Physical Characterisation and Microphytobenthos Biomass of Estuarine and Lagoon Environments of the Southwest Coast of Portugal

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ABSTRACT

Three lagoun-estuavine systems of the Southwest coast of Portugal were compared, on the basis of their pliysical characteristics and microphytobenthos. During a 14-month period (April 1993 to May 1994), monthly samples of sediment were collected intertidally at low tide, in order to characterize the sedinient. Organic matter content, granulometry, chlorophyll a and phaeopigment concentration were estimated. Temperature. salinity, dissolved oxygen and pH of the hottom layer of water were also measured in situ. *Principal Component Analysis (PCA) was used to define and explain relationships between location and the measured variables. Sediment dynamics, driven by tidal currents and runoff during wet periods, apparently control the behaviour of abiotic parameters in these systems.*

Keywords: Estuarine systems; microphytobenthos; organic matter: granulometry; salinity

RESUMEN

El objetivo de este estudio es la comparación de tres sistemas de lagunas estuáricas de la costa suroeste de Portugal en base a sus características físicas y a la biomasa del microfitobentos. Se han tomado muestras mensuales de sedimento en el intermareal durante la marea baja, a lo largo de un período de 14 meses (de abril de 1993 a mayo de 1994), para caracterizar el sedimento (contenido en materia orgánica, granulometria, clorofila a y feopigmentos). También se han medido in situ los parámetros de la capa de agua adyacente o "bottom layer" (temperatura, salinidad, oxígeno disuelto y pH). Para estudiar la relación entre los lugares de muestreo y la distribución de los parámetros se ha utilizado el Análisis de Componentes Principales (PCA). La dinámica del sedimento, causada por las corrientes de marea y por los aportes durante el período de lluvias, parece ser el factor más influyente en el comportamiento de los parámetros abióticos y también para la distribución de microfitobentos en estos sistemas.

Palabras clave: Sistemas estuáricos; microfitobentos; materia orgánica; granulometria; salinidad

INTRODUCTION

In intertidal estuarine ecosystems, particularly shallow aquatic environments, benthic fauna and flora are intimately associated with bottom sediment and exposed to large environmental fluctuations determined by the alternation between emersion and immersion conditions (Day *et al.*, 1987). Wind and, especially, tidal currents are usually the most important causes of mixing in estuaries, and help determine the distribution and abundance of several species of macrofauna and microphytobenthos (Colijn & Dijkema, 1981, Tamaki, 1987, Delgado, 1989, De Jonge & Beusekom, 1995). Other factors that influence the spatial dictribution of different organisms are

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light intensity and granulometric composition, directly affecting many species by limiting vertical distribution and burrowing performance (Asmus, 1982, Riaux-Gobin *et al.,* 1993). Microphytobenthos production and aiochthonous organic matter have a significant importance on the estuarine food web, representing potential food sources for a variety of bentliic invertebrates, ranging from micro- to macrofauna (Fauchald & Jumars, 1979, Montagna, 1984, Plante-Cuny & Plante, 1986, Bianchi *et al.,* 1988). Rainfall, on the other hand, causes a sudden decrease in temperature and salinity and also a strong leaching of the sediment surface (Rasmussen, et al., 1983). These frequent changes in environmental conditions provide an intricate network of biotic and abiotic factors that affect temporal distribution of different organisms. On top of this, the situation in very small systems is a particular case, as these systems may be temporarily ciosed to the sea due to the formation of sand bars. The present work is focused on three small estuaries of the southwest coast of Portugal, which, due to their physical and geomorphological properties (Magalhães *et al.,* 1987), cannot be considered as true estuaries, but rather lagoonal systems (according to Colombo, 1977) or lagoon-estuarine ecosystems (foilowing Day et al., 1987 classification).

The main objectives of the present research were: i) to study the spatiai and temporal distribution of the physical and chemical parameters in the water coiumn and surface sediment; ii) to determine which environmental factors within these three systems are more relevant to their characterisation; and iii) to evaluate the variation of microphytobenthic biomass, and organic matter on both spatial and temporal scales.

MATERIAL AND METHODS

Study area

The streams of Odeceixe (ODX), Aljezur (ALZ) and Carrapateira (CAR) (Fig. 1) drain relatively small watersheds (250, 200 and 110 km^2, respectively). In spite of that, their drainage basins cover most of the SW area of Portugal (Magalhães *et al.,* 1987). The mouths of these estuaries are frequently obstructed by sand bars, resulting sometimes in small temporary coastal lagoons. While the estuaries of Odeceixe and Aljezur were connected with the sea throughout the whole sampling period, the small estuary of Carrapateira was a coastal lagoon, remaining closed most of the year and opening only during winter storm events.

All the sampies were collected between April 1993 and May 1994. Sampling was performed during low tide, in the intertidal area of ODX (stations 7A and 7V) and ALZ (stations 9A, 9V and 18) and in the subtidal area of CAR (stations 1, *3* and 5). The choice of sampling sites and stations, located at the terminal part of these tliree different systems, was based on a previous study (Magalhães *et al.,* 1987). Due to the proximity between the two sampling sites in ODX, water parameters were only collected at station 7V.

Sampling and laboratory procedure

Salinity, temperature (°C), dissolved oxygen (ppt), and pH were measured ***in*** *situ* on the bottom layer, in the vicinity of sediment sampling sites approximately 15 cm above the bottom, using sensors (YSI Model *33,* Engineered Systems and Designs-Model 600, Philips W9424). Sediment samples for granulometric purposes were collected with a hand corer (0.02 m^2, 30 cm deep), and separated through wet sieving in to: gravel (<-1Φ fraction), sand (from -1 to 4 Φ) and mud (> 4 Φ) using the Wentworth scale and phi notation. For water content, organic matter and photosynthetic pigment analysis, the top 1 cm of sediment was sampled with a corer of 5 cm of diameter, and freezed until analysis. Water content (%H_2O) was obtained as the difference between dry and wet weight of the sediment. Organic matter (OM) was obtained as the percentage of weight loss by ignition (450°C) from the dried sediment until attained constant weight. Microphytobenthos biomass was deter-

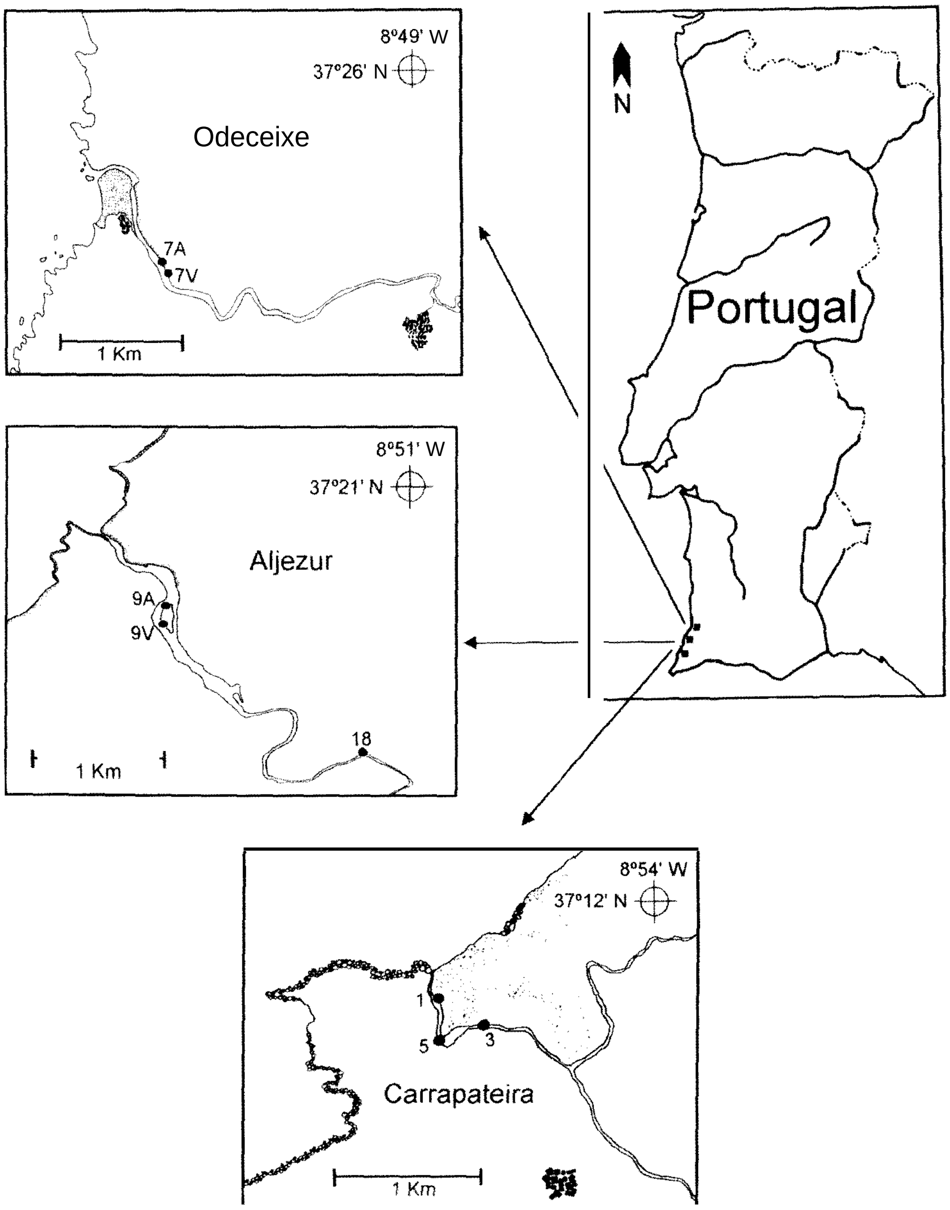


Figure 1. Sampling sites and stations in the southwestem coast of Portugal. *Zonas de estudio y lugares de muestreo en la costa suroeste de Portugal.*

mined as chlorophyll *a* concentration (Chl *a)*; pigments were extracted with 90% acetone during 24 h in darkness at 4°C, chlorophyll *a* and phaeopigments were determined spectrophotometrically by the method of Lorenzen (1967) adapted by Plante-Cuny (1974) and expressed as mg m^{-2}. Monthly data of precipitation and atmospheric temperature were obtained from the National Meteorological Institute and the General Administration of Natural Resources.

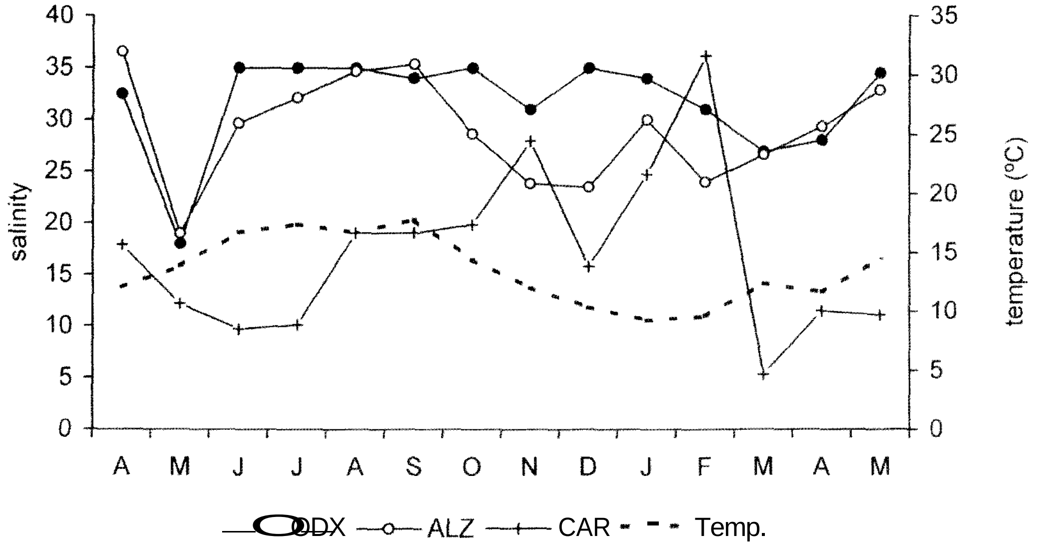


Figure 2. Salinity in ODX, ALZ and CAR, and air temperature ("C) during the sampling period. *Salinidad* **e** *ODX, ALZ y CAR. y temperaturas atmosféricas (ºC) registradas durante* ***el*** *periodo de muestreo*

Multivariate analysis

Principal Component Analysis **(PCA)** was applied in this study to explore the relationships between the sampling sites and the distribution of environmental parameters. The analysis was run using NTSYS-pc package version 1.80, by Rohlf (1 993).

RESULTS

Abiotic parameters

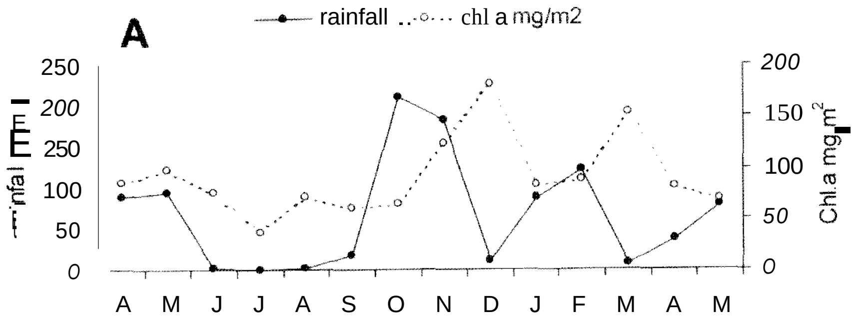
The water parameters measured at each station are presented in Table 1. Differences within each parameter were related mainly to the season and also with biochemical reactions occurring in the surface sediment. Water temperature showed a seasonal variation related to atmospheric temperature values. Differences in salinity variations between the three estuaries studied (Table 1) could be explained by the tidal influence and distance from the sea. The biggest recorded range in salinity was observed in **ALZ** 18, which is the site located further upstream in this estuary. **CAR** estuary showed the lowest average salinity values, as a consequence of beíng closed to the sea throughout most of the year, except in November. However, in this estuary, the small distance from the beach (Fig. 1) and the relatively low elevation of the sand bar, allowed for periodic entrances of saltwater and marine sediments during high water spring tides. The marine water mixes with estuarine water, generating abrupt increases in salinity (Fig. 2). Precipitation was the same at all sites, the highest values occurred during October and November (Fig. **3A).**

Figure 4 displays the maximum grain size variation for all stations during the sampling period. **CAR** is predominantly sandy, ODX7V and ALZ9V are sandy-muddy, ALZ18 is clearly muddy, whereas the others are muddy-sand. It was possible to observe a clear temporal variation particularly in the sandy-muddy stations.

The organic matter content (Table 2) varied markedly among stations and was found to be negatively correlated to grain size ($r = 0.85$, $p<0.001$). **At** CAR, the southernmost estuary, all stations presented the lowest organic matter averages of the three systems. **As** expected, within each estuary, a sharp decrease from the head to the

Table 1. *Range and mean (± S.E.) temperature, salinity, dissolved* ***oxygen*** *and pH.* Rango y valor medio de los factores temperatura, salinidad, oxígeno disuelto y pH, con el respectivo error estándar.

	Temp. (ºC)			Salinity			D.O.			pH		
	range	**average**	**St. error**	**range**	**average**	**St. error**	**range**	**average**	**St. error**	**range**	**average**	**St. error**
ODX7A/V	21-12.0	15.6	± 0.72	35-18.0	31.8	± 1.23	14.5-3.4	8.6	± 0.70	8.2-7.2	7.8	± 0.07
ALZ9A	25.5-13.0	17.0	± 0.77	36.5-29.0	33.9	± 0.61	12.2-2.7	8.5	± 0.71	10.9-7.9	8.3	± 0.21
ALZ9V	23.5-13.0	16.8	± 0.75	36.5-26.5	32.9	± 0.81	14.2-2.7	8.7	± 0.81	10.1-7.7	8.3	± 0.16
ALZ18	27-11.0	18.9	± 1.34	34-0.5	19.0	± 3.51	15.5-3.8	9.7	± 1.00	9.1-7.0	8.0	± 0.16
CAR1	25-13.0	18.8	± 1.02	34-5.0	16.5	± 2.26	10.6-7.5	9.5	± 0.46	8.6-8.0	8.3	± 0.04
CAR3	27-14.0	20.0	± 1.01	28.5-4.0	19.3	± 1.86	14.5-6.2	10.3	± 0.53	8.6-8.1	8.3	± 0.04
CAR5	27-13.0	19.8	± 1.11	32.5-5.0	15.6	± 2.07	11.8-3.0	10	± 0.58	8.7-7.8	8.3	± 0.06



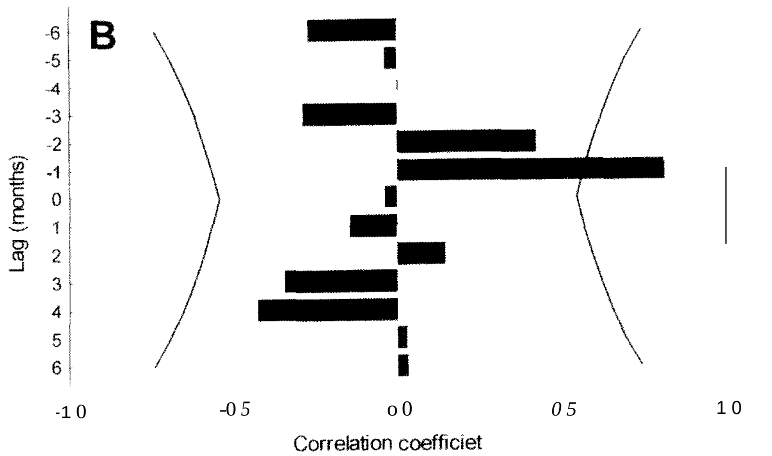


Figure 3. Rainfall regime (mm) and microphytobenthic chlorophyll a in all stations, showing the same distribution thoughout the sampling period, although with a time lag ofone month. B) A cross-correlation grap performed between rainfall and chlorophyll a values. A strong relationship (r=0.8112) between rainfall and biomass increase is observed only, within a time lag ofone month (-1). *Pluviosidad (mm) y clorofila a del bentos* ***en*** *los lugares de muestreo, mostrando* ***el mismo*** *patrón de distribución durante el periodo de muestreo, aunquecon un mes de retarso. B) La correlación cruzada realizada entre los valores* ***de*** *la pluviosidad y la clorofila a.* ***Se puede*** *observar una fuerte correlación (r=0.8112) entre pluviosidad y aumento de biomasa cuando hay un desfase de un mes (-1).*

mouth was observed, associated with a corresponding gradient of increasing grain size sediment.

Phytopigments

Temporal variation of microphytobenthic chlorophyll *a* at the sampling stations is showed in Figure 5, whereas the average and range values are presented in Table 2. The mean data obtained for all sampled stations, is plotted in figure 3A, where it is clearly seen that biomass peaks tend to occur after periods of higher rainfall, namely in winter and/or in spring. A cross-correlation analysis was performed between rainfall and chlorophyll *a* values (Fig. 3B), indicating a strong relationship ($r = 0.811$, $p<0.001$) between rainfall and biomass increase, within a time lag of one month. The stations ODX 7A and ALZ 9A, which can be considered as muddy-sanddy, showed the highest biomass values. The variation of the ratio Chl *a*/Pheopigments (Fig. 5) also indicates that the increase in chlorophyll *a* is due to autochthonous production of microalgae cells.

Multivariate analysis

In order to establish site similarity during the whole sampling period, a PCA was performed using all descriptors from ODX, ALZ and CAR (Fig. **6** and 7). The first three axis explain 58.5% of total variability. A good correlation ($r = 0.892$) was also obtained between the original matrix and the projection matrix. Axis 1 and 2 explain 47.33 % (Fig. 6) and axis 1 and **3** explain 44.05% (Fig. 7) of total variability. The variables with greater contributions to: i) axis 1 are 2Φ (positive) and %H_20, >4 Φ, 4 Φ, and OM (negative); ii) axis 2 are -1 Φ and 0 Φ (negative) and T(ºC) and pH (positive); iii) axis 3 are T(ºC) and 1 Φ (positive) and Salinity (negative).

Viewing projections on planes defined by these three axis, sites may be divided in two groups: stations with predominantly sandy sediment (O7A, A9A, C1, C3, and C5) and stations with high percentage of mud (O7V, A7V and A18). The axis 1 reveals the gradient of riverine/marine sediments. There was a clear opposition between 2 Φ class of grain size, and organic matter, water percentage and the smallest grain sizes (4 and 5 Φ class). Nevertheless in axis 3, salinity is opposed to temperature, reflecting stations with predominance of saltwater (marine), mainly O7A, O7V, A9A, and A9V or freshwater (riverine) influences, in stations A18, C1, C3, and C5.

DISCUSSION

The Portuguese coast is a high-energy coast, where the dominant wave directions are SW-W

Table 2. Range arid mean (± S.E.) chlorophyll *a*, phaeopigments and organic matter concentrations. *Rango y valor medio de las medidas de clorofila u, feopigmentos y materia orgánica, con el respectivo error estándar.*

	Chl. *a* ($mg.m^{-2}$)			Phaeo. ($mg.m^{-2}$)			O.M. (%)			O.M./Chl *a*
	range	average	St. error	range	average	St. error	range	average	St. error	ratio
ODX7A	31.9-356.0	134.6	± 20.26	8.6-239.9	71.1	± 14.74	0.5-2.8	1.22	± 0.15	$2.0x10^3$
ODX7V	18.1-267.3	78.9	± 17.14	8.8-159.1	64.1	± 10.76	1.8-5.8	3.16	± 0.31	$11.4 x10^3$
ALZ9A	40.0-250.7	115.9	± 15.01	18.6-94.5	49.8	± 5.68	0.3-2.3	1.04	± 0.12	$1.9x10^3$
ALZ9V	21.0-271.0	101.3	± 18.40	20.6-166	95.2	± 12.04	1.1-5.8	2.85	± 0.36	$8.6 x10^3$
ALZ18	11.2-177.6	57.7	± 14.71	31.1-230.5	110.2	113.88	4.8-10.8	6.96	± 0.42	$3.1 x10^3$
CAR1	0-112.7	29.1	± 7.95	0-48.5	17.8	± 4.18	0.2-0.8	0.51	± 0.05	$7.9 x10^3$
CAR3	0.8-191.9	87.6	± 13.69	1.8-133.5	36.9	± 8.51	0.2-1.8	0.71	± 0.10	$4.8 x10^3$
CARS	24.2-350.1	100.4	± 20.27	16.4-133.4	54.4	± 7.59	0.5-1.6	0.91	± 0.08	$2.3 x10^3$

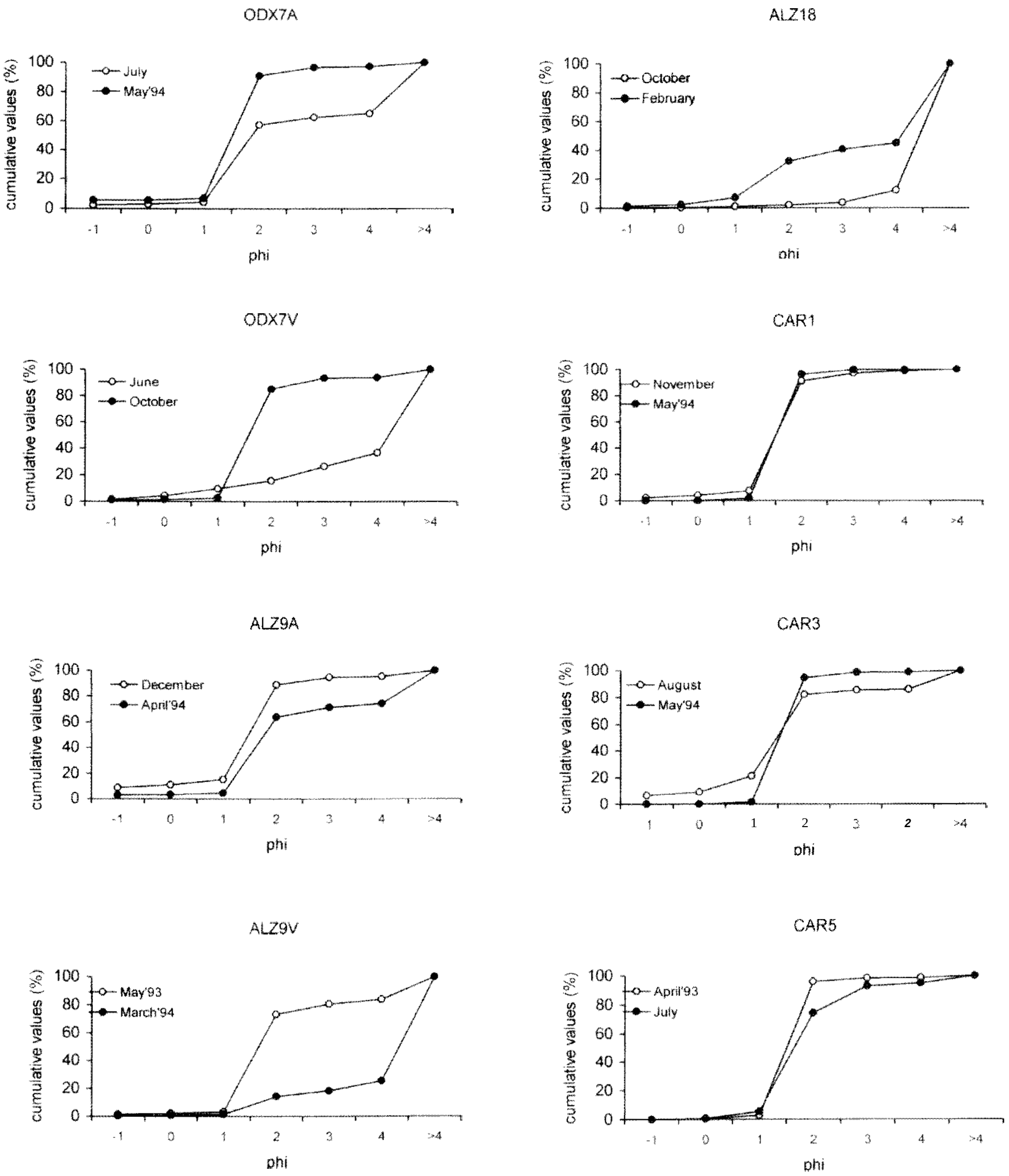


Figure 4. Maximum variation in the granulometric composition of sediment expressed as cumulative percentage at all sampling sites within areas ODX, ALZ and CAR. *Variaciónmáxima de la composición granulométrica expresada como el porcentaje de valores cumulativos en todas las estaciones de muestreo de ODX, ALZ y CAR*

and E, and the most frequent storms are from WNW in the west coast, and from SW in the south coast (Costa, 1994). In the southwest coast, the only existing estuaries are small-systems subject to frequent tidal intake of marine sand, which may lead to obstruction of the inlet. During spring tides, the marine sand is carried further upstream, towards the head of the estuary. Another relevant aspect is the marked interannual variation of rainfall, common to Mediterranean

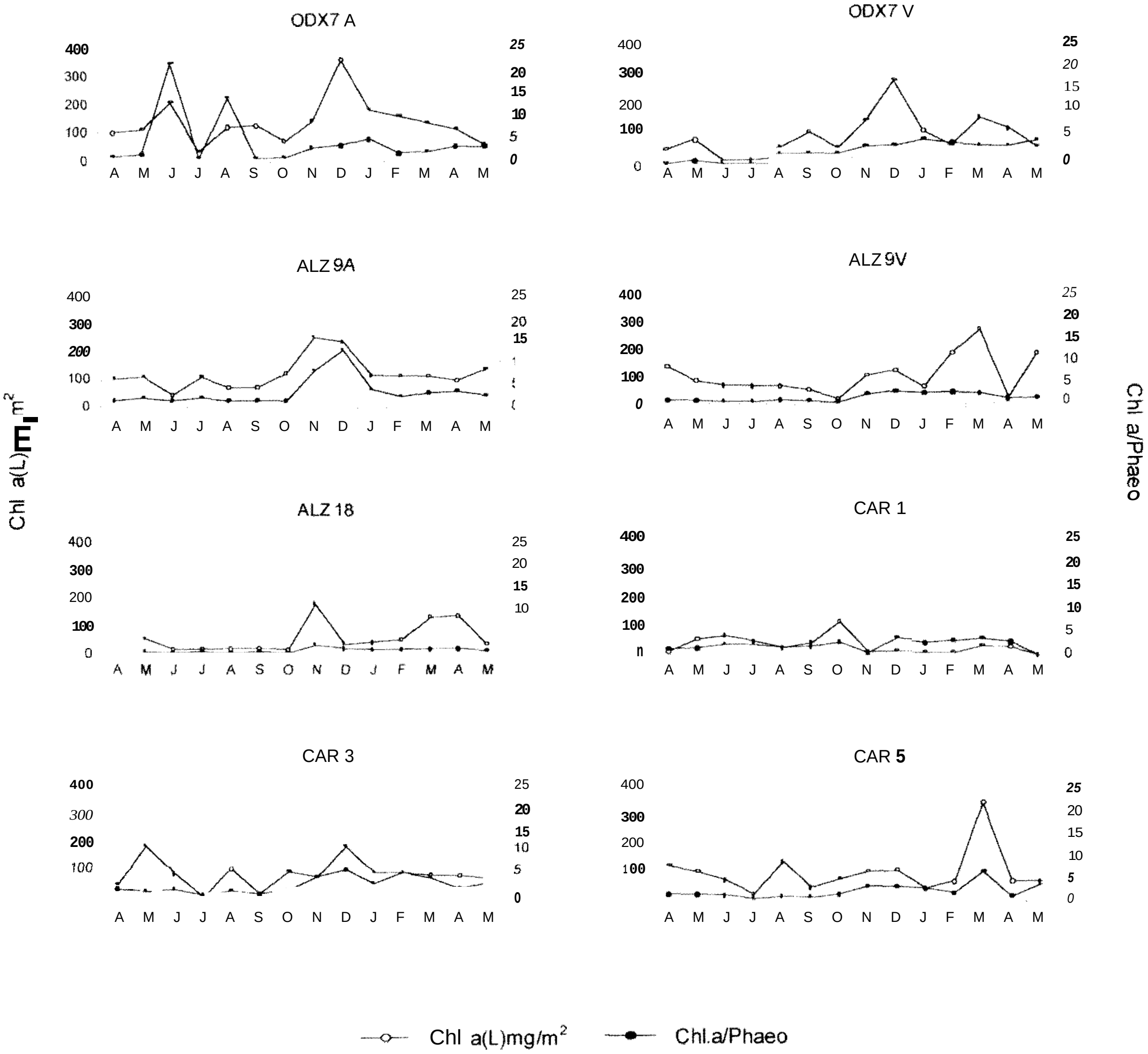


Figure 5. Temporal variation of chlorophyll *a* concentration and the ratio Chla/Pheopigments at all sampling stations within areas ODX, **ALZ** and CAR. *Variación temporal de la clorofila u y del cociente Clorofila a/ Feopigmentos en todas las estaciones de muestreo de ODX, ALZ y* ***CAR.***

climatic regions, which has important consequences on river flows (Magalhães *et al.,* 1987).

Temperatures in shallow estuaries as CAR, change faster compared to ODX and ALZ, attaining the maximum average values encountered (Table 1). The water temperature in these systems is influenced by seasonal inputs of marine water and/or freshwater, as well as by diurnal changes in air temperature. According to Day (1981), rivers are usually cooler than the sea in winter (due to continental drainage of colder water) and warmer in summer (due to diurnal heating of the water mass).

In ODX and ALZ, except in the station ALZ 18, seawater was the dominant water mass, transporting sediment particles of marine origin, as evidenced by the strong presence of the 2Φ fraction. This size class was also charac-

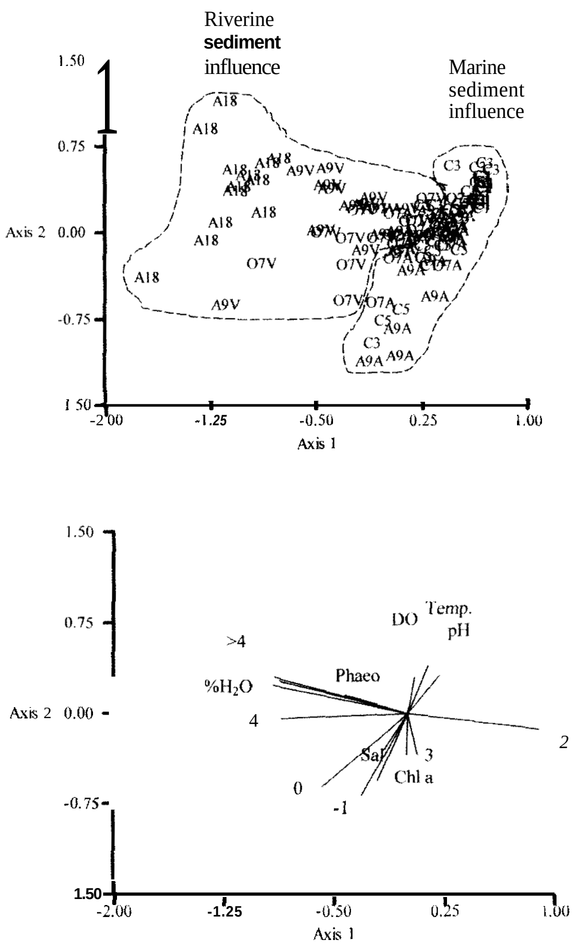


Figure 6. Projection of water (temp., sal., pH, DO) and sediment (MO, Phaeo., Chl., %H_2O and granulometry- Phi) parameters related with all differeiit stations within ODX (O), ALZ **(A)** and CAR (C), in the space defined by axis 1 and zaxis 2. *Proyección de los purametros de agua (temp., sal., pH, DO) y de sedimento (MO, Phaeo., Chl a. % H_2O y granulometria- Phi) relacionados con los distintos lugares de muestreo dentro de ODX (O),ALZ* **(A)** *y CAR (C), en el espucio definido por el eje 1 y el eje 2*

terised as marine origin by Buller & McManus (1979) in Scotland. Similar situations can also be found in Portugal, at the mouth of the Sado (Andrade & Cancela da Fonseca, 1982) and the Mira (Andrade, 1986, Andrade *et al.*, 1991) estuaries. This material is carried into the estuary either as suspended sediment flux or as bedload, in the bottom inflowing currents that characterise salt wedges. Nevertheless, adsorption, flocculation and deposition processes are bound to take place in these estuaries, specially in ODX, as a consequence of the dominance of fine sediments carried from continental runoff. According to several works (Day, 1981, Andrade, 1986, Dyer, 1995), the nature of the sediment and the geomorphology of the drainage basin have extreme importance in the flocculation process. Differences in fine settled sediment during the sampling period can be related to flood regime, which had an important influence on the transport and deposition processes. During periods of highest river discharge, the freshwater flow tends to flush sediment through and out of these systems.

At CAR, although the system was closed to the sea throughout most of the year, all stations were within a short distance from the coast line, suffering the influence of sand dunes, resulting in a strong deposition of aeolian and marine sediment.

Apart from autochthonous primary production, the organic matter sources in these estuaries are the following: i) fragments of terrestrial and riverine vegetation carried by the river flow ii) detached seaweeds, sea grasses (such as *Ruppia cirrhosa* and *R. maritima* in CAR) as well as marine plankton entering into the estuaries due to tidal currents iii) autochthonous decomposed animal and plant material. The detected gradient, upstream/downstream, of organic content in the sediments along the estuary in ODX and ALZ was observed previously for other lagoonal systems of the southwest coast of Portugal (Magalhães *et al.*, 1987, Cancela da Fonseca *et al.*, 1987, Cancela da Fonseca, 1989). Sandy-muds are consistently richer in organic matter than muddy-sands and sands (Table 2), because clay particles tend to bind organic matter in greater quantities (Nichols, 1970, Cancela da Fonseca *et al.*, 1987). Moreover, the effects of runoff are higher during the winter, contributing to the accumulation of allochthonous materials and dead organisms, displaced from other areas of the estuary with different ecological characteristics. The highest values of organic matter were found

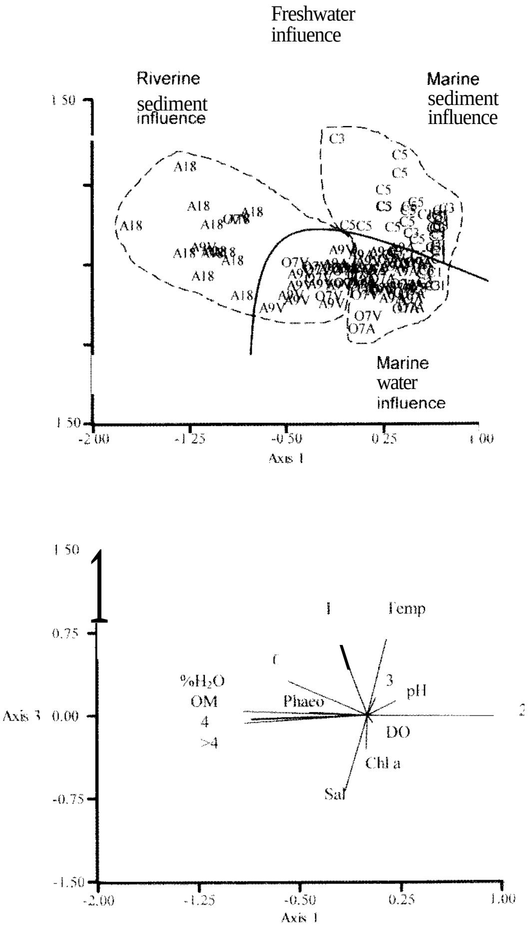


Figura 7. Projection of water (temp., sal., pH, DO) and sediment (MO, Phaeo., Chl., %H_2O and granulometry-Phi) parameters related with all different stations within ODX (O), ALZ **(A)** and **CAR** (C), in the space defined by axis 1 and zaxis 3. *Proyección de los parámetros de agua (temp., sal., pH, DO)* y *de sedimento (MO, Phaeo.. Chl a, % H_2O y granulometria- Phi) relacionados con los distintos lugares de muestreo dentro de ODX (O). ALZ (A) y CAR (C). en el espacio definido* ***por*** *el eje 1 y el eje 3.*

during the rainy season, probably due to riverine input of detritical plant material. The mean ratio of organic matter/chlorophyll *a* recorded ranged between 1.9×10^3 in ALZ9A (muddy-sandy) and 11.4×10^3 in ODX7V (sandy-muddy). Although the stations in CAR are predominantly sandy, the values obtained for this ratio can be considered quite high (Table 2). The abundant presence of seagrass debris, especially after November (overture of sand bar), in this estuary can explain this feature. In general this ratio presents higher values than those found by Brotas et al., 1995 for intertidal mudflats of the Tagus estuary, indicating that most part of organic matter has a detritic origin.

Comparison of chlorophyll *a* results, with those reported by other authors for temperate tidal flats, indicates that microphytobenthos biomass in these small systems exhibit the same order of values (Colijn & Dijkema, 1981, Davis & McIntire, 1983, Brotas *et al.,* 1995). Higher benthic microalgal biomass is displayed in stations with medium sand as the predominant sediment, in comparison with stations with fine sand and mud (Fig. 4 and Table 2). The opposite situation is frequently found in the literature (Colijn & Djikema, 1981, Davis & McIntire, 1983, Brotas *et al,* 1995). However, this outcome may be due to two different reasons: i) chlorophyll *a* was analysed in the first centimetre, and the depth penetration of microphytobenhic cells is higher in sandy sediments (Delgado *et al,* 1991; Brotas & Serôdio, 1995); ii) a negative relationship between percentage of finer sediments and microphytic biomass suggests that in our systems, loadings of fine sediments may reduce biological productivity, as observed by Cahoon *et al.* (1999) for shallow-water ecosystems.

The chlorophyll *a* in these three systems revealed a distinct seasonal cycle, with biomass increases as a consequence of rainfall periods, presenting a particular case within coastal ecosystems. Actually, biomass peaks were strongly dependent on the input of terrestrial nutrients from different origin (e.g. cattle-breeding and agriculture activities) into the estuarine basin.

In conclusion, sediment dynamics promoted by tidal currents and runoff during the rainfall period, seem to be the driving forces that influence the abiotic parameters in these systems and subsequently, biological communities. The ecology of different organisms, namely the macrofauna present in these areas, could be affected through the dragging and redistribution of juvenile post-settlement (Fidalgo e Costa, 1994).

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