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ENVIRONMENTAL GRADIENTS IN A SOUTHERN EUROPE ESTUARINE SYSTEM: RIA DE AVEIRO, PORTUGAL IMPLICATIONS FOR SOFT BOTTOM MACROFAUNA COLONIZATION

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KEY WORDS: environmental gradients; benthos; multivariate analysis; estuaries; Portugal.

ABSTRACT

Four seasonal sampling surveys were carried out between December 1985 and September 1986 in Canal de Mira (Ria de Aveiro, Portugal). A total of 40 sampling stations, distributed over 13 transects, was used. Salinity, temperature, dissolved oxygen and pH of the water mass were measured. Sediment temperature, and salinity and pH of interstitial water were determined. Sediment variables also included granulometric composition and organic matter contents. Bottom macrofauna samples were collected at each station.

Ordination (PCA and MDS) and classification of the sampling stations were performed, using the physicochemical and the biological data sets separately. Average linkage cluster analysis using the unweighted paired-group method, arithmetic averages, was used for both sets of data.

With a salinity range from 35.1‰ to 0.0‰, Canal de Mira behaves like a tidally and seasonally poikilohaline estuary. Water temperature (8.5 - 24.7°C) decreased along the channel towards its inner part during the cold season; an inverse and more pronounced trend was observed during the hot season. Dissolved oxygen contents was generally high during the day (50% to 240% saturation). Oversaturation was observed throughout the growing season, with peaks in areas with large amounts of rooted vegetation. The pH values, largely correlated with dissolved oxygen, ranged from 6.8 to 8.9. Four types of sediment were present in Canal de Mira, medium and muddy sands being dominant.

Two major gradients were identified: (i) a typical longitudinal estuarine gradient, associated with distance from the mouth, representing physicochemical variables such as tidal amplitude, salinity and temperature; this gradient was accompanied by an upstream increase in dominance; the community composition changes were mainly related to salinity; (ii) a lateral gradient, related to current velocity, depth and sediment composition; the subtidal community had a comparatively low species richness and abundance. Groups of stations could be recognized along the environmental gradients. Benthic community changes, however, appeared to be gradual rather than marked by abrupt transitions.

INTRODUCTION

Ria de Aveiro is one of the most outstanding estuarine features on the Portuguese coast. In spite of its environmental, social and economical importance, little biological research has been undertaken in this estuarine system. The most comprehensive work, dating from the beginning of the century, is the one by NOBRE *et al.* (1915), followed by scattered reports and some published works. Recent publications on bottom macrofauna are VIEIRA and FONTOURA (1985), MOREIRA (1988) and QUEIROGA (1990).

The lagoon is subject to considerable pollution stress, ranging from eutrophication of the most remote and enclosed arms, through microbiological

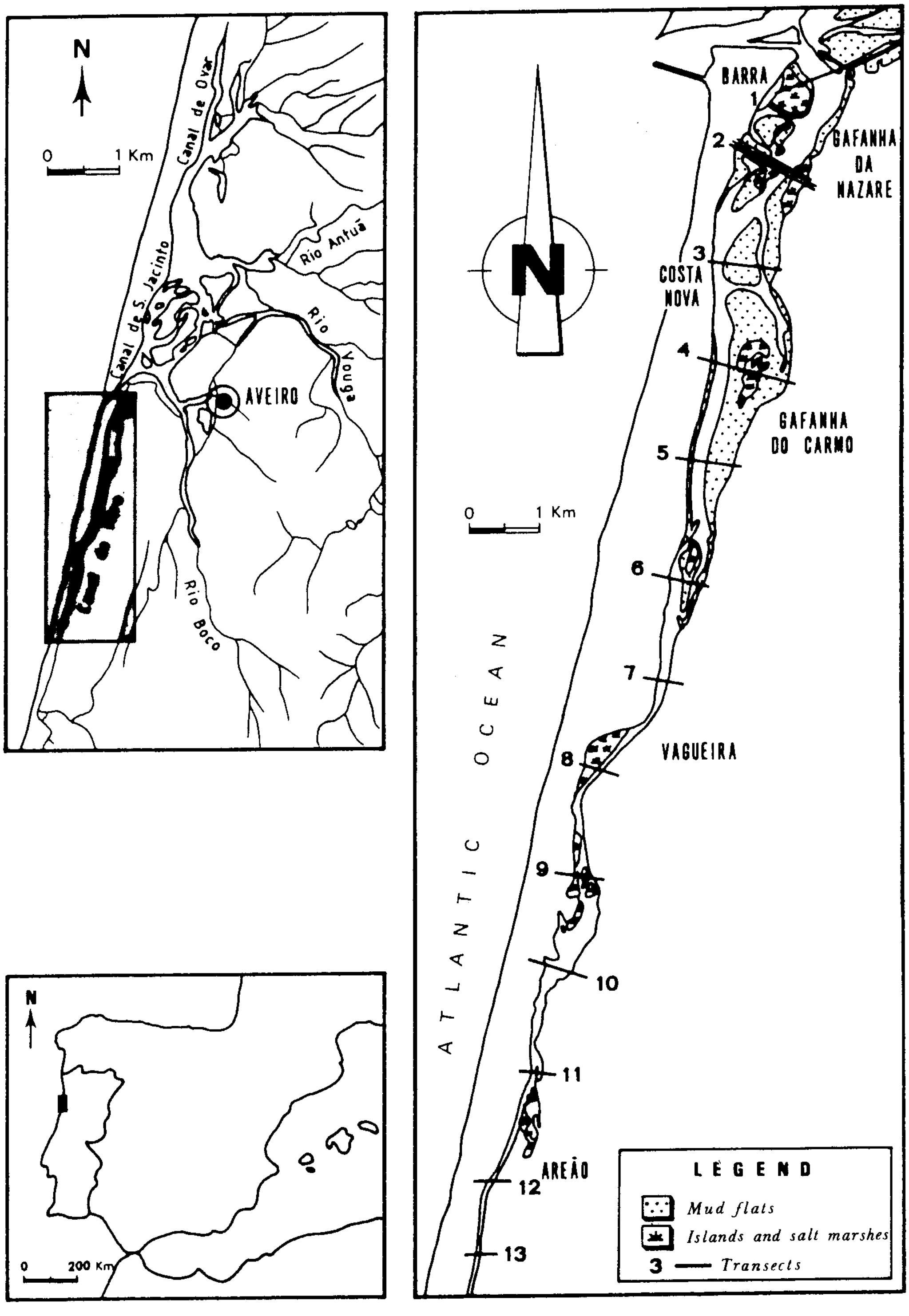

Fig. 1. Ria de Aveiro and Canal de Mira, Portugal, showing site of transects.

contamination from large discharges of untreated sewage to industrial pollution. The latter includes the effluents of a considerable number of light industries scattered throughout the catchment area, of two paper mills and of a chemical complex. HALL (1982) provides a general overview of the water quality problems in the lagoon. Pollution problems caused by industrial effluents are more acute in the northern and central parts of the lagoon.

In order to obtain baseline data concerning the composition and structure of the macrozoobenthos communities and the physical and chemical parameters of water and sediments, a study was undertaken in Canal de Mira. This is a southern arm of the lagoon, least affected by pollution. This study provides information which will be helpful for future comparative studies in areas with more acute pollution problems. The present paper describes the major physicochemical and biological gradients prevailing in Canal de Mira.

Study area

Ria de Aveiro (Fig. 1) is a shallow coastal lagoon on the west coast of Portugal, separated from the sea by a sand bar. Its mouth is artificially maintained. It can be classified as a bar-built estuary (PRITCHARD, 1967).

The lagoon, a very recent geological feature, developed through marine sediment transport along the Portuguese coast and by deposition of solids carried by rivers. These mechanisms have not yet attained an equilibrium and the present tendency is to silt up.

The topography is rather complex. The three main channels which radiate from the mouth with several branches, islands and mudflats, form an intricate system of bays and channels. Of the rivers discharging into the lagoon, River Vouga is the most important, accounting for 2/3 of the total river input.

With a maximum length and width of 45 and 10 km, the lagoon covers an area of 47 and 43 km^2 at high and low tides, respectively. Exchange of water with the sea dominates the hydrological circulation. The volume exchanged during a tidal cycle is about $25 \cdot 10^6$ m^3 for tides with 1 m of amplitude, and increases to $70 \cdot 10^6$ m^3 when the tidal range is 2.5 m, while the mean total river discharge is only $1.8 \cdot 10^6$ m^3. The tidal wave is considerably distorted as it progresses inside the lagoon. With increasing distance from the mouth, the tidal amplitude decreases and the duration of flood becomes shorter than that of ebb. Tidal time delay, relative to the mouth, may reach 6 hours or more in the far reaches of the lagoon (BARROSA, 1985; VICENTE, 1985).

Canal de Mira, which is the second channel in terms of average width, runs south-southwest from the mouth for 25 km, parallel to the coast. This channel can be considered a small estuary in itself. Due to a headland separating the entrance channel in two different arms (Fig. 1), about 20% of the tidal prism of a flowing tide is diverted to Canal de Mira (VICENTE, 1985). Other communications with the system are negligible. At the opposite end, Canal de Mira receives continuous freshwater supply through a small system of lagoons and streams.

METHODS

Sampling strategy

The sampling strategy included 13 transects, spaced by 1.5 km intervals (Fig. 1). To each transect 1 to 5 sampling stations were allocated, according to its width, making up a total of 19 subtidal and 21 intertidal stations. Fig. 2 shows the location and depth of each station in each transect. Transects were numbered from north to south and stations, within each transect, from west to east. Thus station 3.4 is, the fourth station of transect 3.

All stations were sampled in December 1985, March, June and September 1986 in order to reflect the seasonal ecological conditions.

Biological and sediment samples were collected simultaneously at each station. Physical and chemical parameters of the water mass were also measured during each sampling survey. Measurements were taken at the deepest point of each transect, 0.5 m below the surface and at the same distance from the bottom, at the expected times of high and low water. These were obtained by linear interpolation of the time corrections for several points along Canal de Mira, calculated from the tables provided by the Port Authority. In order to obtain comparable measurements of high and low water conditions for a mean amplitude tide, over all the transects and throughout the seasons, all readings at high and low water should be taken during the same half-cycle of a mean amplitude tide, which, in the mouth of Ria de Aveiro, averages 2 m. This would provide 'instantaneous' longitudinal profiles of water characteristics in Canal de Mira. In practice, two or three half cycles of mean amplitude tides were used to obtain each profile.

Water mass

Salinity, temperature, dissolved oxygen and pH of the water were recorded. In December 1985 and

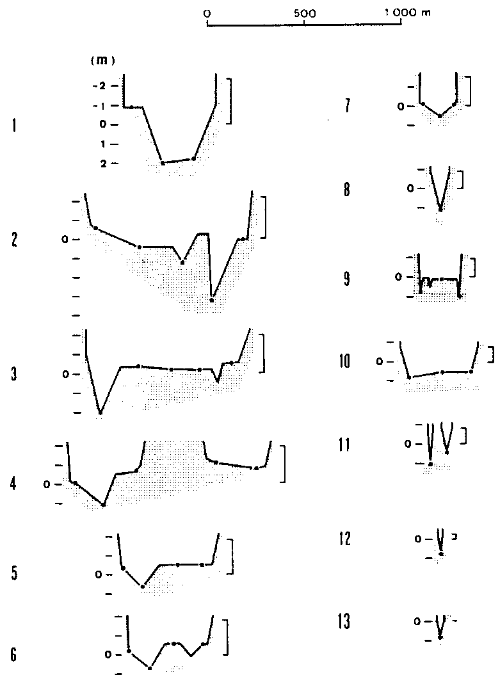

Fig. 2. Approximate channel bed profiles at each transect in Canal de Mira. Only the depth at each station (dots) is accurate. Point 0 in the vertical scale represents the low tide level of a mean amplitude tide; vertical bars represent the tidal amplitude for the same mean amplitude tide.

March 1986 samples of surface and bottom water were taken with a horizontal 5 l Van Dorn bottle. Salinity was measured with an American Optical Instrument Company, model TC 10402 refractometer. Oxygen was determined by the Winkler method (STRICKLAND and PARSONS, 1972) and temperature was measured with a mercury thermometer placed inside the waterbottle. In the other sampling surveys, salinity and temperature were determined with a Yellow Springs Instrument (YSI) model 33 SCT meter and oxygen with a YSI model 57 oxygen meter. The pH was always measured in the laboratory from samples collected with the Van Dorn bottle, using a Radiometer (Copenhagen) model PHM 62 standard pH meter.

Sediment

Intertidal stations were sampled at low tide. Sediment temperature at 2.5 and 10 cm depth was taken with a mercury thermometer. Samples of interstitial water were obtained by allowing water to accumulate in the holes left by a 0.05 m^2 hand-operated Birge-Eckman grab used for the macrofauna sampling. In very compact dry sediments, only water remaining in pools at the surface of the sediment could be taken. A core of sediment, 4 cm in diameter and 20 cm deep, was taken for granulometric analysis. A portion of sediment, collected along the length of the core, was kept separately for determination of organic matter content.

At subtidal stations, samples of sediment were obtained with a 0.05 m^2 Van Veen grab with 1 mm mesh brass sieve covered windows. These windows enable water to pass through the gear on its way down, so reducing the shock wave as it hits the bottom. Rubber flaps over the windows prevent the disturbance of the contents when the grab is pulled up. A hinged edge of one of the windows allows access to the inside.

Sediment temperature at 2.5 cm was recorded. Interstitial water was obtained using a 100 ml syringe imbedded in the sediment. When this procedure did not allow an appropriate amount of water to be collected, a sample of the water contained in the grab was taken. It was assumed that this sample would represent the water just above the bottom. Adequate quantities of sediment were collected along the maximum height of the grab for granulometric and organic matter analysis.

Interstitial water samples were analyzed in the laboratory. pH readings were taken with the standard pH meter. After allowing the sample to settle, salinity was measured with the refractometer.

Sediment samples were frozen until the moment of analysis. Only those obtained during December 1985 were analyzed for granulometric composition. The samples were homogenized and a portion of 150 – 200 g was treated with H_2O_2 and, then, dried in an oven at 105°C to constant weight. A set of 8 sieves, with mesh sizes corresponding to integer values of the Wentworth scale in the range of -3 to 4 Φ (8000 to 63 μm), was used. Mechanical agitation was provided for 25 min with a Retsch Sieve Shaker. Frequency of each grade was expressed as percentage of total weight. Samples used for organic matter determination were also homogenized and about 5 g were used for analysis. The difference between dry weight at 105°C and ash weight at 450°C, expressed as percentage of total dry weight, was taken as a measure of the amount of organic matter present in the sediment.

Sediments were classified according to the following criteria: (i) sediments having >5% silt and clay (particles less than 63 μm diameter) were considered as muddy sediments, and those with less than 5% of this fraction as sands (LARSONNEUR, 1977); (ii) muddy sediments having <25% silt and clay were named as muddy sands, and those with 25 – 75% as sandy muds (LARSONNEUR, 1977); (iii) sands were classified with respect to the median diameter of the particles in Phi (Φ) units, and following the nomenclature of the Wentworth scale (MORGANS, 1956).

In order to characterize the sediments collected in Canal de Mira with regard to deposition processes, a CM diagram was constructed (PASSEGA, 1957), where C is the maximum particle size and M is the median diameter of the particles. To minimize estimate errors, the 95 percentile was used as C.

Biological sampling

Three random replicates were taken at each station, using the Van Veen grab for the subtidal and the Birge-Ekman grab for the intertidal stations. The samples were sieved in bags of 1 mm nylon net. Menthol crystals were added to the collected material to cause relaxation of the animals, thus facilitating identification. The organisms, preserved in 10% buffered formaldehyde, were sorted later, counted and, with a few exceptions, identified to species level.

Multivariate statistical methods

In order to describe the main gradients prevailing in Canal the Mira, a classification and an ordination analysis of the sampling sites were carried out, using the physicochemical data and the biological data separately.

In the case of the physical and chemical parameters the variables used in the data matrix were: depth, tidal amplitude, percentage of each granulometric fraction and, for the four sampling occasions, salinity of interstitial water, temperature at 2.5 cm, pH and organic matter contents of the sediments. The percentage of each granulometric fraction and of organic matter was submitted to the angular transformation (SOKAL and RHOLF, 1969). Missing values were substituted by the average. All the variables were standardized (mean = 0; variance = 1). For the classification, an average linkage cluster analysis, using the unweighted pair-group method, arithmetic averages (UPGMA), based on Euclidean distances, was used. As ordination technique principal components analysis (PCA) was used, where eigenvalues and eigenvectors were computed from a Pearson correlation matrix (SNEATH and SOKAL, 1973; LEGENDRE and LEGENDRE, 1979, GAUCH, 1982).

In the analysis based on the biological data, the total number of individuals of each species collected at each station in the four seasonal surveys was used. Species that occurred only at one sampling station with less than 5 individuals were excluded. Values were transformed to square roots. The classification method was UPGMA based on Morisita's similarity index (KIKKAWA and ANDERSON, 1986). Multidimensional scaling (MDS) was chosen as the ordination technique because of its advantages in the analysis of biological gradients (LUDWIG and REYNOLDS, 1988).

RESULTS

Water mass

Differences between surface and bottom salinity, temperature, oxygen and pH values were, if any, of very little magnitude. It can, therefore, be postulated that vertical gradients are negligible relative to longitudinal variations. Consequently, the results are presented and analyzed on the basis of the average of the surface and bottom values.

Fig. 3 shows the longitudinal profiles of salinity and temperature in the channel at high and low waters for each sampling survey. Fig. 4 presents the course of air temperature and precipitation throughout the study period. The raw data were provided by the meteorological station located on the campus of the University of Aveiro, about 5 km from Canal de Mira. Salinity varied between 35.1‰, recorded at high tide at Transect 1 in December 1985, and 0.0‰, recorded in March, both during high and low tides, at the far reaches of the channel. Salinity profiles changed considerably throughout the year, according to freshwater input. In December 1985, after a period of autumnal moderate precipitation, salinity declined steadily along the channel, from 35.1‰ at high tide in Transect 1, down to 0.1‰ in the two last transects. In March 1986, after a long period of heavy rainfall, salinity at high tide did not exceed 26.7‰ at Transect 1, and declined sharply down to less than 5.0‰ at Transect 6. At low water, salinities higher than 5.0‰ did not reach Transect 3. Throughout the dry season (June and September surveys) salinities over 18‰ extended, during high tide, up to about 15 km from the mouth and then fell down quickly, after Transect 9. According to its salinity regime Canal de Mira can, therefore, be considered like a tidally and seasonally poikilohaline estuary. BOESCH (1977) questions the applicability of the Venice system to estuaries of this kind. It seems, however, reasonable to distinguish the following three main sections in Canal de Mira: (i) the lower section, extending up to Transect 3, with salinities ranging, between tides, from values higher than

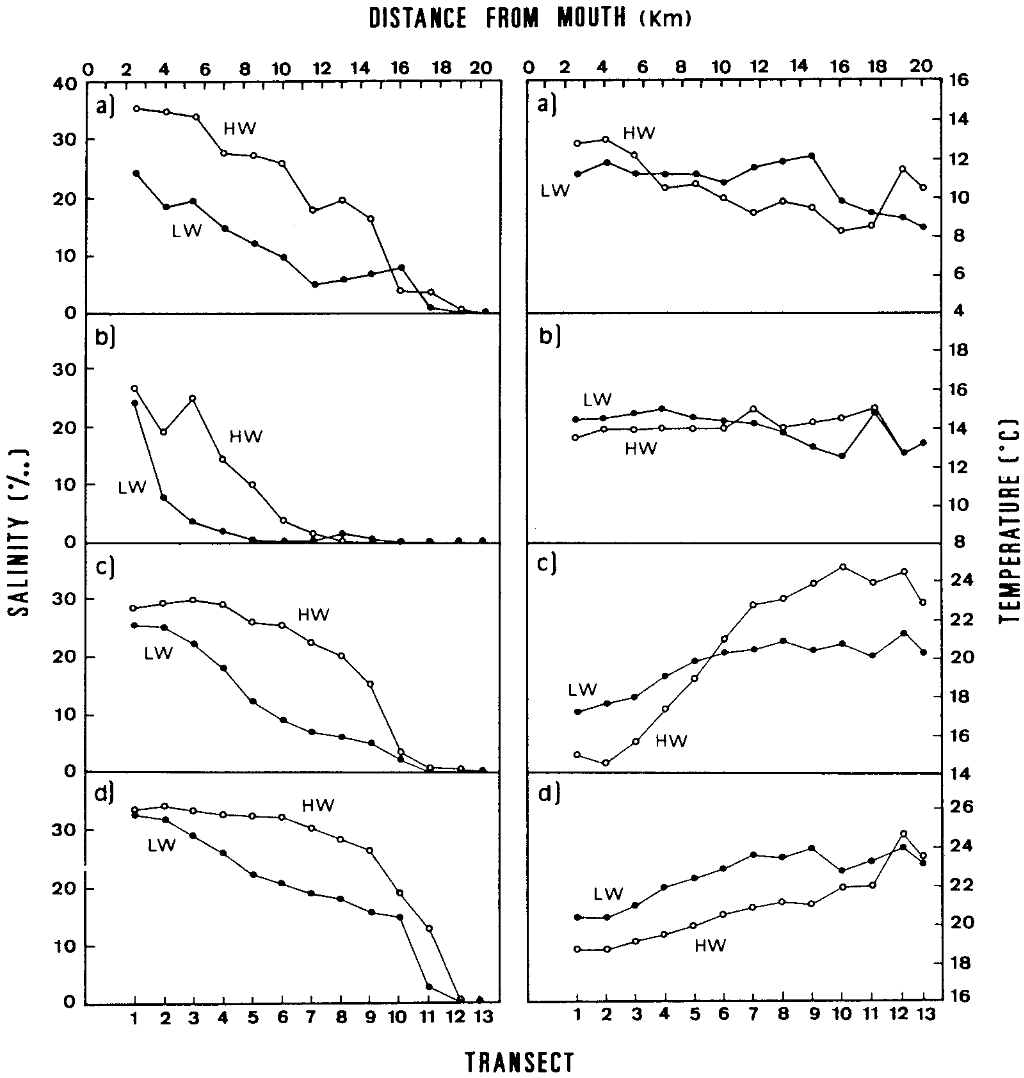

Fig. 3. Canal de Mira. Salinity and temperature longitudinal profiles at high and low waters: a) December, b) March, c) June and d) September.

18‰ to 30-35‰ for most of the year; (ii) a middle section with a highly variable salinity regime; (iii) an upper section, from about Transect 12 inwards, with salinities not higher than 0.1‰ all year round.

Water temperatures varied from 8.3°C, recorded in December 1985 at Transect 10, during high tide, to 24.7°C, recorded in June at the same transect also at high tide. Temperature profiles in the channel changed considerably with the season, in a similar way as in other northern temperate estuaries (PRITCHARD, 1952; GARVINE, 1975; ANDRADE, 1986). Water temperature declined from the mouth inwards in December, was approximately constant along the channel in March, and rose steeply towards its far end during the hot season (June and September). While the difference in the water temperature between the mouth and the end of the channel was about (-)5°C in the cold season, it

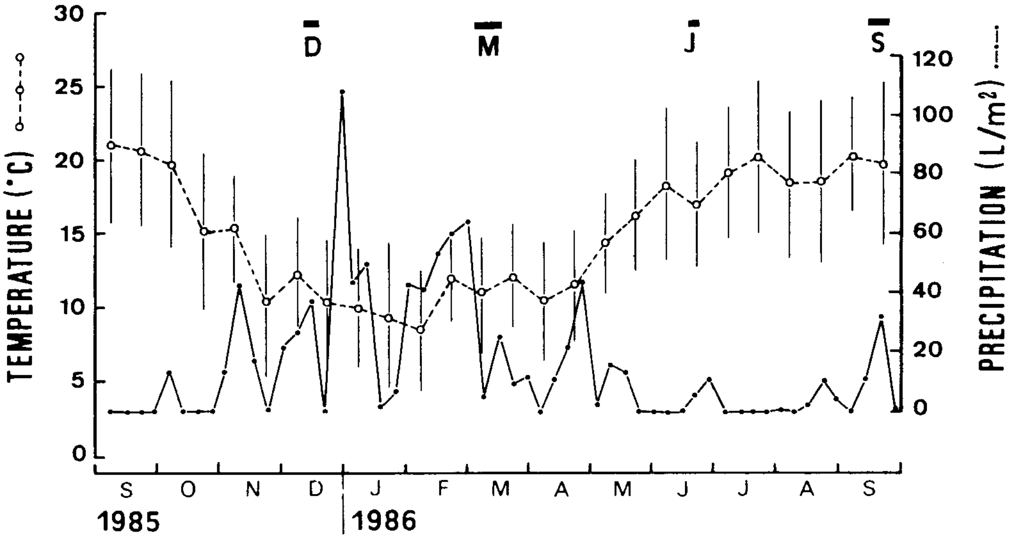

Fig. 4. Air temperature and precipitation in Aveiro, from Sept. 1985 to Sept. 1986. The temperature curve shows the overall daily average air temperature for two-week periods; vertical bars indicate average maximum and minimum temperatures. The precipitation curve shows weekly accumulated rainfall. Horizontal bars on top of the figure represent the sampling periods.

reached (+)10°C on hot summer days. Besides the well known different thermic behaviour of sea and river waters, the small average depth of the channel and the large area of its intertidal flats, contribute to the magnitude of the difference.

Longitudinal profiles of dissolved oxygen (% saturation) and pH measured in Canal de Mira at low and high tides, in the four sampling occasions, are shown in Fig. 5. By late winter (March 1986), the oxygen levels were nearly constant and close to saturation along the channel. In the three other surveys, a large variation in the oxygen levels was observed, with oversaturation values in the middle reaches of the channel in December 1985, in its inner part in July 1986, and from the middle inwards in September 1986. The highest saturation value (240%) was measured in September, during low water, at about 15 km from the mouth (Transect 9). The lowest values, close to 50% saturation, were recorded in December at low water, in the inner part of the channel. The oversaturation values were related to high photosynthetic activity, not only by phytoplankton but also by the large amount of rooted vegetation, which was dominated by *Myriophyllum aquaticum, M. spicatum, Potamogeton crispus, P. nodosus, P. pectinatus* and *Zannichellia obtusifolia* (A. Pereira, pers. comm.). These species proliferated from spring to autumn mainly between Transects 9 and 11. In this period of the year, oxygen declined to very low values throughout the night, down to about 2 mg^{-1} in the summer (CUNHA, 1990).

The pH values varied from 6.8, recorded at Transect 7 in September, to 8.9, at Transect 13, in June. In the outer part of the channel, up to Transect 5, pH values tended to be fairly constant. With only one exception, the values recorded in December, March and June, varied between 7.5 and 8.3. In the same stretch, pH values were slightly lower (6.8-7.5) in September. From Transect 6 inwards, a larger variation in pH was observed, with peak values located in about the same area as the oxygen oversaturation values. The O_2 and pH variations appeared therefore to be closely connected, as observed by MEYBECK *et al.* (1988) and RELEXANS *et al.* (1988).

Sediments

Fig. 6 shows the cumulative frequency curves constructed from the granulometric analysis of the sediments collected in December 1985, at each sampling station. In Canal de Mira the different types of sediments appeared to be restricted to only four classes: medium and fine sands, muddy sand and sandy mud. The dominant sediment types were medium sand and muddy sand. Fine sand was

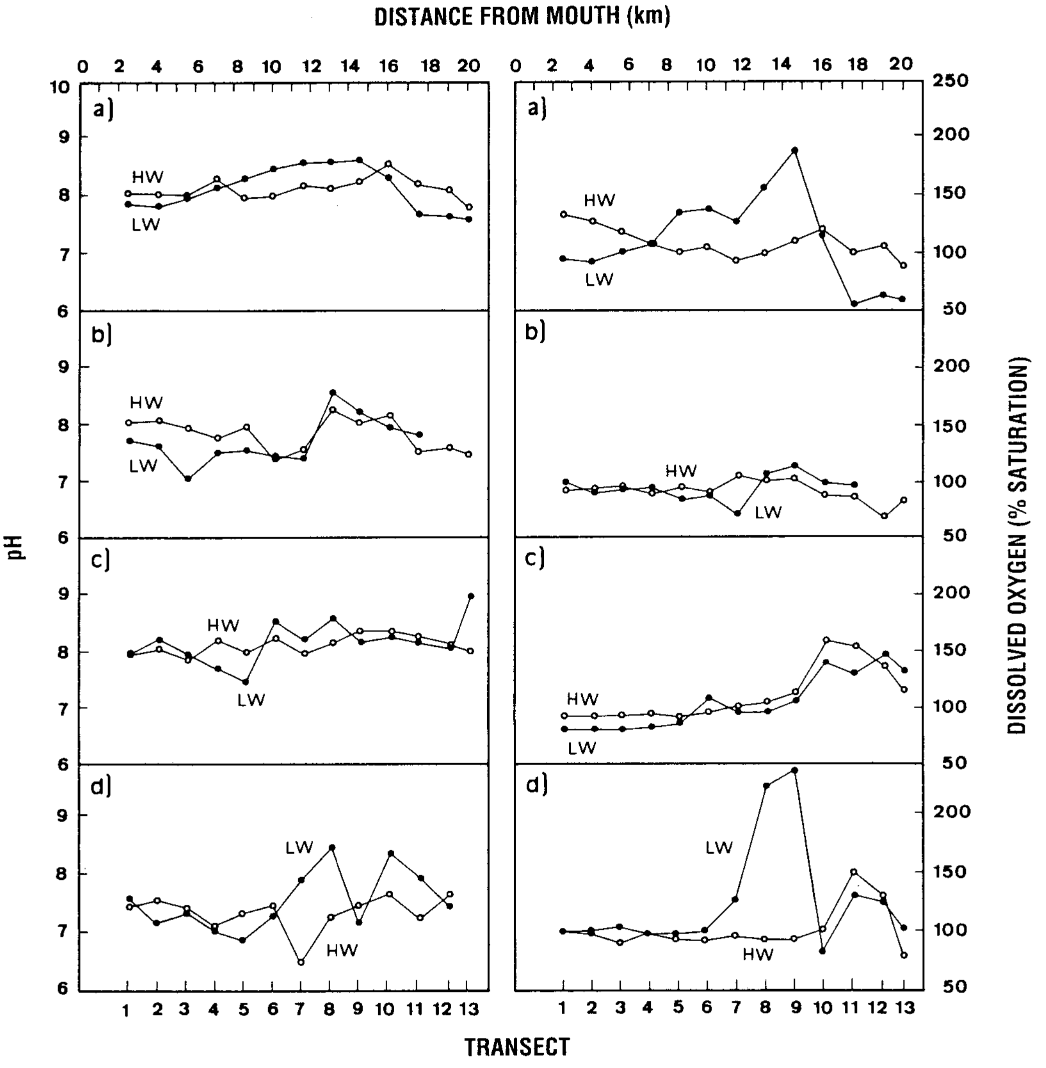

Fig. 5. Canal de Mira. pH and dissolved oxygen (% saturation) longitudinal profiles at high and low waters: a) December, b) March, c) June and d) September.

represented by only 1 sample. Sandy mud occurs in 7 out of the 40 sampled stations.

Three segments corresponding to three main depositional processes are indicated on the CM diagram (Fig. 7). Segment P represents the coarsest material, with C values higher than 1000 μm, which would most probably be transported by traction, rolling on the channel bed. All the samples with non-terrestrial material (shells) belong to this segment. Segment Q, limited by C values of 1000 and 200 μm is approximately parallel to the limit C = M, indicating that C is proportional to M. Sediments within this segment may result from a double sorting effect: transportation in suspension imposes an upper limit to C, while sedimentation deposits mostly the coarsest particles. Segment R

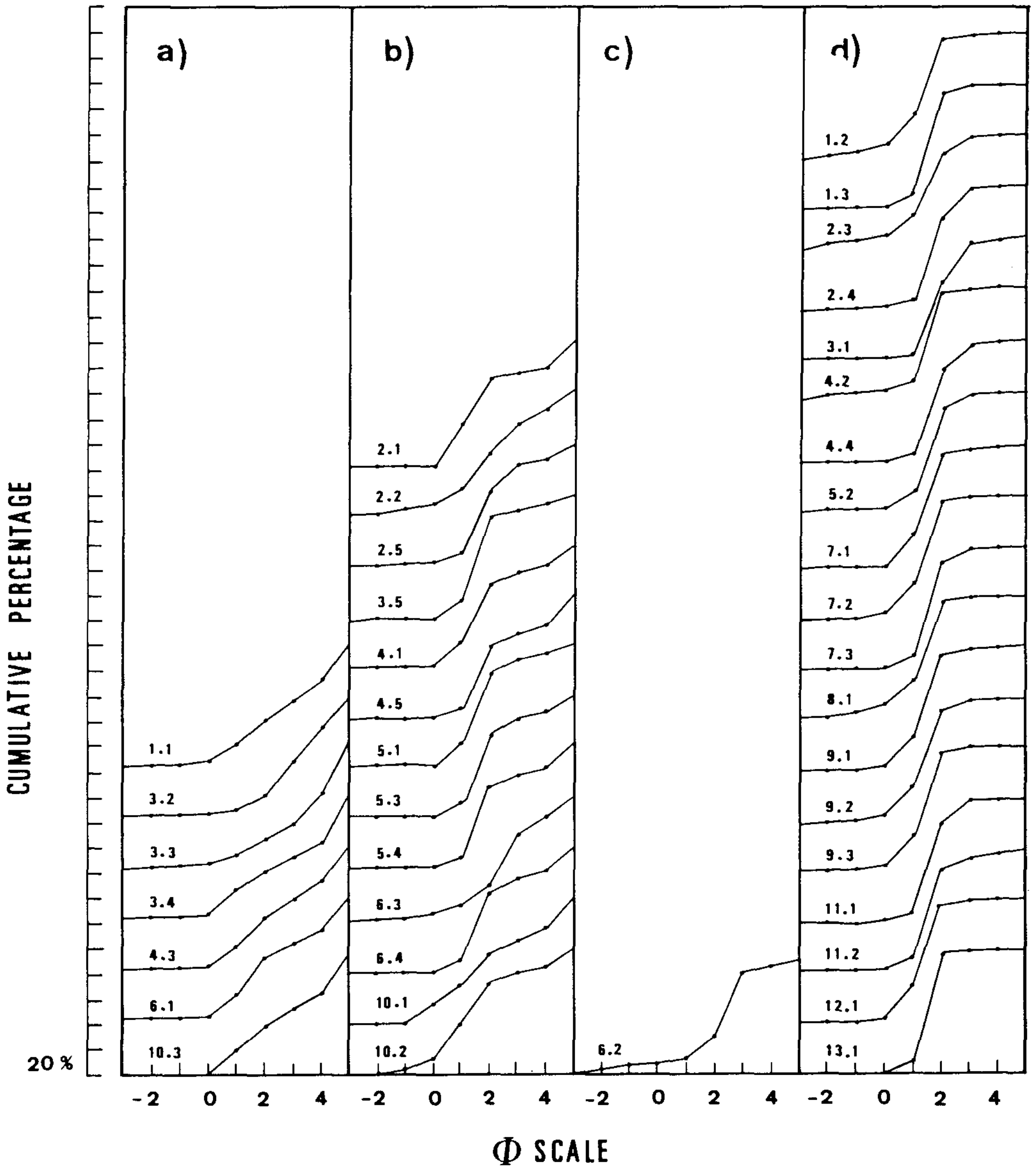

Fig. 6. Canal de Mira. Cumulative curves of particle size frequency of the sediments collected at each station, grouped according to sediment type: a) sandy mud, b) mudy sand, c) fine sand and d) medium sand.

represents the finest sediments, with M lower than 200 μm and C higher than 400 μm, that are deposited in the most protected areas of the channel. Due to the dispersion of M values in segments P and Q, and of C values in segments Q and R, the CM pattern can be interpreted as a not sharply defined river pattern. According to PASSEGA (1957), this pattern may be attributed to the highly variable tidal currents and their tractive effects in areas of scour. The stream discharging into Canal de Mira runs through an area of sand dunes, and probably does not carry significant amounts of suspended

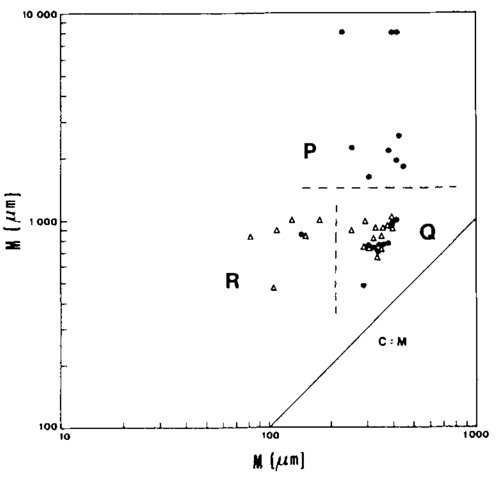

Fig. 7. Canal de Mira. CM diagram of the sediments sampled at each station. (●) subtidal stations; (△) intertidal stations.

Table 1 Canal de Mira. Average organic matter content (% dry weight) of sediment types at each sampling occasion.

	Dec	Mar	Jun	Sep	Average
Medium sand	0.59	6.13	2.14	6.70	3.89
Fine sand	2.65	1.99	1.71	0.63	1.75
Muddy sand	3.64	3.03	11.56	3.67	5.48
Sandy mud	6.78	5.26	7.37	7.03	6.61
Average	3.41	4.10	5.69	4.51	

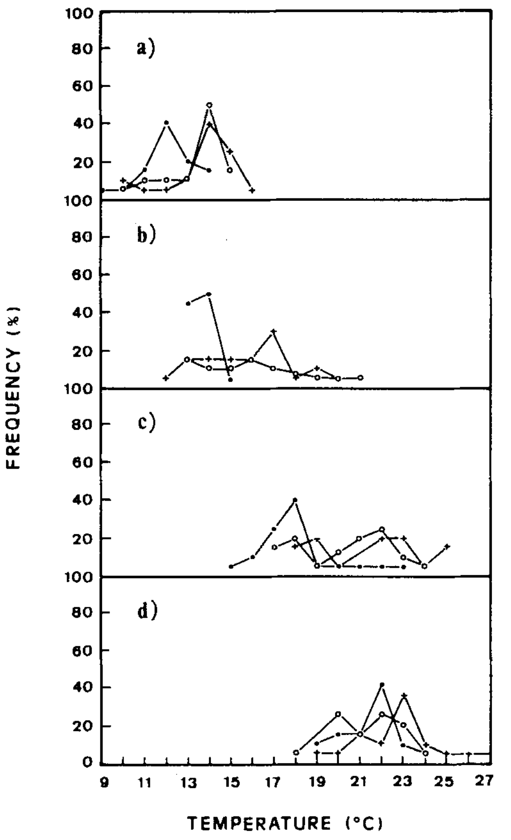

Fig. 8. Canal de Mira. Frequency distribution of sediment temperatures at 2.5 cm depth at subtidal stations (●), at 2.5 cm depth at intertidal stations (+) and at 10 cm depth at intertidal stations (○): a) December, b) March, c) June and d) September.

fine materials, a feature that is reflected in the CM diagram by the lack of sediments with a median diameter under 80 µm.

Table 1 indicates the average organic matter contents for the different sediment types in each sampling occasion. Organic contents increased with the quantity of the finer grades, an exception being the only station with fine sand. A temporal pattern was also observed, consisting of an increase in the average organic matter contents throughout spring and summer, related to the increase in biological production.

Fig. 8 shows the frequency distribution (%) of the sediment temperature registered for the four sampling occasions. On the whole, sediment temperature in the intertidal stations was higher than in the subtidal ones. The only exception was the intertidal temperature at 10 cm in September which was close to those registered at the subtidal stations. The magnitude of the difference of the peak values at 2.5 cm was 2°C in December, 3°C in March, 4.5°C in June and 1°C in September.

Classification and ordination

The physical and chemical data of the water reflect the expected longitudinal environmental gradients along Canal de Mira. Although sediment distribution may be related to these general gradients, local patterns of energy levels may have an additional important effect (PASSEGA, 1957; NICHOLS and ALLEN, 1978).

Aiming at a better discrimination of general and local gradients, a classification and an ordination of the sampling sites was carried out. The results of cluster analysis are shown in Fig. 9. Three main groups of stations can be recognized in the dendrogram. Group I differs from the others as it includes all the intertidal stations located in the outer section of the channel (up to Transect 6), typically with fine sediments (sandy muds and muddy sands). Group II joins together almost all the subtidal stations up to Transect 6, whose sediments are mainly medium sands with fragmented shells. Group III assembles the remaining stations. These are mostly subtidal stations with medium sands located in the middle and far reaches of the channel (Transects 5 to 13).

Fig. 10a shows the projection of the stations on the space defined by components 1 and 2 of the PCA. These components represent 45.4% of the total variance. The groups obtained through the previous cluster analysis are superimposed on the ordination. The projection of variables axis on the space defined by the two first components is shown in Fig. 10b. From the analysis of this figure the following main trends can be recognized: (i) a positive correlation between tidal amplitude and salinity; (ii) a negative correlation between salinity on the four sampling occasions and temperature in spring and summer; (iii) depth shows a positive correlation with the coarser grades of the sediment (Φ-3 to Φ0) and a negative correlation with the finer grades (Φ3 to Φ>4); and (iv) a negative correlation between the finer (Φ3 to Φ>4) and the medium (Φ1 to Φ2) grades of the sediment and the independence of the presence of the coarser grain sizes (Φ-3 to Φ0) relative to the others.

The analysis carried out so far emphasizes the existence of two categories of environmental gradients: (i) a typical longitudinal estuarine gradient, related to distance from the mouth, which includes variables such as tidal amplitude, salinity and temperature; (ii) local, mainly lateral, gradients, related to current velocity, which include depth and sediment composition.

Biological significance of environmental changes

According to the continuum concept (WHITTAKER, 1967; see also BOESCH, 1977, for a discussion concerning estuaries), the bottom fauna varies in relation to the continuous variation of the environmental factors (ecocline) rather like a community

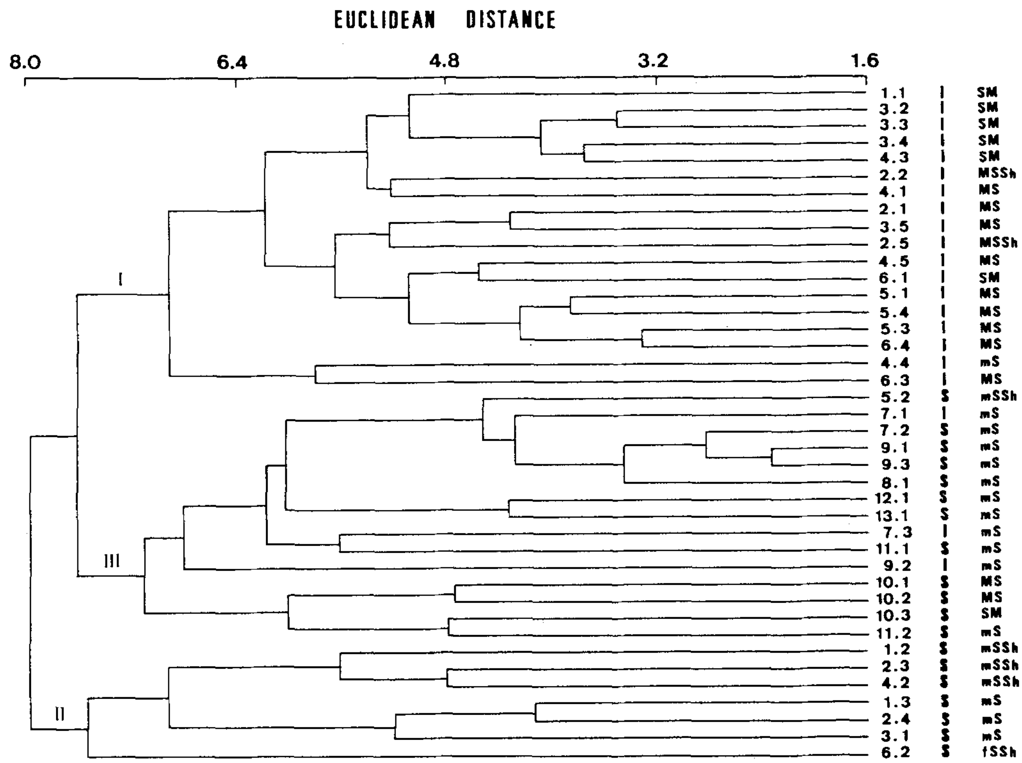

Fig. 9. Classification analysis (UPGMA) of the sampling stations based on the sediment variables plus tidal amplitude and depth. I= intertidal; S= subtidal; SM= sandy mud; MS= muddy sand; mS= medium sand; fS= fine sand; Sh= with shells

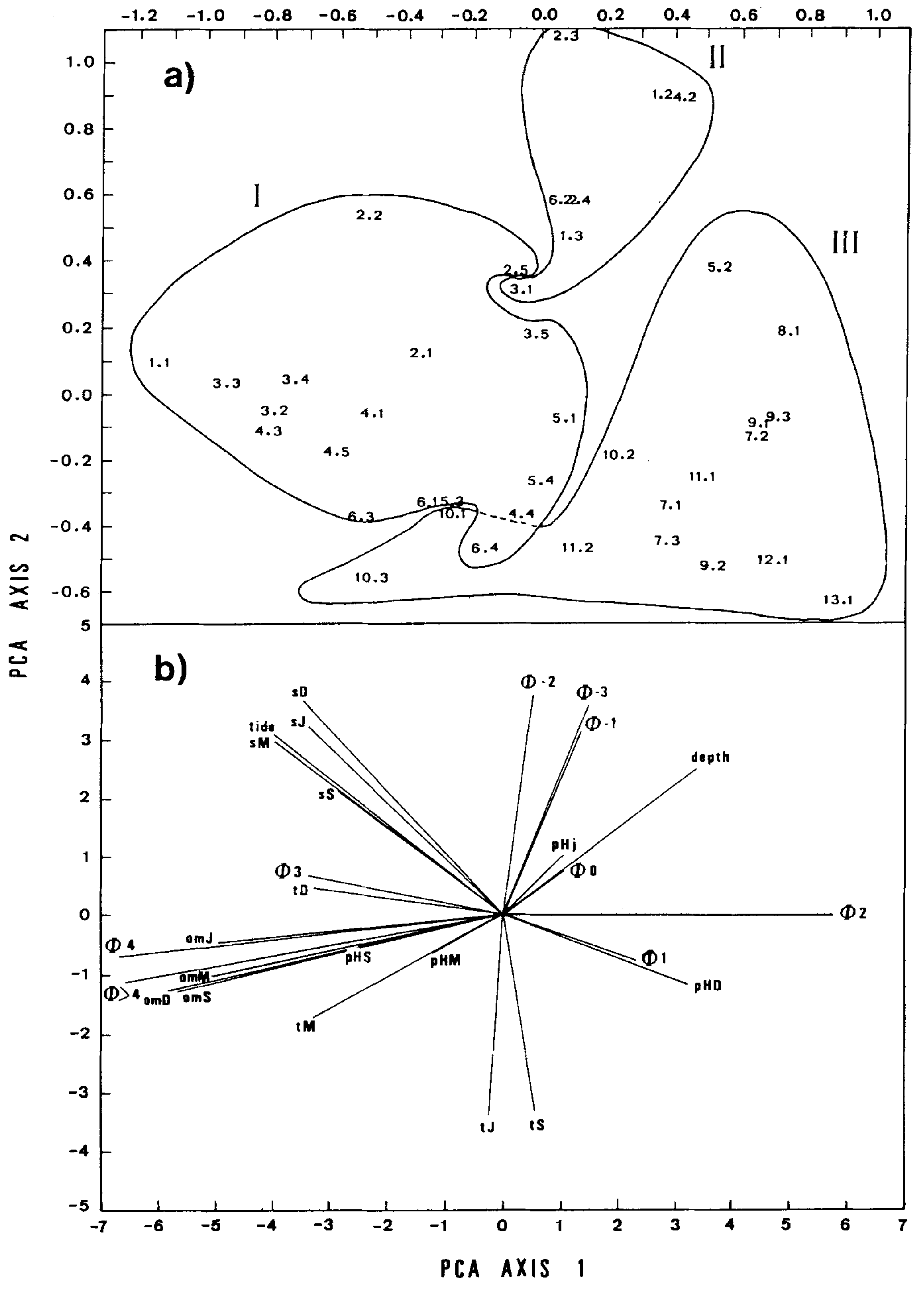

Fig. 10. Two-dimensional plots of PCA analysis of a) sampling stations and b) variables (sediment variables plus tidal amplitude and depth). The groups obtained in the cluster analysis are shown on the ordination of the stations. Φ>4 to Φ-3= sediment grades; s= salinity; t= temperature; pH= pH; om= organic matter; tide= tidal amplitude; D= December; M= March; J= June; S= September

gradient (coenocline) than like a mosaic of discontinuous units. The three groups of stations (Fig. 9) can be considered as the three major types of biotopes available in Canal de Mira for colonization by the soft bottom fauna. As expected, and as shown by the results of the cluster analysis (Fig. 9), these biotopes are not sharply defined, since the magnitude of the Euclidean distances among groups is not very high when compared with the distances within groups. See also Fig. 10a, where the ordination of the stations reflects a continuous gradient, rather than distinct groups. Therefore, it appears that the major biotopes are not limited by abrupt changes in the environmental conditions.

In order to assess the correspondence between the three groups described above and the distribution of the bottom macrofauna, a classification and an ordination of the sampling sites was performed based on the biological data. Fig. 11 shows the results of the classification analysis. Three groups of stations (I', II', III') can be recognized. Group I' can still be further subdivided into subgroups I'a, I'b and I'c. Group I' joins together all intertidal and some subtidal stations from Transects 1 to 9. The overall location of subgroups I'a, I'b and I'c follows, by that order, the main axis of the channel. Group II' is formed by subtidal stations in the outer section of the channel. Group III' includes all the stations upstream Transect 10. These clusters are shown on the ordination of the sampling stations (Fig. 12). From the position of the stations on the subspace defined by MDS I and MDS II, these axis can be related to distance from the mouth and position relative to tide level, respectively.

Table 2 ranks the species that account for 90% of the total abundance within each cluster. Fig. 13 shows the *k*-dominance curves (LAMBSHEAD *et al.*,

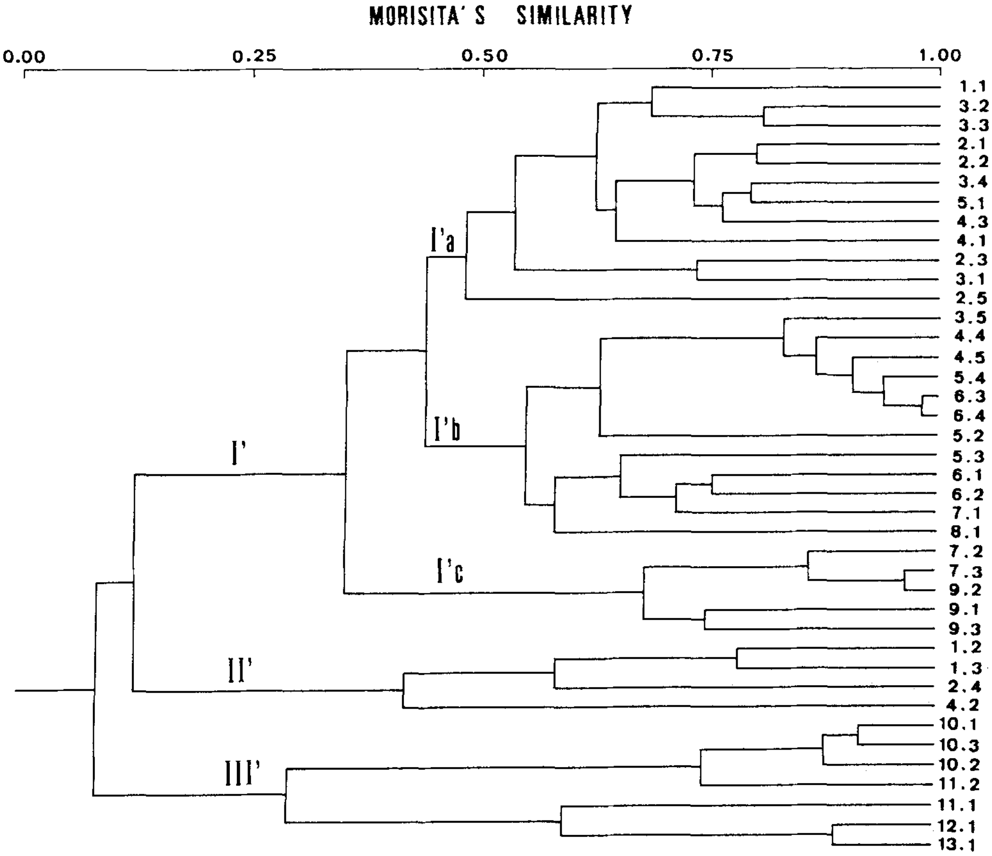

Fig. 11. Classification analysis (UPGMA) of the sampling stations based on the biological data.

Table 2. Macrozoobenthic species accounting for 90% of total abundance in each of the clusters identified by classification analysis of the sampling stations based on the biological data.

Cluster I'a		Cluster I'b		Cluster I'c		Cluster II'		Cluster III'	
Species	%	Species	%	Species	%	Species	%	Species	%
Scrobicularia plana	12.2	*Hydrobia ulvae*	38.9	*Cyathura carinata*	34.3	*Urothoe brevicornis*	30.6	*Potamopyrgus jenkinsi*	48.3
Tharyx marioni	11.8	*Hediste diversicolor*	17.8	*Hediste diversicolor*	24.9	*Angulus tenuis*	16.9	*Corophium multisetosum*	32.3
Heteromastus filiformis	11.3	*Amage adspersa*	15.4	*Streblospio dekhuyzeni*	18.6	*Venerupis pullastra*	8.3	*Chironomus thumni*-group	8.8
Cerastoderma edule	9.0	*Scrobicularia plana*	7.0	*Corophium multisetosum*	7.7	*Scoloplos armiger*	6.9		
Hediste diversicolor	8.5	*Pygospio elegans*	3.7	*Amage adspersa*	3.6	*Heteromastus filiformis*	6.1		
Hydrobia ulvae	7.8	*Abra ovata*	3.3	*Pygospio elegans*	2.6	*Nephthys cirrosa*	3.6		
Amage adspersa	4.1	*Tharyx marioni*	3.0			cf. *Cereus pedunculatus*	2.8		
Streblospio dekhuyzeni	4.0	*Streblospio dekhuyzeni*	1.8			*Cerastoderma edule*	2.7		
Tubificoides benedeni	3.9					*Pomatoceros triqueter*	1.7		
Owenia fusiformis	3.6					*Gastrosaccus spinifer*	1.6		
Pygospio elegans	2.5					*Lekanesphaera levii*	1.5		
Capitella capitata	2.1					*Spio martinensis*	1.4		
Melita palmata	1.8					*Tubificoides benedeni*	1.1		
Angulus tenuis	1.6					*Tharyx marioni*	1.0		
Glycera convoluta	1.5					*Owenia fusiformis*	1.0		
Eumida sanguinea	1.3					*Spisula solida*	0.9		
Venerupis pullastra	1.2					*Scrobicularia plana*	0.9		
Amphithoe valida	0.9					*Autolytus* cf. *aurantiacus*	0.9		
Abra ovata	0.8					cf. *Calliactis parasitica*	0.7		
Cyathura carinata	0.7								
Total number of:									
species in cluster	90		65		32		60		44
stations in cluster	12		12		5		4		7
individuals per station	2415		3179		749		483		14947
species per station	40		23		15		26		19

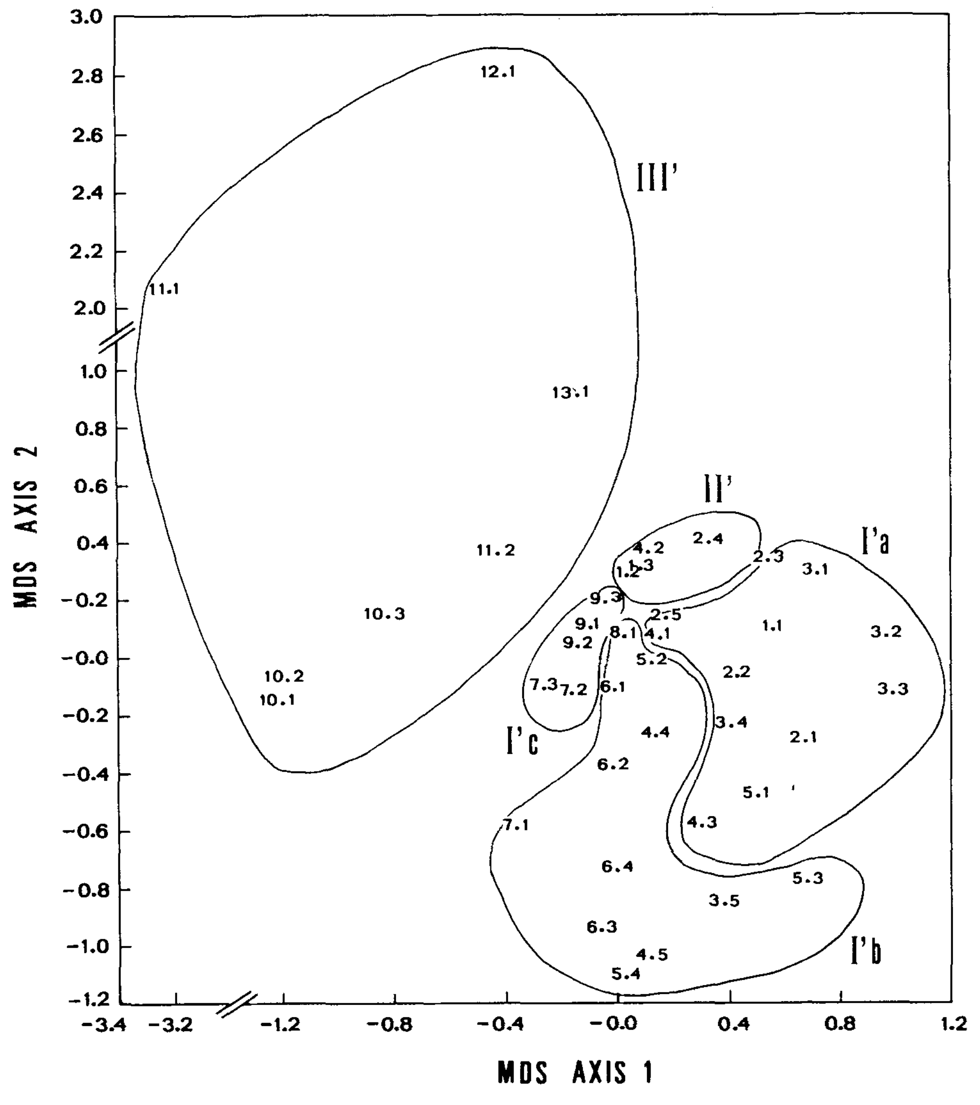

Fig. 12. Ordination of the sampling stations in the subspace defined by the first two MDS axes (stress value: 0.24). The groups obtained in the cluster analysis are also shown.

1983) for the same clusters. Group I' is characterized by the dominance of marine polyhaline and marine euryhaline species (KINNE, 1971) with a large distribution within the channel. This group exhibits a gradual decline in species richness and increase in dominance of the most abundant species, from subgroups I'a to I'c. Four polychaete species are common to all subgroups, increasing their dominance upstream: *Hedistes diversicolor, Amage adspersa, Streblospio dekhuyzeni* and *Pygospio elegans.* The four dominant species in subgroup I'a (*Scrobicularia plana, Tharyx marioni, Heteromastus filiformis* and *Cerastoderma edule*) become less important in subgroup I'b and are absent from subgroup I'c. Subgroup I'a is also characterized by a number of marine polyhaline species, such as *Owenia fusiformis, Angulus tenuis* and *Glycera convoluta. Hydrobia ulvae* and *Cyathura carinata*, typical estuarine species, dominate subgroups I'b and I'c, respectively. The fauna in group II' is mainly

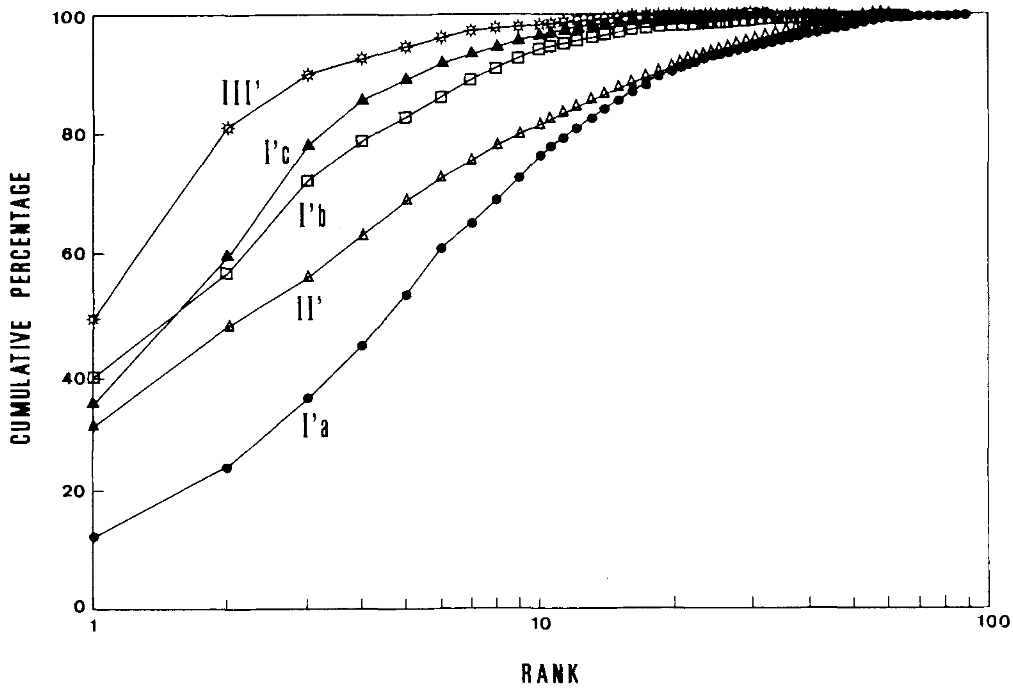

Fig. 13. *k*-dominance curves for the benthic macrofauna of Canal de Mira. Separate curves were constructed for each of the clusters identified in the classification of the sampling stations based on the biological data.

composed of marine polyhaline species. The overall density in this group is very low when compared with the other groups. Group III' is characterized by estuarine and limnic euryhaline species. Three species only account for 90% of the total abundance: *Potamopyrgus jenkinsi*, *Corophium multisetosum* and *Chironomus* sp. (*thumni*-group).

The results obtained by the classification analysis based on the physicochemical and on the biological data are compared in the diagrams shown in Fig. 14. This figure shows a good overall resemblance between the classifications obtained by the two analysis. The main trends identified from the diagrams are: (i) the longitudinal gradient, described in more detail by the biological data and; (ii) the pronounced lateral gradient in the outer section of the channel.

CONCLUSIONS

Canal de Mira behaves like a tidally and seasonally poikilohaline estuary, where vertical gradients appear to be negligible. Seasonal salinity variation is strongly related to precipitation.

The large intertidal areas and the low average depth of the channel have a considerable effect on the temperature regime of the water mass, especially during the hot season.

The water in the channel is well oxygenated during the day. Oversaturation values in the middle and far reaches of the channel indicate high levels of photosynthetic activity.

Medium sand and muddy sand are the dominant types of sediment in Canal de Mira. The scarcity of fine particles is explained by the geological nature of the surrounding areas, which are mainly sand dunes. The pattern of sediment distribution indicates that tidal currents are important agents of transport and deposition.

The classification of sampling sites based on sediment variables plus tidal amplitude and depth shows three major groups of stations corresponding to: (i) the deeper subtidal stations in the outer section of Canal de Mira; (ii) the large intertidal areas in the outer and middle reaches; and (iii) the remaining stations, mostly subtidal from the middle to the far reaches of Canal de Mira.

The classification of sampling sites based on biological data also shows three major clusters: (i)

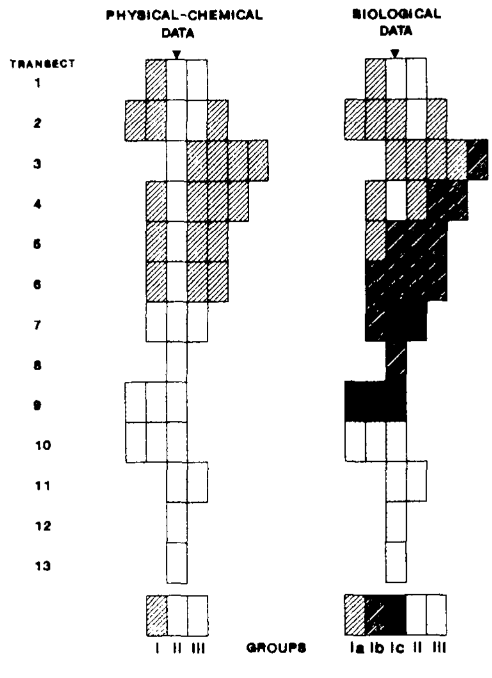

Fig. 14. Graphical comparison of the results of the classification analysis of the sampling stations, using the physicochemical and the biological data separately. Transects were arbitrarily placed, so that the main channel lies aligned with the inverted triangle (not drawn to scale).

subtidal stations at the outer section of the channel; (ii) a large group of stations, mostly intertidal, in the outer and middle reaches, which can be subdivided into three subgroups sequentially located along the channel; (iii) a group of inner stations.

The ordination plots emphasize the existence of longitudinal and lateral gradients, and suggest a gradual variation of the environmental conditions and of the benthic community, rather than abrupt changes.

There is a good overall fit between the description of the longitudinal and lateral gradients given by the physicochemical parameters and by the biological data.

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