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RESPONSES OF BENTHIC INFAUNA TO THE INITIATION AND TERMINATION OF SEWAGE DISCHARGE

by

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SUMMARY AND CONCLUSIONS

The discharge of sewage wastewater to the open ocean off Orange County, California, was diverted from a shallow to a deep water outfall system in March, 1971. The sediments at the two discharge sites were monitored from August, 1970, to August, 1972, by G. Smith (1974). He concluded that the fauna and certain abiotic parameters in the sediments at the shallow outfall had reached background levels within three months after termination of discharge, and initiation of discharge at the deep outfall site resulted in a general increase in the abundance and kinds of animals, a shift in the relative species composition, and a large increase in the abundance of one capitellid polychaete. Sediment organic carbon and sulfide concentration did not noticeably increase.

The present reanalysis of these outfall sites is based on an extensive survey conducted in July, 1975. Concentrations of organic carbon, sulfide, and certain trace metals at the old outfall are now even lower than the earlier background levels. This suggests that the sediments have been subjected to strong mixing activity which may have been, in part, responsible for the rapid recovery reported by Smith. Several "indicator" species characteristic of stressed outfall areas are used to define an area of about 3 sq km at the new diffuser where significant changes in the biota occur. A new index of dominance is used to illustrate strong gradients in species dominance, and the numerical procedures of classification and discriminant analyses are used to evaluate potential cause and effect, biotic-abiotic, relationships in the sediments around this diffuser.

These latter analyses indicate that the most significant present effect of this outfall on the biota is related to organic enrichment, however, the higher than baseline concentrations of trace metals along with the biological changes that have occurred in these sediments since Smith's survey suggest that this type of extensive survey and analysis should be conducted every two or three years to determine whether or not the affected area is continuing to expand or remains relatively stable in size and character.

Rapid ecological recovery from long term discharge should be considered among the criteria for selection of discharge sites. Therefore shallow water open coastal sites (i.e., those under the influence of wave action and rapid mixing), should not be entirely ruled out among alternatives for municipal wastewater disposal.

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INTRODUCTION

A unique opportunity to study the ecological effects of sewage discharged to the marine environment occurred on March 31, 1971, off the coast of Orange County, California, when wastewater discharge was diverted from a shallow, inshore, submarine outfall to a longer, subthermocline system. During the transition period (August, 1970 to August, 1972) the biotic and abiotic conditions at these outfalls were studied by Dr. Gary Smith, with partial support from SCCWRP, as his doctorial research at Scripps Institute of Oceanography (G. Smith, 1974). Like Smith, our primary concerns were the rate and degree of recovery at the old outfall and the rate and kinds of change, if any, that would occur as a result of the modern deep water diffuser system. The project then, as now, was considered to be a study of "Stress and Recovery" from the open ocean discharge of sewage.

Smith's sampling, while limited to a single effective site at each outfall, provides an outstanding temporal record of the events that occurred during the transition period. He concluded that recovery at the old outfall was rapid and most biotic and abiotic factors had reached background levels within the first year after cessation of discharge. Abiotic factors in the sediments around the new outfall did not increase noticeably during the initial seventeen months of discharge, and, aside from the pronounced increase in abundance of a single species, there was a general enhancement in the kinds, density, and biomass of benthic invertebrates.

The present study was undertaken to answer three questions:

(1) What impact, if any, has this modern, well designed, subthermocline diffuser system had on the benthic infauna and sediments of this coastal shelf and slope since discharge was initiated?

(2) Will the multivariate numerical procedures that we have successfully used to relate biotic and abiotic change at a severely effected outfall (Greene, 1975; Smith and Greene 1976; Stephenson, et al, 1975) be of value in an area suspected to show little outfall effect?

(3) How do the present conditions at the old, shallow, outfall compare with those reported by G. Smith (1974).

METHODS

STUDY AREA

Location and Topography

The sampling grid is located on the southeast end of the San Pedro shelf just to the west of Newport canyon and offshore of the Santa Ana River and the Orange County coast in Southern California. The center of the study area is located at approximately 30°35' north latitude and 118°00' west longitude (Fig. 1). The sampling sites are situated along six isobaths that begin at approximately 1.8 km and extend to 9.3 km offshore and range in depth from 13 to 185 meters (8 to 100 fm).

Submarine Outfalls

The sewage disposal system consists of two submarine outfalls. An older, shallow water outfall (198 cm I.D.), installed in 1954, extends 2,440 m from the mouth of the Santa Ana River and discharges at a depth of 16 - 18 m. A second, newer outfall (305 cm I.D.) was placed in operation on March 31, 1971, when continuous discharge from the older outfall was terminated. It extends approximately 7,300 m from shore and terminates in a 1,830 m L-shaped diffuser between 53 - 60 m depth. The average discharge rate of 5.12 x 10^5 cu m/day (135 mgd) in 1971 had increased to 6.47 x 10^5 cu m/day (171 mgd) in the summer of 1975 when the present survey was conducted.

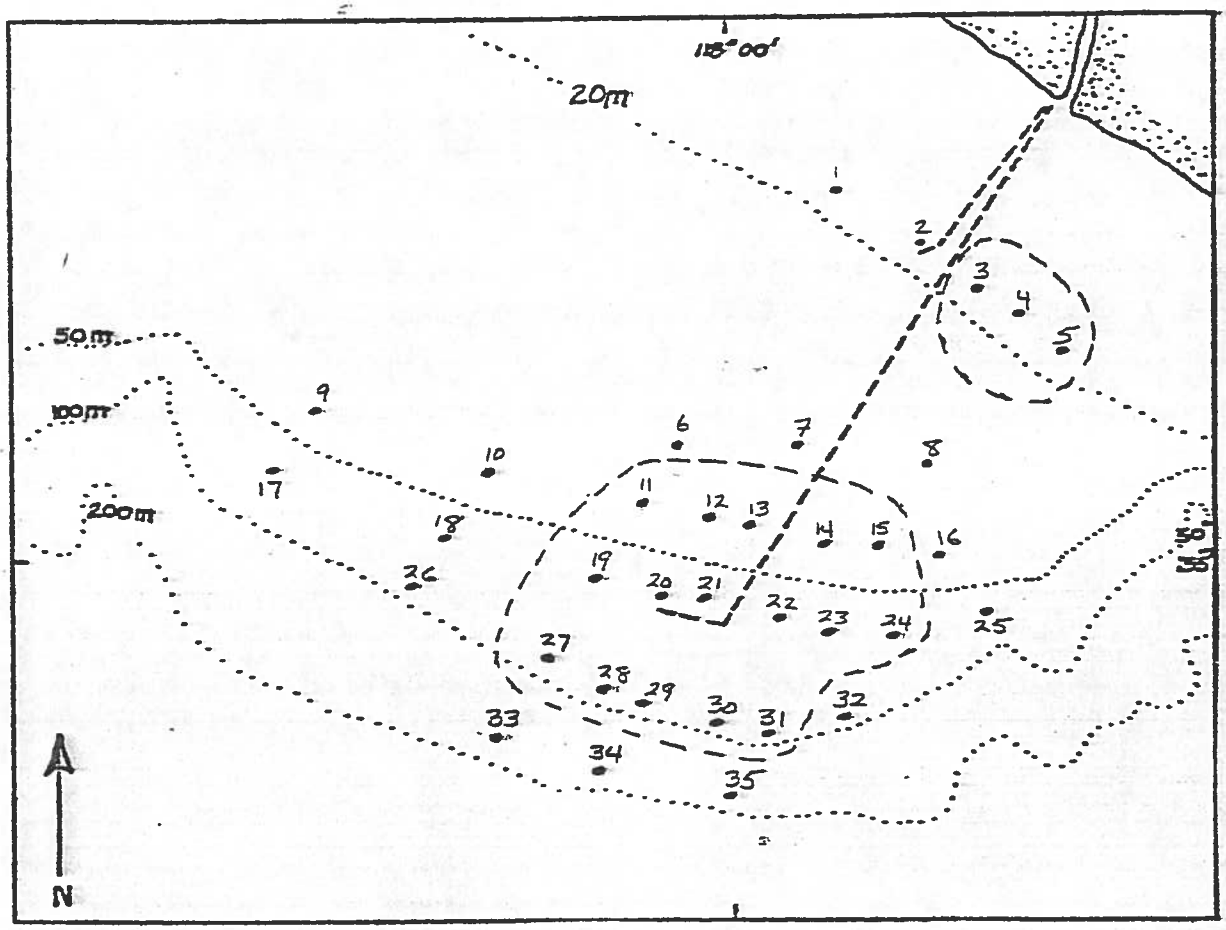


Figure 1. Location of sampling sites around the Orange County outfall pipes. Two replicate van Veen samples were analysed for biological content at the 19 sites enclosed by dashed lines. One sample was analysed from the remaining 16 sites.

FIELD AND LABORATORY PROCEDURES

Sampling Sites

Samples used in this study were collected from sites located along six depth contours (13, 37, 46, 55, 91 and 183 m or 8, 20, 25, 30, 50, and 100 fm). The number and locations of these sites (Fig. 1) were based on two considerations:

(1) sites 3, 4, 5 and 22, 23, 24 correspond with those sampled by G. Smith and,

(2) these sites plus and additional 29 sites were sampled in order to determine the effects, if any, of the deep outfall on the major trends in the distributions of the biota and readily measured environmental variables. These latter sites were selected on the basis of an extensive preliminary survey conducted in February and March, 1975.

Biological Data

A total of 90 benthic samples were collected in late July, 1975, using a 0.1 m^2 Van Veen benthic grab. Smith used this same sampling device. The samples were washed over a 1.0 mm stainless steel screen except as described below and preserved in 7 percent buffered formalin and later transferred to 70 percent ethanol.

Neither the intensity of sampling or identification was the same for all sites. Three replicate samples were taken at each of the 19 sites enclosed by the dashed line on Figure 1. Two samples at each of these sites were thoroughly sorted and the organisms identified to species level whenever possible. Two replicate samples were collected at the remaining 16 sites and the animals in one of these samples at each site were sorted, identified and counted. At the six sites previously sampled by Smith the samples were washed through both a 0.5 and 1.0 mm screen and kept separate during sorting and enumeration. The partitioning of these samples by screen size was done to obtain samples that could be compared with Smith's (0.5 mm) samples and still be used with the other samples in the broader survey. It was not felt that the additional information that could be derived from screening all samples at 0.5 mm would justify the additional time and expense. Thus, a total of 66 separate samples were analysed for biological content.

Environmental Data

Several subsamples of sediment were taken from the biological samples at each site. These samples were used to determine percent volatile solids (a measure of organic material), acid volatile sulfides (ppm S=, dry wt.), total DDT and PCB (ppb, dry wt.), and the trace metals, total mercury, copper, lead, cadmium, chromium, nickel, and zinc (ppm, dry wt.). Standard sediment particle-size grades were combined for % sand, % silt, and % clay and mean grain size and standard deviation (sorting coefficient) were also determined. Depth of the water and sediment temperature were recorded at each sampling site. These data are reported in Appendix A.

Several of these environmental variables displayed skewed distributions, namely depth, PCB's, and cadmium, and were transformed by natural logarthms. The measurements expressed as a percentage, e.g. sand, silt, and clay, were transformed by arcsine of the square root (Barnes 1952; Cassie and Michael, 1968).

ANALYTICAL PROCEDURES

Two essentially different approaches to data analysis are employed in this report: (1) Basic statistical and descriptive (graphic) methods are used for comparisons between recent samples and the results presented by Smith and also to describe the overall distributions of the biotic and abiotic data collected during our recent extensive survey of this area, and (2) multivariate numerical procedures. These latter procedures are designed to classify the compositionally more similar entities (e.g. sampling sites) into groups that can then be described and compared in terms of their attributes (e.g., species in the sites) and also the physical and chemical nature of the environment in which the animals live.

Diversity and Dominance

Shannon's index of species diversity, H', (Pielou, 1975) is used as an index of community organization, where the measure of organization is the number of species weighted by their relative abundances. The index is used in the present study to evaluate the status of the community in terms of environmental conditions. Scaled diversity, H'_S, (Hurlbert, 1971; Fager, 1972; Greene, 1973), is used to measure the evenness of the distribution of individuals among species. H'_S is a scaled form of H' and is one of the two components of community structure that influence the numerical value of H'. Species richness is the other component.

An index of dominance that is much simpler than H'_S is also used. Although this is the first time, to the author's knowledge, that this specific form of the index has been used, its simplicity suggests that it may have been used before. The index of dominance is defined as:

$$ID = 1 - \frac{\text{No. of Species for 90 \% of the individuals}}{\text{Total No. of Species}}$$

where the species are first ranked from most to least abundant and the abundances are summed, beginning with the most abundant, until 90 percent of the individual organisms have been counted. The index is subtracted from 1.0 so that the highest values will correspond with extreme dominance. The values, thus, run opposite to the measure of evenness, H'_S.

Hierarchial Classification

This procedure is used to classify entities into groups according to the similarity of the attributes associated with each entity (Clifford and Stephenson, 1975; Greene, 1976). Similarity is initially determined by calculating the "ecological distance" between all possible pairs of entities. The distance measure used is called the "Bray-Curtis" coefficient (Bray and Curtis, 1957). The method for grouping entities and recalculating distances is called the flexible sorting (clustering) strategy (Lance and Williams, 1967). The adjustable coefficient has been set at the now generally used level of -0.25. The clustering process is agglomerative and the final relationships between the groups of entities is presented as a hierarchial tree-diagram called a dendrogram. The ecologist can choose to define groups for interpretive purposes at any "meaningful" level or levels in the final dendrogram. Although these methods are also used to define species groups, the major emphasis in the present study will be to define groups of sampling sites (site groups).

Multiple-Discriminant Analysis

This procedure is used to study the relationships between groups of entities (site groups in this study) and the environmental variables (attributes) measured at each sampling site (R. Smith, 1976; Hope, 1969; Seal, 1964). In this analysis each site is imagined as a point in a multidimensional space in which each dimension represents one of the measured environmental variables. The distance that a point (site) is along a dimension from the origin is related to the magnitude of the variable at that site. If the sites in the site groups are related in similar ways to one or more of the variables they will tend to cluster together along one or more dimensions. The environmental variables corresponding to these dimensions will be those that vary the least among the sites within the group. On the other hand, the different site groups will tend to separate from one another along those dimensions in terms of the variables that vary the most between the groups.

The results of this analysis will show which, if any, of the environmental variables correspond to the site groups based on the biota. These findings can lead directly to hypotheses that relate environmental factors to the distribution and composition of the biota.

Data Reduction

It is customary to remove the rarer and poorly identified, possibly polyspecific, taxa from the original data lists prior to carrying out numerical analyses on biological data. Aside from contributing little or nothing to species abundance patterns as defined by classification procedures, the statistical reliability of data for rare species is quite low and their omission may actually improve the quality of the final result. There are a large number of very rare species in this collection, and there are also a large number of species that occur at several sites but with very low abundance. Therefore, all species with less than 10 individuals and/or occurring at less than three sites were not considered. Aside from the possible benefits derived from this data reduction, a considerable saving in computor time is realized.

It may also be necessary to reduce the number of abiotic variables used in an analysis. The removal of all but one of a set of highly intercorrelated variables can simplify the interpretation of the discriminant analysis as well as the coefficients of any multiple regression procedures that may be used (Snedecor and Cochran, 1967).

Data Transformation and Standardization

The biotic data used in the classification analysis is first transformed by square root and then standardized by either the species mean for the classification of sites or by the species maximum for classification of species. The transformation removes any extreme skewness in these data and also reduces the scale of the numbers used in the analyses. This later consideration is desirable for obtaining the best results from the Bray-Curtis distance measure. The two kinds of standardizations have recently been shown to be optimum for these respective forms of classification by R. Smith (1976) in an extensive study of these procedures. However, analyses using the species-mean standardization for both the site and species classifications have been quite successful (Greene, 1976; Smith and Greene, 1976; Greene and Smith, 1975).

RESULTS

The biological data collected at 35 sites and retained on the 1.0 mm screens will be considered in the following section. The remaining data will be used later for comparison with G. Smith's "Stress and Recovery" results.

ANALYSIS OF DATA FROM 35 SITES

Biological Data

A total of 397 taxa acounting for 22,870 individual organisms were identified and counted. In order that the data from all sites could be compared, the averages of the counts were used at those sites where replicate samples were analysed (see Fig. 1). It was originally believed that the conditions in the area could be adequately described by the 19 sites where replicate samples were analysed, however, a more representative picture was obtained by including all samples, especially whose located on either side of the deep outfall. The potential bias in numbers of species resulting from the greater surface area sampled at these 19 sites is considered to be more than offset by the increased representitiveness of the average data at these sites.

The spatial patterns of distribution for species, individual organisms, biomass, species diversity (Shannon index, H'), evenness or scaled diversity (H'_S), and an index of dominance are shown on Firgures 2 - 7. It is immediately apparent from these Figures that depth is very important in determining many aspects of the biological organization on this shelf. This is to be expected and even exists in areas of severe sewage impact (Greene, 1975; Smith and Greene 1976). The impact of the outfall and waste materials on these biological

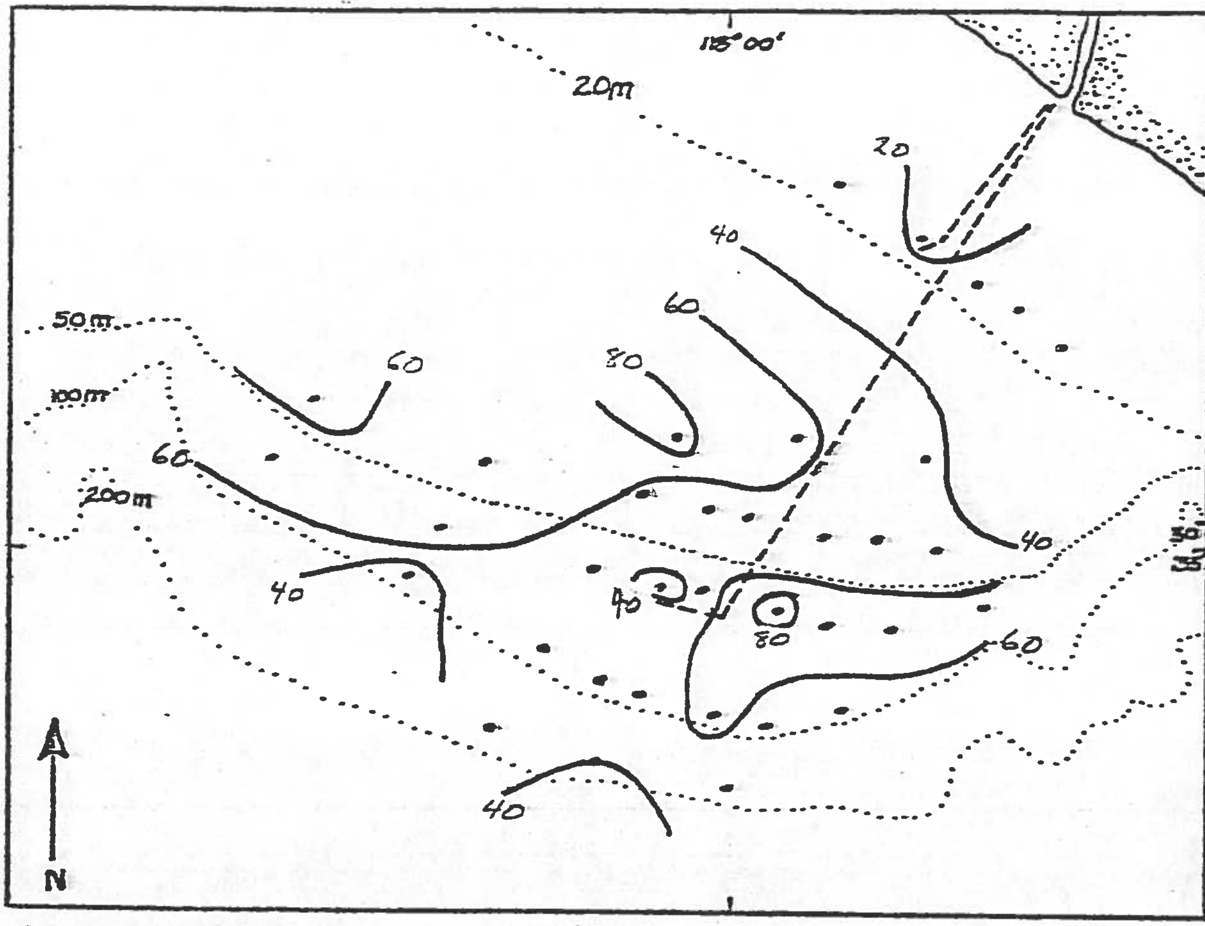


Figure 2. Species per site.

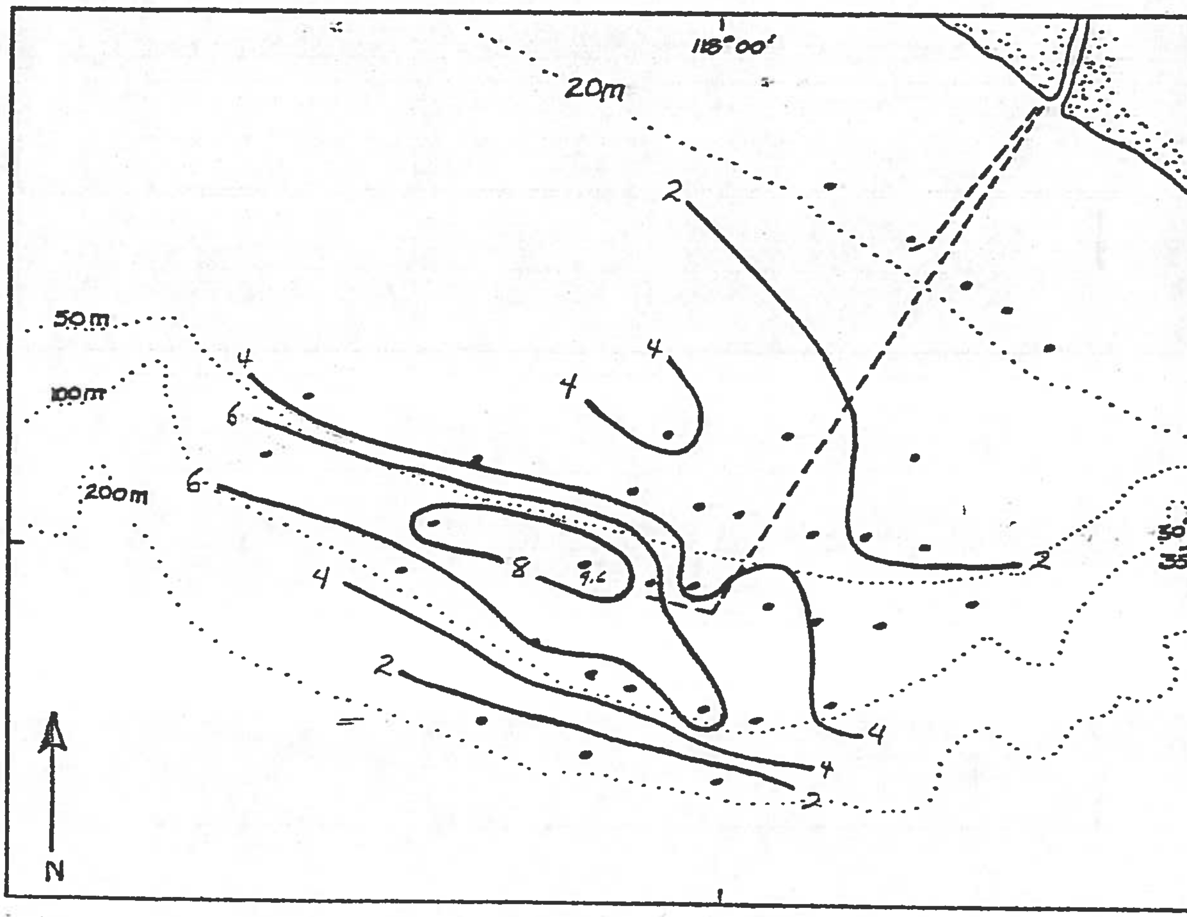


Figure 3. Individuals per square meter (÷ 1,000).

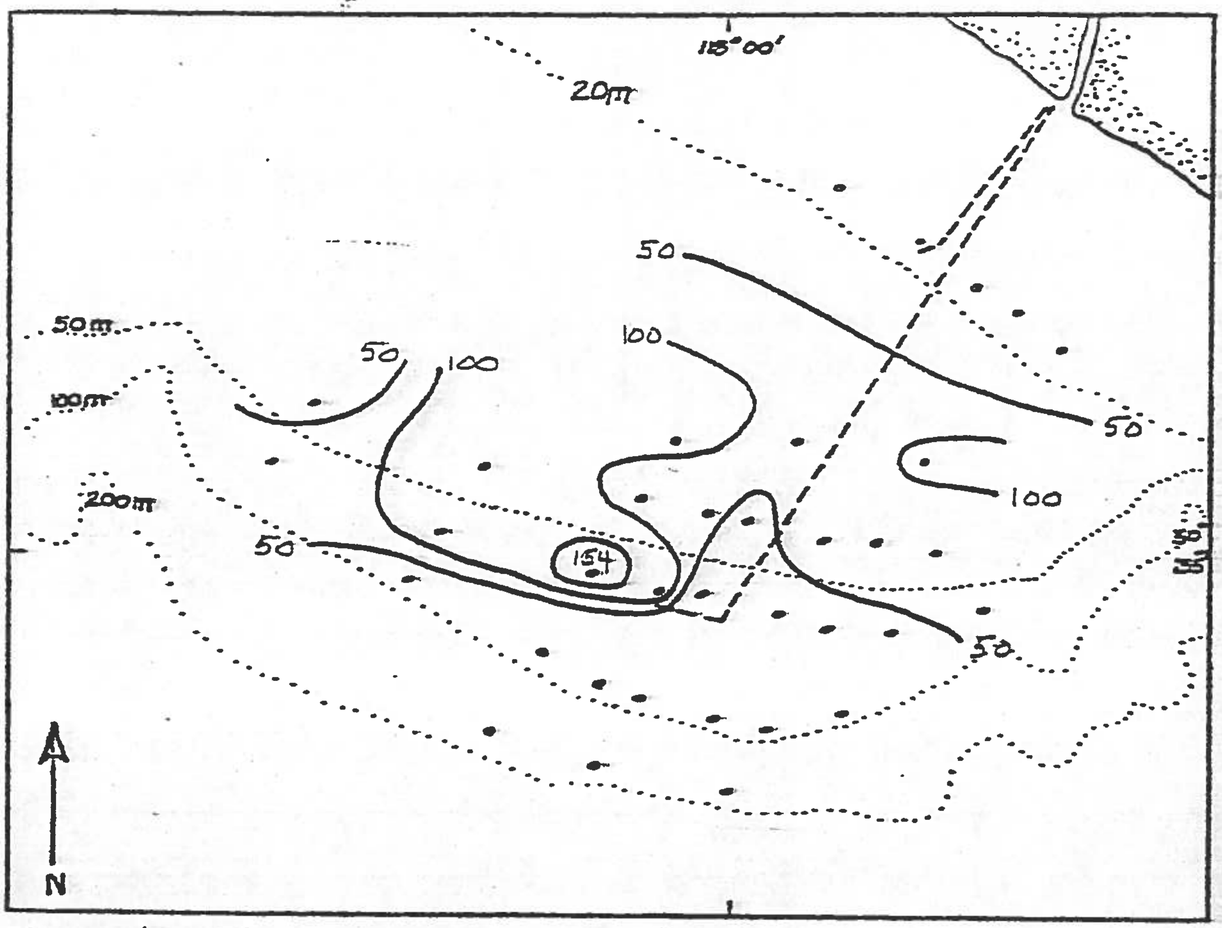


Figure 4. Biomass per sq. meter (gms).

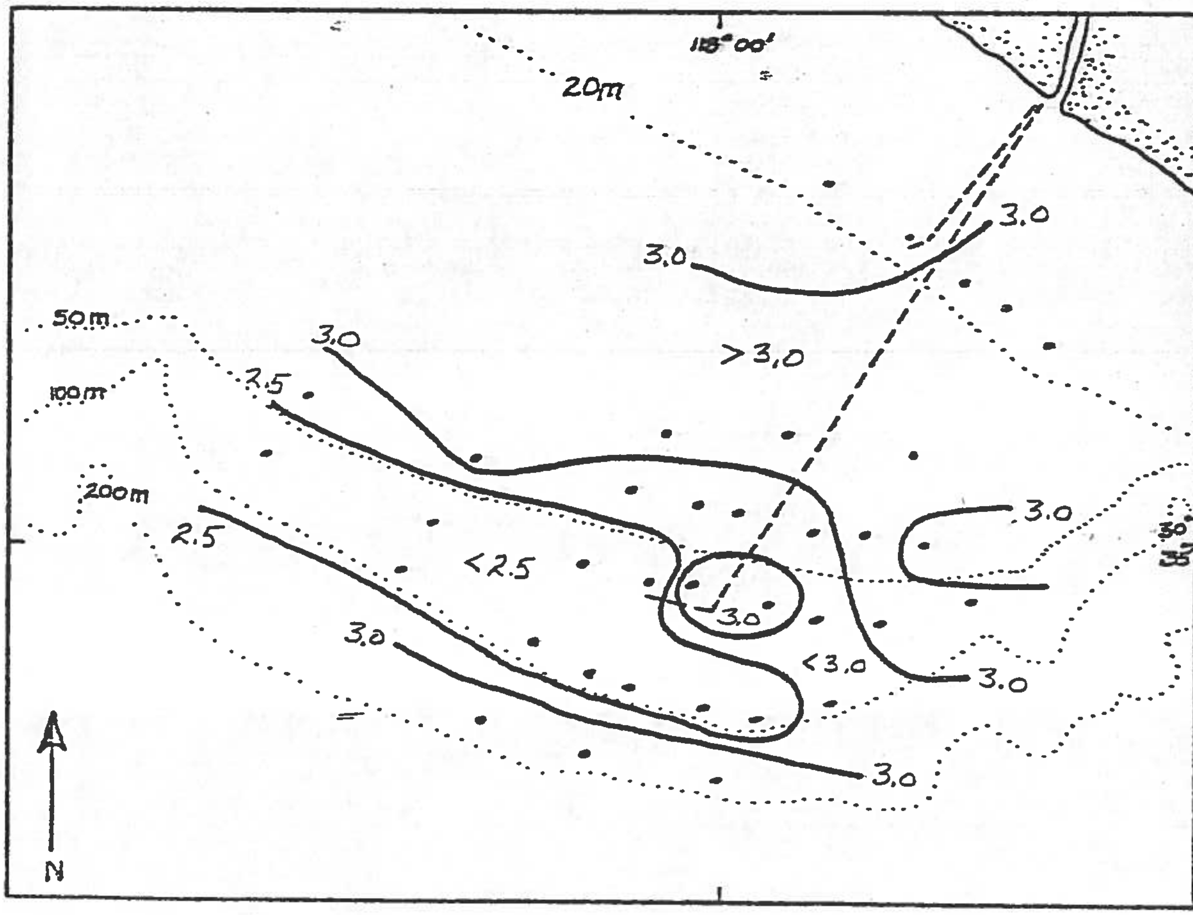


Figure 5. Species diversity (H').

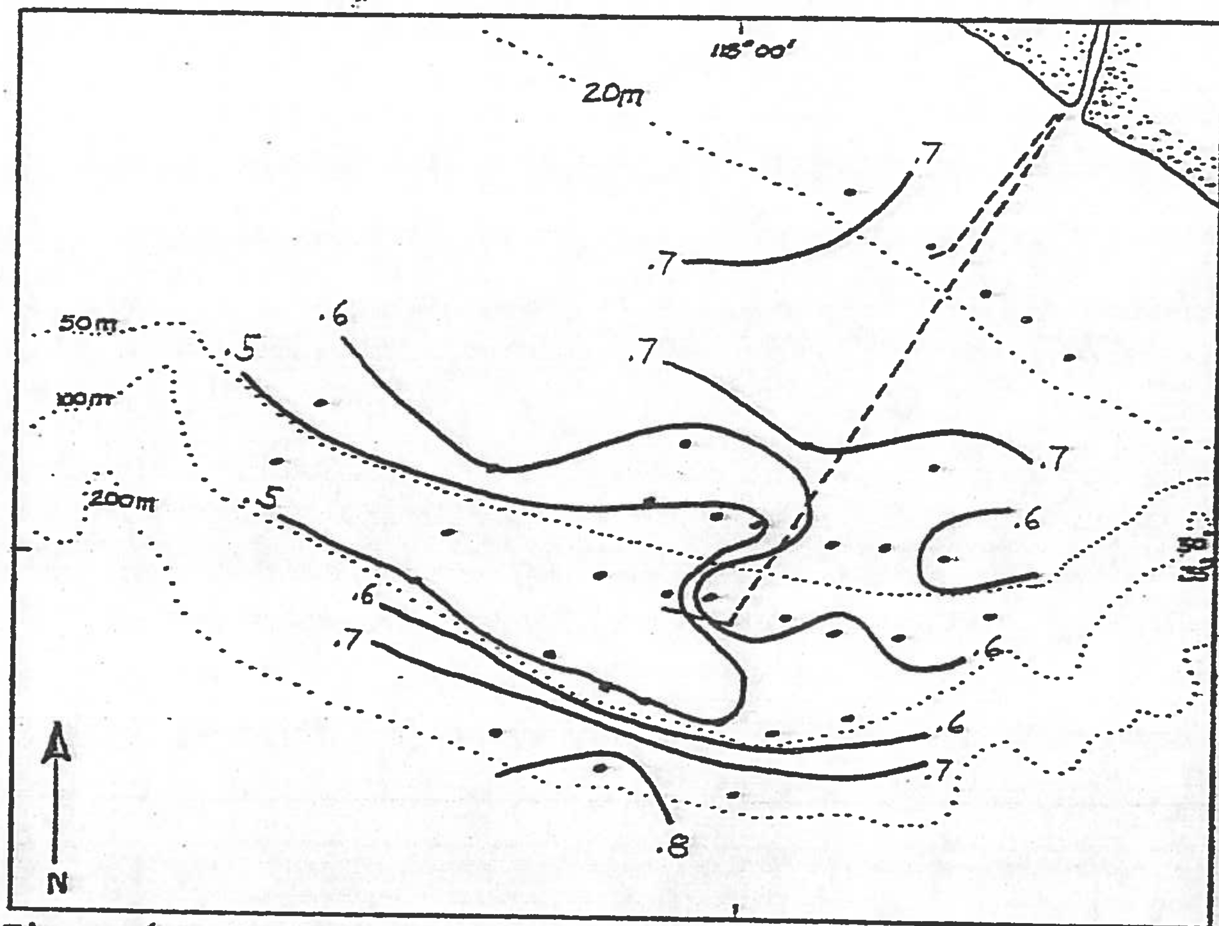


Figure 6. Scaled diversity (evenness).

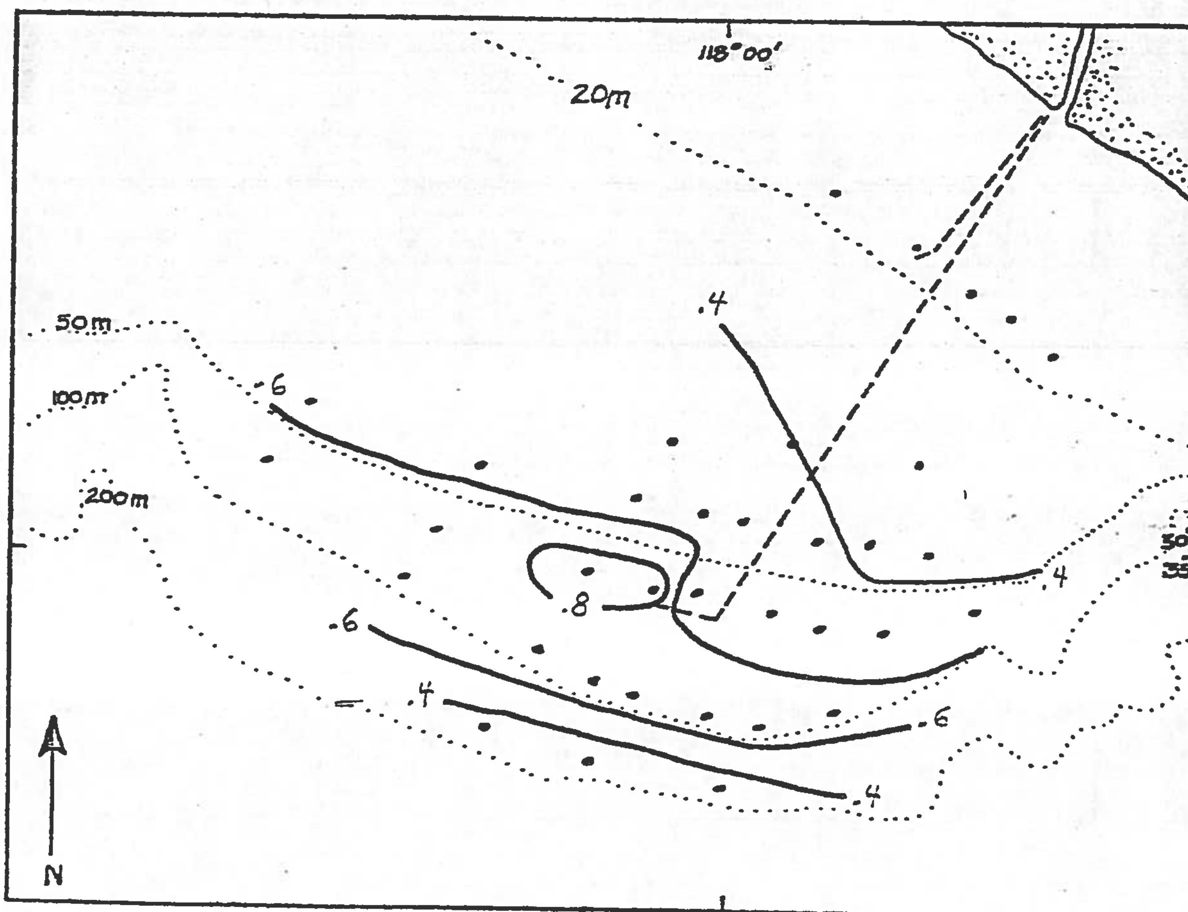


Figure 7. Index of dominance.

variables and parameters is also apparent from these Figures. There is a general trend in each of these variables to either increase or decrease from deeper water and shallower water to diffuser depth. There is also a trend at diffuser depth for the values to be higher to the southeast and lower to the northwest especially just beyond the end of the diffuser. The number of species is lowest and the number of animals and biomass/sq. m. is maximum in this area. These patterns seem to reflect an average annual flow of the currents to the northwest. These same trends are reflected in the statistical measures of species diversity, evenness diversity, and the index of dominance (Fig. 5 - 7).

Physical/Chemical Data

A total of 18 potentially important abiotic variables were measured at most, and in some cases all, of the 35 sampling sites (appendix A). The correlation matrix for all the abiotic variables is shown on Table 1, where all correlations greater than or equal to 0.60 are underlined for emphasis. It can be seen from this Table that the measures of sediment size and composition are highly intercorrelated along with percent volatile solids (a measure of organic material) and, to a lesser extent, total DDT. The trace metals, with the exceptions of lead and mercury, form another group of highly intercorrelated variables. These metals are also correlated with acid volatile sulfides (a form of sulfide in which many of these metals may exist) and total PCB's.

The distribution of mean grain size (Phi units) and copper (ppm) are plotted on Figures 8 and 9 as examples of the areal

Table 1. Intercorrelations (r) between sediment related abiotic variables. Correlations greater than or equal to 0.06 are underlined for emphasis.

	$\bar{x}$ GRAIN-SIZE (PHI)	SORTING COEFFICIENT	% SAND	% SILT	% CLAY	% VOLATILE SOLIDS	TOTAL DDT (PPB)	TEMPERATURE (°C)	DEPTH (M)	ACID VOLATILE SULFIDES	TOTAL PCB (PPB)	COPPER (PPM)	CADMIUM (PPM)	CHROMIUM (PPM)	NICKEL (PPM)	ZINC (PPM)	LEAD (PPM)	MERCURY (PPM)
MEAN GRAIN-SIZE (PHI)	1.00																	
SORTING COEFFICIENT	0.65	1.00																
PERCENT SAND	-0.94	-0.75	1.00															
PERCENT SILT	0.93	0.72	-1.00	1.00														
PERCENT CLAY	0.83	0.82	-0.81	0.78	1.00													
PERCENT VOLATILE SOLIDS	0.82	0.71	-0.74	0.72	0.75	1.00												
TOTAL DDT (PPB)	0.65	0.60	-0.58	0.55	0.64	0.71	1.00											
TEMPERATURE (°C)	-0.52	-0.60	0.50	-0.49	-0.50	-0.54	-0.44	1.00										
DEPTH (M)	0.50	0.59	-0.49	0.48	0.50	0.52	0.45	-0.97	1.00									
ACID VOLATILE SULFIDES	0.37	0.38	-0.31	0.30	0.38	0.43	0.44	-0.34	0.34	1.00								
TOTAL PCB (PPB)	0.37	0.38	-0.31	0.30	0.42	0.46	0.33	-0.47	0.48	0.63	1.00							
COPPER (PPM)	0.37	0.17	-0.24	0.24	0.27	0.47	0.46	-0.33	0.37	0.67	0.70	1.00						
CADMIUM (PPM)	0.39	0.23	-0.26	0.26	0.30	0.51	0.37	-0.43	0.46	0.67	0.75	0.95	1.00					
CHROMIUM (PPM)	0.37	0.16	-0.26	0.26	0.23	0.46	0.40	-0.31	0.37	0.45	0.66	0.91	0.86	1.00				
NICKEL (PPM)	0.70	0.48	-0.62	0.61	0.59	0.67	0.60	-0.60	0.66	0.43	0.58	0.75	0.73	0.81	1.00			
ZINC (PPM)	0.35	0.23	-0.26	0.26	0.26	0.43	0.36	-0.49	0.52	0.43	0.61	0.84	0.83	0.87	0.80	1.00		
LEAD (PPM)	0.37	0.26	-0.24	0.23	0.37	0.42	0.51	-0.00	0.01	0.61	0.36	0.57	0.48	0.32	0.35	0.29	1.00	
MERCURY (PPM)	0.38	0.19	-0.27	0.27	0.27	0.41	0.28	-0.20	0.25	0.43	0.46	0.53	0.54	0.55	0.43	0.46	0.34	1.00

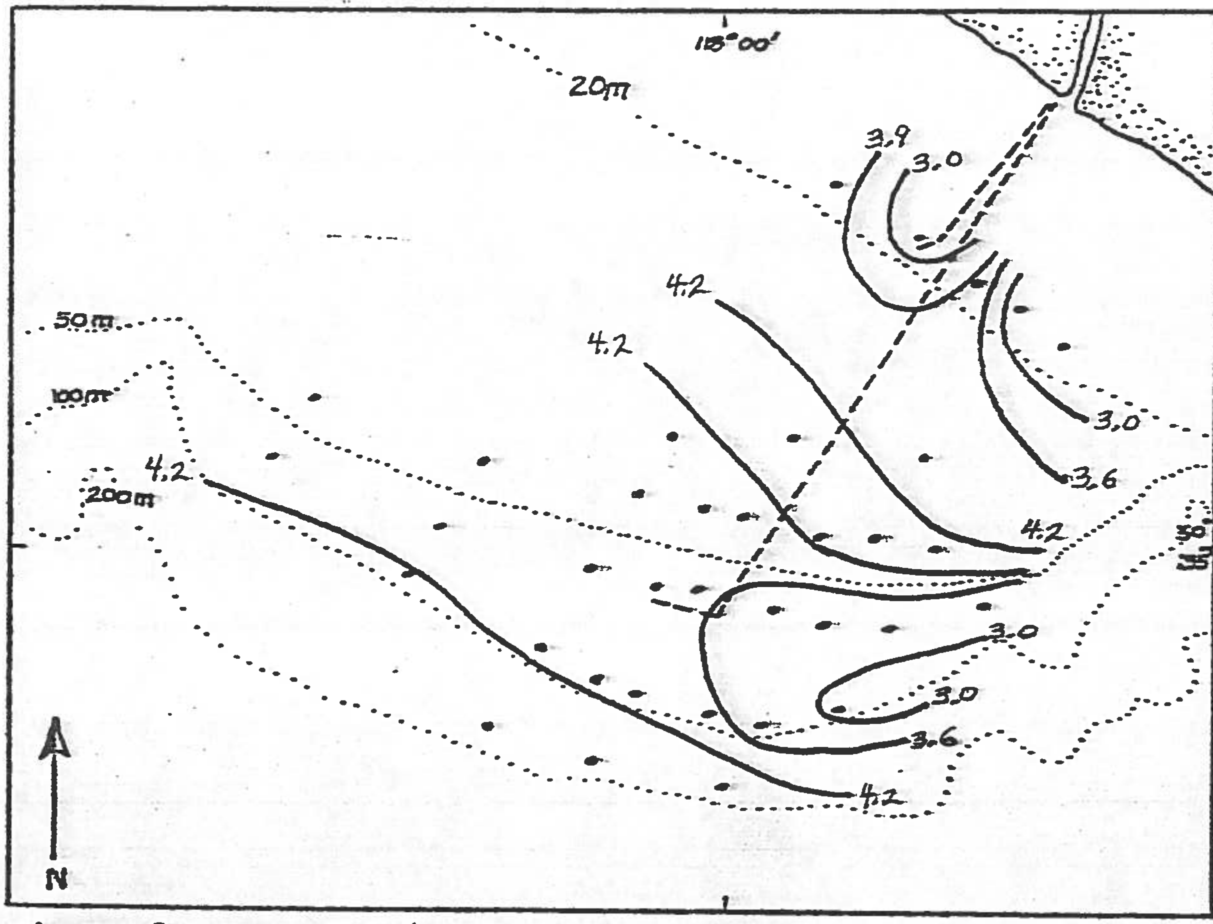


Figure 8. Mean Phi (sediment grain-size).

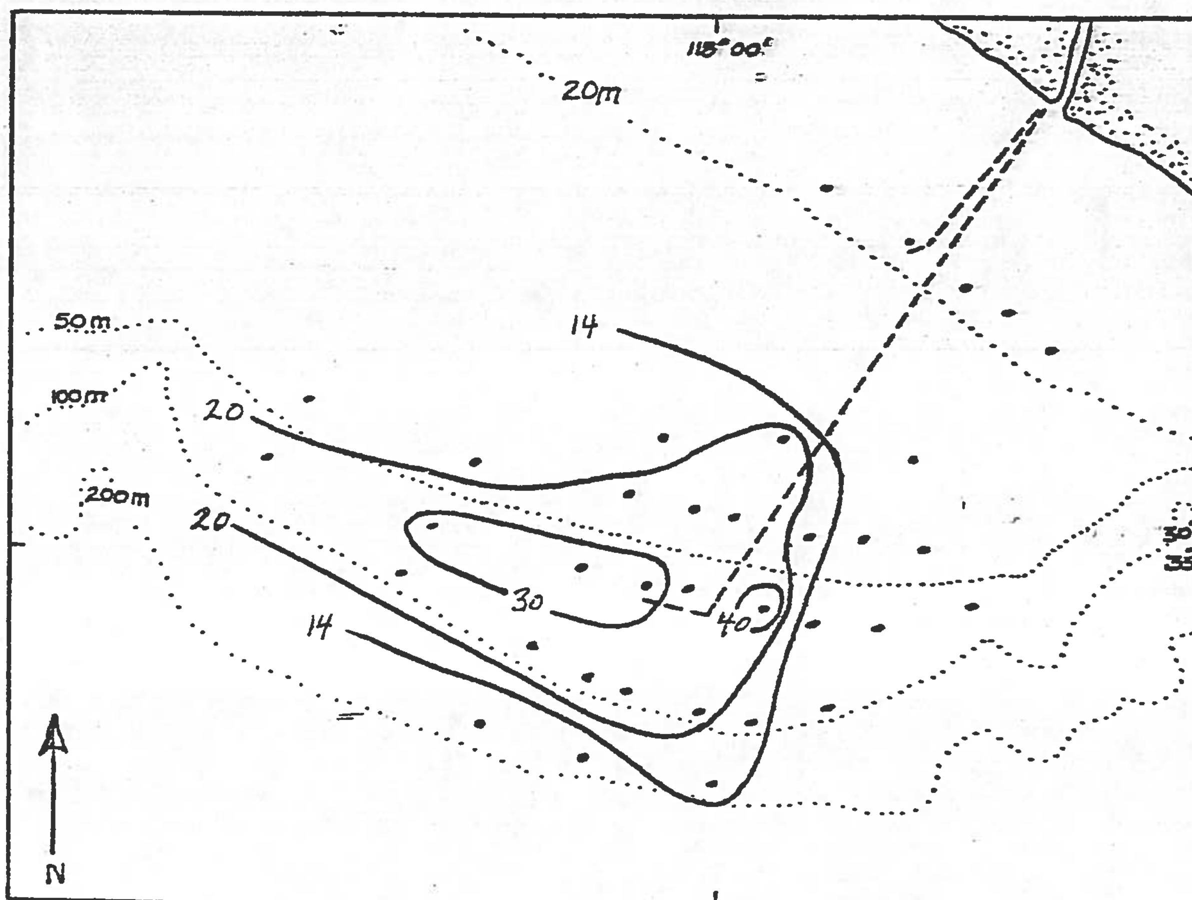


Figure 9. Copper (mg/dry kg) with baseline ≅ 14 mg/dry kg.

patterns displayed by these two groups of correlated variables. The areal distribution of copper on this shelf corresponds with the location of the outfall diffuser. This pattern is strongly skewed to the northwest and probably reflects the direction of the prevailing currents. Generally, sediment grain size shows an inverse relationship to depth. The gross pattern in the study area is, as one would expect, coarsest sediments inshore and finest offshore, however, there is a wedge of finer sediments between 37 and 46 meters depth and sediments to the southeast of the diffuser are much coarser than sediments to the northwest of the diffuser. The finest sediments are, as previously indicated, at the deepest stations. It is interesting to note from Table 1 that, while many of the abiotic variables are significantly correlated with depth, none of the correlations are particularly high (> 0.60) with the exception of nickel.

HIERARCHIAL CLASSIFICATION

Eighty four species remained for use in the classification analyses after data reduction. These species are listed in Appendix B where they are numbered and ranked according to their abundance. Frequency of occurrance and average abundance in sites where they occur is also given.

Site Classification

The dendrogram of the site groups produced by the normal classification and their location in the sampling area are shown in Figure 10. It is apparent from the distributions of the sites within the groups that depth and depth related factors play an important role in determining the distributions of the fauna on this shelf and slope. The first three divisions starting from the top of the dendrogram divide the sites into groups comprised of site group A (shallow), site groups B and especially C, D. E, and F (intermediate), and site groups G, H, and I (deep). The sites in each site group except B, C, and E occur entirely at a single depth. It is interesting to note that no site group at diffuser depth (the sites most likely to be effected by the outfall) stands out from the other site groups on the dendrogram because of its biological uniqueness. It is clear, however, that the outfall exerts an influence on the distribution of the fauna; this can be readily seen from the positions of site groups C, D, E, and F relative to the outfall. The sampling sites in site group F are located at and immediately to the northwest of the diffuser leg. Site group E is comprised of sites located on either side and inshore of site

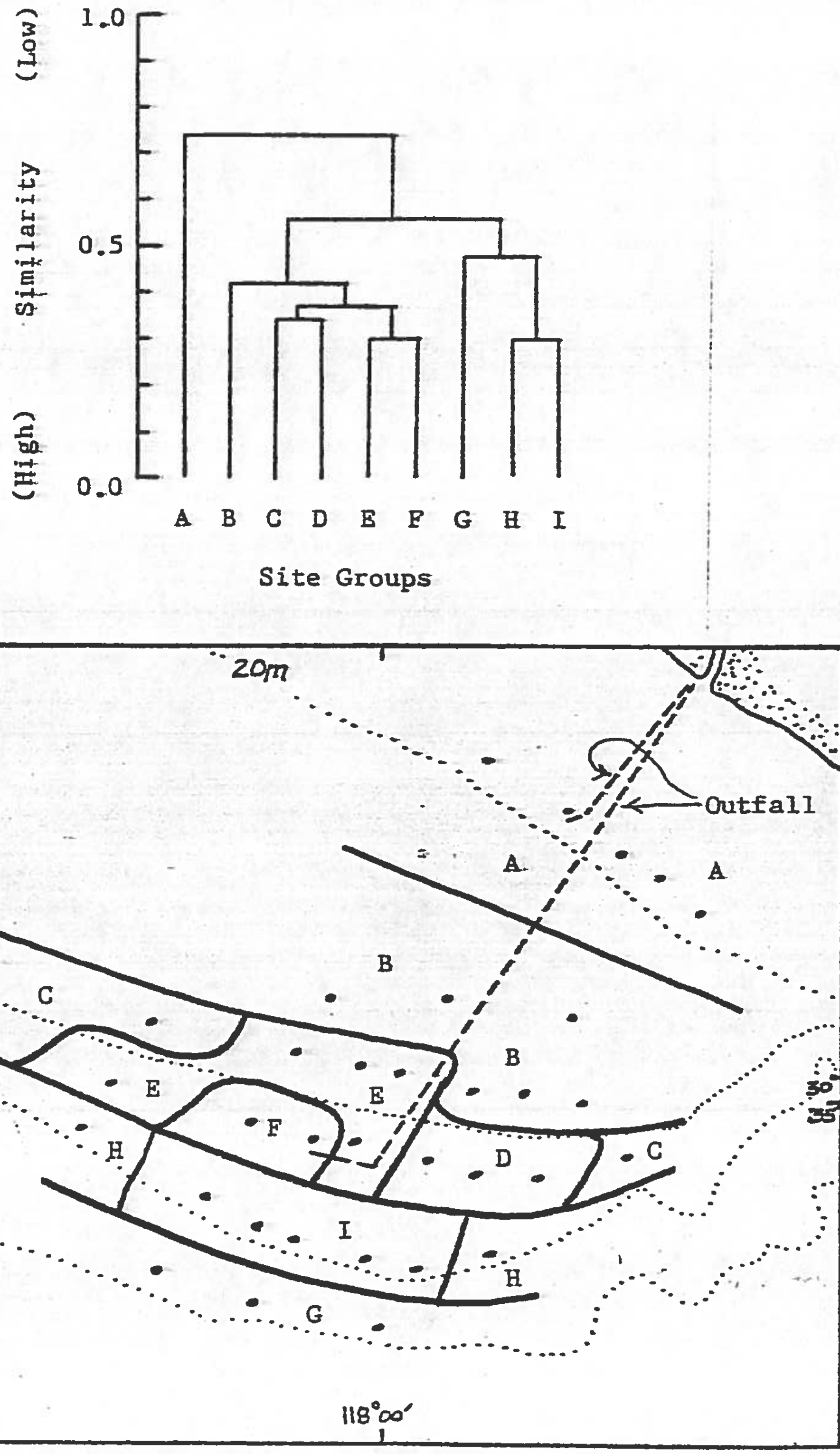


Figure 10. Dendrogram and areal distribution of site groups based on 84 species (Bray-Curtis coefficient, flexible sorting, square root transformation, and species mean standardization.

group F. Site group D is only found to the southeast of the outfall and the sites of site group C are located at either end of this depth contour. This pattern suggests biological gradients radiating to the northwest and southeast from site group F. This same general pattern is indicated for the next deeper depth contour which includes site group I bracketed between the sites of group H.

<u>Species Classification</u>

Because the site groups are comprised of sites that are more similar to one another in terms of their faunal composition, the similarities and differences in composition between the groups can often be clarified by defining species groups and then examining the two-way contingency table of sites versus species. The dendrogram resulting from the classification of species is shown in Figure 11. The two-way coincidance table (Table 2) is organized with the sites (columns) across the top arranged in the same order as they occurred in the normal analysis and the species (rows) arranged in the same order as they occurred in the inverse analysis. The symbols in the table show how the species and species groups are distributed through the site groups. The information in Table 2 is summarized in Table 3 where the contributions of the species groups to each site group is shown in Table 3a and the distribution of each species group through the site groups in Table 3b.

Three significant features of the distributions of the species and species groups are apparent from Table 3b: (1) no species group

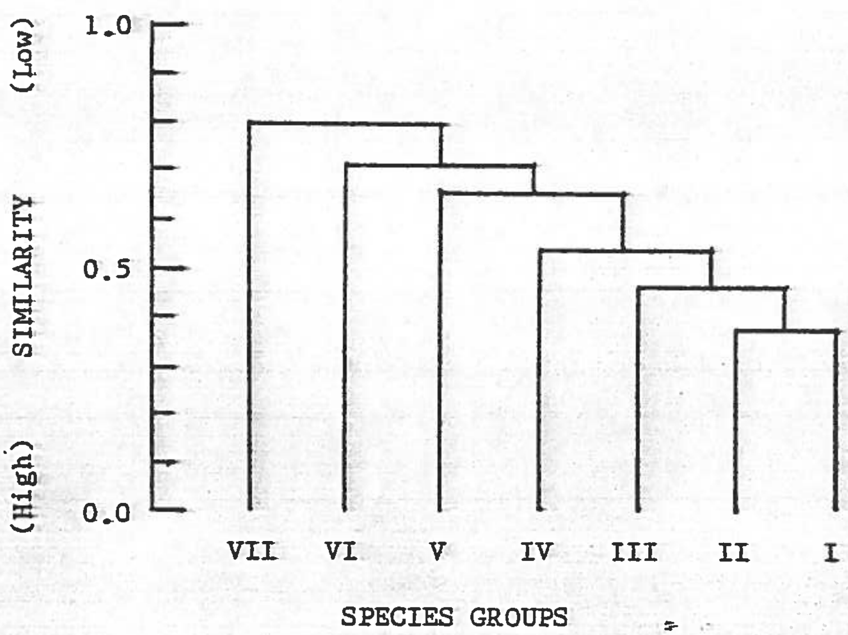


Figure 11. Dendrogram showing the relationships between the species groups. Based on 35 sites (species maximum standardization).

Table 2. Two-way coincidence table relating the site and species patterns. The transformed and standardized data matrix has been translated to symbols representing the quartiles of abundance where: * = most abundant, + next, - next, and · = lowest quartile of abundance. A species' number corresponds with its abundance rank (Appendix B).

SSP GP	SPP NO.	SPECIES NAME	SPECIES GROUP I	H	G	F	E	D	C	B	A
I	4	Tharyx sp.	+——+—+	+	—+···	—	—+——+	+—+	——*	—·——++···	—····
	10	Axinopsida serricatus	+++——	—·	·+	—	++++—+	*·+	—+—	*———	
	8	Lumbrineris sp.	—+—*+	+	—+	—	———	—+	+*—	*+—+——	· · —
	15	Glycera capitata	++++—	—	——	—	——+	+++	—+*—	+—+	——
	14	Pectinaria californiensis	*——+	—	—+*	·	+—+*	*—	—+—	——	
	11	Heterophoxus oculatus	+++—·		++	—	+*+*	——	+*—+	·*++·	
	1	Euphilomedes carcharodonta	————	··	·	·*	+++	——	*·—	·+·+—	····
	2	Parvilucina tenuisculpta	————	+—	···	·*	*·——	*··	··—	·+··—	
	7	Prionospio malmgreni	—·——	··	·	**	——++	++—	—·	++——·	
	27	Notomastus sp.	+—+*+		—+—		——*	++	++	++++—·	
	5	Amphiodia urtica	·——·		—·	·	—··	—+	*·—	+*——+	
	37	Pholoe glabra	——*+		++	—	·+*	+++	++—	++*+*	—
	30	Westwoodilla caecula	——+		+—	—	+—	—+—	++—	— +*·	
II	28	Sthenelanella uniformis	———+			—	———	—+	****	++ + +	
	63	Haliophasma genimata	———+—	—			——	——	——		
	35	Kurtziella beta	** +	++		+	+—+—	++*	*++	+—*	
	23	Leptochelia sp.	· ···	—		—·	+*	*——	—+	·—·	
	74	Langerhansia heterochaeta				+	+++	+**	++	+*	
	54	Modiolus neglectus				+	*—	+—	+++*	— +	
	47	Amphiodia digitata	*— —+	+				+	+++*	++	
	45	Turbonilla sp. G	+ —				—*—*	+++	* —	——	—
	44	Synchelidium Sp.	++—			—	—+	+++	— —	—	—+++
	51	Goniada brunnea	+ ++*		+	—	— —	*—	+	++—+	—*
III	6	Chloeia pinnata	*+***	+*	·	—+	—·+	+++	++	·—	
	19	Paraphoxus bicuspidatus	++++	—+	+	—	··—	——	——*	—·	
	13	Decamastus gracilis	+++++	·+	+	—·	··	—	——	· ·	
	16	Euphilomedes longiseta	++++·	—		·				·	
	3	Euphilomedes producta	*****+	—	···	··	· ··	· ·	·		
	22	Cylindroleberididae, Unid.	****+	—		—	—·	—	++ —		
	21	Rictaxis punctocaelatus	++——*	+		—	—*—	—	+	—+	—
	40	Macoma sp.	+—*+—		—	—	—— +		+	+	—
	52	Glycinde polygnatha	—+*+*	++	+	—		—		+	+—+
IV	25	Gnathia crenulatifrons	···——			—	———	+—·	—*—	···	
	34	Lucinoma annulata	——			+*	·—·	—·	——	—	
	9	Capitita ambiseta	·····	·	·	++	··+	+—	—	····	··
	12	Capitella capitata	·			++	·—			··	
	70	Glycera americana	— ——			++	—			—*	
	20	Amphiodia occidentalus	——		+—		·—	++—	++ +	+—+*	
	48	Spiophanes missionensis	——		—	··	·—	··	*—	——	
	41	Mysella pedroana	·				—·—	—	—	·—*	
V	32	Nereis sp.	————		—	—	+——+	+++	—	—+++	—
	39	Bittium quadrifilatum	——+			—	—+—	+*—	+	— —	
	65	Leptostylis Sp. A	——				———	+*—		—+—	
	49	Aricidae wassi	—	—	+		——+	*+	+		
	82	Mesolamprops bispinosa	—— —				*	—*+		—	
	73	Photis Sp. A						+—			
	83	Acteocina intermedia		+				*++	+	*	
	33	Phoronis sp.						—+*	—	— —	—
	29	Haploscoloplos elongatus	—*				*+*++	+++	—	—+*+—	+*+ *
	46	Turbonilla Sp. E	—				** +*	++		+—	—
	61	Chaetozone setosa				*		—+		—	*+—
	67	Tellina modesta	— +			+**	—+—	+	+	+	
	77	Nephtys ferruginea	— *		*+—		—	—	++		
	43	Edwardsia californica	···				· ·	···	—	· ·	· *
	79	Cooperella subdiaphana					* +	+	+*	*+	*
	69	Photis californica						—	*	—	
	56	Scalpellum californicum							**—	*	
	66	Harmothoe lunulata	—				——	—	—*	+ +	—
VI	17	Listriolobus pelodes	·			·	—	—	*	****+ +	
	36	Panopea generosa	—				—	—·	—	*++—+	
	50	Enteropneusta, Unid.				—	+	—		+—+++	
	72	Listriella goleta					++	—		+—+++	
	62	Volvulella panamica					—			++*—*	
	69	Amphideutopus oculatus					—+*		*	+++**	
	18	Composomyax subdiaphana	·	—		—·	++++	—+·	—+	*++—**	
	24	Ampelisca brevisimulata	—		—	·	+++—	++—	—	*+—+**	
	42	Macoma acolasta				——	+—*			+——*+	
	53	Cylichna diegensis	—			—	++++		+	*+ **	
	82	Pinnixa sp.		+			+	+	+	+++*+	
	31	Hemilamprops californica	—+—+—			—	—	—	+ ++	+—++ +	+—+——
	59	Drilonereis mexicana	—+ —				— —	+	+	+*++++	
	55	Gyptis brevipalpa	— + —			—	++	+	*+	+—++	
VII	78	Paraphoxus obtusidens	— ++				—+		—	*	
	76	Leptognathis sp.	——++		++		*	—		— *	
	81	Ampelisca macrocephala	* ++		+++		+.		+	++	
	64	Adontorhina cyclica	———		+*						
	57	Spiophanes cirrata	—		*+		—			—	
	26	Tellina sp.	————	—	*+—	·	·——	·—		·— —	·
	71	Pista fasciata	—		**		—			—	
	38	Acila castrensis			*—						
	60	Paraonis gracilis oculata	—	++	*+		++—	*++		+ *	
	58	Prionospio pinnata	—		+—+	—	———	—		+	— —
	80	Laonice cirrata	*		*+		—		+	— ++	+
	75	Lumbrineris tetraura	—		*	·					

SPECIES GROUP

(a)

SPECIES GROUP	A	B	C	D	E	F	G	H-I
I	12	26	30	24	31	33	30	29
II	13	8	21	20	12	8	1	11
III	11	3	9	8	7	13	12	31
IV	2	9	10	9	9	28	4	6
V	43	12	14	26	19	8	5	8
VI	11	35	13	9	16	7	1	5
VII	9	6	2	5	6	3	47	10

(b)

SPECIES GROUP	A	B	C	D	E	F	G	H-I
I	1	13	15	15	16	15	11	13
II	3	10	24	28	14	8	1	12
III	3	4	11	13	9	15	9	35
IV	0	12	14	15	11	34	4	8
V	9	11	14	30	19	8	3	6
VI	3	39	15	12	19	7	1	5
VII	3	10	3	10	10	4	46	14

Table 3. Two-way summary coincidence table showing the;

a. Relative distribution of species groups among the sites within each site group. Each column of this table sums to 100 percent.

b. Relative distribution of species groups among the site groups. Each row of this table sums to 100 percent.

is well represented in site group A, (2) species group I is ubiquitous, except for site group A, and (3) each of the remaining six species groups reaches its collective peak abundance in a single site group. For example, species group IV is a major contributor of animals to site group F which is located at the end of the diffuser. Several of the species from this group reach peak abundances in site group F (see Table 2) and are characteristic of disturbed or organically enriched benthic sediments (Reish, 1973; Stephenson _et al._, 1975; Greene, 1976). Three rather ubiquitous species from species group I, _Euphilomedes charcarodonta_, _Parvilucina insculpta_, and _Prionospio malmgreni_, that are typically found in high abundance in organically enriched sediments, also reach their peak abundances in the sites of site group F.

DISCRIMINANT ANALYSIS OF THE SITE GROUPS

Multivariate-discriminant analysis is used in the present study to determine which, if any, of the abiotic variables are significantly related to the faunal patterns and gradients. Initially the sites in all nine site groups were compared to the reduced list of abiotic variables. The results of this analysis are shown on Figure 12 where the discriminant scores are plotted on the first two axes. Sites are identified by the letter assigned to their site group and are enclosed by solid lines. In this analysis, Axis I is highly related to depth and accounts for 96 percent of the total variation. In order to gain a better picture of the possible relationships between the other abiotic factors and the biota, site groups A (13 m) and G (183 m) were omitted to reduce the influence of depth and the analysis was run again.

A plot of the discriminant scores on the first two axes for the analysis of the seven groups is shown in Figure 13. The abiotic factors that are most highly related to these axes indicated along the axes and the mean values of these variables for each group are shown next to the group.

As before, the first axis is related primarily to depth, although it now accounts for only 75.5 percent of the total variability. Thus, even after the omission of the deepest and shallowest sites, depth remains the most significant abiotic factor influencing the distribution of species in this study area. The second axis, which is by definition independent of the first axis and, therefore, of depth, is mainly related to copper and PCB's and secondarily to sediment coarseness (mean phi and % clay):

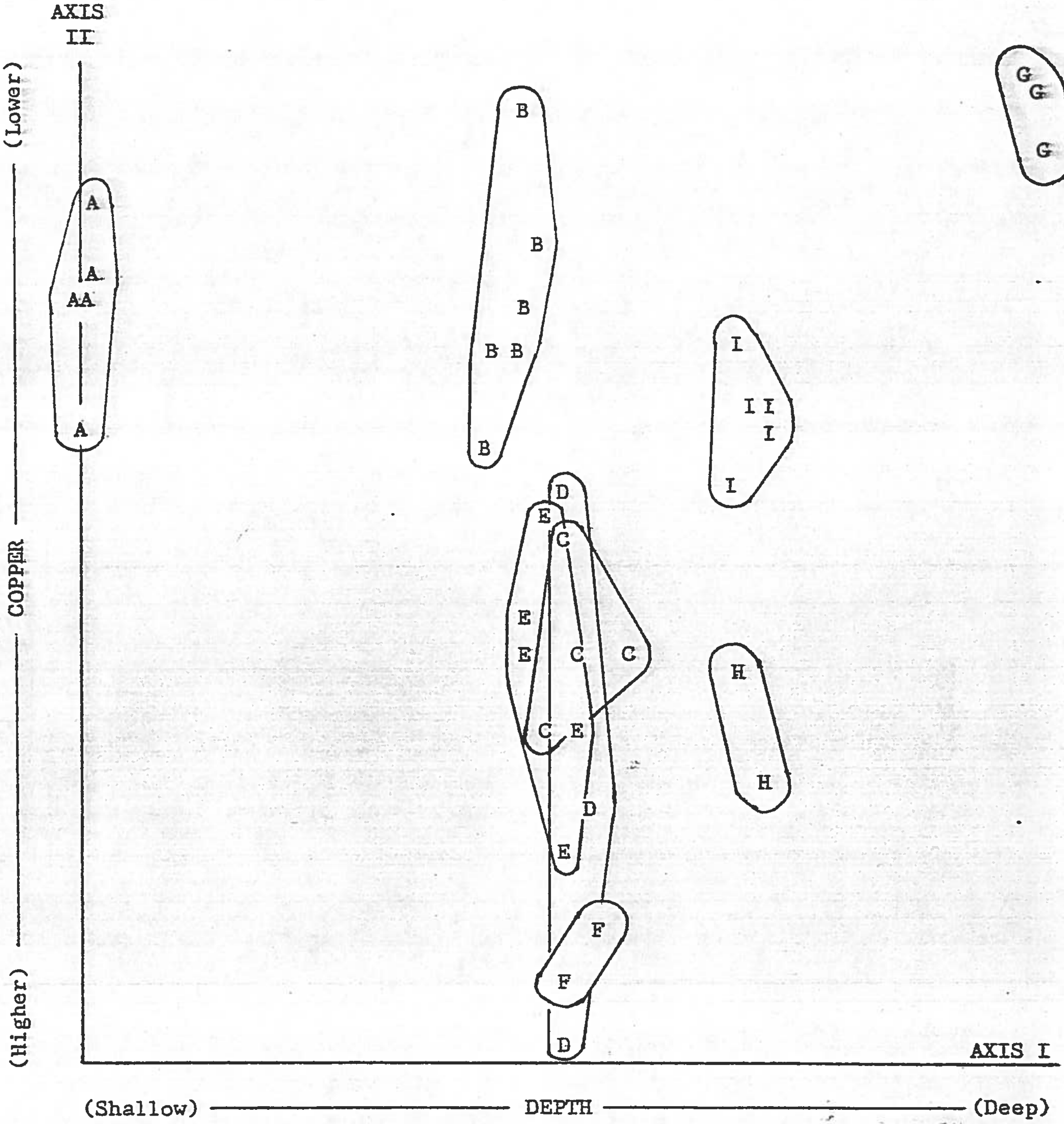


Figure 12. Sites and site groups at the nine group level with important abiotic factors plotted on discriminant Axes I and II. Sites within a site group are inclosed by a solid line and are identified according to the site group designations on Figure 10.

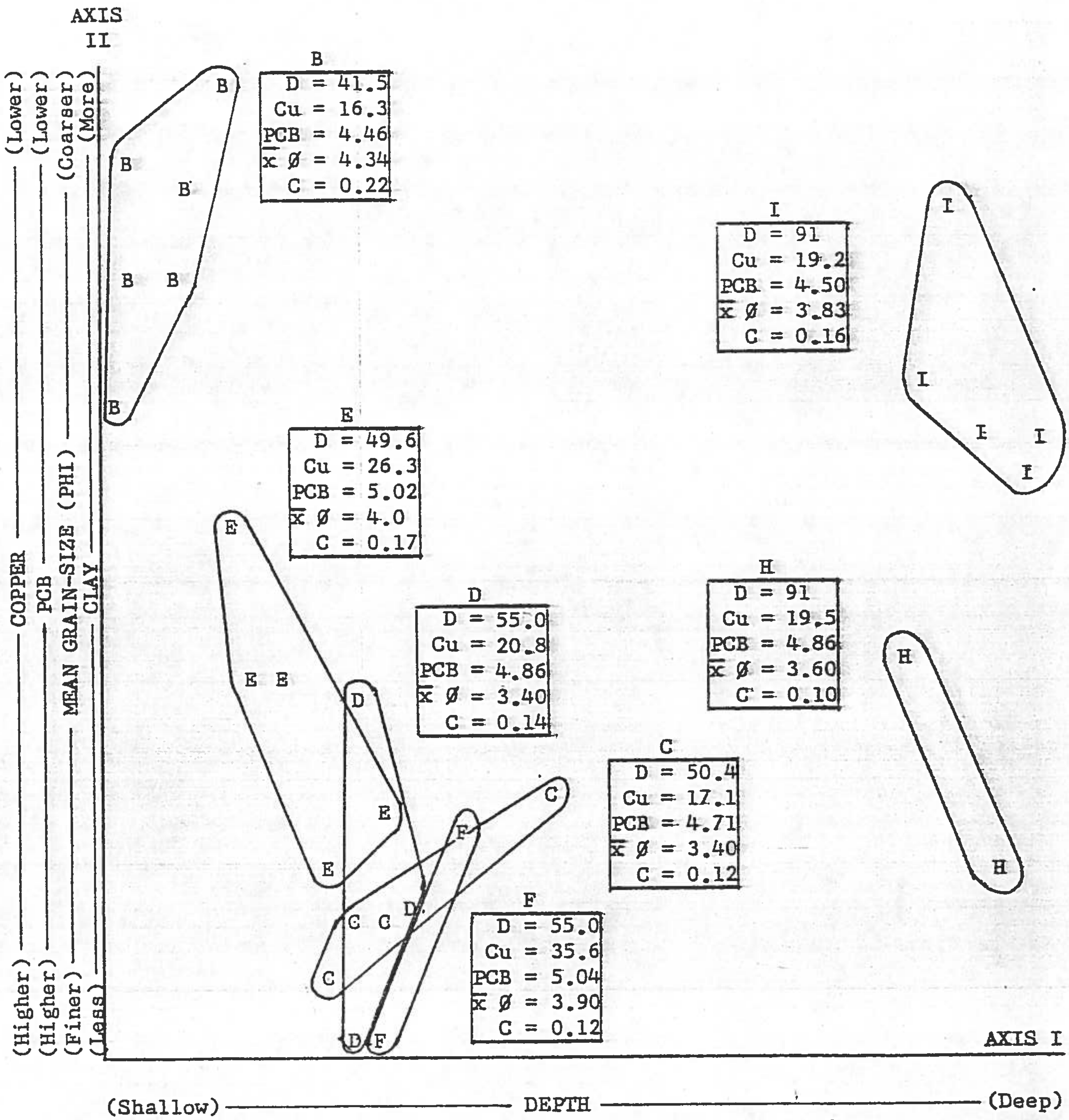


Figure 13. Sites and site groups at the seven group level with the average concentrations of important abiotic factors plotted on discriminant Axes I and II (D = depth, Cu = copper, PCB = total PCB, $\bar{x}$ Ø = mean grain-size (phi), and C = % clay). Transformed values for PCB and % Clay are used.

cadmium and chromium are also important on this axis through their highly significant correlations with copper.

Site groups C, D, E, and F are not well separated when plotted on the first two dimensions as in Figure 13. Because these sites are located at similar depths (46 and 55 m) any abiotic factors that could produce differences would most likely have to come from the outfalls or from differences in sediment grain size. When these site groups are compared on Axes II and III (Fig. 14) they become separated except for a slight overlap between groups C and E. Like Axis II, the most important abiotic factor on Axis III is copper which suggests that copper or some factor(s) related to or behaving like copper may be responsible for the faunal patterns observed at these depths.

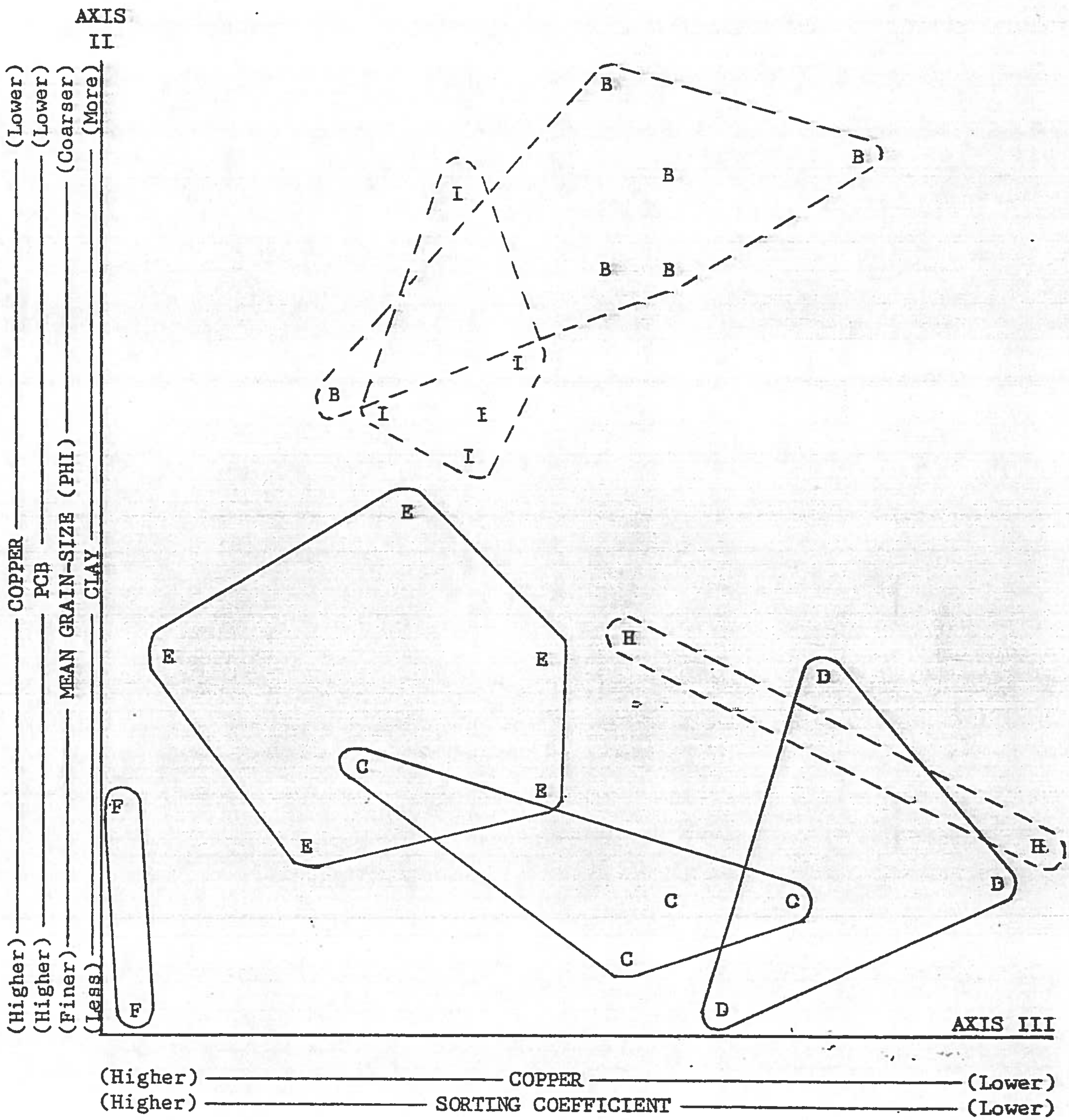


Figure 14. Sites, site groups, and important abiotic factors plotted on discriminant Axes II and III. Transformed values for PCB's and % Clay are used.

"STRESS AND RECOVERY": A FOLLOW-UP ON G. SMITH'S 1970-1972 SURVEY

Smith sampled at six sites, three sites to the southeast of the shallow outfall and three to the southeast of the deep outfall. The sites are located at distances of 0.4, 0.8, and 1.6 km (0.25, 0.50, and 1.0 mi.) from the outfalls and are designated as sites 3, 4, 5, 22, 23, and 24 on Figure 1. Smith sampled each outfall on 12 occassions, six times before and six times after the effluent was diverted from the shallow to the deep outfall. Because the only series of samples that Smith completed were the 0.4 km sites (our No.s 3 and 22), the present comparisons will be limited to these sites.

Abiotic Data Comparisons

During his survey, Smith consistently measured two abiotic sediment parameters, total organic carbon (mg C/gm dry wt sediment) and acid-volatile sulfides (mg S=/gm dry wt sediment). The data from four summer surveys are shown on Figure 15 for the shallow and deep outfalls. The first three surveys (8/70, 8/71, 8/72) were conducted by Smith, the fourth survey was conducted by SCCWRP (7/75). It is apparent from Figure 15 that both organic carbon and acid-volatile sulfides are at or below the background levels determined by Smith for the shallow outfall. It appears that these parameters returned to natural levels within three to eight months following the diversion of wastewater and that these lower levels have persisted to the present. Our measurements of organic carbon and acid-volatile sulfides at the deep outfall are consistent with Smith's measurements and indicate that no accumulation has occurred since this outfall came into operation.

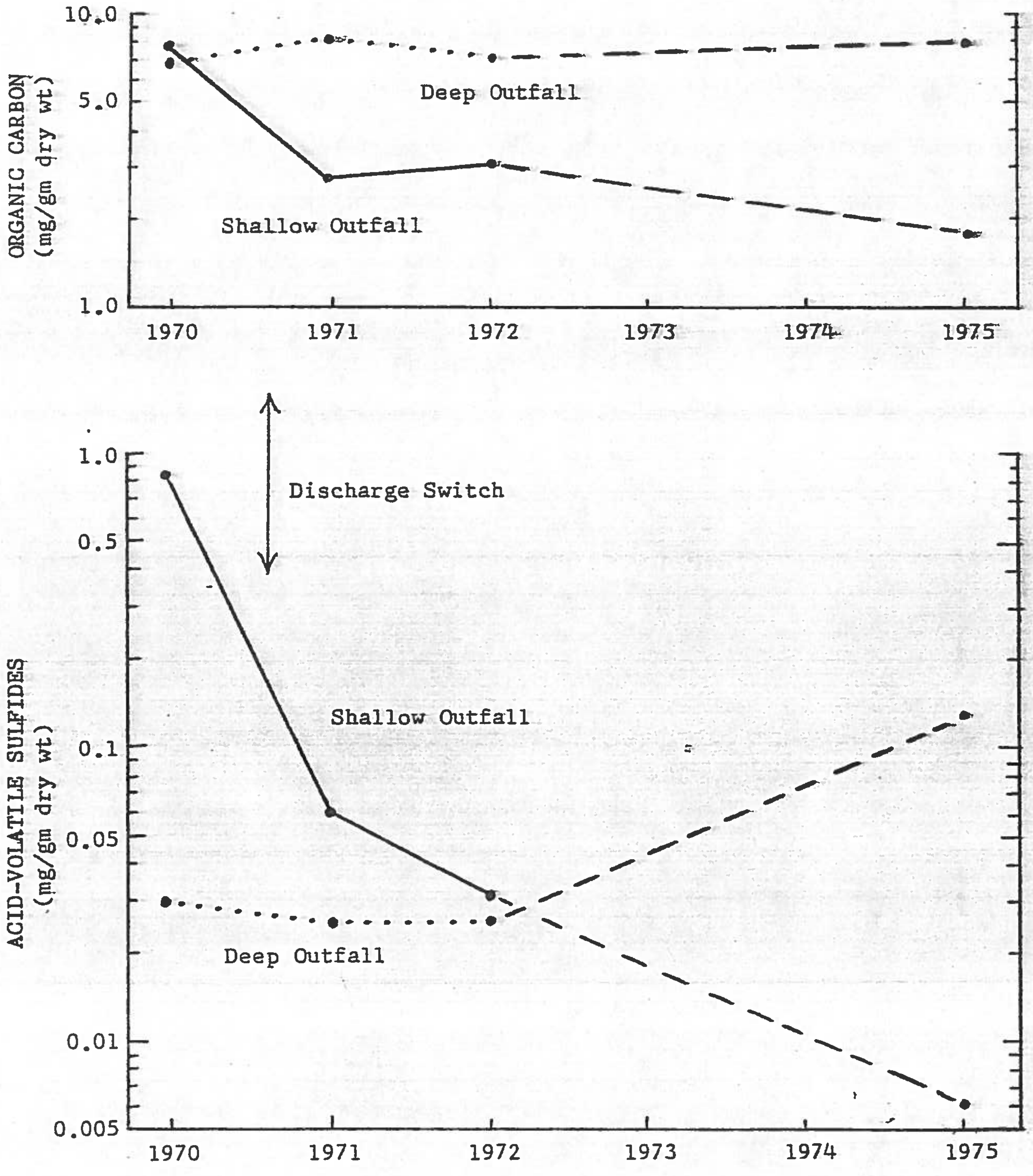


Figure 15. Variations in the concentrations of organic carbon and acid volatile sulfides at Smith's shallow and deep outfall sites (0.4 km) during August surveys in 1970-72 and July, 1975.

Biological Data Comparisons

A comparison of biological data for number of organisms, number of species, species diversity (Shannon's index, H'), and scaled diversity (H'_S) from four summer surveys at Smith's 0.4 km sites is shown on Figures 16 and 17. It is apparent that there are significantly more organisms in Smith's data compared to the present data. The reason for these differences is not readily apparent. They may be due to natural phenomena or they may be, in part, due to different sample sorting procedures. Smith was very careful and spent many hours sorting his samples and may have recovered more of the very small specimens than were retained for our samples. Although I consider all of these samples to be representative of conditions at the time of collection and suspect that the major decrease in abundance is due to natural hydrological phenomena, comparisons between these data should be viewed conservatively.

There are very distinct directional trends in Smith's data that correspond to the diversion of the effluent from the shallow to the deep outfall, Figure 16 and 17, respectively. At the shallow outfall the number of individual organisms decreased, the number of species was unchanged, and both species and scaled (evenness) diversities increased. The exact opposite responses are observed at the deep outfall and the number of species shows a significant increase with time. The response at the shallow outfall was almost immediate, while there seemed to be a lag period at the deep outfall.

Our 1975 data showed a marked decrease in the number of animals and species at both outfalls. The slight decrease in species

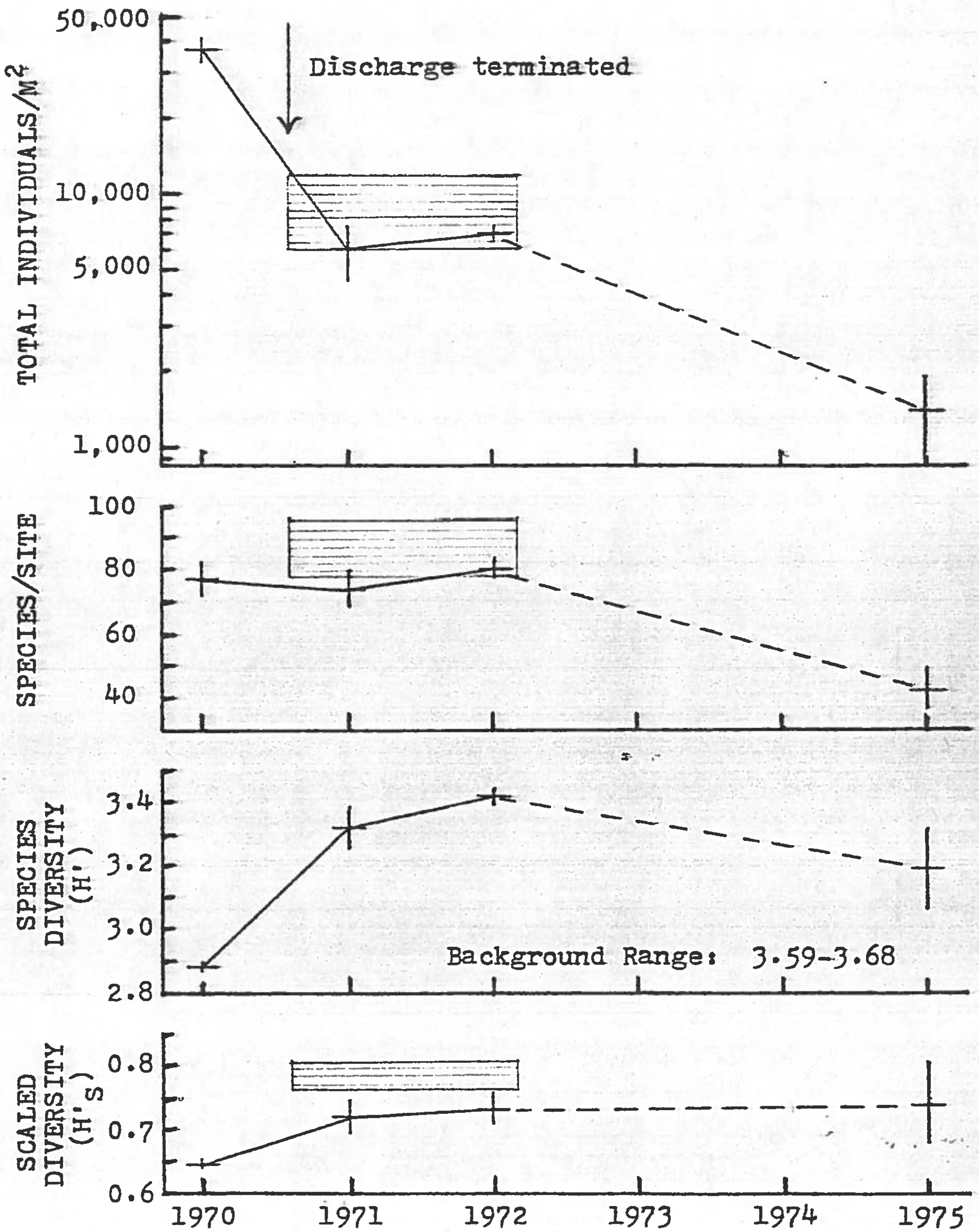


Figure 16. Variations at Smith's shallow, 0.4 km, outfall site in the distribution of individuals per sq. m., species per site, species diversity, and scaled diversity for August surveys in 1970-1972 and July, 1975. Lines show mean values and ranges for two replicate samples. Shaded areas indicate ranges of background values at a "control" station (7 samples).

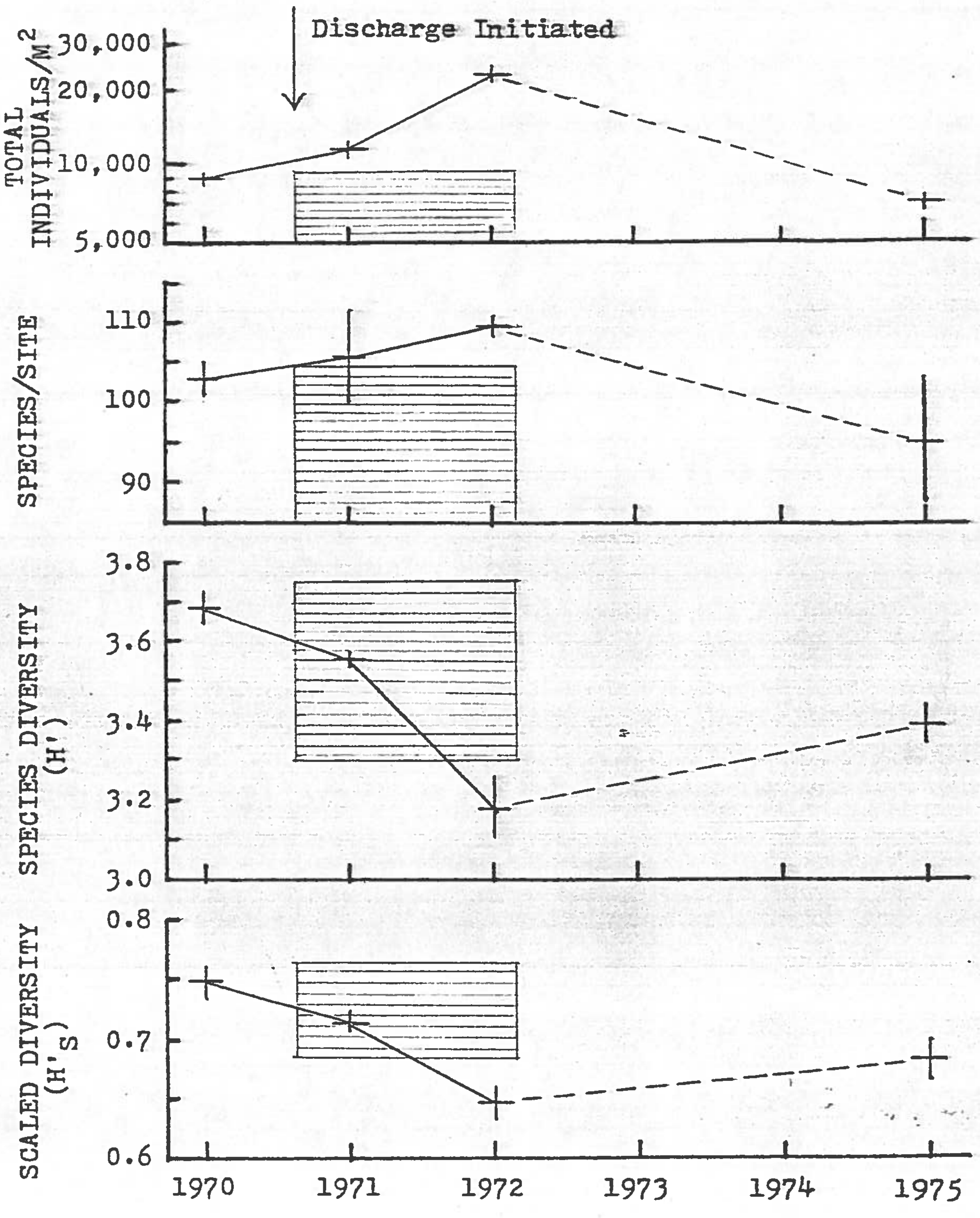


Figure 17. Variations at Smith's deep, 0.4 km, outfall site in the distribution of individuals per sq. m., species per site, species diversity, and scaled diversity for August surveys in 1970-1972 and July, 1975. Lines show mean values and ranges for two replicate samples. Shaded areas indicate ranges of pre-discharge background values (12 samples).

diversity at the shallow site is probably the result of the small sample size. The increase in species diversity at the deep site is related to a decrease in dominance that is reflected in the increase in scaled diversity. Of these four measures of community status, scaled diversity is probably the best for comparing all four dates because it is essentially independent of sample size. The curve on Figure 18 does not reveal a significant decrease in scaled diversity that dropped to a level of about 0.58 in January, 1972. Evenness gradually increased until August, 1972, when Smith stopped sampling. This kind of decrease usually results from a large increase in the abundance of one or a few species relative to the abundance of the other species. In this particular case the sharp drop in H'_S resulted from a correspondingly large increase in the abundance of a single species Capitita ambiseta.

Capitita ambiseta was the second most abundant species at the shallow outfall prior to and after the termination of discharge although its abundance dropped one and a half times. Most of the 10 most abundant species at the shallow outfall became quite rare following the termination of discharge and were replaced by less abundant or rare species. Of the 15 most abundant species found at this site in 1975, only two, Tharyx sp. and C. ambiseta were ranked among the 25 most abundant in Smith's surveys.

The 15 most abundant species at the deep outfall are listed in Table 4 along with their dominance ranking during the periods preceeding and following the initiation of discharge at the deep outfall. The species in this list that typically show a positive

Species Names	ABUNDANCE RANK 7/75	8/70–3/71	4/71–8/72
Tharyx sp. (p)	1	8	5
Euphilomedes carcharodonta (O)	2	18	15
Capitita ambiseta (P)	3	1	9
Photis Spp. (A)	4	11	20
Chloeia pinnata (P)	5		
Prionospio malmgreni (P)	6		
Parvilucina tenuisculpta (PE)	7	5	6
Leptochelia sp.	8		
Glycera capitata (P)	9	12	7
Cumella spp. (CU)	10	19	
Amphiodia urtica (OP)	11	2	3
Axinopsida serricatus (PE)	12	3	4
Lumbrineris spp. (P)	13	4	1
Turbonella spp. (G)	14		
Aricidae spp. (P)	15	13	8

Table 4. Rank order of the 15 most abundant species at G. Smith's 0.4 km deep-outfall station along with their rankings during the periods preceeding and following the outfall switch.

response to organic enrichment include: *Euphilomedes carcharodonta*, *Capitita ambiseta*, *Prionospio malmgreni*, and *Parvilucina tenuisculpta*. Those species that typically show a negative response to very high levels of organic input include: *Amphiodia urtica*, *Axinopsida serricatus*, *Chloeia pinnata*, and *Tharyx* sp. *Tharyx* sp. is the least sensitive species in this group and its abundance was obviously enhanced in the 1975 which indicates that the flux of organic carbon has not been extremely high at this site.

DISCUSSION

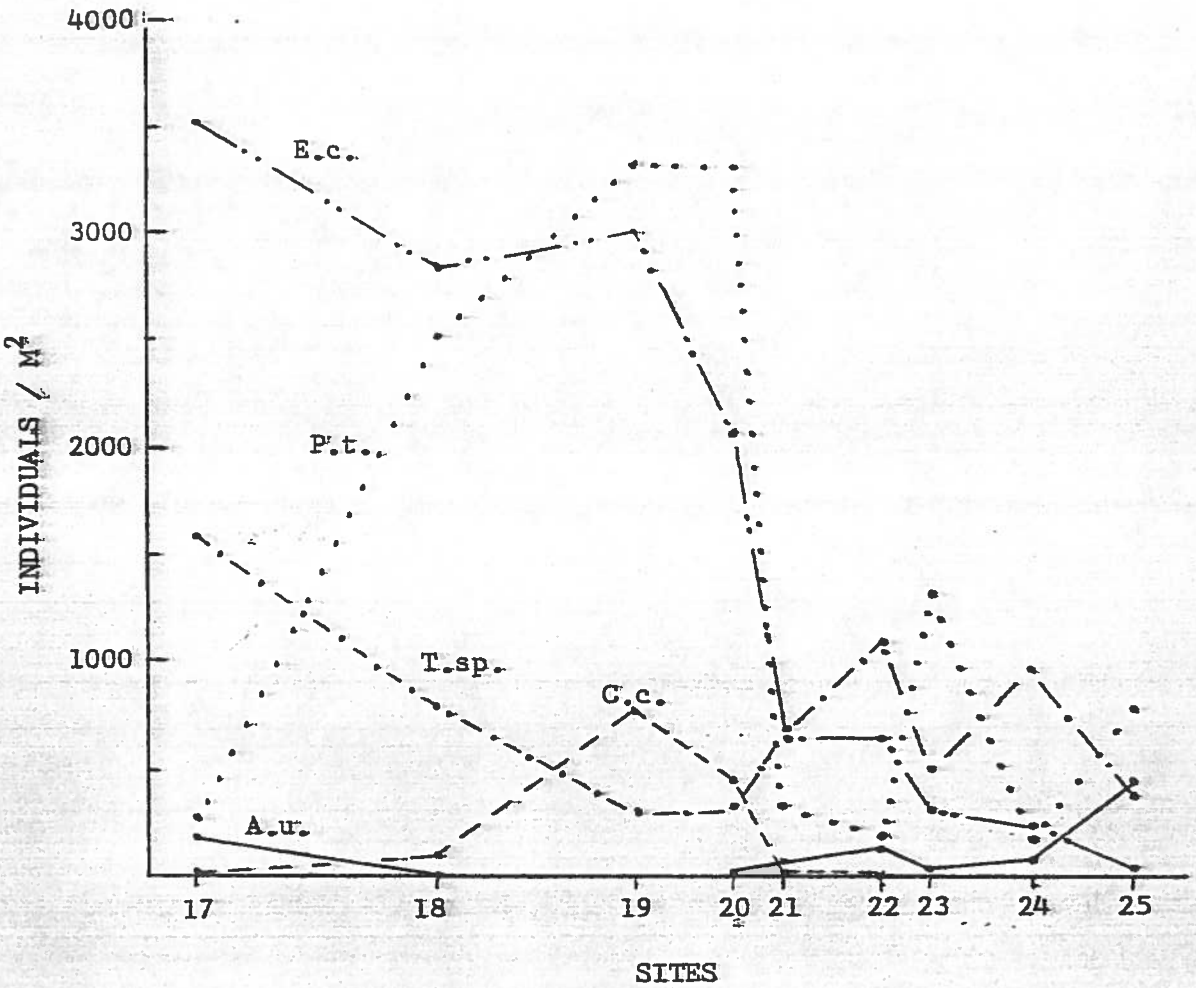
The patterns of spatial distribution for all but one of the six biological parameters measured at all 35 sites and presented in Figures 2-7 clearly reflect the influence of both depth and the outfall. These patterns appear to correspond with or at least reflect the patterns of distribution shown by the mean grain size and copper (Figs. 8 and 9) as representatives of the two major groups of abiotic factors (see Table 1). The exception to the above is the number of species per site (Fig. 2) which, while it tends to reflect both depth and the effect of the outfall, presents a rather confusing pattern. A major problem with using measures of species richness is that they are readily influenced by the chance inclusion of several, or many, rare species. The index of dominance (Fig. 7), by placing a greater emphasis on the more abundant species, tends to reduce this effect. This index also provides a simple and clear method to emphasize one of the pronounced effects associated with the disruption of natural environments. This effect might appropriately be called the "dominance effect" where one or a few species become excessively abundant as a result of a disruptive change in the environment. This response to disturbance is well known on land as well as in the sea, and species that consistantly respond to these conditions are often called "indicator species" (Reish 1973; Stephenson *et al.*, 1975). Certain marine invertebrate species that show this response respond differently to different degrees of disturbance. Two such species, *Capitella capitata* and *Parvilucina tenuisculpta* are present near this diffuser and the latter occurs at relatively high densities.

Capitella capitata is found in areas that have recently undergone or are continually subjected to physical and/or chemical stress. This species is characteristically found in very high numbers in severely affected outfall areas. Parvilucina tenuisculpta commonly reaches very high densities in outfall areas where there is high organic input, little organic build-up, and no anaerobic conditions.

The classification of the 35 sites resulted in a pattern that seems to be characteristic of outfall areas on this coast. The sites and site groups are clustered mainly according to their depth distribution and secondarily with respect to the outfall. At outfall depth the site groups and sites within these groups form gradients that radiate outward from the diffuser in patterns that reflect the average direction of the long-term currents. In this analysis the dendrogram does not reflect a "strong" outfall effect. Site group F and to a lesser degree site group E contain the sites with most altered faunal compositions. If the effect was extreme, these sites would form a major subdivision in the hierarchy of the site group dendrogram. It is apparent from the two-way coincidence table (Table 2) that site groups E and F are not comprised or dominated by a unique group of species. The species that contribute most significantly to these site groups are found in three different species groups, groups I, IV, and V (Tables 2 and 3a).

The faunal gradients that result in the patterns of site groups around the outfall are to a greater extent the product of the more abundant species that show a clear enhancement or avoidance response to the outfall. Five species that show these types of responses and account for 64.9 percent of the fauna at this depth and no less than 40.7 percent at any one site are shown on Figure 18. *Capitella capitata* and *Parvilucina tenuisculpta* were discussed earlier. The presence of *C. capitata* indicates that the environment is disturbed and the relatively high densities of *P. tenuisculpta* suggest that there is high organic input to these sediments. *Euphilomedes carcharodonta* is a small deposit engulfing ostracod that apparently also enjoys an enriched organic environment. This crustacean was found to be quite abundant at some distance from the outfalls on the Palos Verdes shelf (L.A. County outfalls) outside the area where large amounts of DDT still persist but where the influx of organic matter is still significant. The high densities of *E. carcharodonta* at this diffuser suggest that DDT is not a limiting factor here. Both *Tharyx* sp. and *Amphiodia urtica* show avoidance responses to the outfall. *Amphiodia urtica* has been used as a very sensitive indicator of pollution (SCCWRP, 1973), and, although *Tharyx* sp. shows varied responses at different outfalls, it consistently avoids the more affected areas or the areas immediately around municipal outfalls.

The general effect of this outfall, considering the relatively high abundances of *P. tenuisculpta* and *E. carcharodonta* in the immediate vicinity of the outfall, is one of enhancement. The area of maximum impact will be defined as that area that encompasses the sites where *P. tenuisculpta* is present in excessively high density relative to similar sites. This area includes sites 18, 19, and 20 (Fig. 18) and covers an area of about 3 sq km. An area of secondary effect surrounds the above area and is characterized by the high abundance of *E. carcharodonta*.



Euphilomedes characarodonta (E.c.)
Parvilucina tenuisculpta (P.t.)
Capitella capitata (C.c.)
Tharyx sp. (T. sp.)
Amphiodia urtica (A.u.)

Figure 18. Distribution of individuals per square meter for selected "indicator species" in sites at diffuser-depth (55 m).

Up to this point we have considered the faunal distribution patterns in terms of the site groups and several "key" species, and I have casually invoked depth and the influx of organic material as the factors responsible for these patterns. The composition and distributions of faunal assemblages obviously change with any significant change in depth, but when changes in faunal composition and abundance are recorded along a given depth contour factors other than depth must be considered. While the input of organic matter is an obvious candidate, it must be subjected to objective testing and deductive reasoning before such a hypothesis can be justified. For this reason the site groups and their sites were evaluated by multiple-discriminant analysis with the abiotic variables as attributes of the sites.

The fact that the discriminant analysis shows that most of the biotic variation is associated with depth even after elimination of the shallowest and deepest sites is not surprising since many changes in sediment and hydrography are often associated with changes in depth. The second and third discriminant axes are most strongly associated with copper which, in the present study, is highly correlated with cadmium and chromium. Sediment size parameters are also important on these axes. This result logically suggests that the trace metals, sediment parameters, or factors that were not or could not be measured, but responded with similar patterns, were responsible for the biological differences between the site groups.

Most of the metals in sewage effluent are associated with particulate matter (Young <u>et</u> <u>al</u>., 1973) which is often high in organics. Our measurements of organic material in the sediments (volatile solids) shows that the levels are quite low and that there is no indication of a build-up in the area of the diffuser. The fact that both the abundance of organisms and biomass are high to the northwest of the diffuser suggests that there must be a higher input of organic material in this area. The generally low levels of organic material suggests that the populations are either at equilibrium with organic input or that excess organic material is periodically resuspended and transported around in and out of the area. The fact that sediment traps placed in this area at the time of benthic sampling collected considerable quantities of organic material compared to the amounts found in the sediments themselves supports the latter consideration.

If these considerations apply, then it is reasonable to hypothesize that gradients in the biota and the concentrations of animals and biomass are a reflection of the flux of organic material through this area. The higher than background levels of copper, cadmium, and chromium (Appendix A) at these same sites may be the result of extracellular biological concentration of the metals and their incorporation into the sediments as fecal material. Because the majority of the populations at this depth do not appear to be significantly affected by these potentially toxic levels of trace metals, it is reasonable to assume that they exist in biologically unavailable forms.

Smith (1974) concluded from his studies that almost complete recovery had occurred in the sediments around the shallow outfall within three months of termination of discharge. He based this conclusion on changes in the abundance and composition of the fauna and changes in organic carbon and acid volatile sulfides in the sediments. Recovery was equated against what Smith determined to be background levels for that depth. The increases in species diversity and especially scaled (evenness) diversity (Fig. 16) are strong indicators that the fauna was returned to a more balanced state.

Our data support Smith's findings and conclusions and suggest that the sediments are now even less contaminated. The tremendous changes in faunal composition since 1972 and the very low levels of trace metals, e.g. 2-3 ppm copper (Appendix A) versus 31 ppm in 1971, indicate that this environment is periodically subjected to strong mixing which may have been partially responsible for the rapid recovery at this shallow outfall.

Smith also reported that the fauna and sediments at the deep outfall did not undergo dramatic changes within the year and a half following initiation of discharge. He found that the number of species increased and there was an overall increase in abundance of individual organisms for all species. One or two species showed large increases in abundance, i.e. Capitita ambiseta, which produced decreases in both the species and evenness diversities (Fig. 17).

The rate at which the biological parameters changed between March and August, 1971, at the shallow outfall was much greater than the rate of change in these same parameters at the deep outfall. Conversely, there was greater change at the deep site during the following year than there was at the shallow site. These observations serve to support the obvious: Not only are the biotic and abiotic environments at these two depths different, but the rate and sequence of events involved in the recovery of a chronically effected outfall area must differ from those that occur in an area newly subjected to the discharge of a modern diffuser system. What is important from these observations is that the processes of stress and recovery have different rates and with sufficient data it may be possible to determine these rates.

ACKNOWLEDGEMENTS

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REFERENCES

Barnes, H., 1952. The use of transformations in marine biological statistics. J. Const. Perm. Int. Explor. Mer., 18:61-71.

Blackith, R.E. and R.A. Reyment, 1971. Multivariate Morphometrics. Academic Press, New York: 412 pp.

Bray, R.J. and J.L. Curtis. 1957. An ordination of the Upland forest communities of southern Wisconsin. Ecolog. Monog. 27(4):324-349.

Cassie, R.M. and Michael, A.D., 1968. Fauna and sediments of an intertidal mud flat: A multivariate analysis. J. Exp. Mar. Biol. Ecol., 2:1-23.

Clifford, H.T. and W. Stephenson. 1975. An Introduction to Numerical Classification. New York, Academic Press. 240 p.

Fager, E.W. 1972. Diversity: A sampling study. Amer. Natur., 106:293-310.

Greene, C.S. 1973. Zooplankton community structure in Lake Berryessa. Ph.D. Dissertation. University of California, Davis, CA.

Greene, C.S., and R.W. Smith. 1975. Numerical analysis of data on a benthic community. Southern California Coastal Water Research Project. Annual Report. July 1975. 69-77 pp.

Greene, C.S. 1975. Multivariate analysis of benthic ecosystems at a marine wastewater discharge site. A Task Report for Grant R801152 from the U.S. Environmental Protection Agency.

Hope, K. 1969. Methods of Multivariate Analysis. Gordon and Breacti, Science Publishers, Inc., New York 288 pp.

Hurlbert, S.H. 1971. The nonconcept of species diversity: A critique and alternative paramters. Ecol., 52:577-86.

Lance, G.N., and W.T. Williams 1967. A general theory of classificatory sorting strategies, part 1: Hierarchial systems. Comput J. 9:373-80.

Pielou, E.C. 1975. Ecological Diversity. Wiley-Interscience, New York. 165 pp.

McDermott, D.J., T.C. Heesen, and D.R. Young. 1974. DDT in bottom sediments around five southern California outfall systems. TM 217, Southern California Coastal Water Research Project, El Segundo, CA.

Raphael, Y.I., and W. Stephenson. 1972. The macrobenthic fauna of Bramble Bay, Moreton Bay, Queensland, part 1: Preliminary studies. In Report to Comm. Dept. Works and Qd. Dept. Coord. General, 1-32 pp.

Reish, D.J. 1973. The use of marine invertebrates as indicators of varying degrees of marine pollution. FAO technical conference on marine pollution and its effects on living resources and fishing. In: Marine Pollution and Sea Life. Mario Ruivo, ed. Fishing News (books) Ltd. Surrey, England: 203-207.

Seal, H. 1964. Multivariate Statistical Analysis for Biologists. Mathuen, London. 207 pp.

Smith, G.B. 1974. Some Effects of Sewage Discharge to the Marine Environment. Ph.D. Dissertation, University of California, San Diego, CA. 334 pp.

Smith, R.W. 1976. Numerical Analysis of Ecological Survey Data. Ph.D. Dissertation. University of Southern California, Department of Biological Sciences (in preparation).

Smith, R.W., and C.S. Greene. 1976. Patterns in biological communities in an area of wastewater discharge. In Press: J. Water Poll. Cont. Fed.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical Methods. The Iowa State University Press, Ames, Iowa.

SCCWRP. 1973. The ecology of the Southern California Bight: Implications for water quality management. So. Calif. Coastal Water Research Project. El Segundo, Technical Report 104, 531 pp.

Stephenson, W., R.W. Smith, C. Greene, T. Sarason, and D. Hotchkiss. Soft-bottom benthos of the Palos Verdes area of southern California. I. Hierarchial Classification of data from 87 sites. TM 226. Southern California Coastal Water Research Project, El Segundo, CA (1975).

Young, D.R., C.S. Young, and G.E. Halvaka. 1973. Sources of trace metals from higly-urbanized southern California to the adjacent marine ecosystem. In: Cycling and Control of Metals, pp. 21-39. U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio.

APPENDIX A

Concentrations of abiotic factors in the sediments

STATION	DEPTH (m)	TEMPERATURE (°C)	MEAN GRAIN-SIZE (phi)	SORTING COEFF. (phi)	% SAND	% SILT	% CLAY	% VOLATILE SOLIDS	ACID VOLATILE SULFIDES (mg S=/dry kg)
BL[1]									
1	13	60.0	3.84	0.91	69.79	29.15	1.06	1.4	
2	13	60.0	2.50	0.50	100.00	0.0	0.0	0.4	
3	13	61.0	3.75	1.06	61,44	37.71	0.85	1.4	6
4	13	61.0	2.72	0.77	96.83	2.97	0.20	0.8	1
5	13	60.0	2.84	0.71	96.82	2.82	0.36	0.6	9
6	37	56.0	4.08	1.31	63.50	33.39	3.11	2.6	
7	37	56.5	4.92	1.77	32.08	59.54	8.38	4.5	
8	37	57.0	3.84	1.24	89.69	7.53	2.78	2.9	
9	45	55.5	3.85	0.88	76.82	23.18	0.0	2.0	
10	45	55.0	3.99	1.27	73.32	23.69	2.99	3.3	57
11	45	55.0	4.02	1.32	67.28	29.38	3.34	2.5	95
12	45	55.0	4.22	1.29	53.87	42.79	3.34	2.2	136
13	45	56.0	4.04	1.26	68.04	29.09	2.87	2.4	191
14	45	55.0	4.34	1.40	55.60	40.15	4.25	2.8	33
15	45	56.0	4.51	1.55	44.30	50.30	5.40	2.2	62
16	45	55.0	4.34	1.40	54.15	41.59	4.26	1.9	
17	57	54.5	4.00	1.10	71.33	26.94	1.73	2.8	
18	57	56.0	4.03	1.16	67.93	29.36	2.71	2.3	
19	57	56.0	3.89	1.11	77.14	20.53	2.33	2.4	108
20	57	55.0	3.84	0.95	79.83	19.53	0.64	2.2	57
21	57	55.0	3.86	1.15	79.46	18.09	2.45	1.8	137
22	57	55.0	3.43	1.26	84.58	13.81	1.61	2.2	167
23	57	55.0	3.28	1.75	77.20	20.50	2.30	2.1	77
24	57	54.0	3.57	1.30	79.86	17.96	2.18	1.7	56
25	57	55.5	3.17	1.48	83.85	13.55	2.60	1.6	
26	90	54.0	4.32	1.32	50.34	45.73	3.93	2.5	
27	90	54.0	3.98	1.18	74.25	22.79	2.96	2.3	78
28	90	54.0	3.95	1.10	74.94	22.80	2.26	2.2	13
29	90	53.5	3.93	1.20	73.36	23.81	2.83	2.0	103
30	90	54.0	3.83	1.32	73.07	24.24	2.69	1.8	65
31	90	53.5	3.44	1.09	87.21	11.38	1.41	1.5	13
32	90	53.0	2.96	1.21	88.22	11.78	0.0	1.7	
33	180	51.5	4.56	1.59	41.47	52.81	5.72	2.6	
34	180	50.0	4.70	1.57	36.40	57.11	6.49	3.3	
35	180	51.0	4.75	1.53	32.35	61.47	6.18	3.4	

APPENDIX A (Cont'd)

Concentrations of abiotic factors in the sediments

STATION	TOTAL DDT (ppb)	TOTAL PCB (ppb)	COPPER (ppm dry wt)	CADNIUM (ppm dry wt)	CHROMIUM (ppm dry wt)	NICKEL (ppm dry wt)	ZINC (ppm dry wt)	LEAD (ppm dry wt)	MERCURY (ppm dry wt)
BL[1]		0.01	14.-	0.5	34.-	9.-	67.-	10.-	0.02
1	9.0	41.5	4.6	0.2	14.4	4.6	20.1	3.6	
2	0.4	24.0	1.0	0.1	4.0	2.0	6.8	1.4	
3	2.7	21.8	4.6	0.1	15.9	5.6	22.9	4.2	0.08
4	2.4	68.9	1.4	0.1	4.7	1.8	8.9	2.5	0.01
5	2.8	53.9	2.1	0.1	6.0	1.9	11.4	3.2	0.02
6	15.4	54.8	17.2	0.6	15.9	6.3	30.6	7.6	
7	37.4	107.4	24.6	1.0	37.2	11.0	48.1	8.1	
8	24.1	48.8	13.8	0.4	15.2	7.8	31.3	10.4	
9			15.5	0.4	27.1	6.7	29.7	3.6	
10	31.5	132.1	17.6	0.5	30.0	6.9	32.1	4.9	0.08
11	19.1	141.6	24.9	0.9	21.7	7.6	39.2	12.6	
12	19.7	97.3	22.5	1.1	18.1	7.6	36.6	6.7	0.01
13	17.3	142.9	25.5	1.3	21.5	7.7	39.9	12.5	0.09
14	14.7	148.1	17.9	0.6	29.0	9.4	37.8	5.7	0.05
15	31.8	117.3	13.6	0.3	20.8	8.5	30.2	10.9	0.07
16			10.9	0.3	20.5	7.8	29.2	4.0	
17	9.2	127.6	25.4	1.3	35.9	8.7	43.8	5.8	
18	20.7	235.3	36.0	2.6	47.2	12.9	62.0	8.2	
19	14.6	300.9	35.7	2.8	41.0	9.6	59.7	8.7	0.13
20	19.4	78.8	35.5	2.5	42.8	9.1	76.2	5.5	0.07
21	9.7	176.0	20.7	1.0	26.6	5.6	48.7	3.6	0.12
22	35.1	183.3	43.8	1.8	53.0	12.0	84.0	10.5	0.07
23	8.0	91.4	7.8	0.3	14.0	4.3	24.3	2.2	0.04
24	12.3	128.0	10.8	0.4	20.2	7.0	45.8	2.2	
25	10.9	106.8	9.8	0.4	17.3	5.2	24.4	3.4	
26	20.8	207.4	29.9	1.3	42.1	12.3	55.6	3.1	
27									
28	15.8	98.7	23.5	1.0	36.3	11.4	54.2	3.3	0.06
29									0.04
30	7.2	116.9	20.2	0.7	29.0	9.7	49.5	5.9	0.04
31	10.5	44.9	14.2	0.5	23.6	8.0	56.7	2.6	0.06
32			9.1	0.4	15.8	6.0	41.0	2.7	0.05
33	40.7	44.0	10.9	0.2	11.8	9.2	27.1	4.4	
34	23.1	142.7	10.7	0.3	11.8	8.4	33.6	5.3	
35	16.4	121.1	15.8	0.6		13.0	56.2	2.1	

1. Baseline data from SCCWRP (1973) and McDermott et al (1975).

APPENDIX B

Species used in the numerical analyses ranked by abundance with species number, total abundance, frequency of occurrence, and mean abundance where they occur.

Species Number	Species Name	Taxa	Total Abundance	Number of Occurrences	Mean Number Per Occurrence
1	Euphilomedes carcharodonta Smith	Crust.	2,810	33	85.2
2	Parvilucina tenuisculpta (Carpenter)	Pel.	2,053	30	68.4
3	Euphilomedes producta Poulson	Crust.	1,610	18	89.5
4	Tharyx sp.	Pel.	1,580	35	45.1
5	Amphiodia urtica (Lyman)	Echin.	432	29	14.9
6	Chloeia pinnata Moore	Poly.	320	22	14.6
7	Prionospio malmgreni Ehlers	Poly.	255	27	9.4
8	Lumbrineris sp.	Poly.	216	31	7.0
9	Capitita ambiseta Hartman	Poly.	210	24	8.8
10	Axinopsida serricatus (Carpenter)	Pel.	180	30	6.0
11	Heterophoxus oculatus (Holmes)	Crust.	158	26	6.1
12	Capitella capitata (Fabricius)	Poly.	150	7	21.4
13	Decamastus gracilis Hartman	Poly.	140	22	6.3
14	Pectinaria californiensis Hartman	Poly.	118	28	4.2
15	Glycera capitata Oersted	Poly.	114	30	3.8
16	Euphilomedes longiseta Juday	Crust.	108	10	10.8
17	Listriolobus pelodes Fisher	Echiur.	98	12	8.1
18	Composomyax subdiaphana (Carpenter)	Pel.	83	21	4.0
19	Paraphoxus bicuspidatus Barnard	Crust.	80	22	3.7
20	Amphiodia occidentalus (Lyman)	Echin.	80	16	5.0
21	Rictaxis punctocaelatus (Carpenter)	Gast.	76	19	4.0

APPENDIX B (Cont'd)

Species Number	Species Name	Taxa	Total Abundance	Number of Occurrences	Mean Number Per Occurrence
22	Cylindroleberididae, unid.	Crust.	72	17	4.3
23	Leptochelia sp.	Crust.	68	19	3.6
24	Ampelisca brevisimulata Barnard	Crust.	60	19	3.2
25	Gnathia crenulatifrons Monod	Crust.	60	21	2.8
26	Tellina sp.	Pel.	58	22	2.6
27	Notomastus sp.	Poly.	52	23	2.2
28	Sthenelanella uniformis Moore	Poly.	50	20	2.5
29	Haploscoloplos elongatus (Johnson)	Poly.	48	20	2.4
30	Westwoodilla caecula (Bate)	Crust.	44	19	2.3
31	Hemilamprops californica Zimmer	Crust.	42	22	1.9
32	Nereis sp.	Poly.	41	23	1.8
33	Phoronis sp.	Phor.	38	8	4.8
34	Lucinoma annulata (Reeve)	Pel.	38	16	2.4
35	Kurtziella beta (Dall)	Gast.	38	19	2.0
36	Panopea generosa (Gould)	Pel.	38	10	3.8
37	Pholoe glabra Hartman	Poly.	34	22	1.5
38	Acila castrensis (Hinds)	Pel.	32	3	10.7
39	Bittium quadrifilatum Carpenter	Gast.	30	14	2.1
40	Macoma sp.	Pel.	30	17	1.8
41	Mysella pedroana (Dall)	Pel.	30	11	2.7
42	Macoma acolasta Dall	Pel.	30	18	1.6
43	Edwardsia californica McMurrich	Coel.	29	14	2.1
44	Synchelidium sp.	Crust.	28	17	1.6
45	Turbonilla Sp. G	Gast.	27	13	2.1
46	Turbonilla Sp. E	Gast.	27	12	2.2
47	Amphiodia digitata Nielsen	Echin.	27	14	1.9
48	Spiophanes missionensis Hartman	Poly.	26	15	1.7

Species Number	Species Name	Taxa	Total Abundance	Number of Occurrences	Mean Number Per Occurrence
49	Aricidea wassi Pettibone	Poly.	24	12	2.0
50	Enteropneusta, Unid.	Hemich.	24	10	2.4
51	Goniada brunnea Treadwell	Poly.	24	17	1.4
52	Glycinde polygnatha Hartman	Poly.	24	15	1.6
53	Cylichna diegensis (Dall)	Gast.	21	13	1.6
54	Modiolus neglectus Soot-Ryen	Pel.	20	13	1.6
55	Gyptis brevipalpa Hartman-Schroeder	Poly.	20	16	1.3
56	Scalpellum californicum Pilsbry	Crust.	20	4	5.0
57	Spiophanes cirrata Berkeley & Berkeley	Poly.	20	7	2.9
58	Paraprionospio pinnata (Ehlers)	Poly.	20	15	1.3
59	Drilonereis mexicana Fauchald	Poly.	19	14	1.4
60	Paraonis gracilis oculata Hartman	Poly.	18	13	1.4
61	Chaetozone setosa Malmgren	Poly.	18	9	2.1
62	Volvulella panamica Dall	Gast.	18	6	3.0
63	Haliophasma geminata Menzies & Barnard	Crust.	18	16	1.1
64	Adontorhina cyclica Berry	Crust.	18	8	2.2
65	Leptostylis Sp. A	Crust.	16	13	1.2
66	Harmothoe lunulata (delle Chiaje)	Poly.	16	10	1.6
67	Tellina modesta Carpenter	Pel.	16	13	1.2
68	Amphideutopus oculatus Barnard	Crust.	15	9	1.7
69	Photis californica Stout	Crust.	15	4	3.8
70	Glycera americana Leidy	Poly.	15	10	1.5
71	Pista fasciata (Grube)	Poly.	14	7	2.0

APPENDIX B (Cont'd)

Species Number	Species Name	Taxa	Total Abundance	Number of Occurrences	Mean Number Per Occurrence
72	Listriella goleta Barnard	Crust.	13	8	1.6
73	Photis Sp. A	Crust.	13	3	4.2
74	Langerhansia heterochaeta (Moore)	Poly.	12	12	1.0
75	Lumbrineris tetraura (Schmarda)	Poly.	12	4	3.1
76	Leptognathia sp.	Crust.	12	10	1.2
77	Nephtys ferruginea Hartman	Poly.	12	12	1.0
78	Paraphoxus obtusidens (Alderman)	Crust.	11	6	1.8
79	Cooperella subdiaphana (Carpenter)	Pel.	11	8	1.4
80	Laonice cirrata (Sars)	Poly.	11	10	1.1
81	Ampelisca macrocephala Liljeborg	Crust.	10	10	1.0
82	Mesolamprops bispinosa Given	Crust.	10	8	1.2
83	Acteocina intermedia Willet	Gast.	10	6	1.7
84	Pinnixa sp.	Crust.	10	9	1.1