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Sediment characteristics and macrofauna distribution along a human-modified inlet in the Gulf of Oristano (Sardinia, Italy)

S. Como [a,*], P. Magni [a,b], D. Casu [c], A. Floris [d], G. Giordani [e], S. Natale [a], G.A. Fenzi [a], G. Signa [a], G. De Falco [a,b]

[a] *IMC – International Marine Centre, Località Sa Mardini, Torregrande, 09072 Oristano, Italy*
[b] *CNR–IAMC National Research Council, Institute for Coastal Marine Environment c/o IMC, International Marine Centre, Località Sa Mardini, Torregrande, 09072 Oristano, Italy*
[c] *Dip. di Botanica ed Ecologia vegetale, Università di Sassari, Via Muroni 25, 07100 Sassari, Italy*
[d] *Dip. di Zoologia e Genetica evoluzionistica, Università di Sassari, C.so Margherita di Savoia 15, 07100 Sassari, Italy*
[e] *Dip. di Scienze Ambientali, Università di Parma, Via Usberti 33/A, 43100 Parma, Italy*

Abstract

We studied the spatial variability and within-year temporal changes in hydrological features, grain size composition and chemical characteristics of sediments, as well as macrofaunal assemblages, along a heavily modified inlet in the Gulf of Oristano (western Sardinia, Italy). The inlet connects the Cabras lagoon to the gulf through a series of convoluted creeks and man-made structures, including a dam and fish barriers built in the last three decades. Sediments were muddy and mainly composed of the ‘‘non-sortable’’ fraction (i.e., <8 μm particle size) in all four areas investigated: *Lagoon*, *Creeks*, *Channel* and *Seaward*. Along the inlet, however, the ratio between the <8 μm and the 8–64 μm fractions was highest in *Creeks* and *Channel*, between the fish barriers and the dam, suggesting impaired hydrodynamics. Consistently, steep gradients in water salinity, temperature and dissolved oxygen concentrations were found in proximity to the fish barriers. The whole inlet was characterized by a major organic enrichment of sediments, with up to an annual mean of 33.6% of organic matter and 11.7% of total organic carbon in *Seaward* due to the presence of seagrass leaf litter. Acid-volatile sulphide and chromium-reduced sulphur concentrations were highest throughout the year in *Seaward* and *Lagoon*, respectively, with a peak in summer. Consistently, the whole inlet supported low structured macrofaunal assemblages dominated by few opportunist species, with a relatively lower diversity in *Lagoon* throughout the year and the highest abundances in *Seaward* in summer. We infer that the presence of artificial structures along the inlet, such as fish barriers and the dam, impair the lagoon-gulf hydrodynamics, sediment exchange and animal recruitment and colonization. We suggest that the removal of these structures would favour water renewal in the Cabras lagoon, but would also increase the outflow of organic C-bonding fine particles into the gulf with serious consequences for *Posidonia oceanica* and *Cymodocea nodosa* seagrass meadows. We conclude that all possible consequences of such initiatives should be carefully considered before any action is taken.

Keywords: Macrofauna; Total organic carbon (TOC); Benthic species richness; Acid-volatile sulphides (AVS); Artificial structures; Coastal lagoons

1. Introduction

Coastal lagoons and the adjacent marine areas form unique transitional systems whose inlets play a key role (Isla, 1995). Inlets are critical in the interaction between lagoons and the coastal marine ecosystem as they influence the exchange of water masses with different physical and chemical characteristics and ensure the renewal of the water within the lagoon (Guerorget and Perthiusot, 1992). Human control of the inlets has been a common practice since ancient times (e.g. the opening of the Ansedonia channel in the Orbetello lagoon by the Romans;

* Corresponding author. Tel.: +39 0783 22027; fax: +39 0783 22002.
E-mail addresses: s.como@imc-it.org (S. Como), Paolo.Magni@iamc.cnr.it (P. Magni).

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Cognetti et al., 1978). However, in the last few decades major interventions affecting the morphology of inlets, such as the installation of artificial structures and barriers, are profoundly impairing the trophic status and function of these systems worldwide (Lardicci et al., 1997, 2001; Koutsoubas et al., 2000; da Cunha and Wasserman, 2003; Sato, 2006). This results in nutrient enrichment (da Cunha and Wasserman, 2003) and accumulation of fine sediments and organic matter inside the lagoon (De Falco et al., 2004) and, more drastically, the loss of habitats (Elliott and Cutts, 2004). However, the environmental and biological effects of human intervention on these inlets have been poorly investigated, even though artificial structures are known to affect sediment characteristics and the distribution of animals in marine coastal and brackish environments (Cavazza et al., 2000; Frihy, 2001; da Cunha and Wasserman, 2003; Bulleri and Chapman, 2004; De Falco et al., 2004; Bulleri and Airoldi, 2005; Cardoso et al., 2005).

In the Gulf of Oristano (western Sardinia, Italy), where this study was conducted, human intervention has drastically altered the inlets of various transitional systems covering a total surface of about 46 km^2 and representing about 50% of Sardinian wetlands (De Falco and Piergallini, 2003). Of these systems, we find the Cabras lagoon which is renowned both for its fishery activities (e.g. *Liza ramado*, *Mugil cephalus*) involving about 250 fishermen as well as its naturalistic value (e.g. it is part of the Ramsar Convention on Wetlands and the Natura 2000 network following the EU habitat directive). In the last few decades, however, the Cabras lagoon has experienced high anthropogenic pressure mainly due to massive nutrient loading, urban discharge and a progressive reduction of freshwater input due to upland activities (e.g. agriculture). This has led to a periodic crisis of the system, with major dystrophic events causing fish mortality and an impoverished benthic macrofauna (Murenu et al., 2004; Magni et al., 2004, 2005a). In previous studies the surplus of sedimentary organic matter was indicated to be the probable cause of oxygen depletion in near-bottom waters which induce hydrogen sulphide release from the sediments (Magni et al., 2005b). De Falco et al. (2004) suggested that a major change in the sedimentary regime of the lagoon has been occurring over the last few decades and that a cause would appear to be the inlet modification.

The lagoon of Cabras has a single inlet which has been drastically modified in the last few decades. In the early 1970s a connecting channel (200 m wide and about 2 km long) was opened between the lagoon and the gulf to prevent flooding of the villages located around the lagoon. A W-shaped dam was subsequently installed between the lagoon and the connecting channel at the high tide mark in the late 1970s. This structure was intended to control the water level in the lagoon and to prevent the tide from entering. In addition, man-made barriers were built in 1997 in the proximity of the gulf to facilitate fish capture. Today, the water exchange between the lagoon and the gulf is limited to narrow, convoluted creeks which flow into the connecting channel on the seaward side of the dam. The connecting channel is separated from the lagoon by the dam and from the gulf by the fish barriers. Thus, the aim of this study was to assess the spatial variability and temporal changes in the hydrological features, grain size composition and chemical characteristics of the sediments, and macrofaunal assemblages along this modified inlet which connects the Cabras lagoon to the Gulf of Oristano. An initial spatial study was conducted in summer 2003, followed by a second temporal study between autumn 2003 and summer 2004.

2. Material and methods

2.1. Study location

We conducted the field surveys in the inlet which connects the Cabras lagoon to the Gulf of Oristano, in western Sardinia, Italy (Fig. 1). The study location is part of an

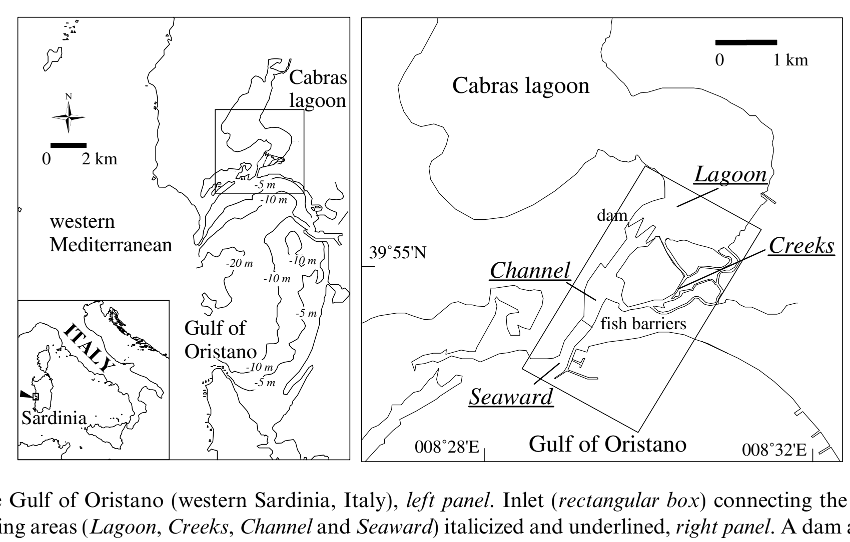

Fig. 1. Study location in the Gulf of Oristano (western Sardinia, Italy), *left panel*. Inlet (*rectangular box*) connecting the Cabras lagoon to the Gulf of Oristano with the four sampling areas (*Lagoon*, *Creeks*, *Channel* and *Seaward*) italicized and underlined, *right panel*. A dam and fish barriers along the inlet are also indicated.

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extensive area of transitional systems and coastal lagoons associated with the Gulf of Oristano. The gulf is characterized by extended *Posidonia oceanica* meadows which cover about 70% of its seabed and are then replaced along the coast by *Cymodocea nodosa* (Cancemi et al., 2000; De Falco et al., 2006). Water circulation of the Cabras lagoon and the Gulf of Oristano was investigated by Cucco et al. (2006) and Ferrarin and Umgiesser (2005). We refer to these previous studies for a detailed description of the hydrodynamic features of the study location.

In summer 2003, three different areas were considered: a seaward area located beyond the fish barriers (hereafter *Seaward*), an area located between the fish barriers and the W-shaped dam (hereafter *Channel*), and an area located in the southernmost sector of the lagoon in the proximity of the W-shaped dam (hereafter *Lagoon*) (Fig. 1). A subsequent temporal study was performed on four sampling dates: in November 2003 (hereafter called autumn 2003), and then in January, May and August 2004 (hereafter called winter, spring and summer 2004, respectively). In addition to the three areas sampled in summer 2003, *Seaward*, *Channel* and *Lagoon*, a fourth area was selected in the creeks (hereafter *Creeks*) located between the *Lagoon* and *Channel* (Fig. 1).

2.2. Field surveys and laboratory analysis

In each area, three plots were sampled in summer 2003, and two plots in the temporal study between autumn 2003 and summer 2004. The replicate plots were randomly chosen and were separated by hundreds of meters. At each replicate plot, two replicate samples were taken for grain size and chemical analyses of sediments using a PVC corer (40 cm long, 5.5 cm inner diameter) while three replicate samples were taken for macrofauna using a 216 cm^2 Ekman–Birge grab (penetration depth of about 15 cm). Macrofauna samples were sieved on the shore through a mesh size of 0.5 mm, fixed with a 5% buffered formaldehyde solution stained with rose Bengal. On each sampling date between autumn 2003 and summer 2004, hydrological measurements were made using a multiprobe cast (Hydrolab Datasonde 4a). Approximately 20–30 points were measured for each vertical profile down to near-bottom water (about 10 cm above the surface sediments). Values were averaged for each 30 cm depth. Water depth was approximately 2 m in all areas.

In the laboratory, the surface layer (0–2 cm) of sediments was carefully sliced off each core. The surface layers from the same replicate cores were mixed together and treated as one single sample. A sub-sample of ca. 4 g was suspended in 500 ml of distilled water and treated with hydrogen peroxide (H_2O_2, 4% solution) in order to eliminate organic matter before being wet sieved through a net of 64 μm. The sand fraction [*Sand* (>64 μm)] remaining in the sieve was dried and weighed. Ten milliliters of suspension with the mud fraction (<64 μm) were then treated with Na-Hexametaphosphate 0.6% to avoid particle flocculation after a dilution to obtain a sediment concentration of ≈0.5 mg ml^{-1}. The grain size analysis of the mud fraction was performed using a laser Galai CIS 1 instrument, at specific size intervals of 0.5 μm (Molinaroli et al., 2000). The percentage of the sortable [hereafter *Sort* (8–64 μm)] and non-sortable [hereafter *Non-sort* (<8 μm)] fractions were then calculated (McCave et al., 1995; De Falco et al., 2004).

The organic matter (OM) content in the sediments was determined from a sub-sample (about 1 g) by loss of ignition at 500 °C for 3 h (Dean, 1974). Total organic carbon (TOC) and total nitrogen (TN) were determined by means of a CHNS elemental analyzer (Froelich, 1980; Hedges and Stern, 1984). The sub-samples for TOC were decarbonated using 1 M hydrochloric acid (HCl) and dried at 60 °C. The reproducibility was satisfactory with an average relative standard deviation (RSD) for replicate analyses of 0.9% for TOC and 1.3% for TN. Carbonates ($CaCO_3$, dry wt%) were determined by dissolution in 1 M HCl for 4 h. After being filtered through Whatman GF/C filters, the residue was dried and weighed. The inorganic reduced sulphur pool was analyzed separately as acid-volatile sulphide (AVS) and chromium-reduced sulphur (CRS) following the two step distillation process (after addition of 1 M HCl for AVS and 1 M $CrCl_2$ acid solution for CRS) under anoxic conditions and measured by the methylene blue method (Fossing and Jørgensen, 1989). AVS includes mainly dissolved sulphide (DS) and iron monosulphide (FeS) while the CRS accounts for pyrite (FeS_2) and elemental sulphur (S^0). The efficiency of this methodology in recovering the S pools is discussed in Fossing and Jørgensen (1989) and Rickard and Morse (2005), and is related to the mineralogical composition of the sediment. The detection limit is 0.01 μmol g^{-1} and RSD is lower than 5%.

Macrofauna were sorted, identified to the species level (when possible), counted and preserved in 70% ethanol.

2.3. Statistical analyses

Data were analyzed using models of analyses of variance (ANOVA, Underwood, 1997) with *Areas* (A) as fixed factor with 3 levels in the summer 2003 study and 4 levels in the temporal (autumn 2003–summer 2004) study. There were three replicates in the summer 2003 study, and two replicates in the temporal study. The factor *Dates* (D; 4 levels, fixed and crossed to A) were included in the temporal study. When available the *Replicate plots* were included as a nested factor. These designs were used for analyzing the changes in the following variables: (i) grain size (percentages of *Sand*, *Sort*, *Non-sort*, and *Non-sort*/*Sort* ratio) and chemical composition (OM, TOC, TN, $CaCO_3$, C/N ratio, and AVS and CRS when available) of sediments, (ii) total number of individuals (N), of species (S) and Shannon index (H'; calculated with natural logarithm), and (iii) the densities of the most abundant taxa (in the summer 2003 study only). The homogeneity of variances was checked using Cochran's C-test and, whenever necessary, data were appropriately transformed and newly tested (Winer et al., 1991). Significant differences among areas detected by ANOVA, were further analyzed using *a posteriori* Student–Newman–Keuls (SNK) tests (Underwood, 1997).

In the temporal study, the relationship between the abiotic data and macrofaunal assemblages was evaluated using the BIO-ENV routine (Clarke and Warwick, 2001). This method was used in order to determine the most important environmental factors influencing macrofauna distribution. The following variables were included in the analysis: near-bottom water temperature, salinity, and dissolved oxygen, *Sand*, *Sort* and *Non-sort* fractions, OM, TOC, TN, $CaCO_3$, AVS and CRS of sediments. Correlation coefficients, R, were calculated in order to further analyze the relationships between abiotic variables and the total number of individuals (N), species (S), and the Shannon index (H').

3. Results

3.1. Summer 2003 study

3.1.1. Sediments

The mud fraction (i.e., <64 μm) represented about 90% of the total sediment dry weight along the inlet (Fig. 2). The analyses of variance detected significant differences in the percentage of *Sand* between *Seaward* (a mean value of 13% of the sediment weight) and the other areas (a mean value of 3%; $F_{2,6} = 13.98$, $P < 0.05$ and SNK test at $P < 0.05$; Fig. 2). The non-sortable fraction (*Non-sort*, <8 μm) made up the largest portion of mud, being around 90% of the mud dry weight (Fig. 2). No differences were found, however, for the *Non-sort* ($F_{2,6} = 1.15$, $P > 0.05$) and the sortable fractions (*Sort*; $F_{2,6} = 0.52$, $P > 0.05$), nor for the *Non-sort*/*Sort* ratio ($F_{2,6} = 0.80$, $P > 0.05$).

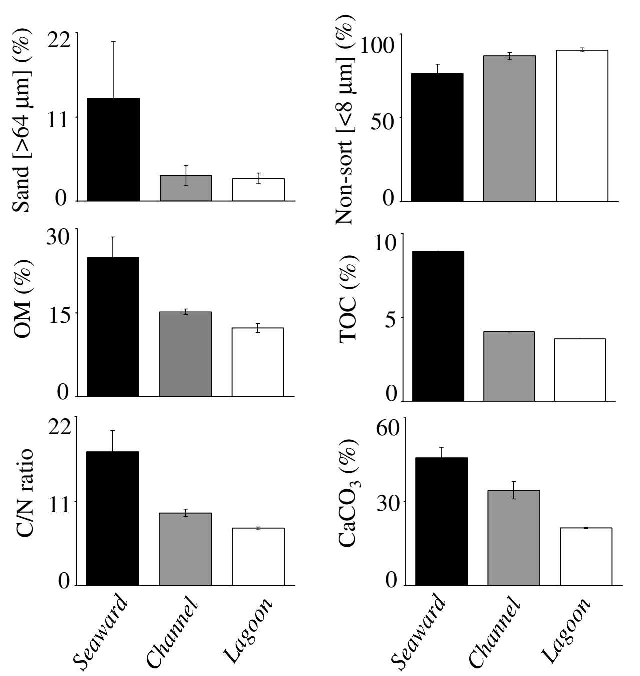

Fig. 2. Summer 2003 study: mean ($n = 3 \pm$ SE) values of *Sand*, non-sortable fraction (*Non-sort*), total organic carbon (TOC), carbonate ($CaCO_3$) content of sediments and C/N molar ratio in each area (*Seaward*, *Channel*, *Lagoon*).

Organic matter (OM) exceeded 10% of the total sediment weight in all three different areas of the inlet (Fig. 2). *Seaward* had a higher OM content (i.e., a mean value of 25% of the total sediment dry weight) with respect to *Lagoon* and *Channel* ($F_{2,6} = 12.66$; SNK test at $P < 0.05$; Fig. 2). In addition, a higher percentage of total organic carbon (TOC; $F_{2,6} = 44.86$; SNK test at $P < 0.05$), C/N ratio ($F_{2,6} = 53.74$; SNK test at $P < 0.05$) and carbonates ($CaCO_3$, $F_{2,6} = 3.30$; SNK test at $P < 0.05$) was found in *Seaward* than in *Lagoon* and *Channel* (Fig. 2). The *a posteriori* comparisons revealed that the mean value of $CaCO_3$ in *Channel* was between those found in *Seaward* and *Lagoon* (Fig. 2). There were no differences among areas in the percentage of total nitrogen (TN; $F_{2,6} = 3.57$, $P > 0.05$).

3.1.2. Macrofauna

A total of 14,452 specimens were collected. The amphipod *Corophium sextonae* accounted for 70% of this amount. There were 62 taxa belonging to polychaetes (35 taxa), crustaceans (20 taxa), mollusks (6 taxa) and pycnogonid (1 taxa). *Seaward* presented the highest number of species (S) with regard to *Channel* and *Lagoon* (S in Table 1; SNK test at $P < 0.05$; Fig. 3). In addition, *Seaward* and *Channel* had higher total abundances than Lagoon (N in Table 1; SNK test at $P < 0.05$; Fig. 3). The analyses of variance did not reveal differences among areas ($P > 0.05$) for the Shannon index (H') (Fig. 3). Most of the abundant taxa (e.g. *Idotea baltica*, *Iphinoe serrata*, *Leucothoe venetiarum*, *Loripes lacteus*, *Melita palmata*, *Microdeutopus gryllotalpa*, *Capitella* cf. *capitata*, *Phylo phoetida*, *Podarkeopsis capensis*, *Abra alba*, *Dexamine spinosa* and *Ptisica marina*) were present only in *Seaward* and *Channel* while others, such as *Neanthes succinea* and *Hydrobia acuta*, were found exclusively in *Lagoon*. Only widespread taxa were further analyzed to test for differences among areas. In *Seaward*, *Protodorvillea kefersteini* was more abundant than in *Channel* and *Lagoon* (Table 1, and SNK test at $P < 0.05$). *Capitella* cf. *capitata*, *Phylo phoetida*, *Podarkeopsis capensis*, *Gammarus aequicauda*, *Abra alba* and *Tapes decussatus* followed a similar pattern among areas, as indicated by the analyses of variance (Table 1, and SNK test at $P < 0.05$). The analyses of variance also revealed differences for *Corophium sextonae*, Ostracods and for the polychaetes *Streblospio shrubsolii* and *Hediste diversicolor* which were more abundant in *Channel* than in the other two areas investigated (Table 1, and SNK test at $P < 0.05$).

3.2. Temporal study (autumn 2003–summer 2004)

3.2.1. Hydrology

In *Lagoon* the water temperature varied mostly between 10 and 28 °C on the winter and summer sampling dates, respectively. Salinity varied between 8.6 (*Lagoon*, spring)

Table 1
Summer 2003 study: (Panel A) analyses of variance for the total number of species (S) and (Panel B) summary of analyses of variance for differences among areas (*Seaward*, *Channel* and *Lagoon*) for the Shannon index (H'), the total number of individuals (N) and the most abundant taxa

Source	S			
	df	MS	F	
Panel A				
Areas	2	5.18	33.94	***
Plots (Areas)	6	0.15	6.08	**
Residual	18	0.03		
Total	26			

Panel B

	MS	$F_{2,6}$	
H'	0.61	3.31	
N	20.19	12.60	**
Protodorvillea kefersteini (P)	14.36	10.00	*
Capitella cf. *capitata* (P)	1.91	19.42	**
Phylo phoetida (P)	4.28	78.01	***
Podarkeopsis capensis (P)	0.97	6.91	*
Gammarus aequicauda (C)	16.38	6.55	*
Abra alba (B)	8.55	8.79	*
Tapes decussatus (B)	9.86	7.06	*
Corophium sextonae (C)	102.70	65.83	***
Streblospio shrubsolii (P)	12.77	60.18	***
Hediste diversicolor (P)	11.02	5.15	*
Ostracoda (C)	35.60	6.29	*

Only taxa which showed significant differences are reported. In parenthesis: P = polychaetes, C = crustaceans and B = bivalves.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

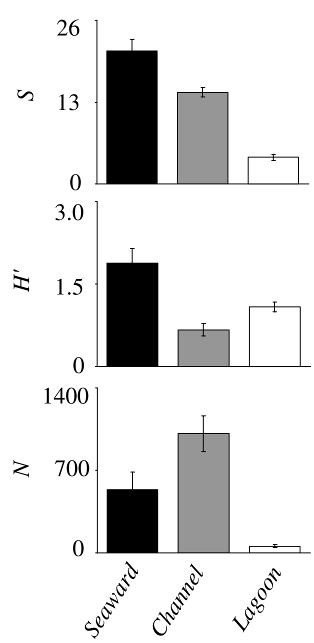

Fig. 3. Summer 2003 study: mean ($n = 9 \pm$ SE) number of species (S), individuals (N, ind. 216 cm^{-2}) and Shannon index (H') in each area (*Seaward*, *Channel*, *Lagoon*).

and 38.0 psu (*Seaward*, summer). Dissolved oxygen (DO) concentrations varied between 4.5 (*Seaward*, near-bottom summer) and 9.5 mg l^{-1} (*Seaward*, near-surface spring). The hydrological variables showed major gradients along the inlet, with a progressively stronger vertical stratification from the lagoon to the gulf in all seasons, except in summer when the water exchange among areas appeared to be more limited (Fig. 4). Overall, changes in water temperature, salinity and DO were most marked between *Seaward* and *Channel* in proximity to the fish barriers, which indicates that these are a major obstacle to the water circulation.

3.2.2. Sediments

The grain size composition along the inlet was similar to that described in the summer 2003 study, with muddy sediments mainly composed of the non-sortable (*Non-sort*) fraction. The temporal study also revealed within-year changes among sampling dates in the *Non-sort*/*Sort* ratio (D in Table 2). This ratio was higher on average in autumn and winter than in spring and summer (SNK test, $P < 0.05$; Fig. 5). The temporal study highlighted differences among areas for this ratio (A in Table 2). The *a posteriori* comparisons revealed that the *Non-sort*/*Sort* ratio increased in *Channel* and *Creeks* with respect to *Seaward* and *Lagoon* (SNK test, $P < 0.005$; Fig. 5). Differences among sampling dates and areas were also detected for the *Sand* fraction (Table 2). It was higher in *Seaward* than in the other areas, and higher in spring and summer than in autumn and winter (SNK test, $P < 0.05$; Fig. 5).

As for the chemical composition of sediments, the annual mean of these variables (Table 3) highlighted a major organic enrichment along the inlet with extremely high OM and TOC values (33.6% and 11.7%, respectively) in *Seaward*, also characterized by a high C/N ratio (18.8) and carbonate content (42.3%). Consistently with the summer 2003 study, organic matter (OM), total organic carbon (TOC), total nitrogen (TN), C/N ratio and carbonates ($CaCO_3$) were highest in *Seaward*, intermediate in *Channel* and *Creeks*, and lowest in *Lagoon* (A in Table 4; SNK test, $P < 0.005$; Fig. 6). For $CaCO_3$, differences among sampling dates were also detected (D in Table 4; SNK test, $P < 0.05$; Fig. 6). In this study, we tested for changes in the inorganic reduced sulphur pools. Spatial variability and within-year changes were found for acid-volatile sulphide (AVS). AVS concentrations were higher in *Seaward* than in the other areas and peaked in summer, as indicated by the significant Dates × Areas interaction term ($D \times A$ in Table 4; SNK test, $P < 0.05$; Fig. 6). Differently, chromium-reduced sulphur (CRS) did not show within-year changes ($P > 0.05$), while it did show a spatial variability among areas (A in Table 4; Fig. 6). CRS concentrations were higher in *Lagoon*, intermediate in *Channel* and *Creeks*, and lower in *Seaward* (SNK test, $P < 0.05$; Fig. 6).

3.2.3. Macrofauna

A total of 8978 specimens were collected; 72 taxa belonging to polychaetes (49 taxa), crustaceans (13),

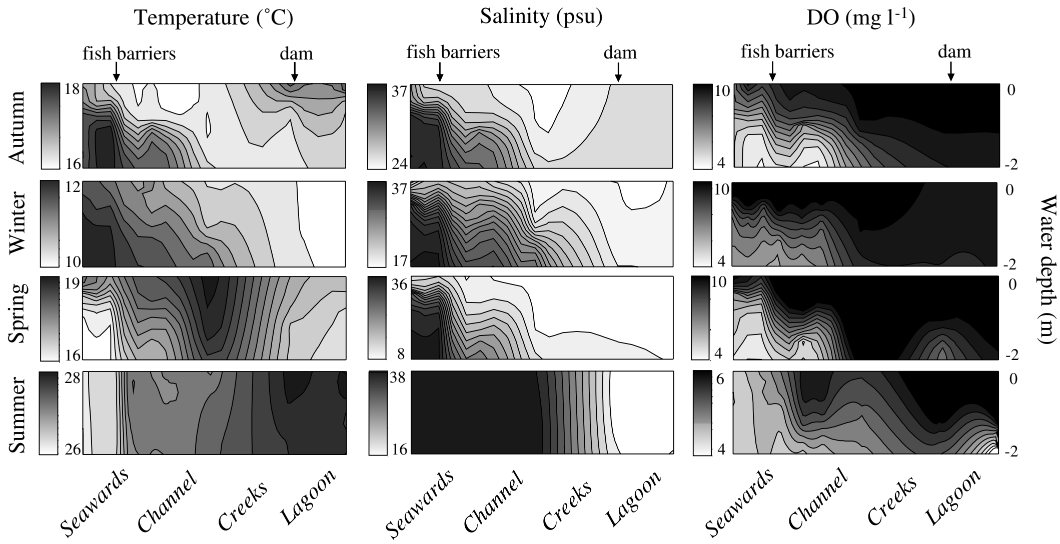

Fig. 4. Spatial and temporal distribution of temperature (°C), salinity (psu) and dissolved oxygen (DO) concentrations (mg l^{-1}) through the water column (water depth approximately 2 m in all areas). Arrows indicate the location of artificial structures (i.e., fish barriers, dam) along the inlet. Note the different scales among different sampling dates (autumn, winter, spring, summer). Areas: *Seaward*, *Channel*, *Creeks* and *Lagoon*.

Table 2
Temporal study (autumn 2003–summer 2004): analyses of variance on grain size fractions of sediments

Source of variation	df	*Sand*			*Sortable*			*Non-sortable*			*Non-sort/Sort* ratio		
		MS	*F*		MS	*F*		MS	*F*		MS	*F*	
Dates (*D*)	3	1.84	5.89	**	0.87	23.17	**	0.20	15.54	***	0.93	23.14	***
Areas (*A*)	3	1.03	3.29	*	0.27	8.59	***	0.08	4.54	*	0.29	8.72	**
$D \times A$ [*,a]	9	0.38	1.23		0.03	0.84		0.02	1.34		0.03	0.82	
Res [*,b]	16	0.27			0.04			0.01			0.04		
Total	31												
Pooled [*]	25	0.31											

[*] $P < 0.05$.
[**] $P < 0.01$.
[***] $P < 0.001$.
[a] Denominator of *A*.
[b] Denominator of $D \times A$, *D*.

mollusks (7) and others (3) were identified. On all sampling dates, the total number of species (*S*) and the Shannon index (H') were lower in *Lagoon* than in the other areas (*A* in Table 5; SNK test, $P < 0.05$; Fig. 7). Significant within-year changes were also found. H' decreased in spring with regard to the other sampling dates (*D* in Table 5; SNK test, $P < 0.05$; Fig. 7), as a result of an increase in the total number of individuals. However, the spring increase in *N* was not statistically significant (Table 5). Instead, only in *Seaward* was the total number of individuals (*N*) higher in summer than on the other sampling dates, as indicated by the significant Dates x Areas interaction term ($D \times A$ in Table 5; SNK test, $P < 0.05$; Fig. 7).

The Spearman rank correlation coefficient from BIO-ENV indicated that there was a good agreement between the distribution of macrofauna and the environmental variables considered. The combination of environmental variables providing the highest value was OM, TOC, TN and CRS (weighted Spearman coefficient = 0.602, un-weighted Spearman coefficient = 0.526). We also found several significant correlations between macrofauna and environmental variables. Most noticeably, *S* and H' were correlated positively with all chemical variables of sediments, except CRS which showed a negative correlation (Table 6). *N* was correlated positively with TN, $CaCO_3$ and AVS (Table 6).

4. Discussion and conclusions

Inlets along coastal marine and transitional systems allow the exchange of water masses with different physical and chemical characteristics, while ensuring the renewal of water in lagoons (Guerorget and Perthiusot, 1992). Human interventions, however, can deeply affect such exchange, subsequently impairing the trophic status and function of these systems (da Cunha and Wasserman, 2003; Sato, 2006). In our study area, De Falco et al. (2004) recently suggested that man-made structures located in the inlet of the Cabras lagoon are an important cause of the changes

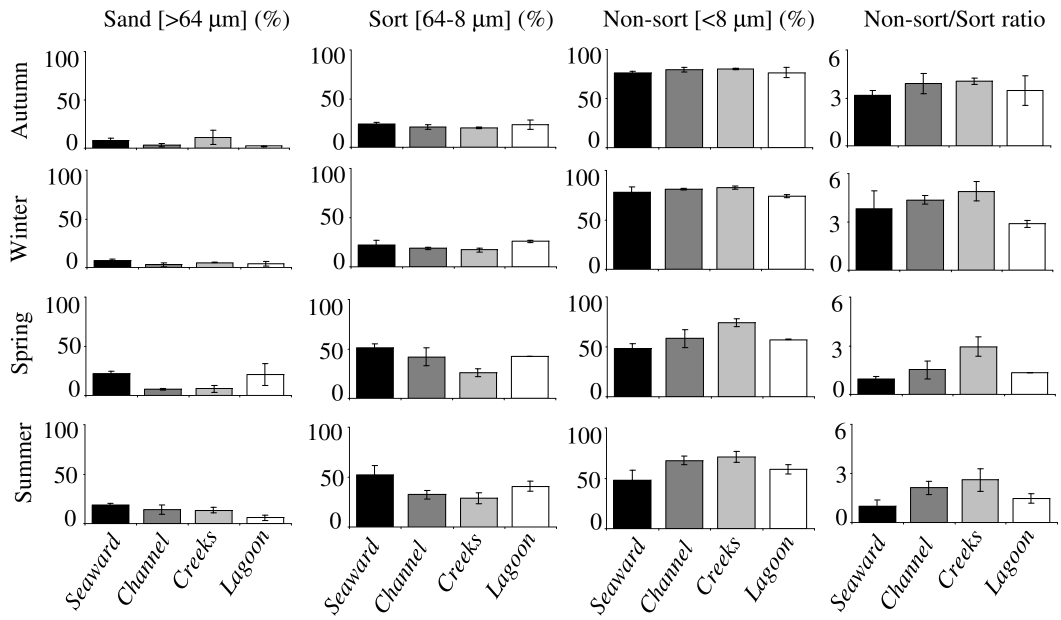

Fig. 5. Temporal study: mean ($n = 2 \pm$ SE) values of *Sand*, sortable (*Sort*) and non-sortable (*Non-sort*) fraction content, and non-sortable/sortable (*Non-sort/Sort*) ratio in each area at each sampling date (autumn 2003, and winter, spring, summer 2004). Areas: *Seaward*, *Channel*, *Creeks* and *Lagoon*.

Table 3
Temporal study (autumn 2003–summer 2004): annual mean values ($n = 8 \pm$ SE) of organic matter (OM), total organic carbon (TOC), total nitrogen (TN), C/N molar ratio, carbonates ($CaCO_3$), acid-volatile sulphides (AVS) and chromium-reduced sulphur (CRS) for each area

	OM%		TOC%		TN%		C/N ratio		$CaCO_3$%		AVS (μmol g^{-1})		CRS (μmol g^{-1})	
Seaward	33.6	1.3	11.7	0.3	0.78	0.02	18.8	1.3	42.3	2.1	5.38	1.39	11.2	3.0
Channel	21.8	1.0	6.3	0.4	0.63	0.02	11.6	0.6	29.5	2.0	0.75	0.65	25.6	3.8
Creeks	16.3	0.9	4.3	0.2	0.55	0.02	9.0	0.2	26.7	2.7	0.14	0.09	22.4	1.6
Lagoon	13.3	0.4	3.3	0.1	0.48	0.03	8.0	0.2	18.2	1.2	0.16	0.09	41.9	6.0

in the sedimentary regime of the lagoon which have occurred over the last three decades. In particular, the construction at the end of the 1970s of an artificial channel closed by a dam may have favoured the accumulation of fine sediments inside the lagoon (De Falco et al., 2004). De Falco et al. (2004) also demonstrated that in the Cabras lagoon the so-called "non-sortable" fraction (i.e., <8 μm particles) of sediments, which tends to flocculate and aggregate with organic matter (McCave et al., 1995), has the greatest affinity (i.e., is most correlated) among various grain size fractions with sedimentary organic carbon. The organic enrichment of sediments, in combination with prolonged climatic stasis, low dissolved oxygen concentrations and high temperatures in summer, may subsequently lead to the production of toxic hydrogen sulphide which rapidly diffuses in the water column with deleterious effects both on the benthic and pelagic components of the lagoon ecosystem (Murenu et al., 2004; Magni et al., 2005b).

In the present study, we found that the surface sediments along the inlet have a grain size composition similar to that previously described for the Cabras lagoon at the basin scale (De Falco et al., 2004). In particular, the <8 μm particles were the most abundant fraction of the surface sediments both inside and outside the lagoon, especially in *Creeks*. These results suggest, to some extent, a lagoon export of organic C-bonding fine sediments. We also found that the ratio between the <8 μm and the 8–64 μm fractions of sediments, assumed to be an index of hydrodynamics (De Falco et al., 2004, 2006), was higher in *Creeks* and *Channel* than in *Seaward* and *Lagoon* in all seasons. We infer that this could be related to the presence of the artificial barriers located between the *Seaward* and *Lagoon* areas. These barriers would impair the water movement and reduce the effect of tide- and wind-induced currents which are the main forces affecting sediment resuspension and transport in shallow micro-tidal environments (Isla, 1995; Cucco et al., 2006; Ferrarin and Umgiesser, 2005). As is consistent with the presence of artificial structures, steep gradients in water salinity, temperature and dissolved oxygen concentrations were found in the proximity of the fish barriers, between *Seaward* and *Channel*. These barriers were installed in 1997 to stop adult fish from trying to go beyond the *Channel* and back to the gulf. Similarly to our study area, the effects of fish barriers on water movement and the supply of organic matter have been described in the Sacramento–San Joaquin River Delta (California) (Jassby and Cloern, 2000). It is worthwhile to note that in summer 2003 the <8/8–64 μm ratio did not

Table 4
Temporal study (autumn 2003–summer 2004): analyses of variance on the chemical characteristics of sediments: OM, organic matter (%); TOC, total organic carbon (%); TN, total nitrogen (%); C/N, carbon to nitrogen molar ratio; $CaCO_3$, carbonates (%); AVS, acid-volatile sulphides (μmol g^{-1}); CRS, chromium-reduced sulphur (μmol g^{-1})

	df	OM		TOC		TN		C/N		$CaCO_3$		AVS		CRS	
		MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*
Dates (*D*)	3	0.02	2.07	0.00	0.09	0.00	0.25	0.00	0.18	0.16	7.80**	11.23	5.61***	337.87	2.96
Areas (*A*)	3	1.17	87.99**	1.80	223.17***	0.05	23.07***	0.95	83.79***	0.91	31.87***	53.84	10.32***	1294.20	18.55***
$D \times A^{*,a}$	9	0.01	1.12	0.00	0.39	0.00	1.45	0.01	0.73	0.03	1.41	5.22	2.61*	69.75	0.61
Res[*,b]	16	0.01		0.02		0.00		0.01		0.02		2.00		114.10	
Total	31														

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.
[a] Denominator of *A*.
[b] Denominator of $D \times A$, *D*.

show significant differences among areas. This could be related to an inter-annual variability in the meteo-marine conditions. In particular, an anomalous long period of high atmospheric pressure (and a decrease of wind stress) was recorded in the Mediterranean Sea region in summer 2003 (Black et al., 2004). This may have resulted in reduced transport and a lower re-suspension also at a local scale. Finally, irrespective of areas, the <8/8–64 μm ratio was higher in autumn 2003 and winter 2004 than in spring and summer 2004, probably due to higher rainfall and greater inflow from the watersheds in autumn and winter in our study area (Pinna, 1989).

The chemical composition of sediments showed additional major spatial differences along the inlet in terms of organic enrichment, with the highest OM and TOC contents found in *Seaward* (Fig. 6). In this area, OM and TOC values, were in the same range as those commonly reported for detritus of *P. oceanica* and *C. nodosa* (Enríchez et al., 1993; Tyson, 1995; and references therein). Consistently $CaCO_3$, which also was highest in *Seaward* (Fig. 6), displayed values similar to those found in the Gulf of Oristano which is about 70% colonized by *P. oceanica* meadows and, along the coast, *C. nodosa* (Cancemi et al., 2000; De Falco et al., 2000, 2006). Our findings suggest that large amounts of seagrass leaf litter accumulate in *Seaward*, but are prevented from upward transport by the presence of the fish barriers. Along with major spatial differences in terms of organic enrichment of sediments among areas, we also found a differential accumulation of inorganic reduced sulphur compounds in the sediments along the inlet. In particular, acid-volatile sulphides (AVS) were highest in *Seaward*, while chromium-reduced sulphur (CRS) accumulated mostly in *Lagoon*. The reasons for such different AVS and CRS accumulation patterns in the different areas (and different sediment types) need further investigation. This includes the study on the reactivity of biogeochemical buffers, such as the iron–iron monosulphide–pyrite system (Jørgensen, 1996; Viaroli et al., 2004). We acknowledge that, although our repeated measures gave valuable information on spatial and temporal changes in pool sizes, only the determination of process rates and fluxes could provide details of the exchanges between pools, pool turnover rates and the transfer of energy (Viaroli et al., 2004). In fact, the highest AVS concentrations were consistently found, irrespective of the season, in the presence of the highest TOC and OM contents which support high sulphate reduction rates, i.e., in *Seaward* (Fig. 6). Low near-bottom DO concentrations found in *Seaward* (Fig. 4) may have concurrently contributed to inhibiting the AVS oxidation to CRS as AVS includes the more reduced S forms (Rickard and Morse, 2005). For the same reason, it is possible that relatively high near-bottom DO concentrations found in *Lagoon* may have favoured CRS accumulation as a result of a faster oxidation of AVS. Sulphide is the end-product of sulphate reduction which represents one of the main pathways of organic matter decomposition in eutrophic coastal environ-

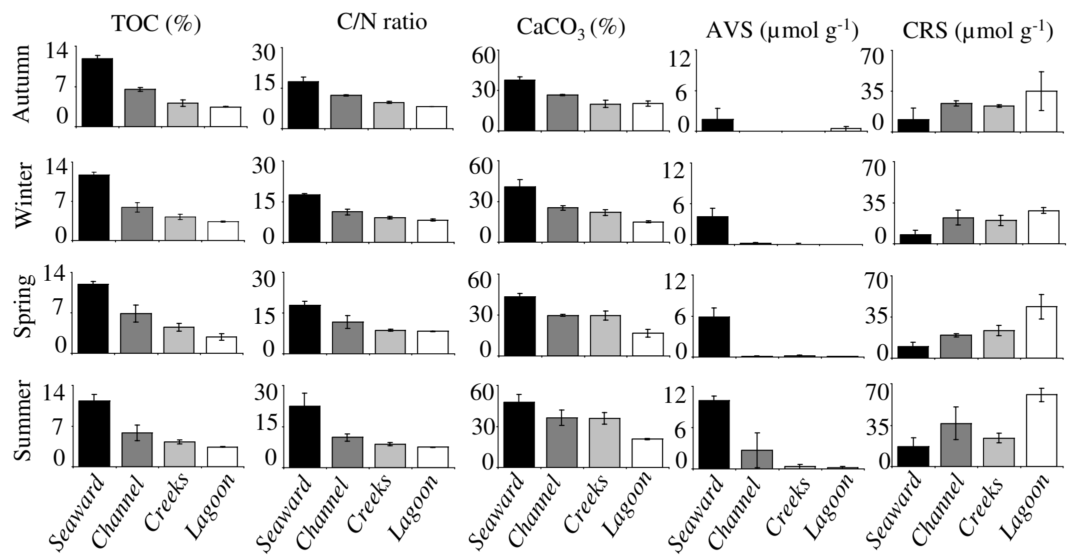

Fig. 6. Temporal study: mean ($n = 2 \pm$ SE) values of total organic carbon (TOC), C/N molar ratio, carbonates ($CaCO_3$), acid-volatile sulphides (AVS) and chromium-reduced sulphur (CRS) in each area at each sampling date (autumn 2003, and winter, spring, summer 2004). Areas: *Seaward*, *Channel*, *Creeks* and *Lagoon*.

Table 5
Temporal study (autumn 2003–summer 2004): analyses of variance on the total number of species (*S*), Shannon index (H') and total number of individuals (*N*)

Source of variation	df	*S*		H'		*N*	
		MS	*F*	MS	*F*	MS	*F*
Dates (*D*)	3	0.28	1.02	0.19	4.27*	22630.60	1.85
Areas (*A*)	3	3.92	26.93**	0.70	10.76**	27528.01	0.87
$D\times A$*,a	9	0.14	0.53	0.05	1.45	12206.28	3.49***
Plots ($D\times A$)*,b	16	0.27	2.81**	0.05	1.72	31824.03	2.61*
Res	64	0.10		0.03		3501.05	
Total	95						

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.
[a] Denominator of *A*.
[b] Denominator of $D \times A$, *D*.

ments (Giordani et al., 1996; Azzoni et al., 2001; Viaroli et al., 2004). This compound is extremely toxic in the dissolved form, and is one of the major causes of the impoverishment of benthic assemblages (Magni et al., 2005b, 2006). Dissolved sulphide (DS) is expected to be higher in the AVS dominated area (*Seaward*) since it contributes to this pool in variable proportions. Its proportions depend on a series of processes such as sulphide production and oxidation rates and the reactivity of the iron buffer system, which can effectively remove pore-water DS by precipitation in insoluble iron sulphides (Giordani et al., in press). Overall, AVS and CRS values found in our study location are comparable to those reported in other similar organic-enriched systems such as Valle Smarlacca (6–25 and 25–75 µmol g^{-1}, respectively; Azzoni et al., 2001), Lesina lagoon (3–30 and 15–90 µmol g^{-1}; Giordani et al., in press) and the Sacca di Goro (1–20 and 15–40 µmol g^{-1}, respectively; Giordani et al., in press).

Examining the relationship between environmental variables (i.e., hydrological features, sediment grain size composition and chemical characteristics) and macrofaunal assemblages in our study area, OM, TOC, TN and CRS provided the leading (‘best-matching’) combination of abiotic factors influencing animal distribution. Organic matter in surface sediments is an important source of food for benthic fauna (Lopez and Levinton, 1987; Snelgrove and Butman, 1994). However, an overabundance may lead to reductions in species richness, abundance, and biomass due to oxygen depletion and a buildup of toxic byproducts (ammonia and dissolved sulphide) associated with the breakdown of these materials (Diaz and Rosenberg, 1995; Gray et al., 2002). Pearson and Rosenberg (1978) developed a conceptual, graphical model to describe a generalized pattern of response of soft-bottom benthic communities in relation to organic enrichment. A recent study by Hyland et al. (2005) has quantified this relation-

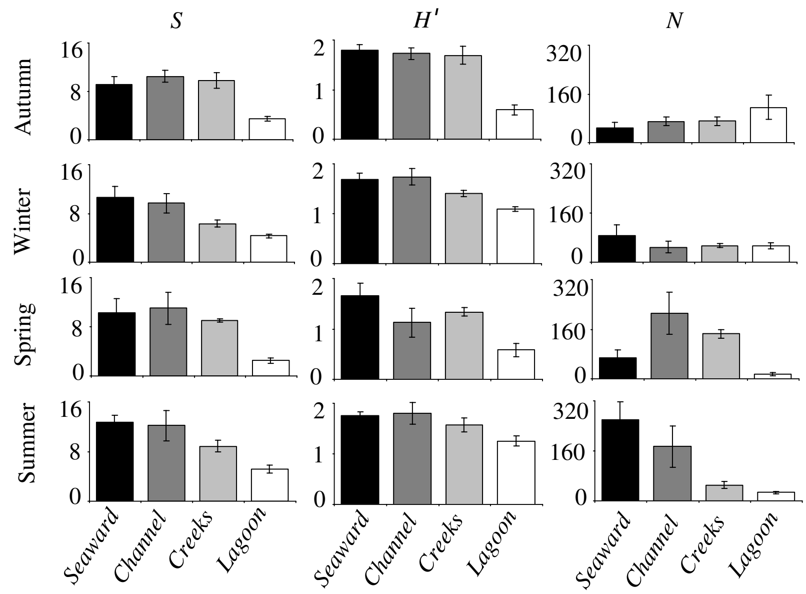

Fig. 7. Temporal study: mean ($n = 6 \pm$ SE) number of species (*S*), individuals (*N*, ind. 216 cm^{-2}) and Shannon index (*H*′) in each area at each sampling date (autumn 2003, and winter, spring, summer 2004). Areas: *Seaward*, *Channel*, *Creeks* and *Lagoon*.

Table 6
Correlation coefficient *R* between environmental variables and *S*, *N* and *H*′

	S		*N*		*H*′	
Temp						
Salin	0.58	**	0.21		0.70	***
DO	**−0.43**	*	**−0.08**		**−0.54**	**
Non-sort			**−0.41**	*		
Sort			0.41	*		
Sand						
Non-sort/*Sort* ratio			**−0.36**	*		
OM	0.62	***			0.56	**
TOC	0.57	**			0.57	**
TN	0.62	***	0.37	*	0.61	***
C/N	0.55	**			0.53	*
$CaCO_3$	0.60	***	0.38	*	0.57	**
AVS	0.43	*	0.43	*	0.38	*
CRS	**−0.43**	*			**−0.48**	*

Temp, temperature (°C); Salin, salinity (psu); DO, dissolved oxygen (mg l^{-1}); *Non-sort*, non-sortable fraction (%); *Sort*, sortable fraction (%); *Sand*, sand fraction (%); OM, organic matter (%); TOC, total organic carbon (%); TN, total nitrogen (%); C/N, carbon to nitrogen molar ratio; $CaCO_3$, carbonates (%); AVS, acid-volatile sulphides (μmol g^{-1}); CRS, chromium-reduced sulphur (μmol g^{-1}). In bold: negative correlations.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

ship and showed that TOC values > about 3.5% pose high risks of impaired benthic assemblages (e.g. reduced species richness) from organic loading and other co-varying stressors in sediments. In our study area, TOC < 3.5% was only found in *Lagoon*, whereas values of <4% are also reported for the Cabras lagoon (De Falco et al., 2004; Magni et al., 2005b). Consistently, poor benthic assemblages occurred throughout the whole inlet, whenever there were temporal changes and spatial differences among areas. In particular, *Lagoon* showed the most different macrofaunal assemblages among areas both in terms of species composition and structure. Similarly to what was previously described (Magni et al., 2004) and even though AVS concentrations recorded in this study in *Lagoon* were low, the *Lagoon* assemblages were extremely poor and dominated by brackish animals (e.g. the gastropod *Hydrobia acuta*; Guerorget and Perthiusot, 1992) and opportunistic taxa (e.g. Tubificidae nc). As a matter of fact, the Cabras lagoon is periodically subjected to an AVS increase leading to a major impoverishment of macrofaunal assemblages, such as that which occurred in the summer of 2001 (Magni et al., 2005b). A relatively higher number of species was found in the other investigated areas, although they were also typical of highly disturbed environments, which are organic-enriched (e.g. *Capitella* cfr. *capitata*, *Streblospio shrubsolii* and *Phylo phoetida*) or commonly associated with detritus (i.e., *Microdeutopus gryllotalpa, Gammarus aequicauda* and *Corophium sextonae*) (Ruffo, 1982; Tagliapietra et al., 1998; Lardicci et al., 2001). The strongest temporal changes in macrofaunal assemblages were found in *Seaward*, with the highest total abundances on the summer date. The presence of opportunist species helps to explain the rapid development of high density populations in summer, in spite of high AVS concentrations. To this regard, it should be mentioned that the presence in *Seaward* of high amounts of seagrass leaf litter may have acted as a different sedimentary environment with respect to the other areas investigated. In particular, the leaf litter substratum may have reduced the amount of sediment particles and consequently sediment compaction, which are known to influence the recruitment and colonization of many individuals (Lee, 1999; Morrisey et al., 2003; Gallmetzer et al., 2005).

Concurrently, a higher refractory nature of OM in *Seaward* (indicated by the C/N ratio, Figs. 2 and 6) may have reduced sulphide production while the relatively lower compactness in this area, coupled with a higher hydrodynamics, could have favoured a faster removal of hydrogen sulphide thereby possibly reducing the exposure time of benthic animals to toxic compounds in the sediments.

In conclusion, this study provides a detailed description of the spatial variability and temporal changes in hydrological features, grain size composition and chemical characteristics of sediments, as well as macrofaunal assemblages occurring in a highly human-modified inlet between a coastal lagoon and the adjacent marine system in the Mediterranean Sea. The strong relationships between organic over-enrichment of sediments, inorganic reduced sulphur pools (i.e., CRS and AVS) and poorly structured macrofaunal assemblages, dominated by few opportunistic species, highlight the highly degraded conditions of the system. We infer that the presence of artificial structures, such as the fish barriers and the dam, impair the water and sediment exchange between lagoon and gulf, while also impairing animal recruitment and colonization along the studied inlet. This is confirmed by Ferrarin and Umgiesser (2005) who investigated the water circulation between the Cabras lagoon and the Gulf of Oristano by means of a numerical modeling approach. They suggested that the removal of the dam would increase the fluxes through the connecting channel to approximately 7 times the present amount. Therefore, we assume that the removal of these structures would increase the water renewal capacity of the Cabras lagoon, but could also increase the outflow of organic C-bonding fine particles into the gulf which would have serious consequences on the *P. oceanica* and *C. nodosa* seagrass meadows. We conclude that all possible consequences of such initiatives should be carefully considered before any action is taken.

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References

Azzoni, R., Giordani, C., Bartoli, M., Welsh, D.T., Viaroli, P., 2001. Iron, sulphur and phosphorus cycling in the rhizosphere sediments of a eutrophic *Ruppia cirrhosa* meadow (Valle Smarlacca, Italy). Journal of Sea Research 45 (1), 15–26.

Black, E., Blackburn, M., Harrison, G., Hoskins, B., Methven, J., 2004. Factors contributing to the summer 2003 European Heatwave. Weather 59 (8), 217–222.

Bulleri, F., Airoldi, L., 2005. Artificial marine structures facilitate the spread of a non-indigenous green alga, *Codium fragile* ssp. tomentosoides, in the north Adriatic Sea. Journal of Applied Ecology 42 (6), 1063–1072.

Bulleri, F., Chapman, M.G., 2004. Intertidal assemblages on artificial and natural habitats in marinas on the north-west coast of Italy. Marine Biology 145 (2), 381–391.

Cancemi, G., Baroli, M., De Falco, G., Agostani, S., Piergallini, G., Guala, I., 2000. Cartografia integrata delle praterie marine superficiali come indicatore dell'impatto antropico sulla fascia costiera. Biologia Marina Mediterranea 7 (1), 509–516.

Cardoso, P.G., Brandao, A., Pardal, M.A., Raffaelli, D., Marques, J.C., 2005. Resilience of *Hydrobia ulvae* populations to anthropogenic and natural disturbances. Marine Ecology Progress Series 289, 191–199.

Cavazza, W., Immordino, F., Moretti, L., Peirano, A., Pironi, A., Ruggiero, F., 2000. Sedimentological parameters and seagrasses distributions as indicators of anthropogenic coastal degradation at Monterosso Bay (Ligurian Sea, NW Italy). Journal of Coastal Research 16 (2), 295–305.

Clarke, K.R., Warwick, R.M., 2001. Changes in Marine Communities: An Approach to Statistical Analysis and Interpretation, second ed. PRIMER-E, Plymouth, UK.

Cognetti, G., Angelis, C.M., Orlando, E., Bonvicini Pagliai, A.M., Cognetti Variale, A.M., Crema, R., Mari, M., Mauri, M., Tongiorgi, P., Zunarelli Vandini, R., 1978. Situazione ecologica e ittiocultura. In: Risanamento e protezione dell'ambiente idrobiologico delle lagune di Orbetello. Regione Toscana Comune di Orbetello.

Cucco, A., Perilli, A., De Falco, G., Umgiesser, G., 2006. A finite element model for the Gulf of Oristano. Chemistry and Ecology 22, 307–331.

da Cunha, L., Wasserman, J.C., 2003. Relationships between nutrients and macroalgal biomass in a Brazilian coastal lagoon: the impact of a lock construction. Chemistry and Ecology 19 (4), 283–298.

Dean, W.E., 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. Journal of Sedimentary Petrology 44, 242–248.

De Falco, G., Piergallini, G., 2003. Mare, Golfo, Lagune – Studi e ricerche. Spring, Oristano, Italia, p. 205.

De Falco, G., Ferrari, S., Cancemi, G., Baroli, M., 2000. Relationship between sediment distribution and *Posidonia oceanica* seagrass. Geo-Marine Letters 20, 50–57.

De Falco, G., Magni, P., Teräsvuori, L.M.H., Matteucci, G., 2004. Sediment grain size and organic carbon distribution in the Cabras lagoon (Sardinia, western Mediterranean). Chemistry and Ecology 20, S367–S377.

De Falco, G., Baroli, M., Murru, E., Piergallini, G., Cancemi, G., 2006. Sediment analysis evidences two different depositional phenomena influencing seagrass distribution in the gulf of Oristano (Sardinia, Western Mediterranean). Journal of Coastal Research 22, 1043–1050.

Diaz, R.J., 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.

Elliott, M., Cutts, N.D., 2004. Marine habitats: loss and gain, mitigation and compensation. Marine Pollution Bulletin 49, 671–674.

Enríchez, S., Duarte, C.M., Sand-Jensen, K., 1993. Patterns in decomposition rates among photosynthetic organisms: the importance of detritus C:N:P content. Oecologia 94, 457–471.

Ferrarin, C., Umgiesser, G., 2005. Hydrodynamic modeling of a coastal lagoon: the Cabras lagoon in Sardinia, Italy. Ecological Modelling 188, 340–357.

Fossing, H., Jørgensen, B.B., 1989. Measurement of bacteria sulphide reduction in sediment: evaluation of a single-step chromium reduction method. Biogeochemistry 8, 205–222.

Frihy, O.E., 2001. Human-induced sedimentation at El Hamra piled mooring pier, western Mediterranean coast of Egypt. Geo-Marine Letters 21, 51–57.

Froelich, P.N., 1980. Analysis of organic carbon in marine sediments. Limnology and Oceanography 25, 242–248.

Gallmetzer, I., Pflugfelder, B., Zekely, J., Ott, J.A., 2005. Macrofauna diversity in *Posidonia oceanica* detritus: distribution and diversity of mobile macrofauna in shallow sublittoral accumulations of *Posidonia oceanica* detritus. Marine Biology 147, 517–523.

Giordani, G., Azzoni, R., Viaroli, P., in press. A rapid assessment of the sedimentary buffering capacity towards free sulphides. Hydrobiologia.

Giordani, G., Bartoli, M., Cattadori, M., Viaroli, P., 1996. Sulphide release from anoxic sediments in relation to iron availability and organic matter recalcitrance and its effects on inorganic phosphorus recycling. Hydrobiologia 329 (1–3), 211–222.

Gray, J.S., Wu, R.S., Or, Y.Y., 2002. Effects of hypoxia and organic enrichment on the coastal marine environment. Marine Ecology Progress Series 238, 249–279.

Guerorget, O., Perthiusot, J.P., 1992. Paralic ecosystems. Vie et Milieu 42 (2), 215–251.

Hedges, J.I., Stern, J.K., 1984. Carbon and nitrogen determinations of carbonate-containing solids. Limnology and Oceanography 29, 657–663.

Hyland, J., Balthis, L., Karakassis, I., Magni, P., Petrov, A., Shine, J., Vestergaard, O., Warwick, R., 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. Marine Ecology Progress Series 295, 91–103.

Isla, F., 1995. Coastal lagoons. In: Perillo, G.M.E. (Ed.), Geomorphology and Sedimentology of Estuaries. Elsevier, The Netherlands, pp. 241–272.

Jassby, A.D., Cloern, J.E., 2000. Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic Conservation: Marine and Freshwater Ecosystems 10 (5), 323–352.

Jørgensen, B.B., 1996. Material flux in the sediments. In: Jørgensen, B.B., Richardson, K. (Eds.), Eutrophication in Coastal Marine Ecosystems, . In: Coastal and Estuarine Studies, vol. 52. Spring, pp. 115–135.

Koutsoubas, D., Dounas, C., Arvanitidis, C., Kornilios, S., Petihakis, G., Triantafyllou, G., Eleftheriou, A., 2000. Macrobenthic community structure and disturbance assessment in Gialoca Lagoon, Ionian Sea. ICES Journal of Marine Science 57, 1472–1480.

Lardicci, C., Rossi, F., Castelli, A., 1997. Analysis of macrozoobenthic community structure after severe dystrophic crises in a Mediterranean coastal lagoon. Marine Pollution Bulletin 34, 536–547.

Lardicci, C., Como, S., Corti, S., Rossi, F., 2001. Recovery of the macrozoobenthic community after severe dystrophic crises in a Mediterranean coastal lagoon (Orbetello, Italy). Marine Pollution Bulletin 42 (3), 202–214.

Lee, S.Y., 1999. The effect of mangrove leaf litter enrichment on macrobenthic colonization of defaunated sandy substrates. Estuarine, Coastal and Shelf Science 49, 703–712.

Lopez, G.R., Levinton, J.S., 1987. Ecology of deposit-feeding animals in marine sediments. The Quarterly Review of Biology 62, 235–260.

Magni, P., Micheletti, S., Casu, D., Floris, A., De Falco, G., Castelli, A., 2004. Macrofaunal community structure and distribution in a muddy coastal lagoon. Chemistry and Ecology 20, S397–S409.

Magni, P., Fenzi, G., Casu, D., Floris, A., De Falco, G., Castelli, A., 2005a. Variabilità stagionale del macrozoobenthos nella laguna di Cabras (Sardegna, Mediterraneo occidentale). Biologia Marina Mediterranea 12 (1), 287–290.

Magni, P., Micheletti, S., Casu, D., Floris, A., Giordani, G., Petrov, A., De Falco, G., Castelli, A., 2005b. Relationships between chemical characteristics of sediments and macrofaunal communities in the Cabras lagoon (western Mediterranean, Italy). Hydrobiologia 550, 105–119.

Magni, P., Como, S., Montani, S., Tsutsumi, H., 2006. Interlinked temporal changes in environmental conditions, chemical characteristics of sediments and macrofaunal assemblages in an estuarine intertidal sandflat (Seto Inland Sea, Japan). Marine Biology 149, 1185–1197.

McCave, I.N., Menighetti, B., Robinson, S.G., 1995. Sortable silt and fine sediment size/composition slicing: parameters for palaeocurrents speed and palaeooceanography. Paleoceanography 10 (3), 593–610.

Molinaroli, E., De Falco, G., Rabitti, S., 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.

Morrisey, D.J., Skilleter, G.A., Ellis, J.I., Burns, B.R., Kemp, C.E., Burt, K., 2003. Differences in benthic fauna and sediment among mangrove (*Avicennia marine* var. *australasica*) stands of different ages in New Zealand. Estuarine, Coastal and Shelf Science 56, 581–592.

Murenu, M., Olita, A., Sabatini, A., Follesa, M.C., Cau, A., 2004. Dystrophy effects on the *Liza ramada* (Risso, 1826) (Pisces, Mugilidae) population in the Cabras lagoon (central-western Sardinia). Chemistry and Ecology 20, S433–S452.

Pearson, T.H., 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. Pizzi Spa, Milano, pp. 38–48.

Rickard, D., Morse, J.W., 2005. Acid Volatile Sulphide (AVS). Marine Chemistry 97, 141–197.

Ruffo, S., 1982. The Amphipoda of Mediterranean, Part 1, Gammaridae (Acanthonomatidae to Gammaridea). In: Ruffo, S. (Ed.), The Amphipoda of Mediterranean. Mem. de l'Inst. Oceanogr. Fond Albert I.er, Prince de Monaco.

Sato, S., 2006. Drastic change of bivalves and gastropods caused by the huge reclamation projects in Japan and Korea. Plankton & Benthos Research 1 (3), 123–137.

Snelgrove, P.V.R., Butman, C.A., 1994. Animal-sediment relationships revisited: Cause versus effect. Oceanography and Marine Biology: An Annual Review 32, 111–177.

Tagliapietra, D., Pavan, M., Wagner, C., 1998. Macrobenthic community changes related to eutrophication in Palude della Rosa (Venetian Lagoon, Italy). Estuarine, Coastal and Shelf Science 47 (2), 217–226.

Tyson, R.V., 1995. Sedimentary organic matter. Chapman & Hall, London.

Underwood, A.J. (Ed.), 1997. Experiments in Ecology: Their Logical Design and Interpretation using Analysis of Variance. Cambridge University Press, Cambridge.

Viaroli, P., Bartoli, M., Giordani, G., Magni, P., Welsh, D.T., 2004. Biogeochemical indicators as tools for assessing sediment quality/vulnerability in transitional aquatic ecosystems. Aquatic Conservation: Marine and Freshwater Ecosystems 14, S19–S29.

Winer, B.J., Brown, D.R., Michels, K.M. (Eds.), 1991. Statistical Principles in Experimental Design, third ed. McGraw Hill, New York.

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