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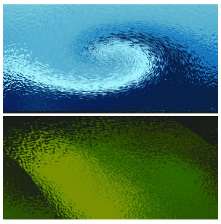

RESEARCH ARTICLE

Brackish-water polychaetes, good descriptors of environmental changes in space and time

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Abstract

1 - -The aim of this study is to review the knowledge on the distribution of soft bottoms polychaete assemblage in Mediterranean brackish-waters.

2 - -The Polychaete distribution of several biotopes located along the Tyrrhenian and Adriatic coast, which has been the object of authors' past studies, is reported and discussed.

3 - -Polychaete species composition was used to identify patterns of distribution inside the same biotope and among different biotopes, as well as changes in time in the same biotope.

4 - -Polychaetes was revealed good descriptors of biotope characteristics, reflecting a pattern similar to that arising from the examination of the entire benthic community.

5 - -We propose the use of polychaete assemblage fearures in assessing the ecological quality status of brackish-water bodies. For this purpose a general model of species distribution is given.

Keywords: Polychates, brachishwaters, ecological indicators, organic enrichment, salinity, Mediterranean sea.

Introduction

Benthic communities are considered the "biological memory" of the system resuming the action of multiple factors. Composition and changes in time and space of benthic assemblages are in fact the resultant of complex interaction among multiple factors difficult to individuate and to measure. For this reason benthic macroinvertebrates are one of the biological elements used for assessing the ecological quality (EcoQ) status of water bodies within the WFD 2000/60/EC. Many benthic indices have been developed and at present a large debate is taking place about the selection of appropriate indices and their performance towards the management of coastal transitional ecosystems (CTEs) (Van Hoey *et al.*, 2010). Brackish-water biotopes represent a good opportunity to study the main factors influencing spatial and temporal distribution of species. Due to their geomorphology and hydrological processes, coastal lagoons are characterized by sharp internal environmental gradients, together with sharp daily and seasonal variations in physico-chemical parameters, mostly salinity (Battaglia, 1959; Kjerfve, 1994). This variation strongly drive species distributional patterns and community structure (Koutsoubas *et al.*, 2000). The role of salinity in species distribution was stressed in a early classification of lagoonal systems, the Venice System (1958), which highlighted some indicative species of different salinity levels; subsequently the role of sea water renewal was underlined in the synecological approach classification of the confinement theory by Guelorget and Perthuisot (1992). Whichever is the predominant controlling factor, one of the main point is that brackish-water benthic assemblages of temperate latitudes often undergo drastic fluctuations in species abundance and richness (Arvanitidis *et al*., 1999). Fluctuations can be cyclic (predictable, e.g. seasonal), or directional (unpredictable), when environmental changes are persistent in time and drive biotic assemblages towards different structures (Boero, 1996; Giangrande and Fraschetti, 1996). Once again brackish-waters represent ideal study cases for assessing different directional factors controlling community structure and dynamics. Lagoonal species, other than being characterized by peculiar life-history traits, are exposed to severe environmental conditions (hypoxia, high temperature, low pH, highly toxic products) and can evolve tolerance, making the community highly resilient and fit for recovering after severe episodic events (Carrada and Fresi, 1988; Lardicci *et al*., 1997; 2001). Finally, brackish-water biotopes are ideal models also for studies on ecological directional changes, since modifications requiring decades in the more stable marine communities, are visible only in few years in brackish biotopes (Lardicci *et al*., 1997, 2001; Nicoletti *et al*., 2006; Schirosi *et al*., 2010).

Moreover, coastal lagoons are highly productive and a very suitable system for aquaculture projects (Ardizzone *et al*., 1988), it is also for these reasons that these shallow environments may suffer from natural disturbance and are frequently stressed by different sources of anthropogenic inputs and human activities. Indeed coastal lagoons are often subjected to high organic enrichment, which can generate oxygen depletion and toxic by-products production; such conditions impair the habitat and progressively reduce the number of species within benthic communities. Although the role of trophic load in conditioning the benthos distribution was already stressed by Fresi *et al*. (1985), only recently Tagliapietra *et al*. (2012) introduced the saprobity conceptual model, with organic matter metabolism as suitable descriptor to characterize the natural conditions of brackish-water bodies and assessing the environmental quality. This hypothesis was than tested by Foti *et al*. (2014) for a Sardinia lagoon.

According to Lardicci *et al*., (1997), in Mediterranean coastal lagoons the macrozoobenthos is represented mainly by three groups of species: a group of typically euryhaline species which are characteristic of brackish-water zone; a group of marine species which prefer sheltered environments with low hydrodynamism; and a group of opportunistic species, such as shallow-dwelling surface deposit-feeders, primarily polychaetes, with short life cycles, which tolerate organic enrichment.

Among benthic invertebrates, polychaetes are one of the most abundant and diverse taxon characterizing the communities. The group include both sensitive and tolerant species along the gradient from pristine to heavily disturbed habitats, showing good indications of environmental level disturbance; for these reasons they are extensively employed in monitoring studies (Giangrande *et al*., 2005). Polychaetes of sheletered brakish-water environments in Mediterranean have been deeply investigated (Gravina *et al*., 1988; Nicolaidou *et al*., 1988; Lardicci *et al*., 1993; Gouvis et al., 1998; Ergen *et al*., 2002; Nicoletti *et al*., 2006; Maggiore and Keppel, 2007; Schirosi *et al*., 2010).

The objective of the present paper is 1) to summarize the results regarding polychaete assemblages from our studies carried out in different brackish-water biotopes along the Tyrrhenian and Adriatic coasts during the last three decades; 2) to prompt a general distribution model, that can be utilized in monitoring studies.

Material and Methods

The polychaete dataset used in the present study includes both published and unpublished material gleaned from samples collected during our studies and carried out in the following brackishwater ecosystems: Fogliano, Monaci, Caprolage, Sabaudia, Fondi, and Lungo, along the Tyrrhenian coast (Latium); Lesina, Varano, Acquatina and Alimini, along the Adriatic coast (Apulia). Investigations cover a long period of time from 1977-1985 (Giangrande and Gambi, 1985; Gravina *et al.*, 1988) to 2011-2012 (unpublished data) in the Tyrrhenian biotopes, from 1989 to 2007 in the Acquatina lagoon (Schirosi *et al.*, 2010), and only the year 2007 relatively to the other Adriatic biotopes (Cardone *et al.*, 2014). To test the role of polychaetes as community descriptors, the abundance of polychaete species found in two replicate samples at each sampling stations, each biotope, each season and each year were considered. Two ordination techniques were used: Factorial Analysis of Correspondence, for Latium lakes and non-metric multidimensional scaling (nMDS) for Apulian coastal lakes. To test resilience and recovery capability of polychaetes, the series of annual changes in the species abundance were analysed between the years 1977-1984 in the Sabaudia lagoon. To test the role of polychaetes in describing spatial and temporal changes in brackish ecosystems, two cluster analysis, based on Bray-Curtis similarity measures, were performed using abundance data of polychaete species on the most complete dataset referred to Fogliano (Latium) and Acquatina (Apulia) covering respectively 28 and 14 years.

Results and Discussion

Community descriptors

The large environmental variability both on spatial and temporal scale in Mediterranean coastal lagoons has been investigated together with the main effects of human activities mostly affecting such ecosystems (sewage discharge, fish farming, eutrophication). These consequences strongly affect the composition, structure and dynamics of the macrozoobenthic community and ultimately the functioning of the entire biotope, triggering, especially during the warm season, dystrophic crises (Lardicci *et al.*, 1997; 2001; Koutsoubas *et al.*, 2000; Mistri, 2002; Kevrekidis, 2004). In addition, some ecological aspects of typically lagoon inhabiting macroinvertebrates have been also studied in some Mediterranean coastal lagoons (e.g. Kevrekidis, 2005a, b; Kevrekidis and Wilke, 2005; Casagranda *et al.*, 2006; Kevrekidis *et al.*, 2009a, 2009b).
Notwithstanding the relative low number of species characterizing the benthic communities of the transitional water bodies, the species composition of soft-bottom polychaete assemblages of Mediterranean brackish-water biotopes showed a surprising biodiversity due to both differences in species richness and species composition, in response to the different environmental features. Gravina *et al.* (1988) analyzed the distribution of polychaetes in several brackish-lakes located along the Tyrrhenian coast (Fogliano, Monaci, Caprolage, Sabaudia, Fondi, and Lungo), characterized by different salinity and trophic status, and found this taxon to be very useful in describing the different environmental situations (Fig 1). The ordination model isolated the lake of Fondi from the remaining ones according to the salinity, this biotope was in fact the only mesoaline biotope, and only few species were present (*Polydora ciliata*, *Ficopomatus enigmaticus*, and

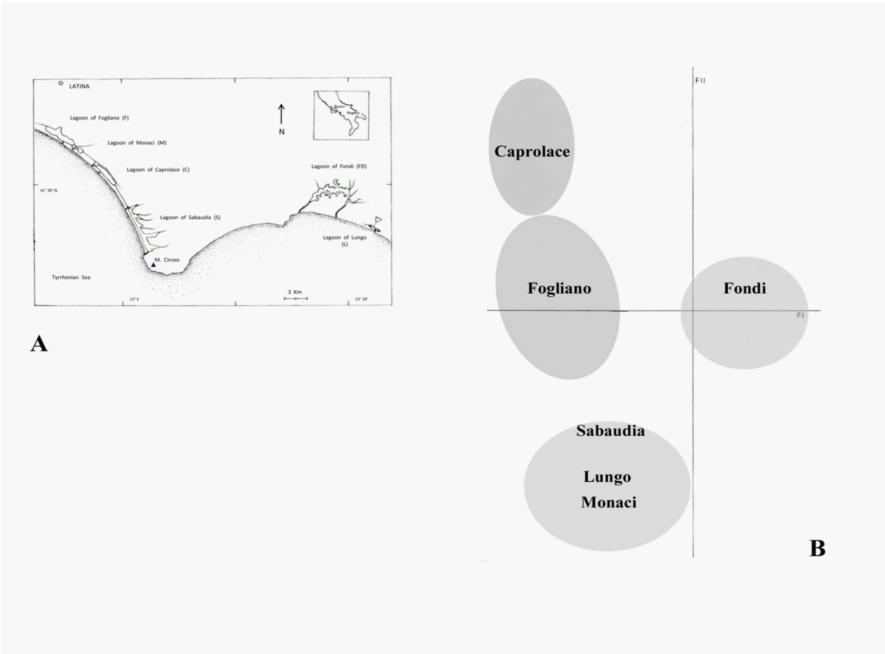

Figure 1 - Pontine brachish water lake polychaete assemblage. A) map of the study sites; B) Ordination model by the Factorial Analysis of Correspondence.

Hediste diversicolor), because the polychaete are strongly negatively selected towards this factors. Although characterized by a similar salinity range (poly-eurialyne biotopes), however, the remaining biotopes, resulted separated along the second factorial axis according to their trophic status, essentially depending on boundary conditions, such as marine inputs and quality and amount of continental inputs. The proper vivified lake of Caprolace was inhabited by numerous marine species coming from the adiacent sea (*Notomastus latericeus*, *Armandia cirrosa*, *Glycera tridactyla*, *Lumbrinereis latreilli*, *Abarenicola claparedi*) and for this reason it resulted clearly separated from the other biotopes more subjected to different organic enrichment levels. At the opposite pole of the trophic ecocline, the lakes of Monaci, Lungo and part of Sabaudia were located, with their polychaete assamblages mostly dominated by the opportunistic species, such as *Capitella capitata*, *Schistomeringos rudolphi*, *Syllis gracilis*, and *Polydora ciliata*. The lake of Fogliano and part of Sabaudia arranged themselves at intermediate position, being principally characterized by marine species commonly inhabiting sheltered coastal areas suffering moderate organic load levels, such as *Neanthes caudata*, *Nereiphylla rubiginosa*, *Malacoceros fuliginosus*, and *Spio decoratus*. This pattern was consistent with the results achieved analyzing the entire benthic assemblages of the lagoons (Gravina, 1986; Gravina *et al*., 1989), revealing polychaetes as useful indicators of the environmental quality of brackishwater systems.

The polychaete assemblages of the brackish -lakes of the Apulia Adriatic coast, Lesina, Varano, Acquatina, Alimini, represent another interesting study case to evaluate the role of such zoobenthic component as biotic indicator. The sampling sites of the Apulian lakes investigated are clustered in four groups each one corresponding to a single biotope. Alimini and Varano lakes lie within the third and fourth quadrants; on the opposite Acquatina sampling sites are placed, while the station points of Lesina are in intermediate position (Fig. 2). These results rejected any hypothesis of relative homogeneity of the polychaete species composition, even among neighbouring ecosystems, such as those object of the study. Parallel differences in taxonomic composition were highlighted by the analysis of the total benthic community of the lakes (Cardone *et al*., 2014). The Apulian biotopes investigated have the same polyhalinity range and also in this case the variations can be mainly explained under the trophic status pattern of the biotopes.

Various processes were discussed as possible causes of shaping faunal assemblages in brackish water lakes, such as, geomorphological, hydrological, physico-chemical features of the basins and dispersal, recruitment, and life history traits of the species.

Resilience and Recovery

Various investigations in coastal lagoons showed that benthic communities undergo both predictable short trend changes, such as seasonal fluctuations, and more or less stable long trend changes, such as variations encountered after a disturbance. Polychaetes have proved to be good descriptors of such modifications, principally these brought about by organic enrichment, oxygen deficiency, and hydrodinamism (Giangrande and Gambi, 1985; Giangrande *et al*., 2005). Including species with long life cycles and active throughout the year (perennial species) and species shortly living and active only during favourable period (opportunistic and seasonal species), polychaetes are showed to be an ideal taxon also for studies about regression and recovery patterns in benthic assemblages after environmental disturbance episodes. One of the first example to which we refer is the study of Giangrande and Gambi (1985) on Sabaudia lake, a polyhaline biotope located along the Tyrrhenian sea (Fig 3), object of investigation during a period of seven years, from 1977 to 1984. In the 1977 a sharp trophic loading gradient was produced by the different levels of accumulation of decaying organic material in the three areas of the lake, from site A to site C. Such

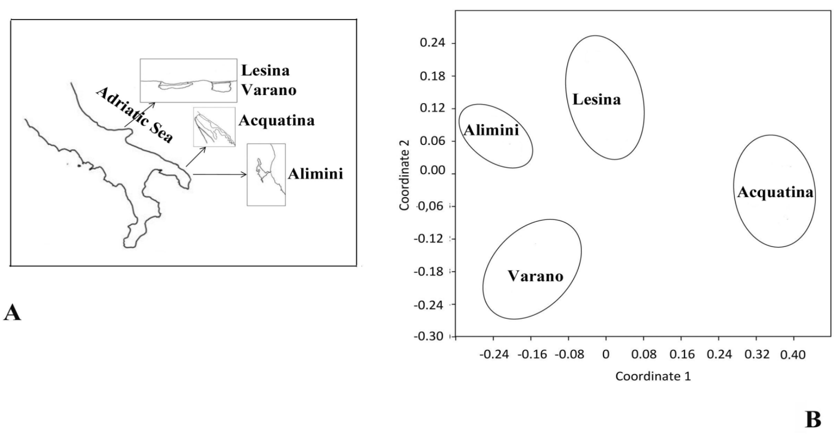

Figure 2 - Apulian brackish water lake polychaete assemblage. A) map of the study sites; B) Ordination model by non-metric Multidimensional Scaling

trophic enrichment was caused by the sewage discharge from the Sabaudia town. At this date twenty species were found all over the lake, but with major biotic differences between distinct zones of the Sabaudia lake: site A was very poor in species (only 6). The increasing anthropogenic pressure related to the excessive sewage discharge loading high input of nutrient and organic matter caused a severe dystrophic event in 1978. This has led to the environmental degradation of the lake and losses of its biological resources, including a marked impoverishment of fish and macrofaunal community, most of the macrobenthic organisms briefly disappeared. In 1980 the domestic wastewaters of Sabaudia town were stopped: more favourable conditions for macrobenthos were achieved and the recovery of polychaete assemblage occurred. This was observed very early in 1981 when the general improvement of the environmental conditions of the lake cancelled the trophic loading gradient previously showed and revealed a closer similarity among the three sites. for the following three years 1983-84 (Fig 3).

Within single biotopes: spatial and temporal descriptors

Temporal changes over a quite long trend period data, from 1983 to 2011, are available for polychaete assemblage of the Fogliano lake, along the Tyrrhenian coast (Latium) (Gravina, 1986 and unpubished data) (Fig. 4). The analysis of the polychaete data set from samples collected in 1983 produced the dendrogam showed in Fig. 4b. Three major clusters resulted, corresponding to three main zones within the lake: the first cluster consisting of the station C at the inlet of the lake was separate from the remaining sites. The second one included all the replicates of the more confined inner stations A and B. A third cluster included the site D located in the area affected by organic enrichment. The comparison between the two different periods showed a complete separation of the

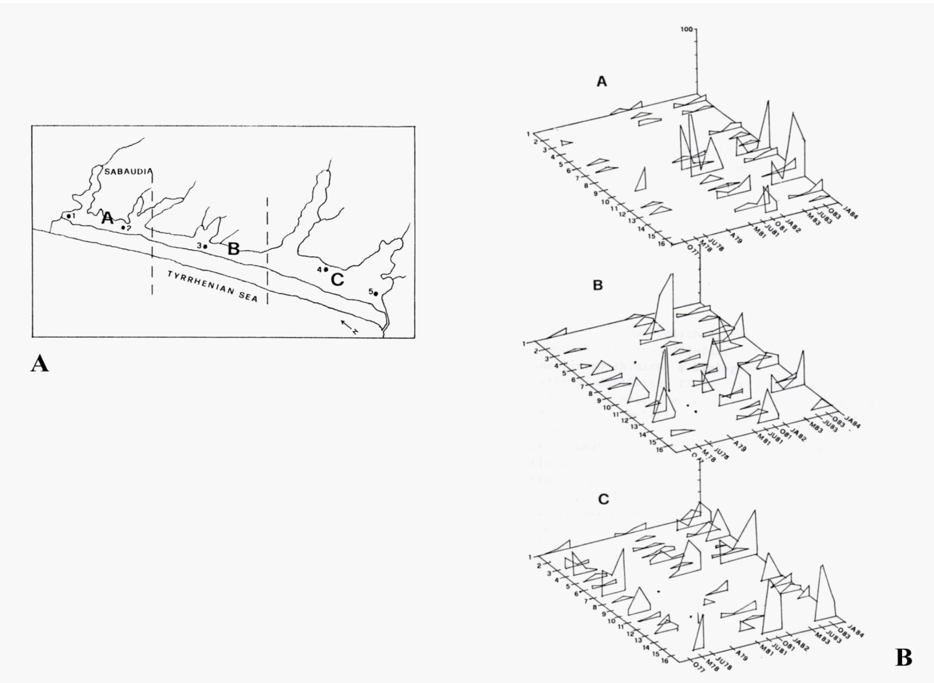

Figure 3 - Sabaudia lake poychaete assemblage. A) map of the Sabaudia lake with the sampling stations; B) Temporal trend of the species abundance computed at the three sampled sites from 1977 to 1984

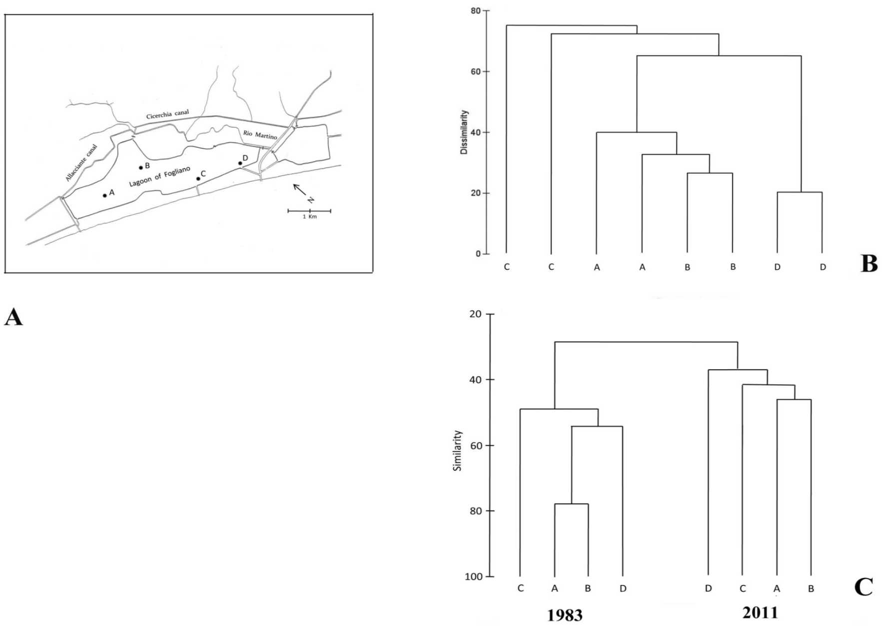

Figure 4 - Fogliano lake poychaete assemblage. A) map of the sampling sites; B) dendrogram of the sampling stations from the study carried out in 1983, where the repetition of letters are referred to two sampling times;C) dendrogram of the sampling stations from the investigations of 1983 and 2011.

two years (Fig 4c), attributable to different faunistic asseblages. In 1983 16 species were found, among them the typically occurring in brackish-waters environments *Nereiphylla rubiginosa*, *Ophiodromus pallidus*, *Hydroides elegans* and *Neanthes caudata* were the dominant species in the inner and confined area of the lake; *Perinereis cultrifera*, *Armandia cirrosa* and *Nainereis laevigata*, commonly reported in sheltered coastal areas, identified the central zone in front of the inlet of the lake, characterized by polyhaline waters; *Capitella capitata*, *Syllis gracilis*, *Malacoceros fuliginosus*, which are known to tolerate heavy organic pollution, were principally localized in the southern sector of the lake affected by an higher trophic loading. In the year 2011 the number of species increased (20) and *Heteromastus filiformis* and *Nainereis laevigata* were dominant.

Changes in species composition are related to changes in biotope management. Before 1985 the lake was managed as fishery basin, after 1985 it was included in the protected area within the National Park of Circeo. We hypothesize that the change of management influenced the properties of the sediment inhabited by the polychaetes where they build their tubes and burrows. Before protection measures, the sediment was continuously disturbed by human activities, limiting colonization and polychaetes distribution. Therefore the change in polychaete assemblage can be a good indication of the effect of the protection measures.

Another example of temporal trend comes from the Acquatina lake, located along the Adriatic coast (Schirosi *et al.*, 2010) (Fig. 5). In this case the temporal trend cover the period from 1992 to 2006. In the 1992 a sharp salinity gradient occurred from north to south, influencing the composition and structure of polychaete assemblage along the basin.

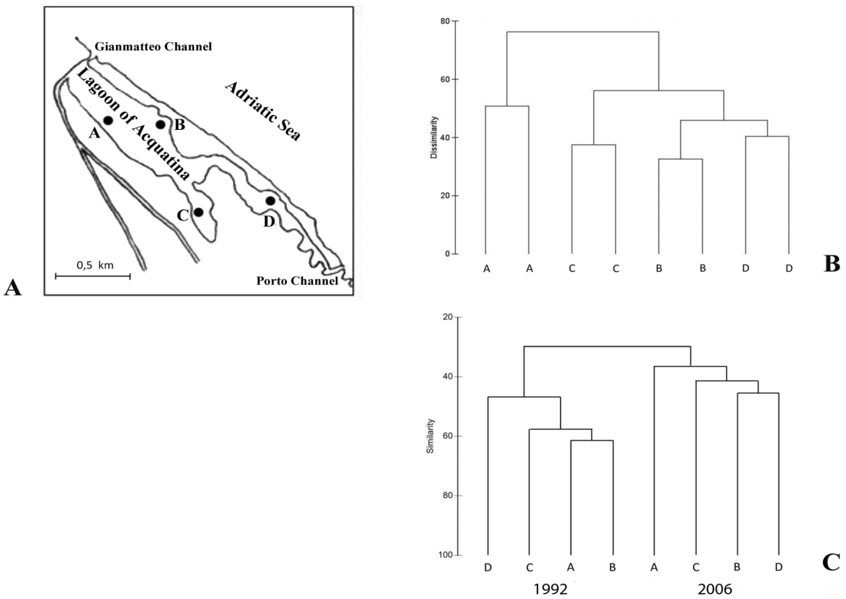

Figure 5 - Acquatina lake poychaete assemblage. A) map of the sampling sites; B) dendrogram of the sampling stations from the study carried out in 1992, where the repetition of letters are referred to two sampling times; C) dendrogram of the sampling stations from the investigations of 1992 and 2006.

Three zones could be identified with site A the more influence by the freshwater input; the site C being the more confined, and sites B and D more influenced by the sea (Fig. 5a). Also in this case, the comparison between the two periods evidenced a completely different situation. The cluster analysis showed a clear separation between the recent and the past situation (Fig. 5c). The four sites sampled during 1992 and during 2006 were respectively grouped together forming two faunistic homogeneous groups.

The species richness increased from 1992 to 2006 from 13 to 19 species. Moreover, the faunistic composition resulted distinctly diversified: some species collected in 1992, such as *Capitella capitata*, *Hediste diversicolor*, *Nereiphylla rubiginosa* and *Syllis gracilis* have not been recorded in 2006. On the contrary, 10 species not present in 1992, were recorded in 2006: among them, as occurred in the previous example of Fogliano lake, *H. filiformis*, became very abundant and was the dominant benthic taxon.

As in the previous example, the main environmental changes occurred in the lake during the 15 years separating the two studies are connected to human activities. The opening of a previously silted large southern channel produced an increase and stabilization of salinity, influencing the general ecological status of the basin. Consequently, the polychaete assemblage showed a different faunistic composition, with the disappearance of the "classic" opportunist *C. capitata*. Moreover, *N. laevigata*, a typical mesohaline species peaked in 1992 (Giangrande and Fraschetti, 1995), became rare in 2006, whilst *H. filiformis*, very rare in the past, became the dominant species in 2006.

Among the possible reasons causing the observed species replacement, the salinity increase can be taken into consideration being *H. filiformis* a typical marine species, even if it can tolerate wide ecological spectrum conditions (Gravina and Somaschini, 1990), including wide variations of salinity (Muus, 1967; Wolff, 1973).

Results from the study of Acquatina lake are in agreement with the results of Nicoletti *et al*. (2006), which examined a long-term trend of benthic communities in three central Italy Tyrrhenian coastal lakes, including Fogliano lake. These authors found an increase of biodiversity linked to improvement of trophic conditions and a notable increase in *H. filiformis* abundance.

We observed parallel long-term variations in species replacement in Acquatina lake, although the central Italy Tyrrhenian lakes and Acquatina lake along the Adriatic costs belong to different bioclimatic areas (Bianchi, 1988).

Conclusions

Polychaetes appeared to be good descriptors in characterizing general community pattern for brackish-water biotopes, as well as spatial environmental gradients and temporal variations are concerned. Moreover, the response of polychaete assemblage was proved to be useful for analyzing recovery after severe episodic events and for assessing different directional community dynamics over the time. Polychaete assemblage of the examined Mediterranean coastal brackish-water biotopes appears formed by a low number of species easily to identify and, although the examined biotopes belong to different bioclimatic areas, their species compositions appear to be very similar.

Based on our result and review and on available literature data, we propose a general model for polychaetes distribution in Mediterranean brackish-water bodies summarized in Fig. 6. The model describes the biological succession along both the gradient of water exchange with the sea, measured by salinity, and the gradient of trophic load, measured by organic matter content. Different indicator species identifies different ecological zones

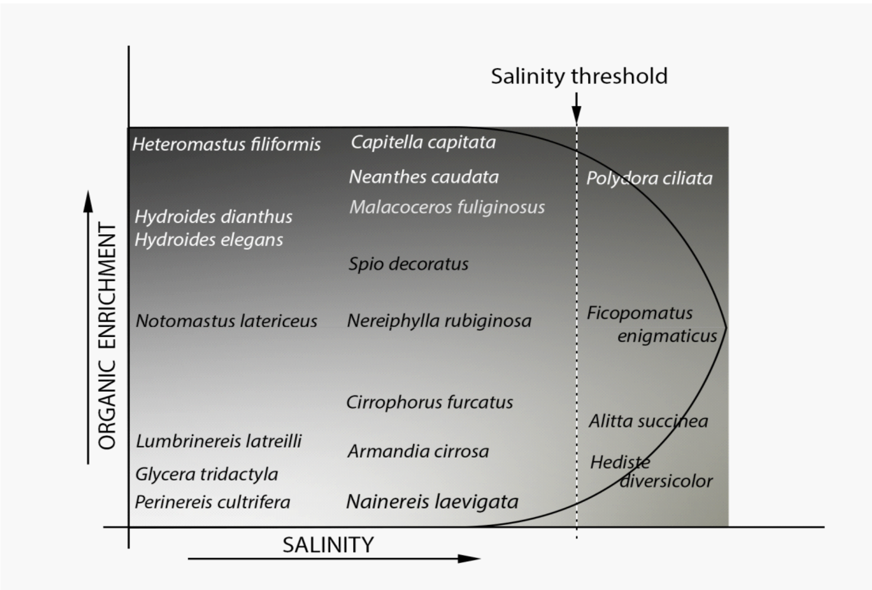

Fig 6 - Scheme of the distribution of dominant polychaete species in some Tyrrhenian and Adriatic transitional waters along two main selective agents: salinity and organic enrichment. The ogive arc on the right highlights the reduction in number of species further the salinity threshold. The species at the top (Heteromastus filiformis, Capitella capitata and Neanthes caudata, Polydora ciliata) are the most tolerant to the organic load within the polyhaline, mesohaline and oligohaline thresholds respectively.

along these gradients: a) a pool of species describing the oligohaline zone, composed by a low number of taxa principally selected against low level of salinity, they are *Hediste diversicolor*, *Alitta succinea*, *Ficopomatus enigmaticus*, and *Polydora ciliata*; b) a group characteristic of mesohaline condition, which includes a larger number of species such as *Nainereis laevigata*, *Armandia cirrosa*, *Cirroforus furcatus*, *Nereiphylla rubiginosa*, *Spio decoratus*, *Malacoceros fuliginosus*, *Neanthes caudata*, and *Capitella capitata*, frequently inhabiting brackish-waters as well as other sheltered marine coastal areas; c) a group of species identifying the polyhaline zone, which contains the highest number of taxa including strictly marine species: *Perinereis cultrifera*, *Glycera tridactyla*, *Lumbrinereis latreilli*, *Notomastus latericeus*, *Hydroides elegans*, *Hydroides dianthus*, *Heteromastus filiformis*. Within each group the species are also selected against trophic load, oligotrophic vs eutrophic pole and, according to their degree of tolerance to organic enrichment, they are listed from bottom to up in the model showed in Fig.6.

The increased number of species accounted in the zone under the marine influence areas depends on both abiotic and biotic determinants, the first essentially hydrodynamism and sea water exchange, the second mainly linked to larval recruitment and life history and adaptive strategy of each species. The effect and the role of such biotic and abiotic factors in driving species distribution in transitional water environments were recently analyzed and discussed for the macrobenthos of the brackish biotopes of the South-eastern Italy (Cardone *et al*., 2014). Below the oligohaline threshold, difference in salinity range turned out to be the main cause of the strong species richness reduction evidenced, within the salinity range over the mesohalinity threshold the sources of dissimilarity in composition and structure of benthos were mainly attributed to some aspects of the species life cycles and to different human activities.

Polychaete species can also be indicator of trophic state of the brackish biotopes. The example case of *Ficopomatus enigmaticus* is worth considering: it is able to built organogenous reefs made up extensive clumps of the calcareous tubes of the worms in the biotopes with low salinity range, resulting in very high abundance values. It is a filter feeder species and its massive abundance is linked to the trophic loading of the waters, in fact *F. enigmaticus* is dominant in the areas with low salinity levels and high organic matter content, but is absent, or occurs with only few individuals, in not organically enriched areas. In this study, the polychaete assemblages of the Sabaudia lake and the Acquatina lake, showed a similar species composition except for *F. enigmaticus*, which was very abundant in Sabaudia but absent in Acquatina. This result is mainly due to the differences in organic matter availability in the two lakes, particularly in the low level of phosphorus availability, which resulted the limiting factor in the Acquatina lake (Vadrucci *et al*., 1995), in contrast to the eutrophic range measured in Sabaudia (Giangrande and Gambi, 1985). The spatial distribution pattern of *F. enigmaticus* in the lake of Lesina confirms such hypothesis: here the species colonizes mainly the central area of the lake, building massive reefs in the zone far from the sea mouth and organically enriched, while it showed much more lower biomass and abundance values in the zone directly connected to the sea, where the degree of sea water exchanges lead to salinity increasing and organic matter concentration decreasing (Nonnis Marzano *et al*., 2003; 2007).

Another noteworthy study case is the peculiar temporal pattern of distribution in *Heteromastus. filiformis* observed in the transitional brackish-water investigated. The ecology of this species is well known: it is considered opportunistic and very common in polluted areas (Holte, 1998). As already pointed out this species is a marine species tolerating large salinity range and able to colonize brackish-water biotopes, acting as an opportunistic form. This species has been found particularly abundant in meso-euhaline brackish coastal habitats (Watling, 1975; Read, 1984; Gouvis *et al.*, 1998; Ysebaert *et al.*, 2005; Maggiore and Keppel, 2007; Lourido *et al.*, 2008). However, Can *et al.* (2009) stated that high levels of salinity, and low oxygen concentration can negatively influence its reproductive activity and survival in Mediterranean eu- to hyperhaline coastal lagoon. In particular, from the results of the present data analysis, recurrent successional changes for *H. filiformis* can be highlighted. This species seems to occur during final stages of the succession in transitional waters, through replacement of the other capitellid species *Capitella capitata*. This was observed during the temporal trend in both Fogliano and Acquatina lakes, and is in agreement with Pearson and Rosenberg (1978), who considered *H. filiformis* a pioneer species occurring at the second stage of the ecological succession, after the first stage dominated by *Capitella* spp. Moreover, the same replacement pattern was enhanced from the long-term temporal studies of Nicoletti *et al.* (2006) and Martinelli *et al.* (1997) carried out in other Italian brackish-water biotopes. Therefore the presence of *H. filiformis* can be considered as indicative of a sort of "mature" stage of the benthic community succession in the brackish-water environments.

In conclusion, this study identified a series of spatial and temporal variations in polychaete assemblages of various brackish biotopes subjected to different degree of salinity and organic enrichment. Species composition of such assemblages showed recurrent patterns, which resulted consistent with the ecological characteristics of the species and the abiotic intra- and inter-ecosystem heterogeneity. We singled out the dominant species at different zones along the salinity and organic enrichment gradients, which can be considered indicator species and thus as good candidate to set up the biotic indices measuring the ecological quality status in transitional waters.

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