CLUSTER ANALYSIS OF BENTHIC COMMUNITIES

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Ecologists have used many parameters as indicators that important properties of a biological community have been altered by physical or chemical factors. Changes in trophic structure, species diversity, community biomass, abundance of dominant species, and productivity are frequently encountered indices. A number of these analyses have been used on data from the Whites Point area, and all reveal essentially the same general pattern: A "depressed" area immediately around the outfall pipes, surrounded by an enhanced area, and finally a return to more "normal" conditions. We need to identify the analysis procedures that will enable us to most efficiently deal with the large quantities of biological data collected in this and other outfall areas and that will give us the most specific information about the health of the area in relation to the outfalls. Other related problems are what type of sampling grid to use, how frequently to sample, and how many replicate samples are needed.

The work described here was undertaken as part of a project sponsored by the Environmental Protection Agency CGrant R801152) to examine and develop statistical procedures to aid in interpreting man's impact on marine communities. The purpose of the procedures is (1) to organize large amounts of biological data into a workable number of ecologically meaningful units and (2) to define the relationships of these biological units to the physical and chemical environment.

METHODS

In developing and testing procedures, we have focused our attention on the benthic macrofauna (invertebrates living in and on the sediments) of the Palos Verdes shelf in the vicinity of the Whites Point outfall system. We used data from three surveys conducted by the Los Angeles County Sanitation Districts in August 1972, January February 1973, and August September 1973. In each survey, four benthic grab samples were taken at each of 40 sites on a rectalinear sampling grid that covered four distinct depths (Figure 1).

The organisms in each sample were identified and counted, and the sediments were evaluated for color and coarseness and the presence of hydrogen sulfide odor and vegetative matter. In the summer 1973 survey, special sediment samples were also collected at each site and analyzed for particle size and percent organic nitrogen, DDT, mercury, and sulfide concentration. The organism identification and the quantitative analyses of physical and chemical factors were made by Sanitation District personnel.

The biological results of the three surveys are summarized in Table 1. The table also shows the results of the first step in the data simplification procedure reducing the number of species to be considered in the analysis. Overall, about 16 percent of the species in each survey accounted for over 95 percent of the organisms present. And, although the number of species and organisms per site was different in each survey, a general pattern of species distribution seemed to prevail. Thus we eliminated species that could contribute little to this general pattern from the analysis, deleting those that occurred in only a few samples, at only one site, or in low numbers. The results, a set of "ecologically significant" species for each survey (last column, Table 1), account for well over 95 percent of the individual organisms taken in the surveys.

The next step was to apply two analytical procedures to the data on the distributions of the key species. First an index of association (the Bray Curtis dissimilarity measure) was used to establish the degree of similarity of the species compositions (species present and abundances of each) at the different sites. Each site was compared to each of the remaining 39 and given a rating, ranging from 0.0 for complete similarity (all attributes with identical values) to 1.0 for complete dissimilarity (no attributes in common).

Next, a sorting strategy was employed: In this procedure, the sites that are defined to be most similar by the index of association were joined. The resulting "clusters" of similar sites were then compared and grouped again according to similarity. This procedure was repeated again and again at higher levels, with the degree of similarity among the sites in groups decreasing at each higher level, until several distinct major groupings emerged. We used a technique called group average sorting, where the similarity between two groups is calculated as the average of all possible similarities between the two groups.

The sorting results were displayed in dendograms (or tree diagrams) such as that shown in Figure 2. The analyses were accomplished with computer programs written by lIr. R.W. Smith of the Allan Hancock Foundation.

At this point, we chose site groups to work with from the dendograms: The choice was based on two criteria we wanted the sites within a group to have a high degree of similarity, yet we wanted to have a fairly small number of groups so that, when they are plotted on a map, as in Figure 3, any general patterns will be apparent.

CHANGES IN SPECIES COMPOSITIONS WITH TIME

The cluster analysis procedure and the resulting dendograms and plots of site groups yield a great deal of diverse information on the biological communities. One area that we are particularly concerned with is changes that occur with time.

When we compared the cluster analyses for each of the three surveys, we found a striking constancy in the patterns of species distributions through time. However, there were some exceptions. For example, in both of the summer surveys, Site Group I (the group closest to the outfalls) was least similar to all other groups and contained three sites. In the winter survey, Site Group I was much more similar to other site groups and contained only two sites. The reason for this change was an offshore shift in the distribution of a few of the more abundant species, the most significant of which is the polychaete worm, *Capitella capitata*, which is considered to be an "indicator" of natural as well as manmade stress. We do not completely understand the reason for this shift at this time. In general, the more abundant species were consistently found in the same areas and depth zones, indicating that the physical and chemical factors to which the majority of these species are responding must be relatively stable through time.

Another type of information to be gained by these analyses is an indication of changes in the biological communities at a particular site. In the first summer survey, Site Group VI (located just southeast of the outfalls) was fairly similar to other site groups at shallow and intermediate depths. But in the second and third surveys, this site group showed stronger affinities to site groups located at deepest depths. This shift in affinities may reflect a change in the direction of movement of material originating from the outfalls.

THE RELATIONSHIP OF SPECIES COMPOSITIONS TO PHYSICAL AND CHEMICAL FACTORS

To evaluate the effects of physical and chemical factors on the communities, we performed a cluster analysis on the data from the summer 1973 survey, converting the raw data on species abundance to relative (rather than absolute) abundance. The site group dendogram produced by this modified procedure (which is slightly different from the one shown in Figure 2) is shown in Figure 4, along with a table giving the physical and chemical characteristics of each site group. The plot of the site groups is shown in Figure 6.

At each of the four depths sampled, we found an "outfall" and a "nonoutfall" area; the outfall area (black symbols on Figure 6) is characterized by such factors as higher nitrogen, more particulate matter, finer sediments, and higher hydrogen sulfide, DDT, and mercury than the nonout fall areas. From the dendogram, it appears that the differences between the outfall and nonoutfall areas are least extreme in the shallowest depths. The well defined patterns indicate that changes in depth and various outfall related factors are responsible for the similarities and dissimilarities in the species compositions at various sites and are causing changes in species abundance.

A similar analysis was performed using the physical/ chemical characteristics of each site instead of species abundance values. We hypothesized that the organisms are not equally sensitive to changes of each physical/chemical factor, and some factors were therefore weighted more heavily than others. The analysis giving results most closely resembling those obtained with the species data is shown in the dendogram of Figure 5 and the site group map of Figure 7. In this analysis, the physical/chemical factors received the following weights: Depth, 2; sediment coarseness, 2i organic nitrogen, 1; vegetative matter, 2 1/2; hydrogen sulfide, 1; mercury, 1; and DDT, 2.

Like the species generated analysis, the physical/ chemical analysis defined outfall areas and nonoutfall areas. The outfall areas (black symbols on Figure 7) were less clearly separated by depth, but in both cases, the outfall areas at the three greater depths were more dissimilar from sites in other areas. In the physical/chemical analysis, the outfall area was enlarged by the inclusion of a few sites to the southeast of the outfall. In the speciesgenerated analysis, the 60 and 150 m nonoutfall groups formed clusters, but in the physical/chemical analysis, 150 and 300 m groups joined.

The differences between the species and physical/ chemical analyses results may be due to a number of factors. The abundance of a species at a given site is more a reflection of past environmental conditions, while measurements of physical and chemical factors may be more of an indication of present conditions. A physical or chemical factor may cause different responses under different conditions, and these responses may not be independent of each other (for example, a large variation in organic nitrogen may have less of an effect on the communities when DDT is very high). Or some of the physical and chemical factors that affect a species' distribution may not have been measured and included in this analysis (for example, the effect attributed to DDT may actually be due to some unknown factor or factors with a distribution similar to that of DDT).

TESTS OF THE PROCEDURES

The cluster analysis procedure is concerned with similarities, and thus species that occur infrequently and in low abundance, contribute little to the general pattern of the results and were eliminated from consideration. To test our procedure, we arbitrarily reduced the 73 species used for analyzing the summer 1973 survey to 45 and 22 species and regenerated the site groups.

The results based on 45 species were essentially identical to the 73 species analysis. But the 22 species analysis produced a substantially different dendogram and significant shifts of sites between groups. The site groups lost or poorly defined were those closest to the outfalls. Outfall areas have been characterized in the past by a few "indicator" species occurring in high abundance. For the Palos Verdes shelf, this approach is valid: However, the results af this analysis indicate that it is equally valid to define these areas by the absence of less dominant species that occur in adjacent, less stressed areas.

We tested the replicability of the four samples per site by generating site clusters for the 160 replicate samples taken in each survey. The criterion for accepting all four replicates was that at least three must occur in the same subgroup and join at low levels (high similarity) in the dendogram. This criterion was satisfied in all cases; in the majority of cases, all four replicates were found together. Thus' all four replicates from each site were retained, and an average value was used in the analysis.

In addition to generating site groups, we also analyzed these data for species groups. The results are not final at this point, but it is obvious that the species are not grouped into unique associations or communities. While groups of species are associated with specific site groups, the distributions of these species overlap to such a degree that unique, persistent groups are difficult to define.

These results were not surprising: There are few sharp boundaries on continental shelves, and as the physical regimes grade into one another, so do the biological communities associated with these regimes. The fact that cluster analysis enables us to define distinct biological areas grading away from a source of stress is significant.

We intent to continue evaluating and perfecting the cluster analysis procedures by applying them to data from a variety of different areas. Criteria will be established to determine the amount and quality of data required to produce valid results. The detailed findings of this study will appear in a report to the Environmental Protection Agency and in a scientific journal.

FIGURES

Figure 1.
Benthic sampling sites on the Palos Verdes shelf

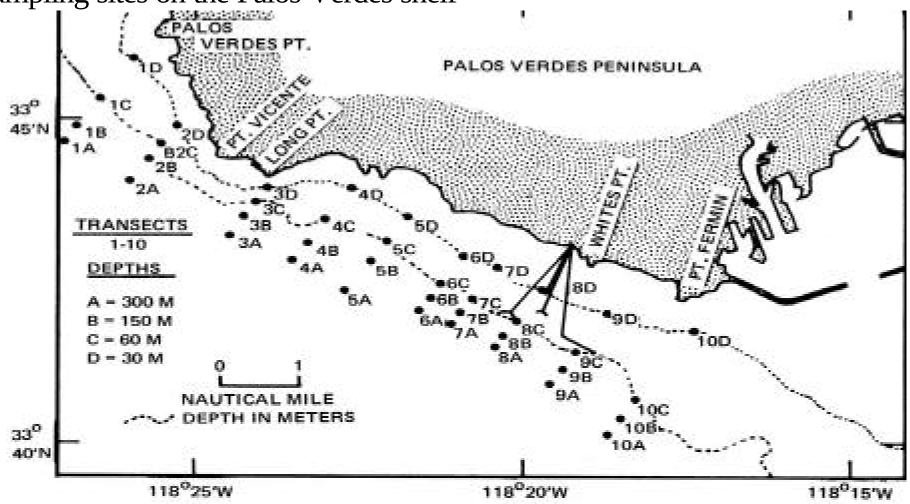


Figure 2.
Dendogram of the site groups in the summer 1973 survey

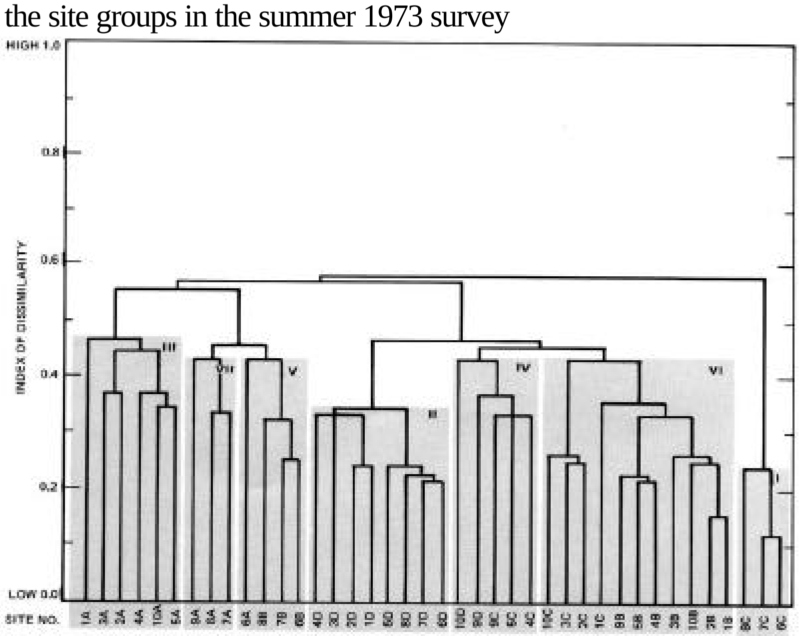


Figure 3.
Site groups in the summer 1973 survey

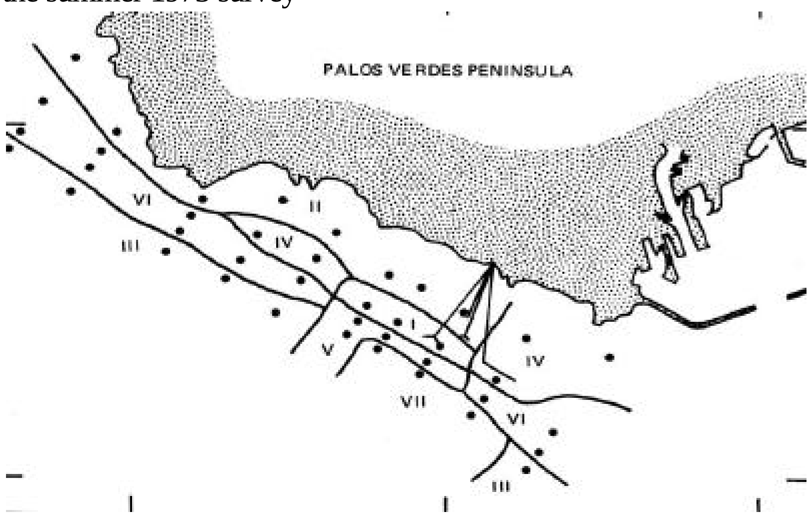
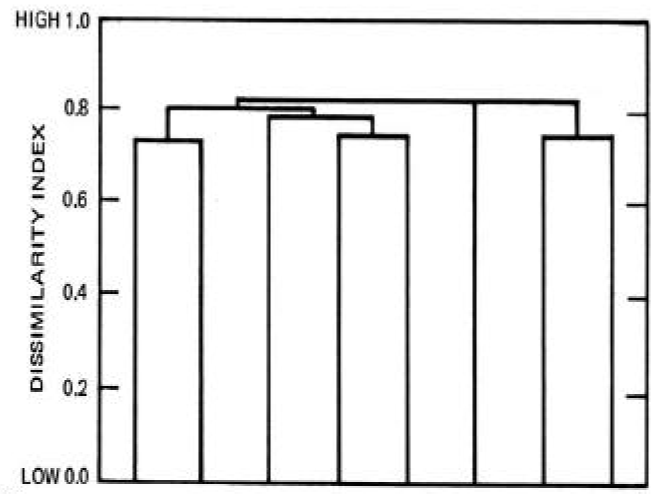


Figure 4.
Simplified dendogram generated using species abundance data for summer 1973 and table of general physical/chemical characteristics of the sites in each site group tH= high, M= medium, L = low, C= coarse, F = fine)



SITE-GROUP NO.	8	7	6	5	4	3	2	1
SYMBOL ON FIGURE 6	△	▲	◊	◘	○	◆	●	■
SITES	1D 2D 3D 4D 10D	5D 6D 7D 8D 9D	1A 9A 2A 10A 3A 4A 5A	2C 9C 3C 10C 4C 5C	1B 9B 2B 10B 3B 1C 4B 5B	6A 7A 8A	6B 7B 8B	6C 7C 8C
% ORGANIC NITROGEN	L	L	L	H & M	M & L	M	H	H
VEGETATIVE MATTER	L	H	L	L	L	M	H	H
SEDIMENT TEXTURE	C	C	M	F	M & F	F	F	F
HYDROGEN SULFIDE	L	M & L	L	M & L	L	M & L	M & L	H & M
DDT	L	M & L	L	H & M	M & L	M	H	H
MERCURY	L	M & L	L	H & M	H,M,L	L	H	H

Figure 5.
Simplified dendogram generated using physical/chemical data taken in the summer 1973 survey

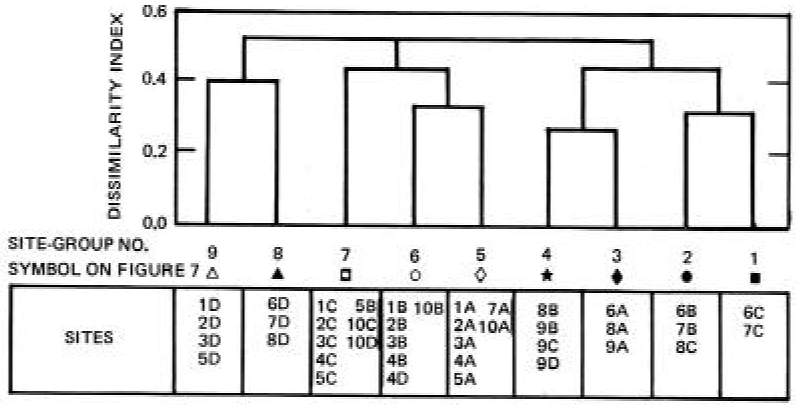


Figure 6.
Site groups generated using species abundance data from the summer 1973 survey. Black symbols define "outfall " areas

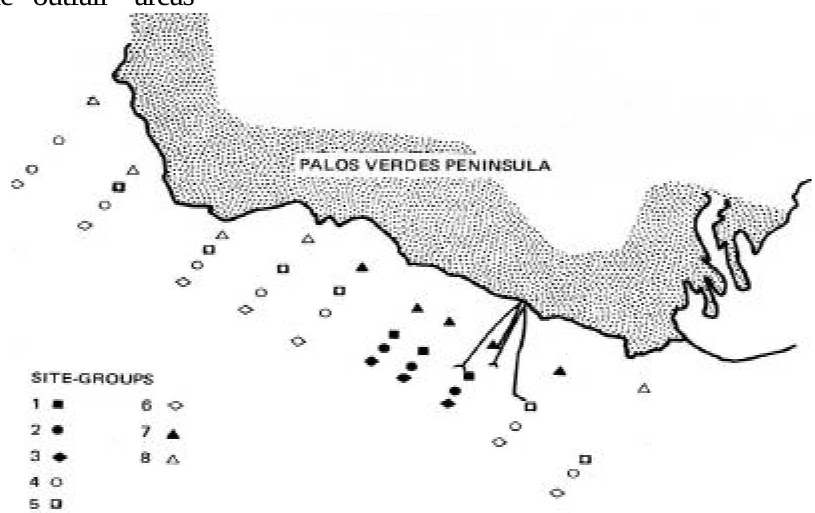
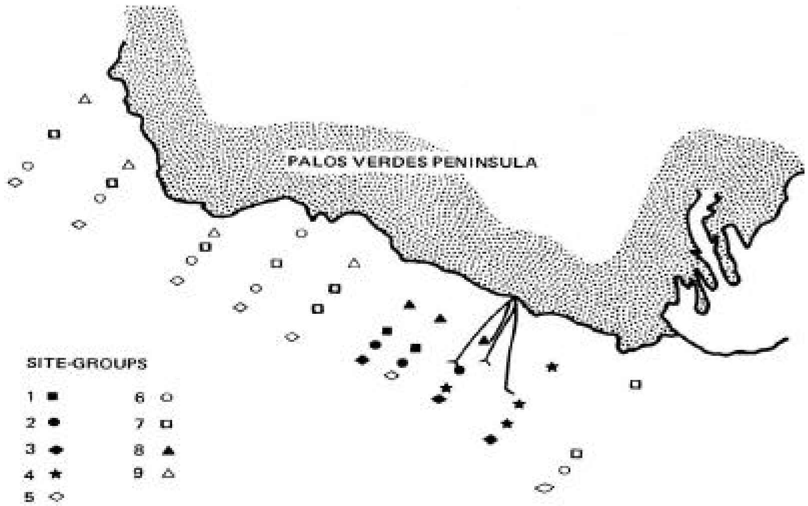


Figure 7.
Site groups generated using physical/ chemical data collected in the summer 1973 survey. Black symbols def ne "outfall " area



TABLES

Table 1.
Biological results of the Whites Point benthic survey, 1972-73

	Total No. of Organisms	No. of Species/Site	No. of Species	"Significant" Species
Summer 1972	28,616	9-75	223	72
Winter 1973	22,340	11-82	230	67
Summer 1973	34,538	14-100	254	73