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Benthic assemblage of Acquatina Lake (South Adriatic Sea): present state and long-term faunistic changes

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SUMMARY: A study on macrobenthos of Acquatina Lake, a transitional water basin, was performed in order to evaluate its present status and detect any faunistic changes after the digging of a larger connection with the open sea that has improved the hydrological conditions. A total of 5029 individuals belonging to 51 taxa were collected. Molluscs were taxonomically the richest group, but polychaetes were the most abundant due to the high abundance of *Heteromastus filiformis*. The sites representing two extremes of the biotope in terms of both the salinity gradient and the distance from the sea had the most variable assemblages, while the central area showed a more homogeneous faunal composition. This was due to the different distribution patterns of molluscs and polychaetes: the former seemed to be more influenced by salinity, while the latter were also influenced by oxygen saturation. The comparison between the present and historical data showed the increase of polychaete diversity, the change in the dominant taxa (from *Naineris laevigata* to *H. filiformis*) and the disappearance of some opportunistic forms (e.g. *Capitella capitata*). Changes in the salinity gradient and the improvement of trophic conditions, possibly enhanced by biotic interactions (e.g. possible competition between the two capitellids *H. filiformis* and *Notomastus latericeus*), may have led the polychaete assemblage towards the new equilibrium.

Keywords: DISTLM-forward, Polychaeta, Mollusca, brackish-water, soft bottom, Mediterranean Sea, human management.

RESUMEN: AGRUPACIÓN BENTÓNICA DEL LAGO ACQUATINA (ADRIÁTICO SUR): ESTADO ACTUAL Y ALARGO PLAZO DE LOS CAMBIOS FAUNÍSTICOS. – Un estudio del macrobentos del lago Acquatina, una cuenca de agua de transición, fue realizado para evaluar su estatus actual y detectar posibles cambios faunísticos después de una intervención humana reciente. Un total de 5029 individuos pertenecientes a 51 taxa fueron recolectados. Los moluscos fueron el grupo más rico, pero los poliquetos fueron el grupo numéricamente dominante debido a la abundancia de *Heteromastus filiformis*. Las zonas que representan los dos biotopos más extremos, en términos de salinidad y confinamiento, fueron las más variables en comparación con las áreas centrales más homogéneas. Este patrón se debe a la diferente distribución entre moluscos y poliquetos: los primeros parecían estar más influenciados por la salinidad, mientras que los segundos están influenciados, además, por los niveles de saturación de oxígeno. La comparación entre la composición actual de poliquetos y los datos históricos muestran un incremento de la diversidad, el cambio de las especies dominantes (de *Naineris laevigata* a *H. filiformis*), y la desaparición de algunas formas oportunistas (por ejemplo *Capitella capitata*). Cambios en el gradiente de salinidad y la mejora de las condiciones tróficas podrían dirigir la agrupación de poliquetos hacia un nuevo equilibrio, sin embargo algunas interacciones bióticas (por ejemplo la posible competición entre los capitélidos *H. filiformis* y *Notomastus latericeus*) también podrían contribuir a explicar el patrón observado.

Palabras clave: DISTLM-forward, Polychaeta, Mollusca, aguas salobres, fondo blando, mar Mediterráneo, gestión humana.

INTRODUCTION

At temperate latitudes, brackish-water benthic assemblages often undergo drastic fluctuations in both species abundance and richness due to phys-

ical-chemical variability (Arvanitidis *et al.*, 1999), which can be cyclic (predictable, e.g. seasonal) or episodic (unpredictable) (Boero, 1996; Giangrande and Fraschetti, 1996). Species colonising these environments are highly adapted to extreme conditions,

and assemblages are characterised by high resilience (Giangrande and Gambi, 1985), so they can recover even after severe episodic events (Carrada and Fresi, 1988; Koutsoubas *et al.*, 2000; Lardicci *et al.*, 2001; Gascón *et al.*, 2007). When environmental changes become permanent the assemblages can be driven towards a different structure (Nicoletti *et al.*, 2006). However, the difficulty in obtaining long-term data limits studies of this type of change (Gray and Christie, 1983; Salen-Picard and Arlhac, 2002). In this context, brackish-water environments might be ideal models for assessing directional changes in the assemblages' structure. In fact, modifications requiring decades in more stable marine communities can happen in only a few years in transitional water environments (Nicoletti *et al.*, 2006).

The present paper describes the soft-bottom benthic assemblages of the Acquatina Lake, a typical xero-Mediterranean biotope (Bianchi and Zurlini, 1984) located in the Salento peninsula along the Southern Adriatic coast. Since 1985 the lake has been managed by Salento University and is the focus of several scientific studies. From 1996 to 2000 the central area of the lake hosted a small experimental aquaculture farm and other similar activities are planned for the future. The rate at which nutrients are renewed in the water column has suggested meso-oligotrophic conditions for the system (Vadrucci *et al.*, 1996). Previous biological screenings revealed that the basin was characterised by low phytoplankton productivity (Giacobbe *et al.*, 1996) and the zooplankton was dominated by calanoid copepods of the family Acartiidae (Belmonte and Bianchi, 1992). An extensive survey of the whole benthic assemblage has never been carried out, and knowledge of groups other than polychaetes is fragmentary. In fact, the Acquatina soft-bottom polychaete assemblages were screened monthly from 1989 to 1992 (Giangrande and Fraschetti, 1996). In that period the lake was suffering from weak connections with the open sea, and a heavy salinity gradient extended from the inner to the least confined part. The main freshwater input was a stream inflow in the northernmost part of the lake, and the amount of incoming water followed the rainfall seasonality. Up to 2003 an additional connection with the open sea was possible through the tight, twisting channel in the southernmost area of the lake. Due to the lack of human management, both connections with the stream and the open sea periodically underwent siltation and during the summer of 1990 the lake underwent a drastic hyperhaline crisis (Giangrande and Fraschetti, 1996).

Since the last screening of the polychaete assemblages in 1992, the general environmental conditions of the lake have changed following the human interventions. In particular, since 2003 the hydrological regime has changed due to the increased water exchange with the open sea after the digging of a new, larger southern channel.

The aim of this work is to increase the knowledge on macrobenthos distribution in the basin, correlating it with the present hydrological conditions, and to screen possible changes and long-term trends in polychaete fauna after human interventions using the available historical data. Our results could make a valuable contribution to understanding how stabilisation processes can influence soft-bottom communities in similar environments.

MATERIALS AND METHODS

Study area

The Acquatina Lake, located close to Lecce (southern Adriatic Sea) ($40^{\circ}27'22''\text{N}$ - $18^{\circ}12'24''\text{E}$), is an artificial brackish-water basin created in the 1930s covering an area of 0.45 km^2 and about 2 km

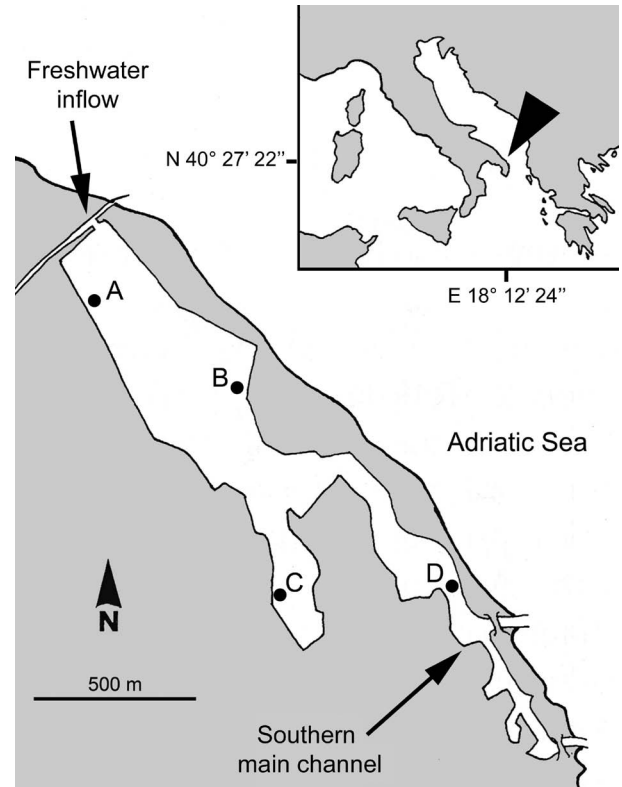


FIG. 1. – Map of the study area (modified from Giangrande and Fraschetti, 1996).

long, with a mean depth of 1.2 m. Shallow calcareous rocks mainly characterise the west coast of the lake, while the eastern border is a sandy belt separating the lagoon from the sea. Since 2003 the lake has been permanently connected to the sea by the new southern main channel (15 m wide and 400 m long), while the old secondary channel is in the southernmost branch of the lake. Tidal variation of the sea level does not usually exceed 35 cm. The principal freshwater inputs are rainfalls and the lateral ramification of the Giammatteo Canal in the northernmost area, so a positive salinity gradient extends from the northern to the southern area. Using a model, the estimate of the mean annual water residence time was evaluated to be 3 days (minimum in winter, 2 days; maximum in summer, 8 days). The estimate of the mean annual residual flux of the system, required to balance water input and output, indicates that the system exports water to the sea during the whole year ($42000 \text{ m}^3 \text{ d}^{-1}$), with minimum values in summer ($8700 \text{ m}^3 \text{ d}^{-1}$) and maximum ones in winter ($76700 \text{ m}^3 \text{ d}^{-1}$). A *Zostera* sp. meadow in association with the algae *Valonia* sp., *Ulva* sp. and *Chetomorpha* sp. characterises particularly the southern and central areas. Further information on the Acquatina system is available in Cappello *et al.* (2005).

Sampling methods

Sampling was carried out in 4 areas already analysed during a survey of the polychaete benthic assemblages in July 1989 (Giangrande and Frascetti, 1996). The experimental design included 4 sites (Fig. 1), 3 replicates for each site and two times (19 July 2006 and 10 January 2007) for a total of 24 samples. Site A is located close to the freshwater inner channel, Site B is in a coastal area located in the middle of the lake, Site C is located in the lateral branch and Site D is the closest to the main channel which connects the lake to the sea. At each site 3 sampling points 2 to 3 metres apart were randomly chosen. Salinity, oxygen saturation and temperature were measured in the water column (about 20 cm from the bottom) using a multiparametric probe (IP050D – IDROMAR). Samples were collected by a Van Veen grab (sampled surface 400 cm^2 , capacity about 2 L) and were sieved in situ through a 0.5 mm mesh. The sieved material was fixed in 4% formaldehyde solution. In the laboratory the sampled material was washed in fresh water and preserved in 70% ethanol. The macrofaunal organisms were sorted under

magnification, identified to the lowest possible taxonomic level and counted.

nMDS analysis

Non-metric multi-dimensional scaling (nMDS) analysis (PRIMER 6 “Plymouth Routines In Multivariate Ecological Research”; Plymouth Marine Laboratory, UK) was performed in order to obtain a graphic visualisation of similarities (Bray-Curtis) among assemblages of the analysed sites at the two sampled times. The contribution of the most abundant species to the similarity among the 24 replicates was analysed by superimposing species abundance on the MDS plots (2-D bubble option in PRIMER 6).

Multiple regression analysis

A non-parametric multiple regression analysis (McArdle and Anderson, 2001) was performed in order to detect possible correlations between community structure and abiotic variables (salinity, oxygen saturation and temperature) at the two sampling times using the DISTLM-forward procedure (*Distance-based multivariate analysis for a linear model using forward selection* - Anderson, M.J., University of Auckland, New Zealand). The multiple regression test was based on Bray-Curtis dissimilarities (untransformed data); *p* values were obtained by 4999 permutations of the original data.

RESULTS

Environmental variables

The mean salinity, temperature and oxygen saturation measured at each site in July and January are reported in Table 1. At both sampling times the highest value of salinity was at Site D and the lowest at Site A, while Sites C and B showed intermediate values. In July temperature increased from Site A to D. By contrast, in January Site A showed the highest temperature and Sites C and D the lowest ones. Site A showed similar oxygen saturation values in July and January; the highest temporal oxygen variations (between times) were observed at Sites B and C, and Site C showed the lowest sampled value (in January). In July both the highest temperature and the lowest and the most variable oxygen saturation co-occurred at Site D.

TABLE 1. – Mean (\pm S.E.) salinity (S), temperature (T) and oxygen saturation (O) measured at each sampling site.

	T (°C)	July 2006 S (psu)	O (% sat.)	T (°C)	January 2007 S (psu)	O (% sat.)
A	23.83 \pm 0.015	28.82 \pm 0.030	95.21 \pm 0.683	13.95 \pm 0.021	20.71 \pm 0.04	96.57 \pm 0.795
B	24.60 \pm 0.015	30.75 \pm 0.030	98.48 \pm 1.002	13.07 \pm 0.021	23.30 \pm 0.021	102.35 \pm 0.802
C	25.17 \pm 0.025	31.81 \pm 0.040	106.43 \pm 3.696	11.04 \pm 0.030	22.90 \pm 0.010	87.25 \pm 1.016
D	25.65 \pm 0.030	36.32 \pm 0.051	87.77 \pm 8.085	12.36 \pm 0.032	25.22 \pm 0.040	98.11 \pm 1.850

TABLE 2. – List of the collected taxa. The mean number of individuals per site (\pm S.D.) in the two sampling times is reported.

	January				July			
	A	B	C	D	A	B	C	D
Annelida Polychaeta								
<i>Armandia cirrhosa</i>	0.67 \pm 1.15	1.00 \pm 1.73						0.33 \pm 0.58
<i>Brania arminii</i>								2.33 \pm 4.04
<i>Cirriformia tentaculata</i>	1.00 \pm 1.00							0.33 \pm 0.58
<i>Cirrophorus furcatus</i>	2.00 \pm 1.73	23.00 \pm 19.92	4.33 \pm 3.79		46.67 \pm 40.08	35.67 \pm 25.66	59.67 \pm 14.01	9.67 \pm 16.74
<i>Dorvillea rubrovittata</i>								0.33 \pm 0.58
<i>Exogone meridionalis</i>								0.33 \pm 0.58
<i>E. naidina</i>								0.67 \pm 1.15
<i>Glycera</i> sp.								0.33 \pm 0.58
<i>Heteromastus filiformis</i>	107.67 \pm 94.59	20.00 \pm 16.00	38.00 \pm 23.30	0.33 \pm 0.58	276.33 \pm 75.12	82.67 \pm 22.74	167.00 \pm 77.66	
<i>Lumbrineris latreilli</i>	19.00 \pm 12.49	1.00 \pm 1.73	6.00 \pm 4.36	1.00 \pm 1.00	4.33 \pm 4.16	6.67 \pm 3.21	7.00 \pm 3.46	2.00 \pm 1.00
<i>Lumbrineris</i> sp.	1.00 \pm 1.73							2.67 \pm 3.06
<i>Naineris laevigata</i>	8.00 \pm 6.00				1.33 \pm 1.53	0.67 \pm 1.15	2.33 \pm 2.08	0.33 \pm 0.58
<i>Neanthes caudata</i>	9.67 \pm 2.52		8.00 \pm 10.44	20.33 \pm 19.73	4.67 \pm 4.51	2.67 \pm 1.53	68.00 \pm 28.51	3.33 \pm 1.53
<i>Notomastus latericeus</i>		1.33 \pm 2.31	4.00 \pm 4.36		0.33 \pm 0.58	20.33 \pm 15.01	6.33 \pm 0.58	17.33 \pm 29.16
<i>Petaloproctus terricolus</i>	1.00 \pm 1.73	1.00 \pm 1.00	3.33 \pm 3.06		2.67 \pm 2.52	11.33 \pm 9.45	1.00 \pm 1.00	
<i>Pionosyllis anophthalma</i>							0.33 \pm 0.58	
<i>Spio decoratus</i>		1.00 \pm 1.73				0.33 \pm 0.58		2.67 \pm 4.62
<i>Syllides japonicus</i>						0.33 \pm 0.58		0.33 \pm 0.58
<i>Terebella lapidaria</i>					0.33 \pm 0.58			
Annelida Oligochaeta	1.67 \pm 2.08	0.33 \pm 0.58						4.33 \pm 5.13
Crustacea Decapoda								
<i>Carcinus aestuarii</i>			0.33 \pm 0.58					
Crustacea Amphipoda								
<i>Corophium cf. acherusicum</i>	11.00 \pm 2.65				1.33 \pm 2.31	2.67 \pm 2.31	5.00 \pm 4.58	6.00 \pm 4.58
<i>Gammarus aequicauda</i>	1.33 \pm 2.31				0.33 \pm 0.58	1.33 \pm 0.58	0.67 \pm 1.15	2.00 \pm 1.00
Phoronida		3.33 \pm 2.52						
Mollusca Polyplacophora								
<i>Chiton olivaceus</i>		0.33 \pm 0.58	0.67 \pm 1.15					
Mollusca Gastropoda								
<i>Bittium reticulatum</i>	1.33 \pm 1.53	1.67 \pm 0.58	2.33 \pm 1.53	3.33 \pm 2.08	3.00 \pm 1.73	1.00 \pm 1.00	0.67 \pm 0.58	1.00 \pm 1.00
<i>Cerithium vulgatum</i>	2.33 \pm 1.53	9.33 \pm 3.06	9.67 \pm 5.51	16.67 \pm 3.79	11.00 \pm 2.65	2.00 \pm 2.00	2.33 \pm 1.53	1.00 \pm 1.00
<i>Clanculus cruciatus</i>		1.67 \pm 0.58	1.00 \pm 1.00	0.33 \pm 0.58		1.33 \pm 1.53	2.33 \pm 1.15	0.33 \pm 0.58
<i>C. jussieui</i>		0.33 \pm 0.58	1.00 \pm 1.00	0.67 \pm 0.58	1.00 \pm 1.00	1.00 \pm 0.00	1.00 \pm 1.73	
<i>Cyclope donovani</i>	2.33 \pm 1.53	1.67 \pm 0.58			5.33 \pm 2.08	3.67 \pm 1.53	2.33 \pm 1.53	2.33 \pm 1.53
<i>C. neritea</i>	3.00 \pm 2.65	2.00 \pm 1.73			0.33 \pm 0.58	1.00 \pm 1.00	2.67 \pm 1.15	1.33 \pm 0.58
<i>Ecrobia ventrosa</i>	1.33 \pm 0.58							
<i>Gibbula albida</i>	18.33 \pm 4.93	13.67 \pm 4.73	14.33 \pm 7.37		2.33 \pm 1.53	2.00 \pm 2.65	3.67 \pm 2.31	1.67 \pm 2.08
<i>Homalopoma sanguineum</i>	0.33 \pm 0.58							
<i>Murex</i> sp.					3.67 \pm 1.53			
<i>Myosotella myosotis</i>	0.67 \pm 1.15							
<i>Nassarius nitidus</i>		0.33 \pm 0.58						
<i>Nassarius</i> sp.	3.67 \pm 1.53	0.33 \pm 0.58			2.00 \pm 1.00	0.33 \pm 0.58	1.00 \pm 1.00	1.00 \pm 1.00
<i>Rissoa variabilis</i>	1.33 \pm 1.15				1.33 \pm 0.58	2.00 \pm 1.00	1.67 \pm 0.58	
<i>R. ventricosa</i>	1.67 \pm 1.15				0.67 \pm 0.58	1.00 \pm 1.00	1.00 \pm 1.00	
<i>Truncatella subcylindrica</i>	2.33 \pm 1.53	0.33 \pm 0.58						
Mollusca Bivalvia								
<i>Abra alba</i>	3.67 \pm 2.89	15.00 \pm 4.00	13.33 \pm 9.71	23.00 \pm 6.08	10.67 \pm 4.04	8.33 \pm 6.66	10.67 \pm 6.11	23.00 \pm 13.53
<i>Acanthocardia tuberculata</i>	0.33 \pm 0.58	3.67 \pm 2.52	2.33 \pm 2.08	2.67 \pm 2.08	2.00 \pm 1.73	0.67 \pm 1.15	2.33 \pm 1.53	2.33 \pm 1.53
<i>Cerastoderma edule</i>			2.33 \pm 1.53	3.33 \pm 1.15	1.33 \pm 1.53	0.33 \pm 0.58		
<i>Chamelea gallina</i>	0.33 \pm 0.58	1.00 \pm 1.00		5.00 \pm 2.00	5.00 \pm 2.00	1.33 \pm 0.58		1.33 \pm 0.58
<i>Loripes lacteus</i>	6.33 \pm 3.79	16.33 \pm 6.51	14.00 \pm 4.58	29.67 \pm 7.09	21.00 \pm 11.53	10.67 \pm 3.21	23.00 \pm 11.00	16.67 \pm 6.43
<i>Mytilus galloprovincialis</i>		0.33 \pm 0.58	1.67 \pm 1.53	0.33 \pm 0.58	2.33 \pm 1.53	1.33 \pm 1.15		
<i>Ruditapes decussatus</i>		0.33 \pm 0.58	0.33 \pm 0.58					
<i>Tellina nitida</i>		3.67 \pm 1.53	2.00 \pm 2.00	2.00 \pm 1.73	2.67 \pm 1.15	1.33 \pm 0.58	2.00 \pm 1.73	
<i>Venerupis corrugata</i>	0.33 \pm 0.58							1.33 \pm 0.58

Faunistic analysis

A total of 5029 individuals belonging to 50 taxa were collected (Table 2); 41 taxa and 3302 individuals in July, and 43 taxa and 1727 individuals in January. Molluscs were the richest group (26 taxa), followed by polychaetes (19 taxa). By contrast, polychaetes were the most abundant at both sampling times (3408 individuals) followed by molluscs (1496 individuals), and in July they represented 77% of the collected benthic macro-organisms. Crustaceans (almost exclusively amphipods) accounted for only 2% of the individuals (mainly represented by *Corophium cf. acherusicum*), while oligochaetes and phoronids were scarce.

Considering the whole benthic assemblage, the number of individuals was higher in July, especially at Sites A and C, and generally lower at Site D (Fig. 2a). This pattern was mainly due to the polychaete abundance (Fig. 2b). Molluscs showed an irregular trend at both times (Fig. 2c) and the mean number of individuals was higher in January than in July at Sites B, C and D. The mean number of taxa decreased from Site D to A in January (Fig. 2d) and

remained similar among the sites in July, although it showed higher variability in D. The high variability observed at Site D in July was clearly due to the patchy distribution of the polychaete taxa (Fig. 2e), while the mollusc richness pattern was more similar to the general trend (Fig. 2f).

Among the most abundant species, the polychaetes *Heteromastus filiformis*, *Cirrophorus furcatus* and *Notomastus latericeus* were more abundant in July, driving the general macrofaunal trend of abundance. By contrast, among molluscs *Gibbula albida* was more abundant in January, while *Cerithium vulgatum*, *Abra alba* and *Loripes lacteus* were constantly abundant at both sampling times. Some polychaetes, represented by few individuals, were collected only in July. This is the case of *Dorvillea rubrovittata*, *Terebella lapidaria*, and the syllids *Exogone naidina*, *E. meridionalis*, *Brania arminii*, *Syllides japonicus* and *Pionosyllis anophthalma* (Table 2).

Heteromastus filiformis was particularly abundant at Site A, but absent at Site D, where *N. latericeus* reached the highest abundance. The inverse trend of abundance between the two polychaete species in

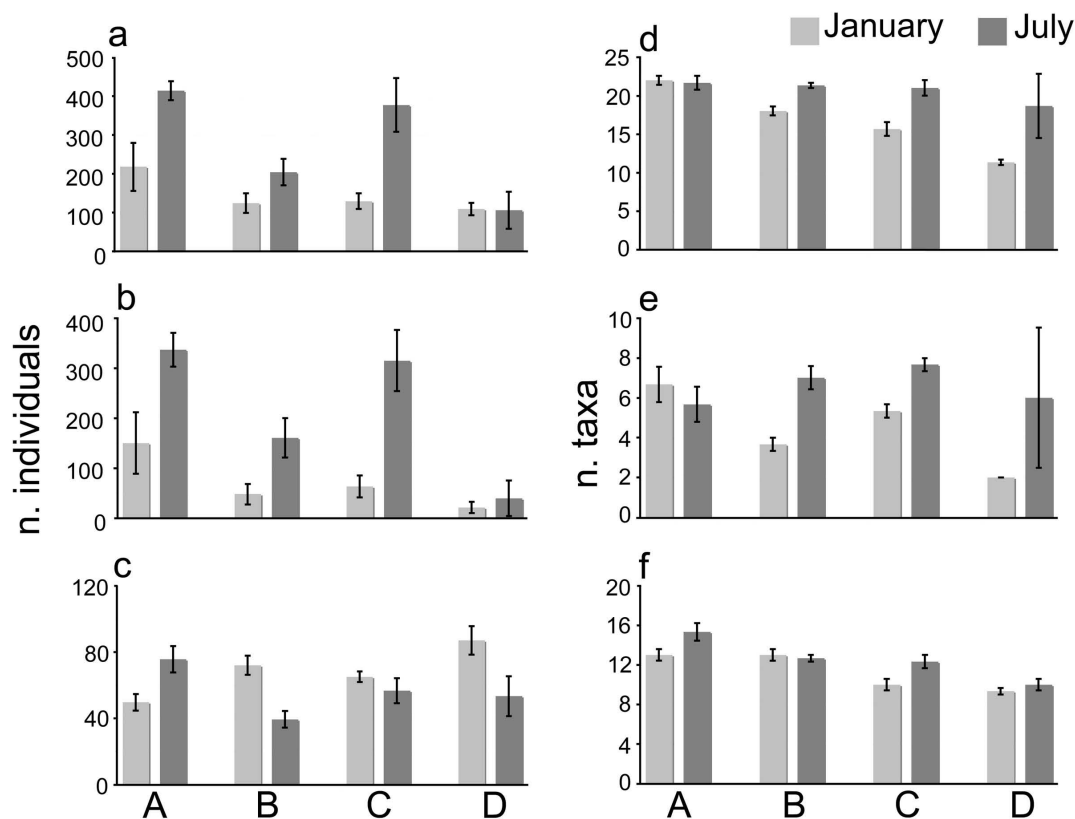


FIG. 2. – Abundance (as mean number of individuals per site \pm S.E.) of the whole assemblage (a), the polychaetes (b) and the molluscs (c), and taxonomic richness (as mean number of taxa per site \pm S.E.) of the whole assemblage (d), the polychaetes (e) and the molluscs (f).

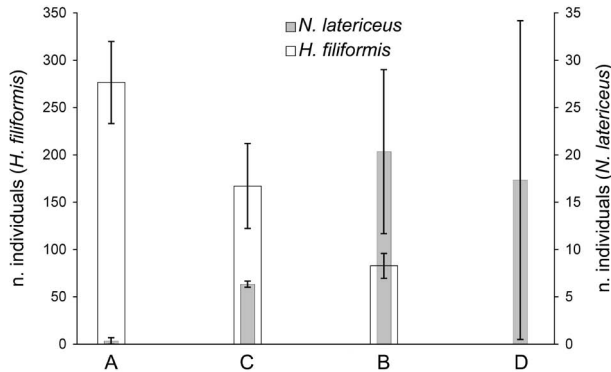


FIG. 3. – Mean number of individuals per site (\pm S.E.) of *Notomastus latericeus* and *Heteromastus filiformis* in July.

July is visible in Figure 3, showing that when one species is abundant the other one is weakly represented or even absent.

Multivariate pattern

In Figure 4 the abundances of the dominant polychaetes *H. filiformis* (Fig. 4a), *C. furcatus* (Fig. 4b), *N. caudata* (Fig. 4c), *N. latericeus* (Fig. 4d) and *L. latreilli* (Fig. 4e) are superimposed on the MDS plot of similarity (2-D bubble plots), representing differences among polychaete assemblages of the analysed replicates. Independently from the sampling time, the model shows the separation of the symbols representing the replicates of Sites A and D, while the symbols relative to the central area (Sites B and C) are located in an intermediate position, though closer to the replicates of A. Apart from the peculiar patchy distribution of *N. latericeus*, the polychaete species mentioned above were scarcely represented or absent at Site

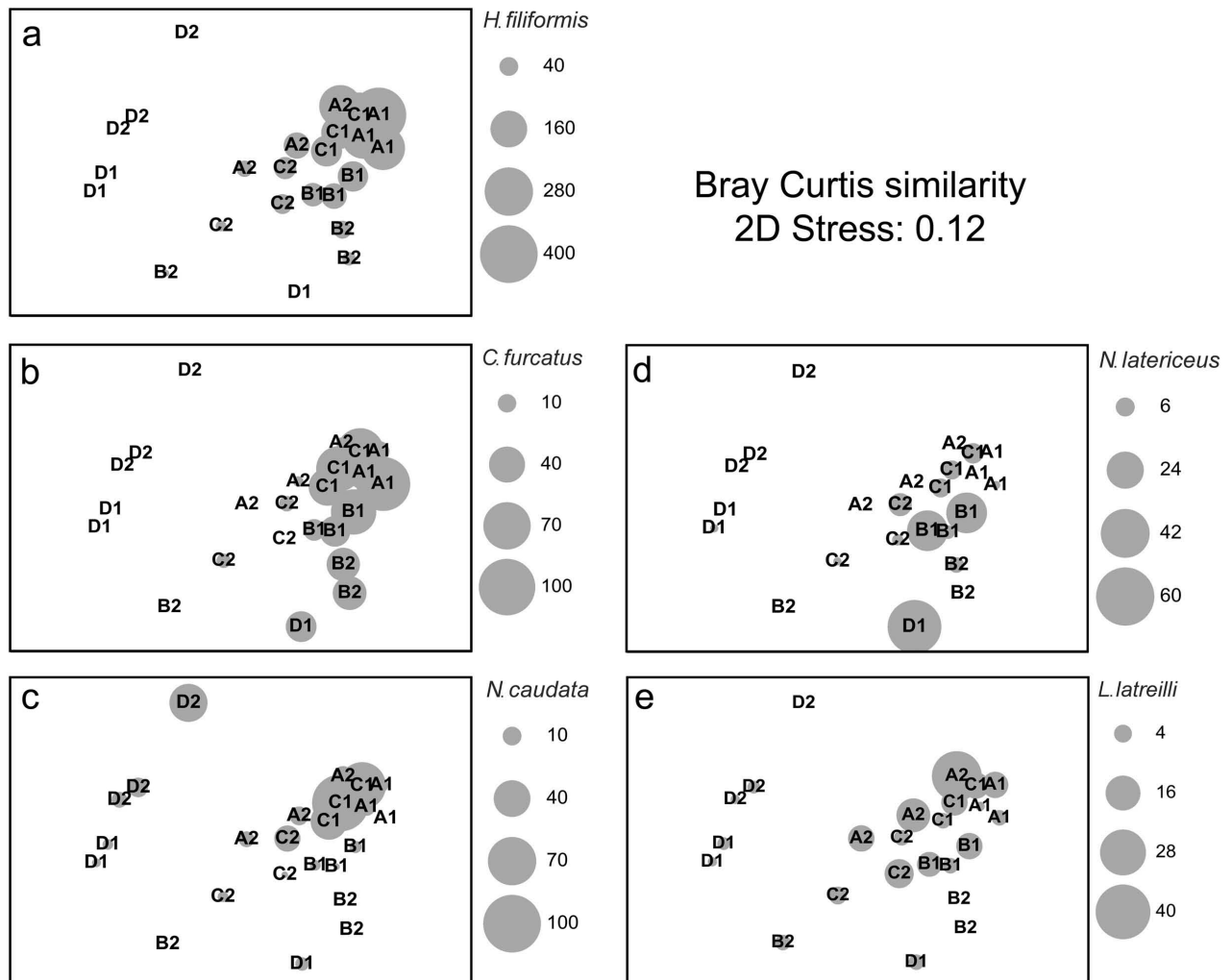


FIG. 4. – nMDS of the polychaete assemblages in July (A1, B1, C1, D1) and January (A2, B2, C2, D2). The abundances of *Heteromastus filiformis* (a), *Cirrophorus furcatus* (b), *Neanthes caudata* (c), *Notomastus latericeus* (d) and *Lumbrineris latreilli* (e) are superimposed on the ordination plots. The diameter of bubbles is proportional to the number of individuals per replicate.

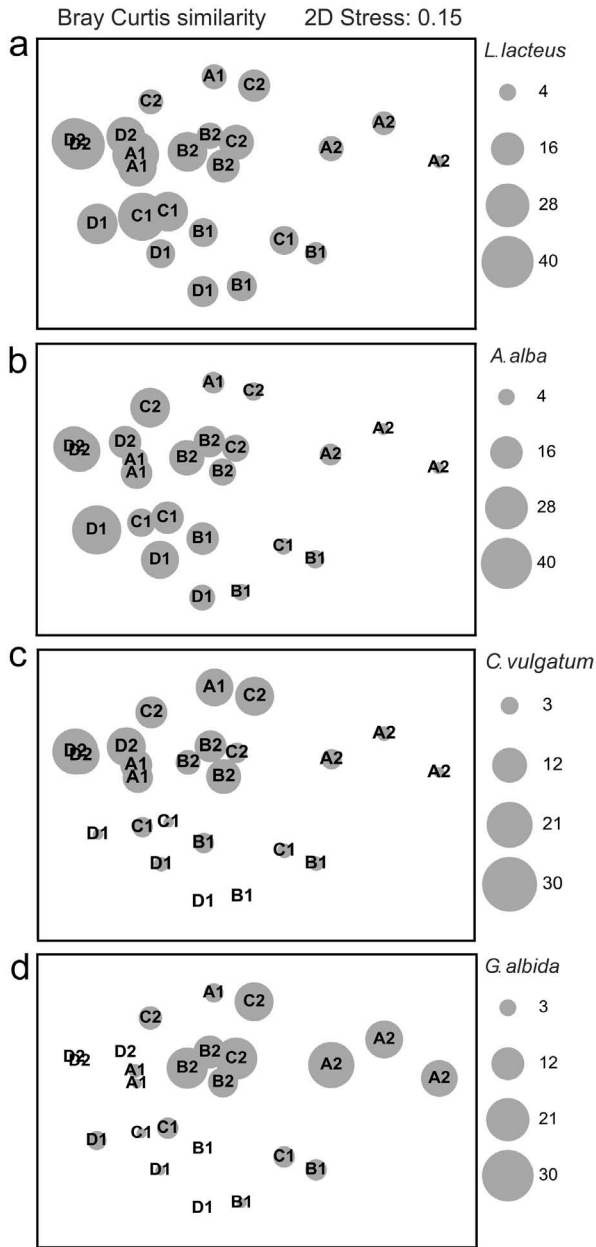


FIG. 5. – nMDS ordination of the mollusc assemblages in July (A1, B1, C1, D1) and January (A2, B2, C2, D2). The abundances of *Loripes lacteus* (a), *Abra alba* (b), *Cerithium vulgatum* (c) and *Gibbula albida* (d) are superimposed on the ordination plots. The diameter of bubbles is proportional to the number of individuals per replicate.

D, driving the separation of its replicates from the rest. Moreover, they are relatively more abundant at Sites A, B and C, allowing the aggregation of replicates of these 3 sites on the right of the plot. In Figure 5 the same analysis representing differences among mollusc assemblages is shown. In this case the abundances of *L. lacteus* (Fig. 5a), *A. alba* (Fig. 5b) and *C. vulgatum* (Fig. 5c) clearly drive the aggregation of replicates on the left of the plot

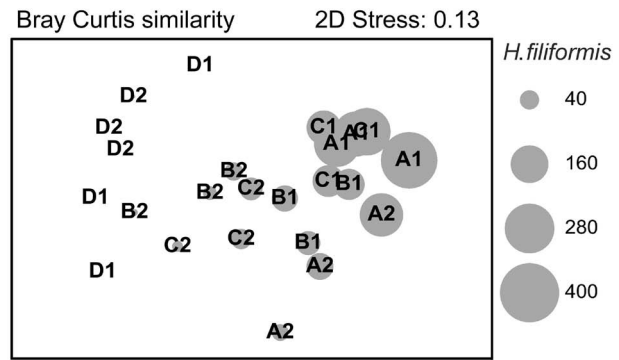


FIG. 6. – nMDS ordination of the whole assemblages in July (A1, B1, C1, D1) and January (A2, B2, C2, D2). The abundance of *Heteromastus filiformis* is superimposed on the ordination plot. The diameter of bubbles is proportional to the number of individuals per replicate.

and the separation of January replicates of Site A on the right. An opposite pattern emerges when the abundance of *G. albida* is superimposed (Fig. 5d).

When the whole assemblage is analysed (Fig. 6) it is evident that the distribution of the dominant species *H. filiformis* leads the general pattern observed. Thus, the model derived from the polychaete matrix (Fig. 4) almost overlaps the one obtained considering the whole assemblage (Fig. 6).

Multiple regression analysis

Table 3 shows the conditional test results of the DISTLM forward analysis. Considering the whole assemblage, in January salinity ranked first among the predictor variables, significantly explaining about 48% of the assemblage variation, followed by temperature (about 10% of variation explained), while the test for the oxygen saturation was not significant. The results, however, are the synthesis of two different patterns in the two major taxa. In fact, in molluscs salinity explained the majority of the variation (64%) in January, while in polychaetes the situation was more complex: although salinity still ranked first among the predictor variables, the oxygen saturation explained 16% of the polychaete assemblage variation, while the test for the temperature was not significant. In July the results for the whole assemblage were similar to those observed in January, with salinity as the most important predictor variable (44%). However, temperature and salinity were strongly correlated, so the proportion of the assemblage variation explained by salinity could also include effects of temperature. Moreover, the forward selection procedure of the analysis indicated that 12% of variation may be exclusively attributed

TABLE 3. – DISTLM-forward analysis: results of the forward selection procedure. SS(Trace) = portion of sum of squares relative to the analysed predictor variable; pseudo-F = statistic; *p* = significance level (in italics the significant *p* values); prop = proportion of variation explained (salinity = S, temperature = T, oxygen saturation = O).

	Variable	January				July				
		SS(Trace)	pseudo-F	<i>p</i>	prop	Variable	SS(Trace)	pseudo-F	<i>p</i>	prop
Whole assemblage	S	9447.3544	9.1113	<i>0.0002</i>	0.4767	S	85481.228	7.7465	<i>0.0008</i>	0.4365
	O	823.6519	0.7766	0.648	0.0416	T	2307.0213	2.379	<i>0.046</i>	0.1178
	T	1986.2102	2.1021	<i>0.05</i>	0.1002	O	1922.3662	2.2598	0.083	0.0982
Molluscs	S	8702.0079	18.0532	<i>0.0002</i>	0.6435	T	2423.1528	3.0499	<i>0.0054</i>	0.2337
	T	455.9496	0.9403	0.537	0.0337	O	1273.4151	1.7179	0.133	0.1228
	O	632.5659	1.3561	0.256	0.0468	S	790.4691	1.0753	0.382	0.0762
Polychaetes	S	7777.3151	3.3112	<i>0.0098</i>	0.2488	S	10883.2827	7.496	<i>0.0016</i>	0.4284
	T	1973.1835	0.8254	0.57	0.0631	T	2712.6816	2.0679	0.097	0.1068
	O	5143.5533	2.5134	<i>0.036</i>	0.1645	O	3448.3444	3.3007	<i>0.05</i>	0.1358
Correlation among variables	T					T				
	S	-0.4894				S	0.9284			
	O	0.7072	0.1705			O	-0.1375	-0.4524		

TABLE 4. – Presence/absence matrix of the polychaete species collected in July 1989 and July 2006 at the 4 analysed sites (* species dominating assemblages in July 2006; in bold the species dominating assemblages in July 1989).

	2006				1989			
	A	B	C	D	A	B	C	D
<i>Armandia cirrhosa</i>				x		x	x	x
<i>Brania armini</i>				x				
<i>Capitella capitata</i>					x	x		
<i>Cirriformia tentaculata</i>				x	x	x	x	x
* <i>Cirrophorus furcatus</i>	x	x	x	x	x	x	x	x
<i>Dorvillea rubrovittata</i>				x				
<i>Exogone meridionalis</i>				x				
<i>Exogone naidina</i>				x				
<i>Glycera</i> sp.			x					
* <i>Heteromastus filiformis</i>		x	x					
<i>Hediste diversicolor</i>					x			
* <i>Lumbrineris latreilli</i>	x	x	x	x		x		
<i>Lumbrineris</i> sp.			x					
<i>Naineris laevigata</i>	x	x	x	x	x	x	x	x
* <i>Neanthes caudata</i>	x	x	x	x				x
<i>Nereiphylla rubiginosa</i>						x		
* <i>Notomastus latericeus</i>	x	x	x	x		x		x
<i>Petaloproctus terricolus</i>	x	x	x			x		
<i>Pionosyllis anophthalma</i>			x					
<i>Spio decoratus</i>		x		x	x			
<i>Syllides japonicus</i>		x		x				
<i>Syllis gracilis</i>					x	x		x
<i>Terebella lapidaria</i>	x							

to the temperature variable. Also in this case the analysis of the most important taxa revealed different patterns. In molluscs the temperature explained only 23% of the assemblages' variation observed in July, while the other variables were not significantly correlated. The analysis of polychaetes showed a higher importance of salinity than in January, while oxygen saturation explained part of the assemblages' variation (14%). In all the analysed cases (especially molluscs in July) the screened predictor variables were not useful for explaining the largest proportion of the variation observed.

Polychaetes: a present-past qualitative comparison

In Table 4 the presence-absence list of the polychaete species collected in July 1989 and July 2006 is reported; for both sampling periods, the numerically dominant species are highlighted.

An increase in taxonomic richness from 1989 (13 taxa) to the present (19 taxa) is evident. Moreover, the faunistic composition appeared distinctly different: some species collected in 1989 such as *Capitella capitata*, *Hediste diversicolor*, *Nereiphylla rubiginosa*

sa and *Syllis gracilis* have not been recorded, while 10 presently collected taxa (particularly *H. filiformis* and 5 syllid species) were not observed in 1989.

In July 1989 the dominant species were *N. laevigata*, *C. tentaculata* and *C. furcatus*; among them only *C. furcatus* was abundant also in July 2006.

DISCUSSION

The benthic assemblage of Acquatina Lake can be considered a typical brackish-water community, mainly composed of “paralic” elements *sensu* Guelorget and Pertuisot (1992).

As a whole, the analysed benthic assemblage may be considered relatively homogeneous, especially in the central area of the lagoon, mainly exhibiting quantitative differences among sites and between sampling times. Considering the multivariate pattern, however, it can be argued that Sites A and D represent the two extremes of the biotope conditions and exhibit the most variable assemblages. Although most of the collected mollusc species are commonly found in lagoon systems, they appeared linked to the southern area (Site D), more influenced by the sea, where also some typically marine species such as *B. reticulatum* have been recorded. By contrast, the typical lagoon taxon *G. albida* was abundant at the northern site (A), the least influenced by the sea influx. Similar taxonomic composition and taxonomic richness have been reported for the mollusc fauna of the Gialova Lagoon in SW Greece, where, however, the inner-outer coenocline between paralic and thalassic species was more marked (Koutsoubas *et al.*, 2000). As far as the polychaetes are concerned, except for some marine species recorded in the southern area, the assemblage is mostly compound of typical brackish-water taxa mainly represented in the northern and inner part of the lagoon (Site A).

The differences between mollusc and polychaete distributions lead us to hypothesise that the two groups are under different controlling factors. During 1992 the salinity was considered the most important factor influencing polychaete distribution in the lagoon, since noticeable differences from north to south were observed (Giangrande and Fraschetti, 1996). At present, though the salinity has been found to be more homogeneous, it remained the most important predictor variable explaining the macrofaunal distribution, especially for molluscs in July. The polychaete distribution, instead,

could be related to different levels of oxygen saturation in the study area. The local accumulation and decomposition of *Posidonia oceanica* detritus incoming from the open sea could have caused the low and variable oxygen saturation observed at Site D in July. Reizopoulou and Nicolaidou (2004) observed that in the Papas Lagoon (W Greece), during dystrophic periods, large decomposing *Ulva rigida* beds led to an abrupt decrease in oxygen concentration, causing azoic conditions in the affected areas. In our case, the decomposing vegetal biomass in the sediment seemed to affect polychaetes, possibly due to their burrowing life style. On the other hand, it might be hypothesised that molluscs, particularly bivalves using siphons, may supply oxygen directly from the water column, which is continuously renewed due to the vicinity to the main channel. Similar outcomes have been reported for the Gialova lagoon, where molluscs appeared not to be affected by stressors (including low oxygen availability in the sediment) limiting the other benthic species (Koutsoubas *et al.*, 2000). That is, in the more “marine” area of the Acquatina Lake, where a complex and diversified assemblage was expected, polychaetes were scarcely represented and only in July were a few marine epibenthic elements—probably living on *P. oceanica* and passively transported inside—observed.

The correlation between assemblage structure and environmental variables does not completely explain the observed assemblage variation. Other abiotic and biotic factors must probably be taken into account. Although the brackish water environments are “physically controlled” and the competitive interactions are considered less important in structuring the community (Whitlatch, 1980; Dayton, 1984), it is possible that competition plays a role. In previous studies on Acquatina polychaetes it was observed that high density of *N. latericeus* limited other species (Giangrande and Fraschetti, 1993, 1995). Particularly, *N. laevigata* showed the changes in population structure during the period of greatest abundance of *N. latericeus* and competitive exclusion was evoked due to the fact that the two species possibly competed for space and not for the food. The effect of the environmental change on polychaete assemblage (abrupt increase in salinity in 1990) was mediated by the biotic component through changes in competition rate as a result of interactions between the life histories of the species involved (Giangrande and Fraschetti, 1996).

During the past 15 years the general environmental conditions of the lake changed following the human interventions. Although hydrological data prior to 2003 are not available, nevertheless, it is clear that the opening of the new large channel allowed an increased water exchange. According to Bachelet *et al.* (2000), this condition leads to more stable benthic communities. Polychaetes proved to be effective indicators of such changes (Giangrande *et al.*, 2005). In our case, it is probable that the increase and stabilisation of mean salinity influenced the health status of the basin. The data on polychaete distributions in July 1989 are unfortunately reported as semi-quantitative estimates (Giangrande and Fraschetti, 1996), thus allowing only a qualitative long-term comparison. It is, however, clear that the presently analysed polychaete assemblage is more diversified, showing a different faunistic composition from the one recorded in 1989. According to Nicolaidou *et al.* (2006), species diversity is not a sensitive parameter in expressing variations in coastal lagoons since, due to their environmental instability, they can be considered as naturally stressed environments where diversity is maintained at low levels. In the Acquatina system, however, the change is permanent and directly influencing the hydrological regime. Among the 25 polychaete species listed (in 1989 and 2006), in fact, only 9 were recorded on both sampling dates. Specifically, faunal changes are further confirmed by the disappearance of the “classic” opportunist *C. capitata*, whilst, *H. filiformis*, which is the characteristic element of the polychaete community and the most abundant macrobenthic species, was not found during 1989–1992 (Giangrande and Fraschetti, 1996).

Heteromastus filiformis is reported to have a wide ecological spectrum (Gravina and Somaschini, 1990) and to tolerate wide salinity ranges (Muus, 1967; Wolff, 1973). Pearson and Rosenberg (1978) consider *H. filiformis* to be a pioneer species appearing in the second stage of the ecological succession, after the disappearance of *Capitella* spp. Reizopoulou and Nicolaidou (2004) observed peaks of abundance of both *H. filiformis* and *C. capitata* in organically enriched areas. In fact, *H. filiformis* is also reported as an opportunistic form common in Mediterranean brackish water basins (Koutsoubas *et al.*, 2000; Reizopoulou and Nicolaidou, 2004; Nicoletti *et al.*, 2006) and in polluted environments (Holte, 1998). Colonisation of the lake by *H. filiformis* may have been favoured by the change in hydrological con-

ditions after the opening of the southern channel. During the hyperhaline crisis in 1990 the dominant taxon was *N. latericeus*, which is now much less abundant, showing a patchy distribution. Moreover, *N. laevigata*, a typical mesohaline species dominant in 1989, is now weakly represented (Giangrande and Fraschetti, 1993, 1996). At present the two capitellid species (*H. filiformis* and *N. latericeus*) show an inverse trend of abundance, possibly due to both competition (they are similar in trophic requirements and life styles) and differences in tolerance of wide salinity ranges (*N. latericeus* is less tolerant to low salinity) (Keppel, 2007). Both species can also be indicators of high concentration of organic matter in the sediment, as well as *N. caudata*, which is particularly abundant in the confined branch of the lake (site C). It is interesting to note that *N. latericeus* reached both the highest and the most variable abundance at the site that was found to be the least suitable for polychaetes, where, in fact, the dominant *H. filiformis* was absent. Thus, the peculiar distribution of *N. latericeus* might result from the combination of some contrasting factors co-occurring at Site D, namely the highest salinity, the absence of competitors and the stress due to the decomposition of vegetal biomass. Particularly, *N. latericeus* can be more tolerant to sediment anoxia since its tube is always in contact with the surface (Keppel, 2007). Future manipulative field experiments in the central part of the lake, where both capitellid species are present and relatively abundant, might help to understand whether competition influences their distribution patterns similarly to what is hypothesised for some amphipod species of the Mazoma lagoon (Greece) (Nicolaidou and Karakiri, 1989). Field experiments might also help to clarify whether differences in species life strategies could play a role, as elsewhere observed (Gascón *et al.*, 2008).

In general, our results are in accordance with observations of Nicoletti *et al.* (2006), who examined long-term trends of benthic communities in 3 central Italian coastal lagoons and found an increased biodiversity linked to an improvement in trophic conditions and a considerable increase in *H. filiformis* abundance. Although the central Italian lakes and Acquatina biotopes belong to different bioclimatic areas (Bianchi, 1988), their species compositions appear to be similar. However, Acquatina Lake showed lower biodiversity, lacking a diversified pool of marine species in comparison with observations of Nicoletti *et al.* (2006) or with similar systems in

other closed Mediterranean areas (e.g. Reizopoulou and Nicolaidou, 2004). As stated above, the accumulation of *P. oceanica* detritus and related oxygen depletion may have disabled the establishment of a well-developed “marine” community at the potentially richer site (Site D). However, the species supply from the sea is still evident mostly in the presence of some typical marine Syllidae. Apart from *P. anophthalma*, a new species to the Adriatic shoreline (see Musco and Giangrande, 2005), which has been found in the lake lateral branch, the syllids were, in fact, particularly recorded in the least confined area.

In conclusion, the long-term data comparison highlights that the improvement of environmental conditions is accompanied by faunistic enrichment and change in the taxonomic structure of the polychaete assemblage. Similarly to the findings of Gascón *et al.* (2005) for Mediterranean NE Iberian salt marshes, in the Acquatina system the hydrological regime seems to summarise the physical factors which ultimately determine benthic fauna. In our case, the presently recorded salinity appears particularly suitable for polychaete colonisation and for the establishment of a rich and diversified benthic community (Gravina *et al.*, 1988).

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