, in part, to the presumably large volumes of interstitial water characteristic of this type of environment (Leppakoski 1968). Penetration of the grab was variable, as was the apparent amount of wood overlying the bottom; the case in point is the observed wood content at station 11, suggesting that the grab may have done little more than scrape the sediment surface. With the presence of wood debris and man-made debris on the harbor bottom, reliable samples will continue to be difficult to obtain with the van Veen grab. An alternative method using a suction dredge proved to be worse in sampling efficiency (Malkoff 1974).

SUMMARY

Everett Harbor was found to be influenced by the discharge of the Snohomish River, and the industrial activities, particularly those related to pulp and paper mill operations, of the adjacent upland sites. Although sampling equipment differed somewhat from the earlier WSPCC work, the data suggest a slight increase in the number of benthic organisms and a reduction of total volatile organic matter in the harbor.

APPENDIX II. The van Veen Grab

TABLE 17. Calculations of van Veen grab volume*

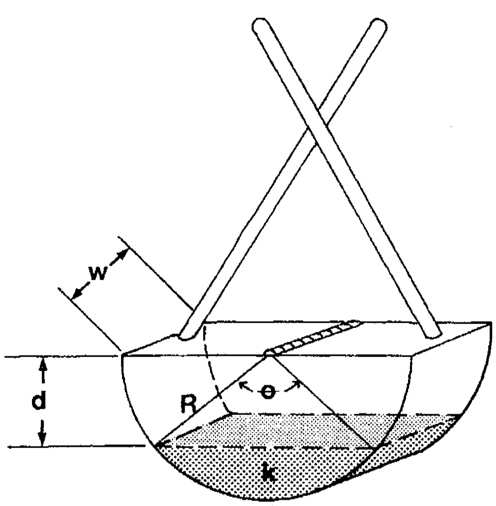
d	Volume	d	Volume	d	Volume
0.0	17.7	7.5	10.1	15.0	3.4
0.5	17.2	8.0	9.5	15.5	3.0
1.0	16.6	8.5	9.1	16.0	2.6
1.5	16.1	9.0	8.5	16.5	2.3
2.0	15.6	9.5	8.1	17.0	2.0
2.5	15.0	10.0	7.6	17.5	1.7
3.0	14.5	10.5	7.2	18.0	1.5
3.5	14.1	11.0	6.7	18.5	1.1
4.0	13.5	11.5	6.3	19.0	0.8
4.5	13.1	12.0	5.8	19.5	0.5
5.0	12.6	12.5	5.5	20.0	0.4
5.5	11.9	13.0	5.0	20.5	0.2
6.0	11.5	13.5	4.5	21.0	0.0
6.5	10.9	14.0	4.3		
7.0	10.5	14.5	3.8		

* Volume = (K)(w), in liters where:

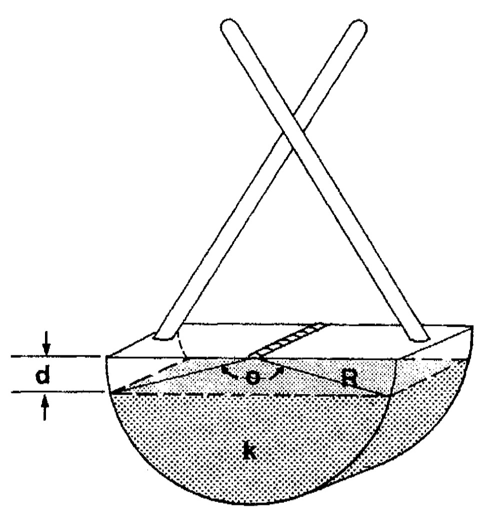
$$K = \text{area of segment } k = \tfrac{1}{2} R^2(\theta - \sin\theta)$$

$$= R^2 \cos^{-1}\frac{d}{R} - d\sqrt{R^2-d^2}$$

d, the variable distance in cm, from the inside edge of the top of the grab to the surface of the contained sediment; w, the width of the grab.



Example 1. Relatively small grab catch



Example 2. Relatively full grab catch

APPENDIX III. Sediment Size Classification

TABLE 18. Wentworth sediment size classes*

Class Name		Limits of Particle Diameter mm	in	microns	Phi (ϕ) Units
BOULDERS	Very Large	4096-2048	160-80		-11
	Large	2048-1024	80-40		-10
	Medium	1024-512	40-20		- 9
	Small	512-256	20-10		- 8
COBLES	Large	256-128	10-5		- 7
	Small	128-64	5-2.5		- 6
GRAVEL	Very Coarse	64-32	2.5-1.25		- 5
	Coarse	32-16	1.25-0.625		- 4
	Medium	16-8	0.625-0.31		- 3
	Fine	8-4	0.31-0.16		- 2
	Very Fine	4-2	0.16-0.08		- 1
SAND	Very Coarse	2.00-1.00		2000-1000	0
	Coarse	1.000-0.500		1000-500	1
	Medium	0.500-0.250		500-250	2
	Fine	0.250-0.125		250-125	3
	Very Fine	0.125-0.062		125-62	4
SILT	Coarse	0.062-0.031		62-31	5
	Medium	0.031-0.016		31-16	6
	Fine	0.016-0.008		16-8	7
	Very Fine	0.008-0.004		8-4	8
CLAY	Coarse	0.004-0.002		4-2	9
	Medium	0.002-0.001		2-1	10
	Fine	0.0010-0.0005		1-0.5	11
	Very Fine	0.0005-0.00024		0.5-0.24	12
COLLOID		< 0.00024		< 0.24	> 12

* Lang, E. W. and others, 1947, Report of the sub-committee on Sediment Terminology, Trans. Am. Geophys. Union, Vol. 28, pp 936-938.

APPENDIX IV

Taxonomic Lists of the Major Faunal Groups

TABLE 19. Polychaete families by transect, station, duplicate and screen number from Port Gardner. Screen 1 = 2 mm and screen 2 = 1 mm mesh.

	1A				1B				1C				2A				2B				2C			
SEDENTARIA	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Orbiniidae										1														
Spionidae																1					8	1		
Cirratulidae																								
Oweniidae			1	1					3			1												
Maldanidae									1															
Scalibregmidae																								
Ampharetidae																								
Terebellidae																								
Opheliidae																						1		
Arenicolidae																								
Capitellidae		98	29	52	87	34	67	12	3	108	5	2				2	24	88	81	136	35	74	12	105
Pectinariidae													2	1										
Sabellariidae																								
Sabellidae																								
Serpulidae																								
Cossuridae																								
ERRANTIA																								
Polynoidae																								
Phyllodocidae																								
Nereidae																								
Nephtyidae						1																		
Glyceridae			1									1	4		1	2					2			
Goniadidae															1									
Onuphidae																								
Lumbrineridae																								
Dorvilleidae																								
Unid.Poly.Sp#1																								
#2																								

TABLE 19. (continued)

	3A				3B				3C				4A				4B				4C			
SEDENTARIA	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Orbiniidae									11								4	5	23		2		1	
Spionidae																			7				1	
Cirratulidae																								
Oweniidae		1		1					2	1		3												
Maldanidae																								
Scalibregmidae																								
Ampharetidae																								
Terebellidae																								
Opheliidae																						1		1
Arenicolidae				1				1																
Capitellidae	2			10	21	10	10	54	50	31	10	31			2	6	11	20	1	1	5	9	30	24
Pectinariidae	3		1	1					1				6	1	3	2	1	1	3	1	1		2	
Sabellariidae																								
Sabellidae																								
Serpulidae																								
Cossuridae																								
ERRANTIA																								
Polynoidae																								
Phyllodocidae																								
Nereidae																								
Nephtyidae	3			4		1				3			1		1	4		5	3	1	2	1	2	2
Glyceridae	4	5	1	1	1	1			6				3	2	2		4	3	10	1	3		16	
Goniadidae				2		1			2	1						1	4		7	1	2	3	3	
Onuphidae																								
Lumbrineridae																								
Dorvilleidae																								
Unid.Poly.Sp#1																							3	
#2																							1	1

TABLE 19. (continued)

	5A				5B				5C				6A				6B				6C			
SEDENTARIA	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Orbiniidae													1				2		4			2	6	
Spionidae				1																				
Cirratulidae	3												1				1			1	1			
Oweniidae	1		4				2			1		2			1				1					
Maldanidae		1	1				3					1			1							1	1	1
Scalibregmidae																								
Ampharetidae			2				1						1			1								
Terebellidae									3										1		6		2	
Opheliidae																2		4				2		
Arenicolidae																								
Capitellidae					3	11		6				1			1			1			4			3
Pectinariidae	1		16												1	1							1	
Sabellariidae																								
Sabellidae																								
Serpulidae																								
Cossuridae																								
ERRANTIA																								
Polynoidae								1		2							2	1			1	1	1	
Phyllodocidae				2	1			6	1	2		2				1		1	2	2	2	3	3	3
Nereidae																								1
Nephtyidae		1															1	2	1			3		
Glyceridae	6	2	6	4	5	2		7	10	9		14	2	3	1	5	8	2	8	3	9	2	10	
Goniadidae								1									1	1	2	1		1	1	1
Onuphidae																								
Lumbrineridae	1			1					1					1										
Dorvilleidae																								
Unid.Poly.Sp#1																								
#2																								

TABLE 19. (continued)

	7A				7B				7C				8A				8B				8C			
SEDENTARIA	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Orbiniidae	1	1	2	6				1			1			2										
Spionidae			2	2	1		1			3	5	7			1		1	1			3	7		
Cirratulidae	1			1						1				2			2	1		3	1	3		1
Oweniidae	4		2	3					2	1	48	20							1		57	24	4	12
Maldanidae	3		2	2	1				4	2	3	3	5		1	1			1	1	14	8		1
Scalibregmidae																								
Ampharetidae	1	1	2	1	3						1		3		2		2				1			
Terebellidae	2				3		2		26	10	2					1					4		9	1
Opheliidae			2						1					1		1								
Arenicolidae																								
Capitellidae		1				1	4	1	1	2	15	2	1						1	1	2	4		1
Pectinariidae	4	1	2										1		2	2	1		1				1	
Sabellariidae																								
Sabellidae	1									1					3	1								
Serpulidae																								
Cossuridae												1												
ERRANTIA																								
Polynoidae						2			2	2	2							1		2	1			
Phyllodocidae		3					3	4	1		3		1	2	1	2	1	4		1	1	4	2	1
Nereidae		1						1								1						1		
Nephtyidae						2		1										1		1	1			
Glyceridae	7	6	2	4	4	4	4	3	5	14	13	8	3	7	4	14	2	5	4	12	13	24	2	7
Goniadidae						1	3	1				5				3		3				1		1
Onuphidae												1				1								
Lumbrineridae	2		1	3					1				2	3		7			2	2				
Dorvilleidae						1																		
Unid.Poly.Sp#1																								
#2																								

TABLE 19. (continued)

	9A				9B				9C				10A				10B				10C			
SEDENTARIA	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Orbiniidae														1										
Spionidae		1	2				1		1		3							1			3		3	
Cirratulidae	2	9	2	8		1		2			2			2			1	2	1				1	
Oweniidae	11	37	71	34	3	6	1	10	62	27	52	8	17	12	1	8	133	5	105	2	77	10	11	6
Maldanidae	7		7		2	1	2	5	1	6	12	1		2	2	8	13	6	49	8	38	3	19	1
Scalibregmidae																	2		2		1	1	1	
Ampharetidae	1	6				1	2						1				4	3	3	1	2	1	2	
Terebellidae			4					1	5		9				22		5		7		2		9	
Opheliidae		1								1			1	2	1	1		2						
Arenicolidae																								
Capitellidae	1	1					3	3	9	5	3	1				1	2		3	2	2	1	2	
Pectinariidae	1	1	1		4	1		3	2		1		2	2	1	2			1		1			
Sabellariidae											4													
Sabellidae	3	49	4	13				1			7						6	1	4	1	2			
Serpulidae											1													
Cossuridae																								
ERRANTIA																								
Polynoidae	1	2		1		1				1	1	5					1	1						
Phyllodocidae		1		1	1	2		3		2	2						5	2	5	1	2	1		2
Nereidae											1	1					2							
Nephtyidae						1		1		1			3				2			1				
Glyceridae		5	3	3	5	7	2	8	5	6	5	5			3		3	4	7	1	10	1	8	3
Goniadidae		2	1	1						5	2	1	1	1	2					1				
Onuphidae																								
Lumbrineridae	2	1				1	1	2		1		1					1	1	2	1	1		2	
Dorvilleidae																								
Unid. Poly.Sp#1																								
#2																								

TABLE 19. (continued)

	11A				11B				11C			
SEDENTARIA	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Orbiniidae		1	1	2								
Spionidae		1	1		1				1	1	1	
Cirratulidae	1	4		10		2	2		1			2
Oweniidae	25	7	18	4	177	97	243	44	156	32	304	82
Maldanidae	2	4	6	25	2	13	19	6	24	16	46	16
Scalibregmidae	2				1		2	2	1	1	3	
Ampharetidae	1	4	1	16	3	13	3	4		1	2	2
Terebellidae					1		2		10	11	14	
Opheliidae			1	1								
Arenicolidae												
Capitellidae						3	3	4	2	4	4	1
Pectinariidae	2	4	2	2			1					
Sabellariidae												
Sabellidae	1	2		3	1	5	3	2	10	1	5	
Serpulidae												
Cossuridae												
ERRANTIA												
Polynoidae	2	1			1				2	2	1	
Phyllodocidae		1				4	6	2		6	1	5
Nereidae					1	1						
Nephtyidae		1										1
Glyceridae		1	1	3	3	3	7	4	3	16	6	4
Goniadidae								1				
Onuphidae												
Lumbrineridae	1		1	1		1	3				1	
Dorvilleidae										1		1
Unid.Poly.Sp#1												
#2												

TABLE 20. Polychaete families taken in intensive sampling at Port Gardner station 9B. Counts are given by replicate and screen number; screen 1 = 2 mm and screen 2 = 1 mm mesh.

	9B		9B		9B		9B		9B		9B		9B		9B	
SEDENTARIA	3-1	3-2	4-1	4-2	5-1	5-2	6-1	6-2	7-1	7-2	8-1	8-2	9-1	9-2	10-1	10-2
Orbiniidae																
Spionidae			2													2
Cirratulidae			2			2				1	1	2	1	2		4
Oweniidae	23	2	35	2	13	2	92		44	3	61	24	25	18	36	14
Maldanidae	7		3	1	2	4	5	1	6	9	17	3	4	6	3	2
Scalibregmidae											1		1			
Ampharetidae		1				2			1	1	1				1	
Terebellidae			7		1		2		2		2			2	3	
Opheliidae						1										
Arenicolidae																
Capitellidae	1	4	4	1	3	1	4	3	6	5	5	4	1	3	5	6
Pectinariidae			1				1			1						1
Sabellariidae																
Sabellidae			1				1	2	3	1	1		1		2	2
Serpulidae																
Cossuridae							1									
ERRANTIA																
Polynoidae	1									1		2		1		
Phyllodocidae		1		2			1	1	2	2		1		4	1	
Nereidae																
Nephtyidae															1	1
Glyceridae		9	13	4	2	11	1	1	7	5	4	2	1	7	4	2
Goniadidae								1	1							
Onuphidae																
Lumbrineridae			2				2				2	1	1	1		1
Dorvilleidae																
Unid.Poly.Sp#1																
#2																

TABLE 21. Molluscan genera by transect, station, duplicate, and screen number from Port Gardner. Screen 1 = 2 mm and screen 2 = 1 mm mesh.

LAMELLI-	1A				1B				1C				2A				2B				2C			
BRANCHIA	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Acila																								
Nucula																								
Nuculana																								
Megacrenella																								
Astarte																								
Cyclocardia																								
Axinopsida																								
Clinocardium																								
Nemocardium																								
Psephidia									1				1	1										
Protothaca																								
Macoma													1		3		3						21	
Solen																								
Hiatella																								
Pandora																								
Unidentified	1			1		6	1		2		4	1		1		3	1	9	5	2	68	27	14	27
GASTROPODA																								
Tachyrynchus																								
Polinices																								
Mitrella																								
Unidentified																								

TABLE 21. (continued)

LAMELLIBRANCHIA	3A 1-1	3A 1-2	3A 2-1	3A 2-2	3B 1-1	3B 1-2	3B 2-1	3B 2-2	3C 1-1	3C 1-2	3C 2-1	3C 2-2	4A 1-1	4A 1-2	4A 2-1	4A 2-2	4B 1-1	4B 1-2	4B 2-1	4B 2-2	4C 1-1	4C 1-2	4C 2-1	4C 2-2
Acila																						1	3	
Nucula																								
Nuculana																								
Megacrenella																								
Astarte																								
Cyclocardia																								
Axinopsida																								
Clinocardium																								
Nemocardium																								
Psephidia	4												5						1					
Protothaca																								
Macoma	5				3		2		55		3		2		4		34		12		21		98	
Solen																								
Hiatella																								
Pandora																								
Unidentified		4		1		1		6	87	29	1	3		8		2	2	12	35	19	35	23	147	11
GASTROPODA																								
Tachyrynchus																								
Polinices																								
Mitrella																								
Unidentified									1															

TABLE 21. (continued)

LAMELLI-BRANCHIA	5A				5B				5C				6A				6B				6C			
	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Acila																								
Nucula	1	29	4	33			1					3		2		1		3		5				5
Nuculana													1											
Megacrenella																								
Astarte																								
Cyclocardia																					1			
Axinopsida																								
Clinocardium																								
Nemocardium																								
Psephidia	68	32	31	48	3	3	29		19	23		44	63	219	79	353	44	36	51	91	22	12	38	46
Protothaca																								
Macoma	2		12		5		24		11		3		2		1				2		10		4	3
Solen														1										
Hiatella																								
Pandora																								
Unidentified		9	5	9		3	22	12	5	46	2	44		6		12	7	9	3	13	3	6	9	20
GASTROPODA																								
Tachyrynchus																								
Polinices																								
Mitrella							1																	
Unidentified																								

TABLE 21. (continued)

LAMELLI-BRANCHIA	7A				7B				.7C				8A				8B				8C			
	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Acila											1										3			
Nucula	1	8			1	1			1	1		1					1	4		3	1			
Nuculana																								
Megacrenella																								
Astarte																								
Cyclocardia									1															
Axinopsida	1	4																	1	1				1
Clinocardium																								
Nemocardium					1																			
Psephidia	128	259	75	305	141	1	125		4		1		95	644	37	412	166	763	71	50	8			8
Protothaca																	1							
Macoma	2	1			6		14		17				4				11	3	10	1	43		33	13
Solen													1											
Hiatella																								
Pandora																								
Unidentified	1	6		4	2	322	8	78	11	30	27	93				1	6	4	3	11	2	114	2	31
GASTROPODA																								
Tachyrynchus																								
Polinices																								
Mitrella					3								1						2					
Unidentified				1																	1			

TABLE 21. (continued)

LAMELLI-BRANCHIA	9A 1-1	9A 1-2	9A 2-1	9A 2-2	9B 1-1	9B 1-2	9B 2-1	9B 2-2	9C 1-1	9C 1-2	9C 2-1	9C 2-2	10A 1-1	10A 1-2	10A 2-1	10A 2-2	10B 1-1	10B 1-2	10B 2-1	10B 2-2	10C 1-1	10C 1-2	10C 2-1	10C 2-2
Acila																								
Nucula				4		2		1						1		2		1		1		1		1
Nuculana																								
Megacrenella														18		4		1						
Astarte													8	1	1									
Cyclocardia											1				1					4				1
Axinopsida	1	6		5	2	10	1	4	3	29	25	14		94		20		70		6	5	27		4
Clinocardium																								
Nemocardium									1															
Psephidia	43	215	40	190	152	497	148	391	187	399	147	216		258	7	58	80	251	57	147	79	205		72
Protothaca																								
Macoma			1		4	2	4	2	65	51	120	84			1	5	1	6	1	4	30	40	8	3
Solen																								
Hiatella							1				52						10							
Pandora	1																							
Unidentified		1			1	4	4	8	15	83	9	96		6	29	36	4	140	8	130	10	200		400
GASTROPODA																								
Tachyrynchus																								
Polinices															1						1			
Mitrella	2										1				3		2				1			
Unidentified	1													6		4								

TABLE 21. (continued)

LAMELLI-BRANCHIA	11A 1-1	11A 1-2	11A 2-1	11A 2-2	11B 1-1	11B 1-2	11B 2-1	11B 2-2	11C 1-1	11C 1-2	11C 2-1	11C 2-2
Acila												
Nucula	1											
Nuculana												
Megacrenella												
Astarte												
Cyclocardia										1	1	
Axinopsida				2								
Clinocardium						2	3				1	
Nemocardium									1		1	
Psephidia	8	41	9	87	52	181	56	11			70	28
Protothaca												
Macoma	3	2			11	11	11		8		52	
Solen												
Hiatella												
Pandora			1									
Unidentified	2	5		1	3	53	4	217		100	4	172
GASTROPODA												
Tachyrynchus	1		7									
Polinices												
Mitrella	2		3			2	1				4	1
Unidentified		6		2								

TABLE 22. Molluscan genera taken in intensive sampling at Port Gardner station 9B. Counts are given by replicate and screen number; screen 1 = 2 mm and screen 2 = 1 mm mesh.

LAMELLI-	9B		9B		9B		9B		9B		9B		9B		9B	
BRANCHIA	3-1	3-2	4-1	4-2	5-1	5-2	6-1	6-2	7-1	7-2	8-1	8-2	9-1	9-2	10-1	10-2
Acila																
Nucula		2		3		2		5	1	3		9		2		1
Nuculana																
Megacrenella																
Astarte																
Cyclocardia												1				
Axinopsida		7	1	8	1	7	3	6		4		4				3
Clinocardium																
Nemocardium													1		1	
Psephidia	147	401	165	316	145	510	140	149	140	442	74	671	186	380	81	217
Protothaca																
Macoma	4		5	3	6	7	8	2	7	2	10	7	4	8	8	6
Solen																
Hiatella															1	
Pandora																
Unidentified		5		124	2		18	141		8		16		10	5	25
GASTROPODA																
Tachyrynchus																
Polinices																
Mitrella			2						4		2		1		1	
Unidentified			1													1

TABLE 23. Crustacean taxa by transect, station, duplicate, and screen number from Port Gardner. Screen 1 = 2 mm and screen 2 = 1 mm mesh.

	1A				1B				1C				2A				2B				2C			
	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Ostracoda		4		6										26		6				3				1
Leptostraca									1													1		1
Mysidacea																								
Cumacea														2		4								1
Tanaidacea																								
Isopoda																								
Gammaridea		1								16				25		27				1	4	219		128
Caprellidea																								
Euphausiacea			1																	1	1			
Brachyura																								
Anomura																								
Macrura																								
Misc. larvae													1											
Cirripedia																								
Copepoda										2														

TABLE 23. (continued)

	3A				3B				3C				4A				4B				4C			
	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Ostracoda		66		13		18		2				1		1		144		31		44				
Leptostraca									2					7					1	1	1	2	3	4
Mysidacea																								
Cumacea		7		8										10		17				1		18		6
Tanaidacea																					2	5	2	2
Isopoda																			1	1				
Gammaridea		14		23		9			8	159		32		33		56	1	22		20	3	196	24	92
Caprellidea									1															
Euphausiacea																		1	5	1		3		
Brachyura							1		1		7		1				1	1	1	1			1	
Anomura																						1		
Macrura																								
Misc. Larvae				1									1											
Cirripedia													15											
Copepoda																								

TABLE 23. (continued)

	5A				5B				5C				6A				6B				6C			
	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Ostracoda		76	2	236		20				16		12		325		262		108	2	175				34
Leptostraca			11	55																		2		
Mysidacea																								
Cumacea		2	4	25		2	1			1		1				2		1		2	2	3	1	10
Tanaidacea								4													1	1	2	9
Isopoda						1																		3
Gammaridea		15	3	58		25	5	40		29		9		7		3		14	1	21		25	1	50
Caprellidea																								
Euphausiacea					1												5		9					
Brachyura			1	2			2								1		2				4		2	2
Anomura								2																
Macrura																								
Misc. Larvae													1		1									
Cirripedia																								
Copepoda																								

TABLE 23. (continued)

	7A				7B				7C				8A				8B				8C			
	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Ostracoda		191		159	1	231		1		17	1	58		456		378		275		41		62		5
Leptostraca																								
Mysidacea																								
Cumacea	2	2		1					1	3	2	3		2		2		1		1	2	17	2	
Tanaidacea												4												
Isopoda																								
Gammaridea		4		2	2	22		13		7		29	2	10		7		15		10	3	26		12
Caprellidea																								
Euphausiacea					1													1		1				
Brachyura					1		1	2	1		1			1		1	1				2	1	1	
Anomura																								
Macrura					1				1							1								
Misc. larvae																								
Cirripedia																								
Copepoda																					1			

TABLE 23. (continued)

	9A				9B				9C				10A				10B				10C			
	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Ostracoda		287		254		84	1	105		29		27		98		100		66	1	102		19		29
Leptostraca				1										2										
Mysidacea												1												
Cumacea		1		2		1	1	1		10		8		1				1	3	9		3		6
Tanaidacea		1															1	1	1	2				
Isopoda																								
Gammaridea	1	11		3		12		12	2	25	2	24		9				15		20		1		4
Caprellidea											3	9												
Euphausiacea							2			2														
Brachyura															1	1								
Anomura																								
Macrura											1													
Misc. Larvae			1																					
Cirripedia																								
Copepoda												1												

TABLE 23. (continued)

	11A				11B				11C			
	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2	1-1	1-2	2-1	2-2
Ostracoda		133		152		61		66		10		30
Leptostraca		1										
Mysidacea				1		1						
Cumacea		2		1	1	16	2	18		8	2	15
Tanaidacea				1			1					1
Isopoda												
Gammaridea	1	10	1	9		14	1	9		10	1	11
Caprellidea		1				4	1		1	3	2	2
Euphausiacea												
Brachyura	1					1	2				1	
Anomura												
Macrura											1	
Misc. larvae												
Cirripedia												
Copepoda						1						

TABLE 24. Crustacean taxa taken in intensive sampling at Port Gardner station 9B. Counts are given by replicate and screen number; screen 1 = 2 mm and screen 2 = 1 mm mesh.

	9B		9B		9B		9B		9B		9B		9B		9B	
	3-1	3-2	4-1	4-2	5-1	5-2	6-1	6-2	7-1	7-2	8-1	8-2	9-1	9-2	10-1	10-2
Ostracoda		81		74		86		71		85		61		83		58
Leptostraca																
Mysidacea						2										
Cumacea		1	1	3		3		7				4		3		3
Tanaidacea				1	2			4				1		1		1
Isopoda																
Gammaridea	1	9	1	19		15		14		12		12		9	1	4
Caprellidea		1		2		2		1				3				
Euphausiacea			2		3	1		1		1			4	2		
Brachyura											1	1				
Anomura																
Macrura																
Misc. larvae																
Cirripedia																
Copepoda						1				2				1		

APPENDIX V

Spearman Rank Correlations

Table 25. Spearman rank correlation coefficient computations. Formulae from Spiegel (1957).

Test	N	Significance	α
Polychaete taxa vs. distance †	11	Yes	0.01
Lamellibranch taxa vs. distance	11	Yes	0.01
Crustacean taxa vs. distance	11	No	----
Minor taxa vs. distance	11	Yes	0.01
Total taxa (all depths) vs. distance	11	Yes	0.01
Total taxa (30 m) vs. distance	11	Yes	0.01
Total taxa (60 m) vs. distance	11	Yes	0.01
Total taxa (90 m) vs. distance	11	Yes	0.01
Number individual Polychaetes vs. distance	11	No	----
Number individual Lamellibranchs vs. distance	11	Yes	0.01
Number individual Crustaceans vs. distance	11	No	----
Total number individuals vs. distance	11	Yes	0.01
Total individuals (30 m) vs. distance	11	Yes	0.05
Total individuals (60 m) vs. distance	11	Yes	0.01
Total individuals (90 m) vs. distance	11	Yes	0.05
Number Polychaete taxa vs. number Lamellibranch taxa	11	Yes	0.01
Number Polychaete individuals vs. number Lamellibranch individuals	11	No	----

† The relationship between number of taxa or number of individuals vs. distance corresponds to an inverse relationship to SWL; the correlation coefficients are the same absolute values but of opposite sign.

Table 25. (continued)

Test	N	Significance	α
Mean phi size vs. organic content	33	Yes	0.01
Sand/mud ratio vs. organic content	33	Yes	0.01
Organic content vs. distance	11	No	----

SECTION IX

Distribution and Abundance of Benthic Macrofauna Adjacent to a Sulfite Pulp Mill Discharge Pipeline in Port Gardner, Washington 1973 and 1974

DISTRIBUTION AND ABUNDANCE OF BENTHIC MACROFAUNA ADJACENT TO A SULFITE PULP MILL DISCHARGE PIPELINE IN PORT GARDNER, WASHINGTON

1974 and 1975

by

Dale S. Kisker

University of Washington

1976

This work was conducted under
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INTRODUCTION

Port Gardner is a portion of the Whidbey Island Basin bounded on the west by Possession Sound and on the northeast by Port Susan. At the southeastern corner of Port Gardner is Everett Harbor, a semi-enclosed basin ranging in depth from 3-68 m. Several industries are located on the harbor including Scott and Weyerhaeuser pulp mills. Since 1951, industrial wastes from both sulfite pulp mills have been combined and discharged into Port Gardner in 90 to 100 m of water through a series of nozzles located along the terminal 1,011 feet of a 3,011-foot diffuser pipeline.

The effects of waste water discharge from the pulp mills on the benthic fauna was studied first in 1962 as part of the Washington State Enforcement Project, a joint program by the Washington State Pollution Control Commission and the Federal Water Pollution Control Administration (U.S. Department of Interior and Washington State 1967). In 1973 additional investigations were undertaken. These included surveys north and south of the pipeline by the Environmental Protection Agency (Malkoff 1974a, unpublished), a group of students from the University of Washington (student report, 1974), and south of the pipeline by Malkoff (1974b).

The present investigation is an outgrowth of the Malkoff survey and is designed to provide a biological baseline for the area of Port Gardner adjacent to the diffuser pipeline. The objective of this study is to assess the effects, if any, on benthic macrofauna of the reduction in effluent discharge through the diffuser pipeline from the pulp mills. To achieve this objective a sampling program has been established to characterize the distribution, abundance, and species composition of the benthos over space and time. The purpose of the present report is to: 1) describe the sampling program, 2) evaluate methods, 3) and describe the distribution, abundance, and species composition of the benthic macrofauna collected in the first 11 months of sampling.

MATERIALS AND METHODS

Stations Sampled. Between August 1974 and July 1975, benthic infauna was collected at 39 stations located within 1.4 nautical miles of the diffuser pipeline (Fig. 1, Table 1). ECOBAM hydrographic stations, 7, 8, and 20 were sampled for benthos twice monthly, when possible, and are referred to as the time series stations (Table 2). Stations 7 and 20, sampled at water depths of 100 and 133 m (MLLW) were located with the ship's radar and fathometer, while station 8 (100 m MLLW) was located with the fathometer and sightings on the pipeline range markers. When necessary the ship was repositioned between replicate samples to obtain the desired depth and location.

Six transects (A, B, ... F) each containing six stations (1, 2, ... 6) were sampled 8-11 October 1974 and are referred to as the intensive series stations. Transects A, B, C, D, E, and F are located approximately 0.2, 0.5, 0.7, 0.9, 1.1, and 1.4 nautical miles from the discharge and stations 1, 2, 3, 4, 5 and 6 on each transect are located along the transects at depths of 15, 30, 45, 60, 75 and 90 m (MLLW). One sample was taken at all stations along a transect prior to taking the next, replicate, sample. Stations were located with the ship's radar and fathometer. Range markers

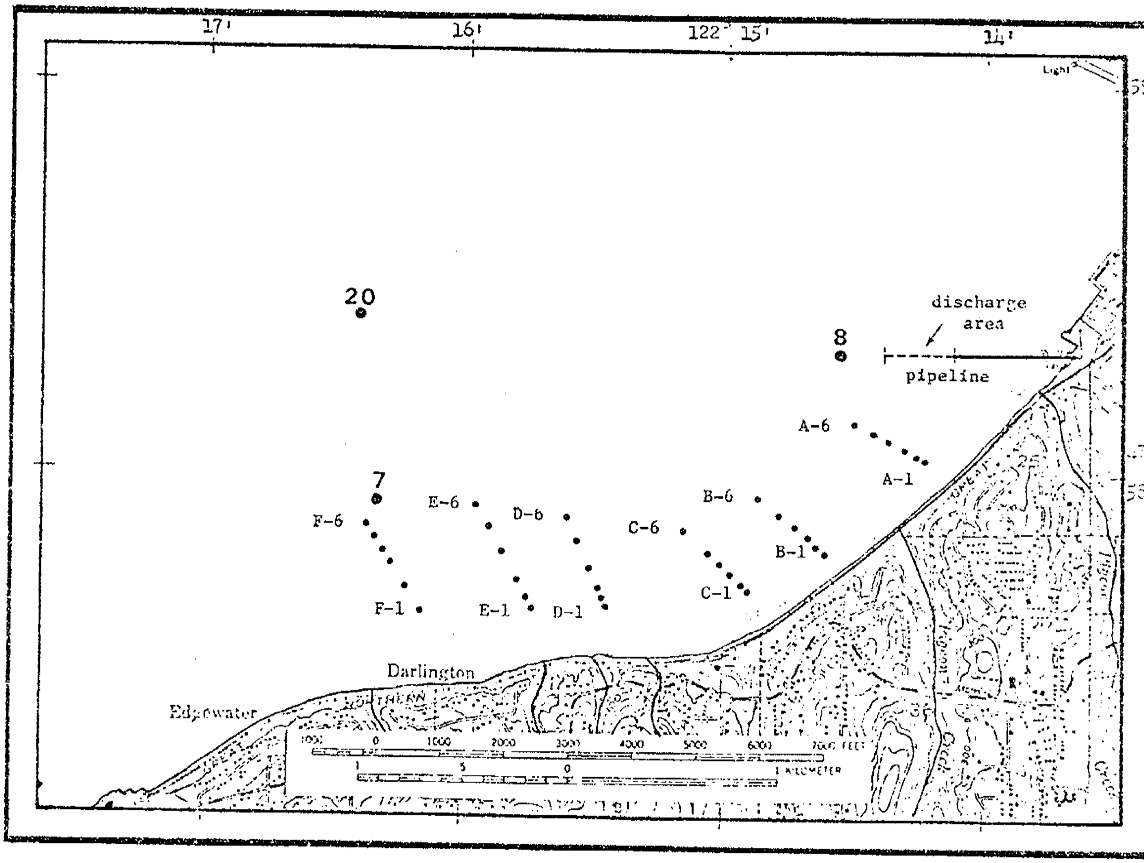

Fig. 1. Benthos station location.

Table 1. Station locations and distance from discharge

Transect Station	Depth[1]	Distance from Discharge[2] Nautical Miles	Meters	Yards	Location Latitude (N)	Longitude (W)
7	100	1.35	2,500	2,734	47° 57.9'	122° 16.3'
8	100	0.11	200	219	47° 58.3'	122° 14.6'
20	133	1.35	2,500	2,734	47° 58.4'	122° 16.4'
A-1	15	0.28	510	558	47° 58.0'	122° 14.2'
A-2	30	0.26	490	536	47° 58.0'	122° 14.3'
A-3	45	0.25	470	514	47° 58.1'	122° 14.3'
A-4	60	0.23	425	465	47° 58.1'	122° 14.4'
A-5	75	0.22	400	437	47° 58.1'	122° 14.4'
A-6	90	0.20	365	399	47° 58.1'	122° 14.5'
B-1	15	0.54	995	1,088	47° 57.8'	122° 14.6'
B-2	30	0.53	990	1,083	47° 57.8'	122° 14.6'
B-3	45	0.52	965	1,055	47° 57.8'	122° 14.7'
B-4	60	0.51	940	1,028	47° 57.9'	122° 14.7'
B-5	75	0.50	930	1,017	47° 57.9'	122° 14.8'
B-6	90	0.50	930	1.017	47° 57.9'	122° 14.9'
C-1	15	0.70	1,305	1,427	47° 57.7'	122° 14.9'
C-2	30	0.70	1,295	1,416	47° 57.7'	122° 14.9'
C-3	45	0.70	1,295	1,416	47° 57.7'	122° 15.0'
C-4	60	0.69	1,280	1,400	47° 57.8'	122° 15.0'
C-5	75	0.69	1,280	1,400	47° 57.8'	122° 15.1'
C-6	90	0.69	1,280	1,400	47° 57.9'	122° 15.2'
D-1	15	0.97	1,790	1,958	47° 57.7'	122° 15.5'
D-2	30	0.96	1,780	1,947	47° 57.7'	122° 15.5'
D-3	45	0.96	1,770	1,936	47° 57.7'	122° 15.5'
D-4	60	0.94	1,740	1,903	47° 57.8'	122° 15.5'
D-5	75	0.92	1,710	1,870	47° 57.8'	122° 15.6'
D-6	90	0.92	1,710	1,870	47° 57.9'	122° 15.6'
E-1	15	1.13	2,095	2,291	47° 57.7'	122° 15.7'
E-2	30	1.12	2,085	2,280	47° 57.7'	122° 15.8'
E-3	45	1.12	2,075	2,269	47° 57.7'	122° 15.8'
E-4	60	1.12	2,080	2,275	47° 57.8'	122° 15.8'
E-5	75	1.12	2,085	2,280	47° 57.9'	122° 15.9'
E-6	90	1.13	2,090	2,285	47° 57.9'	122° 15.9'
F-1	15	1.37	2,535	2,772	47° 57.6'	122° 16.2'
F-2	30	1.37	2,540	2,778	47° 57.7'	122° 16.2'
F-3	45	1.38	2,565	2,805	47° 57.8'	122° 16.3'
F-4	60	1.39	2,575	2,816	47° 57.8'	122° 16.3'
F-5	75	1.39	2,580	2,821	47° 57.8'	122° 16.3'
F-6	90	1.41	2,605	2,849	47° 57.9'	122° 16.4'

[1] Desired depth in meters (MLLW)

[2] Measured as the shortest straight line distance between the station and the area of discharge. Navigational error in locating stations is approximately ± 0.05 nautical mile.

Table 2. Benthic samples collected and processed August 1974 - June 1975

Date		Replicates per station	Replicate area (m^2)	Major taxa counted	Clams identified
Time Series: Stations 7, 8, 20 (total of 3 stations)					
Aug 22	1974	2	0.10	X[1]	X
Sep 10		1	0.20	X	X
Sep 17		1	0.20		
Oct 4		2	0.10	X	X
Oct 16		2	0.10	X	X
Nov 12		2	0.10	X	X
Dec 3		2	0.10	X	X
Jan 31	1975	2	0.10	X	X
Feb 18-19		2	0.10	X	X
Mar 3		2	0.10	X	X
Mar 31		2	0.10	X	X
Apr 16		2	0.10	X	X
May 1		2	0.10	X	X
May 15		2	0.10	X	X
May 27		2	0.10	X	X
Jun 11		2	0.10	X	X
Intensive Series: Stations 1-6 on transects A-F (total of 36 stations)					
Oct 8-11	1974	2	0.03	X	X
		2	0.10		

[1] X indicates those samples which have been processed.

indicating transect locations have been placed on the beach to aid in locating stations in succeeding years.

Sampling Technique. At time series 7, 8 and 20, two replicate 0.1 m^2 van Veen grab (van Veen 1933; Thorson 1957) samples were taken for biological and sediment analyses on each sampling date except September 10 and 17 when one 0.2 m^2 van Veen grab sample was taken. For percent volatile solids and particle-size analyses of sediments, a subsample from each grab sample was taken by inserting a 46-mm diameter polyethylene tube to a depth of 5 cm in the sediment through a door on top of the grab. The remaining grab contents were sieved through a set of two nested stainless steel screens of 2-mm and 1-mm mesh and the retained material on each screen was bottled separately. Samples were fixed by adding formaldehyde saturated with sodium borate ($Na_2B_4O_7 \cdot 10H_2O$) at a 1:9 ratio of 40% formaldehyde with seawater. Samples occupied up to three fourths of the bottle volume.

At the intensive series stations, two replicate 0.03 m^2 and 0.1 m^2 van Veen grab samples were taken for biological and sediment analyses. One additional 0.1 m^2 van Veen grab sample was taken at each station for percent volatile solids analysis by the Environmental Protection Agency. The method for sampling the sediments from the van Veen grab was the same as described for the time series samples; however, due to the smaller door on the 0.03 m^2 grab a 30 mm diameter coring tube was used. The grab contents were sieved through a 1-mm mesh stainless steel screen and the retained material was bottled and preserved as described above.

The volume of sediment in each grab sample was estimated in the field. Since it has been shown that the highest abundance of benthic macrofauna is found in the upper 4-5 cm (Sanders 1960, Jones 1961, Lie and Pamatmat 1965), only those samples which had sediment volumes great enough to indicate a penetration of at least 4 cm were saved for biological and sediment analyses.

Laboratory Procedures. The sediment samples were homogenized and subsampled for granulometric and percent volatile solids analyses. The granulometric subsamples were subjected to routine particle-size analyses as described by Krumbein and Pettijohn (1938). Percentage by weight for every full phi-size of the gravel and sand fractions was determined by dry sieving. For three of the August samples taken at stations 7, 8 and 20, silt and clay fractions were divided into eight full phi-size classes by pipetting. For all the other granulometric subsamples, the percentage by weight of the silt-plus-clay fractions was determined by wet sieving through a 4-phi screen, evaporating the fluid from an aliquot, and weighing the residue. The weights of the various size classes were subjected to statistical analyses and for those samples not subjected to complete pipette analysis the percentages of silt-and-clay fractions were estimated (Creager, McManus, and Collias 1962). Particles greater than 2.0 mm are considered gravel, 0.062-2.0 mm sand, 0.004-0.062 mm silt, and less than 0.004 mm clay. The volatile solids subsamples were analyzed as described in U.S. Department of Interior, Great Lakes Region (1969). All sediment samples were stored wet, in capped bottles, and at room temperature until analysis. The set of intensive series samples taken for the E.P.A. was analyzed for percent volatile solids in October 1974. Granulometric and percent volatile solids analyses on all other samples were done during the period January through May 1975.

The biological samples were stored in the laboratory for a period of up to 6 months. Periodically during their storage the pH was checked and additional sodium borate was added if the pH fell below 7. To avoid the acidic effects of formaldehyde, samples taken after May were fixed in the field with formaldehyde as described above, and upon return to the lab, the formaldehyde was replaced with 70% ethyl alcohol buffered with sodium acetate $NaC_2H_3O_2$ (50 g $NaC_2H_3O_2$ per 1,000 ml 70% ethyl alcohol). Sorting of samples consisted of placing small portions of the sample in white photographic trays with freshwater, picking specimens out with forceps, and separating them into Crustacea, Polychaeta, Echinodermata, Mollusca, and miscellaneous groups. Counts were recorded for the major taxa, and for the dominant groups within the crustaceans and molluscs. Pelecypods (clams) were identified to species, enumerated, and length measurements were made on the numerically dominant species. Taxonomic publications used in species identification include Coan (1971), Dunnill and Coan (1968), Habe and Ito (1965), Keen (1954), Keen and Coan (1971), MacNeil (1965), Oldroyd (1924), and Quayle (1960).

RESULTS

Data Omissions. Prior to the change in preservation methods, the pH of the preservative in the September 17 samples from stations 7, 8, and 20, and the 0.1 m^2 van Veen intensive series samples fell below neutrality resulting in dissolution of calcareous parts in molluscs, crustaceans and echinoderms. Since their absence prevents species identification in many groups, these samples were not sorted, and will be discarded.

Data from October 16 samples at stations 7, 8, and 20 are not presented due to a sorting error which resulted in erroneous counts.

Screen Efficiency. The screen mesh size most frequently used in subtidal benthic macrofaunal surveys in Puget Sound is 1 mm. A substantial amount of time can be saved if a larger mesh is used, provided the retained fauna reflects the macrofauna present. The nested two-screen method of treating samples was designed to test the ability of the 2-mm screen to retain an adequate sample.

The amount retained on the 2-mm screen varies with station and time among and within taxonomic groups (Figs. 2-4). Time, in weeks, is plotted on the X-axis, and abundance per 0.2 m^2 along the Y-axis. Week 1, 12, 24, and 36 are in August, November, January, and April. The dashed line is the number retained in the 1-mm screen, the light solid line the 2-mm screen, and the heavy solid line the total number retained (1-mm + 2-mm screens). Averaged over stations and dates, the percent, of the total abundance, of crustaceans retained on the 2-mm screen was 7, of polychaetes 34, of echinoderms 48, and of pelecypods 49. Variation with time and station is also apparent at the species level as is demonstrated by *Macoma carlottensis* Whiteaves and *Psephidia lordi* (Baird) (Figs. 3, 4; Table 3).

Time Series Stations

Substrate. The silt and clay fractions of the 1974 samples were determined by pipette analyses of 8 full phi-size classes > 4-phi, whereas the 1975 silt and clay fractions were estimates based on a single pipette analysis of the > 4-phi-size classes. The consistently lower clay values

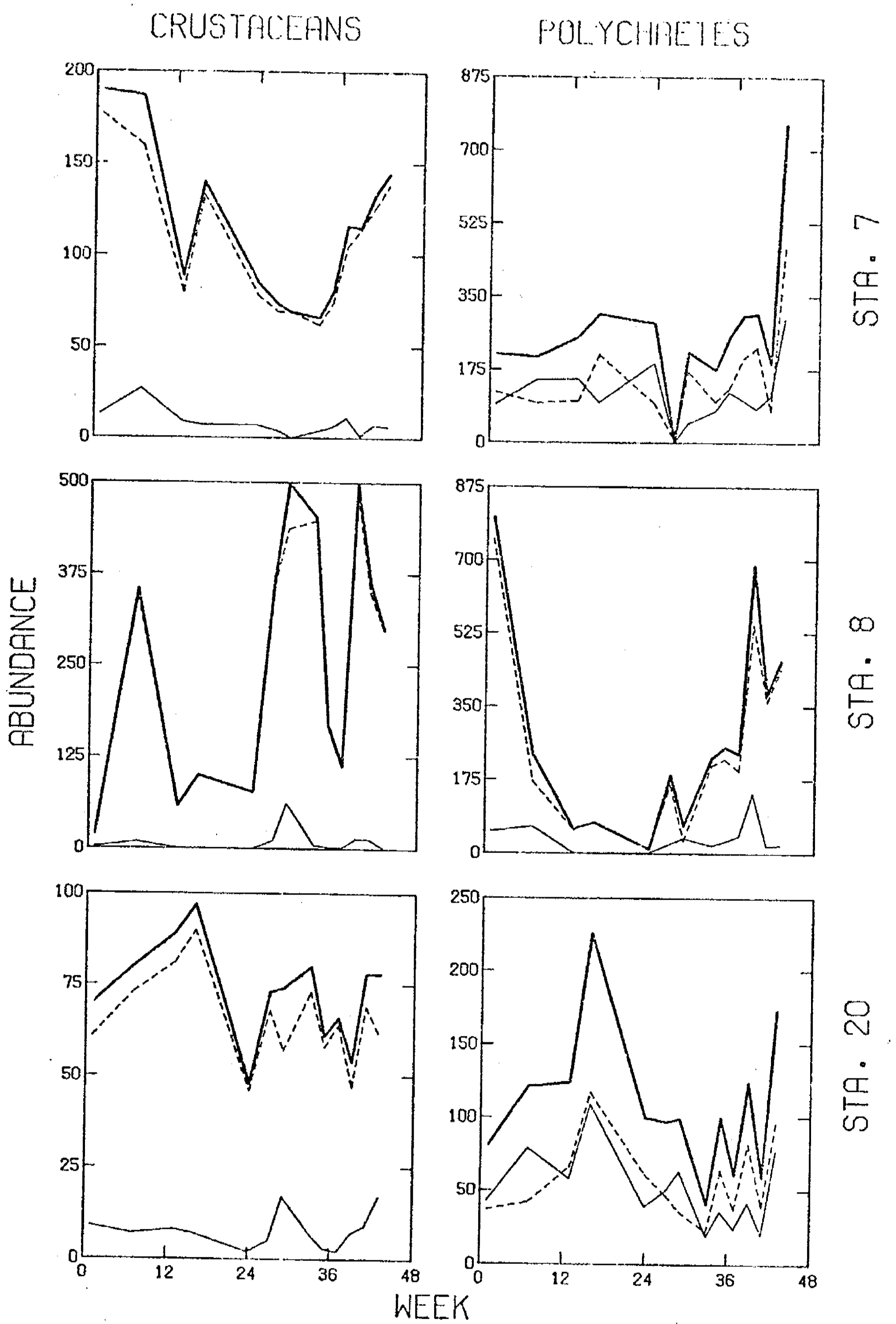

Fig. 2. The abundance of crustaceans and polychaetes per 0.2 m^2 at stations 7, 8, and 20 plotted against time. The solid heavy line is the sum of the organisms retained on 1-mm and 2 mm-screens. The dashed line is the number retained on the 1 mm-screen, and the solid light line the number retained on the 2-mm screen.

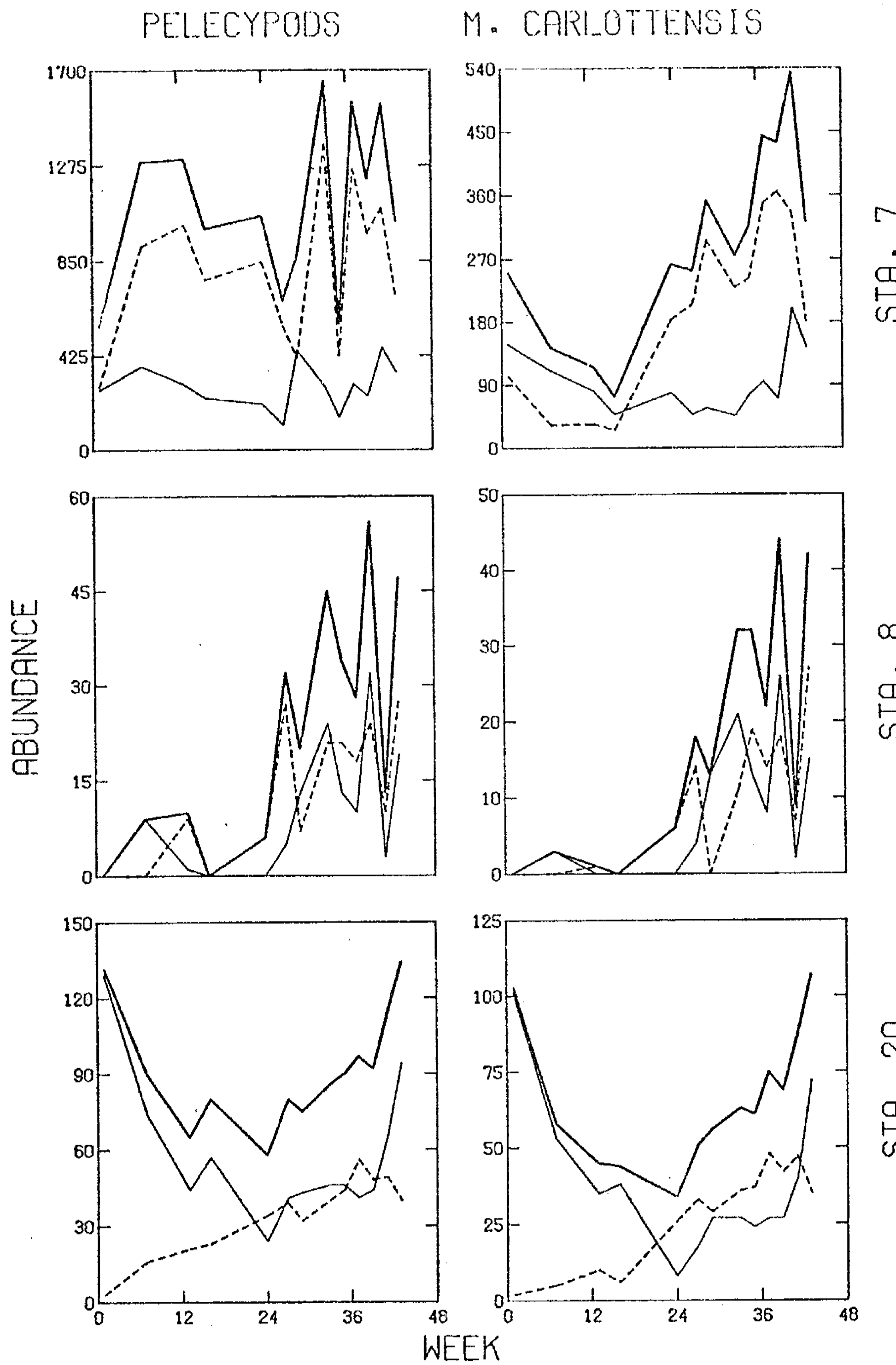

Fig. 3. The abundance of pelecypods and the clam *Macòma carlottensis* per 0.2 m^2 at station 7, 8 and 20 plotted against time. The solid heavy line is the sum of the organisms retained on 1-mm and 2-mm screens. The dashed line is the number retained on the 1-mm screen, and the solid light line the number retained on the 2-mm screen.

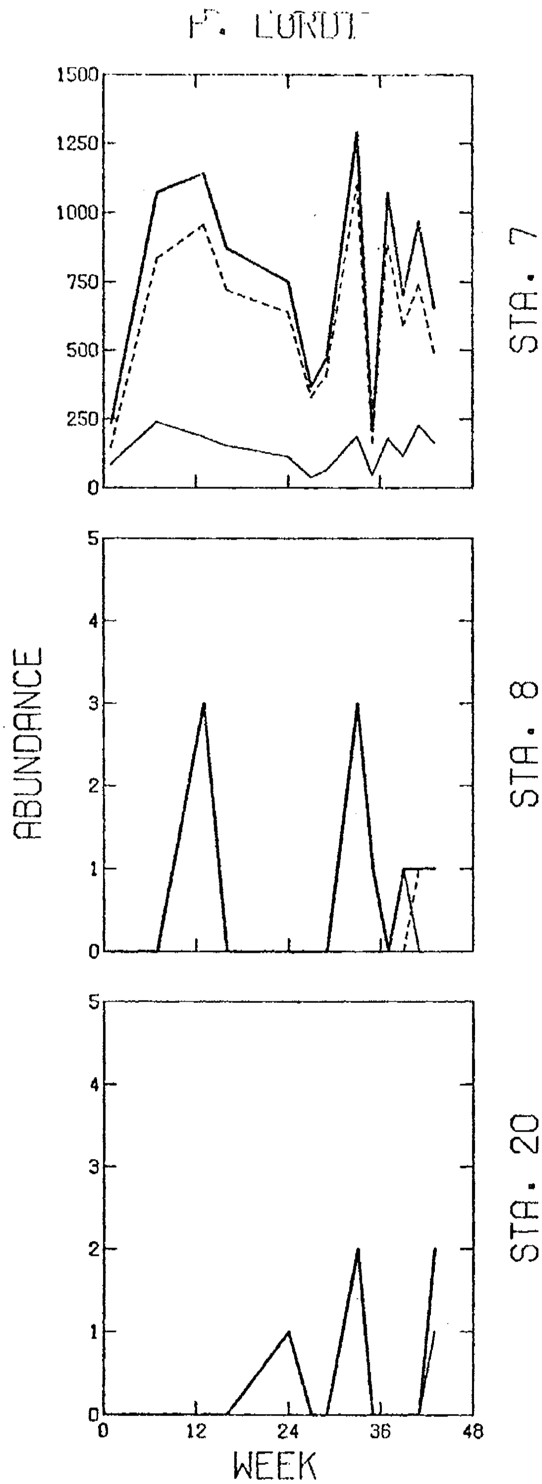

Fig. 4. The abundance of the clam *Psephidia lordi* per 0.2 m^2 at stations 7, 8, and 20 at stations 7, 8, and 20 plotted against time. The solid heavy line is the sum of the organisms retained on 1-mm and 2-mm screens. The dashed line is the number retained on the 1-mm screen, and the solid light line the number retained on the 2-mm screen.

Table 3. The percent of organisms retained on the 2-mm screen, at stations 7, 8, and 20, averaged over sampling dates

	Sta 7	Sta 8	Sta 20
Total Crustaceans	7	4	10
Ostracods	2	0	0
Tanaids	35	10	
Gammarids	7	3	11
Cumaceans	7	0	4
Brachyurans	100	100	67
Total Polychaetes	43	12	47
Total Echinoderms	40	50	54
Ophiuroids	38	50	44
Holothurians	50		100
Total Pepecypods	40	43	63
Psephidia lordi	18	10	60
Macoma carlottensis	32	47	58

in the 1975 samples suggests an error in the estimates (Table 4). However, a meaningful comparison between stations can be based on percentages of sand and the total percentages of silt-plus-clay. Station 7, characterized by a high percent of sand and a low percent of silt-plus-clay, appears quite different from either station 8 or 20, which have low percentages of sand and high percentages of silt-plus-clay. The similarity between stations 8 and 20 is not reflected in the percent volatile solids (Table 4). Station 20, at 6%, is intermediate between a low of 4% at station 7, and a high of 8% at station 8. Additionally, anoxic, black, H_2S sediments characteristic of station 8 are not found at stations 7 and 20.

Macrofauna. Twenty major taxa and 21 pelecypod species were identified and enumerated (Appendix I). Differences between stations is assessed by comparing the abundances of groups on sampling dates (Figs. 5-11). Time, in weeks, is plotted along the X-axis, as in figures 2-4, and abundance per 0.1 m^2 along the Y-axis. A vertical line joins the abundance of the two replicate samples on each sampling date and solid circles appear when the abundance of the two replicate was identical. Data from the September 10 samples are not included, since only one sample was taken.

Ostracoda and Tanaidacea (Fig. 5). Ostracods are most numerous at station 7 and approximately equal in abundance at stations 8 and 20. A seasonal trend in abundance is evident at 7, but not at stations 8 or 20. Tanaids are absent entirely from station 20, present at station 8 on one sampling date only, and regularly present in low abundance at station 7.

Table 4. Sample date, depth (meters), sediment particle size and percent volatile solids as percent weight of sediment

Station-Sample	Date	Depth	Gravel	Sand	Silt	Clay	Volatile Solids
7-1	22 Aug 75	109	6.46	57.90	24.32	11.32	
7-1	19 Aug 75	103	1.19	69.34	29.47	0.00	4.5
7-2	19 Aug 75	103	9.14	66.09	24.58	0.19	3.2
8-1	22 Aug 74	100	0.00	20.32	59.79	19.89	
8-1	19 Aug 75	102	0.40	42.73	54.91	1.96	7.9
8-2	19 Aug 75	102	0.00	31.26	67.43	1.31	8.0
20-1	22 Aug 74	121	0.00	25.71	52.85	21.44	
20-1	31 Mar 75	131	0.13	29.64	62.37	7.85	6.3
20-2	31 Mar 75	131	0.00	31.82	62.81	5.37	5.7
20-1	19 Aug 75	134	0.00	29.17	64.68	6.15	6.0
20-2	19 Aug 75	134	0.00	22.95	70.62	6.43	6.2

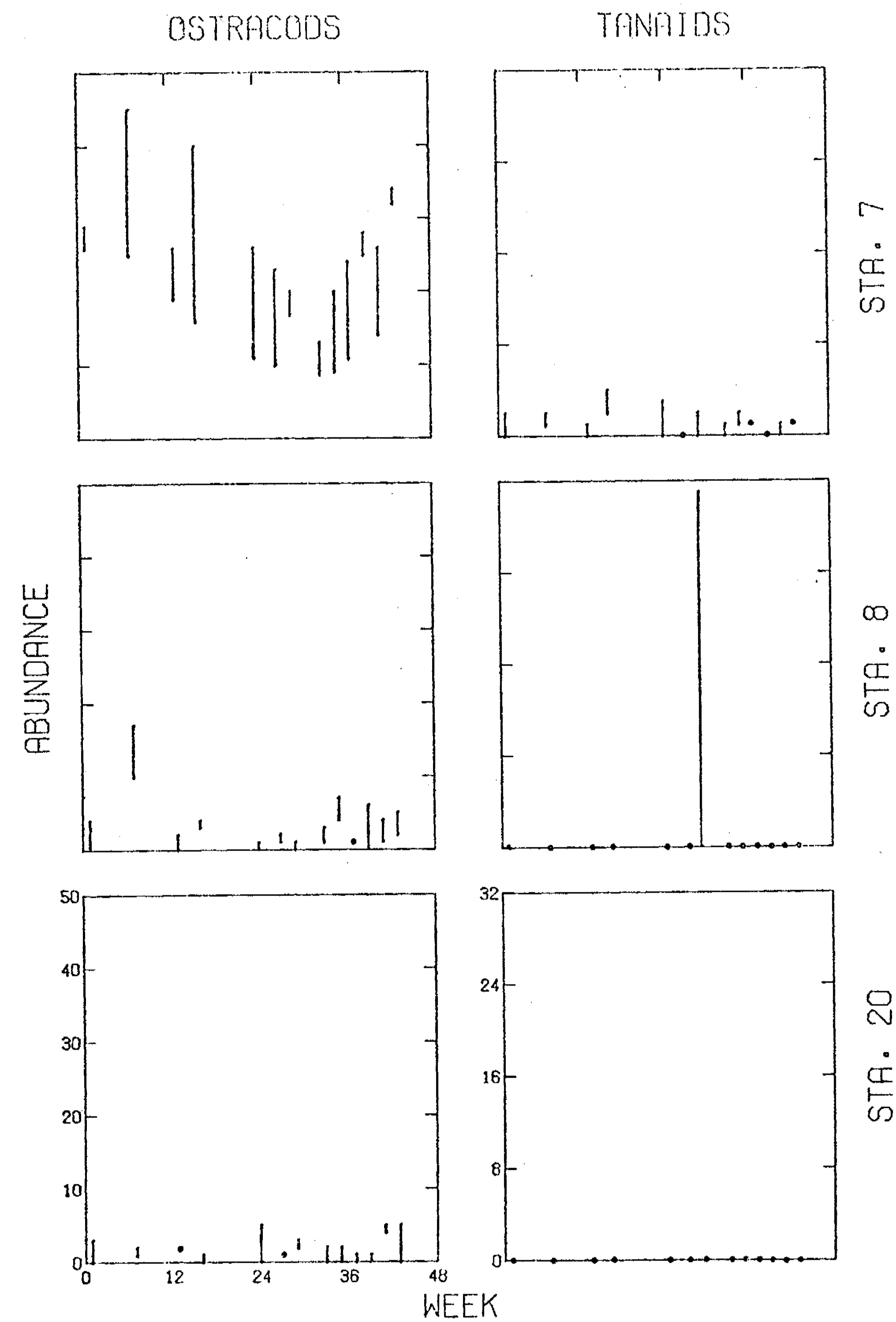

Fig. 5. The abundance of ostracods and tanaids per 0.1 m^2 at stations 7, 8 and 20 plotted against time. Vertical lines connect the abundance of the two replicate samples on each sampling date.

Cumacea and Brachyura (Fig. 6). Cumaceans are most numerous at station 7, less at station 20, and least at station 8. No distinct seasonal pattern in abundance is apparent, although their abundance appears to be somewhat higher at the beginning of the sampling period. Brachyurans (crabs) are not numerous at any station.

Gammarid Amphipoda and Polychaeta (Fig. 7). Gammarids are most numerous at station 8 and approximately equal in abundance at stations 7 and 20. There appears to be higher variability at station 8; however, this may be the result of using the same abundance scale for all stations. Polychaetes (bristle worms) are approximately equal in abundance at stations 7 and 8, and less numerous at station 20. The seasonal cycle in abundance evident at station 8 but not at stations 7 or 20, suggests that the polychaet population at station 8 consists of a small number of species. Gross examination of these indicates that the population is composed entirely of one or a few species of the *Capitella capitata* group (Grassle and Grassle 1976); whereas at stations 7 and 20, large numbers of non-*Capitella* species are present.

Ophiuroids and holothurians (Fig. 8). Both the ophiuroids (brittle stars) and holothurians (sea cucumbers) are most numerous at station 20, and rare or absent (sea cucumbers) at station 8.

Pelecypoda (Fig. 9). The clams are most numerous at station 7, and least at station 8. A seasonal trend in abundance is evident at station 20, but not at stations 7 or 8.

Psephidia lordi and *Macoma carlottensis* (Fig. 10). *Psephidia lordi* is most numerous at station 7, and is rare at stations 8 and 20. A seasonal trend in abundance is not clearly defined at station 7. *Macoma*

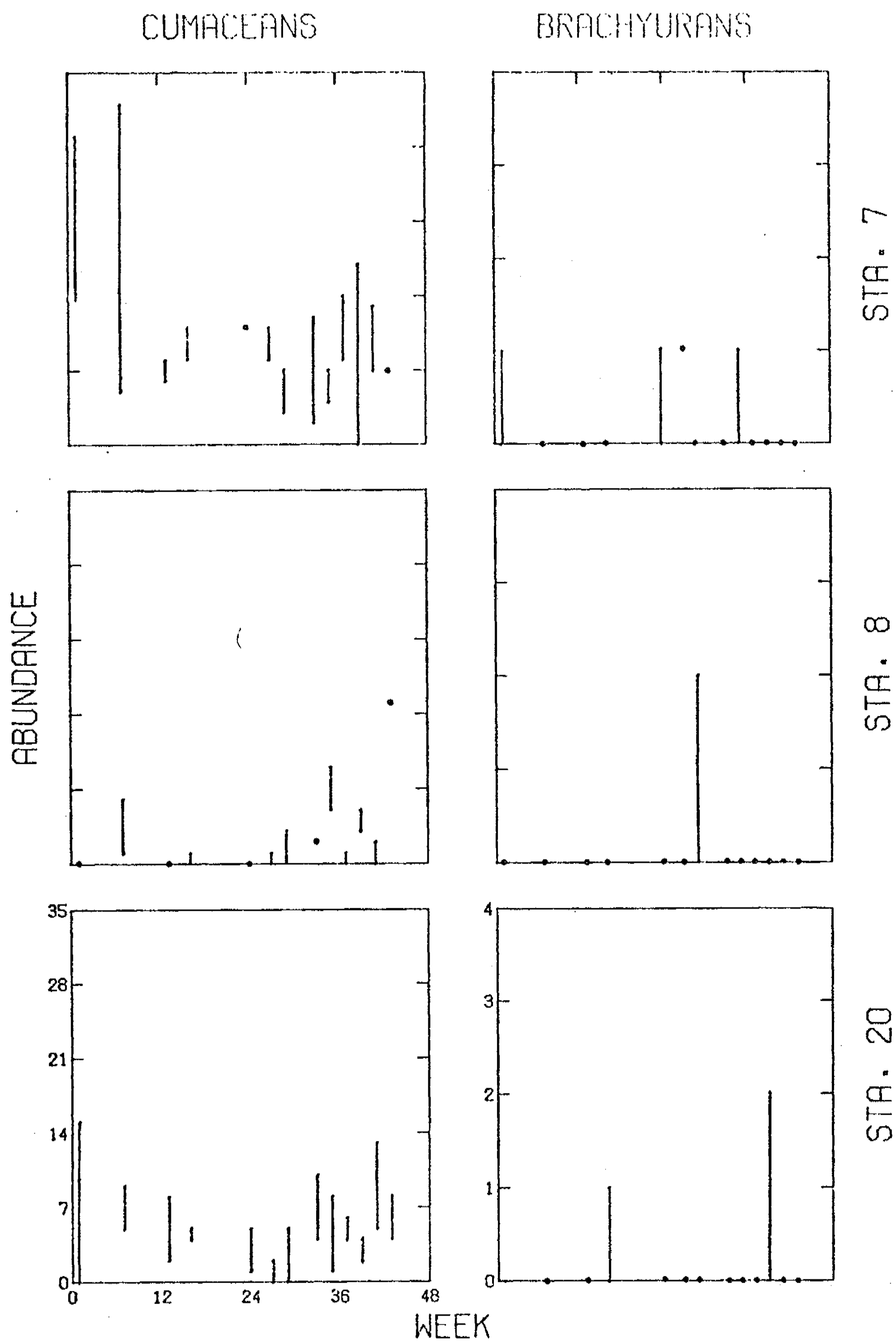

Fig. 6. The abundance of cumaceans and brachyurens per 0.1 m^2 at stations 7, 8, and 20 plotted against time. Vertical lines connect the abundance of the two replicate samples on each sampling date.

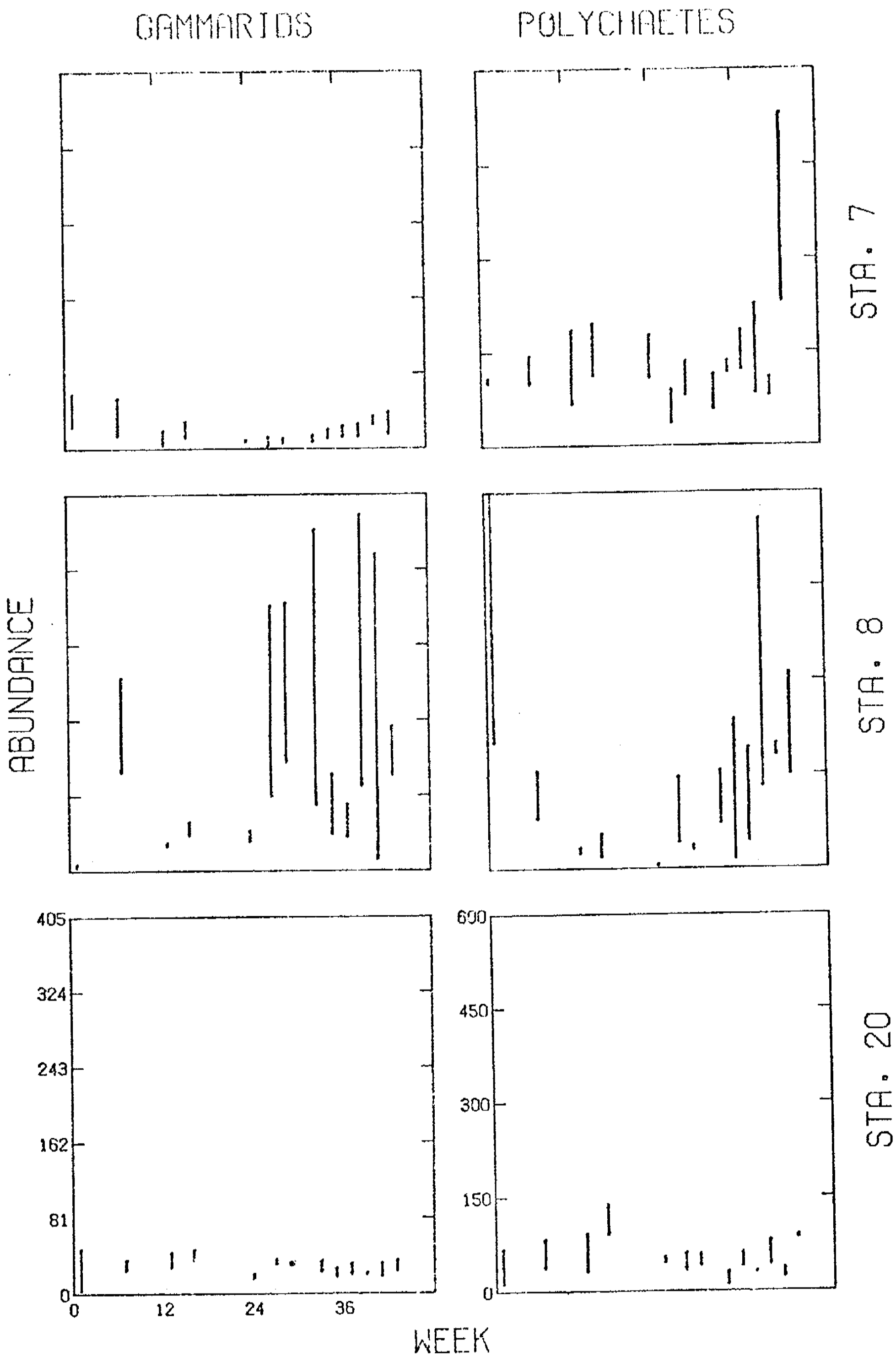

Fig. 7. The abundance of gammarid amphipods and polychaetes per 0.1 m^2 at stations 7, 8, and 20 plotted against time. Vertical lines connect the abundance of the two replicate samples on each sampling date.

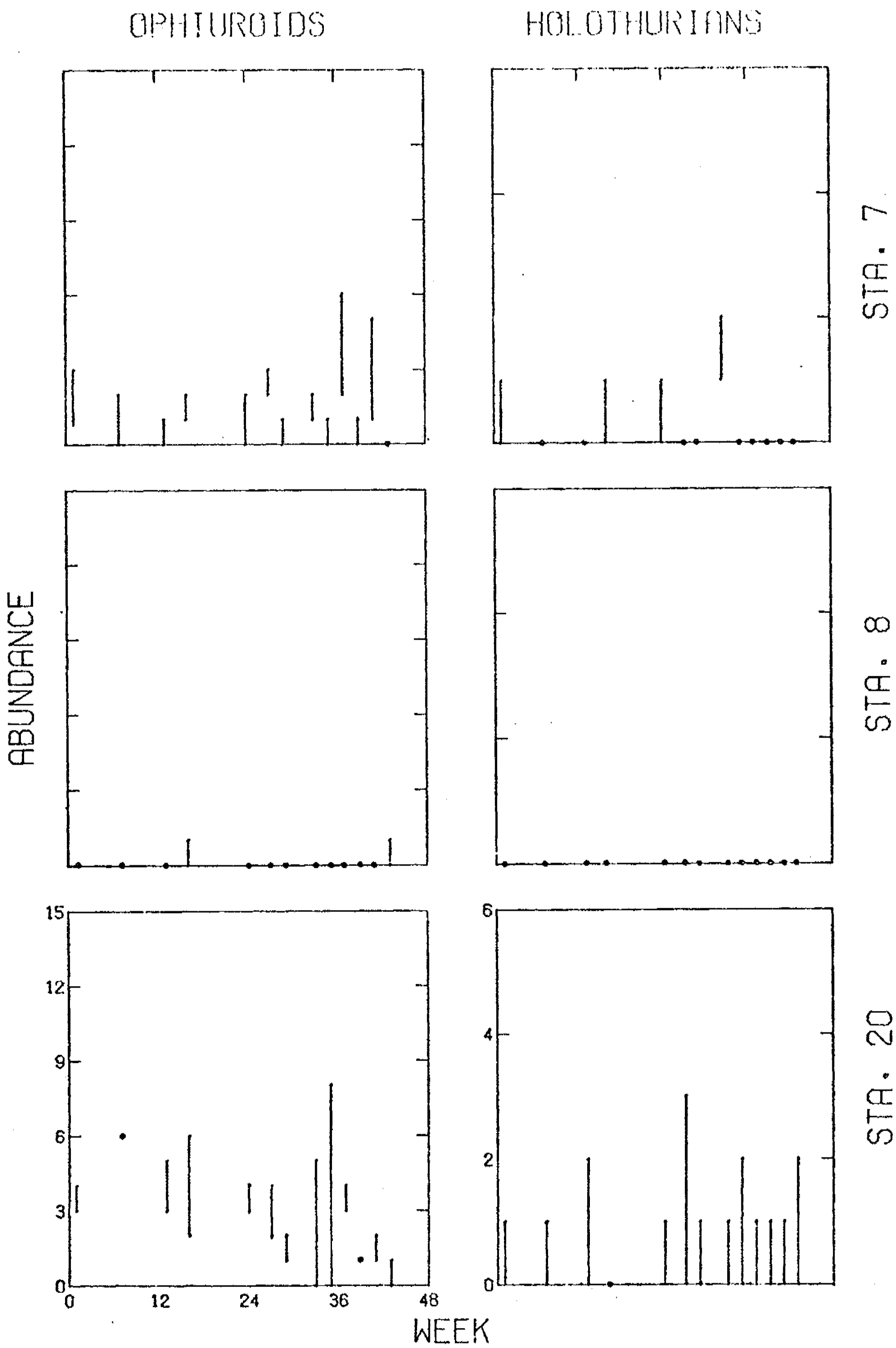

Fig. 8. The abundance of ophiuroids and holothurians per 0.1 m^2 at stations 7, 8, and 20 plotted against time. Vertical lines connect the abundance of the two replicate samples on each sampling date.

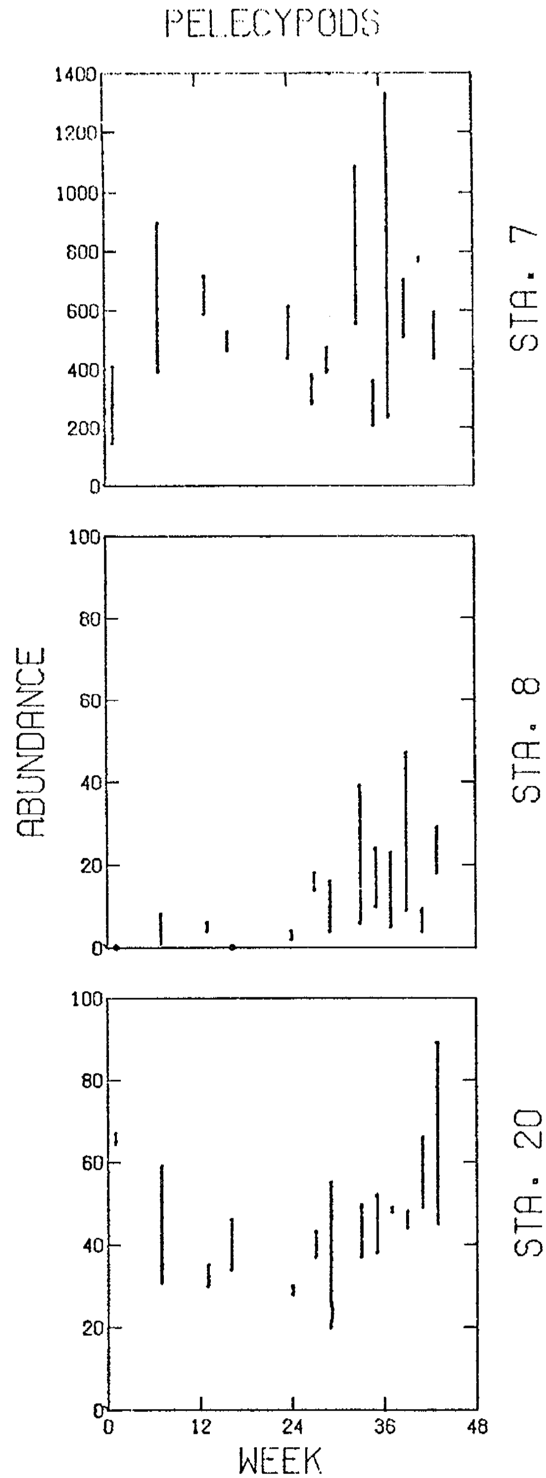

Fig. 9. The abundance of pelecypods per 0.1 m^2 at stations 7, 8, and 20 plotted against time. Vertical lines connect the abundance of the two replicate samples on each sampling date.

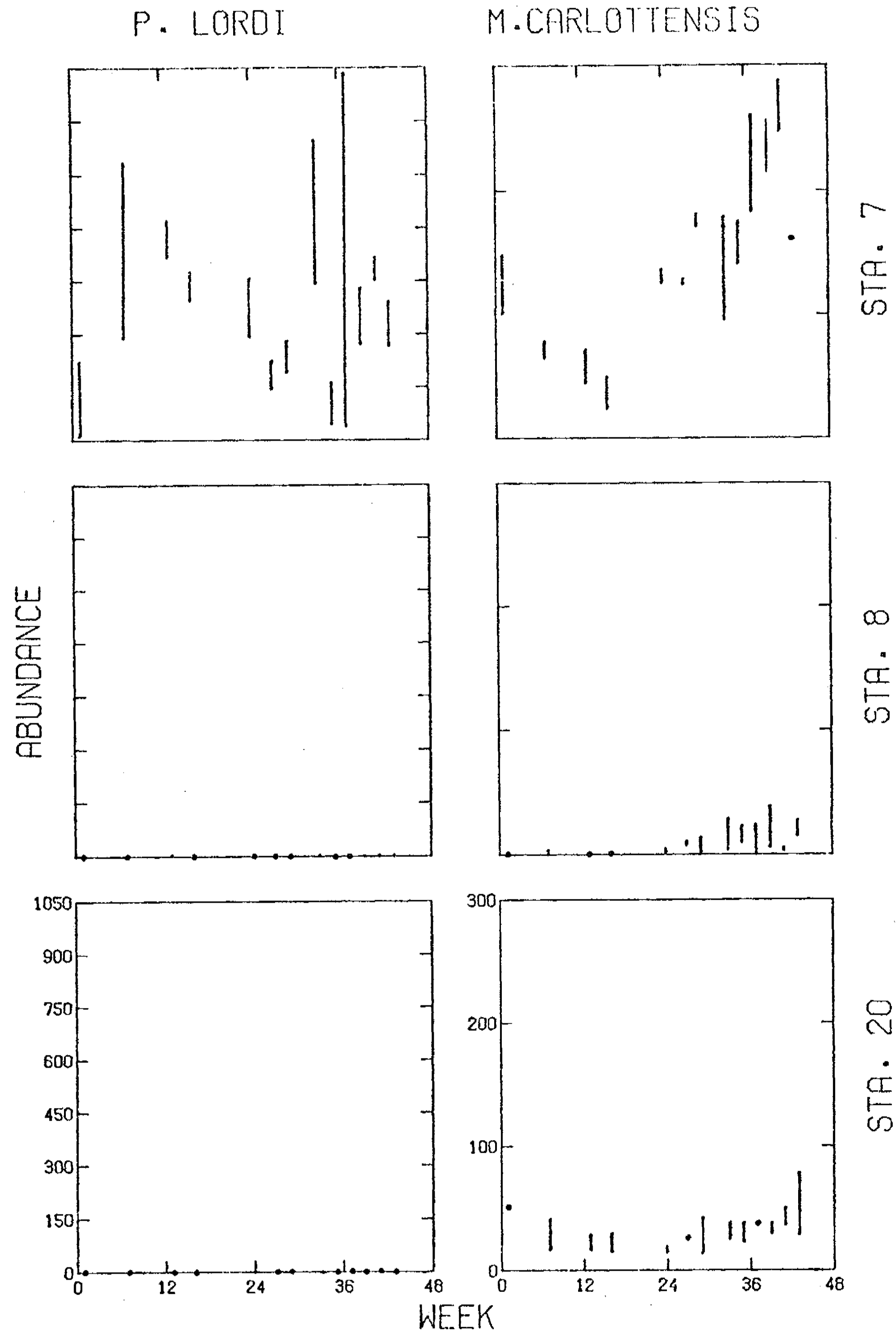

Fig. 10. The abundance of *Psephidia lordi* and *Macoma carlottensis* per 0.1 m^2 at stations 7, 8, and 20 plotted against time. Vertical lines connect the abundance of the two replicate samples on each sampling date.

carlottensis is most numerous at station 7, and least at station 8. A seasonal trend in abundance is evident at station 7, but not stations 8 or 20.

Axinopsida serricata (Carpenter) and *Macoma elimata* Dunnill and Coan (Fig. 11). *Axinopsida serricata* is most numerous at station 20, less at station 7, and rarely occurs at station 8. *Macoma elimata* is most abundant at station 7, and occurs in low abundances at stations 8 and 20.

Figures 2-4 present information on the variability in size distribution of fauna with time and between stations. Averaged over sampling dates, approximately 90% of the polychaetes at station 8 are small, i.e., they pass through the 2-mm screen, compared with 45% at stations 7 and 20 (Table 3, Fig. 2). For pelecypods, a higher percentage of larger clams occurs at station 20 than at station 8. (Table 3, Fig. 3). This is primarily the result of the substantially higher abundance of the small clam *Psephidia lordi* at station 7 than at station 20 (Fig. 4). At stations 7 and 20, increasing percent retention of *Macoma carlottensis* on the 1-mm screen starting around the 15th week of sampling, is interpreted as the entrance of a new year class.

Intensive Series Stations

Substrate. The relatively small differences in percent sand between stations at the same depth indicate that the sediments along depth contours are rather homogeneous (Fig. 12, Table 5). Station C-5 (75 m) is the only station which appears to depart from this pattern and may be the result of errors in the analyses. As with the time series data, the percent clay at all stations appears unusually low, suggesting an error in the estimates.

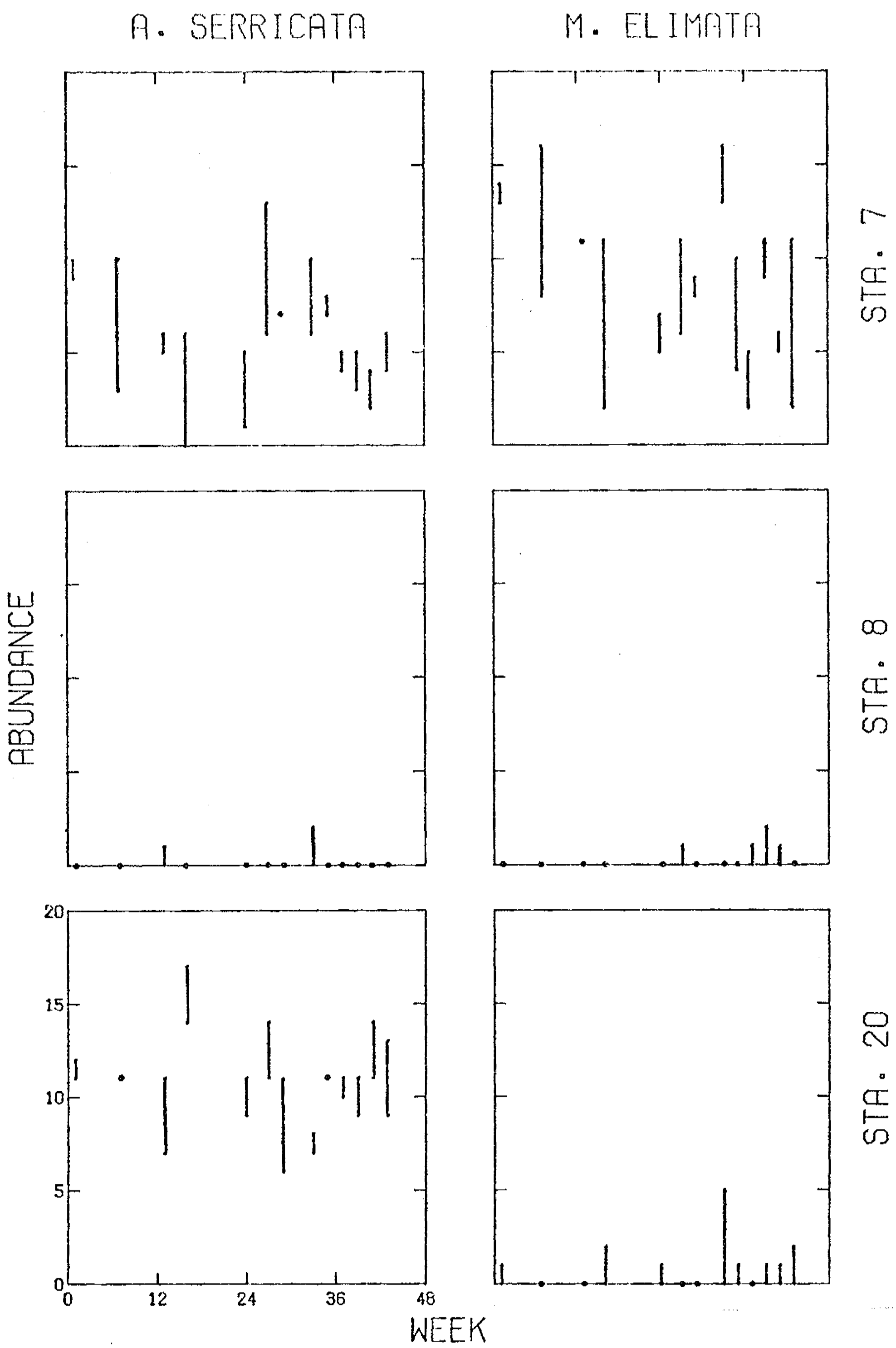

Fig. 11. The abundance of *Axinopsida serricata* and *Macoma elimata* per 0.1 m^2 at stations 7, 8, and 20 plotted against time. Vertical lines connect the abundance of the two replicate samples on each sampling date.

Fig. 12. Sediment particle size distribution at the 36 intensive series stations. Each rectangle represents one station and the histograms within the rectangles represent the percentage of gravel (gr), sand (sa), silt (si), and clay (cl)

Table 5. Depth (meters), sediment particle size and percent volatile solids as percent weight of sediments

Transect-Station	Sample	Depth	Gravel	Sand	Silt	Clay	Volatile Solids
A-1	2	16	0.00	88.27	11.71	0.02	2.1
	3	13					2.1
A-2	2	33	0.00	92.37	7.62	0.01	1.7
	3	31					1.8
A-3	2	46	1.12	80.74	18.14	0.00	4.7
	3	46					1.9
A-4	2	61	0.59	80.24	19.17	0.00	6.3
	3	61					5.0
A-5	2	79	0.51	73.93	25.47	0.09	7.3
	4	76					4.2
A-6	2	95	1.00	72.04	26.83	0.13	9.7
	4	94					7.3
B-1	1	13	0.00	94.19	5.81	0.00	1.4
	3	14					1.6
B-2	1	30	0.00	93.33	6.67	0.00	1.6
	3	32					1.6
B-3	2	44	0.05	87.88	12.07	0.00	2.2
	3	45					2.9
B-4	2	59	0.77	79.85	19.38	0.00	4.3
	3	64					4.1
B-5	2	77	2.30	73.85	23.84	0.01	7.9
	3	74					5.3
B-6	2	96	1.23	71.02	27.51	0.23	5.0
	3	94					6.1
C-1	1	15	0.00	87.96	12.04	0.00	1.4
	3	12					2.7
C-2	1	28	0.00	83.55	16.45	0.00	1.8
	3	30					2.7
C-3	1	47	1.80	81.75	16.45	0.00	2.3
	3	45					2.2
C-4	1	62	0.00	72.27	27.73	0.00	2.5
	3	61					2.8
C-5	1	77	1.95	31.60	65.90	0.55	3.8
	3	77					3.6
C-6	2	96	0.20	55.42	44.37	0.01	3.5
	3	92					5.1
D-1	1	17	0.39	95.13	4.47	0.00	0.9
	3	14					0.8
D-2	2	31	0.14	85.55	14.31	0.00	1.2
	3	28					1.1
D-3	1	48	2.04	89.16	8.78	0.02	1.5
	3	48					2.9

Table 5. (continued)

Transect-Station	Sample	Depth	Gravel	Sand	Silt	Clay	Volatile Solids
D-4	1	65	8.86	75.63	15.51	0.00	1.3
	3	62					1.9
D-5	1	77	1.34	77.37	21.27	0.02	2.5
	3	78					1.9
D-6	2	95	0.23	83.47	15.00	1.31	1.6
	3	94					2.1
E-1	2	15	0.00	96.94	3.06	0.00	0.7
	3	15					1.0
E-2	2	29	0.24	91.83	7.93	0.00	1.2
	3	30					1.3
E-3	1	45	3.98	83.66	12.37	0.00	2.0
	3	47					1.9
E-4	2	61	2.54	69.95	27.50	0.01	1.7
	4	60					2.2
E-5	1	78	0.00	76.42	23.58	0.00	2.0
	3	76					3.2
E-6	2	93	0.43	68.05	31.52	0.00	2.4
	4	94					2.9
F-1	2	16	0.23	93.98	5.79	0.00	0.8
	4	15					1.4
F-2	2	32	0.87	95.52	3.61	0.00	0.9
	4	27					1.4
F-3	2	45	0.11	87.86	12.03	0.00	1.2
	4	48					1.8
F-4	2	62	1.91	88.68	9.41	0.00	1.8
	3	66					1.9
F-5	2	79	4.02	81.25	14.73	0.00	1.7
	3	78					2.5
F-6	2	93	3.42	68.03	28.54	0.01	2.4
	3	93					2.7

Percent volatile solids is best illustrated by a three-dimensional plot where transect is plotted along the X-axis, depth in meters along the Y-axis, and percent volatile solids along the Z-axis (Fig. 13). For graphical purposes, stations on each transect are located at the desired depths of 15, 30, 45, 60, 75, and 90 m, and transect spacing is relative to the average distance (in tenths of nautical miles) from the pipeline (Table 1). The height of the pyramids reflects the percent volatile solids at the stations. The highest percentages occur in deep water adjacent to the discharge area of the pipeline. The percent volatile solids decreases towards shore and away from the pipeline along depth contours. At all transect A stations the sediments were black with a hydrogen sulfide odor.

Macrofauna. Twenty major taxa and 17 pelecypod species were identified and enumerated (Appendix II). The abundance of four numerically dominant major taxonomic groups, and three of the numerically dominant pelecypod species are presented as three-dimensional plots (Figs. 14-20). The axes of the plots are the same as those described for Figure 13 except the pyramids in the following figures represent the abundance of the taxa.

Ostracoda (Fig. 14). Ostracods are most numerous at 15, 30 and 45 m along each transect. The two highest abundances are 129 and 122 per 0.06 m^2 at stations B-1 (15 m) and C-1 (15 m).

Tanaidacea (Fig. 15). The highest abundances of tanaids occur at 75 and 90 m on transects A and B. Of these four stations, the highest abundance is 72 per 0.6 m^2 at station B-5, and the lowest is 53 at B-6.

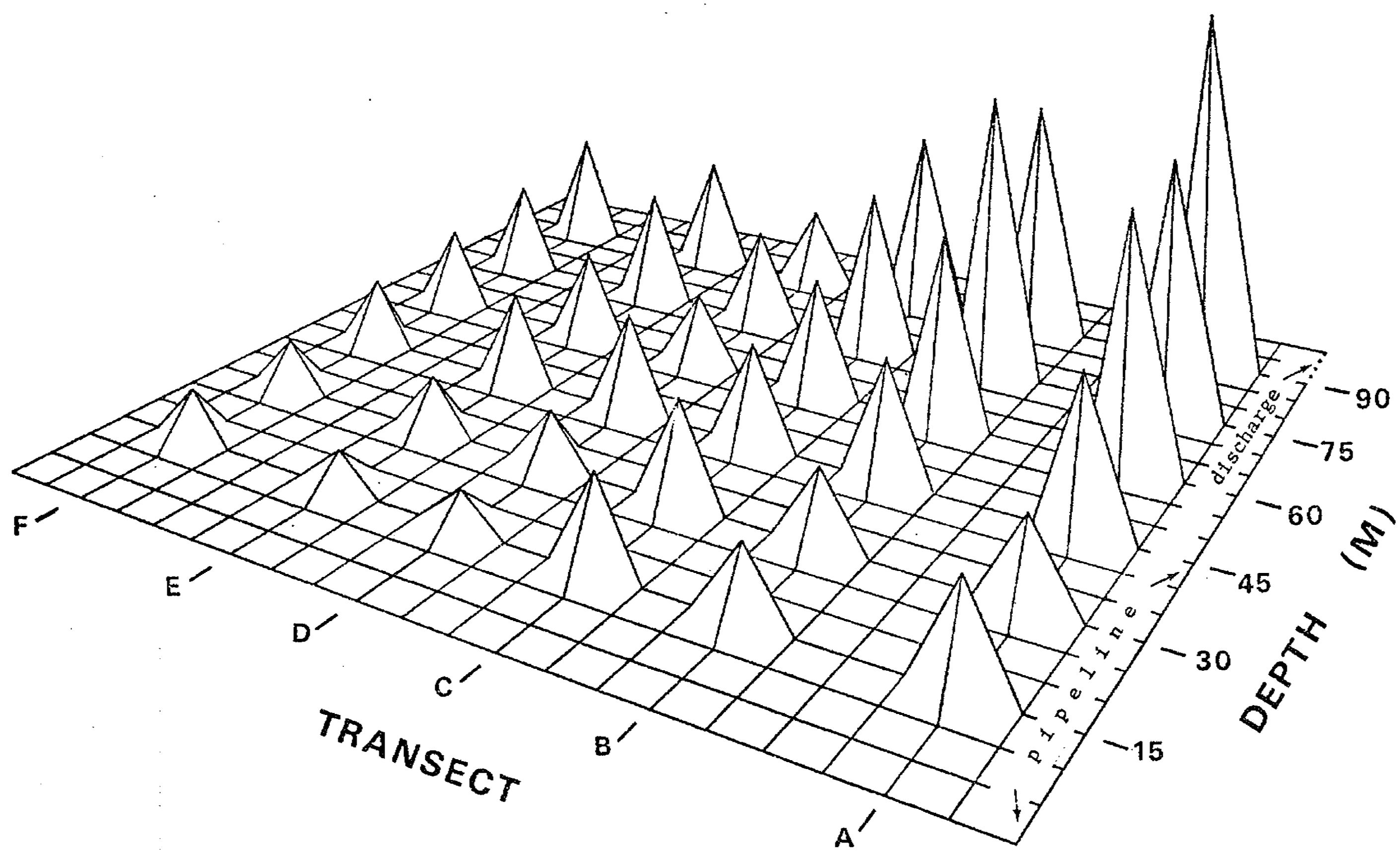

Fig. 13. Percent volatile solids at 36 intensive series stations.

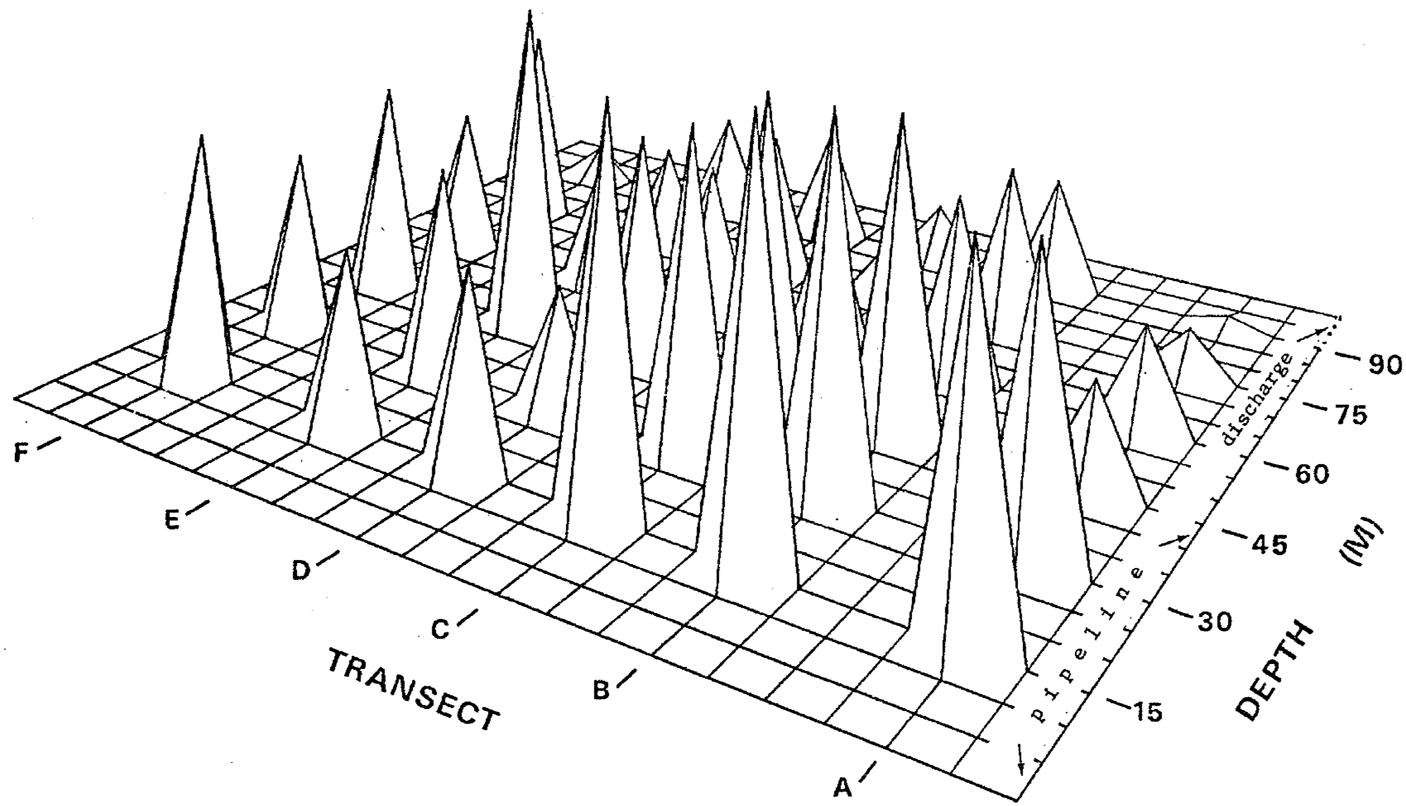

Fig. 14. Abundance of ostracods at 36 intensive series stations.

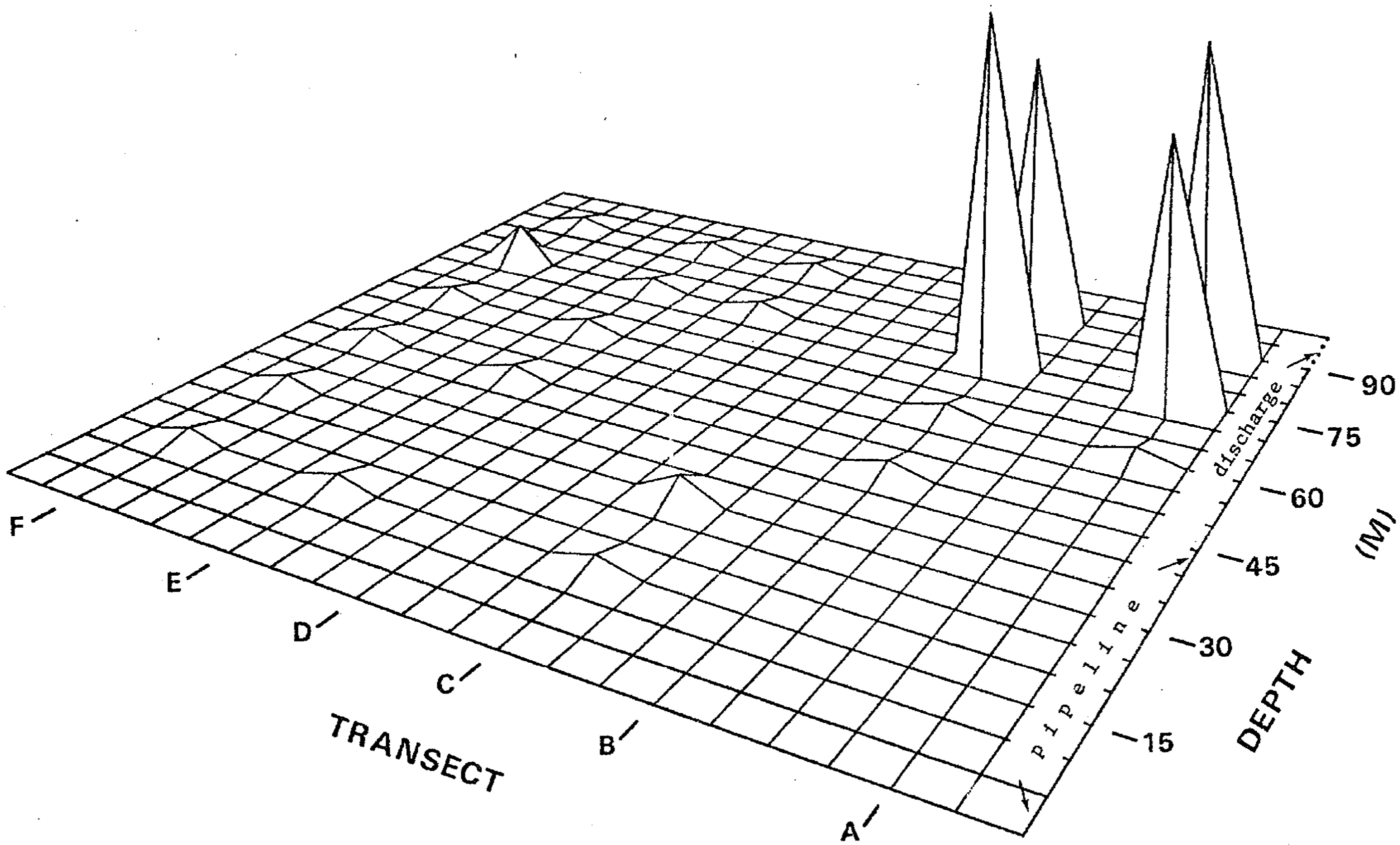

Fig. 15. Abundance of tanaids at 36 intensive series stations.

Gammarid Amphipoda (Fig. 16). Gammarids have a distribution pattern similar to that of the tanaids, with highest abundances occurring at 75 and 90 m along transects A and B. At these four stations their abundance ranges from a high of 245 per 0.06 m^2 at station A-6, to a low of 39 at station B-5.

Polychaeta (Fig. 17). In general, polychaetes seem to be somewhat more numerous along transect F, with abundance values on this transect ranging from 196 per 0.06 m^2 at station F-5 to 64 at station F-1.

Psephidia lordi (Fig. 18). The numerically dominant pelecypod *P. lordi* is least abundant on transect A, and most abundant at stations E-5 and F-6 where the abundances are 696 and 562 per 0.06 m^2.

Macoma carlottensis (Fig. 19). *Macoma carlottensis*, the second most dominant pelecypod species, occurs at the deep stations on each transect and is most numerous at station C-6 at 49 per 0.06 m^2. Relatively high abundances also occur at stations F-5, F-6, E-5, and E-6.

Macoma elimata (Fig. 20). *Macoma elimata* is similar to *M. carlottensis* in that it occurs most frequently in deeper water. It is most numerous at station F-6 at 7 per 0.06 m^2.

DISCUSSION

Methods. To date, the use of sodium acetate buffered 70% ethyl alcohol as a preservative is more satisfactory than the sodium borate buffered formaldehyde. Storage of unsorted samples for periods in excess of 1-2 months, however, may require additions of sodium acetate to maintain the

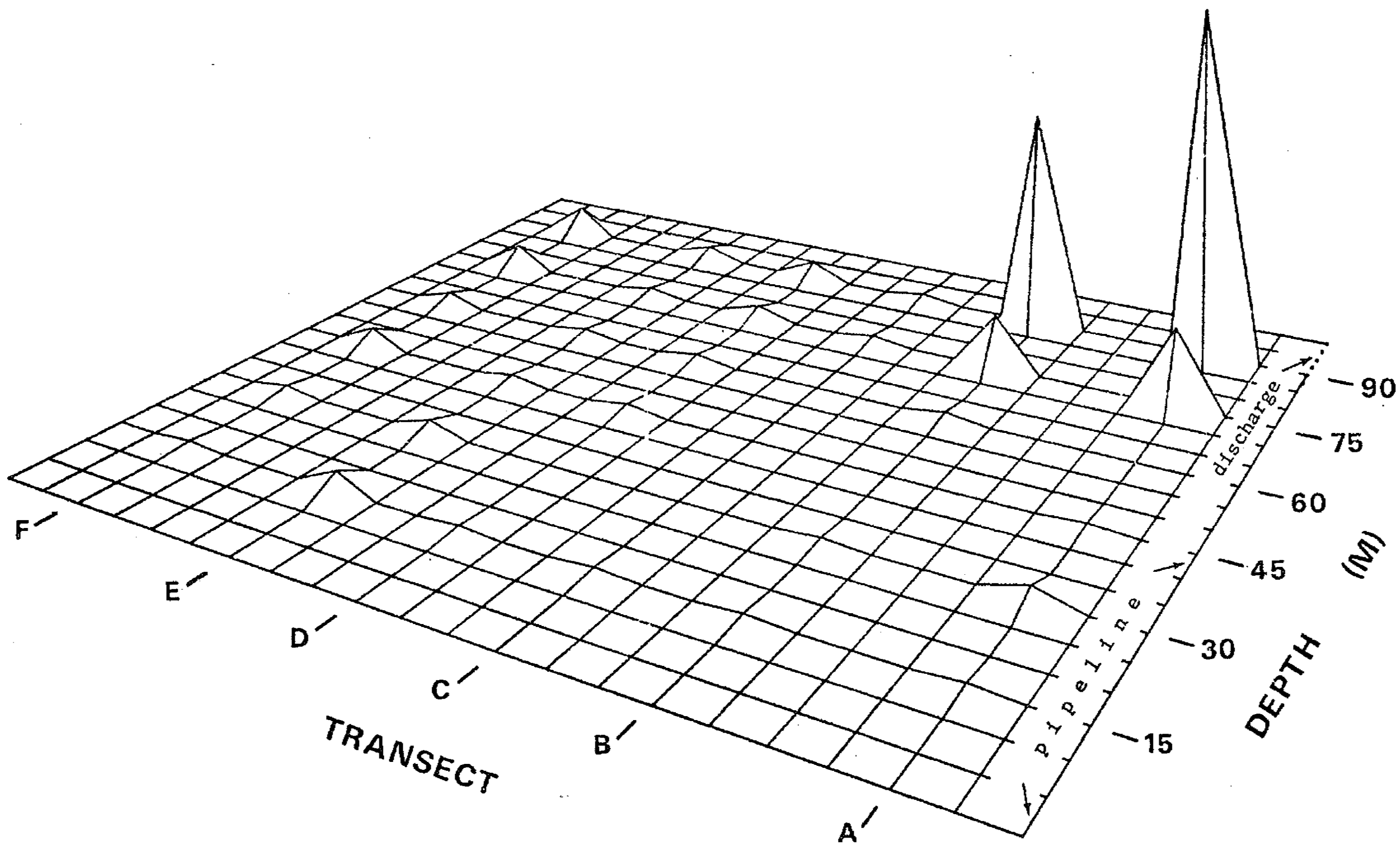

Fig. 16. Abundance of gammarid amphipods at 36 intensive stations.

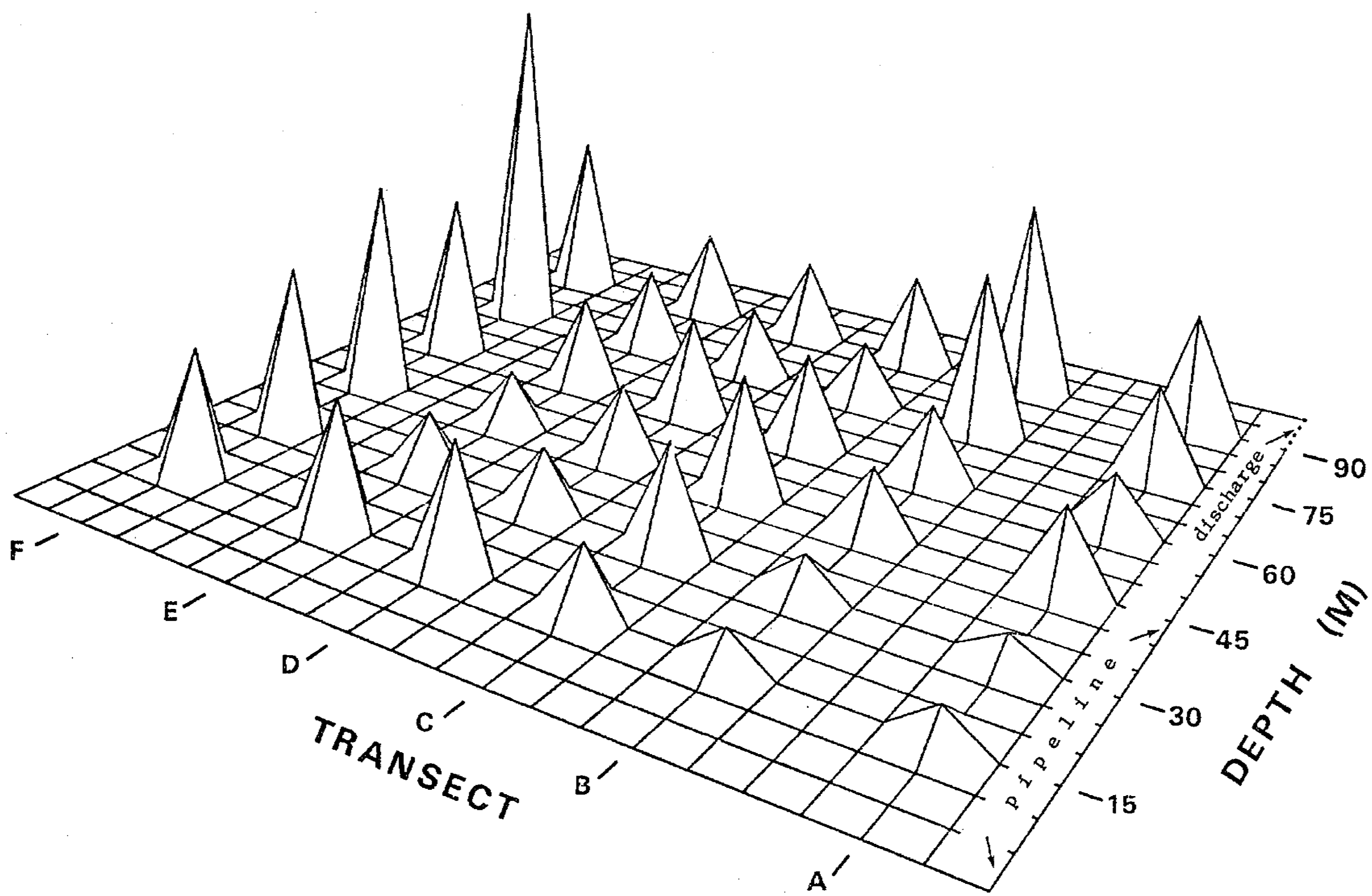

Fig. 17. Abundance of polychaetes at 36 intensive series stations

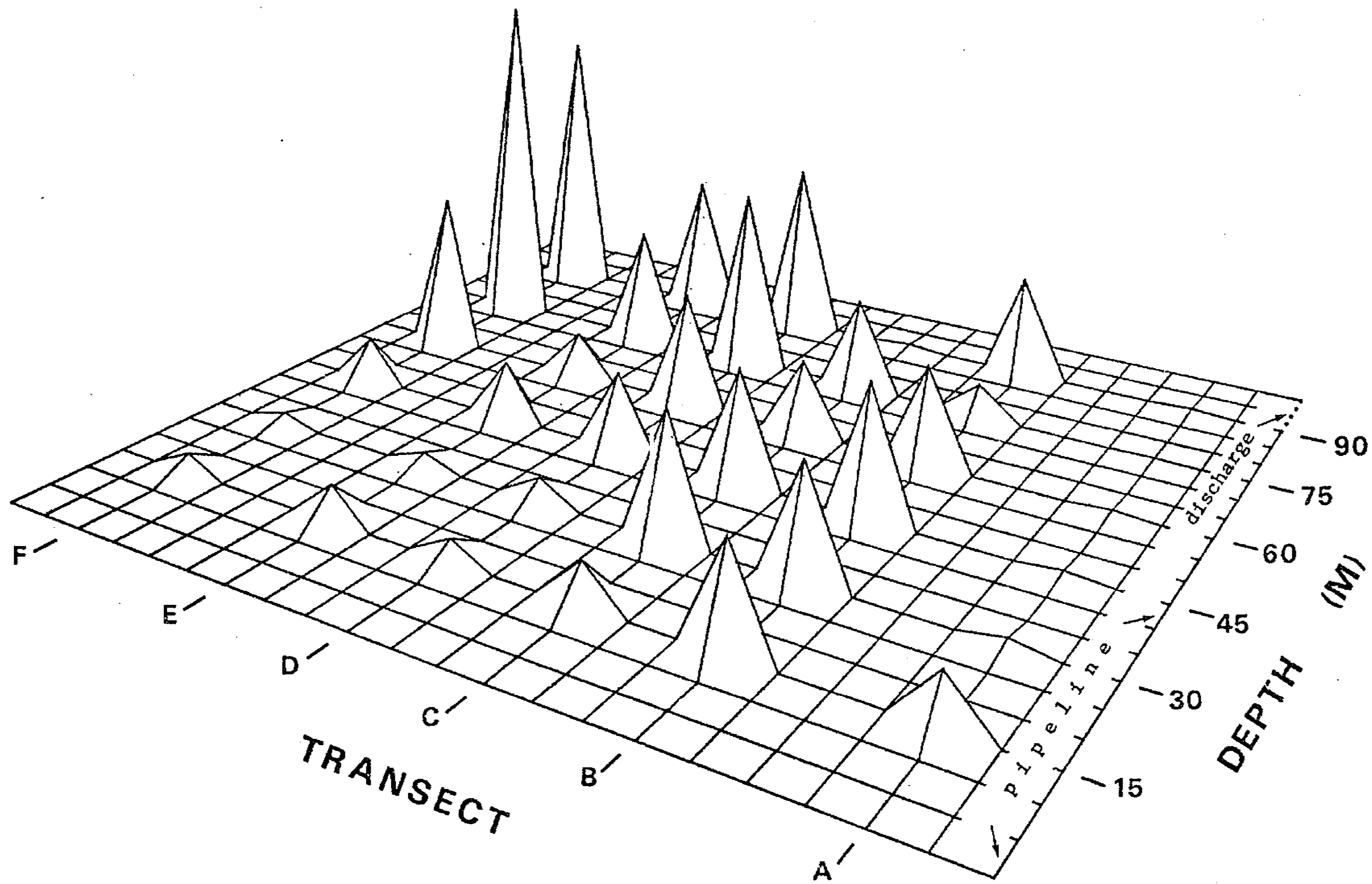

Fig. 18. Abundance of *Psephidia lordi* at 36 intensive series stations.

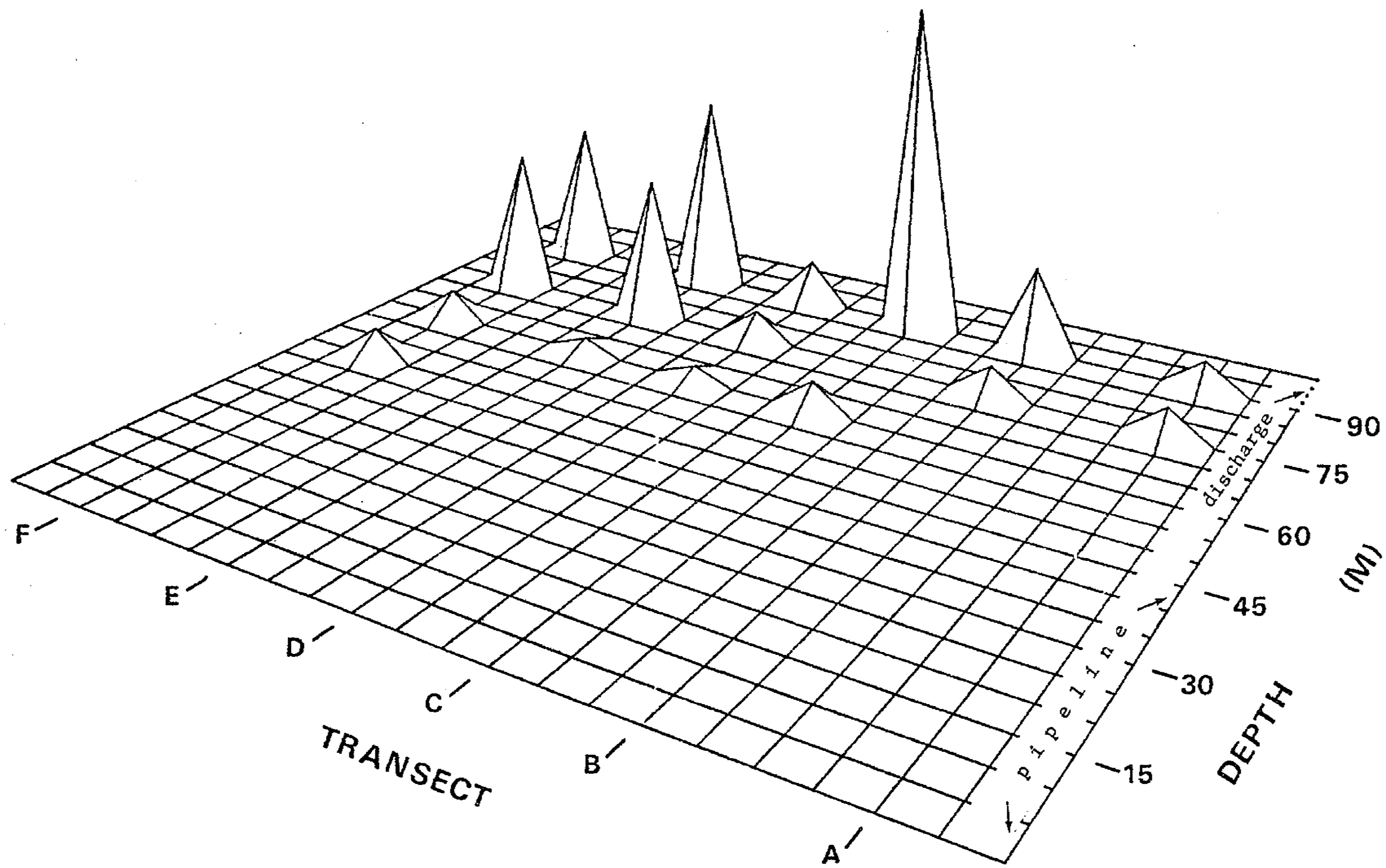

Fig. 19. Abundance of *Macoma carlottensis* at 36 intensive series stations.

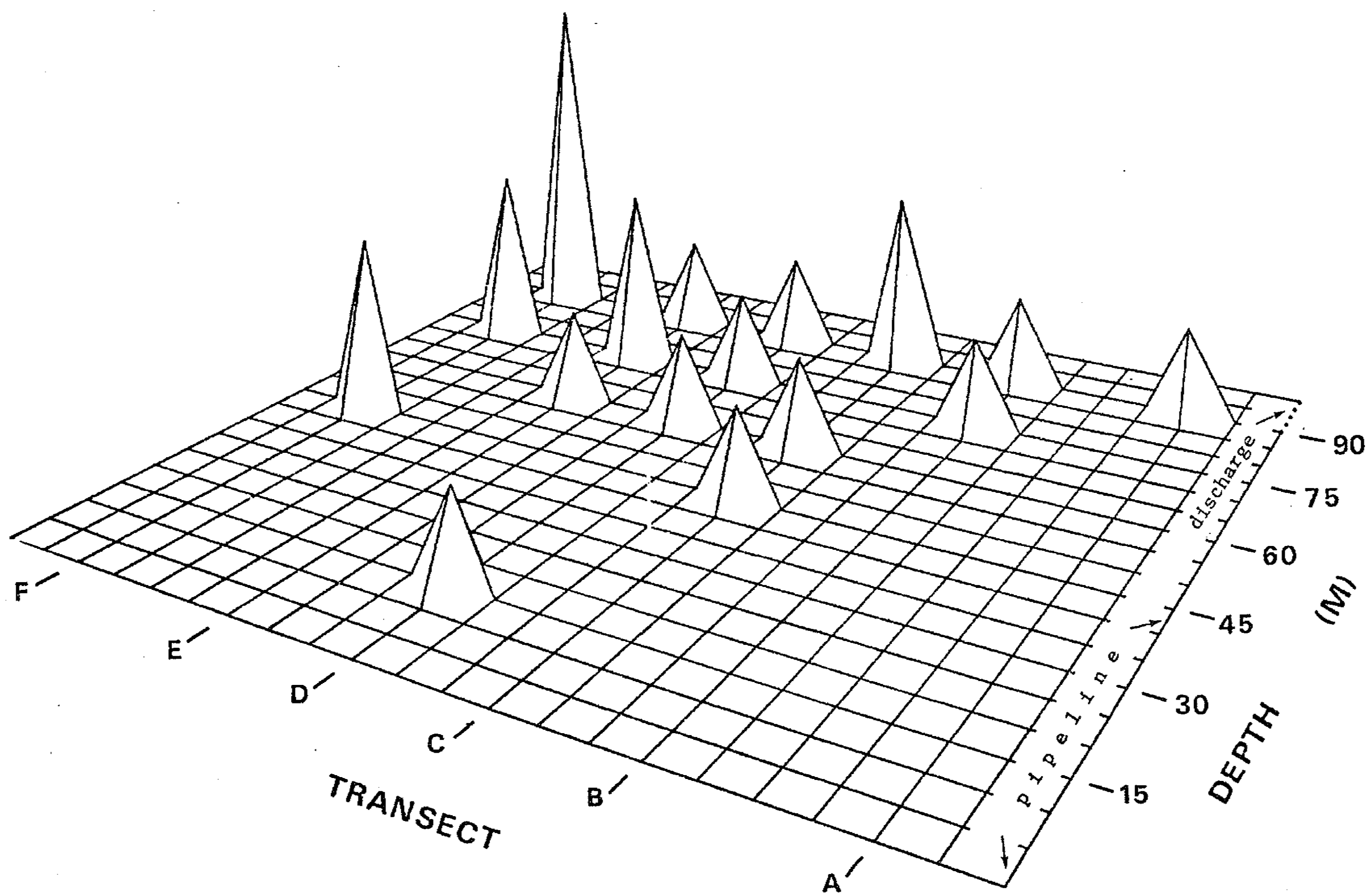

Fig. 20. Abundance of *Macoma elimata* at 36 intensive series stations.

pH above 7. Two factors probably contribute to the increasing acidity in stored samples. First, large quantities of organic matter (wood chips, etc.) commonly occur in samples from the survey area. Presumably this material absorbs the formaldehyde fixative used in the field, and releases it to the alcohol preservative once the formalin is replaced. Allowing samples to stand in fresh water for a period of time after the formalin has been removed and prior to the addition of alcohol may diminish this effect. Second, Steedman (1974) reports that when using formaldehyde as a preservative for zooplankton, a specimen to preservative ratio of 1:9 by volume is necessary to prevent the preservative from becoming acidic. This suggests that by increasing the volume of preservative relative to the volume of organic matter, the declining pH would be prevented or retarded.

The results of the 1-mm and 2-mm screen comparisons indicate that the 2-mm screen is not appropriate for sampling crustaceans in the survey area. With less than 10 percent of the total crustaceans retained on the 2-mm screen, the abundances are so low that distribution and abundance patterns would be difficult to interpret. Taxa such as brachyurans (crabs), ophiuroids (brittle stars), and holothurians (sea cucumbers) were retained in high percentages, but their abundances are low for interpretive purposes. Approximately equal percentages of polychaetes were retained on the 2-mm screen at stations 7 and 20; however, at station 8 only a small percent of the population was retained. Based on the numbers retained on the 2-mm screen, one would erroneously conclude that the polychaetes are roughly equal in abundance at stations 8 and 20, when, in fact, their abundance is substantially higher at station 8.

For pelecypod species, there is considerable variability in the percent retained between species, between stations for the same species, and between sampling dates. The within species variability presumably results from differences in spawning time between locations. Many pelecypod species retained on a 2-mm screen are close to one year in age (Lie 1968). Therefore, using exclusively the 2-mm screen would delay the detection of a species inhabiting a location previously uninhabited by that species.

Based on these observations, the 1-mm mesh screen appears to be best for sampling the macrofauna in the survey area and consequently will be used exclusively in the continuing survey.

Macrofauna. Studies by Lie (1968, 1974), Driscoll (1973), and others have shown that sediment particle size is important in determining benthic macrofaunal distribution patterns. Because stations 20 and 8 are very similar in sediment particle size distributions, one would expect their faunal composition to be similar. The presence of ophiuroids (brittle stars), holothurians (sea cucumbers), echinoids (heart urchins), and the pelecypod species *Macoma carlottensis* and *Axinopsida serricata* characterize station 20 as a typical deep water soft bottom station in Puget Sound (Lie 1974). The absence or low abundance of these groups at station 8 indicates that this station is not typical of areas in Puget Sound which have similar depths and sediment particle size distributions.

The typical number of non-*Capitella* polychaete species expected at stations like 8 and 20 would be about 50 (Lie 1974). The presence of only the *Capitella capitata* group at station 8 further illustrates the uniqueness of this station. Faunal size distribution data reveal another difference between stations 8 and 20. In the crustacea and polychaete groups, the percent retained on the 2-mm screen was less at station 8 than at 20, which may indicate that the macrofaunal population at station 8 is composed of small species and/or small individuals.

At intensive series stations located adjacent to the discharge, the relatively high abundance of tanaids and gammarid amphipods, the absence or low abundance of *Psephidia lordi* and *Macoma carlottensis* cannot be explained on the basis of sediment particle size distributions either. The higher percentages of volatile solids at stations in this area are probably the result of the discharge, although they could be the result of a higher wood chip content which may coincidentally occur in the vicinity of the discharge. The black color and presence of H_2S at these stations indicates that the sediments are anoxic; a condition presumably resulting from the decomposition of the large amount of organic material. Whether anoxic sediments, SWL discharge, or some unknown environmental factor associated with the river discharge is responsible for the macrofaunal distribution and abundance pattern in the discharge area is not known.

The recovery of the benthic macrofauna in a Swedish fjord following reduced waste water discharge from a sulfite pulp mill was studied by Rosenberg (1972). Within 4 years following the termination of the discharge, the abundance and number of echinoderm and non-*Capitella* polychaete species increased. If the discharge from the sulfite pulp mills in Everett is the environmental factor influencing the distribution of fauna, changes in the macrofaunal distribution and abundance patterns in the vicinity of the discharge would be expected once the discharge is reduced. Specifically, station 8 would become similar to station 20, and stations along transect A similar to stations along transects C-F.

The benthic investigation will continue to look at the distribution and abundance of macrofauna on an annual basis at the intensive series stations and one or more times per month at the time series stations. The timing of the entrance of new year classes of the dominant clam species at time series stations will be examined.

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APPENDIX I

Abundance of major taxa and species of Pelecypoda in samples taken August 1974 through June 1975 at time series stations.

Table I.1. Abundance of major taxa at station 7

Date	Aug. 22 '74		Sep. 10	Oct. 4		Nov. 12		Dec. 3		Jan. 31 '75	
Grab size (m^2)	0.1		0.2	0.1		0.1		0.1		0.1	
Depth (m)	109	113	100	104	105	101	104	98	100	97	96
Sample No.	1	2	1	1	2	1	2	1	2	1	2
CRUSTACEA											
Ostracoda	26	29	60	45	25	26	19	16	40	26	11
Leptostraca	0	0	0	0	0	0	0	0	0	0	0
Tanaidacea	2	0	2	2	1	1	0	2	4	0	3
Isopoda	0	0	0	0	0	0	0	0	0	1	0
Amphipoda											
Caprellidea	0	0	0	3	0	0	1	16	0	1	2
Gammaridea	59	24	45	54	15	8	19	14	29	8	9
Mysidacea	0	4	1	1	1	0	0	0	0	0	1
Cumacea	29	14	28	32	5	8	6	8	11	11	11
Euphausiacea	0	2	2	0	0	0	0	0	0	0	0
Decapoda											
Natantia	0	0	1	4	2	1	0	0	0	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0
Brachyura	1	0	1	0	0	0	0	0	0	0	1
ANNELIDA											
Polychaeta	103	109	471	144	101	68	185	113	195	177	110
ECHINODERMATA											
Ophiuroidea	1	3	8	0	2	1	0	2	1	0	2
Holothuroidea	0	1	0	0	0	0	0	1	0	0	1
Echinoidea	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA											
Pelecypoda	406	148	994	896	395	588	717	526	468	613	439
Gastropoda	0	0	2	0	0	0	3	2	0	2	1

Table I.1. (continued)

Date	Feb. 19		Mar. 3		Mar. 31		Apr. 16		May 1		May 15	
Grab size (m^2)	0.1		0.1		0.1		0.1		0.1		0.1	
Depth (m)	102	99	98	100	100	101	101	103	100	98	103	98
Sample No.	1	2	1	2	1	2	1	2	1	2	1	2
CRUSTACEA												
Ostracoda	10	23	17	20	13	9	9	20	11	24	25	28
Leptostraca	0	0	0	0	0	0	0	0	9	0	0	0
Tanaidacea	0	0	0	2	0	1	2	1	1	1	0	0
Isopoda	0	1	0	0	0	0	0	0	0	0	0	0
Amphipoda												
Caprellidea	0	0	0	0	5	2	2	0	0	8	0	0
Gammaridea	3	12	11	6	14	8	20	12	14	24	26	15
Mysidacea	1	2	0	3	0	0	0	2	0	1	3	1
Cumacea	11	8	7	3	12	2	4	7	14	8	17	0
Euphausiacea	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda												
Natantia	0	0	0	0	0	0	0	0	1	0	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura	1	1	0	0	0	0	0	1	0	0	0	0
ANNELIDA												
Polychaeta	37	89	134	83	114	61	135	118	122	182	84	225
ECHINODERMATA												
Ophiuroidea	2	3	0	1	2	1	1	0	2	6	0	1
Holothuroidea	0	0	0	0	1	2	0	0	0	0	0	0
Echinoidea	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA												
Pelecypoda	290	380	393	472	1069	572	208	359	239	1319	510	705
Gastropoda	0	1	0	1	1	1	0	0	0	6	1	0

Table I.1. (continued)

Date	May 27		Jun. 11	
Grab size (m^2)	0.1		0.1	
Depth (m)	99	98	100	95
Sample No.	1	2	1	2
CRUSTACEA				
Ostracoda	14	26	34	32
Leptostraca	0	0	0	0
Tanaidacea	1	0	1	1
Isopoda	0	0	0	0
Amphipoda				
Caprellidea	0	7	2	1
Gammaridea	27	35	17	39
Mysidacea	2	1	0	3
Cumacea	13	7	7	7
Euphausiacea	0	0	0	0
Decapoda				
Natantia	0	0	0	0
Astacura	0	0	0	0
Brachyura	0	0	0	0
ANNELIDA				
Polychaeta	109	80	231	530
ECHINODERMATA				
Ophiuroidea	1	5	0	0
Holothuroidea	0	0	0	0
Echinoidea	0	0	0	0
MOLLUSCA				
Pelecypoda	779	768	438	593
Gastropoda	4	0	1	0

Table I.2. Abundance of pelecypod species at station 7

Date	Aug. 22 '74		Sep. 10	Oct. 4		Nov. 12		Dec. 3		Jan. 31 '75	
Grab size (m^2)	0.1		0.2	0.1		0.1		0.1		0.1	
Depth (m)	109	113	100	104	105	101	104	98	100	97	96
Sample No.	1	2	1	1	2	1	2	1	2	1	2
MOLLUSCA											
Pelecypoda											
Acila castrensis	0	0	0	0	0	0	0	0	0	0	0
? Acila castrensis	0	0	0	0	0	0	0	0	0	0	0
Nucula bellotii	2	0	1	0	0	0	0	0	0	0	0
Megacrenella columbiana	0	0	0	0	0	0	0	1	1	0	0
Modiolus modiolus	1	0	0	0	0	0	0	0	0	0	0
Musculus substriatus	0	0	0	0	0	0	0	0	0	0	0
Cyclopecten randolphi	0	0	0	0	0	0	0	0	0	0	0
Cyclocardia ventricosa	0	0	6	0	0	0	0	0	0	0	1
Mysella tumida	4	1	6	5	4	0	1	5	0	1	6
Parvilucina tenuisculpta	0	0	0	0	1	1	2	0	1	3	1
Axinopsida serricata	9	10	5	0	0	0	0	0	0	0	0
Clinocardium nuttallii	0	0	0	10	3	5	6	0	0	5	1
Nemocardium centifilosum	0	0	0	0	0	0	0	0	0	0	0
Psephidia lordi	222	13	813	1	0	0	0	0	0	1	0
Macoma alaskana	0	0	0	783	292	522	621	475	399	457	295
Macoma carlottensis	148	102	143	0	0	0	0	0	0	0	0
Macoma carlottensis?	0	0	0	78	66	46	71	25	49	136	126
Macoma elimata	14	13	19	0	0	0	0	0	0	0	0
Macoma elimata?	0	0	0	8	16	11	11	2	11	7	5
Macoma inquinata?	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua?	0	0	0	0	0	1	0	0	0	0	0
Macoma nasuta	0	0	0	0	0	0	0	0	0	0	0
Macoma spp?	6	9	0	0	0	0	0	0	0	0	0
Hiatella arctica	0	0	1	11	13	2	5	3	0	0	0
Mya arenaria	0	0	0	0	0	0	0	15	1	3	4
				0	0	1	0	0	0	0	0

Table I.2. (continued)

Date	Feb. 19		Mar. 3		Mar. 31		Apr. 16		May 1		May 15	
Grab size (m^2)	0.1		0.1		0.1		0.1		0.1		0.1	
Depth (m)	102	99	98	100	100	101	101	103	100	98	103	98
Sample No.	1	2	1	2	1	2	1	2	1	2	1	2
MOLLUSCA												
Pelecypoda												
Acila castrensis	0	0	0	1	0	1	1	0	0	0	1	0
? Acila castrensis	0	0	0	0	0	0	0	0	0	0	2	0
Nucula bellotii	0	0	0	0	0	1	1	1	0	1	1	1
Megacrenella columbiana	0	0	0	0	0	2	0	0	0	0	0	0
Modiolus modiolus	0	0	0	0	0	0	0	0	0	0	0	0
Musculus substriatus	0	0	0	0	0	0	0	0	0	0	0	0
Cyclopecten randolphi	0	0	0	0	0	0	0	0	0	0	0	0
Cyclocardia ventricosa	4	3	0	0	6	2	0	0	0	12	0	0
Mysella tumida	1	1	0	0	2	0	1	0	0	2	0	2
Parvilucina tenuisculpta	0	0	0	0	0	1	0	0	0	0	0	0
Axinopsida serricata	6	13	7	7	10	6	8	7	4	5	3	5
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0
Nemocardium centifilosum	0	2	0	1	6	4	2	0	0	0	1	0
Psephidia lordi	147	222	194	280	348	444	47	162	40	1034	273	429
Macoma alaskana	0	0	0	0	0	1	0	0	0	0	0	0
Macoma carlottensis	125	128	181	172	179	96	142	175	184	260	217	257
Macoma carlottensis?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma elimata	6	11	8	9	16	13	4	10	5	2	9	11
Macoma elimata?	0	0	0	0	0	0	2	0	0	0	0	0
Macoma inquinata?	0	0	0	0	0	0	0	1	0	0	0	0
Macoma obliqua	0	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua?	0	0	0	0	0	0	0	0	0	0	1	0
Macoma nasuta	0	0	0	0	0	0	0	1	0	0	0	0
Macoma spp2	1	0	2	0	2	1	0	2	0	3	0	0
Hiatella arctica	0	0	0	2	0	0	0	0	6	0	2	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0	0

Table I.2. (continued)

Date	May 27		Jun. 11	
Grab size (m^2)	0.1		0.1	
Depth (m)	99	98	100	95
Sample No.	1	2	1	2
MOLLUSCA				
Pelecypoda				
Acila castrensis	0	0	0	0
? Acila castrensis	0	0	0	0
Nucula bellotii	1	0	0	1
Megacrenella columbiana	0	0	0	0
Modiolus modiolus	0	0	0	0
Musculus substriatus	0	1	0	0
Cyclopecten randolphi	0	0	0	1
Cyclocardia ventricosa	1	1	1	1
Mysella tumida	0	0	0	1
Parvilucina tenuisculpta	0	0	0	0
Axinopsida serricata	2	4	4	6
Clinocardium nuttallii	1	0	0	0
Nemocardium centifilosum	6	2	1	1
Psephidia lordi	515	455	268	390
Macoma alaskana	0	0	0	0
Macoma carlottensis	248	287	162	161
Macoma carlottensis?	0	0	0	0
Macoma elimata	5	6	2	11
Macoma elimata?	0	0	0	0
Macoma inquinata?	0	0	0	0
Macoma obliqua	0	2	0	1
Macoma obliqua?	0	0	0	0
Macoma nasuta	0	0	0	0
Macoma spp?	0	0	0	0
Hiatella arctica	0	10	0	19
Mya arenaria	0	0	0	0

Table I.3. Abundance of major taxa at station 8

Date	Aug. 22 '74		Sep. 10	Oct. 4		Nov. 12		Dec. 3		Jan. 31 '75	
Grab size (m^2)	0.1		0.2	0.1		0.1		0.1		0.1	
Depth (m)	100	99	102	100	103	92	100	103	99	99	99
Sample No.	1	2	1	1	2	1	2	1	2	1	2
CRUSTACEA											
Ostracoda	0	4	14	17	10	0	2	3	4	1	0
Leptostraca	0	0	2	0	5	0	0	0	0	0	1
Tanaidacea	0	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0
Amphipoda											
Caprellidea	0	0	1	0	0	0	0	0	0	0	0
Gammaridea	7	5	276	108	207	27	29	40	52	43	32
Mysidacea	0	0	0	0	0	0	0	0	0	0	0
Cumacea	0	0	1	1	6	0	0	0	1	0	0
Euphausiacea	1	2	1	0	0	0	0	0	0	0	0
Decapoda											
Natantia	0	0	0	0	0	0	0	0	0	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	0	0	0	0	0	0
ANNELIDA											
Polychaeta	202	600	266	81	155	25	33	55	19	5	6
ECHINODERMATA											
Ophiuroidea	0	0	0	0	0	0	0	1	0	0	0
Holothuroidea	0	0	0	0	0	0	0	0	0	0	0
Echinoidea	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA											
Pelecypoda	0	0	5	1	8	6	4	0	0	2	4
Gastropoda	0	0	0	0	0	0	0	0	0	0	0

Table I.3. (continued)

Date	Feb. 19		Mar. 3		Mar. 31		Apr. 16		May 1		May 15	
Grab size (m^2)	0.1		0.1		0.1		0.1		0.1		0.1	
Depth (m)	99	99	97	100	97	99	102	102	99	98	97	103
Sample No.	1	2	1	2	1	2	1	2	1	2	1	2
CRUSTACEA												
Ostracoda	2	1	1	0	1	3	4	7	1	1	0	6
Leptostraca	0	0	0	55	0	0	0	0	0	0	0	10
Tenaidacea	0	0	0	31	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda												
Caprellidea	0	0	0	1	5	0	0	0	1	0	0	0
Gammaridea	80	285	118	288	73	367	103	40	37	71	92	383
Mysidacea	0	0	0	0	0	0	0	0	0	0	0	0
Cumacea	0	1	0	3	2	2	9	5	0	1	5	3
Euphausiacea	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda												
Natantia	0	0	0	0	0	0	0	0	0	1	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	2	0	0	0	0	0	0	0	0
ANNELIDA												
Polychaeta	42	145	36	30	72	155	237	17	47	191	132	556
ECHINODERMATA												
Ophiuroidea	0	0	0	0	0	0	0	0	0	0	0	0
Holothuroidea	0	0	0	0	0	0	0	0	0	0	0	0
Echinoidea	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA												
Pelecypoda	14	18	4	16	6	39	10	24	23	5	9	47
Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0

Table I.3. (continued)

Date	May 27		Jun. 11	
Grab size (m^2)	0.1		0.1	
Depth (m)	102	103	100	99
Sample No.	1	2	1	2
CRUSTACEA				
Ostracoda	1	4	5	2
Leptostraca	0	1	2	0
Tanaidacea	0	0	0	0
Isopoda	1	0	0	0
Amphipoda				
Caprellidea	0	0	0	0
Gammaridea	13	340	155	106
Mysidacea	0	0	0	0
Cumacea	0	2	15	15
Euphausiacea	0	0	0	0
Decapoda				
Natantia	0	0	0	0
Astacura	0	0	0	0
Brachyura	0	0	0	0
ANNELIDA				
Polychaeta	198	182	150	308
ECHINODERMATA				
Ophiuroidea	0	0	0	1
Holothuroidea	0	0	0	0
Echinoidea	0	0	0	0
MOLLUSCA				
Pelecypoda	4	9	18	29
Gastropoda	0	0	0	0

Table I.4. Abundance of pelecypod species at station 8

Date	Aug. 22 '74		Sep. 10	Oct. 4		Nov. 12		Dec. 3		Jan. 31 '75	
Grab size (m^2)	0.1		0.2	0.1		0.1		0.1		0.1	
Depth (m)	100	99	102	100	103	92	100	103	99	99	99
Sample No.	1	2	1	1	2	1	2	1	2	1	2
MOLLUSCA											
Pelecypoda											
Modiolus modiolus	0	0	0	0	0	0	0	0	0	0	0
Mysella tumida	0	0	0	0	0	0	0	0	0	0	0
Axinopsida serricata	0	0	0	0	0	0	1	0	0	0	0
Psephidia lordi	0	0	1	0	0	1	2	0	0	0	0
Macoma balthica?	0	0	0	0	0	0	0	0	0	0	0
Macoma carlottensis	0	0	0	0	3	0	0	0	0	2	4
Macoma carlottensis?	0	0	0	0	0	0	1	0	0	0	0
Macoma elimata	0	0	0	0	0	0	0	0	0	0	0
Macoma inquinata?	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua?	0	0	0	0	0	0	0	0	0	0	0
Macoma nasuta	0	0	0	0	0	0	0	0	0	0	0
Macoma spp?	0	0	1	0	5	0	0	0	0	0	0
Hiatella arctica	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0
Indeterminate	0	0	3	1	0	5	0	0	0	0	0

Table I.4. (continued)

Date	Feb. 19		Mar. 3		Mar. 31		Apr. 16		May 1		May 15	
Grab size (m^2)	0.1		0.1		0.1		0.1		0.1		0.1	
Depth (m)	99	99	97	100	97	99	102	102	99	98	97	103
Sample No.	1	2	1	2	1	2	1	2	1	2	1	2
MOLLUSCA												
Pelecypoda												
Modiolus modiolus	1	0	0	0	0	0	0	0	0	0	0	0
Mysella tumida	0	0	0	0	0	0	0	0	0	0	0	0
Axinopsida serricata	0	0	0	0	0	2	0	0	0	0	0	0
Psephidia lordi	0	0	0	0	1	2	0	1	0	0	0	1
Macoma balthica?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma carlottensis	8	10	0	13	4	28	10	22	22	0	6	38
Macoma carlottensis?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma elimata	1	0	0	0	0	0	0	0	1	0	0	2
Macoma inquinata?	0	0	0	0	1	1	0	0	0	0	0	0
Macoma obliqua?	0	0	0	0	0	0	0	0	0	0	0	2
Macoma nasuta	0	0	0	0	0	0	0	0	0	0	0	0
Macoma spp?	4	7	1	3	0	6	0	0	0	5	0	4
Hiatella arctica	0	1	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0	0
Indeterminate	0	0	3	0	0	0	0	1	0	0	3	0

Table I.4. (continued)

Date	May 27		Jun. 11	
Grab size (m^2)	0.1		0.1	
Depth (m)	102	103	100	99
Sample No.	1	2	1	2
MOLLUSCA				
Pelecypoda				
Modiolus modiolus	0	0	0	0
Mysella tumida	0	0	0	0
Axinopsida serricata	0	0	0	0
Psephidia lordi	0	1	1	0
Macoma balthica?	0	0	1	1
Macoma carlottensis	3	5	15	27
Macoma carlottensis?	0	1	0	0
Macoma elimata	1	0	0	0
Macoma inquinata?	0	0	0	0
Macoma obliqua?	0	1	0	1
Macoma nasuta	0	0	1	0
Macoma spp?	0	0	0	0
Hiatella arctica	0	0	0	0
Mya arenaria	0	1	0	0
Indeterminate	0	0	0	0

Table I.5. Abundance of major taxa at station 20

Date	Aug. 22 '74		Sep. 10	Oct. 4		Nov. 12		Dec. 3		Jan. 31 '75	
Grab size (m^2)	0.1		0.2	0.1		0.1		0.1		0.1	
Depth (m)	121	133	132	137	137	132	134	131	130	133	134
Sample No.	1	2	1	1	2	1	2	1	2	1	2
CRUSTACEA											
Ostracoda	3	0	5	1	2	2	2	0	1	0	5
Leptostraca	0	0	0	0	0	0	0	0	0	0	0
Tanaidacea	0	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	1	0	1	0	0	0	1	0	0
Amphipoda											
Caprellidea	0	0	0	0	0	0	1	0	0	0	0
Gammaridea	48	4	161	26	36	44	29	47	36	16	21
Mysidacea	0	0	1	0	0	0	0	0	0	0	0
Cumacea	15	0	23	5	9	8	2	5	4	1	5
Euphausiacea	0	0	19	0	0	0	0	0	0	0	0
Decapoda											
Natantia	0	0	2	0	0	0	1	1	0	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	0	0	0	1	0	0
ANNELIDA											
Polychaeta	67	13	154	39	82	32	92	91	135	54	46
ECHINODERMATA											
Ophiuroidea	4	3	20	6	6	5	3	6	2	4	3
Holothuroidea	1	0	1	0	1	0	2	0	0	0	1
Echinoidea	0	0	0	0	0	0	0	0	1	0	0
MOLLUSCA											
Pelecypoda	67	65	85	31	59	30	35	34	46	30	28
Gastropoda	0	0	0	0	2	0	0	0	0	0	0

Table I.5. (continued)

Date	Feb. 18		Mar. 3		Mar. 31		Apr. 16		May 1		May 15	
Grab size (m^2)	0.1		0.1		0.1		0.1		0.1		0.1	
Depth (m)	132	134	134	134	131	131	133	132	132	133	134	134
Sample No.	1	2	1	2	1	2	1	2	1	2	1	2
CRUSTACEA												
Ostracoda	1	1	3	2	0	2	0	2	0	1	1	0
Leptostraca	0	0	0	0	0	0	0	0	0	0	0	0
Tanaidacea	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	1	0	0
Amphipoda												
Caprellidea	0	0	0	1	2	0	0	0	0	0	0	0
Gammaridea	37	32	31	31	35	25	27	21	22	32	21	22
Mysidacea	0	0	1	0	2	0	0	2	0	0	0	0
Cumacea	0	2	0	5	10	4	8	1	4	6	2	4
Euphausiacea	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda												
Natantia	0	0	0	0	0	0	0	0	0	0	2	0
Astacura	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	0	0	0	0	0	2	0
ANNELIDA												
Polychaeta	60	37	57	42	30	11	61	39	31	30	80	44
ECHINODERMATA												
Ophiuroidea	4	2	1	2	5	0	8	0	3	4	1	1
Holothuroidea	0	3	0	1	1	0	0	2	1	0	1	0
Echinoidea	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA												
Pelecypoda	37	43	20	55	37	49	52	38	48	49	44	48
Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0

Table I.5. (continued)

Date	May 27		Jun. 11	
Grab size (m^2)	0.1		0.1	
Depth (m)	130	130	129	128
Sample No.	1	2	1	2
CRUSTACEA				
Ostracoda	5	4	5	0
Leptostraca	0	0	0	0
Tanaidacea	0	0	0	0
Isopoda	0	0	0	0
Amphipoda				
Caprellidea	0	0	0	1
Gammaridea	32	19	25	35
Mysidacea	0	0	0	0
Cumacea	13	5	4	8
Euphausiacea	0	0	0	0
Decapoda				
Natantia	0	0	0	0
Astacura	0	0	0	0
Brachyura	0	0	0	0
ANNELIDA				
Polychaeta	35	24	88	85
ECHINODERMATA				
Ophiuroidea	1	2	0	1
Holothuroidea	0	1	2	0
Echinoidea	0	1	0	0
MOLLUSCA				
Pelecypoda	49	66	89	45
Gastropoda	0	0	0	0

Table I.6. Abundance of pelecypod species at station 20

Date	Feb. 18		Mar. 3		Mar. 31		Apr. 16		May 1		May 15	
Grab size (m^2)	0.1		0.1		0.1		0.1		0.1		0.1	
Depth (m)	132	134	134	134	131	131	133	132	132	133	134	134
Sample No.	1	2	1	2	1	2	1	2	1	2	1	2
MOLLUSCA												
Pelecypoda												
Acila castrensis	0	0	0	0	0	0	0	0	0	0	0	0
Nucula bellotii	1	1	0	1	0	1	2	2	0	1	1	0
Yoldia thraciaeformis	0	0	0	0	0	0	1	0	0	0	0	0
Modiolus modiolus	0	0	0	0	0	0	0	0	0	0	0	0
Mysella tumida	0	1	0	1	0	0	0	1	0	0	0	1
? Mysella tumida	0	0	0	0	0	0	0	0	0	0	0	0
Lucinoma annulata	0	0	0	0	0	0	0	0	0	0	0	0
Parvilucina tenuisculpta	0	1	0	0	0	0	0	0	0	0	0	0
Axinopsida serricata	11	14	6	11	7	8	11	11	10	11	11	9
Compsomyax subdiaphana	0	0	0	0	0	0	0	0	0	0	0	0
Psephidia lordi	0	0	0	0	0	2	0	0	0	0	0	0
Macoma carlottensis	25	26	14	42	25	38	38	23	38	37	31	38
Macoma elimata	0	0	0	0	5	0	0	1	0	0	1	0
Macoma elimata?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma spp?	0	0	0	0	0	0	0	0	0	0	0	0
Indeterminate	0	0	0	0	0	0	0	0	0	0	0	0

Table I.6. (continued)

Date	Aug. 22 '74		Sep. 10	Oct. 4		Nov. 12		Dec. 3		Jan. 31 '75	
Grab size (m^2)	0.1		0.2	0.1		0.1		0.1		0.1	
Depth (m)	121	133	132	137	137	132	134	131	130	133	134
Sample No.	1	2	1	1	2	1	2	1	2	1	2
MOLLUSCA											
Pelecypoda											
Acila castrensis	0	1	0	0	0	0	0	0	1	0	0
Nucula bellotii	0	0	4	3	1	0	0	1	0	0	0
Yoldia thrciaeformis	0	0	0	0	0	0	0	0	0	0	0
Modiolus modiolus	0	0	0	0	0	0	0	1	0	0	0
Mysella tumida	0	0	0	0	0	0	0	0	0	0	0
? Mysella tumida	0	0	0	0	0	1	0	0	0	0	0
Lucinoma annulata	0	0	0	0	0	0	0	0	0	1	0
Parvilucina tenuisculpta	0	0	0	0	0	0	0	0	0	0	0
Axinopsida serricata	11	12	21	11	11	11	7	17	14	11	9
Compsomyax subdiaphana	0	0	0	0	0	1	0	0	0	1	0
Psephidia lordi	0	0	0	0	0	0	0	0	0	1	0
Macoma carlottensis	51	52	59	17	41	17	28	15	29	15	19
Macoma elimata	1	0	0	0	0	0	0	0	2	1	0
Macoma elimata?	0	0	1	0	0	0	0	0	0	0	0
Macoma spp?	0	0	0	0	5	0	0	0	0	0	0
Indeterminate	4	0	0	0	1	0	0	0	0	0	0

Table I.6. (continued)

Date	May 27		Jun. 11	
Grab size (m^2)	0.1		0.1	
Depth (m)	130	130	129	128
Sample No.	1	2	1	2
MOLLUSCA				
Pelecypoda				
Acila castrensis	0	0	0	0
Nucula bellotii	0	1	1	0
Yoldia thraciaeformis	0	0	0	0
Modiolus modiolus	0	0	0	0
Mysella tumida	0	0	0	0
? *Mysella tumida*	0	0	0	0
Lucinoma annulata	0	0	0	0
Parvilucina tenuisculpta	0	0	0	0
Axinopsida serricata	11	14	9	13
Compsomyax subdiaphana	0	1	0	0
Psephidia lordi	0	0	1	1
Macoma carlottensis	37	50	78	29
Macoma elimata	1	0	0	2
Macoma elimata?	0	0	0	0
Macoma spp?	0	0	0	0
Indeterminate	0	0	0	0

APPENDIX II

Abundance of major taxa and species of Mollusca in samples taken October 1974 at intensive series stations.

Table II.1. Abundance of major taxa at time series stations

Transect-Station	A-1		B-1		C-1		D-1		E-1		F-1	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	16	16	13	14	15	13	17	16	15	15	16	14
Sample No.	1	2	1	2	1	2	1	2	1	2	2	3
CRUSTACEA												
Ostracoda	73	34	58	71	60	62	35	27	31	25	35	46
Leptostraca	0	0	0	0	0	0	0	0	0	0	0	0
Tanaidacea	0	0	0	0	1	0	0	0	1	1	2	0
Isopoda	1	0	0	0	0	0	0	0	0	0	0	0
Amphipoda												
Caprellidea	0	0	0	0	0	0	0	1	0	0	0	0
Gammaridea	1	0	1	1	1	0	0	2	4	8	0	2
Mysidacea	0	0	0	0	0	0	0	1	0	0	0	0
Cumacea	0	1	0	1	0	0	0	0	0	0	0	0
Euphausiacea	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda												
Natantia	1	0	0	0	0	0	0	0	0	0	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	2	0	0	0	0	0	0	0
ANNELIDA												
Polychaeta	6	11	6	9	28	3	10	49	56	6	35	29
ECHINODERMATA												
Ophiuroidea	0	0	0	0	0	0	0	0	1	0	0	0
Holothuroidea	0	0	0	0	0	0	0	0	0	0	0	0
Echinoidea	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA												
Pelecypoda	49	48	95	95	48	34	29	16	12	56	15	23
Gastropoda	0	1	0	0	0	0	0	0	1	0	0	1

Table II.1. (continued)

Transect-Station	A-2		B-2		C-2		D-2		E-2		F-2	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	32	33	30	34	28	32	32	31	29	29	32	30
Sample No.	1	2	1	2	1	2	1	2	1	2	2	3
CRUSTACEA												
Ostracoda	37	55	47	70	61	43	21	19	41	28	25	36
Leptostraca	0	0	0	0	0	0	0	0	0	0	0	0
Tanaidacea	0	0	0	0	3	0	0	0	0	0	1	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda												
Caprellidea	0	0	0	0	0	0	0	0	0	0	0	0
Gammaridea	2	6	1	1	0	0	0	0	2	5	2	1
Mysidacea	0	0	0	0	0	0	0	0	0	0	0	0
Cumacea	0	0	0	1	0	0	0	0	0	0	0	0
Euphausiacea	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda												
Natantia	0	0	0	0	0	0	0	0	0	0	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	1	0	0	0	0	0	1
ANNELIDA												
Polychaeta	2	10	5	14	48	4	21	8	10	20	46	40
ECHINODERMATA												
Ophiuroidea	0	0	0	0	0	0	0	0	0	0	0	0
Holothuroidea	0	0	0	0	0	0	0	0	0	0	0	0
Echinoidea	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA												
Pelecypoda	6	29	99	114	110	126	5	42	14	14	15	8
Gastropoda	0	0	0	0	0	1	2	0	0	0	0	1

Table II.1. (continued)

Transect-Station	A-3		B-3		C-3		D-3		E-3		F-3	
Grab size (m^2)	0.03		0.0		0.03		0.03		0.03		0.03	
Depth (m)	47	46	47	44	47	46	48	47	45	44	45	44
Sample No.	1	2	1	2	1	2	1	2	1	2	2	3
CRUSTACEA												
Ostracoda	21	13	37	65	36	63	37	40	47	64	44	29
Leptostraca	0	1	0	0	0	0	0	0	0	0	0	0
Tenaidacea	0	0	0	2	0	0	0	0	1	1	0	2
Isopoda	0	1	0	0	0	0	0	0	1	0	0	0
Amphipoda												
Caprellidea	0	0	0	0	0	0	0	0	0	0	0	3
Gammaridea	1	1	0	0	0	0	4	0	2	2	2	9
Mysidacea	0	0	0	0	0	0	0	0	0	0	0	0
Cumacea	0	0	0	0	0	1	0	0	0	0	0	1
Euphausiacea	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda												
Natantia	0	0	0	0	0	0	0	0	0	0	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	0	0	0	0	0	0	1
ANNELIDA												
Polychaeta	7	33	9	25	24	36	14	24	13	16	41	73
ECHINODERMATA												
Ophiuroidea	0	0	0	0	0	0	0	0	0	0	1	0
Holothuroidea	0	0	0	0	0	0	0	0	0	0	0	1
Echinoidea	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA												
Pelecypoda	6	4	122	127	102	116	79	70	43	66	51	44
Gastropoda	0	0	0	1	0	0	0	0	0	0	2	0

Table II.1. (continued)

Transect-Station	A-4		B-4		C-4		D-4		E-4		F-4	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	60	61	61	59	62	60	65	63	61	65	64	62
Sample No.	1	2	1	2	1	2	1	2	2	3	1	2
CRUSTACEA												
Ostrocoda	20	14	23	40	23	29	32	21	28	15	31	19
Leptostraca	0	1	0	0	0	0	0	0	4	0	0	0
Tanaidacea	1	0	0	1	0	0	0	0	1	1	1	1
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda												
Caprellidea	0	0	0	0	0	0	0	0	0	0	0	0
Gammaridea	0	0	0	4	0	0	2	1	1	3	6	3
Mysidacea	0	0	0	0	0	0	0	0	0	0	0	0
Cumacea	0	0	0	1	1	1	1	0	0	1	2	0
Euphausiacea	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda												
Natantia	0	0	0	0	0	0	0	0	0	0	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	0	0	0	0	0	0	0
ANNELIDA												
Polychaeta	15	12	19	19	11	37	40	11	27	22	36	51
ECHINODERMATA												
Ophiuroidea	0	0	0	0	0	0	0	1	1	0	0	0
Holothuroidea	0	0	0	0	0	0	0	0	0	0	0	2
Echinoidea	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA												
Pelecypoda	1	7	77	115	36	115	110	113	6	83	100	215
Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0

Table II.1. (continued)

Transect-Station	A-5		B-5		C-5		D-5		E-5		F-5	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	79	80	76	77	77	77	77	78	78	77	74	79
Sample No.	2	3	1	2	1	2	1	2	1	2	1	2
CRUSTACEA												
Ostrocoda	11	6	19	39	7	13	32	18	20	15	39	31
Leptostraca	11	0	0	0	0	0	0	0	0	0	0	0
Tanaidacea	12	41	23	49	0	0	0	0	0	0	0	0
Isopoda	0	1	0	0	0	0	1	0	2	0	2	7
Amphipoda												
Caprellidea	0	0	0	0	0	0	0	0	0	0	1	5
Gammaridea	23	28	10	29	2	1	4	5	0	3	8	8
Mysidacea	0	0	0	0	0	0	0	0	0	0	0	0
Cumacea	0	0	0	2	0	0	5	0	1	0	5	3
Euphausiacea	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda												
Natantia	0	0	0	0	0	0	0	0	0	0	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	0	0	0	0	0	0	0
ANNELIDA												
Polychaeta	34	15	12	76	24	9	20	15	24	21	124	72
ECHINODERMATA												
Ophiuroidea	0	0	0	2	0	0	0	0	0	0	0	2
Holothuroidea	0	0	0	0	0	0	0	0	0	0	0	1
Echinoidea	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA												
Pelecypoda	1	7	11	61	15	166	133	229	133	116	324	401
Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0

Table II.1. (continued)

Transect-Station	A-6		B-6		C-6		D-6		E-6		F-6	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	95	96	95	96	92	96	90	95	93	90	89	93
Sample No.	2	3	1	2	1	2	1	2	2	3	1	2
CRUSTACEA												
Ostracoda	1	3	20	19	10	10	20	21	20	15	9	4
Leptostraca	0	2	0	0	0	0	0	0	0	0	0	0
Tanaidacea	4	60	32	25	0	0	0	1	0	2	1	0
Isopoda	0	0	0	0	0	1	0	0	0	1	0	0
Amphipoda												
Caprellidea	0	0	0	0	0	0	0	0	0	0	2	0
Gammaridea	29	216	78	75	4	0	8	5	3	6	15	6
Mysidacea	0	0	0	0	0	0	0	0	0	0	0	0
Cumacea	0	0	0	3	0	1	0	0	1	2	6	2
Euphausiacea	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda												
Natantia	0	0	0	0	0	0	0	0	0	0	0	0
Astacura	0	0	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	0	0	0	0	0	0	0
ANNELIDA												
Polychaeta	14	49	81	27	20	30	22	23	22	27	58	34
ECHINODERMATA												
Ophiuroidea	0	0	3	0	0	0	0	0	0	0	0	0
Holothuroides	0	0	0	0	0	0	0	0	0	0	0	0
Echinoidea	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA												
Pelecypoda	4	8	171	53	11	50	208	147	209	95	307	289
Gastropoda	0	0	0	2	0	0	0	0	0	0	0	0

Table II.2. Abundance of Mollusca at intensive series stations

Transect-Station	A-1		B-1		C-1		D-1		E-1		F-1	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	16	16	13	14	15	13	17	16	15	15	16	14
Sample No.	1	2	1	2	1	2	1	2	1	2	2	3
MOLLUSCA												
Pelecypoda												
Acila castrensis	0	0	0	0	0	0	0	0	0	0	0	0
Nucula bellotii	0	0	0	0	0	0	0	0	0	0	0	0
Megacrenella columbiana	0	0	0	0	0	0	0	0	0	0	0	0
Cyclocardia ventricosa	0	0	0	0	0	0	0	0	0	0	0	0
Mysella tumida	0	0	0	0	0	0	0	0	1	0	0	0
Axinopsida serricata	0	0	0	0	0	2	0	2	0	0	0	1
Clinocardium nuttallii	0	0	1	0	0	0	0	0	1	0	0	0
Nemocardium centifilosum	0	0	0	0	0	0	0	0	0	0	0	0
Compsomyax subdiaphana	0	0	0	0	0	0	0	0	0	0	0	0
Psephidia lordi	44	45	93	94	47	28	28	12	10	56	15	22
Macoma alaskana	0	0	0	0	0	0	0	0	0	0	0	0
Macoma carlottensis	0	0	0	0	0	0	0	0	0	0	0	0
Macoma carlottensis?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma elimata	0	0	0	0	0	0	0	1	0	0	0	0
Macoma elimata?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua	0	1	0	0	0	3	0	1	0	0	0	0
Macoma obliqua?	4	1	0	0	1	0	1	0	0	0	0	0
Macoma spp?	0	0	1	1	0	0	0	0	0	0	0	0
Hiatella arctica	0	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	1	1	0	0	0	1	0	0	0	0	0	0
Indeterminate	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda												
Bittium sp.	0	0	0	0	0	0	0	0	1	0	0	1
?Colus sp.	0	0	0	0	0	0	0	0	0	0	0	0
Naticidae	0	1	0	0	0	0	0	0	0	0	0	0

Table II.2. (continued)

Transect-Station	A-2		B-2		C-2		D-2		E-2		F-2	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	32	33	30	34	28	32	32	31	29	29	32	30
Sample No.	1	2	1	2	1	2	1	2	1	2	2	3
MOLLUSCA												
Pelecypoda												
Acila castrensis	0	0	0	0	0	0	0	0	0	0	0	0
Nucula bellotii	0	0	0	0	0	0	0	0	0	0	0	0
Megacrenella columbiana	0	0	0	0	0	0	0	0	0	0	0	0
Cyclocardia ventricosa	0	0	0	0	0	0	0	0	0	0	0	0
Mysella tumida	0	1	0	1	0	0	0	0	0	0	0	1
Axinopsida serricata	0	0	0	0	0	0	0	0	0	0	0	0
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0
Nemocardium centifilosum	0	0	0	0	0	0	0	0	0	0	0	0
Compsomyax subdiaphana	0	0	0	0	0	0	1	0	0	0	0	0
Psephidia lordi	1	13	96	113	110	124	3	42	12	14	15	6
Macoma alaskana	0	0	0	0	0	0	0	0	0	0	0	0
Macoma carlottensis	0	0	0	0	0	0	0	0	0	0	0	0
Macoma carlottensis?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma elimata	0	0	0	0	0	0	0	0	0	0	0	0
Macoma elimata?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua	5	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua?	0	14	2	0	0	2	1	0	2	0	0	1
Macoma spp?	0	0	0	0	0	0	0	0	0	0	0	0
Hiatella arctica	0	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	1	0	0	0	0	0	0	0	0	0
Indeterminate	0	1	0	0	0	0	0	0	0	0	0	0
Gastropoda												
Bittium sp.	0	0	0	0	0	0	0	0	0	0	0	1
?Colus sp.	0	0	0	0	0	0	1	0	0	0	0	0
Naticidae	0	0	0	0	0	1	1	0	0	0	0	0

Table II.2 (continued)

Transect-Station	A-4		B-4		C-4		D-4		E-4		F-4	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	60	61	61	59	62	60	65	63	61	65	65	62
Sample No.	1	2	1	2	1	2	1	2	2	3	1	2
MOLLUSCA												
Pelecypoda												
Acila castrensis	0	0	0	0	0	0	0	0	0	0	0	0
Nucula bellotii	0	0	0	0	0	0	0	0	0	0	0	0
Megacrenella columbiana	0	0	0	0	0	0	0	0	0	0	0	0
Cyclocardia ventricosa	0	0	0	0	0	0	0	0	0	0	0	1
Mysella tumida	0	0	0	0	0	0	0	0	0	0	0	0
Axinopsida serricata	0	0	1	0	0	6	0	0	0	2	0	0
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0
Nemocardium centifilosum	0	0	0	0	0	0	0	1	0	0	0	0
Compsomyax subdiaphana	0	0	0	0	0	0	0	0	0	0	0	0
Psephidia lordi	0	0	0	0	0	0	0	0	0	0	0	0
Macoma alaskana	1	5	74	115	33	107	107	111	3	81	96	213
Macoma carlottensis	0	0	0	0	0	0	0	0	0	0	1	0
Macoma carlottensis?	0	0	0	0	2	2	2	0	2	0	2	1
Macoma elimata	0	0	0	0	0	0	0	0	0	0	0	0
Macoma elimata?	0	0	0	0	1	0	1	0	1	0	0	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua	0	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma spp?	0	1	0	0	0	0	0	0	0	0	0	0
Hiatella arctica	0	0	2	0	0	0	0	0	0	0	1	0
Mya arenaria -	0	0	0	0	0	0	0	1	0	0	0	0
Indeterminate	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	0	1	0	0	0	0	0	0	0	0	0	0
Bittium sp.	0	0	0	0	0	0	0	0	0	0	0	0
?Colus sp.	0	0	0	0	0	0	0	0	0	0	0	0
Naticidae	0	0	0	0	0	0	0	0	0	0	0	0

Table II.2. (continued)

Transect-Station	A-3		B-3		C-3		D-3		E-3		F-3	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	47	46	47	44	47	46	48	47	45	44	45	44
Sample No.	1	2	1	2	1	2	1	2	1	2	2	3
MOLLUSCA												
Pelecypoda												
Acila castrensis	0	0	0	0	0	0	0	0	0	0	0	0
Nucula bellotii	0	0	0	0	0	0	0	0	0	0	0	0
Megacrenella columbiana	0	0	0	0	0	0	0	0	0	0	0	0
Cyclocardia ventricosa	0	0	0	0	0	0	0	0	0	0	0	0
Mysella tumida	0	0	0	0	0	2	0	0	0	0	1	1
Axinopsida serricata	0	0	0	0	0	0	0	1	0	0	1	0
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0
Nemocardium centifilosum	0	0	0	0	0	0	0	0	0	0	0	0
Compsomyax subdiaphana	0	0	0	0	0	0	0	0	0	0	0	0
Psephidia lordi	5	3	121	127	101	112	79	67	43	66	47	36
Macoma alaskana	0	0	0	0	0	0	0	0	0	0	0	0
Macoma carlottensis	0	0	0	0	0	0	0	0	0	0	1	2
Macoma carlottensis?	0	0	1	0	0	0	0	1	0	0	0	0
Macoma elimata	0	0	0	0	1	0	0	0	0	0	0	4
Macoma elimata?	0	0	0	0	0	2	0	0	0	0	0	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	1	0
Macoma obliqua	0	1	0	0	0	0	0	0	0	0	0	0
Macoma obliqua?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma spp?	1	0	0	0	0	0	0	0	0	0	0	1
Hiatella arctica	0	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	1	0	0	0	0
Indeterminate	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda												
Bittium sp.	0	0	0	0	0	0	0	0	0	0	0	0
?Colus sp.	0	0	0	1	0	0	0	0	0	0	2	0
Naticidae	0	0	0	0	0	0	0	0	0	0	0	0

Table II.2. (continued)

Transect-Station	A-5		B-5		C-5		D-5		E-5		F-5	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	79	80	76	77	77	77	77	78	78	77	74	79
Sample No.	2	3	1	2	1	2	1	2	1	2	1	2
MOLLUSCA												
Pelecypoda												
Acila castrensis	0	0	0	0	0	0	0	0	0	0	0	0
Nucula bellotii	0	0	0	0	0	0	0	0	0	0	1	0
Megacrenella columbiana	0	0	0	0	0	0	0	0	0	0	0	0
Cyclocardia ventricosa	0	0	0	0	0	0	0	0	0	0	0	0
Mysella tumida	0	0	0	0	0	0	0	0	0	1	1	0
Axinopsida serricata	0	0	0	0	1	0	0	0	0	0	0	0
Clinocardium nuttallii	0	0	0	0	0	0	1	0	0	0	0	0
Nemocardium centrifilosum	0	0	0	0	0	0	0	0	0	0	0	0
Compsomyax subdiaphana	0	0	0	0	0	0	0	0	0	0	0	0
Psephidia lordi	0	1	10	54	14	165	130	226	131	94	306	390
Macoma alaskana	0	0	0	0	0	0	0	0	0	0	0	0
Macoma carlottensis	0	3	0	5	0	0	1	2	1	18	15	6
Macoma carlottensis	0	0	0	0	0	0	0	0	0	0	0	0
Macoma elimata	0	0	0	1	0	0	1	1	1	2	1	4
Macoma elimata?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua	0	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma spp?	1	3	1	1	0	1	0	0	0	1	0	0
Hiatella arctica	0	0	0	0	0	0	0	0	0	0	0	1
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0	0
Indeterminate	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda												
Bittium sp.	0	0	0	0	0	0	0	0	0	0	0	0
?Colus sp.	0	0	0	0	0	0	0	0	0	0	0	0
Naticidae	0	0	0	0	0	0	0	0	0	0	0	0

Table II.2. (continued)

Transect-Station	A-6		B-6		C-6		D-6		E-6		F-6	
Grab size (m^2)	0.03		0.03		0.03		0.03		0.03		0.03	
Depth (m)	95	96	93	96	92	96	90	95	93	90	89	93
Sample No.	2	3	1	2	1	2	1	2	2	3	1	2
MOLLUSCA												
Pelecypoda												
Acila castrensis	0	0	1	0	0	0	0	0	0	0	0	0
Nucula bellotii	0	0	0	1	0	0	0	0	0	0	0	0
Megacrenella columbiana	0	0	0	0	0	0	0	0	0	0	0	0
Cyclocardia ventricosa	0	0	0	0	0	0	0	0	0	0	0	1
Mysella tumida	0	0	0	0	0	0	1	2	0	0	2	0
Axinopsida serricata	0	0	1	0	1	1	0	0	1	0	2	0
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0
Nemocardium centrifilosum	0	0	1	0	0	0	0	0	0	0	0	0
Compsomyax subdiaphana	0	0	0	0	0	0	0	0	0	0	0	0
Psephidia lordi	1	2	163	36	1	4	203	141	192	80	292	270
Macoma alaskana	0	0	0	0	0	0	0	0	0	0	0	0
Macoma carlottensis	0	4	5	8	9	40	2	4	13	15	9	11
Macoma carlottensis?	0	0	0	0	0	0	0	0	0	0	0	2
Macoma elimata	0	1	0	2	0	4	2	0	2	0	2	5
Macoma elimata?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0
Macoma obliqua	0	0	0	1	0	0	0	0	0	0	0	0
Macoma obliqua?	0	0	0	0	0	0	0	0	0	0	0	0
Macoma spp?	3	1	0	5	0	1	0	0	1	0	0	0
Hiatella arctica	0	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0	0
Indeterminate	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda												
Bittium sp.	0	0	0	0	0	0	0	0	0	0	0	0
?Colus sp.	0	0	0	2	0	0	0	0	0	0	0	0
Naticidae	0	0	0	0	0	0	0	0	0	0	0	0

SECTION X

Beach Observations in Port Gardner, Washington

1973, 1974 and 1975

BEACH OBSERVATIONS IN PORT GARDNER, WASHINGTON

1973, 1974, AND 1975

by

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1976

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Introduction

An annual beach survey was established along the southeast shore of Port Gardner to attempt to document gross changes in marine populations associated with projected waste load reductions by two sulfite mills on the City of Everett waterfront to the north. The initial years of the survey were considered to be a biological baseline against which a monitoring program would detect beneficial biological changes in the Port Gardner ecosystem. The results of the beach survey are expected to provide ultimately one basis for evaluating the magnitude of benefits from waste treatment.

Materials and Methods

The location of this study is the southeast shore of Port Gardner (Fig. 1). The shore begins at Everett, near the base of the 1000-yard diffuser pipeline, jointly operated by Weyerhaeuser and Scott Paper Companies, and trends southwesterly to the oil storage tanks near Mukilteo.

The necessary materials are taken to the beach (Table 1). Transect #1 is situated along the shore parallel to the pipeline. Each succeeding transect is located about 200 meters farther southwest from the preceeding transect. Each transect is marked by white paint and a (UW) stencil along the top of the breakwater.

The compass direction of the breakwater is determined. Then a point at water's edge, perpendicular to this direction, is sighted with an engineer's compass. A 3-meter pole is pushed into the substrate at the determined point to mark the transect line along which quadrat samples are to be taken.

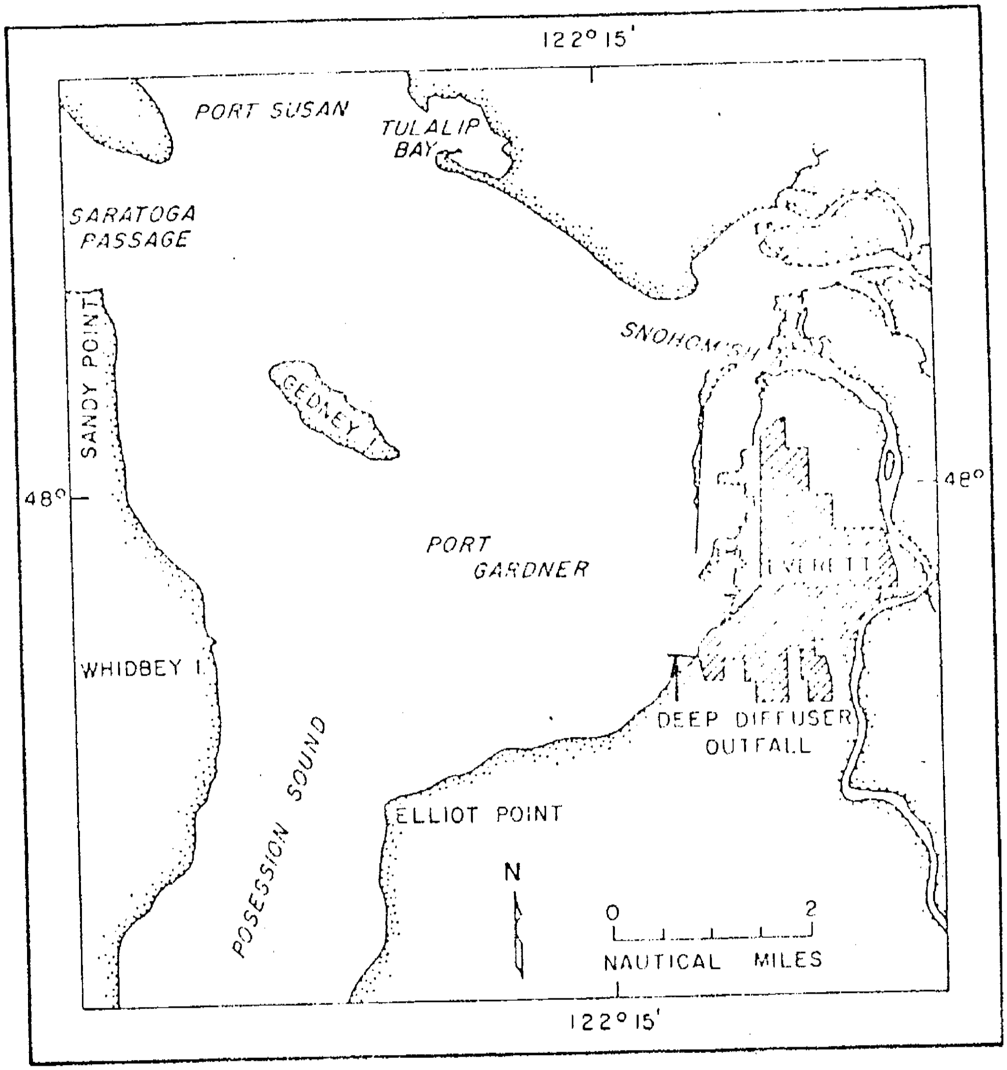

Fig. 1. The beach study area in Port Gardner extends southwesterly from the City of Everett to Elliot Point.

Table 1. Materials used on beach survey

3-meter pole, marked every 0.5 meter with 40-cm crossmembers
2-meter bamboo pole for measuring between transects
1-meter measuring stick marked with millimeters and inches
4 by 4 mm stainless steel screen-bottomed sieve box
25 by 25 cm quadrat, 3/4 inch aluminum frame with 10 cm legs
Monocular-bubble level for determining 0, 1, and 2-meter tide levels
Engineer's compass
Trowel
Small plastic bags, vials and labels
Stencil and white paint to mark stations
Buckets for carrying substrate to sieve, at water's edge
Thermometer
Notebook
Ice chest
Shovel
Pencils

The pole is then adjusted to zero tide level (mean lower low water) (Fig. 2). An example of this method is: The low tide on 4 August 1972 in Everett was at 0710 hours, at -1.3 ft (corrected). A mark 1.3 feet above 1 meter was made on the pole. Using a monocular-bubble level and a 1-meter measuring stick, a point up the beach was determined by trial, so that the top of the 1-meter stick was level with the mark (1 meter + 1.3 ft) on the pole.

Sand temperature is taken with a thermometer inserted to 12 cm below the surface.

Duplicate 25 by 25 cm quadrat samples are taken at the 0, 1, and 2-meter tide levels. The legs of the quadrat are pushed into the substrate, so that the angled aluminum is flush with the surface. The substrate is scooped out with a trowel to a depth of 10 cm and washed through a 4 by 4 mm sieve. The transect lines were displaced along the beach about 1 meter each year to avoid digging in exactly the same location in different years.

Organisms are removed from the sieve and placed in small plastic bags or screw cap vials. To avoid using preservatives, the samples are kept cold in an ice chest until returned to the lab.

In the lab, organisms are counted and identified to species. Free-living animals smaller than 4 by 4 mm which cling to algae or rocks are counted and identified (e.g., Gammarid amphipods). Attached species, smaller than 4 by 4 mm (e.g., barnacles) are counted and identified along with larger organisms. Algae were identified only to genus and presence, but not quantity, was noted.

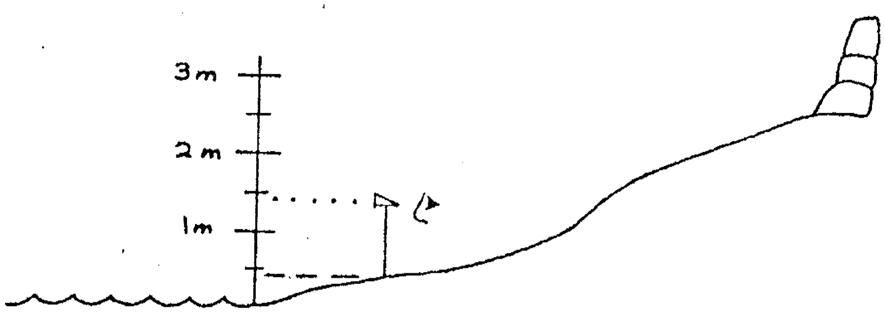

Fig. 2. Schematic representation of the use of the 3-meter pole and monocular-bubble level to determine quadrat locations along transect lines.

Results

The results of the Port Gardner beach survey are contained in the field logs from 1973, 1974, and 1975 (Appendix). A species list of scientific and common names has been assembled for organisms identified from the beach (Table 2).

The average abundance from two quadrats, at three tide heights, for 26 stations, has been tabulated for each of 3 years (Tables 3-11). The most abundant animals are barnacles (*Balanus glandula*) and mussels (*Mytilus edulis*). Other animals occur in few locations and in lower numbers.

Discussion

The annual beach survey has established a biological baseline against which a monitoring program can detect gross changes in marine populations. Several situations might occur which could suggest beneficial biological changes in the Port Gardner ecosystem: (1) organisms might start to occur in areas where they were absent, particularly toward the mills; (2) organisms, particularly barnacles and mussels, might become significantly more abundant.

Table 2. Organisms identified from the beach at Port Gardner

Scientific Name	Common Name	
Acanthodorus brunnea MacFarland, 1905	Brown Nudibranch	sea slug
Acmaea pelta Eschscholtz, 1833	Shield Limpet	
Anisogammurus sp.		amphipod
Anthopleura artemisia (Pickering, 1848)	Burrowing Anemone	
Balanus cariosus (Pallas, 1788)	Horse Barnacle	
Balanus glandula Darwin, 1854	Acorn Barnacle	
Bryopsis sp.		filamentous green algae
Callianassa californiensis Dana, 1854	Pink Mud Shrimp	
Cancer gracilis Dana, 1852	Graceful Cancer Crab	
Cancer oregonensis (Dana, 1852)	Hairy Cancer Crab	
Clevelandia ios (Jordan & Gilbert, 1882)	Arrow Goby	fish
Clinocardium nuttallii Conrad, 1837	Cockle	clam
Crago alaskensis (Lockington, 1877)	Alaska Shrimp	
Cryptomya californica (Conrad, 1837)	False Mya	clam
Dictyosiphon sp.		brown algae
Emplectonema sp.	Ribbon Worm	nemertinean worm
Enteromorpha sp.	Silk Confetti	green algae
Exosphaeroma oregonensis Dana	Oregon Pill Bug	isopod
Fucus sp.	Rockweed	brown algae
Gammurus sp.		amphipod
* *Gigartina* sp.	Turkish Towel	red algae
Glycerid		polychaete worm
Hemigrapsus nudus (Dana, 1851)	Purple Beach Crab	

Table 2. (cont.)

Scientific Name	Common Name	
Hemigrapsus oregonensis (Dana, 1851)	Hairy Shore Crab	
Hyallela ? sp.		amphipod
Idothea (Pentidotes) aculeata (Stafford, 1913)		isopod
Idothea fewkesi Richardson, 1905		isopod
Irodophycus sp.	Iridescent Seaweed	red algae
Ischyrocerus sp.		amphipod
Ligia pallasii (Brandt, 1833)	Sea Slater	isopod
Littorina planaxis Philippi, 1847	Flat Periwinkle	snail
Littorina scutulata Gould, 1849	Checkered Periwinkle	snail
Macoma balthica (Linnaeus, 1758) (= *M. inconspicua*)	Inconspicuous Macoma	clam
Macoma inquinata (Deshayes, 1854)	Polluted Macoma	clam
Macoma nasuta (Conrad, 1837)	Bent-nose Clam	
Macoma secta (Conrad, 1837)	Sand Clam	
Melita sp.		amphipod
Moldanid		polychaete worm
Mopalia lignosa (Gould, 1846)	Hairy Chiton	
Mya arenaria Linnaeus, 1758	Soft-shell Clam	
Mytilus edulis Linnaeus, 1758	Edible Mussel	
Nemertinea		ribbon worm
Nephtyid		polychaete worm
Nereid		polychaete worm
Pagurus hirsutuisculus (Dana, 1851)	Hairy Hermit Crab	
Paraphoxus sp.		amphipod
Pectinariid		polychaete worm

Table 2. (cont.)

Scientific Name	Common Name	
Phyllodocid		polychaete worm
Platyhelminthes		flat worm
Protothaca staminea (Conrad, 1837)	Little-neck Clam	
Saxidomus giganteus (Deshayes, 1839)	Butter Clam	
Thais lamellosa (Gmelin, 1792)	Wrinkled Purple Snail	
Ulva sp.	Sea Lettuce	green algae
Upogebia pugettensis (Dana, 1852)	Marine Crayfish	mud shrimp
** *Venerupis japonica* (Deshayes)	Japanese Little-neck	clam
Zostrea sp.	Eelgrass	

* Observed on breakwater only

** Observed in trenches only

Table 3. Average abundance from two samples of animals at mean lower low water at 26 transects in Port Gardner, 1973.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Platyhelminthes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertinea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	0	3	0	5	7	2	1	0	0	0	0	0	1	0	0	0	1	1	1	0	1	4	0	3	1	1
Cnidaria																										
Anthopleura artemisia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arthropoda																										
Isopoda	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Amphipoda	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cirripedia																										
Balanus cariosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Balanus glandula	0	1	0	15	140	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	790	57	279	0	0
Decapoda																										
Callianassa californiensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Cancer gracilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Cancer oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Crago alaskensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Hemigrapsus nudus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemigrapsus oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pagurus hirsutiusculus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Upogebia pugettensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca																										
Bivalvia																										
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Cryptomya californica	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Macoma balthica	1	0	1	0	0	0	0	0	0	0	0	1	2	0	0	0	1	0	0	1	0	0	2	4	2	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	1	0	0	0
Macoma nasuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mytilus edulis	0	0	0	57	36	0	1	0	23	0	0	0	0	0	0	0	0	0	0	0	0	65	4	22	0	0
Protothaca staminea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	0
Saxidomus giganteus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Gastropoda																										
Acanthodoris brunnea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acmaea pelta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina planaxis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thais lamellosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphineura																										
Mopalia lignosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chordata																										
Pisces																										
Clevelandia ios	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Algae & eelgrass																										
Bryopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosiphon	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0
Enteromorpha	0	0	0	0	0	0	X	0	0	0	0	0	X	0	0	0	X	0	0	0	X	X	X	0	0	0
Fucus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulva	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0
Zostrea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0

Table 4. Average abundance from two samples of animals at 1 meter above mean lower low water at 26 transects in Port Gardner, 1973.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Platyhelminthes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertinea	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	0	5	3	0	0	0	1	0	1	0	1	1	7	1	0	0	1	0	1	1	1	2	0	2	0	0
Cnidaria																										
Anthopleura artemisia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Arthropoda																										
Isopoda	0	4	6	0	0	1	0	0	0	1	0	0	2	0	2	0	0	0	0	1	0	0	3	0	0	0
Amphipoda	0	0	0	0	0	0	0	0	0	25	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Cirripedia																										
Balanus cariosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Balanus glandula	0	234	145	14	5	130	0	0	0	200	347	123	1928	0	421	131	3	252	38	1307	218	1065	890	165	0	0
Decapoda																										
Callianassa californiensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer gracilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crago alaskensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemigrapsus nudus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemigrapsus oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Pagurus hirsutiusculus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upogebia pugettensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca																										
Bivalvia																										
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Cryptomya californica	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	0	2	17	0	0	0	0	1	0	1	0	0	2	14	8	3	1	0	0	0	0	0	0	0	1	4
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma nasuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	1	5	0	0	0	0	0	0	0	0	0	1	0	3	1	0	0	0	0	0	0	0	0	0	0
Mytilus edulis	0	80	172	3	1	5	1	0	0	9	0	0	154	0	0	1	0	0	1	56	3	4	46	2	0	0
Protothaca staminea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxidomus giganteus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda																										
Acanthodoris brunnea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acmaea pelta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina planaxis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thais lamellosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphineura																										
Mopalia lignosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chordata																										
Pisces																										
Clevelandia ios	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Algae & eelgrass																										
Bryopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosiphon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0
Enteromorpha	0	X	X	X	0	0	X	X	0	X	X	X	X	0	X	X	X	X	X	0	0	0	0	0	0	0
Fucus	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulva	0	0	0	0	0	0	0	X	0	0	X	0	X	0	0	X	0	X	X	X	0	0	0	0	0	0
Zostrea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5. Average abundance from two samples of animals at 2 meters above mean lower low water at 26 transects in Port Gardner, 1973.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Platyhelminthes	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Nemertinea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Polychaeta	0	0	0	0	0	-	0	0	0	0	0	0	5	0	1	0	0	0	0	1	-	-	0	-	0	0
Cnidaria																										
Anthopleura artemisia	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Arthropoda																										
Isopoda	0	0	0	0	0	-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Amphipoda	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cirripedia																										
Balanus cariosus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Balanus glandula	2	1	0	1	0	-	0	0	0	0	59	0	349	0	2	275	0	25	4	41	-	-	0	-	0	0
Decapoda																										
Callianassa californiensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cancer gracilis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cancer oregonensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Crago alaskensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Hemigrapsus nudus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Hemigrapsus oregonensis	0	0	0	0	0	-	0	0	0	0	0	0	1	0	0	0	0	0	0	0	-	-	0	-	0	0
Pagurus hirsutiusculus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Upogebia pugettensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Mollusca																										
Bivalvia																										
Clinocardium nuttallii	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cryptomya californica	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Macoma balthica	0	0	0	0	0	-	1	0	0	0	0	0	0	0	7	0	0	0	0	0	-	-	0	-	0	0
Macoma inquinata	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Macoma nasuta	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Mya arenaria	0	0	0	0	0	-	0	0	0	0	0	0	3	0	6	0	0	0	0	0	-	-	0	-	0	0
Mytilus edulis	0	1	1	3	0	-	4	0	0	0	0	0	75	0	3	0	0	0	0	10	-	-	0	-	0	0
Protothaca staminea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Saxidomus giganteus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Gastropoda																										
Acanthodoris brunnea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Acmaea pelta	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Littorina planaxis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Thais lamellosa	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Amphineura																										
Mopalia lignosa	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Chordata																										
Pisces																										
Clevelandia ios	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Algae & eelgrass																										
Bryopsis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Dictyosiphon	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Enteromorpha	0	0	0	0	0	-	X	0	0	0	X	0	X	0	X	X	X	0	0	X	-	-	0	-	0	0
Fucus	0	0	0	0	0	-	0	0	0	0	X	0	0	0	0	0	X	X	0	X	-	-	0	-	0	0
Ulva	0	0	0	0	0	-	X	0	0	0	X	0	X	0	X	0	X	0	0	X	-	-	0	-	0	0
Zostrea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0

Table 6. Average abundance from two samples of animals at mean lower low water at 26 transects in Port Gardner, 1974.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Platyhelminthes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertinea	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	1	1	0	0	0
Polychaeta	2	0	0	0	0	1	0	0	3	0	0	1	1	1	1	0	0	0	0	0	0	3	1	1	0	0
Cnidaria																										
Anthopleura artemisia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Arthropoda																										
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	0	0	0
Amphipoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	3	0
Cirripedia																										
Balanus cariosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Balanus glandula	0	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	953	1241	0	0	0
Decapoda																										
Callianassa californiensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer gracilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crago alaskensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Hemigrapsus nudus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemigrapsus oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0
Pagurus hirsutiusculus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upogebia pugettensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca																										
Bivalvia																										
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Cryptomya californica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	1	2	0	0	0	1	0	0	0	0	1	0	0	1	4	0	1	0	1	1	0	0	0	1	0	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	3	0	0	0
Macoma nasuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mytilus edulis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98	406	0	0	0
Protothaca staminea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0
Saxidomus giganteus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Gastropoda																										
Acanthodoris brunnea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acmaea pelta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina planaxis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Thais lamellosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphineura																										
Mopalia lignosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Chordata																										
Pisces																										
Clevelandia ios	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Algae & eelgrass																										
Bryopsis	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	X	0	0	X	X	0
Dictyosiphon	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enteromorpha	0	0	0	0	X	0	0	0	0	0	0	X	0	X	0	0	0	0	0	0	0	X	X	0	0	0
Fucus	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulva	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	X	X	0	0	0
Zostrea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0

Table 7. Average abundance from two samples of animals at 1 meter above mean lower low water at 26 transects in Port Gardner, 1974.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Platyhelminthes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertinea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Polychaeta	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	3	2	0	0	0
Cnidaria																										
Anthopleura artemisia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arthropoda																										
Isopoda	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cirripedia																										
Balanus cariosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Balanus glandula	0	228	20	0	1	3	18	1	0	3	25	0	0	0	85	6	0	175	0	312	30	330	731	0	0	0
Decapoda																										
Callianassa californiensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer gracilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crago alaskensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemigrapsus nudus	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemigrapsus oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0
Pagurus hirsutiusculus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upogebia pugettensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca																										
Bivalvia																										
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cryptomya californica	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	0	4	1	0	0	0	1	0	0	0	0	1	0	0	4	0	1	0	1	0	0	0	0	0	0	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma nasuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mytilus edulis	0	18	0	0	0	1	16	0	0	0	0	0	0	0	4	21	0	0	0	332	0	3	35	0	0	0
Protothaca staminea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Saxidomus giganteus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda																										
Acanthodoris brunnea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acmaea pelta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina planaxis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0
Thais lamellosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphineura																										
Mopalia lignosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chordata																										
Pisces																										
Clevelandia ios	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Algae & eelgrass																										
Bryopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0	0	0	0	0	0
Dictyosiphon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enteromorpha	0	X	0	0	0	0	X	X	0	0	X	0	X	X	X	X	0	X	0	X	X	X	0	0	0	0
Fucus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulva	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	X	X	X	0	0	0	0
Zostrea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8. Average abundance from two samples of animals at 2 meters above mean lower low water at 26 transects in Port Gardner, 1974.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Platyhelminthes	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Nemertinea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Polychaeta	0	0	0	0	0	-	0	0	0	0	0	1	0	0	0	0	0	0	2	0	-	-	0	-	0	0
Cnidaria																										
Anthopleura artemisia	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Arthropoda																										
Isopoda	0	0	0	0	0	-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Amphipoda	0	0	0	0	0	-	0	0	0	0	0	1	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cirripedia																										
Balanus cariosus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Balanus glandula	0	2	0	0	0	-	128	0	0	0	109	155	520	0	0	0	0	4	205	567	-	-	0	-	0	0
Decapoda																										
Callianassa californiensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cancer gracilis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cancer oregonensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Crago alaskensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Hemigrapsus nudus	0	0	0	0	0	-	0	0	0	0	0	1	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Hemigrapsus oregonensis	0	0	0	0	0	-	0	0	0	0	0	1	0	0	0	0	0	0	1	0	-	-	0	-	0	0
Pagurus hirsutiusculus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Upogebia pugettensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Mollusca																										
Bivalvia																										
Clinocardium nuttallii	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cryptomya californica	0	0	0	0	0	-	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-	-	0	-	0	0
Macoma balthica	0	0	0	0	0	-	4	0	0	0	0	0	1	0	21	0	0	0	0	0	-	-	0	-	0	0
Macoma inquinata	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Macoma nasuta	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Mya arenaria	0	0	0	0	0	-	1	0	0	0	0	0	0	0	3	0	0	0	0	0	-	-	0	-	0	0
Mytilus edulis	0	1	0	0	0	-	27	0	0	0	0	0	10	0	0	0	0	0	0	28	-	-	0	-	0	0
Protothaca staminea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Saxidomus giganteus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Gastropoda																										
Acanthodoris brunnea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Acmaea pelta	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-	-	0	-	0	0
Littorina planaxis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Thais lamellosa	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Amphineura																										
Mopalia lignosa	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Chordata																										
Pisces																										
Clevelandia ios	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Algae & eelgrass																										
Bryopsis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Dictyosiphon	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Enteromorpha	0	0	0	0	0	-	X	0	0	0	X	X	0	0	X	0	X	0	0	X	-	-	0	-	0	0
Fucus	0	0	0	0	0	-	0	0	0	0	0	0	X	0	X	0	X	0	0	X	-	-	0	-	0	0
Ulva	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	X	0	0	X	-	-	0	-	0	0
Zostrea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0

Table 9. Average abundance from two samples of animals at mean lower low water at 26 transects in Port Gardner, 1975.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Platyhelminthes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
Nemertinea	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	2	0	0	1	0	0	0
Polychaeta	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	1	0	1	2	1	2	1	0
Cnidaria																										
Anthopleura artemisia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Arthropoda																										
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	7	4	0	0	0
Amphipoda	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	0	16	6	0	0	0
Cirripedia																										
Balanus cariosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Balanus glandula	0	0	0	0	22	9	15	0	337	0	0	0	0	0	0	0	0	0	1599	0	0	1342	1013	0	0	0
Decapoda																										
Callianassa californiensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer gracilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crago alaskensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemigrapsus nudus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Hemigrapsus oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Pagurus hirsutiusculus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	9	2	0	0	0
Upogebia pugettensis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca																										
Bivalvia																										
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cryptomya californica	0	0	2	1	0	2	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	0	0	2	0	1	0	0	1	0	0	0	0	1	1	2	0	0	0	0	0	1	0	0	1	1	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	0	0	2	2	1	0	0
Macoma nasuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Mytilus edulis	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	53	0	0	79	123	0	0	0
Protothaca staminea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Saxidomus giganteus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda																										
Acanthodoris brunnea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Acmaea pelta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Littorina planaxis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thais lamellosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0
Amphineura																										
Mopalia lignosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chordata																										
Pisces																										
Clevelandia ios	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Algae & eelgrass																										
Bryopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosiphon	0	0	0	0	0	0	0	0	0	X	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enteromorpha	0	0	0	0	0	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X
Fucus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulva	0	0	0	0	0	0	X	0	X	0	0	0	0	0	0	0	0	0	X	0	0	X	X	0	0	0
Zostrea	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0	X	0	0	X	0

Table 10. Average abundance from two samples of animals at 1 meter above mean lower low water at 26 transects in Port Gardner, 1975.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Platyhelminthes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertinea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	2	1	1	3	0	0	0
Cnidaria																										
Anthopleura artemisia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arthropoda																										
Isopoda	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	24	0	0	10	21	0	0	4	0	0	0
Amphipoda	0	1	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	1	6	0	0	0
Cirripedia																										
Balanus cariosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Balanus glandula	0	42	0	0	0	16	169	0	0	0	347	318	0	0	0	555	0	14	649	3017	0	1	1065	54	50	0
Decapoda																										
Callianassa californiensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer gracilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crago alaskensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemigrapsus nudus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	9	0	0	0
Hemigrapsus oregonensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0
Pagurus hirsutiusculus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upogebia pugettensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca																										
Bivalvia																										
Clinocardium nuttallii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cryptomya californica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0
Macoma inquinata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macoma nasuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Mytilus edulis	0	1	0	0	0	0	39	0	0	0	7	1	0	0	0	3	0	0	164	424	0	1	30	0	0	0
Protothaca staminea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saxidomus giganteus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda																										
Acanthodoris brunnea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acmaea pelta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Littorina planaxis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thais lamellosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphineura																										
Mopalia lignosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chordata																										
Pisces																										
Clevelandia ios	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Algae & eelgrass																										
Bryopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosiphon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enteromorpha	0	X	0	0	0	0	0	0	0	0	X	X	0	0	X	0	0	0	0	X	0	0	X	0	0	0
Fucus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	0	0	0	0	0	0
Ulva	0	0	0	0	0	0	X	0	0	0	0	X	0	0	0	0	0	0	X	0	0	0	X	0	0	0
Zostera	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	0	0	0	0	0

Table 11. Average abundance from two samples of animals at 2 meters above mean lower low water at 26 transects in Port Gardner, 1975.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Platyhelminthes	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Nemertinea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-	-	0	-	0	0
Polychaeta	0	0	0	0	0	-	0	0	0	0	0	0	1	0	0	0	0	0	1	2	-	-	0	-	0	0
Cnidaria																										
Anthopleura artemisia	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Arthropoda																										
Isopoda	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	2	0	0	0	1	-	-	0	-	0	0
Amphipoda	0	0	0	0	0	-	0	0	0	0	0	2	0	0	0	3	0	0	0	0	-	-	0	-	0	0
Cirripedia																										
Balanus cariosus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Balanus glandula	0	0	0	0	0	-	61	0	0	0	284	0	8	2	1	5	0	0	40	665	-	-	0	-	0	0
Decapoda																										
Callianassa californiensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cancer gracilis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cancer oregonensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Crago alaskensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Hemigrapsus nudus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Hemigrapsus oregonensis	0	0	0	0	0	-	0	0	0	0	0	2	0	0	0	0	0	0	0	5	-	-	0	-	0	0
Pagurus hirsutiusculus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Upogebia pugettensis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Mollusca																										
Bivalvia																										
Clinocardium nuttallii	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Cryptomya californica	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Macoma balthica	0	0	0	0	0	-	4	0	0	0	0	0	0	0	3	1	0	0	0	0	-	-	0	-	0	0
Macoma inquinata	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Macoma nasuta	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Mya arenaria	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Mytilus edulis	0	0	0	0	0	-	50	0	0	0	0	1	7	0	0	0	0	0	26	187	-	-	0	-	0	0
Protothaca staminea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Saxidomus giganteus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Gastropoda																										
Acanthodoris brunnea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Acmaea pelta	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Littorina planaxis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Thais lamellosa	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Amphineura																										
Mopalia lignosa	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Chordata																										
Pisces																										
Clevelandia ios	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Algae & eelgrass																										
Bryopsis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Dictyosiphon	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0
Enteromorpha	0	0	0	0	0	-	X	0	0	0	X	X	0	0	0	0	X	X	X	X	-	-	0	-	0	0
Fucus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	X	X	X	X	-	-	0	-	0	0
Ulva	0	0	0	0	0	-	X	0	0	0	0	0	0	0	0	0	X	X	X	0	-	-	0	-	0	0
Zostrea	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0	-	0	0

FIELD LOG

PT. GARDNER ECOBAM BEACH TRANSECTS - 1973

Transect #1 21 MAR 73

Parallel and on top of diffuser pipeline. 270° T.
Time: 0915 hrs. Sand temp. 8° C.

2 m level 13 m from seawall. Gravel and coarse sand.

Quadrat #1 nothing

Quad. #2 3 *Balanus glandula*

1 m level 23 m from seawall. Coarse sand and gravel.

Quad. #3 nothing

Quad. #4 nothing

Ø m level 245 m from seawall. 1330 hrs. Sand temp. 16° C. Sand and silt.

Quad. #5 1 *Macoma inconspicua*
2 Nereid worms

Quad. #6 1 *Cryptomya californica*
3 Nereid worms

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #2 20 MAR 73

Adjacent to Pigeon Creek. 317° T.
Time: 0945 hrs. Weather: Clear and sunny.

2 m level 5 m from breakwater. Gravel and coarse sand.

Quad. #7 1 small* *Mytilus edulis*
1 small *Balanus glandula*

Quad. #8 1 small *M. edulis*
1 small *B. glandula*

1 m level 22½ m from breakwater. Gravel, coarse sand, cobbles, barnacles, mussels and algae.

Quad. #9 241 *B. glandula*
87 *M. edulis*
9 *Cryptomya californica*
6 *Exosphaeroma oregonensis*
4 Nereid worms
3 *Macoma inconspicua*
2 *Mya arenaria*
Enteromorpha

Quad. #10 227 *B. glandula*
73 *M. edulis*
3 *C. californica*
2 *E. oregonensis*
5 Nereid worms
Enteromorpha

Deeper holes revealed several small *Mya arenaria* of 15-40 mm in length.

Ø m level 212½ m from breakwater. Sand and silt.

Quad. #11 nothing

Quad. #12 1 loose *B. glandula*

* small = smaller than 4 mm^2.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #3 21 MAR 73

317° T.
Time: 1000 hrs. Sand temp. 7° C.

2 m level 3½ m from breakwater. Gravel, rocks, and sand.

Quad. #13 1 small *Mytilus edulis*

Quad. #14 nothing

1 m level 12½ m from breakwater. Cobbles, gravel, sand, algae, barnacles, and mussels.

Quad. #15
- 153 *B. glandula*
- 56 *M. edulis*
- 114 small *M. edulis*
- 5 Nereid worms
- 4 *Exosphaeroma oregonensis*
- 6 *Macoma inconspicua*
- 4 *Mya arenaria*
- 4 nemerteans
- *Enteromorpha*

Quad. #16
- 136 *B. glandula*
- 127 *M. edulis*
- 47 small *M. edulis*
- 7 *E. oregonensis*
- 27 *M. inconspicua*
- 5 *M. arenaria*
- Enteromorpha

∅ m level 95½ m from breakwater. Sand and silt.

Quad. #17 nothing

Quad. #18 2 *M. inconspicua*

A deep hole dug revealed the presence of the Ghost Shrimp *Callianassa californiensis* and *Macoma inconspicua*.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #4 21 MAR 73

Time: 1030 hrs. 307° T. Sand temp. 7° C.

2 m level at base of breakwater. Gravel, rocks and sand.

Quad. #19 2 *Mytilus edulis*

Quad. #20 3 *M. edulis*
1 *Balanus glandula*

1 m level 9 m below breakwater. Cobbles, gravel, sand, barnacles, mussels, and algae.

Quad. #21 23 *B. glandula*
4 *M. edulis*
Enteromorpha

Quad. #22 5 *B. glandula*
2 *M. edulis*
Enteromorpha

Ø m level 4 APR 73 25 m below breakwater. Sand and silt.

Quad. #23 13 *B. glandula*
17 *M. edulis*
40 small *M. edulis*
8 *Exosphaeroma oregonensis*
7 Nereid polychaetes
1 *Idothea* (*Pentidotea*) *aculeata*

Quad. #24 16 *B. glandula*
27 *M. edulis*
30 small *M. edulis*
1 *E. oregonensis*
2 Nereid polychaetes
1 Phyllodocid polychaete

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #5 22 MAR 73

Time: 1145 hrs. 317° T. Sand temp. 13° C.

2 m level adjusted to 1½ m at base of breakwater. Coarse sand.

Quad. #25 nothing

Quad. #26 nothing

1 m level 6 3/4 m below breakwater. Gravel, rocks and sand.

Quad. #27 2 small *M. edulis*
9 *B. glandula*

Quad. #28 nothing

Ø m level 4 APR 73 1220 hrs. 15 m from breakwater. Cobbles, gravel, sand, algae, barnacles and some mussels.

Quad. #29 215 *B. glandula*
17 *M. edulis*
54 small *M. edulis*
11 Nereid polychaetes
1 Glycerid polychaete
1 unidentified polychaete
3 *Exosphaeroma oregonensis*
1 *Melita* amphipod

Quad. #30 64 *B. glandula*
1 piece of *Fucus*

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #5 Breakwater rocks

At the base of the breakwater, there is a 10 cm barren section, apparently caused by a scouring action of sand and waves at high tides.

Above this to a height of 160 cm is the green algae Enteromorpha, with occasional Ulva plants. Small Balanus glandula barnacles and Mytilus edulis mussels are scattered throughout this algal band. The brown algae Fucus grows in scattered patches up to 140 cm. At least two species of red algae Gigartina and Irodophycus grows in widely scattered tufts to a height of 115 cm.

M. edulis are attached to a height of 145 cm and is especially predominate and much larger in crevices and holes formed by adjacent boulders. The isopod Ligia pallasii and the periwinkle snail Littorina planaxis are also found in the crevices.

Barnacles are found to a height of 180-190 cm, with B. glandula up to 140 cm and B. cariosus in the splash zone above that.

Between and beneath the masses of mussels are the nemertean worms Emplectonema, Nereid polychaete worms, and the amphipod Hyallela ? sp.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #6 4 APR 73

Transect bearing 352° T.
Time: 1300 hrs. Sand temp. 17° C.

2 m level Located about two feet above base of the breakwater. No samples taken.

1 m level 15 m from breakwater. Coarse sand underlain with gravel.

Quad. #31
2 M. edulis
139 B. glandula
1 E. oregonensis

Quad #32
1 M. edulis
6 small M. edulis
121 B. glandula
A small cluster of nudibranch eggs

Ø m level 30 m from breakwater. Sand and silt.

Quad. #33 nothing

Quad. #34 3 Nereid polychaetes

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #7 4 APR 73

Transect bearing 312° T. located 204 m SW of Transect #6 in line with pedestrian bridge leading to beach at Everett's Howarth Waterfront Park.
Time: 1015 hrs.

2 m level 11 m from new breakwater extended 20 m out from old shoreline. Cobbles, gravel, sand, barnacles, mussels and algae.

Quad. #35 3 *M. edulis*
1 small *M. edulis*
1 *E. oregonensis*
2 Nereid polychaetes

Quad. #36 1 *Macoma inconspicua*
3 *M. edulis*
Enteromorpha
Ulva

1 m level 68 m from new breakwater. Gravel, sand, algae and barnacles.

Quad. #37 *Enteromorpha*

Quad. #38 1 *M. edulis*
1 unidentified polychaete
Enteromorpha

Ø m level 115 m from new breakwater. Sand and silt.

Quad. #39 1 *M. edulis*
Enteromorpha
Ulva

Quad. #40 1 Nephtyid polychaete

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #8 5 APR 73

196 m SW of pedestrian overpass and near a tall metal box along railroad.
Time: 1300 hrs. 322° T.

2 m level 7 m from seawall. Substrate predominately sand with scattered small rocks and gravel.

Quad. #41 nothing

Quad. #42 nothing

1 m level 16 m from seawall. Scattered cobbles, gravel and sand. Cobbles are covered with green algae and some barnacles.

Quad. #43 1 *Macoma inconspicua*
Enteromorpha
Ulva

Quad. #44 *Enteromorpha*
Ulva

Ø m level 71 m from breakwater. Sand and silt.

Quad. #45 nothing

Quad. #46 nothing

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #9 5 APR 73

Transect bearing 322° T.
Time: 1230 hrs.

2 m level 5 m from breakwater. Scattered boulders to breakwater. Rocks, gravel and sand.

Quad. #47 nothing

Quad. #48 nothing

1 m level 15 m from breakwater. Cobbles, rocks, gravel and sand.

Quad. #49 1 Nereid polychaete

Quad. #50 nothing

Ø m level 5 APR 73 23 m from breakwater. Sand and silt.

Quad. #51 4 *B. glandula*
4 *M. edulis*
23 small *M. edulis*

Quad. #52 8 *B. glandula*
18 small *M. edulis*

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #10 5 APR 73

Transect bearing 332° T.
Time: 1200 hrs. Sand temp. 14° C.

2 m level 14 m from seawall. Mostly sand on the surface with scattered rocks, underlain with considerably more rocks and gravel.

Quad. #53 nothing

Quad. #54 nothing

1 m level 24 m from seawall. Coarse sand and gravel underlain with finer sand and silt.

Quad. #55 200 tiny *B. glandula*
50 *Gammarus* sp.
18 small *M. edulis*
2 *Macoma inconspicua*
1 *Idothea fewkesi*
Enteromorpha

Quad. #56 200 tiny *B. glandula*
Enteromorpha

Ø m level 44 m from seawall. Sand and silt.

Quad. #57 nothing (sample taken in the sand between bunches of the brown algae *Dictyosiphon*.)

Quad. #58 *Dictyosiphon* (sample taken including a bunch of *Dictyosiphon*.)

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #11 31 MAY 73

Transect bearing 332° T. Located directly in line with a fresh-water stream. Transect line was adjusted another 10 m SW, but never-the-less cuts across the stream's delta. The shoreline has no breakwater or seawall and only subtended by beach grass. Transect was marked at the end of a large log as no other object was available.
Time: 1030 hrs.

2 m level 30 m from edge of beach grass (also parallel to end of culvert pipe). Cobbles sand and gravel. Debris consisting of algae, bark particles and eelgrass.

Quad. #59 8 tiny *Balanus glandula*

Quad. #60 6 *B. glandula*
103 tiny *B. glandula*
Ulva
Enteromorpha
Fucus

1 m level 54 m from beach grass. Rocks, sand, gravel and algae.

Quad. #61 250 tiny *B. glandula*
1 Nereid polychaete
Ulva
Enteromorpha

Quad. #62 438 tiny *B. glandula*
5 *B. glandula*
Ulva
Enteromorpha

Ø m level Coarse sand, small gravel. Polychaete and *Callianassa* holes. 160 m from beach grass.

Quad. #63 nothing

Quad. #64 nothing

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #12 31 MAY 73

Transect bearing 347° T. A small culvert at the top of the breakwater near transect marker. Overcast sky.
Time: 1220 hrs. Air temp. 14° C. Sand temp. 13.5° C.

2 m level 13 m below breakwater. Gravel, coarse sand and cobbles.

Quad. #65 nothing
sampled 10 JUL 73
Quad. #66 nothing

1 m level 23 m below breakwater. Cobbles, coarse sand and scattered boulders.

Quad. #67 100 Balanus glandula
Enteromorpha

Quad. #68 145 B. glandula
2 Nereid polychaetes
2 Anisogammurus amphipods
Enteromorpha

Ø m level 45 m below breakwater. Coarse sand.

Quad. #69 1 small Macoma inconspicua

Quad. #70 1 small M. inconspicua

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #13 31 MAY 73

Transect bearing 357° T.
Time: 1300 hrs.

2 m level 8 m below seawall. Gravel, coarse sand and scattered cobbles.

Quad. #71
197 Balanus glandula
11 Mytilus edulis
2 Nereid polychaetes
3 Mya arenaria (small)
Enteromorpha
Ulva

Quad. #72
500 B. glandula
138 M. edulis
3 Mya arenaria (small)
9 Nereid polychaetes
1 Hemigrapsus oregonensis

Both sampled 10 JUL 73

1 m level 29 m below seawall. Scattered cobbles, small boulders covered with barnacles, mussels and algae.

Quad. #73
1200 tiny Balanus glandula
55 B. glandula
32 M. edulis
54 small M. edulis
6 Nereid polychaetes
1 Macoma inconspicua
Enteromorpha
Ulva

Quad. #74
2600 B. glandula
141 small M. edulis
80 M. edulis
8 Nereid polychaetes
3 Exosphaeroma oregonensis
1 small Mya arenaria
2 M. inconspicua
1 Nemertean worm
Enteromorpha
Ulva
Fucus

Ø m level 70 m below seawall. Silt and sand.

Quad. #75 nothing

Quad. #76
3 M. inconspicua
2 Glycerid polychaetes
Enteromorpha

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #14 10JUL 73

Transect bearing 002° T. 80% overcast with intermittent sunshine.
Air temp. 19° C. Sand temp. 18° C.

2 m level 1 m from breakwater. Coarse sand, gravel, scattered boulders.

Quad. #77 nothing

Quad. #78 nothing

1 m level 19 m from breakwater. Cobbles, gravel and scattered boulders.

Quad. #79 13 Macoma inconspicua

Quad. #80 15 Macoma inconspicua
1 Glycerid polychaete

Ø m level 113 m from breakwater. Silt and sand.

Quad. #81 nothing

Quad. #82 nothing

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #15 11 JUL 73

Transect bearing 357° T. This transect just south of large stream with a large delta and high bridge in the gulley. Weather sunny. Time: 0930 hrs. Sand temp. 18° C.

2 m level 46 m from breakwater. Gravel, cobbles, sand and scattered small boulders.

Quad. #83 7 *Macoma inconspicua*
7 *Mya arenaria*
1 *Mytilus edulis*
1 Nereid polychaete
Enteromorpha
Ulva

Quad. #84 6 *M. inconspicua*
4 *M. arenaria*
4 *M. edulis*
3 *Balanus glandula*
Enteromorpha

1 m level 98 m from breakwater. Gravel, rocks and sand with barnacles and algae on rocks.

Quad. #85 657 *B. glandula*
4 *Exosphaeroma oregonensis*
6 *Macoma inconspicua*
1 *M. arenaria*

Quad. #86 195 *B. glandula*
10 *M. inconspicua*
4 *M. arenaria*

Ø m level 135 m from breakwater. Sand underlain with clay and sandstone.

Quad. #87 nothing

Quad. #88 nothing

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #16 11 JUL 73

Transect bearing 347° T. In line with last piling stump on NE end of large piling group.
Time: 1030 hrs.

2 m level 19 m from breakwater. Cobbles, gravel, sand, algae and barnacles.

Quad. #89 210 *Balanus glandula*

Quad. #90 340 *B. glandula*

1 m level 38 m from breakwater. (Stream causing rapid changes in the beach substrate.)

Quad. #91 in sand underlain with gravel.
21 *B. glandula*
1 *Mytilus edulis*
1 *Macoma inconspicua*
Enteromorpha

Quad. #92 in gravel and rocks.
240 *Balanus glandula*
4 *M. inconspicua*
1 *Mya arenaria*
Ulva

Ø m level 101 m from breakwater. Sand and silt.

Quad. #93 nothing

Quad. #94 nothing

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #17 12 JUL 73

Transect bearing 342° T. Weather sunny.
Time: 0900 hrs. Air temp. 18° C. Sand temp. 17° C.

2 m level 5 m from breakwater. Sand among scattered boulders with barnacles, mussels, Ulva, Enteromorpha and Fucus.

Quad. #95 nothing

Quad. #96 nothing

1 m level 24 m from seawall. Scattered patches of Enteromorpha and Dictyosiphon, sand and silt with polychaete and Callianassa holes at the surface.

Quad. #97 nothing

Quad. #98 6 Balanus glandula
1 Macoma inconspicua
2 Glycerid polychaetes

Ø m level 106 m from seawall. Sand and silt with scattered patches of Enteromorpha, polychaete and Callianassa holes.

Quad. #99 1 Macoma inconspicua
1 Glycerid polychaete

Quad. #100 1 Cryptomya californica

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #18 12 JUL 73

Transect bearing 352° T.
Time: 0945 hrs.

2 m level at base of breakwater. Scattered boulders on coarse sand. Boulders have barnacles, mussels and *Fucus* attached to them.

Quad. #101 50 *Balanus glandula*

Quad. #102 nothing

1 m level 10 m from breakwater. Sand.

Quad. #103 371 *B. glandula*
1 *Ischyrocerus* sp. amphipod
Enteromorpha
Ulva

Quad. #104 133 *B. glandula*

Ø m level Silt and sand. 95 m from breakwater.

Quad. #105 1 fish, the Arrow Goby *Clevelandia ios*

Quad. #106 1 Nephtyid polychaete

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #19 12 JUL 73

Transect bearing 357° T.
Time: 1030 hrs.

2 m level 9 m below seawall. Cobbles and gravel

Quad. #107 8 *Balanus glandula*

Quad. #108 nothing

1 m level 18 m below seawall. Cobbles and gravel.

Quad. #109 74 *B. glandula*
1 *Mytilus edulis*
1 *Anthopleura artemisia*
1 *Ischyrocerus* sp. amphipod

Quad. #110 1 *Macoma inconspicua*
1 *B. glandula*
1 Nephtyid polychaete
Enteromorpha
Ulva

Ø m level 40 m from seawall. Sand and silt.

Quad. #111 1 Nephtyid polychaete

Quad. #112 1 Nephtyid polychaete

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #20 13 JUL 73

Transect bearing 352° T. Weather sunny.
Time: 1010 hrs. Sand temp. 17° C.

2 m level 7 m below breakwater. Sand and gravel. Boulders with *Enteromorpha*, *Ulva* and *Fucus*.

Quad. #113 81 *Balanus glandula*
20 *Mytilus edulis*
1 Moldanid polychaete

Quad. #114 1 Nereid polychaete

1 m level 41 m below breakwater. Rocks, gravel and sand.

Quad. #115 463 *B. glandula*
28 *M. edulis*
1 *Clinocardium nuttallii*
1 *Exosphaeroma oregonensis*
Ulva

Quad. #116 2150 *B. glandula*
83 *M. edulis*
2 Nereid polychaetes

Ø m level 140 m below breakwater. Silt and sand.

Quad. #117 1 *Paraphoxus* sp. amphipod

Quad. #118 2 *Cryptomya californica*
1 *Macoma inconspicua*

PT. GARDNER ECOBAM BEACH TRANSECTS

At transect #20 a hole 60x60 cm and 25 cm deep was dug at the 1 m level above MLLW to determine clam presence and abundance. Only empty *Macoma secta* shells were found. At the same level, but closer to the stream SW of this transect the same size hole was dug with 8 *Mya arenaria* found ranging in size from ½-1½ inches in length. To the NE 4 *Clinocardium nuttallii*, 2 *Protothaca staminea* and 2 *Macoma inquinata* were dug along with seven *M. inquinata* and one *M. nasuta* empty shells. Two *Upogebia pugettensis* and one *Hemigrapsus oregonensis* were also found. Rocks and cobbles are covered by *Balanus glandula*, *Mytilus edulis*, *Ulva* and some *Fucus*.

At the 1½ m level above MLLW the surface is similar to that found at 1 m, but instead a clay-sandstone bed underlies (about 3 inches) the surface gravels and rocks. No clams found.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #21 16 JUL 73

Transect bearing 354° T.
Time: 1030 hrs.

2 m level 4 m from breakwater. In area of jumbled boulders dumped next to the breakwater and extending to about six meters below.

No quadrats taken.

1 m level 12 m from breakwater. Sand between scattered cobbles. At the edge of sand which extends to MLLW.

Quad. #119 259 *Balanus glandula*
5 *Mytilus edulis*
1 Nereid polychaete

Quad. #120 177 *B. glandula*

Ø m level 48 m from breakwater. Silt and sand among *Enteromorpha* and scattered patches of *Dictyosiphon* and *Zostrea*.

Quad. #121 1 Nephtyid polychaete

Quad. #122 1 Nephtyid polychaete

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #21 Breakwater rocks.

At transect #21 there is a large pile of boulders dumped by the railroad which mounds up against the breakwater. It provides a fairly good place for certain organisms to attach and affords protection for them. The boulders extend out from the breakwater to a distance of 6 meters. They are quite massive, 2-3 feet in diameter. A thick band of algae, mostly *Fucus*, grows to a height of $1\frac{1}{2}$ meters above the general level of the beach. The outer and uppermost "exposed" portions of the boulders are primarily devoid of organisms. They grow most profusely on the lower portions, underneath and especially in the cavities between the rocks. The organisms most abundant are *Fucus*, *Mytilus*, *Balanus glandula* and *Enteromorpha* with lesser numbers of *Ulva*, the Checkered Periwinkle Snail *Littorina scutulata*, polychaetes, amphipods and hermit crabs. The splash zone is nearly devoid of organisms except for *Balanus cariosus*.

The only immediately noticeable difference between the breakwater rocks here and that section observed at Transect #5 is more *Fucus* and the presence of Hermit Crabs.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #22 16 JUL 73

Transect bearing 337° T.
Time: 1130 hrs.

2 m level 7 m below breakwater. In area of jumbled boulders. No quadrats taken. Same species of organisms found here as those at transect #21.

1 m level 11 m below breakwater. Cobbles and gravel.

Quad. #123 1150 *Balanus glandula*
4 *Mytilus edulis*
2 Nereid polychaetes
1 *Hemigrapsus oregonensis*

Quad. #124 980 *B. glandula*
3 *M. edulis*
1 Nereid polychaete

Hole dug to 20 cm : 1 *Saxidomus giganteus*, 1 *Protothaca staminea*, and 10 *Macoma inquinata*

Ø m level 21 m below breakwater. Cobbles and small boulders.

Quad. #125 879 *Balanus glandula*
44 *M. edulis*
1 Nereid polychaete
5 *Macoma inquinata*
3 *Protothaca staminea*
1 *Saxidomus giganteus*
2 *Callianassa californiensis*
1 *Pagurus hirsutuisculus*

Quad. #126 700 *B. glandula*
85 *M. edulis*
1 *Callianassa californiensis*
1 *Cancer gracilis*
5 Pectinariid polychaetes
1 Nereid polychaete
11 *M. inquinata*
4 *Protothaca staminea*
Enteromorpha
Ulva

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #23 16 JUL 73

Transect bearing 337° T.

2 m level at base of breakwater. Cobbles, gravel and scattered boulders.

Quad. #127 nothing

Quad. #128 nothing

1 m level 14 m below breakwater. Scattered boulders and cobbles with 3-4 cm of sand and gravel over hard clay-sandstone. Very black H_2S sand and strong odor.

Quad. #129
530 *Balanus glandula*
32 *Mytilus edulis*
6 *Exosphaeroma oregonensis*

Quad. #130
1250 *B. glandula*
53 *M. edulis*
7 small *M. edulis*

Ø m level 32 m below breakeater. Scattered boulders and cobbles over sandstone.

Quad. #131
113 *B. glandula*
8 *M. edulis*
1 *Clinocardium nuttallii*
2 *Macoma inconspicua*
3 *Protothaca staminea*
1 *Hemigrapsus nudus*

Quad. #132
1 *Cancer oregonensis*
1 *Macoma inquinata*
1 *M. inconspicua*
Enteromorpha
Ulva

Other organisms found beneath overturned boulders include *Acanthodoris brunnea*, *Hemigrapsus nudus*, *Acmaea* spp., *Littorina planaxis* and very ornate *Thais lamellosa*.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #24 17 JUL 73

Transect bearing 327° T. Weather sunny.
Time: 1030 hrs. Sand temp. 18° C.

2 m level Base of breakwater less than 2 meters above MLLW.
No quadrats taken.

1 m level 3 m from breakwater. Cobbles, sand and gravel.

Quad. #133 170 *Balanus glandula*
1 *Mytilus edulis*
3 small *M. edulis*
4 Nereid polychaetes

Quad. #134 160 *B. glandula*

Ø m level 25 m below breakwater. Sand and scattered cobbles.

Quad. #135 365 *B. glandula*
43 *M. edulis*
5 *Macoma inconspicua*
4 tiny Nereid polychaetes

Quad. #136 192 *B. glandula*
2 *M. inconspicua*
1 Nereid polychaete

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #25 17 JUL 73

Transect bearing 327° T.
Time: 1130 hrs.

Sand temp. at 1 m level: 28° C.

<u>2 m level</u> At base of breakwater. Coarse sand.

Quad. #137 nothing

Quad. #138 nothing

<u>1 m level</u> 14 m from breakwater. Sand.

Quad. #139 1 *Macoma inconspicua*

Quad. #140 nothing

<u>Ø m level</u> 50 m below breakwater. Silt and sand.

Quad. #141 2 *M. inconspicua*

Quad. #142 1 *M. inconspicua*
1 Glycerid polychaete

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #26 17 JUL 73

Transect lined up with a small railroad switch. 27 m WNW to second and largest of two streams with a large concrete "trap" at the culvert. Time: 1210 hrs. 332° T.

2 m level 8 m below breakwater. Coarse sand.

Quad. #143 nothing

Quad. #144 nothing

1 m level 28 m below breakwater. Coarse sand, fine gravel and scattered boulders.

Quad. #145 5 *Macoma inconspicua*

Quad. #146 3 *M. inconspicua*

Ø m level 80 m below breakwater. Sand and silt.

Quad. #147 1 Glycerid polychaete

Quad. #148 nothing

PT. GARDNER ECOBAM BEACH TRANSECTS

TRENCHES

In addition to the quarter meter quadrats dug at Ø, 1, and 2 m above MLLW, a 2 m trench 25 cm wide and 2Ø cm deep was dug to determine the abundance or lack of, edible pelecypods. In most cases a single trench was dug in the so-called "algae-barnacle band" at each transect station. This band "typifies" areas in which clams are most often found, due to the substrate composition, amount of substrate moisture, relationship to MLLW and the period of time each day it is covered with water.

31 JUL 73

Transect #1 and surrounding area.

Numerous holes (no trench) was dug. No clams were found. An abnormally high concentration of H_2S in the substrate suggests an unfavorable condition for clams.

Transect #2

A 2 m trench was dug 20 m from the breakwater and 7 m SW of the transect line. 134 *Mya arenaria*, the Soft Shelled Clam was dug. These clams were submitted for bacterial analysis, the results are found elsewhere in these notes.

Transect #3

Trench at 10 m from breakwater.
3 *Mya arenaria*

Transect #4

Trench at 14 m from breakwater.
No clams.

Transect #5

Trench at 15 m from breakwater.
1 *Macoma inquinata* the Polluted Macoma

Transect #6

Numerous holes dug as well as a trench at 13 m from breakwater.
No clams. Seems to be too sandy.

Transect #7 (Howarth Waterfront Park)

One trench 27 m from breakwater (47 m from original seawall).
11 *Mya arenaria*. Second trench at 70 m. No clams.

Transect #8

Trench at 18 m from seawall.
1 *Mya arenaria*

At transect #19 through #24 some holes were dug prior to 31 Jul to determine if commercial clam species were present. Those found in this area include:

Saxidomus giganteus	Butter clam
Protothaca staminea	Native Little-neck
Venerupis japonica	Japanese Little-neck
Clinocardium nuttalli	Cockle

FIELD LOG

PT. GARDNER ECOBAM BEACH TRANSECTS-1974

Transect #1 24 APR 74

Parallel and on top of diffuser pipeline. 270° T.
Time: 1045 hrs. Weather: overcast, cool, 10.5° C. Sand temp.: 10° C.

2 m level 13 m from seawall. Gravel and coarse sand.

Quadrat #1 nothing

Quad. #2 nothing

1 m level 23 m from seawall. Coarse sand and gravel.

Quad. #3 nothing

Quad. #4 nothing

Ø m level 245 m from seawall. Sand and silt.

Quad. #5 1 *Macoma inconspicua*
2 Nereid polychaetes

Quad. #6 1 *M. inconspicua*
2 Nereid polychaetes

A trench 2 m long, 25 cm wide and 20 cm deep was dug between the 1 and 2 m tide levels to determine the presence of clams. None were found.

Note: Quadrat samples taken in 1974 will be about one meter NE of those taken in 1973 to eliminate the possibility of digging in the same place.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #2 24 APR 74

Adjacent to Pigeon Creek. 317° T.
Time: 1110 hrs.

2 m level 5 m from breakwater. Gravel and sand.

Quad. #7 1 Balanus glandula
2 Mytilus edulis

Quad. #8 3 B. glandula

1 m level 22½ m from breakwater. Gravel, coarse sand, cobbles, barnacles, mussels and algae.

Quad. #9 1 Cryptomya californica
116 B. glandula
5 young Hemigrapsus nudus
3 Macoma inconspicua
2 M. edulis

Quad. #10 340 B. glandula
2 Exosphaeroma oregonensis
4 H. nudus
4 M. inconspicua
1 Mya arenaria
4 M. edulis > 4mm
30 M. edulis < 4 mm

Ø m level 212½ m from breakwater. Sand and silt.

Quad. #11 nothing

Quad. #12 3 M. inconspicua

A trench was dug at the 1 m level. 6 Mya arenaria

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #3 25 APR 74

Bearing: 317° T. Weather: overcast, air temp. 15° C. Sand temp. 7° C.
Time: 1140 hrs.

2 m level 3½ m from breakwater. Gravel, rocks and sand.

Quad. #13 nothing
Quad. #14 nothing

1 m level 12½ m from breakwater. Cobbles, gravel, sand, algae, barnacles and mussels.

Quad. #15 1 *Macoma inconspicua*

Quad. #16 40 *Balanus glandula*

Ø m level 95½ m from breakwater. Sand and silt.

Quad. #17 nothing

Quad. #18 nothing

A trench was dug between the one and two meter levels. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #4 25 APR 74

Time: 1205 hrs. 307° T.

2 m level at base of breakwater. Gravel, rocks and sand.

Quad. #19 nothing

Quad. #20 nothing

1 m level 9 m from breakwater. Cobbles, gravel, sand, barnacles and mussels.

Quad. #21 nothing

Quad. #22 nothing

Ø m level 18 m (25 m in 1973) below breakwater. Sand and silt.

Quad. #23 nothing

Quad. #24 nothing

A trench was dug at the 1 m level. No clams

A trench at Ø m level. 4 Callianassa californiensis and 2 Macoma inconspicua.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #5 25 APR 74

Time: 1245 hrs. 317° T.

2 m level adjusted to 1½ m at base of breakwater. Coarse sand.

Quad. #25 nothing

Quad. #26 nothing

1 m level 6 3/4 m from breakwater. Gravel, rocks and sand.

Quad. #27 nothing

Quad. #28 1 Balanus glandula

Ø m level 15 m from breakwater. Cobbles, gravel and sand, algae, barnacles and some mussels.

Quad. #29 nothing

Quad. #30 nothing

4 holes dug at various heights on the beach. No clams found.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #6 25 APR 74

Time: 1315 hrs. Transect bearing: 352° T.

2 m level located about 2 feet above base of breakwater. No samples taken.

1 m level 15 m from breakwater. Coarse sand underlain with gravel.

Quad. #31 2 *Balanus glandula*
1 *Mytilus edulis*

Quad. #32 3 *B. glandula*
1 *M.* edulis 4 mm^2

0 m level 30 m from breakwater. Sand and silt.

Quad. #33 1 Glycerid polychaete
1 *Macoma inconspicua*

Quad. #34 nothing

A trench dug at 0 m tide level. 53 *M. inconspicua*.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #7 26 APR 74

Transect bearing 312° T., located in line with the pedestrian bridge at Everett's Howarth Waterfront Park. Time: 1200 hrs. Air temp. 11.5° C., sand temp. 10° C. Overcast.

2 m level 11 m from breakwater. Cobbles, gravel, sand and algae.

Quad. #35
- 45 Balanus glandula
- 1 Exosphaeroma oregonensis
- 4 Macoma inconspicua
- 1 Mya arenaria
- 13 Mytilus edulis 4mm²
- 18 Mytilus edulis 4mm²
- Enteromorpha

Quad. #36
- 211 B. glandula
- 4 M. inconspicua
- 10 M. edulis 4 mm²
- 13 M. edulis 4 mm²

1 m level 68 m from breakwater. Gravel, sand, algae.

Quad. #37
- 6 B. glandula
- 1 Cryptomya californica
- 1 M. inconspicua
- 4 M. edulis
- Enteromorpha

Quad. #38
- 30 B. glandula
- 1 Hemigrapsus oregonensis
- 1 M. inconspicua
- 6 M. edulis 4 mm²
- 21 M. edulis 4 mm²

0 m level 115 m from breakwater. Sand and silt.

Quad. #39 nothing

Quad. #40 nothing

Trench at 2 m. 6 Mya arenaria. Trench at 1 m. nothing.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #8 26 APR 74 322° T.

2 m level 7 m from seawall. Sand and gravel.

Quad. #41 nothing

Quad. #42 nothing

1 m level 16 m from seawall. Scattered cobbles, gravel, sand, algae and a few barnacles.

Quad. #43 nothing

Quad. #44 1 Balanus glandula

0 m level 71 m from seawall. Sand and silt.

Quad. #45 nothing

Quad. #46 nothing

A trench was dug 18 m from the seawall. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #9 21 MAY 74
Time:1155 hrs. Weather: mostly sunny. 322° T.
Air temp. 17° C. Sand temp. 15° C.

2 m level 5 m from breakwater. Rocks, gravel and sand.

Quad. #47 nothing

Quad. #48 nothing

1 m level 15 m from breakwater. Cobbles, rocks, gravel and sand.

Quad. #49 hundreds of tiny young barnacles ~ 1/32 inch.

Quad. #50 same barnacles
1 amphipod (unidentified)

0 m level 23 m from breakwater. Sand and silt.

Quad. #51 hundreds of tiny young barnacles ~ 1/16 inch.
32 larger *Balanus glandula*
1 small Nereid polychaete

Quad. #52 same small barnacles
23 larger *Balanus glandula*
3 small Nereid polychaetes
2 larger Nereid polychaetes

A trench was dug at 19m from the breakwater. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #10 21 MAY 74
Time: 1245 hrs. 332° T.

2 m level 14 m from breakwater. Cobbles, gravel and coarse sand.

Quad. #53 nothing

Quad. #54 nothing

1 m level 24 m from breakwater. Sand, small cobbles, gravel.

Quad. #55 5 *Balanus glandula*

Quad. #56 nothing

0 m level 44 m from breakwater. Sand and silt.

Quad. #57 nothing

Quad. #58 nothing

A trench was dug at 17 m from the breakwater. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #11 16 JUL 74
Time: 0925 hrs. Cloudy with light rain. 332° T.

2 m level 30 m from beach grass. Gravel, cobbles, sand.

Quad. #59 105 *Balanus glandula*
Enteromorpha

Quad. #60 112 *B. glandula*
Enteromorpha

1 m level 54 m from beach grass. This transect cuts through the middle of the stream delta. Sand, gravel, scattered cobbles and abundant *Enteromorpha*.

Quad. #61 1 Nereid polychaete
Enteromorpha

Quad. #62 49 *B. glandula*
1 Nereid polychaete
Enteromorpha

0 m level 112 m from beach grass. (Last year MLLW was 160 m from beach grass.) Sand and silt.

Quad. #63 nothing

Quad. #64 1 *Macoma inconspicua*

Trenches dug at 24 and 52 meters from beach grass on transect line as well as three holes at various other places on the delta. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #12 16 JUL 74
Time: 1010 hrs. 347° T.

2 m level 13 m from breakwater. Cobbles, gravel and sand, underlain with oil.

Quad. #65
- 12 *Balanus glandula*
- 128 small *B. glandula* 2 mm
- 1 Nereid polychaete
- 1 *Hemigrapsus nudus*
- 1 *H. oregonensis*
- 1 unidentified amphipod
- *Enteromorpha*

Quad. #66
- 169 small *B. glandula* 2mm
- 3 *H. oregonensis*
- 1 Nereid polychaete
- *Enteromorpha*

1 m level 23 m from breakwater. Gravel, sand and cobbles. Oily seepage comes to the surface here, the same as in 1973.

Quad. #67 1 *Macoma inconspicua*

Quad. #68 nothing

0 m level 45 m from breakwater. Sand, silt, mud shrimp and polychaete holes, patches of *Enteromorpha*, *Dictyosiphon* and *Zostrea* in the area.

Quad. #69 1 Glycerid polychaete

Quad. #70 pieces of algae.

A trench dug at 1 m level. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #13 16 JUL 74
Time: 1020 hrs. 357° T.

2 m level 8 m from seawall. Scattered boulders with *Fucus* and barnacles.

Quad. #71
94 *Balanus glandula*
16 small *B. glandula* < 2 mm
1 *Macoma inconspicua*

Quad. #72
257 *B. glandula*
673 small *B. glandula* <2mm
19 small *Mytilus edulis* <4 mm^2

1 m level 29 m from seawall. Sand and scattered small boulders with *Ulva* and *Enteromorpha*.

Quad. #73 nothing

Quad. #74 nothing

0 m level 70 m from seawall. Sand, silt and mud shrimp holes. Scattered patches of the filamentous green alga *Bryopsis*.

Quad. #75 1 *M. inconspicua*

Quad. #76 nothing

A trench dug 15 m from the seawall. Coarse sand, boulders covered with barnacles, Enteromorpha and Fucus. A layer of clay about two inches below the surface with a heavy, black H_2S layer and odor. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #13

At the 2 m level, the beach is relatively stable, with one large boulder about 6 feet in diameter, numerous rocks of 2 to 3 feet, 1 foot, smaller boulders and cobbles. These rocks provide surfaces for the attachment of *Fucus*, barnacles, mussels, and beneath them, protection provided for *Hemigrapsus*, isopods, amphipods, *Pagurus* and possible others.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #14 17 JUL 74
Time: 0900 hrs. Overcast, light wind, sand temp. 14.5° C. Air 15.5° C. 002° T

2 m level 1 m from breakwater. Coarse sand and gravel.

Quad. #77 nothing

Quad. #78 nothing

1 m level 19 m from breakwater. Sand, silt and mud shrimp holes, and small patches of *Enteromorpha* and *Bryopsis.*

Quad. #79 nothing

Quad. #80 nothing

0 m level Silt and sand. Large patches of Bryopsis, small tufts of *Enteromorpha*. 113 m from breakwater.

Quad. #81 1 *Macoma inconspicua*
1 Glycerid polychaete

Quad. #82 1 Nemertean

A trench was dug at 1 m
2 *M. inconspicua*
9 *Mya arenaria*

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #15 17 JUL 74

Located and marked at the beginning of the breakwater on the south half of the stream delta. 357° T.

2 m level 46 m from breakwater. Gravel, cobbles, and coarse sand. Enteromorpha and tufts of Fucus.

Quad. #83 12 Macoma inconspicua
4 Mya arenaria

Quad. #84 29 M. inconspicua
2 Mya arenaria
1 Cryptomya californica

A trench- 16 Mya arenaria
22 Macoma inconspicua

1 m level 98 m from breakwater. Sand, gravel, small cobbles with barnacles, Enteromorpha. Patches of Bryopsis on the sand.

Quad. #85 131 Balanus glandula
8 Mytilus edulis

Quad. #86 385 small B. glandula < 2 mm
38 B. glandula
8 M. inconspicua

0 m level 135 m from breakwater. Sand with clay about 1 cm below the surface down to bottom of quadrat hole (10 cm.).

Quad. #87 4 M. inconspicua
1 Glycerid polychaete

Quad. #88 4 M. inconspicua
1 Nemertean

A second trench was dug at 1 m level.
15 Mya arenaria
1 M. inconspicua

12 Mya were dug at a depth greater than the 25 cm deep trench.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #16 30 JUL 74
Time: 0930 hrs. In line with last piling stump on NE end of large piling group. Sand temp. 19° C. 347° T.

2 m level 19 m from breakwater. Stream about 10 m to the NE. Coarse sand gravel, small cobbles.

Quad. #89 nothing

Quad. #90 nothing

1 m level 38 m from breakwater. Coarse sand, gravel, patches of *Enteromorpha*.

Quad. #91 35 Mytilus edulis < 4 mm^2

Quad. #92
2 *M. edulis*
5 *M. edulis* < 4 mm^2
12 *Balanus glandula*
Enteromorpha

0 m level 101 m from breakwater. Sand, silt and mud shrimp holes.

Quad. #93 nothing

Quad. #94 nothing

A trench was dug at the 1 m level. No clams.
Three other holes dug-no clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #17 30 JUL 74
Time: 1000 hrs. 342° T.

2m level 5 m from breakwater. Sand among scattered boulders with barnacles, mussels, *Ulva*, *Enteromorpha* and *Fucus*.

Quad. #95 nothing

Quad. #96 nothing

1 m level 24 m from breakwater. Sand, silt and mudshrimp holes.

Quad. #97 2 *Macoma inconspicua*

Quad. #98 nothing

0 m level 74 m from breakwater. Sand, silt and mudshrimp holes.

Quad. #99 1 *Macoma inconspicua*

Quad. #100 nothing

A trench was dug at $\frac{1}{2}$ m above MLLW. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #18 31 JUL 74
Time: 0940 hrs. Sand temp. 19.5°C. 352° T.

2 m level at the base of breakwater. Gravel and coarse sand.

Quad. #101 7 *Balanus glandula*

Quad. #102 nothing

1 m level 10 m from breakwater. Cobbles, gravel and sand.

Quad. #103 182 *B. glandula*
25 tiny B. glandula <1 mm
Enteromorpha

Quad. #104 70 *B. glandula*
73 tiny *B. glandula* <1 mm
Enteromorpha

0 m level 68 m from breakwater. Sand and silt with mudshrimp holes.

Quad. #105 nothing

Quad. #106 nothing

Trench at 1 m level. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #19 31 JUL 74
Time: 1030 hrs. 357° T.

2 m level 9 m from seawall. Cobbles and gravel.

Quad. #107
3 *Balanus glandula*
187 small *B. glandula* < 2 mm
1 *Hemigrapsus oregonensis*
2 Nereid polychaetes

Quad. #108
64 *B. glandula*
155 small *B. glandula* <2mm
1 Nereid polychaete

1 m level 18 m from seawall. Cobbles and gravel.

Quad. #109 1 *Macoma inconspicua*

Quad. #110 nothing

0 m level Sand, silt and mudshrimp holes. 56 m from seawall. Last year at 40 m.

Quad. #111 1 *M. inconspicua*

Quad. #112 nothing

A trench was dug at the $\frac{1}{2}$ m level about 30 m NE of transect line.
50 *Macoma inquinata*
13 *Protothaca staminea*
2 *Saxidomus giganteus*

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #20 15 AUG 74
Time: 0905 hrs. Sunny, sky clear. Air temp. 15.5° C. Sand temp. 17° C
352° T.

2 m level 7 m from breakwater. Boulders, cobbles and sand. Boulders covered with barnacles, mussels, *Enteromorpha* and *Fucus*. *Hemigrapsus oregonensis* beneath the boulders.

Quad. #113
- 31 *Balanus glandula*
- 2 *Mytilus edulis*
- *Ulva*
- *Enteromorpha*

Quad. #114
- 1100 *B. glandula*
- 2 *B. glandula* 2 mm
- 54 *M. edulis*
- 1 small *Acmaea pelta*
- *Ulva*
- *Enteromorpha*

1 m level 41 m from breakwater. Cobbles, gravel and sand. *Hemigrapsus oregonensis*.

Quad. #115
- 22 *B. glandula*
- 2 *B. glandula* 1 mm
- 9 *M. edulis*
- 5 *M. edulis* 4 mm
- *Ulva*
- *Enteromorpha*

Quad. #116
- 500 *B. glandula*
- 100 *B. glandula*
- 650 *M. edulis* 4 mm
- 1 Nereid polychaete
- 1 Nermertean worm

0 m level 140 m from breakwater. Silt and sand with ghost shrimp and polychaete holes.

Quad. #117
- 1 Nemertean
- 1 tiny unidentified clam

Quad. #118
- 1 *Macoma inconspicua*

Trench dug at 1 m level. 7 *Macoma inquinata*

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #21 15 AUG 74
Time: 0935 hrs. 354° T.

2 m level 4 m from breakwater. In area of jumbled boulders dumped next to the breakwater and extending to about six meters below.

No quadrats taken.

1 m level 12 m from breakwater. Small boulders, gravel and sand. Barnacles, *Ulva* and *Enteromorpha* on the boulders.

Quad. #119 nothing

Quad. #120 50 *Balanus glandula*
1 *B. glandula*

0 m level 48 m from breakwater. Silt, sand, ghost shrimp holes and the green algae *Bryopsis*.

Quad. #121 1 *Crago alaskensis*
2 tiny unidentified white clams

Quad. #122 nothing

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #22 15 AUG 74
Time: 1000 hrs. Air temp. 19.5° C. 337° T.

2 m level 7 m below breakwater. In area of jumbled boulders.

No quadrats taken.

1 m level 11 m below breakwater. Cobbles, gravel, and coarse sand.

Quad. #123
230 *Balanus glandula*
4 *B. glandula* 1 mm
5 *Mytilus edulis* 4 mm
2 Nereid polychaetes
Enteromorpha
Ulva

Quad. #124
290 *B. glandula*
135 *B. glandula* 1 mm
2 Glycerid polychaetes
1 Nereid polychaete
3 *Hemigrapsus oregonensis*
Enteromorpha
Ulva

0 m level 21 m below breakwater. Small boulders, cobbles, gravel and sand.

Quad. #125
750 *B. glandula*
1 *H. oregonensis*
5 *Macoma inquinata*
1 *Mopalia lignosa*
8 *M. edulis*
115 *M. edulis* 4 mm
1 Nemertean worm
1 Nereid polychaete
2 *Protothaca staminea*
Enteromorpha
Ulva

Quad. #126
1 *Anthopleura artemisia*
1155 *Balanus glandula*
4 *Exosphaeroma oregonensis*
1 *Hemigrapsus oregonensis*
5 *Macoma inquinata*
1 *Macoma inconspicua*
3 *Mytilus edulis*
70 *M. edulis* 4 mm
2 *Littorina planaxis*
3 *Orchestia* spp. amphipods
5 Pectinariid polychaetes
3 *Protothaca staminea*
Enteromorpha
Ulva

A trench was dug at the 0 m level.
1 *Macoma inquinata*
1 *Protothaca staminea*
1 *Saxidomus giganteus*

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #23 16 AUG 74
Weather: sunny. 337° T.

2 m level Base of breakwater. Gravel.
Quad. #127 nothing

Quad. #128 nothing

1 m level 14 m below breakwater. Boulders, cobbles, gravel underlain with sandstone and clay.

Quad. #129
395 *Balanus glandula*
390 *B. glandula* <1 mm
2 *Hemigrapsus oregonensis*
1 *Littorina planaxis*
33 *Mytilus edulis*
7 *M. edulis* <4 mm
1 Nereid polychaete
1 *Protothaca staminea*

Quad. #130
465 *B. glandula*
212 *B. glandula* <1 mm
3 *H. oregonensis*
29 *Littorina planaxis*
17 *M. edulis*
12 *M. edulis*
1 Nemertean worm
3 Nereid polychaetes

0 m level Boulders, cobbles, gravel, sand underlain with sandstone and clay one inch beneath the surface. Barnacles, mussels, *Ulva* and *Enteromorpha* on the larger rocks. 32 m from breakwater.

Quad. #131
1 *Anthopleura artemisia*
1685 *Balanus glandula*
125 *B. glandula* <1 mm
11 *Exosphaeroma oregonensis*
3 *Hemigrapsus oregonensis*
13 *Mytilus edulis*
695 *M. edulis* <4 mm
2 Nemerteans
1 small *Protothaca staminea*
Enteromorpha
Ulva

Quad. #132
1 *Anthopleura artemisia*
1 *Balanus cariosus*
610 *B. glandula*
62 *B. glandula* <1 mm
3 *Exosphaeroma oregonensis*
5 *H. oregonensis*
5 *Macoma inquinata*
8 *M. edulis*
95 *M. edulis* <4 mm
1 Pectinariid polychaete
1 *Protothaca staminea*
1 *Saxidomus giganteus*

Enteromorpha
Ulva

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #23 16 AUG 74

Trench dug at 0 m level only one meter long. Substrate consisted of hard clay pitted with small depressions, so that digging had to be done by hand.

26 Macoma inquinata
18 small M. inquinata $< \frac{1}{2}$ inch
17 Protothaca staminea
8 Saxidomus giganteus

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #24 16 AUG 74
Time: 0945 hrs. Sun beginning to shine through the fog. 327° T.

2 m level Base of breakwater less than 2 meters above MLLW.

No quadrats taken.

1 m level 3 m from breakwater. Coarse sand.

Quad. #133 nothing

Quad. #134 nothing

0 m level 25 m from breakwater. Silt and sand, patches of Bryopsis and Zostrea.

Quad. #135
1 Clinocardium nuttallii 4 mm
4 tiny unidentified amphipods
1 Glycerid polychaete

Quad. #136
1 Clinocardium nuttallii 4 mm
1 Macoma inconspicua

A trench was dug at $1\frac{1}{2}$ m tide level. No clams

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #25 16 AUG 74
Time: 0920 hrs. Air temp. 15° C. Sand 15° C. 327° T.

2 m level Base of breakwater. Coarse sand.

Quad. #137 nothing

Quad. #138 nothing

1 m level 14 m below breakwater. Coarse sand and gravel.

Quad. #139 nothing

Quad. #140 nothing

0 m level 50 m below breakwater. Sand and *Zostrea*. *Bryopsis* to minus tide levels.

Quad. #141 3 *Eohaustorius* amphipods

Quad. #142 2 *Eohaustorius* amphipods

A trench was dug at 1 m. No clams

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #26 16 AUG 74
Time: 0900 hrs. Low clouds and fog, clearing rapidly. 332° T.

2 m level 8 m below seawall. Coarse sand.

Quad. # 143 nothing

Quad. # 144 nothing

1 m level 18 m below seawall. Sand and fine gravel.

Quad. # 145 nothing

Quad. # 146 nothing

0 m level 80 m below seawall. Coarse sand.

Quad. # 147 nothing

Quad. # 148 nothing

A trench was dug at 1 m tide level. No clams.

FIELD LOG

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #1 27 MAY 75

Parallel and on top of diffuser pipeline, 270°T.
Time: 1333 hrs. Weather: sunny, some clouds, wind 0-5 knots
Air temperature: 17°C Sand temperature: 18°C

2 m level 13 m from seawall. Coarse sand, gravel, wood chips on surface.

Quadrat #1 nothing

Quad. #2 nothing

1 m level 23 m from seawall. Coarse sand, gravel, rocks underneath surface.

Quad. #3 nothing

Quad. #4 nothing

28 May 1975 1310 hrs.

Ø m level 180 m from seawall. Sand and some gravel.

Quad. #5 nothing

Quad. #6 nothing

A trench 2 m long, 25 cm wide and 20 cm deep was dug at the 1 m tide level to determine the presence of clams. None were found.

Note: Quadrat samples taken in 1975 will be about one meter SW of transect line to eliminate the possibility of digging in the same place as 1973 and 1974.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #2   27 MAY 75

Adjacent to Pigeon Creek. 317°T
Time: 1420 hrs. Weather: Increasing clouds.
Air temp: 17°C Sand temp: 18°C

2 m level 5 m from breakwater. Sand and rocks, cobbles beneath surface.

Quad. #7   nothing

Quad. #8   nothing

1 m level 22 1/2 m from breakwater. Cobbles gravel, sand and piling stubs covered with barnacles and algae. Position of transect moved eight meters south to avoid taking sample in the middle of Pigeon Creek.

Quad. #9
83 Balanus glandula >1 mm
47 B. glandula <1 mm
1 Mytilis edulis >1 mm
1 Nereid polychaete
1 Amphipod

Quad. #10   nothing

28 MAY 75   1325 hours

Ø level 174 m from the seawall. Sand and silt.

Quad. #11   nothing

Quad. #12   nothing

A trench was dug at 1 m, 8 m south of the transect line:

1 Mya arenaria

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #3 27 MAY 75

Bearing: 317°T
Time: 1522 hrs.

2 m level 3 1/2 m from breakwater. Cobbles, rocks, gravel, sand.

Quad. #13 nothing

Quad. #14 nothing

1 m level 12 1/2 m from breakwater. Silty sand, *Zostrea*, few cobbles.

Quad. #15 nothing

Quad. #16 nothing

28 MAY 75 1337 hrs.

Ø level 160 m from breakwater. Sand, silt and mud shrimp holes.

Quad. #17 3 *Macoma balthica*

Quad. #18 3 *Cryptomya californica*

A trench was dug at 1 & 2 m and nothing was found.

PT. GARDNER ECOBAM BEACH TRANSECT

Transect #4   28 MAY 75

Bearing: 307°T
Time: 1400 hrs.
Weather: sun-hot, few high clouds, no wind
Air temp: 16°C
Sand temp: 17°C

2 m level At base of breakwater. Coarse sand and gravel.

Quad. #19   nothing

Quad #20   nothing

1 m level 9 m from breakwater. Rocks and gravel.

Quad. #21   nothing

Quad #22   nothing

Ø m level 25 m from breakwater. Fine sand and silt with *Zostrea* and loose pieces of *Ulva*.

Quad. #23   nothing

Quad. #24   2 *Cryptomya californica*

A trench was dug at Ø m: 1 *Callianassa*, 1 *Cryptomya californica* $<$ 4 mm, 1 *Macoma balthica* $<$ 4 mm.

A trench at 1/2 m level. No clams.

PT. GARDNER ECOBAM BEACH TRANSECT

Transect #5 29 MAY 75

Bearing: 307°T
Time: 1300 hrs.
Weather: sunny, some high clouds, light wind freshening
Air temp: 16°C Sand temp: 17°C

2 m level Base of breakwater. Gravel and sand.

Quad. #25 3 loose Balanus glandula (probably fell off breakwater).

Quad. #26 nothing

1 m level 6 3/4 m from breakwater. Coarse sand underlaid with gravel.

Quad. #27 nothing

Quad. #28 nothing

Ø level 15 m from breakwater. Coarse sand, gravel, scattered cobbles.

Quad. #29 41 B. glandula > 1 mm.
1 Macoma balthica < 4 mm

Quad. #30 2 B. glandula > 1 mm

Trench dug at Ø m level -- nothing

Breakwater Rocks: B. glandula
Mytilis edulis
Fucus
Enteromorpha
Ulva
Acmaea pelta
Hemigrapsus nudus
Gigartina

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #6   30 MAY 75

Bearing: 352°T
Time: 1400 hrs.
Weather: hot, light wind
Air temp: 20°C   Sand temp: 21°C

2 m level Located about 2 feet above base of breakwater. No quadrats taken.

1 m level 15 m from breakwater. Coarse sand and gravel. Scattered boulders covered with barnacles and algae.

Quad. #31   31 *Balanus glandula* < 1 mm

Quad. #32   nothing

29 MAY 75

Ø m level 30 m from breakwater. Silt, sand, eelgrass patches.

Quad. #33   6 *B. glandula* >1 mm
3 *Cryptomya californica*
1 *Upogebia pugettensis*

Quad. #34   11 *B. glandula* >1 mm

Trench at Ø level: 7 *Macoma balthica*
3 *M. balthica* < 4 mm^2

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #7 29 MAY 75

Bearing: 312°T, located in line with the pedestrian bridge at Everett's Howarth Waterfront Park.

Time: 1335 hrs.

2 m level: 11 m from breakwater. Rocks, gravel, coarse sand.

Quad. #35
33 _Mytilis edulis_ >4 mm
48 _M. edulis_ <4 mm
53 _Balanus glandula_ >1 mm
5 _Macoma balthica_
Ulva
Enteromorpha

Quad. #36
7 _M. edulis_ >4 mm
11 _M. edulis_ <4 mm
2 _M. balthica_
14 _B. glandula_ >1 mm
54 _B. glandula_ <1 mm

1 m level: 68 m from breakwater. Gravel, coarse sand, scattered cobbles, barnacles and algae.

Quad. #37
71 _B. glandula_ >1 mm
92 _B. glandula_ <1 mm
17 _M. edulis_
1 _M. balthica_

Quad. #38
31 _M. edulis_ >4 mm
29 _M. edulis_ <4 mm
64 _B. glandula_ <1 mm
111 _B. glandula_ >1 mm
Ulva

Ø level: 105 m from breakwater. Wind may push water higher than - 0.6'. Gravel and sand.

Quad. #39
1 _B. glandula_ >1 mm

Quad. #40
3 _B. glandula_ >1 mm
26 _B. glandula_ <1 mm
1 _Upogebia pugettensis_
Ulva

Trench at 2 m -- nothing
Trench at 1 m -- nothing
Trench at Ø m -- nothing

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #8 6 JUNE 75

Bearing: 322°T
Time: 0920 hrs.
Weather: Overcast, wind 10-15 knots
Air temp: 15°C Sand temp: 12°C

2 m level: 7 m from breakwater. Coarse sand, gravel, scattered boulders.

Quad. #41 nothing

Quad. #42 nothing

1 m level: 16 m from breakwater. Coarse sand, gravel, scattered boulders

Quad. #43 1 Nephtyid polychaete

Quad. #44 nothing

Ø m level: 71 m from breakwater. Sand and silt

Quad. #45 1 Macoma balthica

Quad. #46 1 polychaete

Trench at 1 m -- no clams

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #9   6 JUNE 75

Bearing: 322°T
Time: 1000 hrs.

2 m level: 5 m from breakwater. Rocks, gravel, coarse sand between boulders.

Quad. #47   nothing

Quad. #48   nothing

1 m level: 15 m from breakwater. Rocks, gravel, scattered boulders, coarse sand.

Quad. #49   nothing

Quad. #50   nothing

9 JUNE 75

Time: 1017 hrs.   Air temp: 17°C   Sand temp: 17°C
Weather: calm, clear, warm.

Ø m level: 23 m from breakwater. Sand, cobbles and boulders covered with barnacles and algae. Eelgrass beds below Ø m.

Quad. #51
- 118 *Balanus glandula* > 1 mm
- 5 *B. glandula* < 1 mm
- *Ulva*
- *Enteromorpha*

Quad. #52
- 240 *B. glandula* > 1 mm
- 310 *B. glandula* > 1 mm
- 2 *Mytilis edulis* > 4 mm
- 1 Nereid polychaete
- 1 Amphipod
- *Ulva*

Boulders with *Fucus*, *Enteromorpha* and *Ulva*;
Mytilis edulis
B. glandula
Acmaea pelta
Littorina planaxis
Nereis
Hemigrapsus oregonensis
Hemigrapsus nudus
Idothea wosnesenskii
Exosphaeroma oregonensis
Amphipods

Trench -- 19 m from breakwater -- no clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #10   6 JUNE 75

Bearing: 332°T
Time: 1045 hrs.

2 m level: 14 m from breakwater. Rocks, gravel, coarse sand.

Quad. #53   nothing

Quad. #54   nothing

1 m level: 24 m from breakwater. Coarse sand, gravel.

Quad. #55   nothing

Quad. #56   nothing

9 JUNE 75

Time: 1040 hrs.

Ø m level: 44 m from breakwater. Sand and silt, occasional *Dictyosiphon*, some eel grass and mud shrimp holes.

Quad. #57   1 *Cryptomya californica*

Quad. #58   nothing

A trench was dug 17 m from breakwater. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #11   9 JUNE 75

Bearing: 332°T
Time: 1120 hrs.
Stream flowing 20-30 m NE of quadrats

2 m level: 30 m from breakwater. Coarse sand, gravel, rocks & cobbles covered with barnacles and algae.

Quad. #59	160 Balanus glandula > 1 mm
	208 B. glandula < 1 mm
	Enteromorpha
Quad. #60	106 B. glandula > 1 mm
	93 B. glandula < 1 mm
	Enteromorpha

1 m level: 54 m from breakwater. Coarse sand, gravel, rocks and cobbles covered with barnacles and algae.

Quad. #61	71 B. glandula > 1 mm
	230 B. glandula < 1 mm
	5 Exosphaeroma oregonensis
	10 Mytilis edulis > 4 mm
	3 M. edulis < 4 mm
Quad. #62	168 B. glandula > 1 mm
	225 B. glandula < 1 mm

Ø level: 102 m from breakwater. Silt and sand, mud/ghost shrimp holes

Quad. #63	nothing
Quad. #64	1 Nereid polychaete
	1 Emplectonema sp.

A trench was dug at 24 m and 54 m from breakwater. Four other holes were dug nearby. Nothing was found.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #12 10 JUNE 75

Bearing: 347°T
Time: 1015 hrs.
Weather: slight overcast, warm, calm.
Air temp: 21°C Sand temp: 20°C

2 m level: 13 m from breakwater. Cobbles and rocks covered with algae, coarse gravel, blue clay underneath. Iron cable ran through the quadrat. Petroleum contamination of substrata.

Quad. #65 — 2 *Mytilus edulis* >1 mm

Quad. #66 — 4 Amphipods
3 *Hemigrapsus oregonensis*

1 m level: 23 m level. Sand, rocks and cobbles with barnacles and algae.

Quad. #67 — 11 *Balanus glandula* >1 mm
4 *B. glandula* <1 mm

Quad. #68 — 97 *B. glandula* >1 mm
523 *B. glandula* <1 mm
1 *M. edulis* >4 mm
13 Amphipods
1 *Clevelandia ios*
Enteromorpha
Ulva

Ø m level: 45 m from breakwater. Silty sand with *Dictyosiphon* beds

Quad. #69 — 1 Nephtyid polychaete
1 *Emplectonema* sp.

Quad. #70 — nothing

A trench was dug at 1 m. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS

Transect #13 10 JUNE 75

Bearing: 357°T
Time: 1138 hrs.

2 m level: 8 m from breakwater. Blue clay under coarse sand, gravel, rocks and cobbles covered with barnacles and algae. Clay closer to the surface than at last transect.

Quad. #71
1 Nereid
1 *Balanus glandula* >1 mm
Enteromorpha

Quad. #72
14 *B. glandula* >1 mm
13 *Mytilis edulis* >1 mm
1 *M. edulis* <1 mm

1 m level: 29 m from breakwater. Silty sand.

Quad. #73
1 Nephtyid polychaete

Quad. #74
1 *Macoma balthica*
1 Pectinarid polychaete

Ø m level: 70 m from breakwater. Silty sand.

Quad. #75
1 *M. balthica* <4 mm

Quad. #76
nothing

A trench was dug to 10 cm when hit a clay layer. Nothing was found.

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #14 10 JUNE 75

Bearing: 002°T
Time: 1235 hrs.

2 m level: 1 m from breakwater. Gravel, coarse sand, several scattered boulders with barnacles and algae attached to them.

Quad. #77 3 *Balanus glandula* >1 mm

Quad. #78 nothing

1 m level: 19 m from breakwater. Silty sand with mud shrimp holes.

Quad. #79 nothing

Quad. #80 nothing

Ø m level: 113 m from breakwater. Silty sand.

Quad. #81 nothing

Quad. #82
1 *Macoma balthica*
1 *Macoma inquinata*
1 *Mya arenaria*
1 *Cryptomya californica*

A trench was dug at 1 m -- 1 *Cryptomya californica*
1 *Macoma balthica*

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #15 11 JUNE 75

Bearing: 357°T
Time: 1130 hrs.
Weather: 5-10 knot wind, clear and warm
Air temp: 19°C Sand temp: 18.8°C

2 m level: 46 m from breakwater. Gravelly sand, slight smell of H_2S.

Quad. #83 3 Macoma balthica

Quad. #84 2 M. balthica
1 Balanus glandula > 1 mm

1 m level: 98 m from breakwater. Rocks with barnacles and algae, silty sand and clay.

Quad. #85 1 M. balthica
Quad. #86 1 Mya arenaria

0 m level: 135 m from breakwater. Silty sand with some rocks with clay underneath.

Quad. #87 1 M. balthica

Quad. #88 3 Cryptomya californica
2 M. balthica

A trench was dug at the 1 m level. Seven M. arenaria were found.

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #16   11 JUNE 75

Bearing: 347°T
Time: 1217 hrs.

2 m level: 19 m from breakwater. Sand and cobbles with attached barnacles and algae.

Quad. #89	1 Macoma balthica
Quad. #90	9 Balanus glandula >1 mm
	6 Amphipods
	4 Exosphaeroma oregonensis

1 m level: 38 m from breakwater. Sand with rocks and cobbles

Quad. #91	48 E. oregonensis
	455 B. glandula >1 mm
	641 B. glandula <1 mm
	3 Mytilis edulis >1 mm
	2 M. edulis <1 mm
Quad. #92	14 B. glandula >1 mm
	2 Nereid polychaetes

0 m level: 101 m from breakwater. Sand and input of freshwater from nearby stream.

Quad. #93	nothing
Quad. #94	1 Clevelandia ios

A trench was dug at the 1 m level. One Hemigrapsus oregonensis was found.

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #17 12 JUNE 75
Bearing: 342°T
Time: 1145 hrs.
Weather: Clear, winds 0-5 knots.
Air temp: 20.6°C Sand temp: 19.4°C

2 m level: 5 m from breakwater. Coarse sand, rocks and cobbles with some barnacles and algae.

Quad. #95 nothing

Quad. #96 nothing

1 m level: 24 m from breakwater. Sand and mud shrimp holes.

Quad. #97 nothing

Quad. #98 nothing

0 m level: 78 m from breakwater. Silty sand with occasional patches of eelgrass.

Quad. #99 nothing

Quad. #100 nothing.

Some *Macoma balthica* observed but <4 mm, therefore they went through the screen.

A trench was dug at 1/2 m level. No clams.

One live *Protothaca staminea* was found along the transect line, on the surface.

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #18 12 JUNE 75
Bearing: 352°T
Time: 1233 hrs.

2 m level: Base of breakwater -- coarse sand.

Quad. #101 nothing

Quad. #102 nothing

The boulders of the breakwater were covered with *Fucus*, *Ulva*, *Enteromorpha*, *Mytilis edulis*, *Balanus glandula*, *Acmaea* sp. and *Thais lamellosa*.

1 m level: 10 m from breakwater. Coarse sand and sand.

Quad. #103 nothing

Quad. #104 24 *Balanus glandula* > 1 mm
4 *B. glandula* < 1 mm

0 m level: 68 m from breakwater. Silty sand with occasional patches of eelgrass.

Quad. #105 1 *Pagurus hirsutuisculus*

Quad. #106 nothing

A trench was dug at the 1 m level. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #19 23 JUNE 75

Bearing: 357°T
Time: 1030 hrs.
Weather: Overcast, wind 5-10 knots.
Air temp: 16.1°C Sand temp: 15°C

2 m level: 5 m from breakwater. Coarse sand, rocks, cobbles and small boulders.

Quad. #107 (coarse sand area)
2 Nereid polychaetes
3 *Mytilis edulis* >4 mm
4 *Balanus glandula* >1 mm

Quad. #108 (boulder)
76 *B. glandula* >1 mm
48 *M. edulis* >1 mm
Fucus
Enteromorpha
Ulva

1 m level: 13 m from breakwater. Sand, cobbles and boulders covered with algae, barnacles and mussels.

Quad. #109 (rocks under sand)
312 *B. glandula* >1 mm
30 *M. edulis* >4 mm

Quad. #110 (boulders)
20 *Exosphaeroma oregonensis*
2 *Hemigrapsus nudus*
850 *B. glandula* >1 mm
135 *B. glandula* <1 mm
297 *M. edulis* >4 mm
Fucus
Ulva

0 m level: 48 m from breakwater. Sand, rocks, cobbles with algae and barnacles.

Quad. #111
763 *B. glandula* >1 mm
427 *B. glandula* <1 mm
12 *E. oregonensis*
1 Corophiidae amphipod
38 *M. edulis* >4 mm
Ulva

Quad. #112
1 Nephtyid polychaete
1 Nemertean
4 Corophiidae amphipods
33 *E. oregonensis*
1 *Anthopleura artemisia*
Ulva

Quad. #112 (continued)

1 *Acmaea* sp.
1509 *B. glandula* >1 mm
499 *B. glandula* <1 mm
68 *M. edulis* >1 mm
5 *Macoma inquinata*

A trench was dug at the 1/2 m level, 30 m N.E.

1 *Prototheca staminea*
1 *M. inquinata*
1 *Saxidomus giganteus*

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #20 12 JUNE 75

Bearing: 352°T
Time: 1450 hrs.

2 m level: 9 m from breakwater. Coarse sand, large cobbles to small boulders with barnacles and algae.

Quad. #113
- 235 *Mytilis edulis* > 1 mm
- 546 *Balanus glandula* > 1 mm
- 87 *B. glandula* < 1 mm
- 2 *Exosphaeroma oregonensis*
- 7 *Hemigrapsus oregonensis*
- 1 Nereid polychaete
- *Enteromorpha*
- *Fucus*

Quad. #114
- 3 *Hemigrapsus oregonensis*
- 52 *M. edulis* > 4 mm
- 87 *M. edulis* < 4 mm
- 460 *B. glandula* > 1 mm
- 236 *B. glandula* < 1 mm
- 3 Nereid polychaete
- 1 Nemertean worm
- *Fucus*
- *Enteromorpha*

24 JUNE 75

Time: 1120 hrs.
Weather: Raining, wind 0-5 knots
Air temp: 15°C Sand temp: 13.9°C

1 m level: 30 m from breakwater. Sand, rocks and cobbles covered with algae and barnacles.

Quad. #115
- 3132 *B. glandula* > 1 mm
- 210 *M. edulis* > 4 mm
- 443 *M. edulis* < 4 mm
- 41 *E. oregonensis*
- 4 Nereid polychaetes

Quad. #116
- 2555 *B. glandula* > 1 mm
- 347 *B. glandula* < 1 mm
- 188 *M. edulis* > 4 mm
- 7 *M. edulis* < 4 mm

0 m level: 96 m from breakwater. Sand.

Quad. #117
- 1 *Macoma balthica*
- 2 Nemertean worms

Transect #20 (continued):

Quad. #118   1 _M. balthica_
              2 _Nemertean worms_

A trench was dug at 1 m

1 _Macoma inquinata_
2 _Cryptomya californica_

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #21   25 JUNE 75

Bearing: 354°T
Time: 1158 hrs.
Weather: Overcast, some rain, wind 0-5 knots
Air temp: 16.7° Sand temp: 15.6°C

2 m level: No quadrats taken. 4 m from breakwater. In area of jumbled boulders dumped next to the breakwater and extending to about six meters below.

1 m level: 12 m from breakwater. Sand and *Zostrea* beds

Quad. #119 nothing

Quad. #120 1 *Macoma balthica*
2 Nephtyid polychaetes

0 m level: 48 m from breakwater. Silty sand and mud/ghost shrimp holes.

Quad. #121 nothing

Quad. #122 1 *M. balthica*
1 Nephtyid polychaete

A trench was not dug.

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transects #22 24 JUNE 75

Bearing: 337°T
Time: 1230 hrs.

2 m level: No quadrats taken

1 m level: 2 m from breakwater. Coarse sand, cobbles and rocks.

Quad. #123
1 *Balanus glandula* > 1 mm
1 *Mytilis edulis* > 4 mm
1 Corophiid amphipod

Quad. #124
2 *Exosphaeroma oregonensis*
1 *M. edulis* > 4 mm
4 *Hemigrapsus oregonensis*
1 Nereid polychaete

0 m level: 13 m from breakwater. Sand, rocks and cobbles with barnacles and algae. *Zostrea* beds nearby.

Quad. #125
1608 *B. glandula* > 1 mm
107 *B. glandula* < 1 mm
70 *M. edulis* > 4 mm
9 *Pagurus hirsutuisculus*
7 *E. oregonensis*
1 *Macoma inquinata*
7 *Thais lamellosa*
32 Corophiid amphipod
Ulva

Quad. #126
686 *B. glandula* > 1 mm
282 *B. glandula* < 1 mm
88 *M. edulis* > 4 mm
1 *Acanthodora brunnea*
5 *H. oregonensis*
9 *Pagurus hirsutiusculus*
1 *Macoma nasuta*
2 *M. inquinata*
1 Nereid polychaete
3 Pectinariid polychaetes
Ulva

A trench was dug at 0 m.
1 *Protothaca staminea*
2 *M. nasuta*

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #23   22 JULY 75

Bearing: 337°T
Time: 1100 hrs.
Weather: Warm, hazy day. Wind: 0-5 knots
Air temp: 16.7°C
Sand temp: 15.6°C

2 m level: Base of breakwater. Coarse sand and gravel.

Quad. #127 nothing
Quad. #128 nothing

1 m level: 14 m from breakwater. Coarse sand, cobbles, small boulders with algae and barnacles.

Quad. #129
1258 *Balanus glandula* >1 mm
20 *B. glandula* <1 mm
39 *Mytilis edulis* >4 mm
33 *Thais emarginata*
1 *Collisella (Acmaea) pelta*
7 *Hemigrapsus nudus*
5 *Exosphaeroma oregonensis*
6 Nereid polychaetes
12 Corophiid amphipods

Quad. #130
Dry *Ulva* and *Enteromorpha*, clinging to rocks
672 *B. glandula* >1 mm
179 *B. glandula* <1 mm
20 *M. edulis* >4 mm
1 *M. edulis* <4 mm
10 *H. nudus*
1 *Hemigrapsus oregonensis*
3 *E. oregonensis*
21 *T. emarginata*

0 m level: 32 m from breakwater. Coarse sand, rocks, cobbles and small boulders covered with algae, barnacles and mussels.

Quad. #131
494 *B. glandula* >1 mm
87 *B. glandula* <1 mm
163 *M. edulis* >4 mm
5 *H. nudus*
8 Polyclad flatworms
1 *Emplectonema* sp.
3 *E. oregonensis*
1 *Pagurus hirsutuisculus*
12 Corophiid amphipods
3 *Macoma inquinata*
Ulva

Transect #23 (continued);

Quad. #132

1352	*B. glandula* >1 mm
93	*B. glandula* <1 mm
80	*M. edulis* >4 mm
3	*M. edulis* <4 mm
8	*H. nudus*
2	*P. hirsutuisculus*
1	*Emplectonema* sp.
1	*Protothaca staminea*
5	*E. oregonensis*
1	*Thais lamellosa*
1	Nereid polychaete
	Ulva

A trench was dug at the 0 m level for only 1 meter long and 4 cm deep due to blue clay layer beneath surface.

3 *P. staminea*

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #24   23 JULY 75

Bearing: 327°T
Time: 1135 hrs.
Weather: warm, clear day. No wind.
Air temp (shade): 22.2°C   Sand temp: 20.6°C

2 m level: No quadrats taken. Base of breakwater less than 2 meters above MLLW.

1 m level: 3 m from breakwater. Coarse sand, some rocks and cobbles with attached algae.

Quad. #133   nothing

Quad. #134   102 *Balanus glandula* <1 mm
6 *B. glandula* >1 mm

0 m level: 25 m from breakwater. Silty sand.

Quad. #135   1 *Macoma balthica*
2 Nereid polychaetes
1 Nephtyid polychaete

Quad. #136   2 *Macoma inquinata*
1 Nephtyid polychaete

A trench was dug at the 0 m level. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #25 23 JULY 75

Bearing: 327°T
Time: 1235 hrs.

2 m level: Base of breakwater. Coarse sand.

Quad. #137 nothing

Quad. #138 nothing

1 m level: 14 m from breakwater. Sand

Quad. #139 nothing

Quad. #140 87 Balanus glandula $<$ 1 mm (Rock just below surface)
13 B. glandula $>$ 1 mm

0 m level: 50 m from breakwater. Silty sand in Zostrea bed.

Quad. #141 Zostrea
2 Nereid polychaetes

Quad. #142 Zostrea
2 Macoma balthica

A trench was dug at the 1 m and 1 1/2 m level. No clams.

PT. GARDNER ECOBAM BEACH TRANSECTS - 1975

Transect #26   24 JULY 1975

Bearing: 332°T
Time: 1230 hrs.
Weather: Overcast, wind 0-5 knots
Air temp: 17.8°C   Sand temp: 18.9°C

2 m level: 8 m from breakwater. Sand and small boulders.

Quad. #143   nothing

Quad. #144   nothing

1 m level: 18 m from breakwater. Coarse sand, gravel and cobbles.

Quad. #145   nothing

Quad. #146   nothing

0 m level: 80 m from breakwater. Silty sand, some algae and mud/ghost shrimp holes.

Quad. #147   Enteromorpha proliferata

Quad. #148   Enteromorpha proliferata

A trench was dug at the 1 m level. No clams.