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MACROFAUNAL COMMUNITY STRUCTURE AND DISTRIBUTION IN A MUDDY COASTAL LAGOON

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Macrofaunal communities and specific bulk properties of organically enriched sediments were investigated in the coastal lagoon of Cabras (Sardinia, western Mediterranean) on a grid of twenty-nine sampling stations, in spring 2001. Species composition and community structure indicated poor and heterogeneous macrofaunal communities, characterized by few predominant *taxa* typical of degraded environments, such as *Polydora ciliata*, Tubificidae and *Neanthes succinea*, distributed differently in some areas of the lagoon. Sediments were homogeneously muddy, with a mean silt + clay content of 93%. The analysis of specific grain size intervals within the mud fraction, however, highlighted a marked spatial variability of sediment particle distribution. Simple associations included a positive relationship of both *Ficopomatus enigmaticus* and *Corophium sextonae*, patchily distributed along the shores, with sediment sorting (σ), an index of sediment selection due to hydrodynamic energy. By contrast, inner areas, characterized by a major accumulation of finer particles (and organic matter), with a sediment mean size (Φ) up to 8.2 phi, were least populated. The results suggest the existence of an early stage of faunal succession which might be related to an excessive organic content of sediments and the tendency to dystrophic events in the Cabras lagoon.

Keywords: Benthic macrofauna; Spatial distribution; Sediment grain size; Mediterranean Sea

1 INTRODUCTION

Enclosed shallow systems such as coastal lagoons are increasingly affected by nutrient and organic matter enrichment as a direct (*e.g.* sewage discharge, fish farming) or indirect (*e.g.* eutrophication) consequence of human activities (Nixon, 1995; Sorokin *et al.*, 1996; Karakassis *et al.*, 2000; Cloern, 2001).

It is well known that sedimentary organic matter represents a major factor controlling the composition, structure and distribution of macrofaunal communities. Classical studies have shown that in organically enriched sediments, polychaetes tend to dominate (Rhoads, 1974; Pearson and Rosenberg, 1978). A shift to fewer, small and more resistant (*e.g.* opportunistic) polychaete species occurs in the case of further organic enrichment which may subsequently lead to oxygen depletion and benthic macrofaunal collapse (Friligos and Zenetos, 1988; Diaz and Rosenberg, 1995; Magni and Montani, 1998). By contrast, in

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less organically stressed environments, the numerical proportion of polychaetes is expected to decrease in favour of molluscs and crustaceans (Beukema, 1991). Such a general pattern of macrofaunal responses to an organic gradient has been demonstrated in a variety of marine coastal ecosystems (Weston, 1990; Tsutsumi *et al.*, 1991; Dauwe *et al.*, 1998).

In coastal lagoons, matters may be complicated by the large environmental variability in both water and sediments (Pusceddu *et al.*, 1996, 1999; Giordani *et al.*, 1997; Viaroli *et al.*, 2001), and, if any, seagrass or seaweed coverage and cycle (Villano and Warwick, 1995; Balducci *et al.*, 2001; Sfriso *et al.*, 2001). Yet, relevant works in organically polluted lagoons have consistently shown a marked impoverishment of macrofaunal communities on both temporal and spatial scales (Lardicci *et al.*, 1997; Tagliapietra *et al.*, 1998). Even when a partial recovery was observed, secondary disturbances were envisaged due to unstable conditions of the benthic environment related to persisting organic matter load of sediments (Lardicci *et al.*, 2001a).

The level of organic matter in sediments is known to be related to the sediment grain size (Tyson, 1995). In particular, a higher content of organic matter tends to occur with an increasing mud fraction due to a relatively higher surface area and higher number of complexing sites of the sediments. Analyses of benthic communities and sediment types have been conducted for some time in many coastal and estuarine systems, too. Accordingly, consistent patterns of macrofaunal distribution have been shown in the presence of a marked gradient of sediment grain size (and organic matter) and depth (Fresi *et al.*, 1983; Jones *et al.*, 1986; Ishikawa, 1989; Quintino and Rodrigues, 1989; Marques *et al.*, 1993; Schlacher and Wooldridge, 1996; Karakassis and Eleftheriou, 1997). However, more uncertainty may arise when grain size variability becomes restricted, *i.e.* in systems characterized by homogeneous sediments. In this case, a simple classification of the sediments based on sand vs. silt + clay content may be of little use. It appears that less work has been conducted on a more detailed analysis of sediment bulk properties to evaluate animal–sediment relationships (Mancinelli *et al.*, 1998). In particular, little is known on the relationship between muddy sediments, as it is often the case of organically enriched systems, and the spatial distribution of macrofaunal communities in enclosed coastal lagoons.

In this study, we aimed to investigate, at the basin scale, the distribution of macrofaunal communities of a coastal lagoon characterized by muddy sediments and high organic carbon concentrations (De Falco *et al.*, 2003). Secondly, we aimed to assess the relationship between distributional patterns, if any, of dominant macrofaunal *taxa* and sediment bulk properties.

2 MATERIAL AND METHODS

2.1 Study Area

The Cabras lagoon is an enclosed and large water body (surface of 22 km²) located on the west coast of Sardinia, western Mediterranean sea (Fig. 1). The northern sector of the lagoon is connected to a small river which represents the major source of freshwater. Riverine discharge, however, is rather limited and periodic due to a low rainfall regime in the region (ca. 10–100 mm from July to December, respectively; Pinna, 1989), and increasing upland demand of freshwater (*i.e.* for agriculture) during the past few decades. Accordingly, salinity may vary greatly throughout the year from <10 PSU to ca. 30 PSU (Magni *et al.*, unpubl. data). In the southern sector of the basin, a low dam rising up to the high-tide level allows the flushing of excess water only in case of flood. Partial connection between the lagoon and the adjacent sea mainly relies on secondary eastward creeks flowing into a major channel

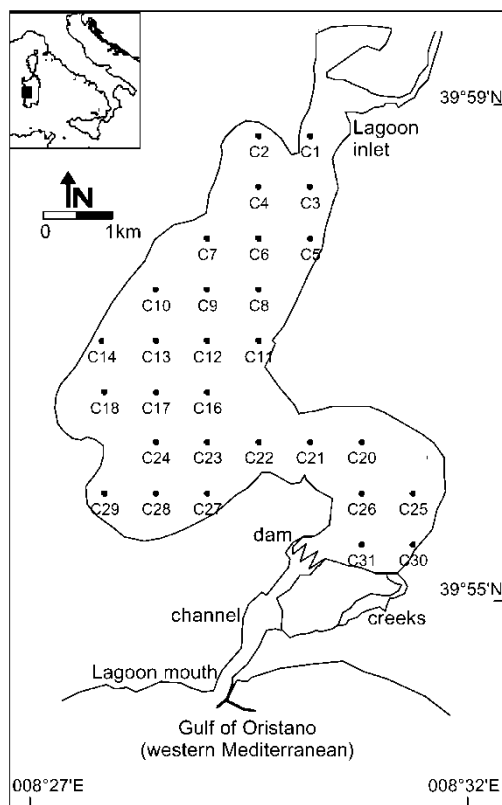


FIGURE 1 Study area and sampling stations in Cabras lagoon (western Sardinia, Italy).

dredged in the late 1970s (Fig. 1). As such, water exchange between the lagoon and the Gulf is very limited.

The lagoon of Cabras historically has an important economic value due to fishery activities (e.g. *Liza ramada*, *Mugil cephalus*, *Anguilla anguilla*) involving about 300 fishermen, with a yearly total fish catch, as in 1998, of ca. 400 tonnes and an income of 3.5 million Euros. However, a drastic reduction of fish catch has occurred in recent years (ca. 50 tonnes of fish catch in 2002), following a severe dystrophic crisis in June 1999 (IMC, 1999), which caused a massive fish mortality.

2.2 Field Surveys

Sampling campaigns were conducted on four different dates between the end of April and the beginning of May 2001. Twenty-nine sampling stations spaced 750 m apart were selected on a regular grid covering the whole lagoon, which coupled investigations on sediment characteristics and macrofaunal communities (Fig. 1). Two additional stations, close to the shore on the eastern sector of the lagoon, could not be sampled properly as they occurred on a harder and coarser substratum represented by large serpulid reefs (Stns C15 and C19 not shown; in De Falco *et al.*, 2004).

On each sampling date, temperature, salinity and dissolved oxygen in surface water were measured at most stations using a portable oxymeter (WTW Oxi197) and a salinometer

(WTW LF197). At each station, duplicate core samples were collected using a manual corer (40 cm long, 10 cm \varnothing) for sediment grain-size analysis. Additionally, duplicate sediment samples were collected for the determination of macrofauna using a 216 cm² Ekman-Birge grab. The grab was fitted to a steel pole which allowed the collection of sediments to a maximum depth of ca. 15 cm. The samples were subsequently sieved on a 0.5 mm mesh size, and the residue was fixed with a buffered formaldehyde solution (final concentration 5%), stained with rose Bengal, and brought to the laboratory for later determination of macrofauna. Water depth was simultaneously measured using a calibrated staff.

2.3 Sample Treatment and Analysis

Sediment cores collected for grain size analysis were frozen before being stored. Subsequently, the surface (0–2 cm) layer of each sample was carefully sliced off the frozen core. For each station, sediments from the same layer were mixed together and treated as one single sample. Samples were dried at 50 °C for 24 h, and the water content (WC) was determined as a loss of weight. A subsample of ca. 4 g was used for grain size analysis. This subsample was treated with hydrogen peroxide (H₂O₂) in order to eliminate organic material, wet-sieved through a 63 μ m mesh, dried and weighed. The determination of the <63 μ m fraction was done using a laser Galai CIS 1 instrument at analytical size intervals of 0.5 μ m (Molinaroli *et al.*, 2000). Subsequently, specific sedimentary indices, such as sediment mean size (Φ) and sorting (σ), were calculated (Blott and Pye, 2001). Additional core samples were used to measure the redox potential (Eh) in the surface (0–2 cm) and subsurface (2–4 cm) layers using a Crison pH-meter 507 provided with a redox platinum electrode. Macrofauna were separated from the residue and transferred into a 75% ethanol and 2.5% ethylene-glycol solution. For each replicate, animals were sorted, counted and identified at the species level when possible.

The environmental and macrofaunal data were analyzed by univariate, graphical and multivariate methods. Similarity matrices based on the Bray-Curtis similarity index were calculated on fourth root transformed abundance data. These similarity matrices were used to perform hierarchical agglomerative clustering and multidimensional scaling ordination (MDS), using the Plymouth Routines In Multivariate Ecological Research (PRIMER) programme (Clarke and Warwick, 1994). Patterns were generated by factor analysis using the principal components analysis (PCA) as an extraction method (Le Maitre, 1982; Swan and Sandilands, 1995). Factors were rotated using the Varimax rotation. These factors were used to ordinate the spatial distribution of dominant macrofauna according to their abundance, sediment bulk properties (Φ and σ) and water depth. PCA extraction was carried out based on a correlation matrix as a means of 'standardizing' the data. Significant factor weights were evaluated as >0.70. The graphical representation of the spatial distribution of macrofaunal abundances and of the score values obtained from the factor analysis was performed using the Surfer software. Smooth-line kriging was used as the gridding method, where the x and y data columns are the latitude and longitude of the sampling stations, respectively, and the z data column is the selected variable.

3 RESULTS

3.1 Environmental Variables

Table I includes major hydrological and sedimentary features of the Cabras lagoon during the study period. The surface water was characterized by relatively low salinity, with a mean of 9.9 PSU. Temperature varied widely according to the time of measurement, with a mean of

TABLE I Mean \pm Standard Deviation (SD) of Major Environmental Variables of Surface Water and Surface (0–2 cm) Sediments. Minimum (Min) and Maximum (Max) Values at Individual Stations (Stns) for Each Variable are also Shown.

	Mean	SD	No. Stns	Min–Max
Depth (m)	1.7	0.2	29	1.3–2.1
Surface Water				
Salinity (PSU)	9.9	1.7	21	6.6–12.0
Temperature ($^{\circ}$ C)	18.3	2.9	21	14.3–22.2
DO (mg l^{-1})	8.6	1.0	21	5.9–10.2
Surface Sediments (0–2 cm)				
WC (%)	79.4	4.0	29	70.0–85.0
Clay (%)	44.3	6.8	29	29.0–56.6
Silt (%)	48.7	7.7	29	31.3–65.3
Sand (%)	6.9	10.2	29	0.4–39.8
Mean size (Φ) (phi)	7.7	0.5	29	6.3–8.2
Sorting (σ) (phi)	1.5	0.3	29	1.2–2.2
Eh (mV)	–109	56	12	–30/–220
Eh (2–4 cm) (mV)	–216	92	12	–90/–395

Note: DO: dissolved oxygen; WC: water content.

18.3 $^{\circ}$ C. Dissolved oxygen concentrations in surface water were normoxic throughout the whole basin. Water depth at the sampling stations varied between 1.3 and 2.1 m, with a mean of 1.7 m (Tab. I).

The surface sediments were homogeneously muddy with a mean water and a mean mud content of 79.4% and 93.0%, respectively, and a similar contribution of the clay and silt fractions (Tab. I). This was associated with a very high sediment mean size (Φ) of 7.7 phi and a sediment mean sorting (σ) of 1.5 phi (Tab. I). Eh values at both the surface and subsurface layers were negative, indicating markedly reduced conditions of these sediments, further worsening with depth (Tab. I).

A detailed analysis of the distribution of specific bulk properties of the sediments, within the muddy fraction, highlighted a remarkable spatial variability. In particular, the sediment mean size (Φ) tended to increase noticeably towards the inner sector of the lagoon, while the sediment sorting (σ), an index of sediment dynamics, tended to increase towards the shores (Fig. 2).

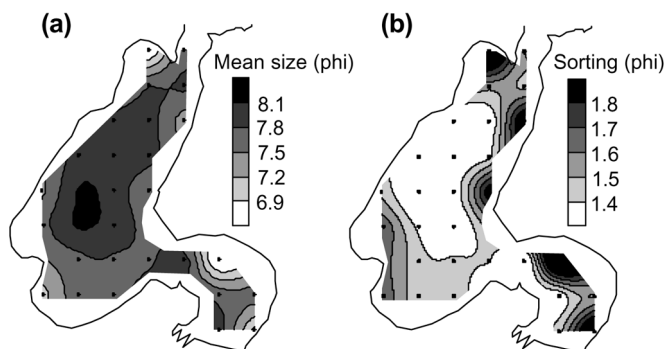


FIGURE 2 Spatial distribution of sediment bulk properties: (a) sediment mean size and (b) sediment sorting.

3.2 Macrofaunal Communities

A total of 8228 individuals belonging to 15 *taxa* were collected. Two polychaete species alone, *Ficopomatus enigmaticus* and *Polydora ciliata*, accounted for 71.0% of the total abundance, and only eight *taxa* comprised up to 99.2% of it (Tab. II). Among the rarest species found, polychaetes included *Syllides endentulus* and Sabellidae nc, and crustaceans included the amphipod *Dexamine spinosa*, the decapod *Pachygrapsus marmoratus* and *Balanus amphitrite amphitrite*. Among bivalves, besides the presence of relatively abundant *Cerastoderma glaucum* (Tab. II), very few individuals of *Abra* sp. were found, while gastropods were represented only by *Hydrobia* cfr. *ventrosa*. On an areal basis, the total abundance at individual stations varied from 27 to 3105 ind. 432 cm⁻², with a mean of 283.7 ind. 432 cm⁻² (Tab. II).

Figure 3 shows the spatial distribution of the abundance of the eight most dominant *taxa*. In particular, *F. enigmaticus* and *Corophium sextonae* tended to be abundantly present in patchy areas along the shores, while *P. ciliata* showed a preferential and wider distribution in the central-southern part of the lagoon, and was to some extent accompanied by the presence of *C. glaucum* at several stations. Differently, Tubificidae nc and Chironomidae larvae were more localized in proximity of the narrower areas of the lagoon (Fig. 3). By contrast, *Neanthes succinea* and *Hediste diversicolor* were most abundant on the western shore, showing a rather overlapped distribution, although the latter nereidid species was ca. 5 times less abundant (Fig. 3).

3.3 Multivariate Analysis

Cluster analysis classification and non-metric multidimensional scaling (nMDS) ordination of total samples showed a high heterogeneity of the stations (Fig. 4), with those having the lowest affinity (Stns C2, C8, C10, C18, C20) being scattered along the shore in different areas of the lagoon (Fig. 1). Within such a low affinity, three additional groups of stations

TABLE II Mean \pm Standard Deviation (SD) of the Abundance (ind. 432 cm⁻²) of the Eight Most Dominant *Taxa* (Comprising >1% of the Total Abundance).

	Abundance					
	Mean	SD	No. Stns	Min-Max	Relative %	Cumulative %
<i>Ficopomatus enigmaticus</i> (Polychaeta)	116.0	370.3	29	0-1777	40.9	40.9
<i>Polydora ciliata</i> (Polychaeta)	85.3	121.6	29	0-585	30.1	71.0
Tubificidae nc (Oligochaeta)	28.2	56.0	29	0-270	9.9	80.9
<i>Neanthes succinea</i> (Polychaeta)	19.8	23.5	29	0-85	7.0	87.9
<i>Corophium sextonae</i> (Crustacea)	15.4	74.5	29	0-402	5.4	93.3
<i>Cerastoderma glaucum</i> (Bivalvia)	9.0	19.4	29	0-83	3.2	96.4
Chironomidae larvae (Insecta)	4.5	17.6	29	0-95	1.6	98.0
<i>Hediste diversicolor</i> (Polychaeta)	3.3	4.3	29	0-15	1.2	99.2
Total	283.7	581.0	29	27-3105	100.0	100.0

Note: Minimum (Min) and maximum (Max) values at individual stations (Stns), and the relative and cumulative percentages on the total abundance are also shown.

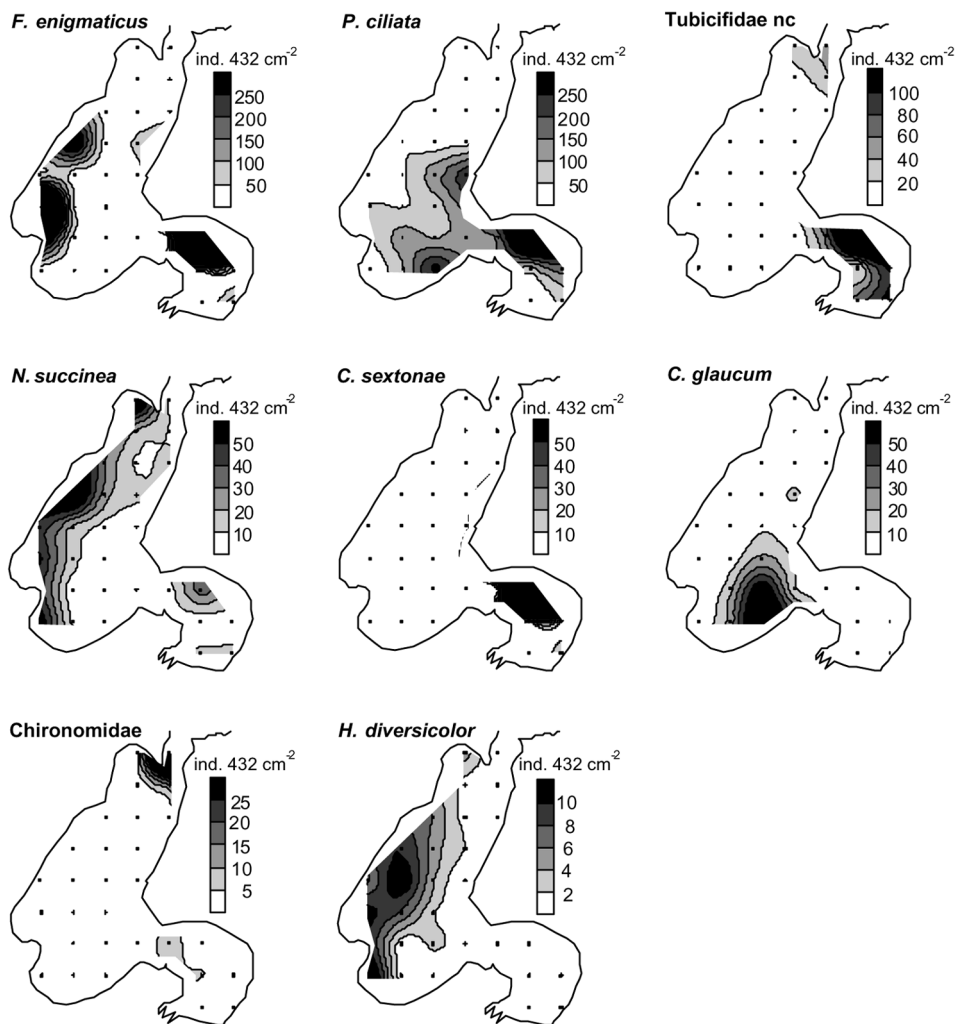


FIGURE 3 Spatial distribution of the abundance (ind. 432 cm⁻²) of the eight most dominant *taxa* (comprising >1% of the total abundance). Top-bottom order: from the more abundant to the less abundant *taxa* (Tab. II).

could be somehow described (Fig. 4a). They included a spatially heterogeneous group, comprising Stns C1 and C3, at the inlet of the lagoon, and Stns C21, C25, C26, C30 and C31, in the southern sector of the lagoon, and a larger group of relatively inner stations, sub-divided into a northern (Stns C4 to C7, C9, C13, C14, C17 and C29) and a more central (Stns C11, C12, C16, C22 to C24, C27 and C28) area (Figs. 1 and 4).

The eight most dominant *taxa*, whose distribution suggested distinct spatial trends (Fig. 3), were tested for any significant association with each others, and possible relationships with the sediment mean size (Φ) and sorting (σ), and with the water depth, using the factor analysis. The first three factors contributed a similar percentage to the cumulative explained variance (72.6%), accounting for 27.3, 24.2 and 21.1% of the matrix variation, respectively (Tab. III). The first factor was dominated by the weights of *P. ciliata* and *C. glaucum*, which were also correlated negatively with *N. succinea* and positively with water depth. The second factor was dominated by the weights of *F. enigmaticus* and *C. sextonae*, which were correlated inversely with the sediment mean size (Φ) and positively with the sediment sorting (σ). The

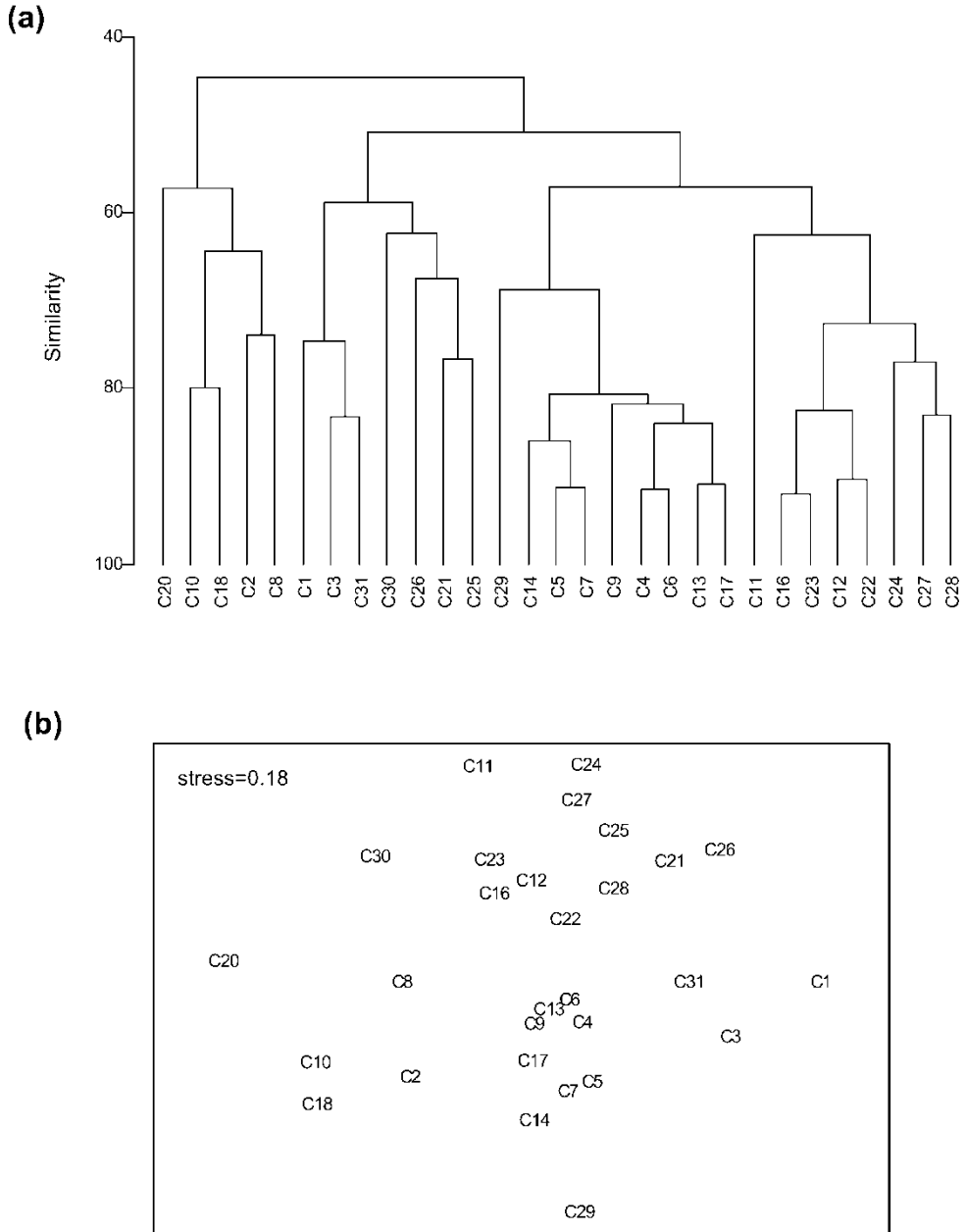


FIGURE 4 Cluster analysis (a) and nMDS ordination plot (b) of the 29 stations.

third factor indicated a negative correlation of Tubificidae nc and Chironomidae larvae with *H. diversicolor*, while showing no significant correlation with the environmental variables considered (Tab. III). The plots of the three factors, used to construct 2-D representations, successfully individuated three major areas in the Cabras lagoon, including a central-southward area (factor 1), an inner area (factor 2), and a central-westward area (factor 3) (Fig. 5). These areas demonstrated spatial trends of a preferential distribution of dominant *taxa* and species-specific associations with the sediment bulk properties (Tab. III).

TABLE III Factor Scores and Explained Variance for Each Factor Extracted From Variables Describing Associations of Dominant Macrofaunal *Taxa* (Comprising >1% of the Total Abundance), Sediment Bulk Properties and Water Depth.

Variable	Factor 1	Factor 2	Factor 3
<i>F. enigmaticus</i>	-0.19	-0.76	0.28
<i>P. ciliata</i>	0.83	-0.39	0.12
Tubificidae nc	-0.29	-0.31	-0.75
<i>N. succinea</i>	-0.79	-0.26	0.45
<i>C. sextonae</i>	0.10	-0.78	-0.06
<i>C. glaucum</i>	0.75	0.19	-0.12
Chironomidae larvae	0.14	0.01	-0.82
<i>H. diversicolor</i>	-0.47	0.05	0.81
Sediment mean size	0.10	0.75	0.21
Sediment sorting	-0.31	-0.70	-0.27
Water depth	0.79	0.28	-0.03
Explained variance (%)	27.3	24.2	21.1
Cumulative variance (%)	27.3	51.5	72.6

Note: Highest weights/factors loadings are those in bold which characterize the factors and which are discussed in the text.

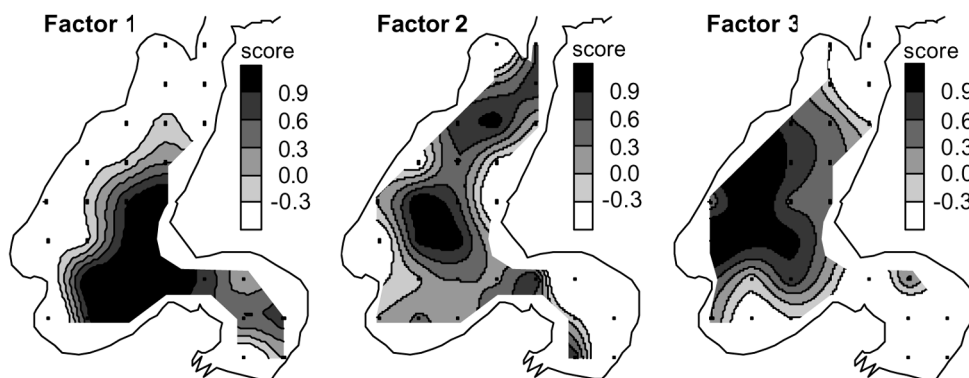


FIGURE 5 Spatial representation of the three factor scores as resulting from the factor analysis of the eight most dominant macrofaunal *taxa*, sediment bulk properties and water depth (variable weights for each factor are given in Tab. III).

4 DISCUSSION

Very poor macrofaunal communities, compared to other lagoon systems (Martinelli *et al.*, 1999; Lardicci *et al.*, 2001b; Mistri *et al.*, 2001; 2002), characterized the benthic environment of the Cabras lagoon. Few predominant *taxa* included small-size surface (e.g. *Polydora ciliata* and *Corophium sextonae*) and subsurface (e.g. Tubificidae nc) deposit feeders, and larger nereidid polychaetes (i.e. *Neanthes succinea* and *Hediste diversicolor*), typically occurring in degraded environments. Consistently, the opportunistic *P. ciliata* is described as common in waters affected by heavy organic pollution (Mistri *et al.*, 2002), and *C. sextonae*, *H. diversicolor* and oligochaetes are typically dominating early stages of macrofaunal succession (Tagliapietra *et al.*, 1998). Filter feeders were almost exclusively represented by the reef-like builder polychaete *F. enigmaticus* (Bianchi and Morri, 1996; 2001) and the hard-shelled bivalve *Cerastoderma glaucum*. Yet, the former species was

localized in patchy areas along the shores of the lagoon, while the latter appeared to be limited both in distribution and in number. *F. enigmaticus* is also known to tolerate wide variations of salinity, ranging from oligohaline to euhaline waters (Bianchi, 1981), and this was consistent with the large salinity fluctuations occurring through the year in the Cabras lagoon (Magni *et al.*, unpubl. data). Among the rarest species, *Syllides endentulus*, found at two seawards stations (Stns C20 and C30, Fig. 1), has been reported in areas heavily disturbed by anthropogenic activities, such as ports (Cognetti-Varriale, 1971).

Although an environmental (*e.g.* salinity) gradient from the inlet of the lagoon towards the sea could be expected to influence the composition and structure of macrofaunal communities along the basin, there was a major difficulty identifying similar community structures in the Cabras lagoon (Fig. 4). This fact could be related to the existence of a pioneering situation of macrofaunal communities, where few resistant *taxa*, differently distributed in some areas of the lagoon, may inhabit. Our sampling scheme, based on a grid of stations covering the whole lagoon, was also aimed at obtaining an overall picture, at the basin scale, of the macrofaunal communities of the Cabras lagoon, for which little information was available prior to this study.

By applying factor analysis we distinguished three statistically significant trends and demonstrated some ecologically relevant associations. In particular, the polychaete *P. ciliata* and the bivalve *C. glaucum* formed a first association which identified a relatively deeper area, localized in the central-southward sector of the lagoon (factor 1, Tab. III and Fig. 5). The positive correlation of *C. glaucum* with water depth may indicate more suitable conditions of relatively deeper waters, characterized by higher and less fluctuating salinity, to the settlement of bivalves. On the other hand, we found a high incidence of younger forms (<3 mm) of *C. glaucum*, while adults larger than 10 mm were only a few (Magni *et al.*, unpubl. data). This was consistent with the sampling period, but also indicated that the recruitment of *C. glaucum* is hardly followed by a successful colonization, suggesting not suitable conditions throughout the year for bivalves. Possible explanations to the low diverse age-class structure of *C. glaucum* in the Cabras lagoon may include periodic hypoxic conditions, which tend to occur in near-bottom water of dystrophic lagoon systems (Viaroli *et al.*, 2001) and can strongly affect long-lived macrofaunal species, and the structural properties of the muddy sediments of the lagoon. By contrast, *N. succinea* correlated negatively with *P. ciliata* and *C. glaucum*, and was excluded from this area. We argue that a greater ability of larger and mobile polychaete species, such as *N. succinea* (and *H. diversicolor*), may allow them to escape from more stressed situations and to colonize more oxygenated (and shallower) areas (Fig. 3).

A second association was dominated by the abundances of *F. enigmaticus* and *C. sextonae* along the shores which highlighted, by contrast, an inner area of the lagoon (factor 2, Tab. III and Fig. 5) characterized by an overall lack of macrofauna and very muddy conditions of the sediments (Figs. 2 and 3). Over a long period of time, many authors have investigated the role of sediment type as a major factor determining macrofaunal community composition and structure (Sanders, 1958; Rhoads, 1974). Marked patterns of macrofaunal distribution have been recognized along an apparent sedimentary gradient of grain size composition and organic matter enrichment (Fresi *et al.*, 1983; Jones *et al.*, 1986; Ishikawa, 1989; Quintino and Rodrigues, 1989; Bachelet *et al.*, 1996; Schlacher and Wooldridge, 1996). However, less work has been done in homogeneous sediments, particularly in enclosed muddy lagoons, where a more detailed analysis of sediment grain size distribution is needed to discriminate between different zones and to unravel possible animal-sediment relationships. In these systems, such analysis is particularly important because the partitioning and transport of finer particles of sediments may influence the accumulation of large amounts of organic matter, which in turn may strongly affect the macrofaunal communities. In this study, we demonstrated that enclosed and shallow systems characterized by poor macrofaunal

communities and muddy sediments may indeed show distinct associations between predominant species and sediment particle distribution. In particular, *F. enigmaticus* and *C. sextonae* showed a positive correlation with the sediment sorting (σ), an index of sediment selection due to hydrodynamic energy (Tab. III). Increasing σ values towards the shores of the lagoon (Figure 2b) indicated more sorted sediments in shallower areas with a relatively higher hydrodynamic energy, which is mainly caused, in micro-tidal lagoons, by the action of currents and waves (Isla, 1995). This was consistent with the distribution and the ecological characteristics of *F. enigmaticus* and *C. sextonae*, i.e. the former taking advantage of resuspended food particles along the shores, the latter finding a refuge within the serpulid's reefs. By contrast, areas with a lower hydrodynamic energy will favour the accumulation of fine sediments (and organic matter) due to an easier settlement of clay particles. The high sediment mean size (Φ) found in the inner part of the lagoon (Fig. 2a) indicated a further increase of finer particles within the muddy fraction and matched with much reduced macrofaunal communities (Fig. 3). A companion paper demonstrated that inner areas of the Cabras lagoon are indeed major sites of transport and accumulation of fine sediment particles and organic matter (De Falco *et al.*, 2004).

A third major area, identified in a westerly direction of the Cabras lagoon (factor 3, Tab. III and Fig. 5), was dominated by *H. diversicolor*. Interestingly in this area, the preferential and rather overlapped distribution of *H. diversicolor* and *N. succinea*, generally characterized as surface deposit feeders, excluded the presence of Tubificidae and Chironomidae larvae, the two major subsurface deposit feeders encountered in the Cabras lagoon, suggesting different areas of distribution between different feeding guilds.

We conclude that the reduced macrofaunal communities and the simple benthic associations found in this study were a major evidence of the existence of a pioneering situation in the Cabras lagoon. Among the possible reasons causing the present disturbed state, we hypothesize the occurrence of periodic events of oxygen depletion in near-bottom waters, especially in relatively deeper areas, and the subsequent release of toxic hydrogen sulfide from the sediments. A major event of this kind occurred in summer 1999 when a severe dystrophic crisis at the basin scale caused a massive mortality of the biological resources of the Cabras lagoon, from benthic fauna up to higher trophic level, such as commercially important fish (IMC, 1999). These processes may thus depress the activity and limit the occurrence of benthic fauna throughout the year.

Future studies should evaluate the seasonal trends of macrofaunal communities in the Cabras lagoon, and their relationships with the chemical characteristics of the sediments and the hydrological features of near bottom waters, on different temporal and spatial scales. In particular, one important issue will be to investigate the effects of organic matter and inorganic reduced sulphur concentrations of sediments on the distribution and the dynamics of macrofaunal communities, in order to evaluate the extent and the time needed for a possible recovery process from the present early stage of faunal succession.

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References

- Bachelet, G., de Montaudouin, X. and Dauvin, J. C. (1996). The quantitative distribution of subtidal macrozoobenthic assemblages in Arcachon Bay in relation to environmental factors: a multivariate analysis. *Estuarine, Coastal and Shelf Science*, **42**, 371–391.
- Balducci, C., Sfriso, A. and Pavoni, B. (2001). Macrofauna impact on *Ulva rigida* C. Ag. Production and relationship with environmental variables in the lagoon of Venice. *Marine Environmental Research*, **52**, 27–49.
- Beukema, J. J. (1991). Changes in composition of bottom fauna of a tidal-flat area during a period of eutrophication. *Marine Biology*, **111**, 293–301.
- Bianchi, C. N. (1981). *Policheti serpuloidi*. Guide per il riconoscimento delle specie animali delle acque lagunari e costiere italiane. CNR, Roma, Collana del progetto finalizzato 'Promozione della qualità dell'ambiente' (serie AQ/1/96), **5**, 187.
- Bianchi, C. N. and Morri, C. (1996). *Ficopomatus* "reefs" in the Po river delta (Northern Adriatic), their constructional dynamics, biology, and influences on the brackish-water biota. *Pubblicazioni della Stazione Zoologica di Napoli: Marine Ecology*, **17** (1–3), 51–66.
- Bianchi, C. N. and Morri, C. (2001). The battle is not to the strong, serpulid reefs in the lagoon of Orbetello (Tuscany, Italy). *Estuarine, Coastal and Shelf Science*, **53**, 215–220.
- Blott, S. J. and Pye, K. (2001). Gradstat: a grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms*, **26**, 1237–1248.
- Clarke, K. R. and Warwick, R. M. (1994). *Changes in marine communities: an approach to statistical analysis and interpretation*. Plymouth Marine Laboratory, Plymouth, UK.
- Cloern, J. E. (2001). Our evolving conceptual model of the coastal eutrophication problem *Marine Ecology Progress Series*, **210**, 223–253.
- Cognetti-Varriale, A. M. (1971). Sur un Syllidien des eaux polluées du port de Livourne: *Syllides edentula* Clap. *Cahiers de Biologie Marine*, **12**, 111–115.
- Dauwe, B., Herman, P. M. J. and Heip, C. H. R. (1998). Community structure and bioturbation potential of macrofauna at four North sea stations with contrasting food supply. *Marine Ecology Progress Series*, **173**, 67–83.
- De Falco, G., Magni, P., Teräsvuori, L. M. H. and Matteucci, G. (2004). Sediment grain size and organic carbon distribution in the Cabras lagoon (Sardinia, western Mediterranean). *Chemistry and Ecology*, **20** (Supplement 1), S367–S377.
- Diaz, R. J. and Rosenberg, R. (1995). Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanography and Marine Biology: An Annual Review*, **33**, 245–303.
- Fresi, E., Gambi, M. C., Focardi, S., Barbagli, R., Baldi, F. and Falciai, L. (1983). Benthic community and sediment types, a structural analysis. *Pubblicazioni della Stazione Zoologica di Napoli: Marine Ecology*, **4**(2), 101–121.
- Friligos, N. and Zenetos, A. (1988). Elefsis bay anoxia, nutrient conditions and benthic community structure. *Pubblicazioni Della Stazione Zoologica di Napoli: Marine Ecology*, **9**(4), 273–290.
- Giordani, G., Azzoni, R., Bartoli, M. and Viaroli, P. (1997). Seasonal variations of sulphate reduction rates, sulphur pools and iron availability in the sediment of a dystrophic lagoon (Sacca di Goro, Italy). *Water, Air and Soil Pollution*, **99**, 363–371.
- IMC – International Marine Centre (1999). Controllo ambientale nella laguna di Cabras (Periodo: luglio 1999). Technical report (unpubl.).
- Ishikawa, K. (1989). Relationship between bottom characteristics and benthic organisms in the shallow water of Oppa Bay, Miyagi. *Marine Biology*, **102**, 265–273.
- Isla, F. I. (1995). Coastal lagoons. in Perillo, G. M. E. (ed.), *Geomorphology and sedimentology of estuaries*. Elsevier Amsterdam, The Netherlands.
- Jones, A. R., Watson-Russell, C. J. and Murray, A. (1986). Spatial patterns in the macrobenthic communities of the Hawkesbury estuary, New South Wales. *Australian Journal of Freshwater Research*, **37**, 521–543.
- Karakassis, I. and Eleftheriou, A. (1997). The continental shelf of Crete: structure of macrobenthic communities. *Marine Ecology Progress Series*, **160**, 185–196.
- Karakassis, I., Tsapakis, M., Hatziyanni, E., Papadopoulou, K. N. and Plaiti, W. (2000). Impact of cage farming of fish on the seabed in three Mediterranean coastal area. *ICES Journal of Marine Science*, **57**, 1462–1471.
- Lardicci, C., Rossi, F. and Castelli, A. (1997). Analysis of macrozoobenthic community structure after severe dystrophic crisis in a Mediterranean coastal lagoon. *Marine Pollution Bulletin*, **34**, 536–547.
- Lardicci, C., Como, S., Corti, S. and Rossi, F. (2001a). Recovery of the macrozoobenthic community after severe dystrophic crises in a Mediterranean coastal lagoon (Orbetello, Italy). *Marine Pollution Bulletin*, **42**(3), 202–214.
- Lardicci, C., Como, S., Corti, S. and Rossi, F. (2001b). Changes and recovery of macrozoobenthic communities after restoration measures of the Orbetello Lagoon (Tyrrhenian coast, Italy). *Aquatic Conservation Marine and Freshwater Ecosystems*, **11**, 281–287.
- Le Maitre, R. W. (1982). *Numerical petrology: statistical interpretation of geochemical data*. Elsevier, Amsterdam, 318 pp.
- Magni, P. and Montani, S. (1998). Responses of intertidal and subtidal communities of the macrobenthos to organic load and oxygen depletion in the Seto Inland Sea, Japan. *Journal de Recherche Océanographique*, **23**(2), 47–56.
- Mancinelli, G., Fazi, S. and Rossi, L. (1998). Sediment structural properties mediating dominant feeding types patterns in soft-bottom macrobenthos of the Northern Adriatic Sea. *Hydrobiologia*, **367**, 211–222.

- Marques, J. C., Maranhão, P. and Pardal, M. A. (1993). Human impact assessment on the subtidal macrobenthic community structure in the Mondego estuary (western Portugal). *Estuarine, Coastal and Shelf Science*, **37**, 403–419.
- Martinelli, M., Cadalano, R., Floris, A., Santoni, M., Rossi, F., Lardicci, C. and Castelli, A. (1999). Polychaete distribution in some Sardinian brackish ponds. *Biologia Marina Mediterranea*, **6** (1), 399–402 (in Italian).
- Mistri, M., Fano, E. A. and Rossi, G. (2001). Redundancy of macrobenthos from lagoonal habitats in the Adriatic Sea. *Marine Ecology Progress Series*, **215**, 289–296.
- Mistri, M., Fano, E. A., Ghion, F. and Rossi, R. (2002). Disturbance and community pattern of polychaetes inhabiting Valle Magnavacca (Valli di Comacchio, Northern Adriatic Sea, Italy). *Pubblicazioni della Stazione Zoologica di Napoli: Marine Ecology*, **23**(1), 31–49.
- Molinarioli, E., De Falco, G., Rabitti, S. and Portaro, R. (2000). Stream scanning laser system, electric sensing Counter and settling grain size analysis: a comparison using reference materials and marine sediments. *Sedimentary Geology*, **134** (3–4), 269–281.
- Nixon, S. W. (1995). Coastal marine eutrophication: a definition, social cause, and future concerns. *Ophelia*, **41**, 199–219.
- Pearson, T. H. and Rosenberg, R. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: An Annual Review*, **16**, 229–311.
- Pinna, M. (1989). Il clima. in *La Provincia di Oristano: il territorio, la natura e l'uomo*. Provincia di Oristano ed, Pizzi Spa, Milano, pp. 38–48.
- Puscaddu, A., Serra, E., Sanna, O. and Fabiano, M. (1996). Seasonal fluctuations in the nutritional value of particulate organic matter in a lagoon. *Chemistry and Ecology*, **13** (1), 21–37.
- Puscaddu, A., Sarà, G., Armeni, M., Fabiano, M. and Mazzola, A. (1999). Seasonal and spatial changes in the sediment organic matter of a semi-enclosed marine system (W-Mediterranean Sea). *Hydrobiologia*, **397**, 59–70.
- Quintino, V. and Rodrigues, A. M. (1989). Environment gradients and distribution of macrozoobenthos in three Portuguese coastal systems: Obidos, Albufeira and Alvor, in Ryland, J. S. and Tyler, P. A. (eds.), *Reproduction, Genetics, and Distribution of Marine Organisms*, Olsen & Olsen, Fredensborg, pp. 441–450.
- Rhoads, D. C. (1974). Organism-sediment relation on the muddy sea floor. *Oceanography and Marine Biology: An Annual Review*, **12**, 263–300.
- Sanders, H. L. (1958). Benthic studies in buzzards bay. I. Animal sediment relationship. *Limnology and Oceanography*, **3**, 245–258.
- Schlacher, T. A. and Wooldridge, T. H. (1996). Axial zonation patterns of subtidal macrozoobenthos in the Gamtoos estuary, South Africa. *Estuaries*, **19**, 680–696.
- Sfriso, A., Birkemeyer, T. and Ghetti, P. F. (2001). Benthic macrofauna changes in areas of Venice lagoon populated by seagrasses or seaweeds. *Marine Environment Research*, **52**, 323–349.
- Sorokin, Y. I., Sorokin, P. Y. and Gnes, G. (1996). Structure and functioning of the anthropogenically transformed Comacchio lagoonal ecosystem (Ferrara, Italy). *Marine Ecology Progress Series*, **133**, 57–71.
- Swan, A. R. H. and Sandilands, M. (1995). *Introduction to geological data analysis*. Blackwell Science, Oxford, 446 pp.
- Tagliapietra, D., Pavan, M. and Wagner, C. (1998). Macrobenthic community changes related to eutrophication in *Palude della Rosa* (Venetian lagoon, Italy). *Estuarine, Coastal and Shelf Science*, **47**, 217–226.
- Tsutsumi, H., Kikuchi, T., Tanaka, M., Higashi, T., Imasaka, K. and Miyazaki, M. (1991). Benthic fauna succession in a cove organically polluted by fish farming. *Marine Pollution Bulletin*, **23**, 233–238.
- Tyson, R. V. (1995). *Sedimentary Organic Matter*. Chapman & Hall, London, 615 pp.
- Viaroli, P., Azzoni, R., Bartoli, M., Giordani, G. and Taje', L. (2001). Evolution of the trophic conditions and dystrophic outbreaks in the Sacca di Goro lagoon (Northern Adriatic Sea), in Faranda, F. M., Guglielmo, L. and Spezie, G. (eds.), *Mediterranean Ecosystems: Structure and Processes*. Chapter 59, 467–475. Springer Verlag, Italia, Milan.
- Villano, N. and Warwick, R. M. (1995). Meiobenthic communities associated with the seasonal cycle of growth and decay of *Ulva rigida* Agardh in the Palude della Rosa, Lagoon of Venice. *Estuarine, Coastal and Shelf Science*, **41**, 181–194.
- Weston, D. P. (1990). Quantitative examination of macrobenthic community changes along an organic enrichment gradient. *Marine Ecology Progress Series*, **61**, 233–244.