

# INFLUENCE OF SOME ENVIRONMENTAL FACTORS ON THE STRUCTURE AND DISTRIBUTION OF THE ROCKY SHORE MACROBENTHIC COMMUNITIES IN THE BAY OF GIBRALTAR: PRELIMINARY RESULTS

*Darren A. Fa / Clive Finlayson / E. García Adiego / E. Sánchez Moyano / J. C. García Gómez*  
Instituto de Estudios Campogibraltares

## Abstract

The Bay of Gibraltar contains a high biological diversity which is conditioned by a suite of both biotic and abiotic factors of natural origin. However, the Bay is also subjected to a variety of anthropic impacts which have a considerable effect on the marine biota. The rocky littoral is particularly useful in environmental monitoring programmes as it is easily accessible and amenable to sampling, and the sessile nature of the majority of the species make long-term monitoring relatively simple.

In this study we compare data obtained for a number of environmental variables using a range of statistical methods to the community data obtained at six sites inside the Bay and two sites immediately outside, one to the East and another to the West. The results of these preliminary analyses indicate that, within the range of environmental parameters measured, small and intermediate-scale natural variables such as microtopography and exposure to wave action are important. However, within the Bay, the effects of urban and agricultural effluents and associated variables assume a greater role in the structuring of these intertidal communities.

## Resumen

La Bahía de Gibraltar contiene una alta riqueza biológica que se ve condicionada por factores bióticos y abióticos de origen natural. Sin embargo, la Bahía también sufre una gran variedad de actividades antrópicas que afectan a la biota marina de manera considerable. El litoral rocoso es relativamente accesible y sencillo de muestrear, y es un ecosistema muy útil para estudiar el posible efecto de estas alteraciones, pues las especies son generalmente sésiles y la composición y estructura de sus comunidades reflejan su historia.

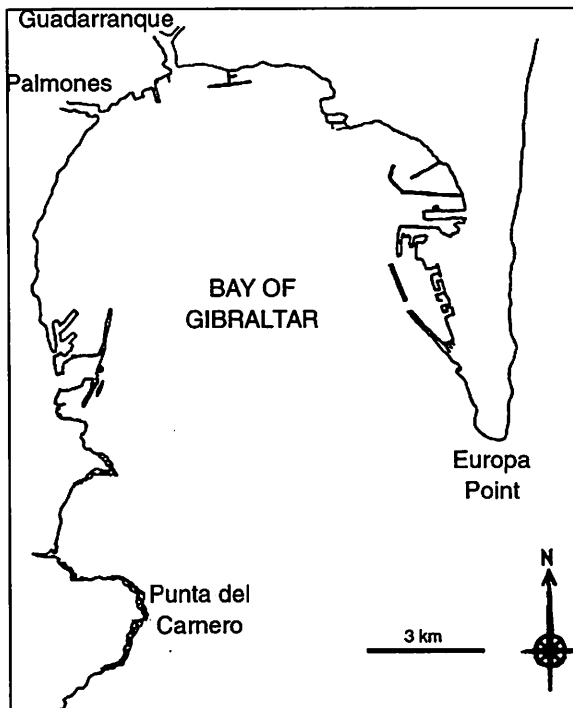


Figure 1. Plan of the Bay of Gibraltar showing main features.

En este trabajo se comparan datos obtenidos de un número de variables medioambientales utilizando métodos estadísticos multivariantes aplicados a las comunidades presentes en seis puntos en el interior de la Bahía y otros dos puntos inmediatamente en el exterior de la misma, al oeste y al este. Los resultados de estos análisis preliminares indican que, dentro del número de parámetros muestreados, las variables naturales de pequeña y mediana escala, como microtopografía y exposición al oleaje, son importantes; pero los efluentes procedentes de fuentes urbanas y agrícolas y sus variables asociadas, asumen una importancia relevante como factores estructurales de estas comunidades.

### Introduction

The Bay of Gibraltar (one of the deepest in Europe) is found at the extreme south of the Iberian Peninsula between  $36^{\circ}6'$  and  $36^{\circ}11'$  North and  $5^{\circ}45'$  and  $5^{\circ}21'$  West. It can be approximated to a semicircular littoral around 30km long starting at Punta del Carnero and ending at Europa Point.

A number of rivers and tributaries empty into the Bay, the most important of which with regard to volume being the rivers

Palmones and Guadarranque. During the Pleistocene, periods of constant and intense rainfall dramatically increased the volume and rate of water from such rivers as the Guadiaro and Hozgarganta (which now flow out into the Mediterranean to the North-east of Gibraltar), Guadarranque and Palmones (Fernandez-Palacios *et al.*, 1988). This large output of water, together with the low sea levels caused by the previous glaciation (Valenzuela, 1995; Fa *et al.*, 2000), gouged out a deep estuary in the Bay. Following the Pleistocene deluge, small-scale tectonic upheavals diverted the Guadiaro and Hozgarganta to the East, and rising sea-levels helped to carve out the now-familiar profile of the Bay.

In the Bay a number of different coastal systems are found such as salt marshes (Palmones Nature Park), sand dunes (Rinconcillo), sandy beaches (Getares, Rinconcillo, Palmones, Guadarranque, Puente Mayorga, Campamento and Western Beaches) gravel beaches (Camp Bay, Little Bay) and of course, rocky shorelines, both natural (Punta del Carnero, La Ballenera, Rosia Bay, Europa Point) and man-made (Saladillo Harbour, Port of Algeciras, Acerinox, CEPESA, Campamento, Crinavis, Pantalón de San Felipe, Gibraltar Airport runway, Moles and Port of Gibraltar, Rosia Bay breakwater). In this study we focussed on rocky shores as they are relatively easy to sample (rocks creating essentially a two-dimensional surface) and yet are dominated by relatively sessile organisms (Fa *et al.*, 2000). The composition of sessile communities is particularly useful as a baseline for ecological monitoring, because such organisms are unable to avoid disturbances in the marine environment and thus the composition of the community reflects their common history.

Most species exist in a "web of complex interactions" (Darwin 1859). These interactions involve both abiotic interactions with the physical environment and biotic interactions with other species. There is evidence that marine benthic animal communities are structured by a variety of factors such as food availability, water movement, salinity, temperature, oxygen

concentration and other physiochemical parameters which are further modified by biotic interactions (Băcescu, 1983; Pearson & Rosenberg, 1989; Vermeij, 1991; Rosenberg *et al.*, 1992). At the local scale, the majority of the small-scale vertical gradients of conditions in many rocky littoral habitats are extreme (e.g. vertical gradients of temperature and humidity). This creates a range of microclimates which allow the community composition of littoral biotas to move vertically from highly diverse assemblages at the water's edge (being structured locally mainly through biotic factors) through to more stressful (and consequently species poor) upper shore environments where structure is believed to stem from physical factors (e.g. Connell, 1972; Lewis, 1976).

### Methods

A number of sampling points along rocky coastlines were established along the Bay (B2–B7), with two nearby locations selected outside the Bay for comparative purposes. To the west a site close to Tarifa was selected (B1), and site B8 (Ailsa Craig) was selected on the eastern (Mediterranean) side of the Rock of Gibraltar. Fig. 2 shows the location of these sites.

Due to the need to quantitatively assess changes in abundance and distribution of littoral organisms, a systematic method based on a fixed belt transect (Eberhardt, 1978; Jones *et al.*, 1980; Fa, 1990) was selected as the sampling method at each site. At each site a generalised shore search was undertaken in order to both select the most appropriate location for the transect and also to ensure that it was as representative as possible of the area being studied. Each transect was also selected to be (in terms of general profile, slope and topography) as consistent throughout all sites as possible. This was done so as to minimise the effects of topographical heterogeneity and allow the data from all sites to be more favourably cross-compared.

Once the transect area had been chosen, the transect itself was measured and marked off. Vertical heights (from MLW) were measured using a technique adapted from Eifon Jones (1980). Sampling points (stations) were marked off at 25cm intervals and later correlated to the relevant chart datum (information supplied by the Gibraltar Meteorological Office, Instituto de Meteorología, Madrid and the Admiralty Tide Tables). This narrow vertical height was selected as the small tidal amplitudes encountered (the tidal amplitude in the Bay averages around 0.7m) meant that the recognised littoral zones showed extreme vertical compression. This process was continued until a vertical height of 3m had been achieved, providing twelve stations for the littoral zone.

A variant of Pielou's pooled quadrat method (1975) was used to assess minimum quadrat size, which was established as  $0.25\text{m}^2$  (see Fa, 1998). A rectangular fixed-area  $0.25\text{m}^2$  ( $1\text{m} \times 0.25\text{m}$ ) quadrat, placed vertically against the substrate and parallel to the air-water interface, was then used to sample the macrofaunal assemblages. Such a quadrat was used as it helped to maintain the area being sampled as environmentally homogeneous as possible. The quadrat was made of PVC strips which

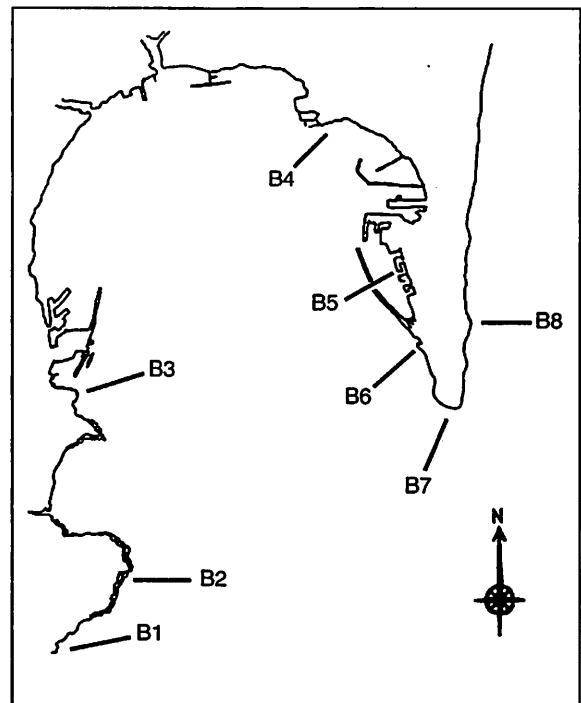


Figure 2. Location of the study sites. In order these are: B1 Tarifa, B2 Punta del Camero, B3 Punta del Rodeo, B4 El Campamento, B5 the Boat Camber, B6 Rosia Bay, B7 Europa Point and B8 Ailsa Craig.

made it both lightweight and flexible; this latter property allowed it to conform to any irregularities in shore topography, lessening the risk of counting individuals which lay outside the quadrat area. These strips were held together by plastic nuts and bolts which also helped the quadrat to “grip” the substrate. The quadrat was further subdivided into one hundred 25cm<sup>2</sup> squares with thick fishing line, strengthened at their junctions by cyano-acrylate based adhesive. These helped in the estimation of numbers for superabundant species and also algal cover.

Within each of these stations, a census of the species richness (S) and the number of individuals (I) encountered was taken during the month of July 1993. These were assessed visually on site, with the more ‘difficult’ species being removed for later identification. Unfortunately, a few of the smaller and more motile species proved difficult to capture and consequently only a rapid visual identification was possible, allowing identification only down to genera. In any case, it is important to note that in almost all the above cases, the species in question were rare and only encountered at a single location, making the degree of taxonomic resolution less important. In other cases identification was purposefully taken only to genera due to the difficulties of on-site separation of very similar co-existing species (e.g. *Mytilus edulis* Linnaeus 1758 and *Mytilus galloprovincialis* Lamarck 1819, whose morphs grade into each other and consequently were grouped as *Mytilus* spp.). As entire sites were to be compared in this analysis, the values for each site were aggregated to give a single value for S and I at each site. Both Simpson’s (D) and the Shannon-Weiner (H’) diversity indices (Simpson, 1949; Shannon & Weaver, 1949, respectively) were applied to the whole-site data.

In addition to species/abundance counts and diversity statistics, a variety of environmental parameters were measured. Whole-site parameters were measured at approximately monthly intervals during July, August and September 1993. Three readings at each site at each monthly sampling were taken and averaged to provide an indication of the conditions the animals would be subjected to when exposed during low tide at each station. All station readings were taken between 12 noon and 3pm, so as to make these as comparable between sites as possible. Meteorological data supplied by the Instituto de Meteorologia, Madrid, and by the Gibraltar Meteorological Office, suggested very constant weather conditions during the study months, and it was expected that this would make the measurements more representative.

Air temperature (AirT) and relative humidity (RelHum) were measured at each site, using a Hanna®2000 Thermohygrometer. Both of these were expressed as percentages of the mean of twelve values taken at the rock face against the prevailing atmospheric values. A fundamental parameter in the structuring of populations and communities (Hutchins, 1947; Hall, 1964; Rohde, 1992), temperature has direct links to other variables such as metabolic rate, reproduction (Orton, 1920), and in extreme cases, to severe physiological stress due to effects such as desiccation (Evans, 1948; Southward, 1958). Relative humidity is linked to temperature and has a direct influence on rocky shore organisms, where rates of transpiration are critical in determining distribution limits and abundances.

The amount of incident (LightIn) and reflected light (LightOut) was also measured, using the light meter from a NIKON® F301 SLR Camera. The camera was set at the aperture - priority setting (aperture = f/8) and incident (overall) and reflected (overall) light readings were taken as a shutter speed. Again these were expressed as a percentage of prevailing incident light. The first of these variables is often measured in phytosociological studies (e.g. Coppejans, 1980) but rarely finds its way into many ecological works. Its true value is unclear, although it has a direct link with productivity (Ryther, 1956; Drew, 1983). The reason for measuring reflected light was an attempt at quantifying the amount of organic matter by measuring the amount of light absorbed (see Fa, 1998 for details).

Algal Cover is a variable that has been ascribed a dual role in the literature, both as a source of primary productivity and as a contributor to habitat complexity (Mann, 1973; 1982; Bosman & Hockey, 1988; Markager & Sand-Jensen, 1992). This was expressed as a percentage of the total area sampled.

Topographical parameters were also measured, as shore topography and complexity is considered by Lewis (1964) as one of the three major factors that influence and modify the composition and abundance of littoral biota. In fact, in littoral communities, habitat complexity is often enhanced by the structural role played by the organisms themselves, e.g. mussels (*Mytilus* spp.) form dense beds along the lower shore and can increase diversity through the creation of microclimates and structural components in the ecosystem, being a biotic contributor to habitat complexity (e.g. McCoy & Bell, 1991). Substrate hardness is also important, as if the substrate is too hard, it may well restrict the number and type of species which are present, as many littoral organisms have life histories that involve their burrowing into or at least modifying the rocky substrate for purposes of attachment, protection, feeding, etc. On the other hand, too friable a substrate also reduces numbers (due to rapid erosion rates, easy dislodgement and lack of permanence). This may create communities that are continually in successional flux and create niches for other opportunistic pioneer species.

Below are listed the topographical parameters that were measured (modified from Trudgill, 1988):

Number of pits (np);

Average size per pit (As);

Micromorphology (Mi): 1-Tabular, 2-Rounded, 3-Pitted 4-Honeycombed, 5-Pinnacled, 6-Angular, 7-Blocky;

Texture (Tx): 1-Smooth, 2-Intermediate, 3-Rough, 4-Coarse;

Roughness ratio (Rr):  $Tr/Tt$ , where  $Tr$  = distance between two points following all the indentations of the rock and  $Tt$  = distance between the same points with the tape stretched tight;

Perpendicular Dissection (PD):  $Tt/h$ , where  $h$  = perpendicular distance from the stretched tape to the substrate;

Hardness (Hard): 1. Rock crumbles when touched; 2. Rock can be scratched by fingernail; 3. Rock can be scratched by pen-knife but not fingernail; 4. Rock cannot be scratched by pen-knife.

(Rock type was also noted, although this data could not be quantified).

Some of the above values were converted into indices:

Density of Pits ( $Dp$ ) =  $np / 0.25$  (Total Area Sampled)

Total Area of Pits ( $Ap$ ) =  $As \times np$

Index of Area of Pits ( $IAP$ ) =  $(Ap / 0.25) \times 100$

Index of Pitting ( $Ip$ ) =  $As / Ap$

Index of Complexity of Pits ( $ICp$ ) =  $Iap / np$

Orientation from North for each site was also measured (Orient). The inclusion of this surrogate variable was an attempt to have some form of quantitative data that could be closely correlated with parameters that might vary in effect and intensity due to a site's actual positioning within a location.

Exposure to wave action is arguably the single most important factor in modifying the vertical extent of zonation patterns and the nature of the organisms inhabiting these zones (Southward, 1957; Newell, 1972). Moreover, experimental studies indicate that wave exposure may also act indirectly by altering competitive interactions and predation (Connell, 1975; Dayton, 1975; Menge, 1976; Menge & Sutherland, 1976), which together with possible differences in recruitment (Roughgarden *et al.*, 1984; Connell, 1985), growth rates, intraspecific competition and substratum stability (Page, 1986), may also influence population structure.

In this study, a three different measures of exposure were used:

1. Local Exposure angle (LocEx), which is the value of the angle that is open to the sea on a local scale (hundreds of metres);

2. Regional Exposure angle (RegEx), which is the value of the angle that is open to the sea on a regional scale (kilometres). This may be larger or smaller than the Local Exposure angle;
3. Thomas's (1983) Index of Exposure to wave action (Expos), which is calculated using the following equation which sums calculated exposure values of each 30° sector which is open to the sea:

$$\text{eqn 1} \quad \text{Expos} = \sum \log W \times \log [1 + F/(CS + 0.1DS)] \times SI$$

where

W = Wind energy measured in km/h (Thomas used knots where 1knot=1.85km/h);

F = Fetch in kilometres (Again Thomas used 100 Nautical Miles maximum = 183km);

CS = Extent of water (km) <6m deep adjoining the shore;

DS = Extent of water (km) within the fetch <6m deep but not adjoining the shore;

SI = Decimal fraction of % slope (As overall slope was very similar throughout all the sites, and moreover was already included as a separate variable, this parameter was not included so as to simplify the calculation of the index).

Overall Slope was also quantified for each site using a hand-held clinometer. As already mentioned when dealing with exposure, slope can be very important in modifying the degree of direct wave impact. The steeper the slope, the less the amount of energy expended by the wave in its approach and subsequent surge, and consequently the greater the impact. Conversely, shallower slopes (aided by the degree of shore 'brokenness') dissipate the wave's energy sooner (Southward, 1953). Slope also modifies an organism's aspect to other important environmental factors such as direct sunlight, which could have important effects on species presence and abundance.

Sea water parameters were also measured (Table 1).

Increased values for pH have usually been linked to increased CO<sub>2</sub> levels caused by either increased respiration, reduced photosynthesis, or both (Agnew & Taylor, 1986).

Sea temperatures are considered to be of prime importance in determining the distribution of marine organisms, not only for the reasons already outlined for air temperature, but also when one considers that most littoral species have a planktonic larval stage.

Phosphates are extensively used in detergent formulations and washing powders. Agricultural fertilizers also have a high phosphate content. Phosphates are also used in the food processing industry and in industrial water treatment processes. Thus, the presence of phosphates in water can then be due to a variety of reasons particularly from domestic and industrial effluents and run-off from agricultural land. Whilst phosphates are not generally considered harmful for human consumption, they do have a complex effect on the natural environment, contributing to rapid unwanted algal and plant growth in aquatic environments (Klein, 1959; American Public Health Association, American Water Works Association and Water Pollution Control Federation, 1989).

Nitrites and nitrates, or nitrogen compounds subsequently oxidized to form nitrates, may enter water supplies from sewage effluents and from some industrial wastes. In particular, the use of chemical fertilizers in modern agriculture has led to a rapid rise in nitrate levels of water sources and it is predicted that these levels will continue to rise. Within the marine environment, such enrichment can cause increases in phytoplankton which may initially support a richer community but which if unchecked, cause an algal bloom with all its accompanying deleterious effects. However, these parameters are both spatially and temporally variable and consequently have limited usefulness. Nonetheless, they were measured as the level of organic enrichment is known to be closely linked to productivity.

Dissolved Oxygen (DO) and Oxidation-Reduction Potential (ORP) are important parameters in that the amount of oxygen available to organisms has direct repercussions on metabolism, and ultimately, presence or absence of species. However, possible reasons for fluctuation in this parameter can be varied, such as water movement, temperature, salinity, etc. (which are themselves interrelated - Brower *et al.*, 1990), and can all contribute to variations in oxygen levels as can biotic factors such as algal blooms.

Many papers (e.g. Earll & Farnham, 1983; Cortes, 1992; Grillas *et al.*, 1993 and references therein) have been published about the distribution of species along gradients of salinity. Remane (quoted in Margalef, 1985) has suggested that definite values of salinity can be considered as boundaries in species' distributions. However, this effect is probably significant only at the local level (Margalef, 1985). Differences in salinity have many physiological implications but the osmotic effect is usually considered to be the most significant (Kinne, 1971). In environments of changing salinity, survival is dependent on the capacity to conserve constant osmolarity of the body fluids in the face of large fluctuations in external salinity. The physiological regulation requires energy, and this means an increase in metabolism, that is oxygen consumption.

The action of bacteria on organic matter is to convert the organic matter into simple organic salts. If sufficiently high levels of organic matter exist, the amount of oxygen used by the bacteria during the aforementioned process becomes significant, reducing dissolved oxygen levels and adversely affecting other lifeforms. Biological Oxygen Demand (BOD) is defined as "...the amount of oxygen, in mg, taken during a five-day period by one litre of the sample." (Walters, 1989), in this study measured using the Lovibond® four-hour permanganate test.

Spectral analysis of water has previously been used to estimate amounts of photosynthetic pigments and other suspended matter in the water column (Menez, 1996). These wavelengths were selected as they are the wavelengths at which algae absorb the highest amounts of light radiation (Levring, 1947; Parsons *et al.*, 1977) and consequently could allow a crude estimate of phytoplanktonic primary productivity (*sensu* Yoder *et al.*, 1993). There is evidence that such large-scale, essentially pelagic processes can be an important food supply for benthic species (Witman *et al.*, 1993).

Parameter	Measured using:
pH	Pye Unicam® 292 pH meter
Temperature (Temp)	Jenway® 9070 temperature-oxygen meter
Oxidation - reduction potential (ORP)	Hanna® water meter
Nitrates (Nitra)	Lovibond® test kit
Nitrites (Nitri)	Lovibond® test kit
Phosphates (Phos)	Lovibond® test kit
Dissolved Oxygen (DO)	Jenway® 9070 temp-oxygen meter
Salinity (Sal)	Titration with Silver Nitrate (Mohr's method)
Biological Oxygen demand (BOD)	Lovibond® test kit (permanganate value)
Absorbance at 450 and 650nm	Cecil® CE 2343D digital grating spectrophotometer

Table 1. The various seawater parameters measured and the methods used. Details of the methods outlined above can be found in Fa (1998). All of these were sampled over a two-day period, again to increase comparability, and final values were the average of three separate measurements taken at each location.

Finally, an index of Anthropogenic stress (measure of human disturbance) was also used Fa (1998),

$$\text{eqn 2} \quad A_s = (\sum P_a / D_l) \times \emptyset$$

where

$A_s$  is the general anthropogenic stress (Anthrop);

$P_a$  is the total area of each of the main population centres in a 5km radius from the site;

$D_i$  is the distance of the focus of each population centre to the site.

$\emptyset$  is a measure of disturbance which was based on the subjective assessment of both ease of access and levels of human activity, ranked in the following way:

1. Very difficult access - little or no direct influence
2. Difficult access - little human activity
3. Moderate ease of access / moderate human activity
4. Moderate access/high activity or easy access/moderate activity
5. Extremely easy access together with high levels of human activity

A number of parameters such as tidal and meteorological variables were not included as they varied little between Bay sites. See Fa, (1998) for a more detailed description of methods and rationale.

It is intended to correlate all this environmental data with biotic data in order to establish which parameters, if any, are primarily responsible for the community patterns encountered. The analysis of variation in community composition and structure was explored following the basic strategy outlined by Clarke (1993) which was in turn, a development on the proposal made by Field, Clarke & Warwick (1982). This involves four main stages:

1. Representation of community structure through classification and ordination;
2. Determination of the species responsible for the previously observed associations;
3. Test for spatial and temporal differences in the community structure;
4. Exploration of biotic-abiotic relationships so as to establish possible structuring factors.

The similarity between any two samples and was calculated using the Bray-Curtis similarity index (Bray & Curtis, 1957). However, this index is very sensitive to extreme values (Digby & Kempton, 1987), and consequently transformation of the raw data is advisable in order to avoid the 'swamping' of rarer species by overabundant ones. This stabilization of variances can best be achieved by using either the logarithmic transformation  $y = \log(x+c)$ , where  $0.2 < c < 1$  (Field & McFarlane, 1968; Clifford & Stephenson, 1975), or the root-root or fourth root transform  $y = \sqrt[4]{x}$  (Field *et al.*, 1982; Field *et al.*, 1987). For the cluster analysis (as for the MDS - see below) the root-root transform has been used as it has the further property of being relatively insensitive to sampling area, (Field *et al.*, 1982; Clarke & Warwick, 1994) and would simplify comparisons of results to those from other data sets. Data reduction was not used as it was believed that rare species could be of particular importance in helping to identify changes in the prevailing faunal assemblages. Following this transformation, triangular similarity matrices between each pair of samples were calculated and a dendrogram created by hierarchical agglomerative clustering with group-average linking (e.g. Clifford & Stephenson, 1975), with which the existence of groupings between stations based on their similarities was obtained.

The ordination technique used to explore these patterns was non-metric Multi-Dimensional Scaling (MDS) (Shepard, 1962; Kruskal 1964a, b; see Kruskal & Wish, 1978, for an introduction). It is an ordination technique that is based on similarities between samples and allows species to 'tell their story' (Field *et al.*, 1982), by employing an iterative algorithm that progressively arranges samples in multi-dimensional space so as to best preserve their inter-sample dissimilarities and consequently arrive at the best ordination of these, where the distance between points in the ordination is proportional to the similarity between these (Gauch, 1982; Smith *et al.*, 1988). The degree to which the final representation fits the data is measured by a coefficient of stress. Generally, values below 0.1 can be taken as significant.

The main method used to explore biotic-abiotic relationships in the data is a technique which uses the MDS rank-similarity matrix calculated between sites and systematically compares this with the Euclidean distance matrices obtained via Principal



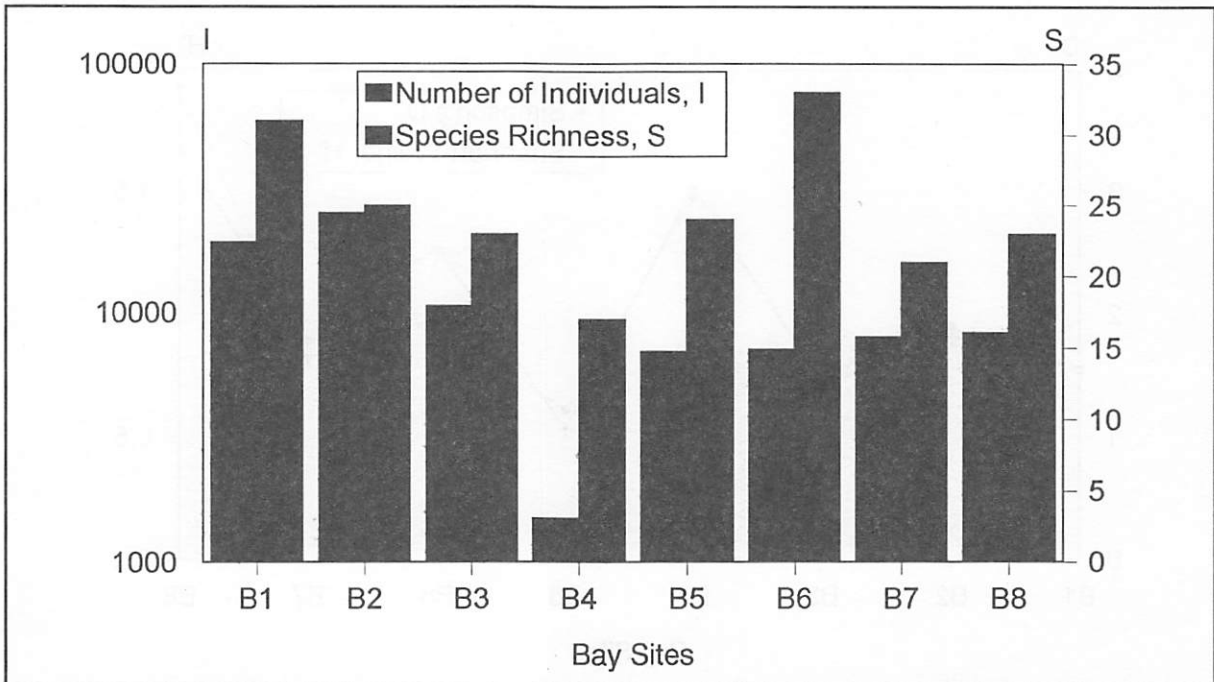


Figure 3. Graph showing changes in species richness (S) and number of individuals (I) at each Bay site. Note how in general, both S and I decrease into the Bay although S falls again outside the Bay to the east and values for I are more constant along the eastern side of the Bay but show a strong gradient along the west coast.

Component Analyses (PCAs) of all possible permutations of environmental variables (Clarke & Warwick, 1994). Spearman's harmonic rank-correlation test for non-parametric ranges ( $r_r$ ) is used to establish the degree of correlation between the ranked values in each matrix, with a value of 0 indicating no correlation and 1 a perfect correlation. The main assumption here is that variables that are not strongly correlated will degrade the fit of the model, whereas the opposite will be the case for variables that correlate well. Consequently, the subset of environmental factors that provides the highest overall correlation value is selected as the model that 'best explains' variation in the community data.

This was achieved using the BIOENV extension to the PRIMER software package (Clarke & Ainsworth, 1993). The nature of the BIOENV analysis is such that different ordination techniques are used depending on the variable type (biotic or abiotic) and furthermore it does not restrain species-environment relationships to linear, monotonic, unimodal or even multimodal forms (Clarke, 1993). By matching two separate ordinations, it leaves the analysis of the relationships between species' and environmental factors till the end, avoiding possible unwanted statistical influences on the observed biotic patterns.

### Results for Diversity Measures

Figure 3 shows the results obtained for species richness (S) and number of individuals (I) across the eight sites.

In contrast to the results obtained in Fig. 3, however, the diversity values are relatively consistent across sites, with peaks in diversity occurring at sites B4, B6 and B8. Interestingly, only the weakest peak (site B6) is mainly due to high species richness. Site B4 is actually the most species-poor location sampled in the Bay. However, its sheltered locality (little zonal extension)

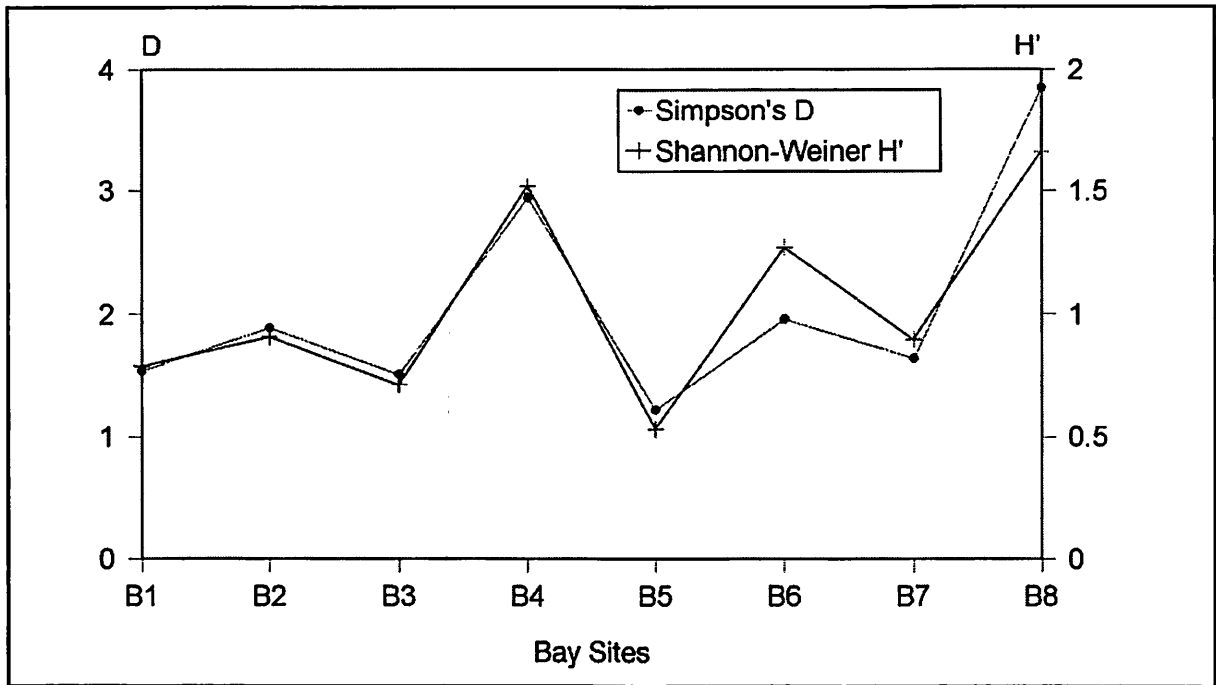


Figure 4. Changes in values obtained for Simpson's diversity index (D) and Shannon-Wiener diversity index (H') at each Bay site.

and sandstone composition (poor substrate for attachment) mean that usually dominant species like *Chthamalus stellatus* (Poli, 1791) and *C. montagui*, Southward, 1976 (here grouped as *Chthamalus* spp.), are reduced in density and therefore overall equitability is quite high. This may also be compounded by the proximity of urban and industrial effluents. The same explanation of high equitability can be extended to account for the peak at site B8 but the reasons for it are very different. Inspection of the species' dataset for this site show that unusually high numbers of Mussels (*Mytilus* spp.) are present, together with relatively low numbers of upper-shore Barnacles (*Chthamalus* spp.). These, together with *Littorina neritoides* (Linnaeus, 1758), form a dominant subgroup that have very similar numerical densities and consequently raise the overall site diversity.

Site B8 is very exposed, facing directly out into the open Mediterranean and the strong and regular levanter (easterly) winds. However, the sea-bed is sandy and slopes gently away from the coast, so that approaching waves arrive as surging breakers. This might help to explain the high densities of *Mytilus* spp., as direct impact on the lower and middle shores would be reduced, whilst enhancing transport of nutrients and materials. This set of conditions could allow this species to become the dominant monopolizer of space at this shore level. In the upper shore very high numbers of the related barnacle *Chthamalus depressum* (Poli) almost seem to replace *Chthamalus* spp. at upper shore levels. *C. depressum* has specific adaptations that allow it to inhabit the topmost levels of the upper shore, but its densities are usually low compared with *C. stellatus* and *C. montagui*. The existence (or not) of some form of interaction between these barnacles would need to be proven but it does appear that in this site, conditions are somehow more suitable for *C. depressum* which in turn cause the increase in overall equitability.

In general, the blanket application of diversity indices provide little information regarding the composition of communities. However, when taken into account together with other parameters such as *S* diversity indices can allow a measure of inference

with regard to the general degree of equitability within each site, which in turn allows a degree of speculation as to possible structuring parameters to be attempted.

**Results for Seawater Parameters**

Only some of the more noteworthy results are covered in this section. The reader is directed to Fa, (1998) for the complete set of results.

The values obtained for Sea Temperature and pH are shown in Fig. 5. An expected result is the increased water temperatures as one moves further into the Bay, probably due to reduced water movement. In contrast, the values for pH are highest outside the Bay and fall within. Rises in pH are usually linked to increased levels of CO<sub>2</sub>. Unless this is the case at sites outside the Bay (unlikely due to increased hydrodynamism and aeration), it may be that anthropogenic throughputs into the Bay of an alkaline nature may be affecting this balance.

Fig 6 Shows the results obtained for Oxidation-Reduction Potential and Salinity. Both of these parameters show an increase within the Bay with respect to the general trends identified previously.

Similarly, the three measures of exposure; regional exposure angle, local exposure angle and Thomas' index (T) decreased into to Bay (Fig 7).

Fig. 8 shows the results obtained for Phosphates and Biological Oxygen Demand. Both of these variables show similar distributions, and show particularly high values at sites B3 and B5. Both of these sites are close to river estuaries and to sewage outfalls.

As regards Nitrates and Nitrites, the most noticeable results in the values obtained are the highly elevated levels of both these parameters in site B3, probably due to the combined industrial/sewage and other outflows close to this site (see Estacio *et al.*, 1997).

Our index of Anthropogenic stress gave higher values within the Bay, although it must be remembered that similar values need not be due to similar processes.

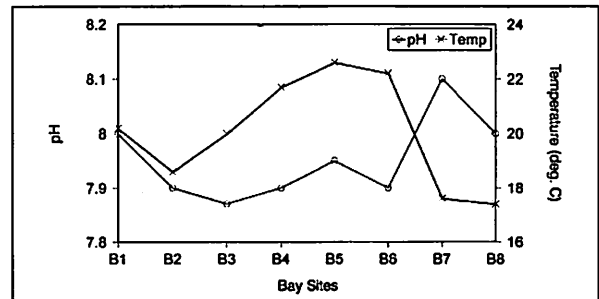


Figure 5. Values obtained for seawater temperature (°C) and pH at each of the Bay of Gibraltar sites.

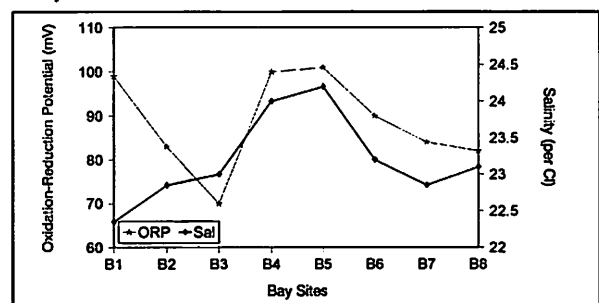


Figure 6. Values obtained for oxidation-reduction potential (mV) and salinity (per Cl) at each of the Bay sites.

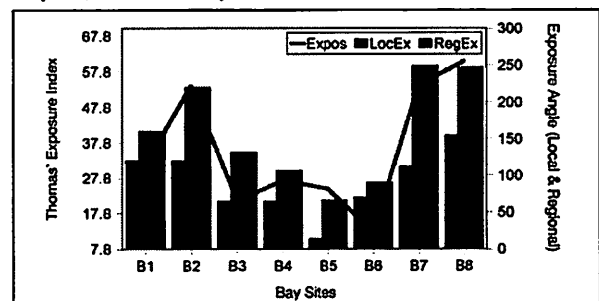


Figure 7. Values obtained for Thomas' exposure index (Expos), regional (RegEx) and local (LocEx) exposure angles at each of the Bay of Gibraltar sites. Note that very similar results were obtained for all three parameters throughout.

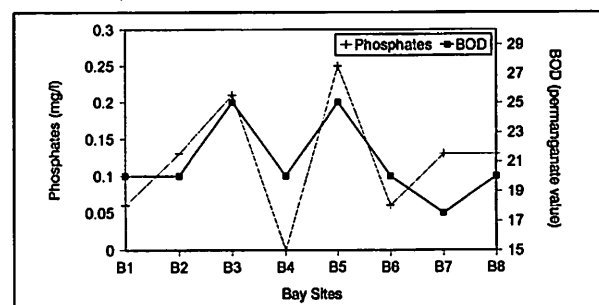


Figure 8. Values obtained for Phosphates (mg/l) and BOD at each of the sites sampled.

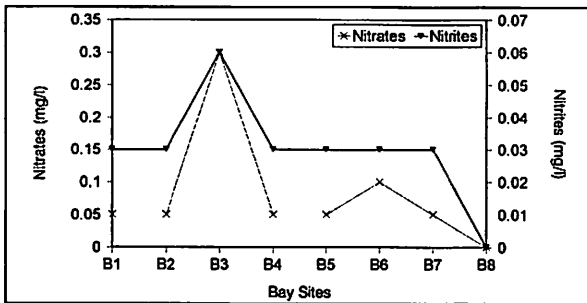


Figure 9. Values obtained for Nitrates and Nitrites (mg/l) at each of the Bay of Gibraltar sites.

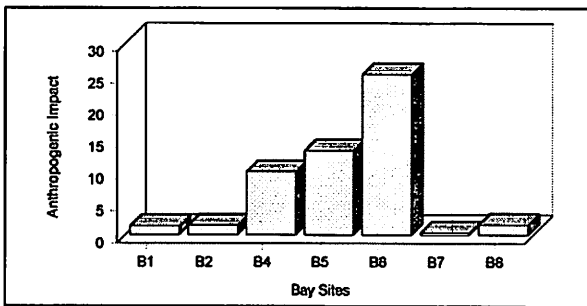


Figure 10. Values obtained for index of Anthropogenic stress at each of the sites. Note the higher values within the Bay.

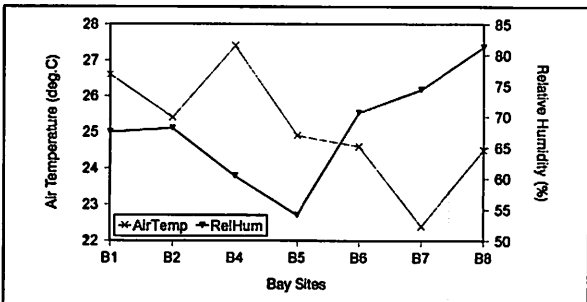


Figure 11. Values obtained for air temperature (°C) and relative humidity (%) at each of the Bay of Gibraltar sites.

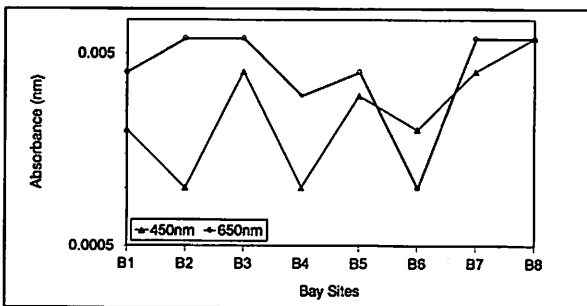


Figure 12. Values obtained for absorbance of the seawater at 450 and 650 nm at each site.

In Fig. 11, air temperature seems to be falling from east to west, whilst the reverse is true of relative humidity. In retrospect this result is not surprising, as during the summer months the prevailing easterly winds create a standing cloud above the Rock of Gibraltar. This cloud greatly increases the humidity levels in the area of the Rock and has already been suggested as a possible factor in affecting the osmotic balance of the Rock's littoral organisms (Fa, 1990).

Finally, absorbance at 450nm and 650nm had been selected as an important factor structuring littoral communities at biogeographical scales (Fa, 1998). In Fig. 12 it can be seen that absorbance at 450nm fluctuates more along the west side of the Bay, with the reverse being the case for absorbance at 650nm, which is relatively constant along the western coast.

### Results obtained for Biotic – Abiotic analyses

The cluster analysis (Fig. 13) shows that most sites are very similar (> 60%), but a clear pattern still emerges. There seems to exist an east-west dichotomy in the Bay, i.e. sites B1 to B3 on the east cluster closely as do sites B5 to B8, but the order of relative similarity is surprising. The most similar sites are B1 and B2, which are Tarifa and Punta del Carnero, respectively. Around this discrete cluster a number of sites arrange themselves in order of decreasing similarity. However, the next most similar sites are not at adjacent locations along the Bay, but rather the sites that are farthest, i.e. a cluster composed of two subclusters: sites B7 and B8, and sites B5 and B6 respectively. Similarity then continues to decrease as we move further into the bay, with B3 being the next in line and the most dissimilar site being the innermost, B4 (similar results were obtained by Conradi Barrena (1995) in her study of peracarid spatiotemporal distributions in the Bay).

This result of decreasing similarity into the Bay may be due to a number of reasons such as the proximity of the Guadarranque and Palmones rivers to sites B3 and B4, low hydrodynamism due to nearby coastal developments, high pollutant levels from adjacent industrial sources or other anthropogenic effects. However, similar arguments could be extended to site B5, and an objective analysis of possible

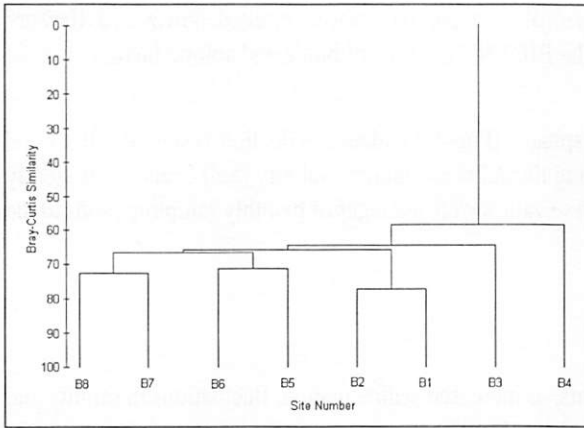


Figure 13. Cluster analysis obtained using the Bray-Curtis index of similarity for the eight Bay sites.

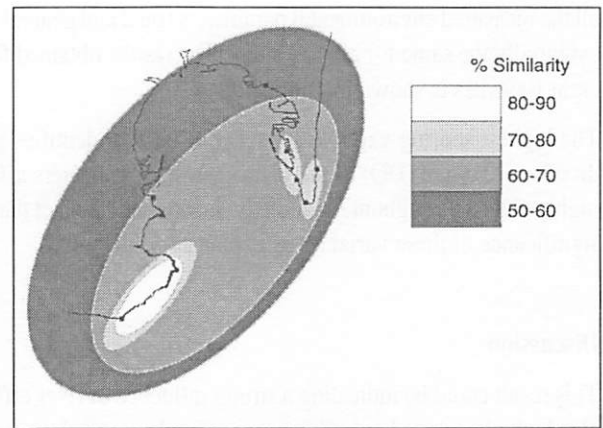


Figure 14. Similarity contour plot of the Bay sites. Note how similarity decreases into the Bay. However, the overall degree of similarity was very high between sites, with no two sites falling below 50% similarity.

k	Best combinations of Environmental Parameters:				
1.	Phos (0.486)	RelHum (0.471)	DO (0.349)	IAp (0.288)	LocEx (0.278)
2.	IAp RelHum (0.549)	Phos RelHum (0.520)	DO RelHum (0.508)	DO IAp (0.487)	DO LocEx (0.480)
3.	Phos IAp RelHum (0.610)	DO RegEx RelHum (0.579)	DO IAp RelHum (0.567)	Slope DO IAp (0.559)	
4.	Phos Slope DO IAp (0.607)	Phos DO Sal IAp (0.591)	Phos DO IAp RelHum (0.580)	Phos LocEx IAp RelHum (0.569)	
5.	Phos Slope DO IAp AirTemp (0.623)	Phos Slope DO Sal IAp (0.606)	Phos DO IAp Anthrop RelHum (0.585)		
6.	Phos DO Sal IAp Anthrop RelHum (0.609)		Phos DO Sal IAp Anthrop AirTemp (0.596)		
7.	Phos Slope Orient DO Sal RegEx Anthrop (0.620)		Phos Slope DO Sal IAp Anthrop AirTemp (0.611)		
8.	Phos Slope Orient ORP DO RegEx IAp RelHum (0.650)		Phos BOD Slope Orient Sal RegEx IAp Anthrop (0.611)		
9.	Phos Slope Orient DO Sal RegEx IAp Anthrop RelHum (0.645)				
10.	Phos Slope Orient DO Sal LocEx RegEx IAp Anthrop RelHum (0.619)				
11.	Phos Slope Orient ORP DO Sal LocEx RegEx IAp Anthrop RelHum (0.619)				
12.	Phos BOD Slope Orient ORP DO Sal LocEx RegEx IAp Anthrop RelHum (0.582)				

Table 2. Results of the BIOENV analysis carried out for seven Bay sites (unfortunately site B3 was excluded from the analysis as it was not possible to measure all relevant parameters at this location). Only up to the twelve highest-scoring variables are shown.

structuring parameters is required. In order to observe these relationships more clearly, the similarity data were plotted as contours which were superimposed on the map of the study sites (Fig. 14). Thus, sites with high similarities share similar contours, allowing a direct geographic perspective to bear.

In order to investigate possible reasons for the patterns observed, an MDS analysis was performed on the data for all sites. Both the 2 and 3-dimensional MDS plots show a clear gradient from outer sites towards the interior of the Bay. Moreover, the 3-dimensional MDS also suggests an east-west gradient with western sites appearing lower in the ordination than eastern sites.

In attempting to elucidate the main factors affecting these distributions was achieved using the BIOENV extension to the PRIMER package. In order to investigate what parameters could be causing this, a BIOENV analysis was carried out using

all the measured environmental parameters (tidal and general meteorological parameters were omitted, however, as they are essentially the same for all Bay sites). The results obtained for the BIOENV analysis of biotic and abiotic factors over the eight Bay sites is shown in Table 2.

The highest-scoring variable subset ( $r_s = 0.650$ ) identifies phosphates (Phos), Oxidation-reduction potential (ORP) and dissolved Oxygen (DO) as the main seawater parameters affecting littoral communities. Salinity (Sal) is also consistently highly placed throughout. As already mentioned, the fact that these values were averages of monthly samplings adds to the significance of these variables as explanatory factors.

### Discussion

This result could be indicating a strong influence of river effluents, as increased sedimentation, fluctuations in salinity and also high phosphate loads (due to runoff and seepage from agricultural fertilizers) are to be expected close to river mouths (Camiñas, 1987; Gil Fernandez, 1987). Regional exposure angle (RegEx), shore slope (Slope) and orientation (Orient) indicate the importance of exposure (LocEx also placed highly but surprisingly, neither of the two exposure indices used placed in the final parameter subsets, possibly due to the similarity in wind direction and strength across the Bay sites). Such exposure-based parameters can now be seen to assume a greater importance as predicted by Lewis (1964), but only after the effective removal of tidal variation between sites. Other factors such as Index of area of pits (IAp) and relative humidity (RelHum), point towards an increased influence of site-specific complexity-based parameters in the structuring of communities over local scales. This is in keeping with results obtained over larger scales and highlights the importance of these variables.

Finally, Anthropogenic stress (Anthrop) also placed highly throughout the BIOENV analysis, although it did not form part of the highest-scoring subset, indicating that anthropogenic activities do have an important effect on the composition of littoral biotas, although the exact nature of these could and probably do, vary along the Bay. This is further corroborated by the high placing also obtained by biological oxygen demand (BOD), indicative of high bacterial action and often an indicator of sewage pollution. See Camiñas (1987), for a more detailed discussion of the various anthropogenic impacts on the Bay.

Notwithstanding, one must always remember that correlation does not necessarily mean causality (Pianka, 1988). Highly correlated variables may simply be covariant by chance or the variables may be functions of another variable (Sokal & Rohlf, 1995) and moreover may be collinear with other, unmeasured parameters (Clarke, 1993; Clarke & Ainsworth, 1993 - although in this instance they provide a highly plausible set of explanatory variables). Moreover, it may well be possible that some important structuring parameter varied significantly over larger temporal scales, was not measured (e.g. pollutants such as hydrocarbons or tributyltins), or that the ways in which these were measured was not valid or representative. Consequently, the results of temporally limited observational field studies such as this one need to be further investigated by extending such an analysis to include more parameters and monitoring these more frequently, hence our conclusions can only be taken as preliminary observations. These would in turn need to be followed up by direct manipulation and experimentation which in any case carry their own caveats and difficulties of interpretation (Underwood & Peterson, 1988).

We conclude that although similar to results obtained for the similar analyses at provincial, and to a lesser extent, biogeographic scales (Fa, 1998), it does appear that patterns at the local scale in the Bay of Gibraltar are to a large extent controlled by intermediate-scale phenomena such as river and urban effluents and the effects of related variables, rather than larger-scale patterns of productivity or temperature.

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