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Features of spatial distribution of benthic infauna in a Mediterranean shallow-water bay

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Abstract. The unique hydrography of the Western Mediterranean Sea does not favour the formation of typical estuaries, although it does favour that of other land-sea systems. However, in Els Alfacs, a shallow-water bay situated in the Ebre Delta (northeast Spain), where there are considerable continental inputs, the distribution patterns of the macrofauna and the meiofauna reflect a hydrographical regime very similar to that of an estuary. During July 1987, 23 stations were sampled in the Alfacs Bay using plastic cores. The distribution pattern of the meiofauna follows a gradient and presents a less marked zonation than the macrofauna. Nevertheless, in both cases the peak densities of both faunal components are spatially separated from the principal site of freshwater inflow. The average density of the macrofauna (10 430 individuals/m^2) and the meiofauna (704 100 individuals/m^2) occurs in the bay during the period of maximum flow (spring-summer), and as such this bay is one of the most productive areas of the Western Mediterranean.

Introduction

The dynamic processes of coastal currents and recent changes in sea level have restructured the Mediterranean coast, remobilising sediments and eroding their outline in recent history. Big deltas and coastal lagoons have been formed as a result of these processes. There are few estuarine zones in the Western Mediterranean (Pritchard 1967) because of negligible tidal movements and the large amounts of fluvial deposits, which prevent ingression of marine water.

As recently reported (Morri et al. 1988), there is a certain uniformity detectable in the faunistic composition of various littoral environments that are partially isolated from coastal waters and, in the Mediterranean, have been named "paralic" environments by Guelorget and Perthuisot (1983). Amongst these are coastal lagoons, semi-enclosed bays and small estuaries. Nevertheless, the infaunal structure in each of these communities is different. This is reflected in the faunal distribution patterns, which are sometimes highly characteristic.

Coastal lagoons are one of the most studied systems in the Mediterranean Sea (e.g. Amanieu et al. 1977, Bedulli and Peretti 1979, Guelorget and Michel 1979a, b, Sacchi 1979, Curini Galleti et al. 1984, Carrada et al. 1987, Gravina et al. 1989). They are characterized by a comparatively small area and exhibit a great variability of physical and chemical parameters. Nevertheless, the uniformity of composition of the species assemblages of these coastal lagoons, along with their long-term stability are remarkable (Guelorget and Perthuisot 1983, Giangrande et al. 1983–1984). Variations in the population structure of the different lagoons reflect the extent of the interchange between freshwater inputs and the sea (Gravina et al. 1989). In each case where a serial gradation exists, its origin is centred at the interface between marine and freshwater systems (Bacci 1954, Guelorget and Perthuisot 1983).

Coastal zones, such as semi-enclosed bays, that are deeper and more extensive than coastal lagoons, have received little attention in the Mediterranean Sea. Their depth as well as their sediment structure seem to be important factors that correlate closely with the species distribution patterns observed. Nevertheless, the relationship between the degree of water-mixing and/or water stratification is probably crucial in determining the abundance of species and individuals (Nicolaidou and Papadopoulou 1989), and may even result in the total disappearance of a given population (Friglos and Zenetos 1988). The distribution patterns of infaunal species in these environments are largely unexamined. The benthic communities of the smaller Mediterranean estuaries vary both qualitatively and quantitatively, depending on sediment type. A zonation extending from the most inland sites to the adjacent marine habitats was established by Abbate et al. (1988) and Morri et al. (1988).

In this study, the spatial distribution pattern of benthic infauna in a semi-enclosed coastal bay has been examined in detail. The bay is shallow and, with its extensive surface area, resemble a coastal lagoon. However, it

differs from a lagoon in other aspects, namely in its unrestricted communication with the open sea and its constant seasonal freshwater imput. The latter is similar to that encountered in many estuarine systems. Emphasis has been placed on defining the distribution patterns of macrofauna and meiofauna and their relationship with distribution models defined by the environmental parameters which characterize the area.

Study area

We conducted our study in the Ebre Delta, on the northeast coast of the Iberian Peninsula (Western Mediterranean, 40°33′ to 40°38′N; 0°32′ to 0°44′E). The Ebre Delta has an extended apron of 350 km^2, with two lateral bays. Els Alfacs, the southern bay (Fig. 1), is 50 km^2 in area, with a mouth 3 km in width; the average depth is 4 m (max. = 6 m). The central area is 3 to 6 m deep and the littoral platform between 0 and 2 m deep. Both are connected by a narrow slope (2 to 3 m deep). The total water volume of the southern bay is about 200 million m^3. Water from the Ebre River reaches the bay through outlet channels across rice fields; 29 to 50 million m^3 are transported to the bay from April to October each year (7 to 8 mo/yr), i.e., a quantity that represents, <1% of the total capacity of the bay.

The hydrographic structure of this area is characterized by permanently stratified conditions. However, the hydrography of the region is highly complex and depends on many different factors including seasonal variables (Camp and Delgado 1987). A less-saline upper water layer advances out across the bay towards the sea

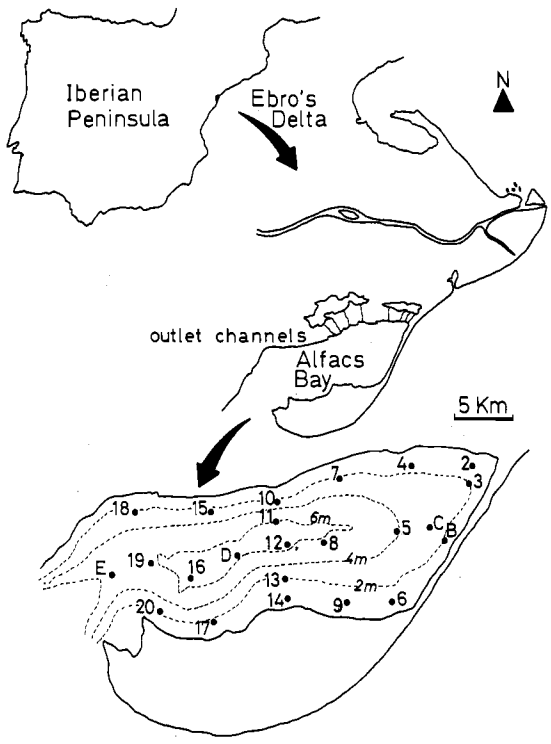

Fig. 1. Study area, showing 23 sampling stations in Alfacs Bay

(Fig. 2A), sliding over a more saline and dense water layer beneath (Fig. 2B). The water circulation in the bay is regulated by this structure. Because of the shallowness of the margins of the bay and the many days of strong sunshine, evaporation also plays a prominent rôle in formation of the salinity gradient. As a result of this stratification, the littoral platform of the bay is not affected by the freshwater flow (except in the immediate vicinity of the outlet channels). In the deeper parts of the bay, a much more constant marine-water salinity prevails. The shallow areas are affected by small, sporadic variations in the sea level.

Temperature variations parallel those of salinity. Shallow waters exhibit high daily and seasonal variations, while the temperature of the deeper water in the bay is much more stable. Fig. 2C shows sediment temperatures at the times at which samples were taken. During the day, the sediment temperature is lower in the middle of the bay than at the edge; at night, the opposite situation obtains.

The percentage of silt and clay in sediments is widely accepted as a valid parameter for identifying different sediment types (Fig. 2D). The distribution pattern recorded for the bay sediments result from its hydrography and bathymetry. Silty sediments are present along the courses of the freshwater outflows, and extend into the bay. The highest percentage of muddy sediments was observed in the middle of the bay (97.96%). Silty sediments disappeared at the eastern margin of the bay (0.05%).

The organic content of the sediment (Fig. 2E) gradually increased from the northern margin to the centre (7.37%), and decreased towards the southeastern margin (0.59%). Major differences in organic matter content are revealed by the comparison of surface redox values (Fig. 2F). Hig redox values were found at the southeastern margin, indicating well-oxygenated sediments. Values declined rapidly towards the source of the fresh-water input, becoming completely reduced at the sediment surface near that outlet channels (−347.7 mV). Intermediate values were observed in the centre of the bay, but surface anoxia was not recorded.

Materials and methods

Samples were collected from 23 stations in Els Alfacs Bay during July 1987, using plastic corers. The sampling strategy was designed with reference to the hydrographic conditions of the bay. Sediment samples were taken along two transects; one orientated north to south along the axis of the freshwater input, the other orientated east to west from the open sea and perpendicular to the first transect. Samples were collected only when freshwater input was maximum and all outlet channels were open.

Benthic samples were divided into two faunal fractions, macrofauna and meiofauna. Different corers were used for these: a 200 cm^2 section to a depth of 20 cm for macrofauna, a 12.5 cm^2 section to a depth of 8 cm for meiofauna.

Meiofaunal samples were separated in the laboratory using an elutriator (after Boisseau 1957) and collected on a 55 μm sieve. Macrofauna were collected on a 500 μm sieve. The collected material were preserved in buffered formalin (10% v:v of a 40% formaldehyde solution). Characteristic taxonomic groups at each station were defined as those accounting for >50% of the taxa present in any given sample.

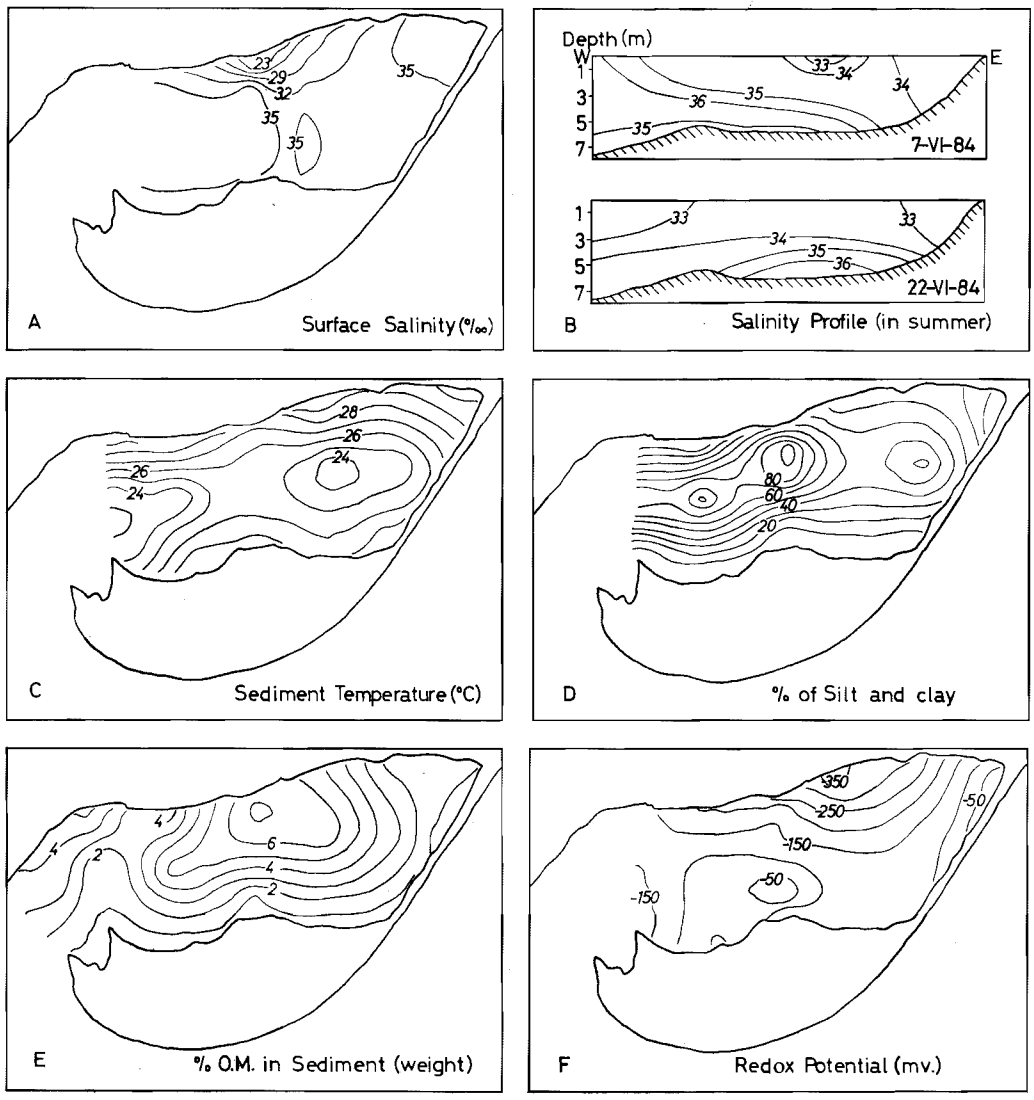

Fig. 2. Spatial distribution of physical factors in Alfacs Bay. All profiles are from east to west (mouth) across bay (from data of Camp and Delgado 1987). Organic matter (O.M.) in sediments was measured by Greiser and Fauvel's (1988) method, the redox potential with a platinum microelectrode

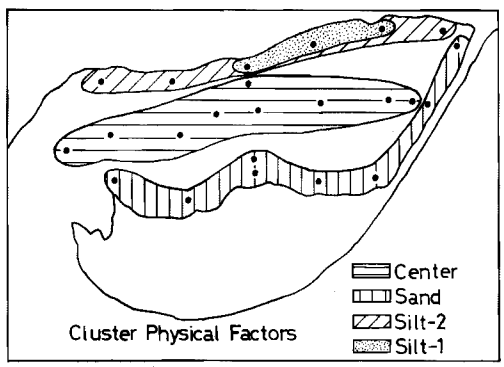

Fig. 3. Spatial plot of groups of four stations obtained by cluster analysis using salinity, temperature, % silt content, % organic matter and redox potential of sediment

Fig. 2 was constructed by interpolation of environmental values between stations and shows general features in the form of countours rather than data points. They were drawn by the Surfer Program. Statistical studies were carried out using the LAWI Program (written by J. Lleonart, I.C.M., Barcelona).

Results

Environmental factors

Three assemblages: central zone, sandy, and silty (the last comprising two subgroups, S-1 and S-2), were revealed by cluster analysis using environmental factors (sediment temperature, % silt content, % sediment organic matter and redox potential; Fig. 3). The key environmental features of these assemblages are summarised in Table 1.

Macrofauna

The mean density of the macrofauna was 10 430 individuals m^2 and ranged from 1 850 to 37 150 individuals/m^2. A total of 21 taxonomic groups of macrofauna were identified in the bay, polychaetes, phoronids and amphipods being the most abundant and widespread (Table 2).

The mean densities of the macrofauna were similar in the south of the bay and in the central zone. However, in the northern part of the bay, densities were lower due to the influence of transported sediments and freshwater

Table 1. Maximum/minimum values recorded for environmental factors in sediment assemblages revealed by cluster-analysis

Factors	Assemblage							
	Center		Sand		Silt-1		Silt-2	
Bathymetry (m)	3.00/	6.00	0.50/	3.00	1.00/	1.00	0.50/	1.00
Salinity (‰)	23.00/	37.00	35.00/	37.00	20.00/	33.00	29.00/	35.00
Temperature (°C)	23.00/	26.20	23.00/	29.50	27.20/	29.00	29.30/	30.70
% Silt	66.10/	97.96	0.05/	0.07	23.42/	36.73	2.55/	16.56
% Organic matter	0.74/	7.37	0.59/	0.78	1.30/	6.25	0.90/	4.12
Redox (mV)	−73.40/	−172.70	16.50/	−179.60	−284.50/	−374.70	−87.80/	−200.00

Table 2. Macrofauna. Average density (individuals/m²) in sediment assemblages, presented in order of decreasing abundance

Groups	Assemblage			Total
	Center	Sand	Silt	
Polychaeta	3 683.33	4 793.75	9 566.67	5 604.35
Phoronidea	127.78	4 381.25	41.67	1 584.78
Amphipoda	1 761.11	1 575.00	841.67	1 456.52
Bivalvia	1 244.44	343.75	625.00	769.57
Tanaidacea	38.98	712.50	0	263.04
Oligochaeta	5.56	0	775.00	204.35
Ophiuroidea	316.67	6.25	0	126.09
Isopoda	33.33	156.25	191.67	117.39
Cumacea	83.33	162.50	0	89.13
Anthozoa	55.56	12.50	41.67	36.96
Ostracoda	0	93.75	8.33	34.78
Gastropoda	44.44	12.50	50.00	34.78
Copepoda	5.56	62.50	25.00	30.43
Nemertini	16.67	56.25	0	26.09
Sipunculida	16.67	18.75	0	13.04
Decapoda (larvae)	5.56	25.00	0	10.87
Holothuroidea	16.67	6.25	0	8.70
Mysidacea	0	25.00	0	8.70
Bryozoa	5.56	0	0	2.17
Nematoda	0	0	5.56	2.17
Scaphopoda	0	0	8.33	2.12

Table 3. Macrofauna. Percentage (%) of various groups present in each sediment assemblage. –: < 50%

Groups	Assemblage		
	Center	Sand	Silt
Bryozoa	100.00	–	–
Scaphopoda	100.00	–	–
Ophiuroidea	98.06	–	–
Holothuroidea	72.73	–	–
Bivalvia	56.23	–	–
Anthozoa	50.63	–	–
Mysidacea	–	100.00	–
Phoronidea	–	96.28	–
Tanaidacea	–	94.82	–
Ostracoda	–	91.84	–
Decapoda (larvae)	–	81.82	–
Nemertini	–	77.14	–
Copepoda	–	67.16	–
Cumacea	–	66.10	–
Sipunculida	–	52.94	–
Nematoda	–	–	100.00
Oligochaeta	–	–	99.29
Polychaeta	–	–	53.02
Isopoda	–	–	50.27

flow entering the bay through the outlet channels. The highest macrofaunal densities were observed at sites located on both sides of the outlet channels where these entered the bay. This was predominantly due to polychaete populations. Similar high macrofaunal densities were observed in the samples collected from the slope connecting the central area with the littoral platform, but could not be ascribed to any single macrofaunal group (see Fig. 4A).

Three different assemblages could be recognized as a result of a cluster analysis using macrofaunal data (Fig. 4B). These corresponded directly to those revealed by the environmental analyses already described, i.e., central zone, sandy area and silty area. Table 3 shows the fauna associated with the different assemblages.

The mean densities of each group of macrofauna in each assemblage are given in Table 2. The central zone was dominated by polychaetes (49.33%), amphipods (23.59%) and bivalves (16.67%). In the sandy assemblage, polychaetes, phoronids and amphipods were dominant, accounting for 38.52, 35.21 and 12.66%, respectively. The silty assemblage was dominated by polychaetes (78.58%) only.

Although the polychaetes constituted the principal faunal group, the species that characterized each of the three station assemblages were very different. In the central area, *Pseudoleiocapitella* cf. *fauveli* Harmelin and *Heteromastus filiformis* (Claparède) were dominant; in the sandy zone the most abundant species were *Paraonis fulgens* (Levinsen), *Neanthes caudata* (Delle Chiaje) and *Mediomastus fragilis* Rasmunsen; finally, in the silty assemblage, *Streblospio shrubsoli* (Buchanan) and, to a lesser extent, *Capitella capitata* (Fabricius) were the key species observed.

As regards the remaining dominant groups, the amphipod species characteristic of the central zone was *Pseudoysus kröyeri* and the molluscs *Abra alba* (Wood) and *Loripes lacteus* (Linné). In the sandy zone, the comparatively high density of the phoronids resulted from the only species of this group that has been found in Els Alfacs, *Phoronis psammophila* Cori. The amphipod *Amphelisca* sp. was also an important component of the macrofauna in this latter zone.

Meiofauna

The mean meiofaunal density was 70.41 individuals/cm² (max. = 162.88; min. = 12.96). A total of 19 major taxo-