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RESEACH ARTICLE

Small-scale perturbation on soft bottom macrozoobenthos after mechanical cleaning operations in a Central-Western Mediterranean lagoon

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Abstract

1 - Sardinia Island (Italy), even if relatively small, has over 100 lagoons totalling some 12,000 ha. Yet their potential yield remain often unexpressed because they are subjected to environmental stress and degradation. As far as benthic communities are concerned, one of the main disturbances is certainly the accumulation of shell detritus, which progressively modifies the way benthic organisms interact with the sediment.

2 - An experimental dredging study was therefore performed in the Calich lagoon (NW Sardinia), due to its particular interest for fishing activities and potential semi-intensive mollusc culture. Changes in benthic community structure were examined in two areas of the lagoon by analysing both the demographic profile of several abundant species and the features of sedimentary matrix immediately after the cleaning operations and seven months later. Data obtained were compared with those collected in undisturbed areas of the lagoon. This allowed us to evaluate the effects of dredging operations on the benthic assemblages unaffected by natural temporal shifts of the system.

3 - Univariate and multivariate analyses indicated a strong relationship between macrofaunal community structure and intensity of the cleaning activities. At the dredged sites benthic fauna was not depleted but did exhibit higher diversity and evenness indexes than at the undisturbed sites. This seemed to be a consequence of decrease in the density of some abundant species at the dredged sites. Furthermore, a general reduction of total organic content was observed in the upper sediment layer. Lastly, the cleaning method employed is discussed in relation to its potential for impacting the benthos.

Keywords: coastal lagoons, dredging, macrozoobenthos, Mediterranean, Sardinia

Introduction

Coastal lagoons are generally considered highly productive ecosystems (Whittaker, 1975). Perturbation of their sediments, often due to human activities, may disturb or modify soft bottom communities (Barnes, 1980). While in marine ecosystems the natural accumulation of mollusc shell debris may actually increase the benthic β diversity (Hewitt *et al.*, 2005), in brackish ecosystems, where the α diversity of benthic communities is usually low, this effect is negligible. On the other hand, the accumulation of shell debris progressively changes the mechanical properties of sediment, thus affecting benthic communities structure and productivity. This may be due to low hydrodynamism and can affect production at various level of the trophic chain.

In the Mediterranean lagoons, human impacts (i.e. watershed pollution, mechanical dredging, fishery, aquaculture) are undoubtedly more frequent than natural ones, and can dramatically alter the features of the bottom. Investigations of benthic recolonisation in the aftermath of dredging in Italian lagoons are limited at present, and are mainly focused on fishing activities in the Adriatic basin (Pranovi and Giovanardi, 1994; Pranovi *et al.*, 1998; Castaldelli *et al.*, 2003; Fiordelmondo *et al.*, 2003; Mistri *et al.*, 2004).

Sardinia (Central-Western Mediterranean, Italy) is relatively small but has over 100 lagoons with a surface area of some 12,000 ha. Often, however, they do not reach their potential yield because they suffer from environmental stress and degradation (Cataudella *et al.*, 1995). In the Calich lagoon of NW Sardinia, in particular, there is a great accumulation of coarse shell detritus. It covers 70% of the total surface and its fraction >1 mm can reach 32% in weight. As the lagoon is of importance for both fishing activities (Chessa *et al.*, 2001) and, potentially, for semi-intensive mollusc culture (Chessa *et al.*, 2005), an experimental dredging study was performed. Our aims were: 1) to analyse the environmental impact of a cleaning machine on the benthic communities; 2) to verify the recovery process several months after cleaning; and 3) to assess if the coarse sediment fraction was really extracted by the cleaning operations.

Methods

Study area

The Calich lagoon (Figure 1) is located in North-Western Sardinia and is a typical coastal Mediterranean lagoon of 97 ha with a mean depth of 1.30 m. It is separated from the sea by a barrier spit. Sea water enters and leaves the lagoon through a narrow channel in its South-Western part. The lagoon has a mean annual salinity of 28 P.S.U., with a minimum of 15 P.S.U. in January and a maximum of 38 P.S.U. in September. The mean annual temperature is 18.9°C, with a minimum of 9°C in March and a maximum of 31°C in July. The lagoon receives freshwater on its landward margin from 3 small rivers, which drain water from a watershed area of about 42,500 ha. During summer there is a sharp decrease in runoff. As a result, in this period the hydrodynamics of the lagoon are mainly determined by the ebb and flow of the tide, which has a maximum range of 60 cm. In the lagoon traditional fishing is practiced by local fishermen and some low impact aquaculture activities have recently been started.

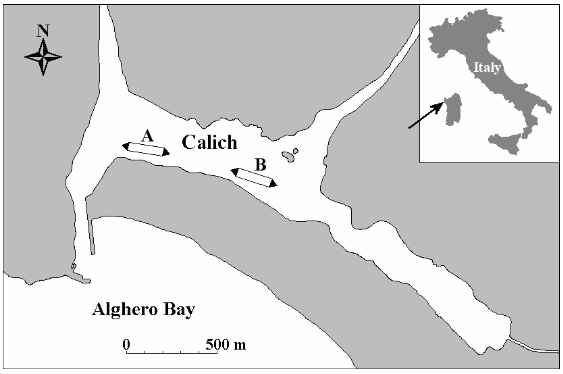

Figure 1. Map of the Calich lagoon and location of study areas. Black triangles represent the external control areas.

Cleaning operations

The boat used for cleaning operations in the Calich lagoon was 15 m long and had a 5 m arm. The mesh size of the sliding sieve of the arm was 5 mm, so that most of the shell detritus was collected. This boat cleaned a total area of about 55 ha in the lagoon, including the central part and important portions of its Eastern and Western sides. The edges of the lagoon were not cleaned, so that the hard bottom communities were preserved. In addition, the penetration of the arm into the sediment was fixed at about 5 cm in order to limit the impact of the cleaning activities.

Sampling of benthos and sediment

Benthos and sediment sampling was carried out in two areas (hereafter named A and B) of the lagoon where the cleaning boat operated (Figure 1). Six sampling stations, at a distance of 10 m from each other, were established in each area (of 75 m^2) during two different periods: autumn

2002 and spring 2003. Samples were taken in both areas, before (hereafter phase 1) and, along an adjacent transect, immediately after (hereafter phase 2) the cleaning operations, in autumn 2002. In order to evaluate the recovery capacity of benthic communities, the same stations were sampled 7 months later (hereafter phase 3) in late spring 2003. The real impact on the dredged areas after a putative re-adjustment of the communities was also tested at the same time, with two triangular un-dredged sub-areas being used as controls at the Eastern and Western sides of each cleaned area (Figure 1). In this way the medium term evolution of the benthic communities after the cleaning operations could be compared with the natural variations in undisturbed populations. Three sampling replicates were performed for both the macrobenthos and the sediments at all the above mentioned stations.

Four benthic macrofaunal sample replicates were collected with a 0.045 m^2 (5 l of volume) Van Veen grab within each of the 6 sampling stations in both A and B areas. Samples were then sieved through a 1 mm mesh and preserved in 4% buffered formaldehyde. Rose Bengal solution was used as a staining agent to facilitate the sorting. All the collected specimens were identified at the lowest possible taxonomic level.

Sediment samples were collected using the procedure described above for benthos samples. The organic content of the samples was determined by immediately freezing them at -20°C, and then analysing them with the Walkley and Black (1934) method. The samples were treated with 6% hydrogen peroxide to remove the organic fraction for granulometric analysis. The particle size distribution was expressed as percentages of: coarse fraction (>2 mm, mostly mollusc shell debris); very coarse sand (2 to 1 mm); coarse sand (1 to 0.5 mm); medium sand (0.5 to 0.25 mm); fine sand (0.25 to 0.125 mm); very fine sand (0.125 to 0.062 mm); and silt-clay (<0.062 mm).

Statistical analysis

In order to analyse the variations in the structure of the macrobenthic communities in all the stations and time periods, non-Metric Multidimensional Scaling (nMDS, Kruskal, 1964) procedures based on Bray-Curtis and Euclidean distances were used. A Multi Response Permutation Procedure (MRPP, Zimmerman *et al*., 1985) was used to test the environmental compatibility of the cleaning operation. An Indicator Species Analysis (ISA, Dufrene and Legendre, 1997) was also carried out to establish which were the most typical species in each group of samples. Species richness, Shannon-Wiener diversity index (H') and evenness were also calculated.

The Kolmogorov-Smirnov test was used on the most abundant species (not less than 50 individuals each) to check the medium term recovery ability of the major benthic populations in impacted and unaffected areas 7 months after cleaning. Finally, the Kruskal-Wallis test was used to compare the organic content of the sediment in the various phases.

Results

Structure of the macrobenthos before the cleaning operations

A total of 6,006 individuals from 54 taxa were collected in the two areas studied, and 96.4% of them were identified at species level. Polychaetes were the most abundant taxon (4,707 individuals), followed by Amphipods (1,144), while Molluscs were an order of magnitude lower (only 131).

Polychaetes were also dominant in species richness (31), followed by Molluscs (13), Amphipods (7) and then other minor groups such as Decapods, Isopods and Echinoderms. The dominant pool of species consisted of 5 Polychaetes (*Heteromastus filiformis*, *Myriochele oculata*, *Cirriformia tentaculata*, *Prionospio multibranchiata* and *Neanthes caudata*) and 2 Amphipods (*Corophium acherusicum* and *Pseudolirius kroyerii*): 84% of the specimens belonged to these 7 species.

The results for biomass were very different. Molluscs accounted for 87% of total wet weight and 2 Bivalves (*Tapes decussatus* and *Cerastoderma glaucum*), together with the Gastropod *Cerithium vulgatum*, contributed

77% of total sampled biomass. These Molluscs had such a high biomass value because they were larger and so had heavier shells. By contrast, Polychaetes contributed only 8% of total biomass.

Structure of the macrobenthos immediately after the cleaning operations

In all, 2,385 individuals from 47 taxa were sampled in areas A and B immediately after the cleaning operations. Cleaning caused a marked reduction in the number of individuals collected, but only a slight decrease in the number of species. As before, Polychaetes were dominant (2,197 individuals), followed by Amphipods (127) and Molluscs (56). Polychaetes were also the group with the most species present (29), followed by Molluscs (10), and Amphipods (5).

There was a dramatic reduction in total macrobenthic biomass collected after dredging (72.9 g before vs. 15.1 g after). Once again most biomass was Molluscs (60% of total wet weight). Although 47% of total sampled biomass was *Abra segmentum* and *Cerastoderma glaucum*, they were not among the dominant species. These were 6 species of Polychaetes (*Heteromastus filiformis*, *Myriochele oculata*, *Cirratulus chrysoderma*, *Neanthes caudata*, *Prionospio multibranchiata* and *Phylo foetida*) and the Amphipod *Pseudolirius kroyerii*.

Structure of the macrobenthos seven months later

A total of 23,025 individuals from 57 species were recorded in the two areas studied 7 months after dredging. Once more Polychaetes were the numerically dominant taxon (17,024 individuals), followed by Amphipods (3,641), and Molluscs (2,239). The highest number of species were Polychaetes (32), followed by Molluscs (14) and Amphipods (7). The results for both abundance and species richness were very similar to those observed before cleaning.

The results for biomass were different: Molluscs accounted for 51%, Amphipods for 34%, and Polychaetes for only 14%; 76% of total biomass were *Microdeutopus gryllotalpa* (Amphipods), *Cerastoderma glaucum* and *Abra segmentum* (Molluscs), and *Heteromastus filiformis* (Polychaetes). Three of these species (*Microdeutopus gryllotalpa*, *Abra segmentum*, and *Heteromastus filiformis*) belonged to the dominant pool.

Statistical analysis

The non-Metric Multidimensional Scaling (nMDS) ordination plot based on Bray-Curtis distance is shown in Figure 2.

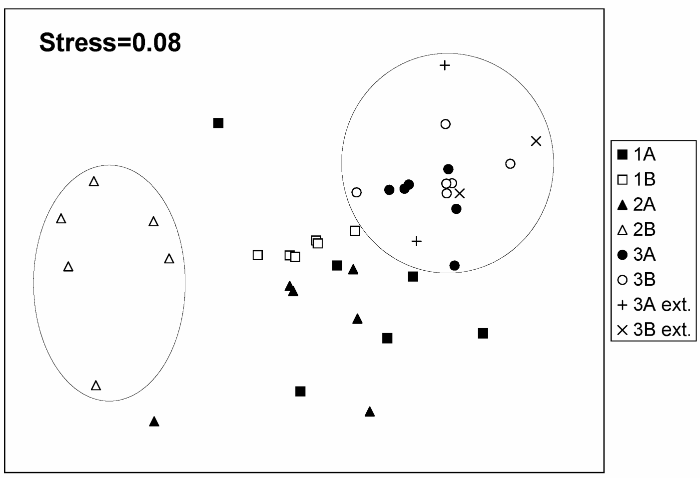

Figure 2. Non-metric Multi Dimensional Scaling (nMDS) ordination plot of individual replicates comparing benthic communities from areas A and B (1=before dredging; 2=immediately after dredging; 3=seven months later; ext.=external control areas).

Only samples collected immediately after cleaning (i.e. 2B) were clearly separated from the others. It is worth noting that a less distinct group was formed by the samples collected 7 months after the dredging activities (i.e. 3A-3B and 3A ext.-3B ext.). The observed variability can, however, be more clearly seen by plotting the first axis coordinate rank of all the samples against the sampling phases (Figure 3).

The structure of the samples collected immediately after cleaning (phase 2) was clearly affected by the perturbation of the sediment. After 7 months (phase 3), however, the zoobenthic community began to recover, which resulted in the community being similar to the first phase (before dredging). It is worth mentioning that the heterogeneity of the response was higher in area A than in B. Variations were also wider and more persistent in area A. While the aforementioned ordination method was based on the relative abundance of the taxa (i.e. it was qualitative), the samples were also compared by using a Euclidean distance matrix (i.e. quantitative). Once again the plot of the first axis coordinate rank of all the samples against sampling phases (Figure 4) produced an arch-shaped pattern, thus highlighting a transient change in community structure immediately after cleaning. Even when a quantitative metric was used, perturbation of the sediment seemed to affect the community in area B more strongly that it did in area A.

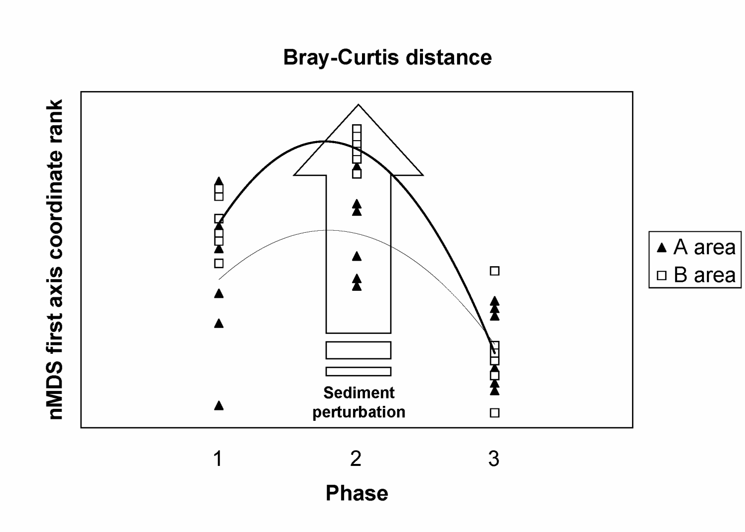

Figure 3. nMDS first axis coordinate rank based on Bray-Curtis distance of all the samples against sampling phases.

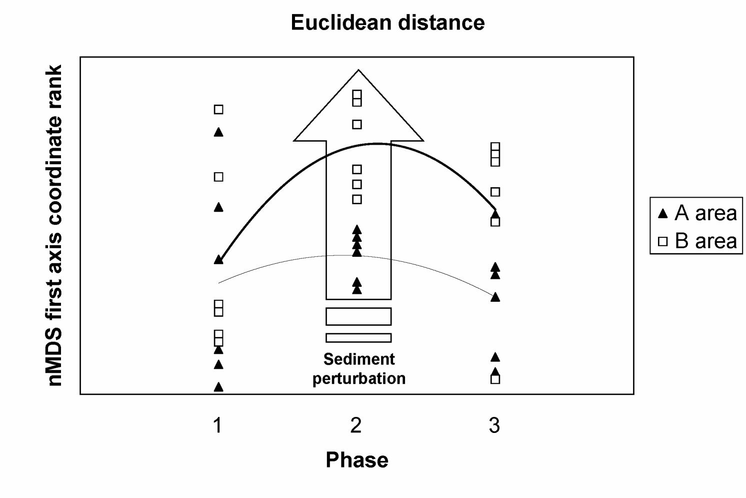

Figure 4. nMDS first axis coordinate rank based on Euclidean distance of all the samples against sampling phases.

A Multi Response Permutation Procedure (MRPP) was used starting from both a Bray-Curtis and a Euclidean distance matrix, and a Bonferroni correction was used to adjust α values for multiple comparisons (α'=α/n). When Bray-Curtis was used most of the comparisons between phases for both areas A and B gave significant values for the "r" statistic (Table 1). The results of the comparison between the dredged areas 7 months after cleaning (3A and 3B) and areas which had not been cleaned (3A ext. and 3B ext.) were not significant (Table 1). This indicates that after 7 months the community structure in treated areas was similar to that in untreated areas. With reference to the Euclidean distance (Table 2), it is interesting to note that only in the case of the area A is the comparison of the community structure before (1A) and immediately after the cleaning operations (2A) non-significant. This could be because this approach gives less importance to rare species. Finally, comparison of both areas during the same sampling phase (Tables 1 and 2) found that the benthic communities were more heterogeneous immediately after cleaning.

Table 1. Multi Response Permutation Procedure (MRPP) results based on Bray-Curtis distance. Significant values are indicated in bold.

Area A			Area B			Both areas		
Phase and area	r	p	Phase and area	r	p	Phase and area	r	P
1A vs. 2A	**0.168**	**0.002**	1B vs. 2B	**0.221**	**0.001**	1A vs. 1B	0.032	0.125
1A vs. 3A	**0.168**	**0.001**	1B vs. 3B	**0.374**	**0.001**	2A vs. 2B	**0.338**	**0.001**
1A vs. 3A ext.	0.038	0.216	1B vs. 3B ext.	**0.391**	**0.007**	3A vs. 3B	0.075	0.016
2A vs. 3A	**0.255**	**0.000**	2B vs. 3B	**0.359**	**0.001**	3A ext. vs. 3B ext.	n.d.	n.d.
2A vs. 3A ext.	0.148	0.019	2B vs. 3B ext.	**0.282**	**0.008**			
3A vs. 3A ext.	0.086	0.031	3B vs. 3B ext.	0.032	0.212			

Table 2. Multi Response Permutation Procedure (MRPP) results based on Euclidean distance. Significant values are indicated in bold.

Area A			Area B			Both areas		
Phase and area	r	p	Phase and area	r	p	Phase and area	r	p
1A vs. 2A	0.028	0.195	1B vs. 2B	**0.304**	**0.004**	1A vs. 1B	0.069	0.067
1A vs. 3A	0.114	0.011	1B vs. 3B	**0.271**	**0.003**	2A vs. 2B	**0.304**	**0.004**
1A vs. 3A ext.	-0.012	0.492	1B vs. 3B ext.	**0.369**	**0.007**	3A vs. 3B	0.056	0.060
2A vs. 3A	**0.286**	**0.001**	2B vs. 3B	**0.427**	**0.001**	3A ext. vs. 3B ext.	n.d.	n.d.
2A vs. 3A ext.	0.180	0.011	2B vs. 3B ext.	**0.482**	**0.007**			
3A vs. 3A ext.	0.025	0.245	3B vs. 3B ext.	-0.015	0.393			

The Indicator Species Analysis found a significant association between species and group of observations only in the 6 cases (out of 77) shown in Table 3 (namely for the Mollusc *Paphia aurea*, the *Polychaetes Cirrophorus furcatus*, *Lumbrinereis latreilli* and *Neanthes caudata* and the Amphipods *Melita palmata* and *Pseudolirius kroyerii*). Five of these species (4 from area A and only 1 for area B) were significantly associated with one of the un-dredged areas, although they were also present in other samples.

Generally there were no noteworthy differences in species richness, diversity (H') and evenness indices among the samples collected during the same phase in any of the examined areas. By contrast, there were significant differences (Kruskal-Wallis test: H=22.4, p<0.0001) in species richness in the different sampling phases (Figure 5). To be precise, there was a slight decrease in species richness immediately after cleaning (phase 2) and an increase for both dredged and un-dredged areas 7 months after cleaning (phase 3). The higher species richness 7 months after dredging was probably due to the seasonal evolution of the community, rather than to the effect of cleaning. This seems to be confirmed by the high species richness in the un-dredged areas (3 ext., Figure 5).

The Kruskal-Wallis test showed significant differences (H=10.2, p=0.0168) in evenness in the different sampling phases (Figure 6). To be precise, there was an increase of evenness immediately after cleaning (phase 2), while 7 months later (phase 3) the results for both dredged and un-dredged areas were similar to those calculated for the pre-cleaning (phase 1).

A Student t test found no significant differences (t=-2.007, p=0.065) in the biomass of the benthic fauna collected in dredged and un-dredged areas during phase 3.

The Kolmogorov-Smirnov test used to check the recovery ability of the major benthic populations found a significant difference only in the case of the Polychaete *Prionospio multibranchiata* (Table 4). This species was, however, characterised by an irregular spatial distribution.

Table 3. Indicator Species Analysis (ISA) results for species significantly associated with group of observations. Significant values are indicated in bold.

	Phase and area								
Species	1A	1B	2A	2B	3A	3B	3A ext.	3B ext.	p
Paphia aurea	0	1	0	1	0	0	**88**	0	0.001
Cirrophorus furcatus	15	0	0	0	3	3	**61**	1	0.005
Lumbrineris latreilli	7	1	0	1	3	1	**75**	3	0.005
Neanthes caudata	1	1	2	0	20	21	1	**54**	0.000
Melita palmata	0	0	0	2	1	0	**90**	0	0.001
Pseusolirius kroyerii	20	0	7	0	**54**	5	0	11	0.003

Table 4. Kolmogorov-Smirnov test results for the most abundant benthic species. Significant values are indicated in bold.

	Area A		Area B	
Species	D	p	D	p
Tapes decussatus	0.1250	0.990	-	-
Abra segmentum	-	-	0.4667	0.0515
Cerastoderma glaucum	-	-	0.3125	0.3481
Heteromastus filiformis	0.3330	0.308	0.2000	0.8899
Prionospio multibranchiata	0.3077	0.489	0.7692	**0.0003**
Corophium acherusicum	0.4615	0.087	0.1539	0.9950

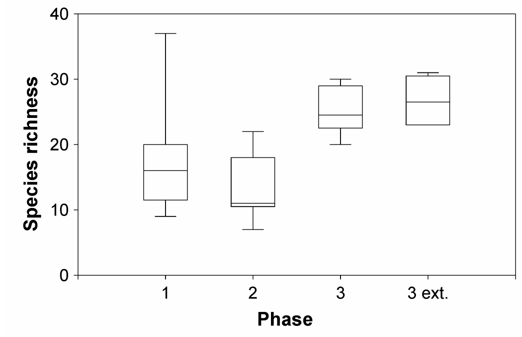

Figure 5. Boxplots of species richness values recorded during all the sampling phases. Values are median (horizontal lines inside box), 1st and 3rd quartiles (box) and min/max values (whiskers).

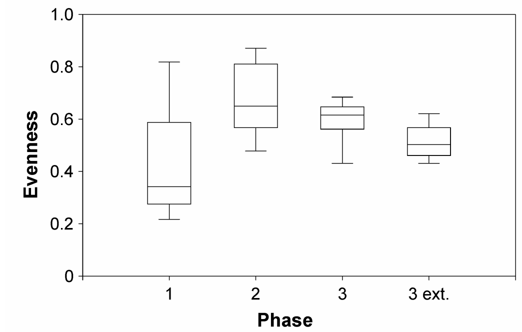

Figure 6. Boxplots of evenness values recorded during all the sampling phases. Values are median (horizontal lines inside box), 1st and 3rd quartiles (box) and min/max values (whiskers).

Sediments

The sediment grain size of samples collected in all the areas during all the phases is shown in Figure 7. In general, the sediments were silt and clay and the sandy fraction was rarely greater than 10%. Three samples collected before cleaning had an abundance of a coarse fraction of bioclastic origin (shell detritus). The separation of these samples from all the others shown in Figure 7 demonstrates the cleaning efficiency of the machine.

On the whole, the total organic content of the sediments was quite homogeneous in all the areas and phases, with the exception of phase 2 (Figure 8). In this case cleaning significantly reduced this fraction (Kruskall-Wallis test: $H=10.4$, $p=0.0156$).

Discussion

The cleaning machine used to dredge the sediments in the Calich lagoon had short-term effects on the benthic fauna in terms of both species composition and reduction of their abundance and biomass. This agrees with the results obtained by Kenny and Rees (1994) in their work on a small area of sea bed off the English East coast.

In undisturbed conditions (phase 1), evenness (*sensu* Stirling and Wilsey, 2001) in the benthic communities of the Calich lagoon was low, because some species were very redundant. This is not uncommon in coastal lagoons, where instability of chemical and physical parameters may hinder less tolerant species (Remane, 1934; Reizopoulou *et al.*, 1996). Actually, as found by Grassle and Grassle (1974) for opportunistic marine Polychaetes, wide fluctuations in abundance in brackish ecosystems are most probably the result of intense adaptive selection driven by unpredictable environmental conditions.

By contrast, immediately after dredging (phase 2) there was a slight increase in evenness, due to the reduction in the number of individuals belonging to highly redundant species. Consequently, the perturbation of the benthic communities at the dredged sites seemed to set the community structure back to earlier successional stages. These communities were dominated by a high number of specimens (with low individual biomass) of 6 species of Polychaetes (*Heteromastus filiformis*, *Myriochele oculata*, *Cirratulus chrysoderma*, *Neanthes caudata*, *Prionospio multibranchiata* and *Phylo foetida*) and 1 species of Amphipod (*Pseudolirius kroyerii*), as well as by low densities of large Bivalve Molluscs (*Tapes decussatus*, *Cerastoderma glaucum* and *Abra segmentum*). Among the Polychaetes, it is worth noting that *H. filiformis*, *N. caudata* and *P. foetida* are opportunistic species that account for large densities in muddy environments (Pearson and Rosenberg, 1978; Badalamenti and Castelli, 1993). *Heteromastus filiformis*, in particular, is tolerant to a wide range of environmental conditions and is found in organically enriched areas (Reizopoulou *et al.*, 1996). This species is also among the first colonizers of areas disturbed by dredging or dumping activities (Gosner, 1978). There was not, however, a common pattern in changes in the benthic communities in areas A and B in the Calich lagoon before and immediately after cleaning. This might be due to small-scale variations in the functioning of the cleaning machine or, most probably, due to variations in the bottom profile, the depth, and the texture of the sediments.

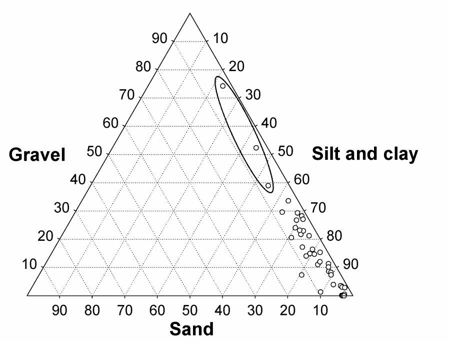

Figure 7. Sediment grain size composition (as percent) of the samples collected in all the areas during all the sampling phases. The 3 points inside ellipse are samples collected during phase 1 (before dredging).

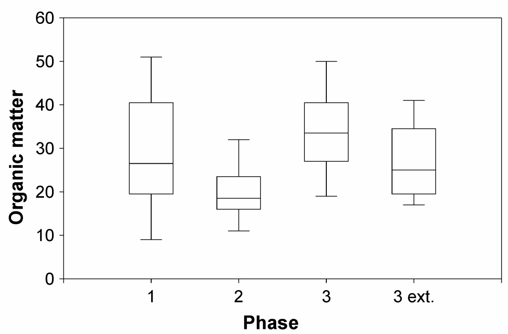

Figure 8. Boxplots of organic matter content values recorded in sediment during all the sampling phases. Values are median (horizontal lines inside box), 1st and 3rd quartiles (box) and min/max values (whiskers).

Seven months after cleaning (phase 3), the benthic communities were very largely re-established. This was assessed by evaluating adjacent uncleaned areas which were not significantly different from the previously disturbed ones. In dredged areas there were a large number of individuals of the Amphypod *Microdeutopus grillotalpa.* This species, although not an early colonizer, can reach high densities in brackish environments (Drake and Arias, 1995; Mancinelli *et al.*, 2005).

The overall species diversity in dredged areas was a little higher than in un-dredged ones. This small difference was probably related to dredging, because the disturbed communities might need more than 7 months to recover completely. Thus, our results seem to confirm the "intermediate-disturbance" hypothesis (Grime, 1973; Connell, 1978; Fox, 1979): species excluded from a climax community may occur in moderately disturbed conditions, and thus contribute to overall biodiversity.

An efficient and time-persistent removal of the bioclastic coarse fraction was observed in the superficial layer of the sediments of cleaned areas. There was, by contrast, a marked but only short-term reduction in the organic matter content.

To summarize, our results found that cleaning activities caused no overall marked changes in the structure of infaunal communities in the Calich lagoon. This agrees with the results reported by De Grave and Whitaker (1999). There was no notable damage to the benthic fauna, such as those reported as a consequence of beam-trawling (Kaiser and Spencer, 1996), or at dredged sediment disposal sites (Harvey *et al.*, 1998). The cleaning operations in the Calich lagoon had only a short-term impact on the benthic fauna and there was a substantial re-adjustment (*sensu* McCauley *et al.*, 1977) 7 months after dredging. This could be due to: 1) the great care taken when using the cleaning boat (i.e. limiting the penetration of its arm into the sediment and using a suitable mesh size); 2) the high resilience of the benthic communities and their consequent rapid recolonization; and 3) the small-scale perturbation at which the experiment was carried out. Moreover, the role of seasonal conditions, which may be relevant in macrofaunal recovering process, is still to be investigated in detail at the Calich lagoon.

Further research over different spatial and temporal scales is thus needed to confirm and generalize our results. In any case, sediment cleaning seems to be a viable practice that can be routinely used to improve fishery and aquaculture activities in Mediterranean lagoons, provided that it is not carried out on a whole basin at the same time. In fact, our study showed that small-scale sediment cleaning produced no adverse effects after a few months, but it was not aimed at defining the dynamics of recolonization processes nor at identifying sources of meroplanktonic larvae. Therefore, a precautional approach should be adopted by performing sediment cleaning according to a rotational scheme, thus allowing recolonization from surrounding undisturbed areas.

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