

Discrimination between disturbed coastal ecosystems by using macrobenthos at different taxonomic levels

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ABSTRACT

The taxonomic level required to detect changes in the macrobenthic communities of disturbed coastal ecosystems was assessed by applying multivariate statistical methods to macrobenthic data. Community data sets were analysed from three estuarine salt marshes on the Gulf of Cadiz (southwest of Iberian Peninsula), affected mainly by agricultural sewage (Barbate River estuary), urban effluents (Cadiz Bay) and mining/industrial sewage (Odiel salt marsh). For both abundance and biomass data, aggregation of macrobenthic densities to Families or Orders did not cause any substantial loss of information, and statistically identical inferences from the macrobenthic community structure could be made, with an obvious saving of time and taxonomic expertise. Aggregating data to Classes or Phyla had some effects on consequent analyses: the more similar communities began to be confounded.

Key words: Macrobenthic community, taxonomic level, disturbance, coastal ecosystem, Gulf of Cadiz.

RESUMEN

Diferenciación de ecosistemas costeros alterados utilizando distintos niveles taxonómicos

Mediante el uso de técnicas multivariantes de análisis de datos se investiga el nivel taxonómico necesario para detectar cambios en la estructura de la comunidad macrobentónica en ecosistemas costeros alterados. Se analizan los datos correspondientes a las comunidades de tres zonas de marismas estuáricas del golfo de Cádiz (suroeste de la península Ibérica) que están sometidas a contaminación principalmente procedente de los cultivos agrícolas (estuario del río Barbate), vertidos urbanos (bahía de Cádiz) y desechos mineros y vertidos industriales (marisma del Odiel). Tanto para la abundancia numérica como para la biomasa, la agregación de las densidades del macrobentos a los niveles de familia u orden no significa una pérdida sustancial de información y se pueden hacer las mismas inferencias estadísticas sobre la estructura de la comunidad, lo que significa un ahorro en tiempo y en la destreza taxonómica requerida. Por el contrario, agregar los datos a los niveles de clase y phylum supone un efecto en los consiguientes análisis: se empiezan a confundir las comunidades con mayor semejanza.

Palabras clave: Comunidad macrobentónica, nivel taxonómico, alteración, ecosistema costero, golfo de Cádiz.

INTRODUCTION

The study of changes in macrobenthic community structure has been widely used for detection of man's impact on marine ecosystems. A major cost and time constraint on this kind of study is the sorting and identification of all organisms present in a community, to the species level. An additional problem is to discriminate between the natural stress of the community and that caused by human perturbations. In recent studies (Warwick, 1988a, 1988b, 1993; Ferraro and Cole, 1990; Gray *et al.*, 1990; Warwick and Clarke, 1993; Somerfield and Clarke, 1995), it has been suggested that working at a taxonomic level higher than species may be a possible solution to such major constraints. This implies an obvious cost and time reduction in processing samples. Furthermore, there are theoretical and empirical reasons for supposing that community responses to pollution is easily detected above the natural noise when working at higher taxonomic levels, because natural environmental variables usually influence the fauna more by species replacement than by changes in the proportions of major taxa present in the community (Warwick, 1988a, 1993).

Coastal ecosystems, such as estuaries and associated habitats (salt marshes, tidal channels, and lagoons), are often stressed by anthropogenic activities. The present study is a part of an extensive research project (AMB94-0291) on the determination of environmental quality in coastal ecosystems of the gulf of Cadiz, where estuaries and salt marshes are a good example of such a situation (Gómez-Parra, Establier and Escolar, 1984, Gómez-Parra, González Mazo and Blasco, 1994; Izquierdo, Usero and Gracia, 1997). The project involves the measurement, in sediments, of contamination levels, toxicity and changes in the benthic community structure. The aim of the present study was to determine, by using multivariate statistical methods, the taxonomic level required to discriminate between different macrobenthic communities in coastal ecosystems disturbed by different mining, industrial, urban and agricultural sewage inputs.

MATERIALS AND METHODS

The study was carried out in three estuarine salt marsh areas of the Gulf of Cadiz (southwest of Iberian Peninsula): the Barbate, Cadiz Bay and

Odiel salt marshes (figure 1). The main pollution sources affecting each area were different: agricultural sewage in the Barbate River estuary, urban effluents in Cadiz Bay, and mining waste and industrial sewage in the Odiel River estuary (Gómez-Parra, Establier and Escolar, 1984, Gómez-Parra, González Mazo and Blasco, 1994; Izquierdo, Usero and Gracia, 1997). Two sampling sites were chosen in both the Barbate (B₁, B₂) and Cadiz Bay (C₁, C₂) salt marshes, and five in the Odiel (O₁, O₂, O₃, O₄, O₅) salt-marsh area. Ten replicate samples of the macrobenthic community were taken randomly at each sampling site in June 1996, with an Ekman-Birge grab (15 × 15 cm²) modified to close by hand. After a pre-sieving (0.5-mm mesh) to eliminate the finest fraction of the sediment, samples were preserved using 5 % formalin in seawater. Later, animals were sorted by species, counted, and their biomass estimated by previously obtained using size-weight regression equations.

Macrobenthic abundance and biomass data of the different species were aggregated to the levels of family, order, class and phylum using the PRIMER (Plymouth Routines In Multivariate Ecological

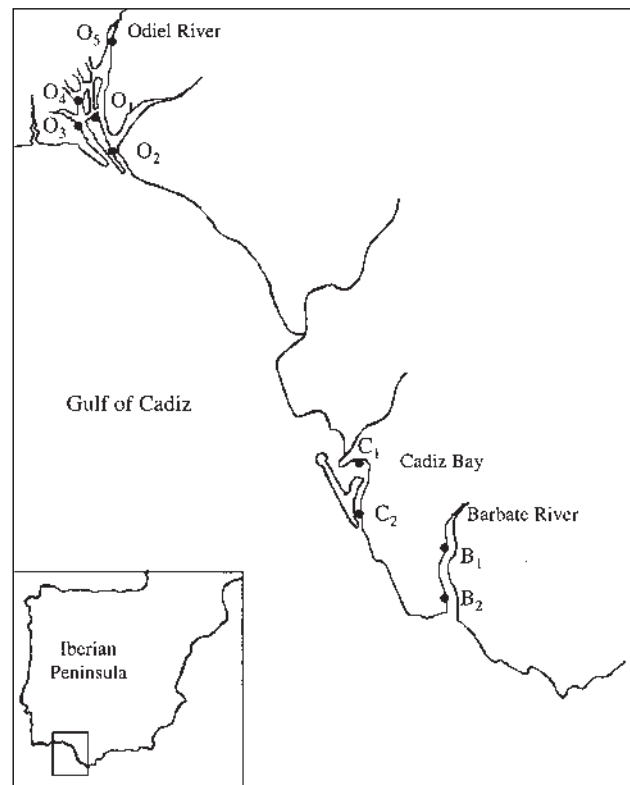


Figure 1. Location of study areas in the Gulf of Cadiz: Barbate (B₁, B₂), Cadiz Bay (C₁, C₂) and Odiel (O₁, O₂, O₃, O₄, O₅) salt-marsh sampling sites

Research) program AGGREG. To ascertain community structure differences, multivariate approaches were conducted according to Somerfield and Clarke (1995). Ranked lower triangular similarity matrices among samples were constructed using the Bray-Curtis similarity measure calculated on root-root transformed abundance and biomass data. To compare similarity matrices, a Spearman rank correlation (R) was computed between the corresponding elements of each pair of matrices, and the significance of the correlation coefficient determined by a permutation procedure using the PRIMER program RELATE. Samples ordination was by non-metric multidimensional scaling (MDS). Significant statistical differences between samples were determined by using the ANOSIM permutation test.

RESULTS

The data set analysed in this study consisted of 23 742 individuals belonging to 5 phyla, 8 classes, 35 orders, 64 families and 100 species (table I).

Table I. Number of different taxa by level of taxonomic identification on the macrobenthic data set analysed in this study. (*): Nemertea species were only identified to phylum

| Phylum | Class | Order | Family | Species |
|---------------|-------|-------|--------|---------|
| Nemertea | 1* | 1* | 1* | 3 |
| Annelida | 2 | 12 | 18 | 33 |
| Mollusca | 2 | 12 | 16 | 21 |
| Arthropoda | 2 | 9 | 28 | 42 |
| Echinodermata | 1 | 1 | 1 | 1 |

Pairwise Spearman rank correlation coefficients between similarity matrices, derived from abundance and biomass data aggregated to different taxonomic levels, show that the matrices are significantly (permutation test; $P < 0.01$) correlated at all taxonomic levels (table II). Nevertheless, correlation coefficients decrease as taxonomic levels increase, especially for taxonomic aggregation high-

er than order. Thus, for both abundance and biomass, benthic macrofaunal data aggregated to different taxonomic levels present a similar pattern that is partially altered for aggregation higher than order. To visualise these interrelationships, and according to Somerfield and Clarke (1995), we used the inter-matrix correlations (table II) as input similarities in the creation of MDS ordination plots (figure 2), so that the distance between taxonomic groups in the plot reflects the degree to which the similarity matrices are correlated.

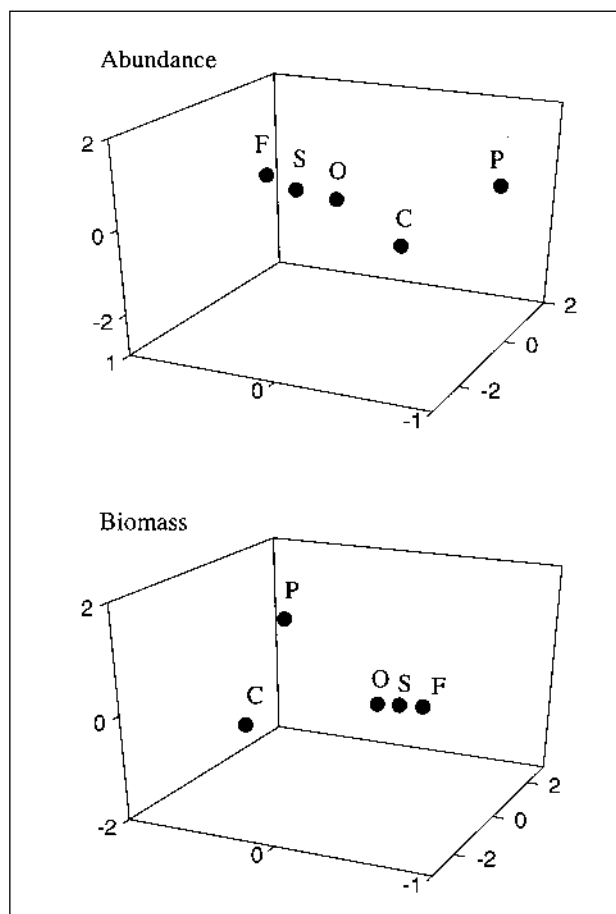


Figure 2. Ordination of the different taxonomic levels by MDS of ranked inter-matrix rank correlations from table I. Taxonomic levels: (S): Species; (F): Family; (O): Order; (C): Class; (P): Phylum

Table II. Pairwise Spearman rank correlation coefficients between similarity matrices (Bray-Curtis index), derived from species abundance and biomass data aggregated to different taxonomic levels. All correlation coefficients are significantly different from zero (permutation test, $P < 0.01$)

| | Abundance | | | | Biomass | | | | |
|--------|-----------|--------|-------|-------|---------|--------|-------|-------|--|
| Family | 0.943 | | | | 0.969 | | | | |
| Order | 0.886 | 0.888 | | | 0.924 | 0.934 | | | |
| Class | 0.712 | 0.772 | 0.814 | | 0.725 | 0.756 | 0.812 | | |
| Phylum | 0.603 | 0.666 | 0.699 | 0.812 | 0.651 | 0.682 | 0.743 | 0.910 | |
| | Species | Family | Order | Class | Species | Family | Order | Class | |

One-way ANOSIM tests were used to test for differences in community structure among the nine sampling sites, using abundance and biomass data aggregated to different taxonomic levels. Results of global tests indicated that intersite community differences were significant at all taxonomic levels, and most pairwise intersite differences were significant, so only pairwise tests in which differences were not significant were given (table III). For both abundance and biomass data, we found that aggregating benthic macrofaunal data above the level of order alters the perceived pattern of the community structure. Thus, the pattern of benthic community discrimination begins to break down at the level of class.

Table III. Results from one-way ANOSIM tests conducted to test for intersite differences in macrobenthic communities from the Barbate (B₁, B₂), Cadiz Bay (C₁, C₂) and Odiel (O₁, O₂, O₃, O₄, O₅) salt-marsh sampling sites. For each comparison, value of ANOSIM statistic (R) for global test, its significance level (P), and results of pairwise tests in which R was not significant (P > 0.01) are given

| | | Abundance | | Biomass | |
|---------|--------------------------------|-----------|--------|---------|--------|
| | | R | P | R | P |
| Species | Global | 0.833 | < 0.01 | 0.761 | < 0.01 |
| | O ₁ -O ₂ | 0.059 | 0.16 | 0.062 | 0.11 |
| Family | Global | 0.714 | < 0.01 | 0.753 | < 0.01 |
| | O ₁ -O ₂ | 0.057 | 0.12 | 0.054 | 0.13 |
| Order | Global | 0.826 | < 0.01 | 0.671 | < 0.01 |
| | O ₁ -O ₂ | 0.067 | 0.13 | 0.054 | 0.13 |
| Class | Global | 0.684 | < 0.01 | 0.603 | < 0.01 |
| | C ₁ -C ₂ | 0.082 | 0.10 | 0.055 | 0.16 |
| | O ₁ -O ₂ | 0.076 | 0.12 | 0.079 | 0.08 |
| Phylum | Global | 0.655 | < 0.01 | 0.578 | < 0.01 |
| | C ₁ -C ₂ | -0.038 | 0.76 | 0.011 | 0.35 |
| | O ₁ -O ₂ | 0.137 | 0.07 | 0.091 | 0.09 |
| | O ₂ -O ₅ | 0.155 | 0.03 | 0.197 | 0.02 |
| | O ₃ -O ₄ | 0.158 | 0.03 | | |

DISCUSSION

Ecosystems manifest their stress through changes in the structure of their communities. A shift in species dominance to opportunistic short-lived species is one such change. However, it is well known that the various taxa of marine organisms vary in their sensitivity to disturbance, and that pollutants from different sources may affect them differently. The macrobenthic data set analysed in this study belongs to three salt marsh areas with considerable differences in pollution levels and in the nature of their pollutants. The three most wide-

spread sources of pollution on the southwest Spanish coast are represented: agricultural sewage (Barbate River estuary), urban effluents (Cadiz Bay), and mining waste and industrial sewage (Odiel River estuary) (Gómez-Parra, Establier and Escolar, 1984; Gómez-Parra, González Mazo and Blasco, 1994; Izquierdo, Usero and Gracia, 1997). Consequently, we believe that conclusions from this paper could be extrapolated to other studies on macrobenthic communities from disturbed coastal ecosystems of the Gulf of Cadiz.

The results of the multivariate analyses of the macrobenthic community's abundance and biomass, which showed high correlation coefficients for data aggregated to different taxonomic levels, indicate that there was redundant information in our dataset expressed at the lowest taxonomic levels considered (family and species). Therefore, no information would have been lost, and we would have drawn the same inferences, if the organisms had been identified to the level of order. It could mean a considerable saving of time and taxonomic effort. Similar conclusions have been previously reported for other coastal ecosystems from northern Europe (Warwick, 1988a, 1988b; Gray *et al.*, 1990; Somerfield and Clarke, 1995). For such ecosystems, family was considered the taxonomic level above which the pattern of benthic community discrimination begins to break down. However, no intermediate taxonomic levels between family and phylum were included in the data aggregation of these studies, which could have caused the observed discrepancy with our results.

All the data analysed in our study are from disturbed ecosystems, although with different sources of perturbation. Ferraro and Cole (1990) hypothesise that, as stress increases, the adaptability of first individuals, then the species, genus, family, and so on, is exceeded. Consequently, the community's response to increasing stress is manifested at higher and higher taxonomic levels (hierarchical-response-to-stress theory). According to such a hypothesis, the taxonomic level required to detect changes in the macrobenthic community could depend on the degree of environmental alteration. Therefore, comparisons with undisturbed estuarine ecosystems from our zone (if any) should be carried out before concluding whether order is also the taxonomic level sufficient to assess the smallest pollution impacts.

Results of the present study agree with previous observations in the sense that taxonomic levels

higher than species may be recommendable for detecting community structural changes in response to pollution. But, as indicated by Somerfield and Clarke (1995), the detection of a change in community structure tells us little about the nature of that response, and in order to assess issues of causality we should know which species are present and their ecology.

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