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NUMERICAL ANALYSIS PF DATA ON A BENTHIC COMMUNITY

Large quantities of physical, chemical, and biological data are collected annually by monitoring groups in areas where major municipal outfalls discharge wastes. Typically these data are compiled and submitted to overseeing agencies, where they are reviewed. Potentially valuable information contained in these data is not always revealed because methods for analyzing the data are unknown or unavailable.

In the research described here, we are attempting to identify and apply multivariate numerical techniques for efficiently reducing and analyzing these masses of data. We are particularly interested in identifying procedures that will shed light on potential cause and effect relationships between changes in the number of animals present at a site and their physical/chemical (abiotic) environment.

In last year's Annual Report, we presented examples of results obtained using a classification technique (hierarchial cluster analysis). Applying this technique to data collected around an outfall, we effectively defined patterns in the spatial distributions of benthic animals. However, efforts to quantitatively associate the biological (biotic) results of cluster analysis with abiotic factors in the environment have, until now, proved less than satisfactory.

This year, we have applied a type of ordination, Gower's Principal Coordinant Analyses, that more effectively satisfies this goal. Ordination and classification are complementary although conceptually different procedures. Our clustering methods classify the stations or species, whichever is being considered, into discrete groupings; ordination arranges the data along a continuum or set of continua. Here we present examples and compare the types of results obtained from these techniques.

METHODS AND GENERAL RESULTS

In summer 1973, the Los Angeles County Sanitation Districts conducted a benthic survey at 40 sites off Palos Verdes Peninsula; in the present analysis, we used the data from 10 of those sites (Sites 11 through 20) located along the 60-m depth contour (Figure 1). The original biological data on 34,538 infaunal organisms (animals living in the sediments) and 254 taxa were reduced to 73 "significant species," which represented more than 96 percent of the total organisms taken. At each site, measurements of total DDT, total mercury, sulfide and redox potentials, percent organic nitrogen, depth, descriptive sediment coarseness (DSC), and standard quantitative sediment grain-size parameters were made. Mercury was the only metal analyzed; however, previous experience with various metals from the Palos Verdes shelf shows that the distributions of all heavy metals are highly correlated with one another and also with total DDT and percent organic nitrogen. All of the 13 abiotic measurements (except depth, which is constant) are considered in conjunction with the ordination analysis.

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The presence of two active outfalls that discharge 380 million gallons of treated effluent per day between Sites 17 and 19 is reflected in the distributions of total species, total individual organisms, and total biomass (weight of organisms) along this depth contour (Figure 2). The asymmetrical distribution of these data in the immediate outfall area is probably due to the general northwestward flow of bottom currents. It is apparent from Figure 2 that the number of species per site is greatly reduced at stations near the outfalls. Furthermore, biomass appears to be slightly depressed at Stations 16, 17, and 18 compared to Station 11 (the station farthest from the outfalls) and to be enhanced at stations on either side of the outfall area.

The distribution of numbers of individuals per station, on the other hand, presents a more complex picture. For example, the number of individuals is very high at Stations 12 and 13 away from the outfalls; organisms are also very abundant at Stations 16, 17, and 18 in the immediate vicinity of the outfalls. Furthermore, these two areas are separated by stations with relatively low numbers of animals. Although we could provide a subjective evaluation of these data, we prefer to stand on the quantitative statements that follow.

CLUSTER ANALYSIS (HIERARCHIAL CLASSIFICATION)

The classification of these ten sites, based on the similarity of their biological composition, produced three distinct site-groups:

- Site-Group I, containing Stations 11, 12, 13, and 20.
- Site-Group II, containing Stations 14, 15, and 19.
- Site-Group III, containing Stations 16, 17, and 18.

The dendrogram for these groups (Figure 3) indicates that the faunal compositions of the stations comprising Site-Group III are quite different from that of the other two Site-Groups. It is also apparent that the areal distribution of these site-groups, as indicated on Figure 1, reflects the general distribution of animals at this depth (Figure 2).

Classification of species for these stations resulted in four distinct species-groups. The distributions of these groups are shown in Figure 4, where the numbers of individuals per species-group per station are plotted. Species-Group A is a rather ubiquitous group dominated by two small clams, *Macoma carlottensis* and *Tettina carpenteri*, and a polychaete worm, Glycera *branchiopoda*. Although this group of species is more evenly distributed along the contour than the other groups, it shows a slight avoidance of the outfall area. The animals in Species-Group B, which comprises over 47 percent of the animals at this depth, show a strong preference for areas away from the outfalls and reach peak abundance in Site-Group I. This group is also dominated by two small clams, *Parvilucina tenuisculpta* and *Axinopsida* sp., and a polychaete worm, *Capitita ambiseta*.

Species-Group C is dominated by a large echiuroid, *Listriolobus pelodes*, and reaches peak abundance in the stations of Site-Group II. These stations, which are located on either side of the outfall area, appear to be zones of biological transition. In addition to the appearance of Species-Group C, the abundance curves of the two dominant Species-Groups (B and D) cross in the areas defined by Site-Group II. If the species comprising Species-Groups B and D are better adapted to different abiotic conditions, then the areas defined by Site-Group II may also represent regions of significant abiotic transition. The fact that *L. pelodes* tends to disappear in Site-Groups I and III also supports the idea of a set of unique biotic/abiotic conditions at the Site-Group II stations. The moderately high biomass found at these stations is almost entirely accounted for by *L. pelodes*, and the reason for the very low numbers of animals at these stations may be related to the feeding behavior of this large echiuroid (the animal engulfs whole sediment particles, which probably contain the larvae and small animals of other species).

Species-Group D, which is most abundant in the immediate outfall area (Site-Group III), accounts for more than 45 percent of the animals at this depth and is dominated by three polychaete worms, *Capitella capitata*, *Shistomeringos longicornis*, and *Dorvilleidae* sp. 1. When these three species, especially *C. capitata*, are excessively abundant, as they are in Site-Group III, they can be considered indi-cators of severe environmental stress. This situation seems only to occur when an environment is disturbed to such a degree that other species are greatly reduced in numbers or completely eliminated.

ORDINATION (GOWER'S PRINCIPAL COORDINANT ANALYSIS)

We have applied this technique to define mathematically independent trends, called axes, in the spatial distributions of the number of animals per species. Because it is presumed that each axis or combination of axes is related to a biological gradient, the collections of animals from each station can be evaluated against and positioned along each of these gradients. The results of these comparisons are numerical scores that establish the order of the stations on each axis.

An advantage of this technique over classification is that the numerical scores for each station relative to each axis can be used in additional analyses. We have used these scores in regression analyses to identify the species varying in some nonrandom, systematic manner along each axis. We have also used this same procedure to identify abiotic factors that are significantly correlated with the axes and, therefore, possibly responsible for the distributions of the species that are significantly correlated with the axes.

Each separate axis can be displayed with its stations as a single gradient, or a pair of axes can be combined as independent coordinates (as in Figure 5), with the stations displayed in two-dimensional space. This procedure can be extended to a third dimension if it helps clarify relationships.

The present analysis revealed two major biological axes that account for 78 percent of the total variance (biological information) contained in these data. These two gradients are shown as independent axes on Figure 5. Axis I is by far the most important and accounts for over 61 percent of the total information. The circled numbers on Figure 5 show the positions of the stations relative to these two axes, and the notations at the ends of Axis I indicate the distribution of abiotic parameters that are significantly correlated with the station scores along this axis. No abiotic parameters exhibited significant linear correlations with Axis II.

The species and abiotic parameters that are significantly correlated with these axes are listed in Table 1, along with the species-group affiliation of each species. Species and abiotics with positive correlations are most abundant or highest at the stations located near the ends of Axis I or Axis II that are indicated as positive (+). The reverse is true for species and abiotics with negative (-) correlations.

The four sites to the extreme right on Figure 5 correspond to the sites in Site-Group I and are characterized by species from Species-Groups A and B. The three sites to the extreme left correspond with the sites of Site-Group III and are characterized solely by species from Species-Group D. These two groups of stations form the poles of Axis I, and the species and abiotics listed in Table 1 under Axis I represent the significant biotic and abiotic differences between these areas. The sites in the center of Figure*5, along Axis II, correspond with stations comprising Site-Group II, and the species listed in Table 4 under Axis II correspond with the species comprising Species-Group C.

The species comprising Species-Group D are apparently tolerant of conditions that are toxic or otherwise reduce the numbers or presence of other species. The results suggest that free sulfide, total DDT, and organic nitrogen are the most important abiotic factors affecting the fauna along this depth contour. These results must be interpreted with caution because the cause of the changes has not been proven. However, these abiotic factors are good candidates for further research.

The examples above demonstrate two important independent approaches to evaluating the effects of wastewater on benthic communities. When used together, as in this report, they complement one another; each adds clarity to the results of the other yet contributes uniquely to the overall results.

In this study, we have defined groups of stations that form meaningful patterns around the outfalls. We have also identified ecologically and spatially distinct groups of species that conform to the site-group pattern. Finally, we have identified five significant abiotic factors that may be responsible for (or at least contribute to) the spatial distributions of the species correlated with Axis I of the ordination. Of these five abiotic factors, free sulfide appears to be the most important.

These techniques can be applied to the data from any well-designed sampling program. We have successfully used these and other techniques to analyze data from all 40 stations shown on Figure 1. This broader research, which was supported by the Environmental Protection Agency, will be published in detail in scientific journals.

Table 1. Species and abiotoc parameters significantly correlated with the scores for stations on Axes 1 and 11 of the principal coordinant ordination. The sign (+ or-), significance of the correlation and species-group affiliation are given.

Parameter	Sign of Correlation	Significance of Correlation[1]	Species — Group
AXIS I			
Species			
Glycera branchiopoda	+	$P < 0.001$	A
Notomastus tenuis	+	$P < 0.001$	B
Tharyx "parvus"	+	$P < 0.005$	B
Capitita ambiseta	+	$P < 0.005$	B
Axinopsida sp.	+	$P < 0.005$	B
Prionospio malmgreni	+	$P < 0.005$	B
Parvilucina tenuisculpta	+	$P < 0.025$	B
Nemertea, small white	+	$P < 0.025$	A
Pectinaria californiensis	+	$P < 0.05$	B
Decamastus gracilis	+	$P < 0.05$	B
Eumida "sanguinea"	–	$P < 0.001$	D
Capitella capitata	–	$P < 0.001$	D
Nassarius mendicus	–	$P < 0.001$	D
Shistomeringos longicornis	–	$P < 0.001$	D
Armandia bioculata	–	$P < 0.001$	D
Solemya panamensis	–	$P < 0.005$	D
Glycera americana	–	$P < 0.025$	D
Dorvilleidae Sp. 1	–	$P < 0.05$	D
Abiotic			
Sulfide potential	–	$P < 0.001$	
Total DDT	–	$P < 0.005$	
Percent organic nitrogen	–	$P < 0.005$	
Total mercury	–	$P < 0.025$	
Redox potential	–	$P < 0.025$	
AXIS II			
Species			
Listriolobus pelodes	+	$P < 0.005$	C
Telepsavus costarum	+	$P < 0.005$	C
Harmothoe "lunulata"	+	$P < 0.025$	C
Spiophanes fimbriata	+	$P < 0.025$	A
Cerebratulus sp.	–	$P < 0.025$	NC[2]
Tellina modesta	–	$P < 0.05$	NC

[1] P – probability that the correlation is not significant.

[2] NC = not considered in the classificaton of species.

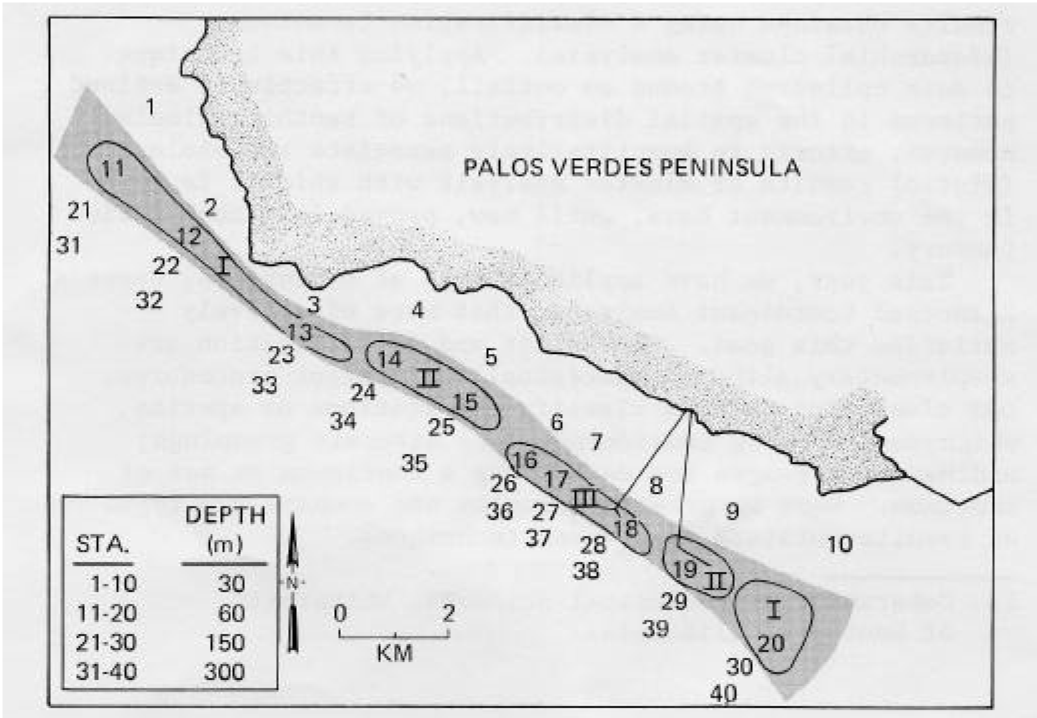

Figure 1. Benthic sampling stations on the Palos Verdes shelf and slope. Shaded area identifies samples used in the present study. Encircled stations with Roman numerals are the site-groups defined by cluster analysis

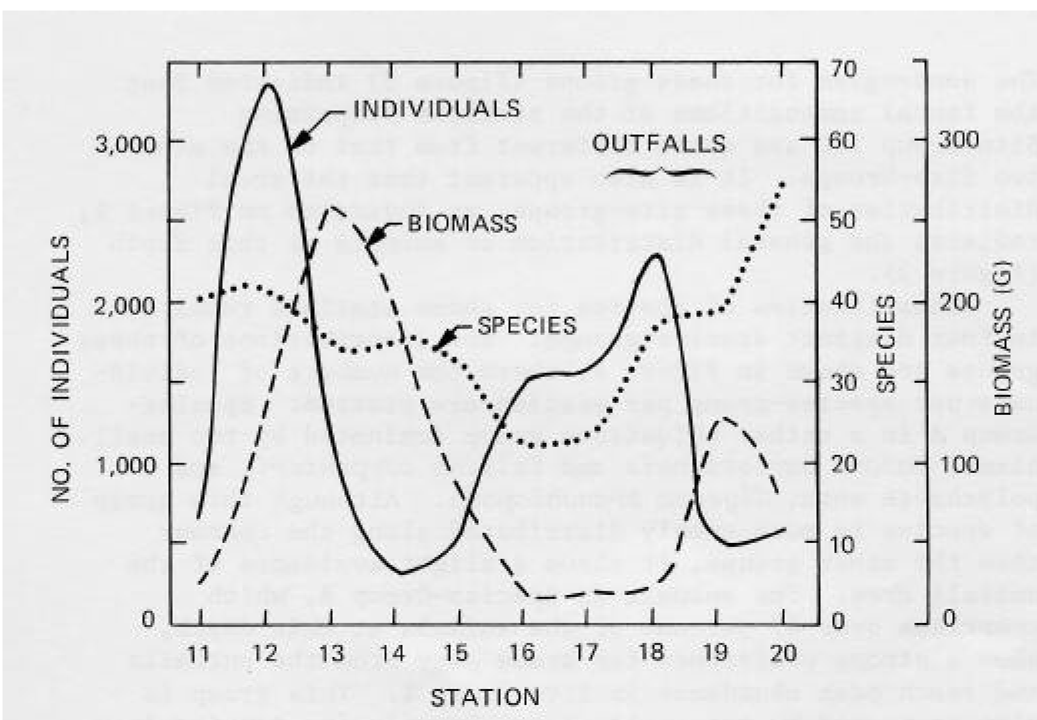

Figure 2. The distributions of total species, individual organisms, and biomass per station along the 60-m depth contour.

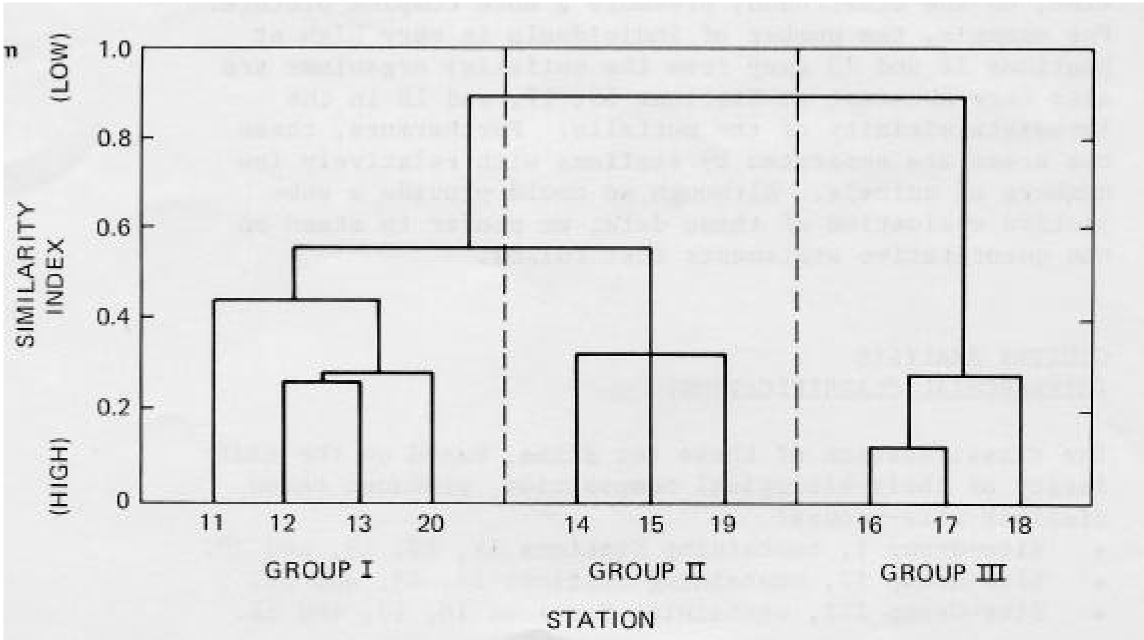

Figure 3. Dengrogram from the hierarchial classification of stations used to define Site-Groups I, II, and III.

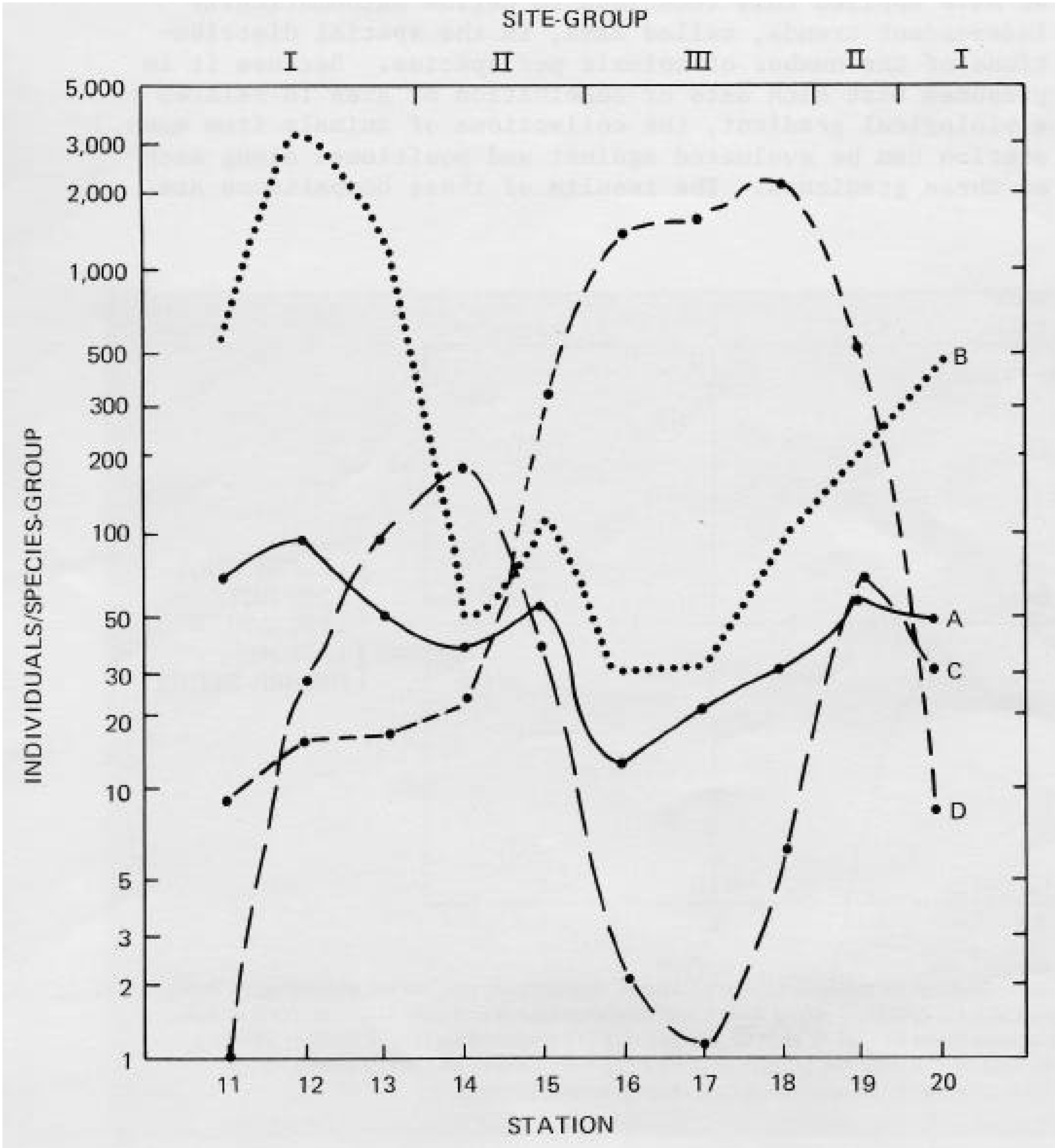

Figure 4. Distributions of total individual organisms (logarithmic scale) in each of the four major species-groups at each station along the 60-m depth contour.

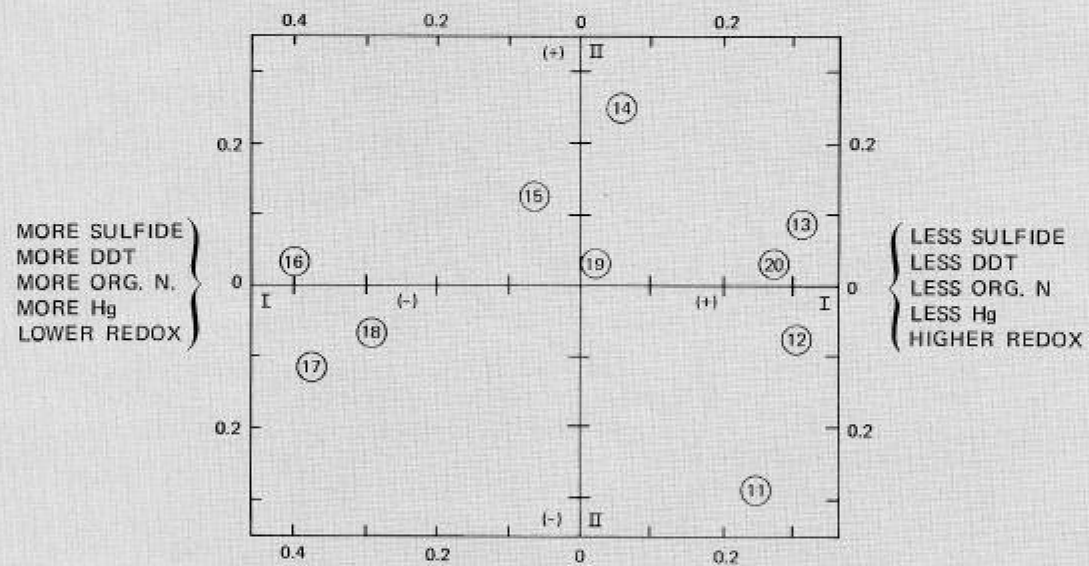

Figure 5. Principal coordinate ordination of stations on Axes I and II. Stations are positioned according to their scores on each axis. Significant abiotic gradients along Axis I are indicated (see also Table 1). Note, for example, that Station 14 has a faunal composition similar to that of the positive (+) end of Axis II and Station 16 has a faunal composition similar to that of the negative (-) end of Axis I. Station 14 is in an area of intermediate abiotic conditions; Station 16 is located in the area of highest abiotic concentrations.