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MONITORING OF MARINE MACROBENTHIC COMMUNITIES AT A DUMPING SITE: ARE CAUSE/EFFECT RELATIONSHIPS CLEAR?

Riassunto - *Monitoraggio di comunità marine macrobentoniche in un sito di discarica: sono chiare le relazioni causa-effetto?* In questo lavoro sono riportati e criticati i risultati di uno studio sulle comunità del macrozoobenthos realizzato secondo la normativa italiana in uso nel 1991 relativa ai rifiuti non tossici allo scopo di valutare l'eventuale impatto causato dallo sversamento di sedimenti provenienti dal dragaggio del porto di Livorno.
L'indagine è stata condotta in un'area posta a 6 miglia dalla costa livornese prima e dopo lo sversamento di 100.000 metri cubi di materiale. Sono state fissate 15 stazioni di prelievo ed il campionamento è stato effettuato tramite draga prima e dopo lo sversamento. I dati ottenuti sono stati rielaborati tramite l'analisi multivariata (nMDS). Inoltre sono stati calcolati i parametri strutturali e sono state realizzate le curve ABC. La descrizione del popolamento è stata effettuata tramite approccio biocenotico.
Prima dello sversamento le comunità erano risultate ben strutturate, *unpolluted* secondo le curve ABC, e con un quadro biocenotico molto eterogeneo. Dopo lo sversamento solo le comunità biocenoticamente eterogenee hanno mostrato evidenti cambiamenti e sono state definite *sensibili*. Tuttavia non è stato possibile rispondere in maniera inequivocabile alla domanda «lo sversamento induce cambiamenti nel popolamento? Dato il crescente impatto antropico che grava sulle nostre coste, i risultati di questo lavoro, suggeriscono la necessità di aumentare gli sforzi per pianificare attività di monitoraggio sempre più efficaci che superino gli approcci descrittivi attraverso la formulazione di ipotesi e la loro successiva verifica formale.

Parole chiave - Benthos, sversamento, nMDS, curve ABC, parametri strutturali, bionomia, monitoraggio.

Abstract - This paper reports and criticises a study carried out in the Thyrrhenian coastal zone to assess the impact of harbour dredged material on marine macrobenthic community. Unpolluted sediments dredged from Livorno harbour were dumped at sea 6 nautical miles NW of the city. Procedures and methodological approaches were according to Italian rules and regulations running in Italy in 1991. Fauna was collected dredging in 15 stations before and after dumping and data analysis included multivariate analysis (nMDS), structural parameters, ABC curves and biocoenotic approach. Before dumping communities were well structured (high diversity), unpolluted (ABC method), and with a «heterogeneous» biocoenotic composition. After dumping only «heterogeneous» communities showed modifications and were considered *sensitive* communities. No clear and univocal answer to the question «does dumping affect the benthos?» can be achieved by the methods suggested by regulations. The need for planning more consistent monitoring programs to identify disturbance from dumping which can really answer the question if impact exists is suggested.

Key-words - Benthos, dumping, nMDS, ABC curves, structural parameters, bionomy, monitoring.

Introduction

Sea dumping of wastes from harbour dredged sites has been common practice in the waters all over the world. For many years sea dumping has not been regulated or regulated by domestic or local legislation. As Government policy has moved to increase protection of both land and marine environments, waste reduction and environmentally sustainable disposal methods have become increasingly important. Several rules and laws had been proposed and each country developed a set of rules for dumping of harbour dredged material.
Also in Italy discharge at sea has been a traditional, economical and widespread disposal method for material dredged from ports and channels to keep them open to shipping (Cognetti & Cognetti, 1992). Interest in the impact of this activity increased, mainly because of increased awareness on the part of the public and decision-makers (O'Connor, 1998) with regard to environmental problems. Nevertheless, scientific papers on the effects of dumping on benthic communities in the Mediterranean Sea are scarce and the specific problems of Mediterranean Sea are poorly addressed (Salen-Picard, 1981; Bonvicini-Pagliai *et al.*, 1985; Nicolaidou *et al.*, 1993).
This paper is an example of monitoring of marine macrobenthic communities carried out in the Thyrrhenian coastal zone according to Italian laws and regulations for dumping of non-toxic/unpolluted wastes. Different techniques for benthic community analysis applied to the specific problem of dumping are briefly discussed.
Benthic communities are particularly suitable for pollution assessment (Bilyard, 1987; Hartley, 1982) because their species composition and the interspecific relationships reflect broad environmental conditions (Jackson, 1993). Their complexity and variability has forced scientists to adopt numerous different approaches (Gray *et al.*, 1988; Warwick, 1988; Simboura *et al.*, 1995, Roberts *et al.*, 1998) to summarise changes in species and abundance patterns and to identify sensitive, robust and repeatable methods to relate these changes to pollution ones (Underwood & Peterson, 1988).
Common methods for analysing quantitative data were synthesised in three categories: univariate, multivariate and graphic/distribution methods (Warwick & Clarke, 1991).

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A qualitative method summarised by Pérès and Picard (1964) in their manual and revised by Pérès (1982) is widely applied in the Mediterranean Sea (Bellan *et al.*, 1985). These authors stressed the importance of changes in the «biocoenotic structure» and focused on indicator species which they termed «characteristic species».
Pollution-induced changes in marine benthic communities have been the subject of numerous papers, most of these related to the effects of organic enrichment, eutrophication and oil spills (Pérès & Bellan, 1972; Pearson & Rosemberg, 1978; Gray *et al.*, 1990; Rees *et al.*, 1992; Feder & Blanchard, 1998). By contrast, relatively few papers regarded the biological consequences of other types of pollution events (Nicolaidou *et al.*, 1993; Olsgard & Hasle, 1993; GCSDM, 1996, Newell et al., 1998). Furthermore, the different kinds of effects identified by several authors in previous studies (Harrison, 1967; Van Dolah *et al.*, 1984) make it impossible to draw up a general impact model on marine benthic communities (Harvey *et al.*, 1998).

MATERIALS AND METHODS

Study area and sampling

The disposal site (43°38.00' N 10°09.50' E) was in the open sea, 6 nautical miles to the NW of Livorno harbour at a depth of 40 m. The study area included the disposal site (station M) and extended from the mouth of the river Arno to the Meloria Shoals (Fig. 1).
Large scale information on the area are available from a multidisciplinary study performed in the 80s (Aa.Vv., 1993) and this survey also included benthic communities in the area that 10 years after became dumping site (Aliani *et al.*, 1995). Soft bottoms cover almost all of the continental shelf, with finer sediments offshore and sandy sediments close to the coast. Rocky bottoms found at the Meloria Shoals are dominated by «coralligenous» elements (De Biasi, 1998, De Biasi & Gai, 2000).

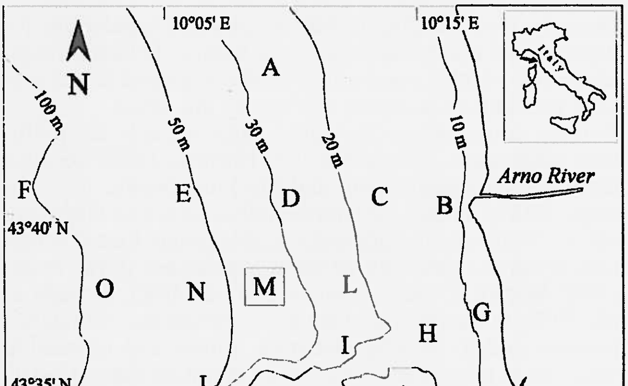

Fig. 1 - Map of the investigation area including the sampling stations. M is the dumping site.

Accurate in-situ water current measurements had never been performed on the continental shelf off Thyrrenian coast but a lot of data are available on the general circulation pattern and at mesoscale (Astraldi & Gasparini, 1992). These data, together with some hydrological survey performed in the 80ties on the shelf, were used to assess that offshore currents flow mainly northwards, transporting most of the river Arno plume. Long shore opposite current weakly flows along the coast in the southern direction. The tidal range is very low, as usually in the Mediterranean Sea, and consequently tidal currents are weak (Aa.Vv., 1993).
Macrofauna was collected in 15 stations positioned along three transects perpendicular to the coastline. Soft bottom samples were collected by a double sided anchor dredge and the volume of the sample was always 70 litres (Salen-Picard, 1981). Dredge was used because was the traditional tool for benthic sampling in biocenotic studies in the Mediterranean Sea and because of the possible risk that the coarser component of the dredged material or debris may partly affect the bite of the grab jaws. Sediments were washed over a 1 mm mesh sieve. Fauna was preserved in 10% buffered formaldehyde. Organisms were sorted out, counted and identified at the lowest possible taxonomic level. Abundance data were standardised according to the Preston scale (Grey, 1981). Biomass measurements were as wet weight.
The first survey was in July 1991, before the dumping activity; the second was in March 1992 immediately (1 week) after the discharge of 100,000 m^3 of material dredged from Livorno harbour. The dredged material was mud, sand or gross debris according to the different dredged areas of the harbour but it was always classified as non-toxic by chemical analysis.

- *Data analysis*

Multivariate analysis

Multivariate methods are common tools in benthic fauna analysis (Gauch, 1982) because they are objective (Jackson, 1993) and consider many variables at the same time. Multivariate analysis was performed on abundance matrices (one for each survey) with and without reduction of rare species. Similarity between samples was computed using the Bray-Curtis coefficient (Bray & Curtis, 1957), and the similarity matrices were subjected to both clustering and ordination methods. Clustering was performed by a hierarchical, agglomerative method employing group average linkage, and clustering results were used to separate groups on the ordination plots. Ordination plots were performed by nMDS.

Statistical indices

Under conditions of pollution, a few tolerant species will became relatively more numerous and will dominate the community, while less tolerant species becoming increasingly rare or disappearing (Rygg, 1985). These changes are reflected in structural parameters such as diversity indices.

For each station. Shannon-Wiener index (H') was calculated being one of the most widely used and synthetic parameter (Shannon & Weaver, 1963).

Graphical method

ABC (Abundance-Biomass Comparison) curves (Warwick, 1986; Warwick *et al.*, 1987) which use the *k*-dominance curves of Lambshead *et al.* (1983), were plotted for abundance and biomass data. Plots were performed for each station and for each cluster. The relation between species abundance and biomass curves can indicate pollution-induced stress: when the biomass curve lies above the abundance curve throughout its length the assemblage is not affected by pollution; the reverse occurs for grossly disturbed communities. In moderately disturbed areas - or in the first stages of pollution as well - the two curves are closely coincident and may cross each other one or more times.

Biocoenotic approach

The biocoenotic approach arises from the hypothesis that natural benthic communities in the Mediterranean Sea are organised in some well-defined biocoenoses described in a general model by Pérès & Picard (1964). This approach is widely used in the Mediterranean Sea, particularly in the Western Mediterranean, where it is a very suitable tool for identifying and describing macrobenthic communities. The percentage of affinity of each sample with the theoretical biocoenosis was calculated using a mathematical method proposed by Picard (1965). In polluted areas, benthic assemblages display changes in the «biocoenotic structure», the appearance of indicative species, and the development of «edaphic facies» dominated by one or few species (Bellan *et al.* 1985). The affinity index is used as an indicator of changes in biocoenotic structure.

RESULTS AND DISCUSSION

Benthic fauna

In the first survey a total of 1,141 infauna invertebrates belonging to 147 species were collected. The list included polychaetes (48% of the total species), crustaceans (23%), molluscs (16%), echinoderms, sipunculans, cnidarians, pycnogonida, and bryozoans (13% all). Some epibenthic species such as *Vermiliopsis infundibulum*, *Spirobranchus polytrema* and *Calpensia nobilis* were collected only at stations H and I where large pebbles and dead shells allowed their settlement, supporting in turn a diverse assemblage of smaller motile invertebrates.
After dumping the total number of individuals decreased (1,030 individuals) and the number of species fell slightly as well (141 species). No areas without macrofauna were found, not even at the disposal site, where 40-50 cm high mounds of dumped sediments were observed during some ROV surveys (Cocito *et al.*, 1994). The immediate physical impact found by ROV was probably quickly obscured by opportunistic colonisation of surface sediments, either by larval recruitment or redistribution of adults as suggested by Rees *et al.* (1992). This patchy distribution of the mounds, which was maintained for several days because of the very weak bottom currents, produces a checker-board impact that can be the source of the adults' colonisation.
Small differences were observed in the proportional abundance of the dominant phyla. Polychaetes displayed an increase from 47% to 57%. Many of them belonged to the Cirratulidae and Capitellidae families which are typically r-strategists associated with disturbed environments.
The most significant changes occurred at sites I and H, where epibenthic species dropped sharply after dumping. In addition, the abundances of indicative and opportunistic species changed: *Notomastus latericeus* increased from five specimens (sum of the two stations before dumping) to 96 (station H) and 13 (station I). After dumping, 90 specimens of *Lumbrineris latreilli*, previously absent, were found in station H and five in station I. Large numbers of specimens of *L. latreilli* have also been found in other dumping sites in the Mediterranean (Salen-Picard, 1981), probably favoured by sediment instability due to disposal. In the same stations the amphipods *Ampelisca sarsi* and *Atylus massiliensis*, mobile species usually associated with the sediment surface, reduced their abundance, providing another indication of pollution-induced stress (Bellan-Santini, 1980). In station H, the polychaetes *Aonides oxicephala* (12 individuals) and *Laonice cirrata* (30 individuals), unrecorded before dumping, were found as well, yet another indicator of disturbance (GCSDM, 1996).

Multivariate analysis

nMDS ordination plots of stations for both surveys, with the results from clustering superimposed on the ordination plot, are reported in Fig. 2 and Fig. 3.
Before dumping, three clusters were identified. The biggest cluster grouped stations A, C, D, E, L and M, located between 15 and 60 m depth. Another group included deeper stations (F, N, K). Stations close to the Meloria Shoals (I and H) were in the third group. Here sand-loving species were dominant.
After dumping, the ordination plot and cluster analysis changed. The main cluster of the first survey was separated into smaller groups. Stations E and D were included in a single cluster, and station M (the dumping site) shifted toward the cluster of deep stations. Stations C and L grouped together with stations I and H to make a new cluster. Groups from cluster analysis were superimposed on the sampling map (Fig. 3).
Fragmentation of large clusters into smaller groups is the most evident difference found after dumping but it is difficult to relate this increased patchiness to pollution. The general rarefaction of species and reduction in abundance that commonly occurs in the Mediterranean Sea from summer to winter reduces similarity between samples and increases patchiness as well as pollution disturbance (Warwick & Clarke, 1993).
Stations I and H showed an opposite trend of increasing similarity towards stations C and L. This change was not a result of a larger number of species in common but depended on the loss in stations H and I of their exclusive or characteristic elements whose presence allowed separating the community near the Meloria Shoals from the others.

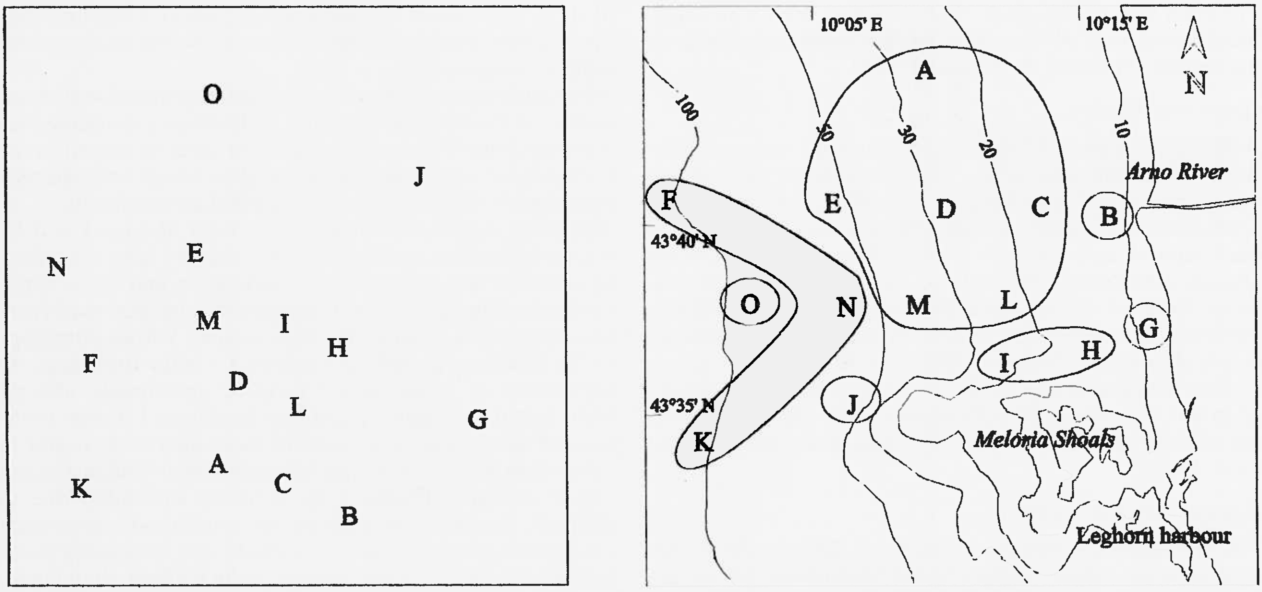

Fig. 2 - Ordination plot of the nMDS before dumping. The similarity matrix was calculated using the Bray-Curtis index. Stress value: 0.01. Clusters were superimposed on the sampling map.

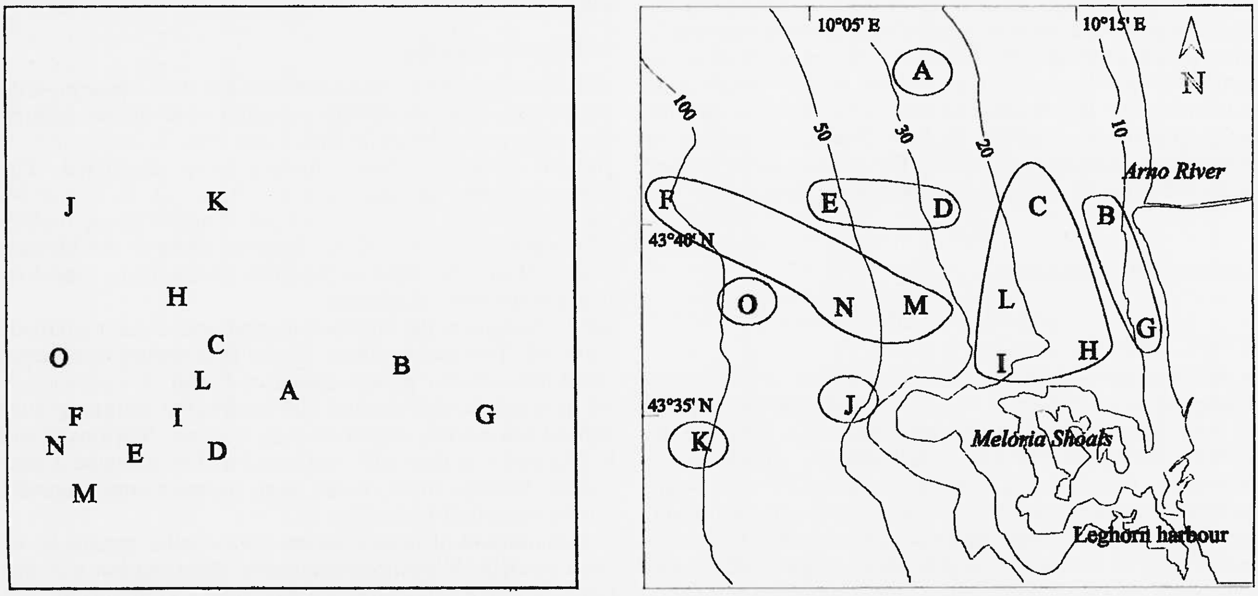

Fig. 3 - Ordination plot of the nMDS after dumping. The similarity matrix was calculated using the Bray-Curtis index. Stress value: 0.02. Clusters were superimposed on the sampling map.

Statistical indices

Before dumping, stations H and I showed high diversity (Fig. 4).
After dumping a general decrease in species richness was found. The change of diversity in the dumping site was not different from the mean decrement found in the other stations.

As discussed for MDS, a cause and effect relation with dumping activity is not clear because the importance of season in influencing the structure of the communities is unclear. In any event, I and H, i.e. the most complex and structured stations before dumping, were again the most affected by the increase of abundance and decrease of diversity and equitability. This suggests that there was a disproportionate increase in the abundance of a few

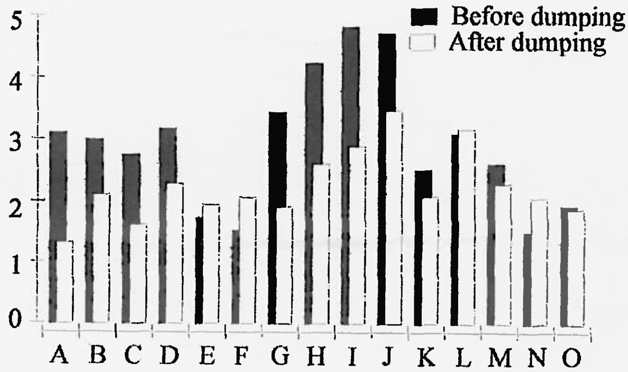

Fig. 4 - Shannon-Wiener diversity before (black columns) and after dumping (white columns).

dominant species, a response typically predicted for a disturbed area (Rosenberg *et al.*, 1987; Warwick, 1986). According to these authors the most structured communities seem to evidence the early effects of disturbance better because their complexity makes them more friable and less resilient with a longer time of recovery. The increased complexity reduces the likelihood of such systems being stable (Warren, 1990).

Graphical methods

Before dumping, the *k*-dominance curve of abundance was above the biomass in most of the stations. According to Warwick's criteria the area can be considered unpolluted. Only station B, directly opposite the mouth of the river Arno, was indicated as polluted, probably because of organic enrichment or metal contamination related to the influence of the river outflows. Similar results were obtained using the ABC method on each cluster.
After dumping, no great changes were detected in the dumping area. Nevertheless, ABC curves indicated moderate pollution in stations H and I, quite far from the dumping site (Fig. 5). Changes were also detected in station B, which became «unpolluted»: the sediment instability of this area is related to the strong influence of the river Arno outflow (De Biasi *et al.*, 1997), making the interpretation of this result unclear and stressing the need for further studies.

Biocoenotic approach

The biocoenotic structure in every station, before and after dumping, is reported in Table 1.
During the first survey the well-defined community labelled Well Sorted Fine Sand Biocoenosis (SFBC for Sables Fins Bien Calibrés) was found in the shallow stations G and B. This biocoenosis is typically related to high hydrodynamic energy environments with sandy bottoms characterised by small amounts of fine fractions and organic matter contents and by high quantities of organogenous debris.
Stations C, D, H, I and L, where the sediment texture had the highest diversity, represent the transition between sandy and muddy sediments. Here, widely distributed biocoenotic elements coexist with specialised (preferential or characteristic) elements from the neighbouring biocoenoses. A faunistic stock which can be related to a well-defined biocoenosis was not found.
This biocoenosis is gradually replaced by Coastal Terrigenous Mud Biocoenosis (VTC for Vase Terrigène Côtière) extending down to 30 metres depth (stations E, F, K and M). Stations J and O, where the lowest silt/clay ratio values were found, were characterised by the lowest number of species. The affiliation to a standard biocoenosis was not possible.
Strong changes after dumping were not detected and the biocoenotic structure was generally confirmed. Very small variations were detected in those stations previously characterised by a standard biocoenosis. Characteristic or preferential species remain the most important elements shaping the physiognomy of the community.
Major changes were detected in the stations C, L, D, H and I, which previously were a transition community. Stations C, L and D increased the number of mud-loving species and other stations increased in sand-loving species.
Biocoenoses with mixed faunal stock evidenced more changes than typical ones. In typical biocoenoses, species have similar ecological constraints so under stress (if low in intensity and short in duration) some of them can replace the disappeared species, partly filling their ecological niches («substitution») but without changing the nature of the biocoenosis. In the transition community, where species with wider ecological constraints and with different natural abilities to survive or tolerate disturbance live together, stress will be favourable or unfavourable in different ways for different species. The most tolerant species will be the key elements in reorganising the biocoenosis, shaping its composition according to their biocoenotic affinities («prevarication»).

Conclusion

This study evidenced changes in the benthic communities under dumping impact through changes in composition, structure and biocoenotic affinity.
As pointed out by Aliani et al. (1994) in their preliminary paper, the most evident modifications were observed for stations H and I, the same stations that - before dumping - showed the highest level of structure (higher diversity index), were unpolluted (according to the ABC curves), and characterised by a heterogeneous biocoenotic composition. The authors suggested that these communities can be considered «sensitive communities», i.e. communities that can detect low level stress-induced effects in advance. Similarly, other authors (Bellan *et al.*,1985) observed that unpolluted communities are more strongly influenced by disturbance, showing early effects by modifications in structure. By contrast, there was no evidence of large changes at the dumping site as similarly observed by Rees *et al.* (1992) who failed to detect wide effects at the disposal site in Liverpool Bay despite ample evidence of the physical presence of dredging.
We would like to stress that our study do not fail in detecting community changes, but it is not possible to distinguish between a reasonable interpretation of a sequence

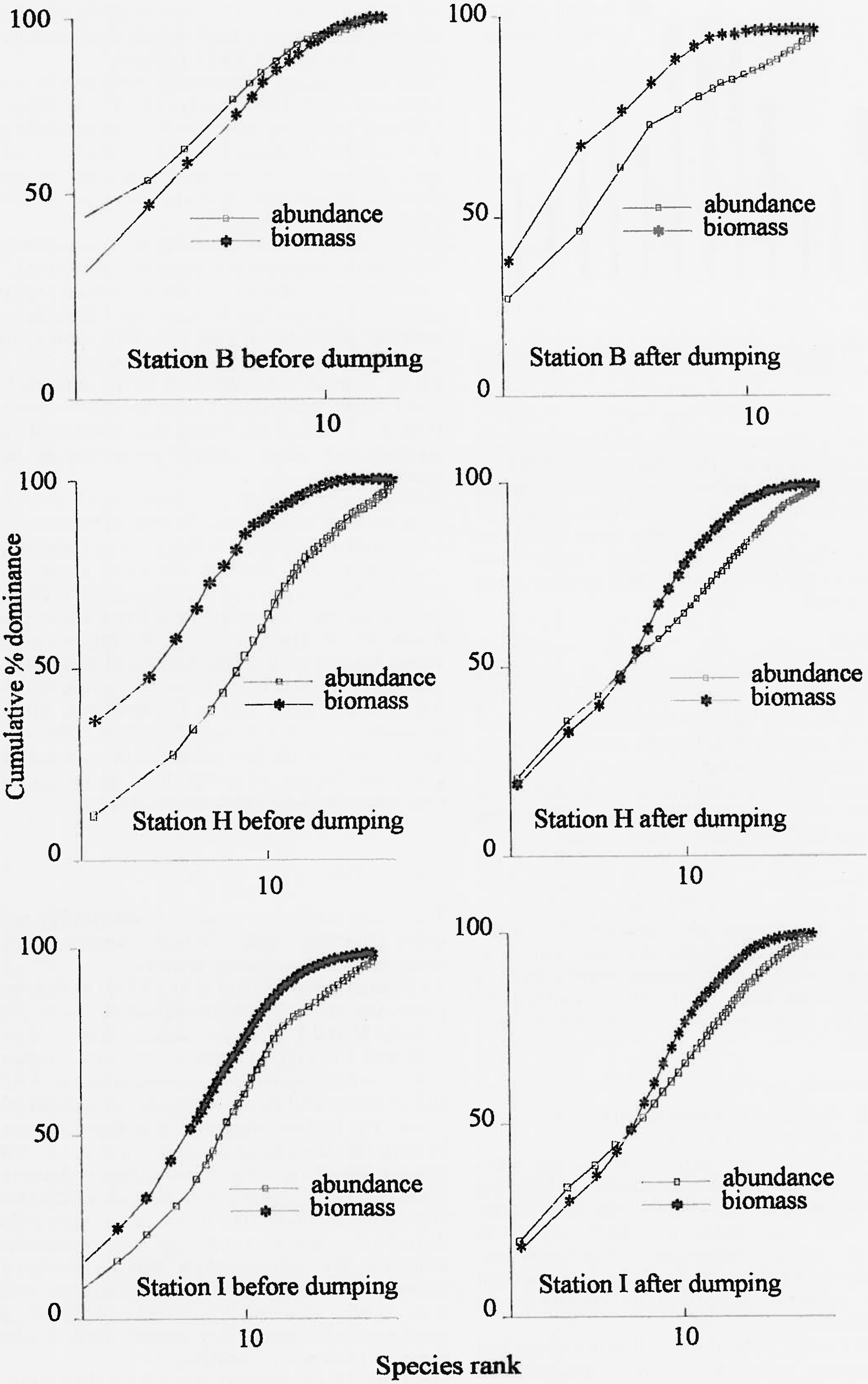

Fig. 5 - ABC curves for stations B, H, I, before and after dumping.

Tab. 1 - Picard's percent biocenotic affinity (Picard, 1965).

	A	B	C	D	E	F	G	H	I	J	K	L	M
	First survey												
SFBC %	0	100	69	40	0	0	100	66	61	0	0	47	0
VTC %	100	0	31	60	100	100	0	34	39	0	100	53	100
	Second survey												
SFBC %	49	100	32	0	0	0	100	93	85	0	0	40	0
VTC %	51	0	68	100	100	100	0	7	15	100	0	60	100

of observations in space and time and an objective explanation of a phenomenon. In fact although methods do not fail in detecting community changes, they can not clearly state relationships between causes and effects (detected changes) and they cannot give clear and univocal answer to the key question «does dumping affect the benthos?».
What matter is not only the choice of the most appropriate statistical method to re-elaborate the data set, but mainly to plan an *ad hoc* monitoring program through formulating an *a priori* hypothesis and therefore to test it formally.
The major question in environmental monitoring is to understand if the observed changes are really related to the human impact (Keough & Quinn, 1991). The problem arise from the practical experience which suggests that natural populations show a consistent temporal and spatial variability which confound any potential effect of the human activity. This problem can be partly solved measuring this variability and taking it into account for a correct monitoring planning (Morrisey et al., 1992a,b). There is a conspicuous scientific literature about methods for detecting human impact on natural populations and procedures for optimising cost/effectiveness ratio in monitoring program (Underwood, 1991, 1992, 1996). In Australia, for example, the Beyond-BACI (Before-After Control Impact) procedure is widely adopted, not only in scientific research, but successfully in applied ecology too. In Italy this procedure is known and appreciated by different scientists (Benedetti-Cecchi, 2001), but poorly or at all utilised in impact assessment studies such as disposal of wastes. Ecological research should offer much to environmental managers, but current interactions between ecologists and managers are not always as effective as they might be.
This paper is an example of the approach used in Italy since 1991 (Virno-Lamberti et al., 2000, Bonvicini Pagliai et al., 2000). Some minor changes to this procedure had been adopted after then. The dredge was substituted by the grab as the possibility that coarse sediment or debris from the waste may leave partly open the jaws of the grab resulted negligible after long field work experience. But many procedures still under use are ambiguous in assessing environmental impact when descriptive approach rather than quantitative/objective analyses are followed. Also when a change is identified, as in our study, it is not clear if the relationship between the impact and the perceived change of the environment is causal.
This paper highlights the need for planning consistent monitoring programs and more powerful tests to detect disturbances and subsequently producing information relevant to and necessary for correct environmental management. This goal con be achieved only through an increasing cohesion between the goals and products of ecological research and decision makers and regulators of environmental problems.

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