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Biodiversity in transitional waters: steeper ecotone, lower diversity

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Abstract

Benthic communities were studied in four transitional water ecosystems in the Mediterranean, located in Albania (Narta), Greece (Logarou) and Italy (Grado-Marano and Margherita di Savoia), with different degrees of salinity ranges, in order to investigate biodiversity trends across a scale of environmental stress. The intensity of natural stress in the transition zones, from the marine-based to the land-based influence, varied from gradual to sharp. The spatial variability in the physical environment had a stronger effect on species richness than did the temporal fluctuations. The sharper the spatial variations of salinity, the lower the number of species and the diversity level of the system. The differences in intensity of natural instability were also reflected by the presence of different sets of species, with the euryhaline species developing large populations and dominating the more enclosed systems, whereas the marine component of the fauna plays the most important role in increasing the level of benthic diversity.

Introduction

Coastal lagoons are ecotones between marine and terrestrial environments, receiving variable amounts of fresh water. Mediterranean lagoons are usually shallow water bodies and, due to their geo-morphological and hydrological characteristics, environmental conditions in them undergo frequent fluctuations on a spatial and seasonal basis.

Seawater renewal, depending on the degree of enclosure of the lagoon, affects most environmental variables and has a prominent role in the organization of biological communities. Natural instability leads to wide variations in species diversity. The recurring pattern of species richness, decreasing from the marine regions to the inner parts of the lagoon, has been widely documented (Guélorget & Perthuisot 1983; Lardicci *et al.* 1993; Koutsoubas *et al.* 2000; Bazaïri *et al.* 2003; Reizopoulou & Nicolaidou 2004). A strong relationship is documented between diversity and confinement (*sensu* Guélorget & Perthuisot 1992), as environmental instability increases in relation to the degree of isolation from the marine influence (Reizopoulou & Nicolaidou 2004).

In coastal ecosystems with poor seawater inflow, several lagoon specialist species may tolerate extreme environmental conditions, and potentially develop large populations in a wide range of salinity gradients. Bamber *et al.* (1991) stated that lagoon specialists are better adapted to the environmental variability, most likely afforded by a degree of genetic plasticity; however, in salinity extremes a drop of species richness is expected (Cognetti 1992).

It is essential to investigate and compare spatial and temporal patterns of biota in coastal lagoons with various degrees of natural stress, in order to distinguish and classify the principal factors structuring communities, the role of critical extremes, and the degree of instability as a predictor of species distribution.

The present study is an attempt to link the degree of natural variability with biota variations in coastal transitional ecosystems, investigating the spatial and temporal variations of the zoobenthic communities along a range of environmental gradients in four saline and brackish Mediterranean lagoons.

Material and Methods

Sampling was carried out in four Mediterranean transitional ecosystems (Fig. 1) with a variable degree of enclosure and marine influence that was reflected by the salinity ranges within each system.

Grado-Marano, a lagoon characterized by high exchange with the sea, is situated in the North Adriatic Sea. Sampling was performed in the Marano basin. Grado-Marano has estuarine features, receiving fresh water input and being subjected to tides. The lagoon is affected by chemical pollution and eutrophication (Ianni *et al.* 2008; Ponti *et al.* 2008).

Logarou is on the north coast of Amvrakikos Gulf with inflow from the Louros and Aracthos rivers. The lagoon is separated from Amvrakikos by a narrow barrier, with openings allowing limited water exchange with the marine environment.

Margherita di Savoia is located along the Adriatic coast in Southern Italy and Narta in the Adriatic Sea in Western Albania.

Sampling in the lagoons was mostly performed in the bare sediment habitats during autumn of 2004 and spring/early summer of 2005. Six stations were sampled in Narta and eight stations in each of Margherita di Savoia, Grado-Marano and Logarou. Five replicate benthic samples were taken at each station with a box corer sampling 0.03 m^2 of the bottom. The samples were sieved through a 0.5-mm-mesh sieve and stained with Rose Bengal. Samples were preserved in 4% formalin. In the laboratory, the macrofauna was sorted, identified to a species level where possible, and counted. Temperature, salinity and dissolved oxygen were measured just above the bottom by temperature/salinity and oxygen probes at all stations for each study area over the two sampling occasions.

Spearman's rank correlation was employed to investigate the possible correlation between biotic and abiotic parameters. Community structure is described by multidimensional scaling (MDS) based on a similarity matrix constructed using the Bray–Curtis similarity index. The data were first transformed by $Y = \log(x + 1)$. The ANOSIM test was applied to the species abundance matrix testing the null hypothesis that there were no significant

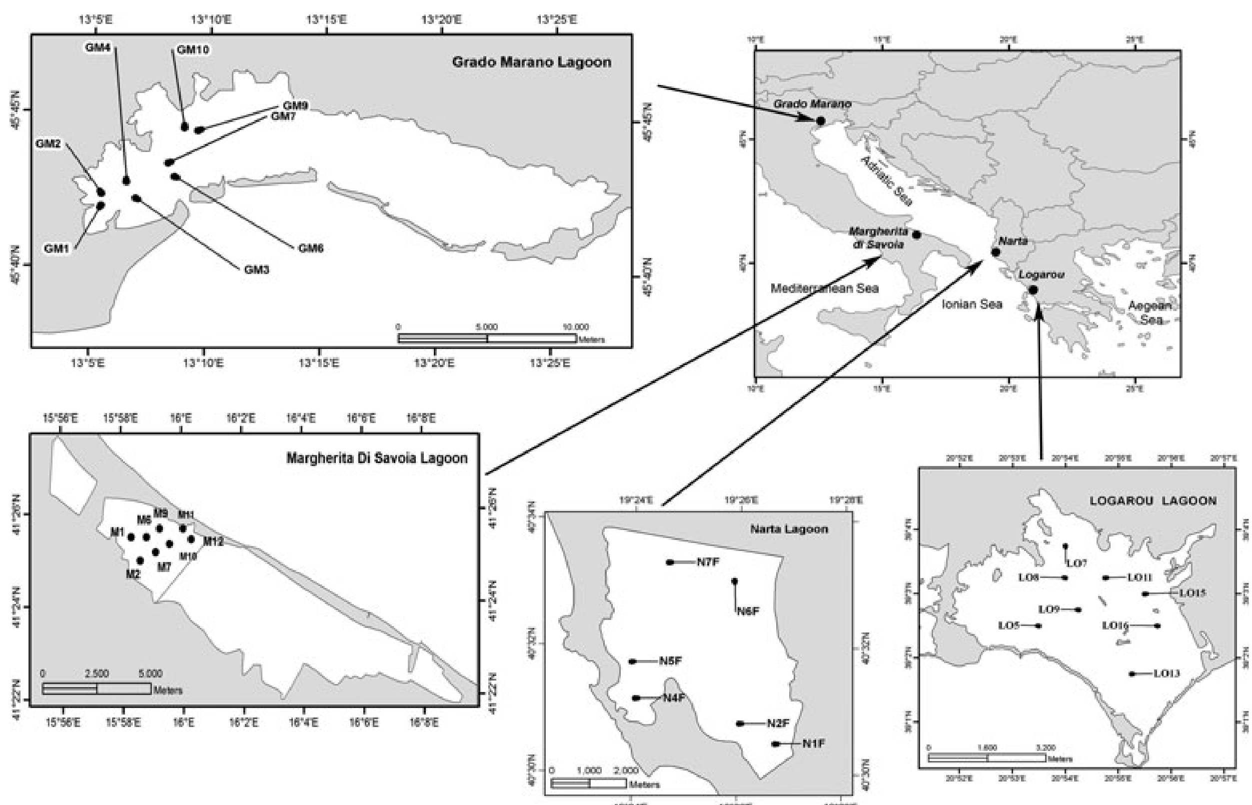

Fig. 1. Maps of the study sites.

differences among study areas and sampling times. Statistical analyses were performed using the PRIMER v5 software package.

Results

The surface area, tidal range and variations of the environmental parameters for each lagoon over the sampling seasons are shown in Table 1. In general, Grado-Marano and Logarou had high temporal ranges of the abiotic variables, whereas Margherita di Savoia and Narta mostly had high spatial ranges of environmental conditions. Salinity ranges in Margherita di Savoia and Narta reflected a strong spatial gradient, whereas Grado-Marano and Logarou demonstrated more marked seasonal changes.

Differences in the variation of abiotic parameters among the study areas could be attributed mostly to the degree of communication with the sea, the tidal range, the climatic factors including rainfall and wind, and the hydrogeomorphological characteristics, including depth.

Multidimensional scaling analysis based on species abundance identified distinct benthic assemblages associated with the different lagoon sites (Fig. 2). Seasonal differentiation was more evident in Narta, whereas Logarou, with high temporal variation in salinity, demonstrated a low seasonal variability in community structure. An ANOSIM test applied to the matrix of species abundances indicated that the lagoons differ significantly at a 0.001 level, except for Margherita di Savoia and Narta, where the significance level was 0.05. Logarou and Margherita di Savoia were the most different ($R = 0.87$, $P < 0.001$). The comparisons between autumn and spring for each lagoon showed a seasonal difference at the 0.05 level in all the study areas. The greatest seasonal effect was observed in Narta ($R = 0.63$, $P < 0.05$).

The species matrix compiled from the whole dataset can be classified in three major groups: euryhaline species (including lagoon specialists and species tolerant of broad salinity and temperature ranges), opportunistic species and marine species.

The species composition is similar to that of other Mediterranean transitional waters, with wide distribution of euryhaline species such as *Abra segmentum*, *Cerastoderma glaucum*, *Hediste diversicolor*, *Corophium* sp., *Gammarus* sp. and *Nephtys hombergii* (Guélorget & Perthuisot 1983; MarLIN 2006); however, the dominance of these species differed among the lagoons. The dominant species (>3%) for each study site are shown in Table 2.

Figure 3 shows the main groups of species forming the benthic communities: euryhaline, opportunistic and marine species. In the more eutrophic lagoon, Grado-Marano, the community shifts between opportunists and

Table 1. Surface, tidal range and variation of abiotic parameters for each study area over the sampling occasions.

Lagoon	Surface (km^2)	Tidal range (m)	Salinity				Temperature (°C)				Oxygen ($mg\ l^{-1}$)			
			Autumn		Spring		Autumn		Spring		Autumn		Spring	
			Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)
Grado-Marano	142.0	0.65	23.0–30.0	26.5 (3.3)	17.4–27.2	22.3 (4.6)	5.3–7.7	6.5 (1.0)	19.9–21.9	20.9 (0.7)	9.7–10.6	10.2 (0.4)	6.3–7.9	7.1 (0.7)
Logarou	24.2	0.40	36.3–38.8	37.5 (0.8)	26.4–30.9	28.7 (1.7)	22.2–23.5	22.9 (0.4)	25.5–29.1	27.3 (1.4)	5.1–5.6	5.4 (0.2)	8.2–9.5	8.85 (0.8)
Margherita di Savoia	12.0	0.10	37.1–52.0	44.6 (5.4)	26.2–48.6	37.4 (3.2)	8.2–14.2	11.2 (2.9)	19.1–23.5	21.3 (1.9)	3.7–8.4	6.1 (2.0)	5.3–7.0	6.15 (0.7)
Narta	29.9	0.10	37.6–54.3	44.7 (7.7)	26.1–49.6	36.5 (10.5)	6.3–7.5	6.8 (0.4)	15.9–24.0	18.8 (3.5)	10.2–12.5	11.3 (1.0)	6.6–9.7	7.7 (1.3)

SD, standard deviation.

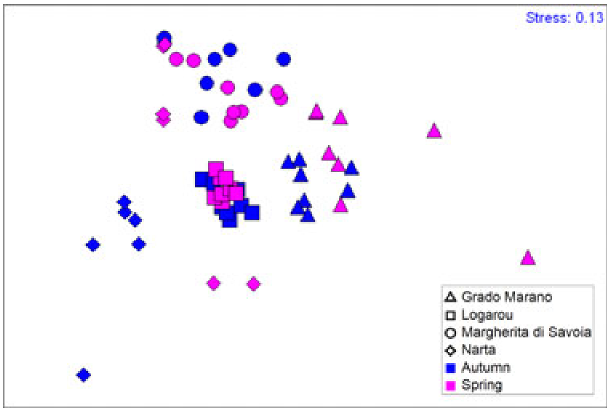

Fig. 2. Multidimensional scaling plot based on species abundance.

tolerant euryhaline species, depending on the seasonal variation of the environmental parameters and probably on the intensity of the eutrophication phenomena. The opportunistic group in Grado-Marano is largely composed of *Cirratulus* sp., which in autumn reached up to 90% of the total community abundance. In the more confined and undisturbed lagoons, euryhaline species form a predominant part of the community in both seasons.

The number of species forming each group is shown in Fig. 4. In Grado-Marano the higher number of species and the resulting higher diversity are associated with the marine influence, as evidenced by the elevated number of marine species. The rest of the lagoons dominated by the euryhaline species reflect their higher degree of enclosure.

The overall data analysis (Fig. 5) confirmed a large-scale pattern related to the degree of environmental changes, with mean species richness ($P = 0.0001$, $R = -0.86$) and mean diversity ($P = 0.0002$, $R = -0.70$) across lagoons being strongly correlated with the salinity variance, expressed as the standard deviation of the salinity values within each lagoon for each sampling occasion. The stronger the spatial salinity gradient, the lower the diversity and number of species of the ecosystem. Abundance and salinity variance showed a weak relationship ($P = 0.03$, $R = -0.44$). The correlations among the benthic descriptors and the mean values of salinity were not statistically significant.

Discussion

The contribution of different variables in structuring the natural gradient of transitional waters depends on the main hydrodynamic energy source of the system (Tagliapietra *et al.* 2009). The chemical and physical gradients influence the biota in many ways (McLusky 1993), so in coastal lagoons, species richness is not dependent on

Table 2. Dominant species (>3%) for each study area.

Species	Grado-Marano	Logarou	Margherita di Savoia	Narta
Polychaeta				
Armandia cirrhosa		+		
Capitella capitata			+	
Capitellidae	+			
Cirratulus sp.	+			
Glycera convoluta	+			
Glyceridae				+
Hediste diversicolor	+		+	
Hydroides dianthus		+		
Lumbrineridae			+	
Malacoceros fuliginosus	+		+	
Mediomastus sp.	+			
Micronephthys sp.	+			
Naineris laevigata		+	+	
Nephtys hombergii	+	+		
Nephtyidae				+
Nereis sp.	+			
Paraonidae	+			
Phyllodocidae				+
Prionospio caspersi	+			
Spio decoratus	+			
Streblospio shrubsolii	+			
Mollusca				
Abra alba	+			
Abra prismatica	+			
Abra segmentum	+	+	+	
Acanthocardia paucicostata	+			
Cerastoderma glaucum	+	+	+	+
Cyclope neritea		+		+
Cypraeidae			+	
Hydrobia acuta				+
Hydrobia ventrosa			+	
Loripes lacteus	+		+	
Mysella bidentata	+			
Pirenella conica				+
Scrobicularia cottardi				+
Tellina sp.			+	
Tellina tenuis	+			
Venerupis aurea				+
Ventrosia ventrosa				+
Crustacea				
Ampelisca diadema	+			
Ampelisca sp.	+			
Amphilochus sp.	+			
Corophium acherusicum		+		
Corophium sp.	+		+	
Cumacea	+			
Dexamine spinosa	+			
Elasmopus sp.	+			
Gammaridae	+			
Gammarus aequicauda	+			
Gammarus insensibilis		+	+	
Gammarus sp.				+
Idotea balthica		+		

Table 2. Continued

Species	Grado-Marano	Logarou	Margherita di Savoia	Narta
Iphinoe serrata		+		
Lekanesphaera hookeri			+	
Lekanesphaera monodi		+		
Microdeutopus gryllotalpa		+	+	
Paramysis helleri	+			
Phtisica marina	+			
Upogebia pusilla	+			
Miscellanea				
Amphiura chiajei	+			
Insecta larvae			+	+
Oligochaeta	+	+	+	+
Ophiuridae			+	

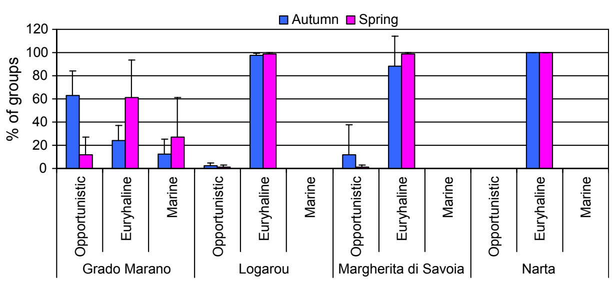

Fig. 3. Percentage abundance of groups of species for each study area over the sampling occasions.

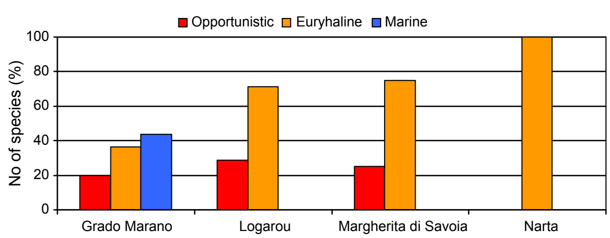

Fig. 4. Percentage of number of species forming the benthic community for each study area.

salinity alone but is the result of a complex of factors, described by the term 'confinement' – the time required to renew the marine element (Guélorget & Perthuisot 1983; Reizopoulou & Nicolaidou 2004).

In estuaries, the salinity variation is considered a major environmental factor in structuring species distribution (Holland *et al.* 1987; Attrill 2002; Ysebaert *et al.* 2003; Wijnhoven *et al.* 2008). Attrill & Rundle (2002) investigating gradients in estuarine systems proposed a two-ecocline model, considered to overlap the gradients from river to mid-estuary for the freshwater species, and from

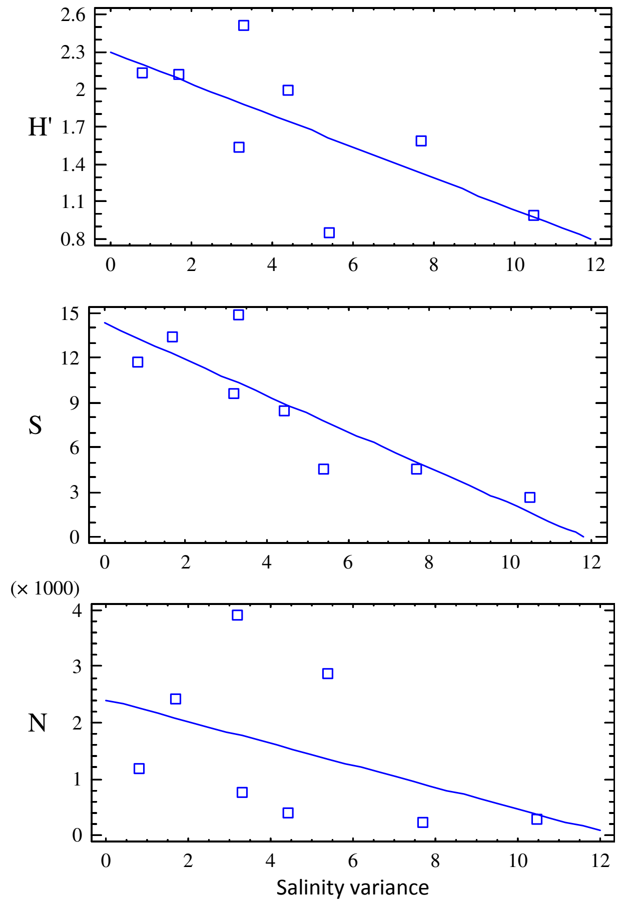

Fig. 5. Mean diversity (H′), mean number of species (S) and mean abundance (N) *versus* salinity variance over the sampling occasions.

sea to mid-estuary for the marine species. In coastal lagoons it is mainly the marine influence that structures the environmental gradient, strongly determined by the sea–land axis, with species richness following a single-scale pattern.

In the present study, the influence of seawater was the primary factor that determined the diversity level of the ecosystems studied, whereas the degree of isolation of each lagoon was better reflected in the variance in salinity.

The differences in natural stress were also reflected by the presence of different sets of species. The main groups forming the communities studied were the widely occurring group of euryhaline species comprising the lagoon specialists (e.g. *Abra segmentum*), with a high tolerance to osmotic stress, inhabiting the transition zone. The presence of the marine group, with more restricted ranges, inhabiting the edge of the system in Grado-Marano, increased the species richness of the ecosystem.

The ecological relevance of the relationships between marine water movements within the system and biotic zonation was emphasized by Millet & Guelorget (1994). In the four Mediterranean lagoons examined, there was a positive linear association of species richness and community diversity with the sharpness of salinity drop within each water body, indicating their dependence on the degree of marine influence.

The sharper the spatial salinity gradient, the lower the mean number of species and diversity level of the ecosystem. Abundance followed the same pattern; however, the correlation with salinity variance was weak. Abundance is probably related more to food availability and biological seasonal cycles, whereas species richness is mainly related to the intensity of the gradients of environmental stress.

Temporal variations seem to have less of an effect on the community structure of Logarou, with higher seasonal salinity changes, which demonstrated the lowest temporal community variation as indicated by the MDS plot. Temporal changes of species richness and community structure are often found to be non-significant in coastal lagoons (Nicolaidou *et al.* 2006; Nicolaidou 2007). This lack of seasonality has been attributed mainly to the continuous reproduction of some abundant species and to species interactions (Nicolaidou 2007).

Environments that exhibit a low number of species and a low diversity are often considered impacted. In transitional water ecosystems, however, this is a natural stress resulting from (i) the edge-point or extreme values of some environmental parameters, such as salinity, that benthic species are required to endure to survive and (ii) the areas of variation of environmental parameters causing the natural instability imposed on the organisms. The latter is reflected in the gradient zone, and the structure of this zone has proved to be the most important factor in the distribution of biological communities. This transition zone from the marine-based to the land-based influence may vary from gradual to sharp, and natural stress levels can be expressed by the intensity of variation of the physical environment controlled by the hydrodynamic status of each system.

Diversity measures and biotic indices that combine them have not proved very efficient for transitional waters because these ecosystems naturally host species tolerant to natural stressors (Reizopoulou & Nicolaidou 2007; Zettler *et al.* 2007; Simboura & Reizopoulou 2008; Texeira *et al.* 2008). This situation has been outlined as the 'Paradox of Estuarine Quality' and may lead to misclassifications (Dauvin 2007; Elliott & Quintino 2007).

Establishing patterns of diversity changes across gradients of changing environment over large geographical areas could help test predictions on the extent of natural stress *versus* anthropogenic disturbance. Species richness and community diversity in transitional waters are strictly related to the environmental gradients overlapping anthropogenic degradation, therefore indices used for ecological quality assessment that include diversity indices should also take into account the degree of natural instability.

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References

Attrill M.J. (2002) A testable linear model for diversity trends in estuaries. *Journal of Animal Ecology*, **71**, 262–269.

Attrill M.J., Rundle S.D. (2002) Ecotone or ecocline: ecological boundaries in estuaries. *Estuarine, Coastal and Shelf Science*, **55**, 929–936.

Bamber R.N., Batten S.D., Bridgwater N.D. (1991) The brackish ponds at Killingholme, Humberside, UK. *Aquatic Conservation*, **1**, 173–181.

Bazaïri H., Bayed A., Glémarec M., Hily C. (2003) Spatial organisation of macrozoobenthic communities in response to environmental factors in a coastal lagoon of the NW African coast (Merja Zerga, Morocco). *Oceanologica Acta*, **26**, 457–471.

Cognetti G. (1992) Colonization of stressed coastal environment. *Marine Polution Bulletin*, **24**, 12–14.

Dauvin J.C. (2007) Paradox of estuarine quality: benthic indicators and indices, consensus or debate for the future. *Marine Pollution Bulletin*, **55**, 271–281.

Elliott M., Quintino V. (2007) Estuarine quality paradox, environmental homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas. *Marine Pollution Bulletin*, **54**, 640–645.

Guélorget O., Perthuisot J.P. (1983) Le domaine paralique. Expressions geologiques, biologiques et économiques du confinement. *Travaux du Laboratoire de Geologie, Ecole Normale Superieure de Paris* **16**, 136 pp.

Guélorget O., Perthuisot J.P. (1992) Paralic ecosystems. Biological organization and functioning. *Vie Milieu*, **42**, 215–251.

Holland A.F., Shaughnessy A., Heigel M.H. (1987) Long-term variation in mesohaline Chesapeake Bay benthos: spatial and temporal patterns. *Estuaries*, **10**, 227–245.

Ianni E., Ortolan I., Scimone M., Feoli E. (2008) Assessment of management options to reduce nitrogen load from agricultural source in the Grado-Marano Lagoon (N-E Italy) applying spatial decision support system techniques. *Management of Environmental Quality: An International Journal*, **19**, 318–334.

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

Lardicci C., Abbiati M., Crema R., Morri C., Bianchi C.N., Castelli A. (1993) The distribution of polychaetes along environmental gradients: an example from the Orbetello Lagoon, Italy. *Marine Ecology*, **14**, 35–52.

MarLIN (2006) *BIOTIC - Biological Traits Information Catalogue*. Marine Life Information Network. Marine Biological Association of the United Kingdom, Plymouth. www.marlin.ac.uk/biotic (accessed 22 July 2012).

McLusky D.S. (1993) Marine and estuarine gradients. An overview. *Netherlands Journal of Aquatic Ecology*, **27**, 489–493.

Millet B., Guelorget O. (1994) Spatial and seasonal variability in the relationships between benthic communities and physical environment in a lagoon ecosystem. *Marine Ecology Progress Series*, **108**, 161–174.

Nicolaidou A. (2007) Lack of temporal variability in the benthos of a coastal brackish water lagoon in Greece. *Mediterranean Marine Science*, **8**, 5–17.

Nicolaidou A., Petrou K., Kormas K., Reizopoulou S. (2006) Inter-annual variability of soft bottom macrofaunal in two Ionian Sea lagoons. *Hydrobiologia*, **555**, 89–98.

Ponti M., Pinna M., Basset A., Moncheva S., Trayanova A., Georgescu L.P., Beqiraj S., Orfanidis S., Abbiati M. (2008) Quality assessment of Mediterranean and Black Sea transitional waters: comparing responses of benthic biotic indices. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **18**, S62–S75.

Reizopoulou S., Nicolaidou A. (2004) Benthic diversity of coastal brackish-water lagoons in western Greece. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **14**, S93–S102.

Reizopoulou S., Nicolaidou A. (2007) Index of Size Distribution (ISD): a method of quality assessment for coastal lagoons. *Hydrobiologia*, **577**, 141–149.

Simboura N., Reizopoulou S. (2008) An intercalibration of classification metrics of benthic macroinvertebrates in coastal and transitional ecosystems of the Eastern Mediterranean ecoregion (Greece). *Marine Pollution Bulletin*, **56**, 116–126.

Tagliapietra D., Sigovini M., Volpi Ghirardini A. (2009) A review of terms and definitions to categorise estuaries, lagoons and associated environments. *Marine and Freshwater Research*, **60**, 497–509.

Texeira H., Salas F., Borja A., Net J.M., Marques J.C. (2008) A benthic perspective in assessing the ecological status of estuaries: the case of the Mondego estuary (Portugal). *Ecological Indicators*, **8**, 404–416.

Wijnhoven S., Sistermans W., Hummel H. (2008) Historic developments in macrozoobenthos of the Rhine–Meuse estuary: from a tidal inlet to a freshwater lake. *Estuarine, Coastal and Shelf Science*, **76**, 95–110.

Ysebaert T., Herman P.M.J., Meire P., Craeymeersch J., Verbeek H., Heip C.H.R. (2003) Large-scale spatial patterns in estuaries: estuarine macrobenthic communities in the Schelde estuary, NW Europe. *Estuarine, Coastal and Shelf Science*, **57**, 335–355.

Zettler M.L., Schiedek D., Bobertz B. (2007) Benthic biodiversity indices versus salinity gradient in the southern Baltic Sea. *Marine Pollution Bulletin*, **55**, 258–270.