

TM 226
DECEMBER 1975

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HIERARCHIAL CLASSIFICATION OF DATA

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This study was partially funded by
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under Grant R801152

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ABSTRACT

During July 1971, benthic infauna was collected by a single sample at 87 sampling sites on a preliminary sampling grid off the Palos Verdes Peninsula in southern California; the 150-sq-km sampling area contains two submarine outfalls of a major municipal wastewater discharge system. The fauna was identified and counted and analyzed for topographic and biotic patterns using cluster analyses (hierarchical classification) with the "Bray-Curtis" coefficient of dissimilarity and group-average sorting.

The final, reduced data matrix was comprised of species showing "conformity" to the initial site patterns as determined by the Kruskal-Wallis nonparametric ANOVA. An independent pattern for non-conforming species was sought but not found. A more equitable procedure for interpreting two-way tables produced by combining the site (normal) and species (inverse) classifications was proposed and its value demonstrated.

Ecologically meaningful site patterns with their associated species was demonstrated relative to the sewage outfalls, although the species analysis alone was not readily interpreted due to strong chaining in the dendrogram.

A comparison of the hierarchical structure of the site classification with the distribution of abiotic parameters and the reduced two-way tables provided a comprehensive summarization of the results.

A brief discussion of procedures for evaluating the effect of pollution indicated that the types of methods used in the present study both complement and improve upon the results obtained from other, more standard procedures.

A preliminary analysis of species' feeding strategies indicated that significant gradients exist relative to the effects of the outfalls.

INTRODUCTION

This paper deals with the analysis of benthic data resulting from a preliminary survey of a single sample from each of 87 sampling sites around the Los Angeles County municipal wastewater outfall off Whites Point, Palos Verdes Peninsula, in the Southern California Bight. Other analyses of the data have already been published (Southern California Coastal Water Research Project 1973, Sanitation Districts of Los Angeles County 1973). In the present paper, we have reanalyzed the original data using methods of hierarchical classification. Such methods have been applied to a variety of benthic situations by Stephenson et al. (1970), Stephenson and Williams (1971), Day et al. (1971), Field (1971), Raphael and Stephenson (1972), Stephenson et al. (1973,1974), Williams and Stephenson (1973), Boesch (1973), and Smith (1973), among others.

The present methods use most of the available data on the species in samples in an attempt to derive a conceptual picture of faunal distributions of species-groups occurring in site-groups and relationships between spatial changes in the abiotic environment and changes in faunal composition. Previous studies of the subtidal soft bottom benthos of southern California include Hartman (1955, 1960), Hartman and Barnard (1958,1960), Barnard and Hartman (1959), Reish (1959), Barnard and Ziesenhenne (1961), Jones (1969), and Smith (1974). In all but the last two of these studies, data were analyzed by classical and somewhat subjective techniques dating from Petersen (1914). Jones and Smith used methods somewhat resembling our own.

Contrasted with our approach are many other works on pollution in which emphasis is placed on a small number of indicator species or an index of species diversity calculated for each collection. The former approach is another manifestation of Petersen's method in which only a few dominant species are considered, with the neglect of the bulk of the data. The latter approach uses all the data but represents the biota of a collection by a single number, which, when used by itself, can lead to an oversimplified picture

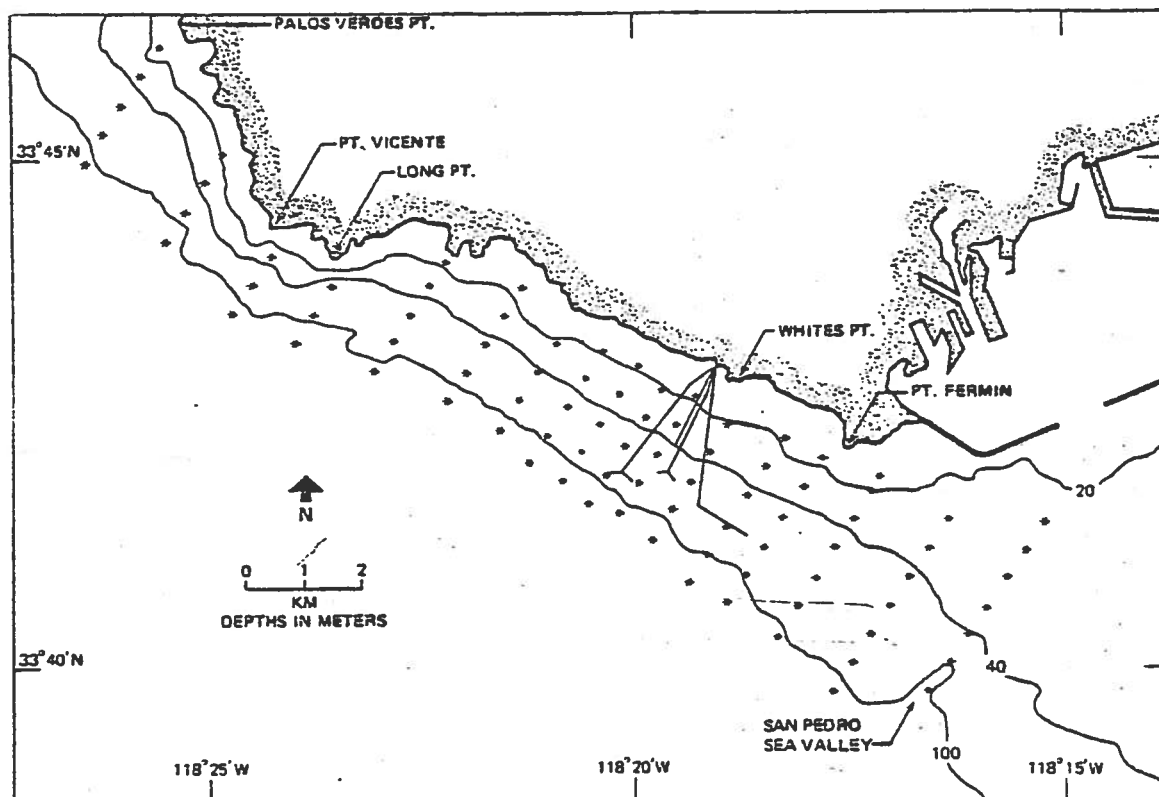


Figure 1. Eighty-seven-station sampling grid used in benthic survey off Palos Verdes, July 1971. From Southern California Coastal Water Research Project 1973.

of a possibly complex biotic pattern.

DATA COLLECTION

Collections of species and observations on sediments were made in July 1971. Additional data on abiotic factors were obtained at different times (May 1970 to July 1971) and to a different sampling pattern.

The study area (Figure 1) is situated on the continental shelf off Palos Verdes Peninsula in southern California. It is bounded on the northwest and southeast by the submarine canyons, Redondo Canyon and San Pedro Sea Valley, respectively. Two operative

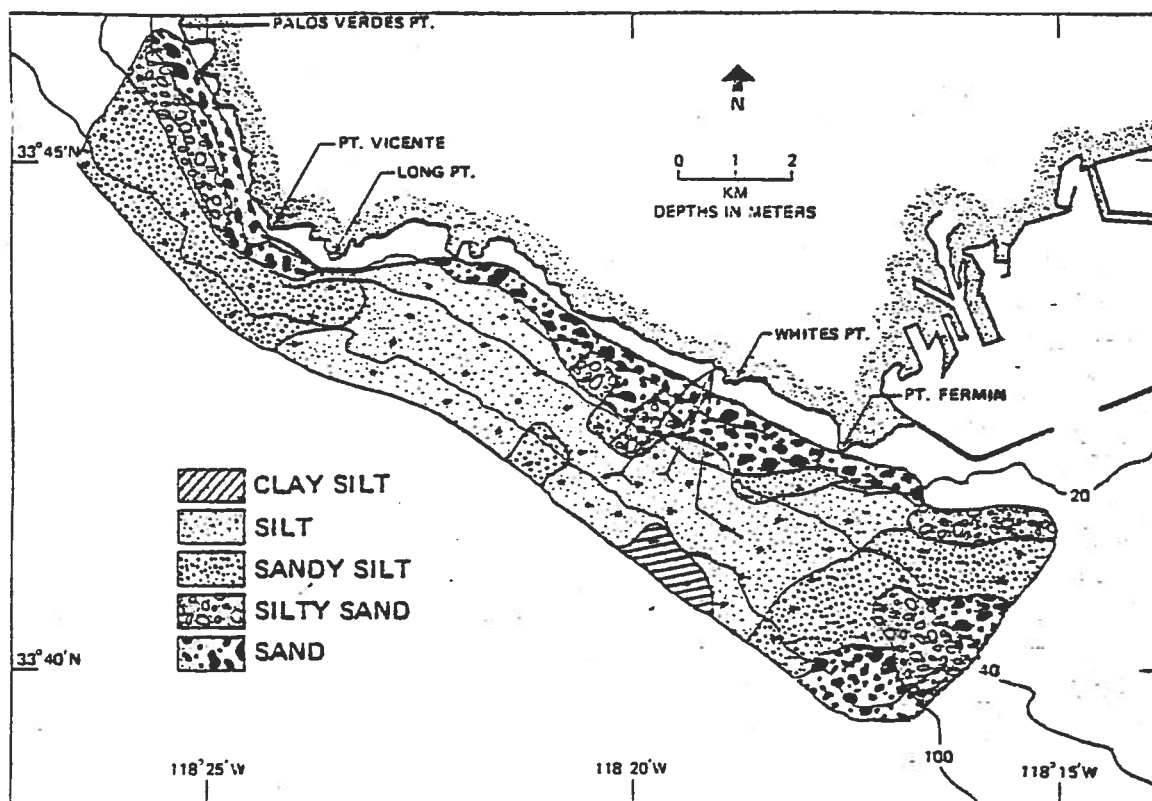


Figure 2. Qualitative analyses of sediment types off Palos Verdes, July 1971. From Southern California Coastal Water Research Project 1973.

outfall pipes presently discharge approximately 380 million gallons of domestic and industrial waste into the area each day. Sewage was first discharged in the area in 1937 through outfalls that are still present but no longer in use. Currents in the area are predominately in the west-northwest to west-southwest direction (Parkhurst et al. 1964; Southern California Coastal Water Research Project 1973).

FAUNAL DATA

In July 1971, 87 sites within a total area of about 150 sq km were sampled (Figure 1). Depths ranged from 10 to 183 m. Single samples were obtained with a Shipek grab, which takes a semicylindrical sample with an 0.04-sq-m surface area to a maximum penetration

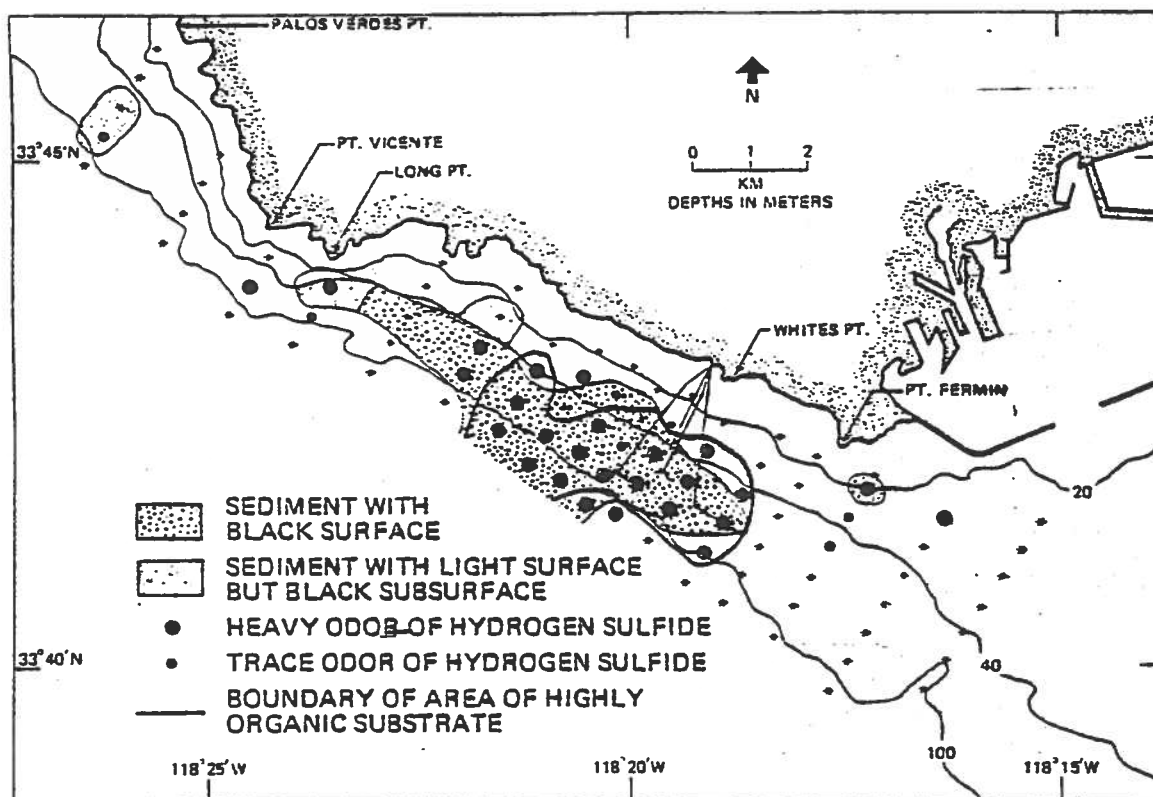


Figure 3. Qualitative analyses of the presence of organic substrate, hydrogen sulfide, and blackened sediments off Palos Verdes, July 1971. From Southern California Coastal Water Research Project 1973.

depth of about 15 cm. Samples were washed through a 1.0-mm mesh screen, and retained organisms were preserved in 10 percent buffered Formalin preparatory to laboratory sorting and final preservation in 70 percent ethanol. Faunal identifications were made by biologists of the Los Angeles County Sanitation Districts in consultation with Dr. D. J. Reish of California State University, Long Beach.

This is first of several sampling surveys in this area, and as such, is only preliminary in nature. Only single grab samples were taken at each site to afford maximum coverage. The results from this data should aid in the planning of subsequent surveys

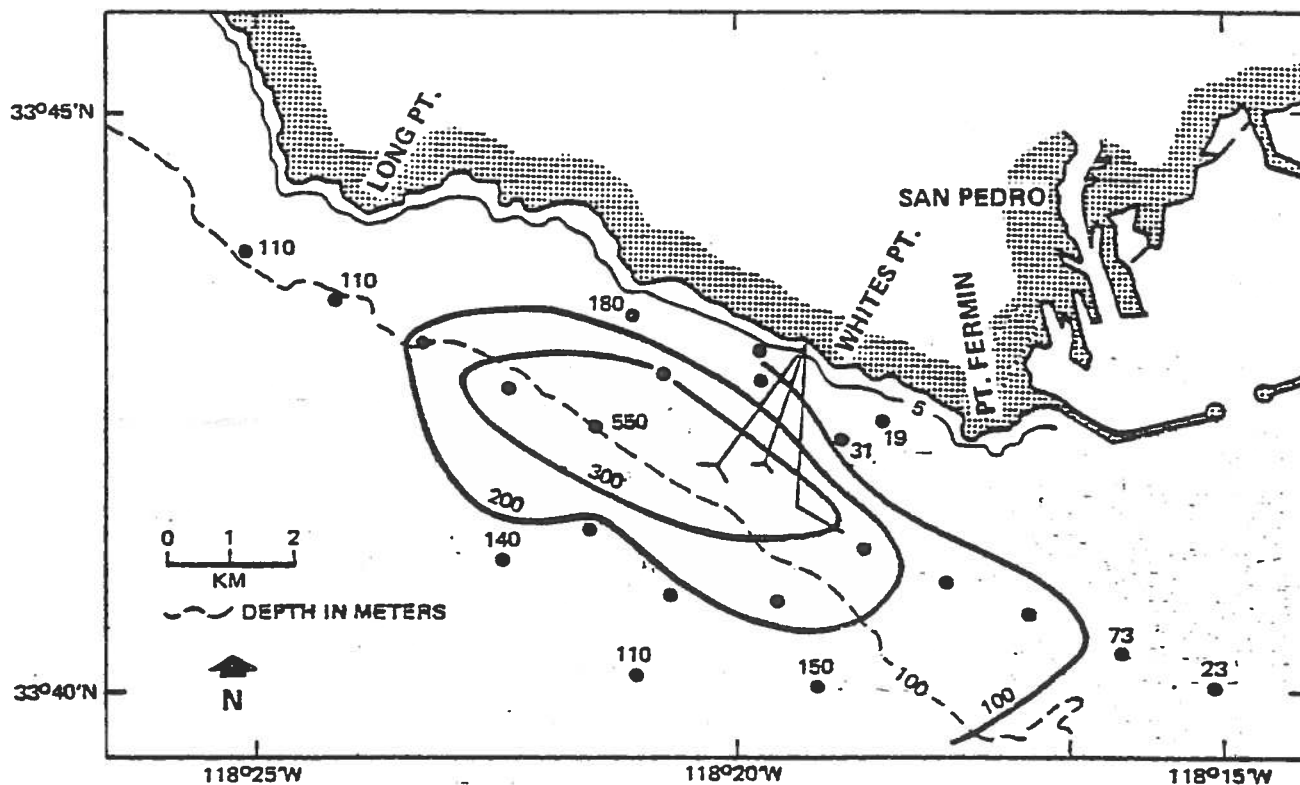


Figure 4. Copper concentrations (mg/dry kg) in surface sediments off Palos Verdes, May 1970 (Phleger cores). From Southern California Coastal Water Research Project 1973.

where each site can be sampled more intensively and more extensive abiotic data can be measured. The methods used to analyze the data should be powerful enough to at least display the large-scale relationships between the biotic and abiotic patterns in the area.

ABIOTIC DATA

Data on sediment coarseness, sediment color, presence of particulate organic matter, and occurrence of hydrogen sulfide odor were derived from descriptive rather than quantitative analyses. They were made from the same samples used for the faunal analyses.

Surface sediments were quantitatively analyzed for concentrations of heavy metals, DDT, and PCB (Southern California Coastal

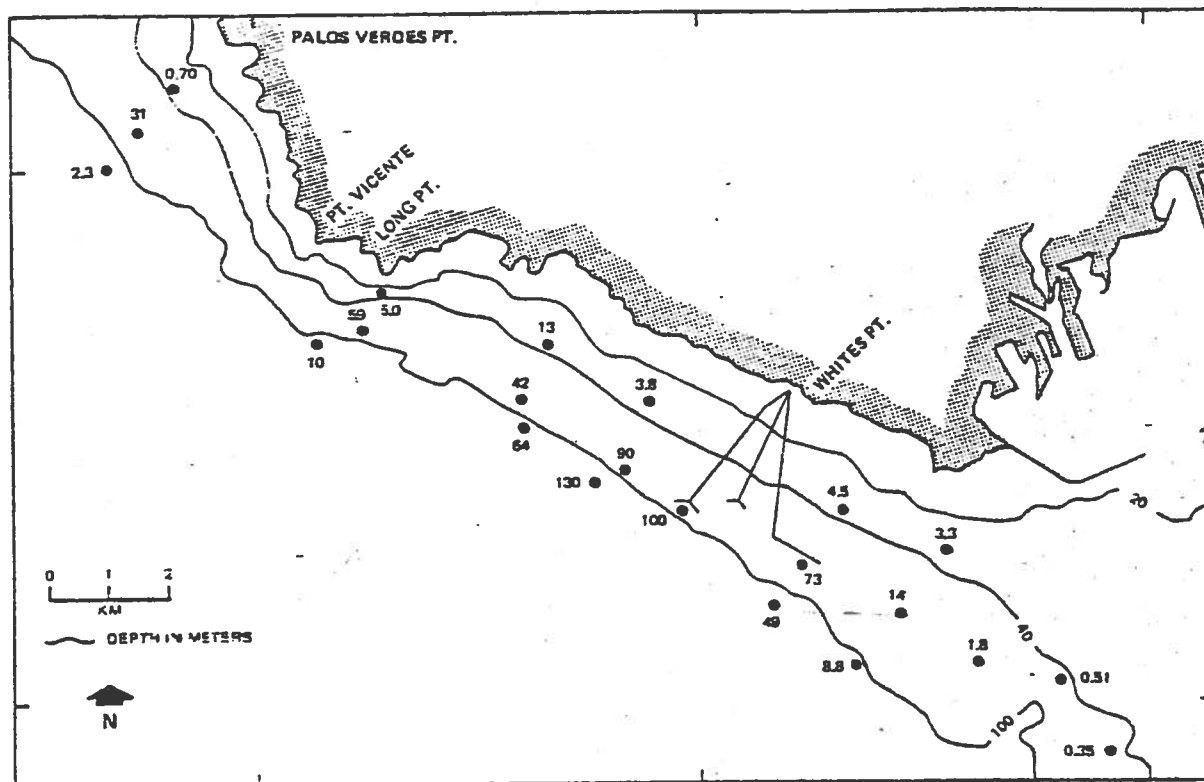


Figure 5. Total DDT concentrations (mg/dry kg) in surface sediments off Palos Verdes, June 1972 (Phleger cores). From Southern California Coastal Water Research Project 1973.

Water Research Project 1973). Samples were taken off Palos Verdes in May 1970 and July 1971 at sites different from those used for the faunal data, and the values obtained were extrapolated for use in the present study.

Results of the abiotic data are shown in Figures 2 through 5. Copper and DDT are used to illustrate distributions of trace contaminants.

CHOICE OF ANALYTICAL METHODS

With the method used in this study, species that occur infrequently and in low abundance will contribute little to the general pattern of the results; thus, initially we eliminated species occurring at

fewer than five sites if the mean number of individuals per site was less than three. This removed 117 taxa. An additional 23 taxa were removed because of the possibility of their being polyspecific. Of the original 206 taxonomic entities, 66 were considered in the initial analysis. Appendices A, B, and C list the 84 species eventually considered in these analyses in order of decreasing frequency of occurrence. Mean abundance per occurrence is also included.

The first methodological choice was in the dissimilarity measure to be used; here we followed Raphael and Stephenson (1972) in using the so-called "Bray-Curtis" measure. This measure, which had earlier been employed in benthic studies by Field and his coworkers (Field and MacFarlane 1968; Field 1969; Day et al. 1971; Field 1971), is defined as:

$$\text{Dissimilarity} = \frac{\sum_{j=1}^n |x_{1j} - x_{2j}|}{\sum_{j=1}^n (x_{1j} + x_{2j})},$$

where, for site clustering, x_{1j} and x_{2j} are abundance values of the j^{th} species at two respective sites and n is the total number of species at the two sites. For species clustering, x_{1j} and x_{2j} are abundance values at the j^{th} site for two species and n is the total number of sites. The measure takes a value of 1.0 for complete dissimilarity and 0.0 for complete similarity.

A possible disadvantage of this measure is the disproportionate weight given to species with relatively high abundance counts. This problem can be overcome somewhat by the application of a data transformation, which will decrease the magnitude of the higher counts to a proportionally greater degree than it will the smaller counts. In the end, the larger values are still dominant, but the degree of the dominance is decreased to reasonable proportions. Some dominance by the more abundant species is considered justified and even desirable since the sampling error associated with such organisms will be lower than it will be for the rarer species.

7.

When no species is outstandingly dominant, and when there may be a requirement to "sharpen" such dominance as exists, "raw" numbers, i.e., untransformed data, may be used, as was done by Stephenson and Williams (1971) and Raphael and Stephenson (1972). In a preliminary trial of the Bray-Curtis measure, Stephenson et al. (1972) used a square-root transformation, but most workers using this measure with marine benthic data have used the transformation of $\log(n + 1)$. Williams and Stephenson (1973) used a cube-root transformation with a Euclidean distance dissimilarity measure, and we decided to use this in the present case with the Bray-Curtis measure. The choice was subjective: Use of a square-root transformation would give a single value of ca. 32 in our matrix (with the next highest value ca. 22). A cube-root transformation reduces the highest value to ca. 10, which we felt was reasonable.

We next considered standardizations of data. The experiences of Boesch² and Stephenson et al. (1974) have shown that the requirements for optimal site classifications and optimal species classifications are not identical. In site classifications, differences in absolute magnitude of the species-in-sites records are important, and the advantages in site standardization of data are not very compelling. The main advantage of site standardization of data is adjustment for different sampling intensities--in the present work, these can be assumed constant. The disadvantage is that the importance of species in impoverished sites is increased. Because the present data include relatively impoverished sites, we have avoided site standardization. On the other hand, in species classification, we are interested in species proportionality between different sites. Only with this information can similar species patterns between common and uncommon species be revealed. Thus we have used unstandardized data to obtain site-groups and data standardized by totals to obtain species-groups.

In selecting a sorting strategy, the effective choice is between group-average and flexible strategies (Lance and Williams 1966a and

2. D. F. Boesch, Virginia Institute of Marine Sciences, personal communication.

b, 1967). Comparisons of the results using these strategies are given by Stephenson et al. (1972) while Pritchard and Anderson (1971) give other comparisons.

Each strategy, expectedly, gives different results, and there is no general consensus of opinion as to which might be preferable in a given set of circumstances. For group-average sorting, the similarity between one site or a group of sites (or species) and a second group of sites (or species) is calculated as the average of all possible similarities between the two groups. The advantage of the group-average method over the flexible is that, for the former, there is minimal group-size dependence in the formation of the groups and thus less distortion from group-size dependence in the dendrogram of group affinities (Williams et al. 1971; Stephenson and Williams 1971). We tried group-averaging in a preliminary way and concluded that the conceptual pictures of the site-groupings was satisfactory and also that the combination of strategies as employed by Stephenson et al. (1972) was not justified here. Hence, group-average sorting was employed throughout.

Each species will not have equal influence in forming the site patterns that emerge in the analysis. The Bray-Curtis index gives greater weight to the more abundant species and to those with greater intersite variation. While the species receiving little weight in the analysis will not in themselves contribute much to the final results, they may constitute a "noise" factor that causes the main patterns to be less distinct. With this in mind, each species was tested for conformity to the site pattern of the original normal analysis. The Kruskal-Wallis nonparametric, one-way analysis of variance test (Siegel 1956) was used to find the species that displayed a random pattern of abundances in the site groups. These species were eliminated, and the analysis was rerun using only "conforming" species. Because the discarded species might be non-conforming in that they followed a pattern independent from the main site pattern, we analyzed these species separately.

RESULTS OF ANALYSES

PRELIMINARY ANALYSIS

These were undertaken with the 66 original species (listed in Appendix A) and 87 sites. Results of the preliminary site classifications are not detailed here--it suffices to say that site-groupings gave good topographic sense and that 18 site-groups were provisionally accepted. On the other hand, the species classification did not form relatively distinct groups, partially because some species appeared to be distributed almost at random through the site-groups; this led directly to the conformity tests.

CONFORMITY TESTS

The conformity of species to the 18 site-groups in terms of nonrandomness was tested, and three grades of conformity were adapted:

- o High: 1 percent or less probability that distributions were random.
- o Medium: Between 1 and 5 percent probability that distributions were random.
- o Low: 5 percent or greater probability that distributions were random.

The 66 species graded as follows (numbers are the original species numbers given in Appendix A):

- o High: 1-23, 25, 26, 30, 32, 34, 37-39, 41, 45-47, 49, 50, 52, 53, 66 (40 species in all).
- o Medium: 29, 33, 40, 43, 44, 48, 61, 62, 65 ((species in all).
- o Low: 24, 27, 28, 31, 35, 36, 42, 51, 54-50, 63, 64 (17 species in all).

The 40 species of high conformity comprised the first 23 in the hierarchy of occurrence and clearly would have a predominant effect in establishing the site-grouping. The high conformity species were renumbered 1 through 40 (as shown in Appendix A).

Following Stephenson et al. (1974), we then applied the same

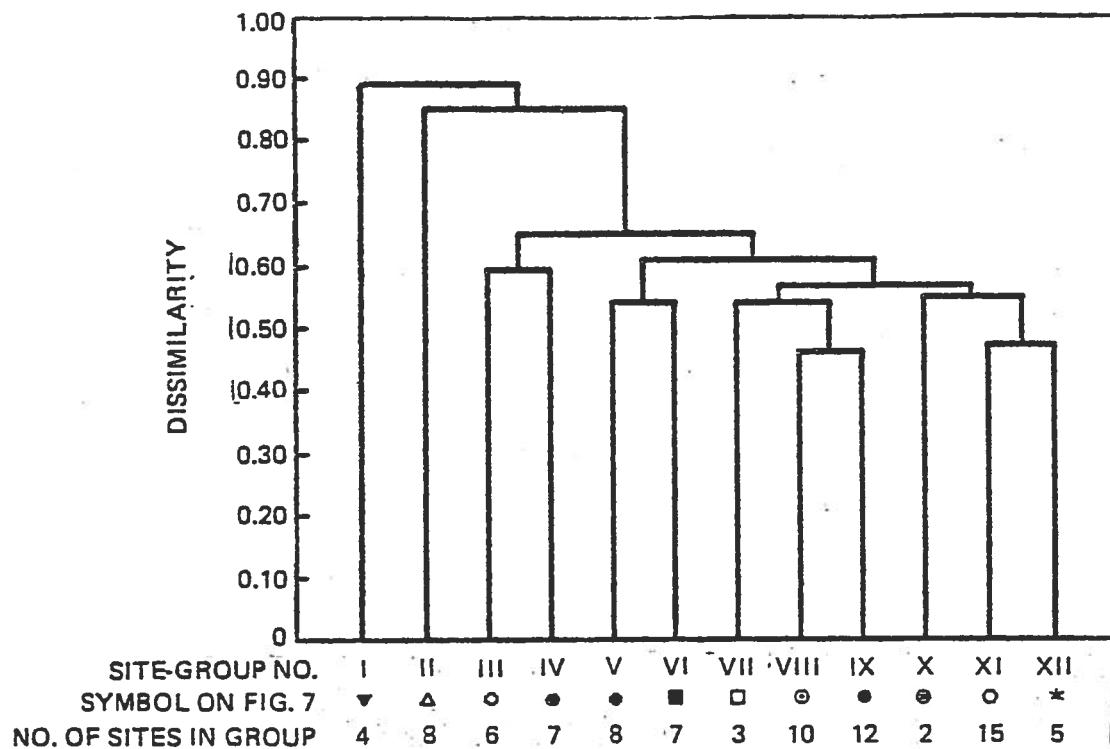


Figure 6. Site-group dendrogram

conformity test to the species originally excluded to see if any might fit the site pattern. First to be tested were 18 organisms that had fairly high frequency of occurrence but were possibly polyspecific (listed in Appendix B). Only four of these species were of high conformity, suggesting that the majority had diffuse patterns of site occupation and hence were polyspecific. Of the four, one was still unacceptable because of taxonomic uncertainty, but the remainder were included in later analyses and were given final numbers (listed in Appendix B).

Species of lower ubiquity were then considered, these being the 18 that occurred at three or four sites. Only three were of high conformity, suggesting that the original level of data reduction had been approximately correct. Of the three (Appendix C), one was taxonomically uncertain, and two were incorporated in later analyses. Thus we have 45 species of high conformity to the 18 provisional site-groups.

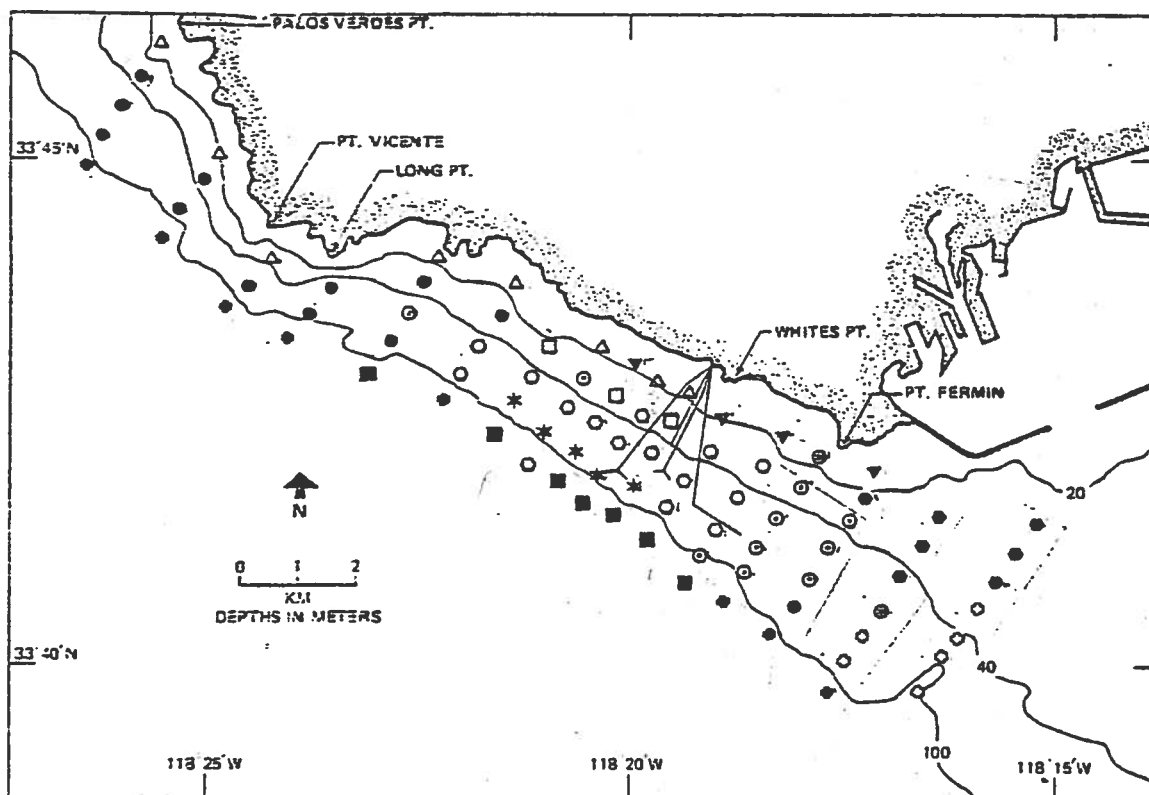


Figure 7. Locations of the samples in the site-groups.

SITE RECLASSIFICATION USING SPECIES OF HIGH CONFORMITY

Results are given by dendrogram on Figure 6. Groups at a given level on the dendrogram were noticeably dissimilar in size; for example, at the four-group level, there are groups with 4, 8, 13, and 62 sites. Interpretation is facilitated by subdividing the larger site-groups and accepting groups at different levels. This may be justified on the basis that different variations in abiotic conditions will impose different levels of site dissimilarity.

Of the 14 resulting site-groups, two consisted of single sites. These were reassigned to those groups to which they were most similar, resulting in a final total of 12 groups. Figure 7 shows the location of these site-groups; the Roman numerals are equivalent to those in the site dendrogram.

SITE CLASSIFICATION USING NONCONFORMIST SPECIES

Stephenson et al. (1974) have considered the possibility that

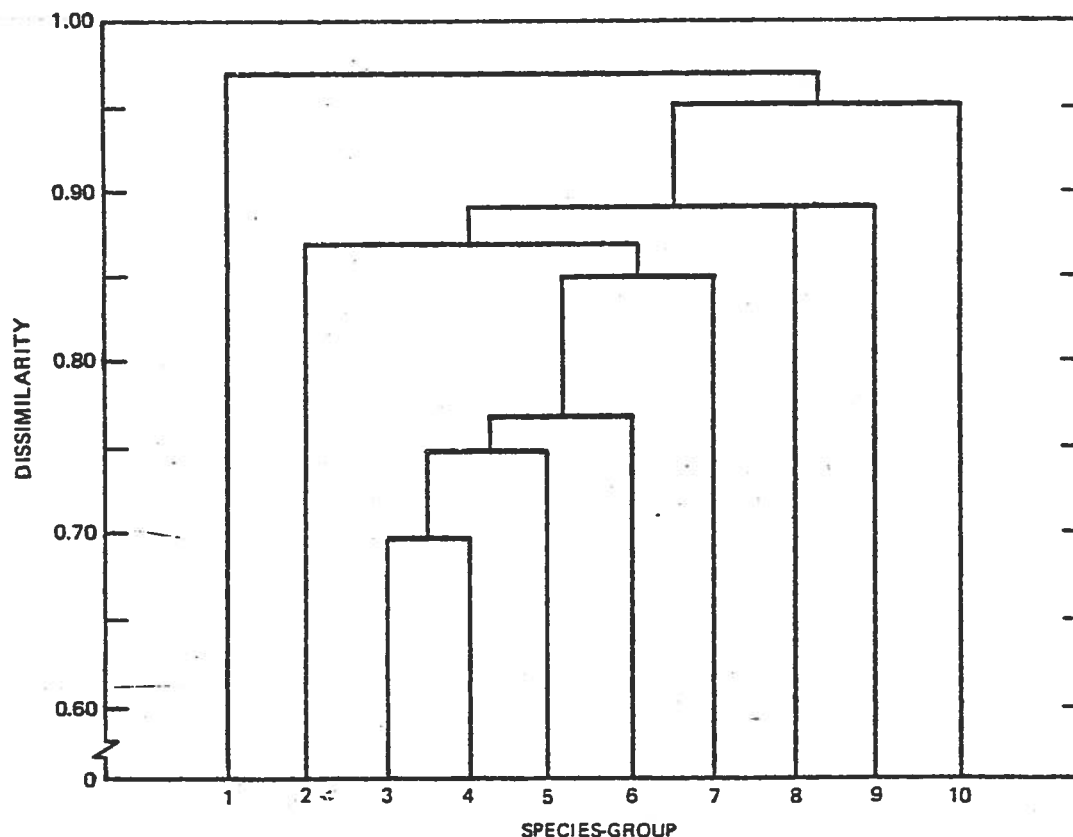


Figure 8. Species classification using the 45 "conforming" species. See Table 1 for the species in each group.

some species in an area might conform to one site pattern and other species to another pattern. However, they failed to demonstrate this on grab data from Moreton Bay, Queensland. In the present work, we classified the 87 sites using as attributes the data on the 26 species of the original list of 66 that were of medium or low conformity to the previous 18 site-groupings. Taken to the 26-group level, results showed that 15 sites had virtually no affinity with any others and that the remainder formed 11 groups, all in the upper portions of the dendrogram. Only three of the site-groups, comprising less than one-third of the total sites, showed any indications of topographic coherence or obvious relationship to abiotic factors; hence, this line of analysis was not pursued.

SPECIES CLASSIFICATION

As indicated earlier, in species classifications, we preferred

to use proportionality of species in the different sites rather than their absolute numbers. The final 45 species were standardized by their totals and classified using the 87 sites as attributes. The dendrogram is shown on Figure 8. As with the site dendrograms, groups have been accepted at different levels. The species comprising the 10 species-groups are shown in Table 1, along with basic distributional data and probable feeding strategy (discussed later).

TWO-WAY TABLES

Two-way coincidence tables were used as an aid in selecting both the species-groups and the site-groups. After the groupings are decided upon, comprehension and display of the relationships between the site and species patterns shown in such a table can be facilitated by some form of simplification or summary. Since the table resulting from the present study was rather large and complex, this approach was pursued.

The entire two-way table can be divided into cells, which are the blocks of entries where a site-group and a species-group coincide. By somehow summarizing each cell with a single number, it is only necessary to consider a table with dimensions of the number of species-groups times the number of site-groups instead of the number of species times the number of sites (as in the complete table). One such method, used by Williams et al. (1969), Webb et al. (1966), Kikkawa (1968), and Stephenson et al. (1972) is to calculate the cell density, which is the percent of the cell with abundance entries greater than zero. A second method (Stephenson and Williams 1971; Williams and Stephenson 1973) involves the use of the mean abundance of all the entries of a cell.

There are inherent weaknesses in both the above methods of summarization. The first method is concerned only with species constancy and does not take abundance into account. The second method can result in low cell-summarization entries if the species-group in question contains some species that are generally low in abundance or constancy. In both methods, the rare and infrequent species can cancel out the effect of the more abundant or constant

Table 1. Faunal composition of species-groups with frequency of occurrence, mean abundance, and feeding behavior.

Species-Group	Taxonomic Group	Feeding Behavior	No. of Sites of Occurrence	Mean No. of Individuals/ Occupied Site
1 <i>Olivella baetica</i>	Gastropod	Scavenger; carnivore	9	4.7
<i>Magelona sacculata</i>	Polychaete	Selective deposit feeder	4	5.0
<i>Paraphoxus epistomus</i>	Amphipod	Deposit engulfer	4	2.5
<i>Prionospio pygmaeus</i>	Polychaete	Selective deposit feeder; suspension feeder	4	1.2
2 <i>Macoma</i> sp.	Pelecypod	Selective deposit feeder	24	25.0
<i>Nassarius perpinguis</i>	Gastropod	Scavenger; carnivore	14	3.6
3 <i>Tharyx</i> sp.	Polychaete	Deposit engulfer	47	86.5
<i>Capitella ambiseta</i>	Polychaete	Deposit engulfer	46	25.7
<i>Cauterella alata</i>	Polychaete	Deposit engulfer	46	40.7
<i>Spiochaetopterus costarum</i>	Polychaete	Suspension feeder	40	5.9
<i>Ampharete labrops</i>	Polychaete	Selective deposit feeder	24	3.6
<i>Nassarius mendicus</i>	Gastropod	Scavenger; carnivore	22	5.2
<i>Cerebratulus</i> sp.	Nemertean	Carnivore	10	1.3
<i>Chone</i> sp.	Polychaete	Suspension feeder	9	1.6
<i>Photis</i> sp.	Amphipod	Suspension feeder	11	2.6
4 Small pink nemertean	Nemertean	Carnivore	27	6.3
<i>Prionospio malmgreni</i>	Polychaete	Selective deposit feeder; suspension feeder	24	2.5
<i>Lumbrineris japonica</i>	Polychaete	Deposit engulfer	21	2.8
<i>Rictaxis punctocoelatus</i>	Gastropod	Carnivore	17	2.4
5 <i>Shistomeringos longicornis</i> *	Polychaete	Deposit engulfer (selective)	69	85.1
<i>Nereis</i> nr. <i>procera</i>	Polychaete	Deposit engulfer; carnivore	48	3.8
<i>Ophiodromus pugettensis</i>	Polychaete	Scavenger; carnivore	46	4.0
<i>Capitella capitata</i>	Polychaete	Deposit engulfer	43	16.9
6 <i>Parvilucina tenuisculpta</i>	Pelecypod	Selective deposit feeder	67	59.3
<i>Spiophanes fimbriata</i>	Polychaete	Selective deposit feeder (suspension feeder)	31	4.6
<i>Notomastus tenulis</i>	Polychaete	Deposit engulfer	31	6.3
<i>Tellina carpenteri</i>	Pelecypod	Selective deposit feeder	25	2.8
<i>Axinopsida</i> sp.	Pelecypod	Selective deposit feeder	17	12.2
<i>Lucinoma annulata</i>	Pelecypod	Selective deposit feeder	17	2.8
<i>Cylichna</i> sp.	Gastropod	Deposit engulfer	17	1.5
<i>Chloelia entypa</i>	Polychaete	Browser	11	3.3
7 <i>Glycera branchiopoda</i>	Polychaete	Carnivore	14	1.6
<i>Cossura candida</i>	Polychaete	Deposit engulfer (selective)	9	5.2
<i>Amphisamya bioculata</i>	Polychaete	Selective deposit feeder	7	5.1
<i>Euchone arenae</i>	Polychaete	Suspension feeder; selective deposit feeder	3	3.0
8 <i>Pitar newcombianus</i>	Pelecypod	(no data)	6	2.5
<i>Conus californicus</i>	Gastropod	Carnivore	6	1.5
<i>Photis brevipes</i>	Amphipod	Suspension feeder	5	1.3
<i>Crepidula</i> sp.	Gastropod	Suspension feeder	8	2.0

*Actually two species (*S. longicornis* and an unidentified Dorvillidae) which were not systematically separated at the time the data were collected.

Table 1 Continued

Species-Group	Taxonomic Group	Feeding Behavior	No. of Sites of Occurrence	Mean No. of Individuals/ Occupied Site
9 <u>Pectinaria californiensis</u>	Polychaete	Deposit engulfer	17	5.3
<u>Melinna oculata</u>	Polychaete	Selective deposit feeder	6	3.2
10 <u>Paraphoxus obtusidens</u>	Amphipod	Deposit engulfer	7	3.6
<u>Armandia bioculata</u>	Polychaete	Deposit engulfer	5	3.8
<u>Caecum crebicinctum</u>	Gastropod	(no data)	4	14.0
<u>Crenella sp.</u>	Pelecypod	Suspension feeder	5	8.6

species, even if the infrequent or rare species are at their maximum in the cell. This is due to the fact that the cell entries are divided by the number of species in the corresponding species-group, and the rare species can contribute a significant amount to this denominator while at the same time contributing relatively little to the cell sum.

Upon reflection, it became evident that we were interested in two separate questions: How is each species-group distributed throughout the site-groups? and, What is the relative dominance of the species-groups at each site group? Experimentation with the various possibilities showed that two separate tables were required to best answer these questions.

To construct the first table, the raw data were modified by a data transformation or standardization prior to calculation to give each species the same weight that it had in the classification analysis. The mean abundance per site within the cell was then calculated as follows:

$$C_{ij} = \frac{\text{sum of all abundances in Cell } ij}{\text{number of sites in Site-Group } j},$$

where i represents the i^{th} row of the summarization table and the i^{th} species-group, j represents the j^{th} column of the table and the j^{th} site-group, and C represents the summarization table entry at this point in the calculations. This table will subsequently be referred to as Matrix C . Division by the number of sites in the respective site-group was necessary to adjust for the variation in sampling intensities in the different site-groupings. Finally, a table intended to answer the first question posed above was constructed by converting each entry of Matrix C to percentages of the total of the row in which the entry was found. Each row of such a table sums to 100 percent and shows, in percentage terms, how a species-group is divided among the site-groups. The conversion to percents was found to facilitate interpretation. The resulting table is shown in Figure 9, Part b; here the raw data were first standardized by the species totals to correspond to the species weights used



SPECIES-GROUP

SPECIES-GROUP

in the species classification.

A table directed at the second question was constructed by converting each entry in Matrix C to percentages of the total of the column in which the entry is found. In each case, each column sums to 100 percent and shows, in percentage terms, the relative dominance of the species-groups within each site-group. The resulting table is shown in Figure 9, Part c; here the raw data were first transformed by the cube root as was done in the site classification.

It is important to note the effect on these tables if each entry in Matrix C was first divided by the number of species representing the corresponding row. The first table would be unaffected since each number in a row would be divided by the same number, and the relative proportions of the entries in a row would remain the same. The second table, however, would be affected, since each element of a column would not necessarily be divided by the same number, and the relative proportionality of the entries would be changed. Since we are interested in the way in which the total abundance of all the species occurring at a site-group are proportioned among the species-groups, division by the number of species corresponding to the entry is inappropriate. Since there is no need at any stage of calculation to divide the cell sums by the number of species in the species-groups, the rare species cannot distort the pattern of cell entries as is possible in the summarization methods already in use.

Figure 9. Summary of the relationships between the site-groups, species-groups, and abiotic variables.

- a. Abiotic characteristics of the site-groups.
- b. Relative distribution of species-groups among the site-groups. Each row of this table sums to 100 percent.
- c. Relative distribution of species-groups among the sites within each site-group. Each column of this table sums to 100 percent; the entries are based on cube-rooted values.

THE RELATIONSHIP OF SITE-GROUPS TO ABIOTIC FACTORS

A comparison of the site-group topography (Figure 7) with the distribution of the abiotic factors (Figures 2 through 5) makes it apparent that depth, sediment coarseness, and outfall-related factors are related to the distribution of site-groups and thus to faunal composition. Also, the orientation of site-groups to the northwest of the outfall is consistent with the prevailing northwest direction of currents in the area.

We would expect a group of sites that show a certain amount of faunal homogeneity to show a corresponding homogeneity in the environmental variables that are important to the organisms at those sites. Furthermore, one would expect the measured levels of the important environmental variables (and/or the variables correlated with them) to show differences that correspond with the faunal differences between the site-groups.

This approach is illustrated in Figure 9, Part a, which shows the site dendrogram with each level of dissimilarity characterized by possible causative abiotic factors. Characterization was accomplished by comparing means and overlap of ranges of the abiotic factors for each site-group. Because of the semiquantitative and descriptive nature of some of the abiotic factors, the absence of direct measurements for others (e.g., organic matter), and the absence of replicate samples, no attempt was made to apply more rigorous statistical tests such as used by Field (1971) in a similar analysis.

Figure 9 shows that the site-groups, as defined by the fauna, differ from one another with respect to one or more abiotic factors. The two shallow site-groups (I and II) are quite dissimilar from one another and from all other groups. The next major subdivision separates Groups III and IV, located at intermediate depths near the San Pedro Sea Valley, from other intermediate and deep site-groups. Groups III and IV differ from each other in terms of depth, sediment coarseness, and outfall influence.

The next subdivision separates the remaining intermediate depth groups from the deep groups. The former are divided into

"semioutfall" and "outfall" groups. The semioutfall groups, characterized by fine dark sediments, are split into a shallow group, VII, and two groups with sites on both sides of the outfall area (Site-Group VIII is more prominent to the southeast, and Group IX to the northwest). Of the three outfall groups, two (XI and XII) are characterized by high levels of outfall-related factors (fine black sediments, hydrogen sulfide odor, particulate organic material, and moderate to high levels of trace metals and DDT). The third outfall group (X), as defined by faunal composition, does not appear to fit the abiotic description of Groups XI and XII. This anomalous group is however, composed of only two dis-junct sites.

The deep sites are partitioned into a nonoutfall group (V) and an outfall group (VI). The abiotic characterizations of these site-groups conform with those presented above.

Major faunal breaks appear to be dependent on an interaction between natural factors, especially depth, and outfall-related factors. Conditions associated with the San Pedro Sea Valley seem to be exerting some influence, as does sediment coarseness, which is probably related to both depth and siltation from the outfall. Areas of similar depth are divided into subgroups apparently on a basis of the degree of influence from outfall-related factors including sediment color (probably an indication of organic content and state of oxidation or reduction of iron (Sverdrup et al. 1942, pp. 967-9)), particulate organic matter, hydrogen sulfide, trace metals, and pesticides.

Thus, with a few exceptions, individual and composite site-groups can be characterized by two sets of abiotic factors, one set consisting of those factors that may be responsible for the uniqueness of the group from the next most similar site-group and a second set that it holds in common with that group.

CONSIDERATION OF SPECIES-GROUPS AND SPECIES

The structure of the species dendrogram (Figure 5) shows a tendency for chaining and the merging of groups at levels only

slightly above the levels at which they were selected. While this may be due in part to sampling variability, it is apparent that, for the data dealt with here, the species cannot be grouped into distinct faunal associations or communities. A similar conclusion was reached by Jones (1969) in his analysis of data representative of the soft bottom benthos of a large portion of the southern California shelf:

"Benthic marine associations are not discrete assemblages or organisms bound together by the biological interactions of their component species or determined by precise limits of the environment. They are, rather, roughly definable units, with fairly recognizable geographic limits, consisting of organisms that have some similar reactions to their total environment, the physical and biological factors taken together."

While the selection of the groups is in part subjective, they can nevertheless be useful in describing faunal distributions and the influence of abiotic factors. They can also be useful in investigating the relationship between co-occurring species and their adaptive strategies such as feeding behavior. (Table 1 includes the distribution of probable feeding types by species-group for the species used in the analysis.)

The pattern of entries in the two-way table (not shown) and the two-way table summaries (Figure 9, Parts b and c) were useful in forming a conceptual picture of faunal gradients as they related to the distribution of abiotic factors.

Species-Group 5 reaches maximum abundances at intermediate depths and in dark sediments. It is the most widely distributed of the species-groups--some of its species occur in each of the site-groups. Included in this group are three small polychaetes, all of which can feed as deposit engulfers, and a larger polychaete, probably a scavenger or carnivore. The engulfers include Shistomeringos longicornis³ and Capitella capitata, both recognized

3. Formerly Stauronereis rudolphi. At the time this data was collected, S. longicornis and an unidentified Dorvilleidae were not systematically separated; thus our values for S. longicornis represent both species.

as opportunistic species and indicators of environmental disturbances and stress (Grassle and Grassle 1974), being tolerant of low oxygen conditions associated with high levels of organic matter and hydrogen sulfide (Reish 1970). This group greatly dominated the outfall site-group (XII) from which species of most other groups were excluded.

From the species dendrogram and Part b of Figure 9, it can be seen that Species-Groups 3, 4, and 6 are most closely related by distribution to Species-Group 5. These three species-groups were absent from Site-Group XII, and were found in low abundance in Site-Groups X and XI, reaching their highest levels in what has been termed the semioutfall area (Site-Groups VII, VIII, and IX). Species-Group 4 reaches its highest density in the dark sediment of the San Pedro area, and Species-Group 6 in the "clean" deep area. Species-Group 6 includes a number of species that are probably functioning as selective deposit feeders, of which the bivalve Parvilucina tenuisculpta was the dominant species. This small clam has been noted to occur in a number of other outfall areas in southern California (Southern California Coastal Water Research Project 1973). Species-Group 3, like Species-Group 5, is quite ubiquitous, contributing significantly to 9 of the 12 site-groups (Figure 9, Part c). In contrast to Species-Group 5, it appears primarily in slightly shallower areas. It was dominated by the polychaetes Tharyx parvus and Caulleriella alata, both of which are tentacle deposit feeders. The small deposit engulfing polychaete Capitita ambiseta is also a fairly abundant member of this group and is typically found in high abundance around predominantly domestic deep-water outfalls in the Los Angeles area. Several suspension feeders were also included in Species-Group 3.

Species-Group 2 consisted of only two species, Macoma carlottensis, a selective deposit feeding bivalve, and Nassarius perpinguis, a scavenger snail. These species preferred the deeper areas and possibly were enhanced in the deep outfall area (Site-Group VI).

Groups 7 and 8 included a variety of feeding types--deposit feeders, suspension feeders, and predators. Group 7 reached

highest levels at a few shallow areas of Site-Group IX, and Species-Group 8 reached its peak at about the same depths in Site-Group VII.

Species-Group 7 consisted of two selective deposit feeding polychaetes, a sand-eater, Pectinaria californiensis, and a surface tentacle feeder, Melinna oculata. These species appeared to favor the mixed and sandy sediments of Site-Group III and IV, near the San Pedro Sea Valley.

The shallow areas, Site-Groups I and II, both with sandy, light colored sediments are characterized by Species-Groups 10 and 1, respectively. Species-Group 10 includes the deposit engulfing polychaete Armandia bioculata, which is the only species other than the members of Species-Group 5 that achieves any noticeable abundance in the extreme outfall area (Site-Group XII). This polychaete was also reported by Smith (1974) to be the dominant species around a moderately large (150 million gallons per day), shallow (20 m) outfall in nearby San Pedro Bay prior to but not after the termination of discharge from that outfall. In addition to the above, semioutfall Species-Group 3 accounts for approximately 33 percent of the organisms in both of these site-groups. Altogether, this information suggests that these shallow site-groups are, to some degree, under the influence of the Palos Verdes deep-water outfalls.

DISCUSSION

The present study was undertaken to evaluate the usefulness of a hierarchical classification procedure in describing the effect of a major municipal outfall system on the benthic infauna. The general picture obtained is one of low species numbers and extreme dominance by a small group of widely occurring polychaetes, probably deposit engulfers, in what may be considered the center of the area of outfall impact (Site-Group XII). This group of organisms includes Shistomeringos longicornis and Capitella capitata, both of which are often considered indicators of stressed conditions. It is evident, however, that the mere presence of these species does not indicate a highly stressed condition. This species-group is

found in comparable levels at other, more species-enriched sites farther from the immediate outfall area, suggesting that these species are indicative of high stress only when they are very dominant.

As the distance from the center of impact increases, the number of species and variety of feeding types increases. The remaining nine species-groups reach their peak abundances at sites farther from the outfall. From Figure 9, Part b, it can be seen that a good proportion of most of the species-groups are found in Site-Group IX, which is located downcurrent but relatively distant from the waste discharge. This apparent enhancement of the fauna is possibly due to the direct or indirect utilization of some components of the sewage effluent. Most of the species in this area are deposit feeders. Such an effect is probably not found closer to the point of discharge due to higher levels of toxic materials and/or lower levels of dissolved oxygen in this area.

Sediment stability may also be an important factor in regulating the number of species and feeding types in a given area. The shifting of the light, flocculant sediments surrounding these outfalls would make survival difficult for animals not adapted to frequent burying. Rhoads and Young (1970) have shown this to be an important factor in limiting the number of species in other types of unstable bottoms. Furthermore, it was shown that the remaining species were exclusively deposit feeders, which are evidently better adapted for this type of environment. It is interesting to note that, in the study by Jones (1973) on kelp holdfasts, suspension feeders predominated in the area of sewage discharge. The elevated position of the holdfasts would presumably decrease the possibility of being buried and would expose the animals to more reasonable concentrations of particulate matter.

The value of the present procedure lies in its ability to sort through large matrices of meristic data, define the best discontinuities between entities (sites or species) in a nearly continuous system based on the dissimilarity of the distributions of their attributes (species or sites), and organize the results in a manner that

readily lends itself to ecological interpretation.

There are two basically dissimilar biological views on how to describe the effects of pollutants on the fauna and flora of marine ecosystems. The most widely used of these approaches employs the concept of "indicator species." Reish (1970) reviews this concept and presents results of its application and related research. This approach is founded on the principle that pollutants will kill varying proportions of the naturally occurring biota, depending on the quantity and toxicity of the pollutants. The species that survive and often increase in numerical abundance under these stressful conditions and reduced competition are cited as indicators of the prevailing environment. Following this approach, polluted areas are subjectively subdivided into three or four zones (healthy, semipolluted, polluted, and no life) based on the presence of indicator species, knowledge of some abiotic factors, and experience. Grassle and Grassle (1974) have discussed and defined the characteristics of indicator species and aptly termed them opportunistic species. Two basic characteristics of a good indicator or opportunistic species are that it is (1) widely distributed--ideally, cosmopolitan--and (2) predictable in its response to environmental disturbances.

A second conceptual view is that expressed by Stirn (1970, 1971), who advocates a community approach to the assessment of the effects of pollution. Generally, this approach involves the measurement of some aspect of community structure or organization, such as diversity indices, that is not dependent upon the presence or absence of particular species.

Stirn contends that although many large regions, like the Mediterranean Sea, appear to be faunistically homogeneous, they are in fact comprised of a number of biogeographically and hydrographically distinct ecosystems, where most species that could qualify as pollution indicators are indigenous to these ecosystems. Stirn supports this point of view by showing that only 3 of 107 species recorded for a number of polluted communities in the faunistically rather cognate Eastern Atlantic/Mediterranean area were common to most, but not all, of these communities. He feels that to attempt to assess the

impact of pollutants based on the presence or absence of a limited number of widely distributed indicator species presents a real chance of reaching erroneous conclusions.

In general, the investigators who employ multivariate numerical procedures (e.g., classification, ordination, etc.) also advocate the community approach. However, only a few of these researchers in addition to ourselves (e.g., Roback et al. 1969; Moore 1973; Smith 1973; Buchanan and Lighthart 1973; and Smith 1974), have applied these procedures in pollution studies.

Our method overlaps and complements the two approaches presented earlier. We approach the problem by considering a major proportion of the species (i.e., the community) with respect to numerical abundance, regardless of their identity. This mass of data is then condensed into workable groups (site- and species-groups) that complement the zones of indicator species defined in other studies but which we believe are easier to work with and to interpret. Also none of the original information is lost, as it is with statistical methods, such as diversity indices, that effectively obscure the behavior of the contributing components (Levins 1966).

Another benefit to be derived from these classification procedures is the identification and/or substantiation of potential indicator species in areas where this information is sparse or does not exist. For example, it is apparent from Figure 9, Part c, that some species-groups contribute substantially more to certain site-groups than others, e.g., Species-Group 5 in pollution Site-Groups XI and XII, Species-Group 3 in semipollution Site-Groups VII and IX, and Species-Group 6 in nonoutfall Site-Group V. However, more recent experience in this same area by several of the authors shows that some of these species are transient and may shift from one site-group to another or disappear entirely. On the other hand, certain species are quite consistently found under similar environmental conditions. This experience demonstrates a potential weakness in the indicator species approach and emphasizes the need for repeated studies through time.

In addition to the classification of sites and species and

the comparison of these results with the distribution of abiotic factors, we have considered the distribution of the fauna in terms of feeding types or habits. Reish (1970) recommended this procedure as criteria for evaluating the effects of pollutants on marine communities; however, the approach has received only limited attention to date (see Jones 1973 for an example). Although we have not made full use of this strategy, it is apparent that various feeding types are distributed along definite spatial gradients relative to the outfalls.

ACKNOWLEDGMENTS

This paper is Contribution 30 of the Southern California Coastal Water Research Project, El Segundo, California. Special thanks are due to Mr. Jack Q. Word for clarification of taxonomic problems and to Ms. Robin A. Simpson for editorial work. This research was supported in part by the U.S. Environmental Protection Agency under Grant R 801-152.

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Appendix A. Species used in preliminary analyses with allocated numbers, frequency of occurrence, and abundance.

Species	Taxonomic Group	Allocated Number Ori- ginal Final	No. of Sites of Occurrence	Mean No. of Indiv. / Occupied Site
<u>Shistomeringos longicornis</u> (Ehlers)*	Polychaeta, Dorvilleidae	1 1	69	85.1
<u>Parvilucina tenuisculpta</u> Carpenter	Pelecypoda, Lucinidae	2 2	67	59.3
<u>Nereis</u> nr. <u>procera</u>	Polychaeta, Nereidae	3 3	48	3.8
<u>Ophiodromus</u> <u>pugettensis</u> (Johnson)	Polychaeta, Hesionidae	4 4	46**	4.0
<u>Tharyx</u> sp.	Polychaeta, Cirratulidae	5 5	47	86.5
<u>Capitita ambiseta</u> Hartman	Polychaeta, Capitellidae	6 6	46	25.7
<u>Caulleriella alata</u>	Polychaeta, Cirratulidae	7 7	46	40.7
<u>Capitella capitata</u> (Fabricius)	Polychaeta, Capitellidae	8 8	43	16.9
<u>Telepsavus costarum</u> Claparède	Polychaeta, Chaetopteridae	9 9	40	5.9
<u>Spiophanes fimbriata</u> Moore	Polychaeta, Spionidae	10 10	31	4.6
<u>Notomastus tenuis</u> Moore	Polychaeta, Capitellidae	11 11	31	6.3
<u>Nemertean</u> "small pink"	Nemertea	12 12	27	6.3
<u>Prionospio malmgreni</u> Claparède	Polychaeta, Spionidae	13 13	24**	2.5
<u>Tellina carpenteri</u> Dall	Pelecypoda, Tellinidae	14 14	25	2.8
<u>Ampharetē labrops</u> Hartman	Polychaeta, Ampharetidae	15 15	24	3.6
<u>Macoma</u> sp.	Pelecypoda, Tellinidae	16 16	24	25.0
<u>Nassarius mendicus</u> (Gould)	Gastropoda, Nassariidae	17 17	22	5.2

*Actually two species (S. longicornis and an unidentified Dorvilleidae) which were not systematically separated at the time the data were collected.

**Misplaced due to errors in the data as originally presented.

Appendix A continued

Species	Taxonomic Group	Allocated Number	No. of Sites of Occurrence	Mean No. of Indiv. / Occupied Site
<u>Lumbrineris japonica</u> (Marenzeller)	Polychaeta, Lumbrineridae	18	18	2.8
<u>Axinopsida</u> sp.	Pelecypoda, Thyasiridae	19	19	12.2
<u>Pectinaria californiensis</u> Hartman	Polychaeta, Pectinariidae	20	17	5.3
<u>Rictaxis punctocoelatus</u> (Carpenter)	Gastropoda, Acteonidae	21	17	2.4
<u>Lucinoma annulata</u> (Reeve)	Pelecypoda, Lucinidae	22	17	2.8
<u>Cylichna</u> sp.*	Gastropoda, Scaphandridae	23	17	1.5
<u>Periploma</u> sp.	Pelecypoda, Periplomatidae	24	16	3.2
<u>Glycera branchiopoda</u> Moore	Polychaeta, Glyceridae	25	14	1.6
<u>Nassarius perpinguis</u> (Hinds)	Gastropoda, Nassariidae	26	14	3.6
<u>Nemertea "brown"</u>	Nemertea	27	14	1.4
<u>Prionospio pinnata</u> Ehlers	Polychaeta, Spionidae	28	13	1.2
<u>Solemya panamensis</u> Dall	Pelecypoda, Solemyidae	29	13	2.0
<u>Chloeia entypa</u> Chamberlin	Polychaeta, Amphinomididae	30	11**	3.3
<u>Tellina modesta</u> (Carpenter)	Pelecypoda, Tellinidae	31	12	2.5
<u>Cerebratulus</u> sp.	Nemertea	32	10	1.3
<u>Lumbrineris minima</u> Hartman	Polychaeta, Lumbrineridae	33	9	9.7
<u>Cossura candida</u> Hartman	Polychaeta, Cossuridae	34	9	5.2
<u>Gyptis arenicola</u> glabra Hartman	Polychaeta, Hesionidae	35	9	2.7

*May be partially another genus.

**Misplaced due to errors in the data as originally presented.

Appendix A continued

Species	Taxonomic Group	Allocated Number	No. of Sites of Occurrence	Mean No. of Indiv./ Occupied Site
<u>Pherusa papillata</u> Hartman	Polychaeta, Flabelligeridae	36	9	1.9
<u>Chone sp.</u>	Polychaeta, Sabellidae	37	9	1.6
<u>Olivella baetica</u> Carpenter	Gastropoda, Olividae	38	9	4.7
<u>Amphisamytha bioculata</u> (Moore)	Polychaeta, Ampharetidae	39	7	5.1
<u>Luciniscia nuttalli</u> Conrad	Pelecypoda, Lucinidae	40	7	1.6
<u>Paraphoxus obtusidens</u> (Alderman)	Amphipoda	41	7	3.6
<u>Spiophanes bombyx</u> (Claparède)	Polychaeta, Spionidae	42	6	1.2
<u>Platynereis bicanaliculata</u> (Bourd)	Polychaeta, Nereidae	43	6	2.0
<u>Chaetozone corona</u> Berkeley and Berkeley	Polychaeta, Cirratulidae	44	6	2.7
<u>Melinna oculata</u> Hartman	Polychaeta, Ampharetidae	45	6	3.2
<u>Pitar newcombianus</u> (Gabb)	Pelecypoda, Veneridae	46	6	2.5
<u>Conus californicus</u> Reeve	Gastropoda, Conidae	47	6	1.5
<u>Cooperella sp.</u>	Pelecypoda, Cooperellidae	48	6	1.3
<u>Armandia bioculata</u> Hartman	Polychaeta, Opheliidae	49	5	3.8
<u>Magelona sacculata</u> Hartman	Polychaeta, Magelonidae	50	4	5.0
<u>Pista cristata</u> (Müller)	Polychaeta, Terebellidae	51	4	4.0
<u>Caecum crebicinctum</u> (Carpenter)	Gastropoda, Caecidae	52	4	14.0
<u>Euchone arenae</u> Hartman	Polychaeta, Sabellidae	53	3	3.0

Appendix A continued

Species	Taxonomic Group	Allocated Number Ori- ginal Final	No. of Sites of Occur- rence	Mean No. of Indiv./ Occupied Site
<u>Dendroaster excentricus</u> (Eschscholtz)	Echinodermata, Echinoidea	54	3	5.3
<u>Boccardia basilaria</u> (Hartman)	Polychaeta, Spionidae	55	2	5.0
<u>Tellina idae</u> Dall	Pelecypoda, Tellinidae	56	2	3.0
<u>Aorides columbiae</u> Walker	Amphipoda	57	2	3.5
<u>Diastylopsis tenuis</u> Zimmer	Cumacea	58	2	6.0
<u>Lumbrineris erecta</u> (Moore)	Polychaeta, Lumbrineridae	59	5	1.8
<u>Raricirrus maculata</u> Hartman	Polychaeta, Cirratulidae	60	5	1.6
<u>Asabellides lineata</u> Berkeley and Berkeley	Polychaeta, Ampharetidae	61	5	2.6
<u>Eumida bifoliata</u> (Moore)	Polychaeta, Phyllodocidae	62	5	1.2
<u>Marphysa disjuncta</u> Hartman	Polychaeta, Eunicidae	63	5	1.2
<u>Ampelisca cristata</u> Holmes	Amphipoda	64	5	1.0
<u>Nemertean "small white"</u> <u>Photis brevipes</u> Shoemaker	Nemertea Amphipoda	65 66	5 5	1.3 1.3
		40		

Appendix B. Incompletely identified species used in analyses with allocated number, frequency of occurrence and abundance.

Species	Taxonomic Group	Allocated Number		No. of Sites of Occurrence	Mean No. of Individ. Occupied Site
		Additional	Final		
Juvenile bivalves	Pelecypoda	67		23	9.9
Pelecypod sp.	Pelecypoda	68		20	1.9
Lumbrineris sp.	Polychaeta, Lumbrineridae	69		20	1.8
Tellina sp.	Pelecypoda, Tellinidae	70		16	2.4
Nemertean "Large white"	Nemertea	71		16	2.0
Pagurid	Decapoda, Paguridae	72		13	2.0
Photis sp.	Amphipoda	73	41	11	2.6
Crepidula sp.	Gastropoda, Calyptraeidae	74	42	8	2.0
Polydora sp.	Polychaeta, Spionidae	75		8	1.3
Glycera sp.	Polychaeta, Glyceridae	76		8	1.0
Pteropoda sp.	Gastropoda	77		7	1.9
Trophonopsis sp.	Gastropoda, Muricidae	78		7	8.1
Ostracod unident. spp.	Ostracoda	79		7	8.1
Tanaids	Tanaidacea	80		6	1.0
Anaitides sp.	Polychaeta, Phyllodocidae	81		6	1.3
Nereis sp.	Polychaeta, Nereidae	82		6	1.7
Oligochaete	Oligochaeta	83		6	1.3
Crenella sp.	Pelecypoda, Mytilidae	84	43	5	8.6

Appendix C. Additional, less ubiquitous species used in analyses with allocated numbers, frequency of occurrence, and abundance.

Species	Taxonomic Group	Allocated Number		No. of Sites of Occurrence	Mean No. of Individ. Occupied Site
		Original	Final		
Cumacean (unident.)	Cumacea	85		4	3.5
Paraphoxus epistomus	Amphipoda	86	44	4	2.5
(Shoemaker)					
Prionospio pygmaeus	Polychaeta, Spionidae	87	45	4	1.2
Hartman					