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RESEARCH ARTICLE

Hierarchical scaling of biodiversity in lagoon ecosystems

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Abstract

1 - Lagoons are habitat islands in the coastal landscapes characterised by both among ecosystems heterogeneity, due to different terrestrial-freshwater, freshwater-marine interfaces, and within ecosystem heterogeneity, due patchy spatial and temporal distribution of biotic and abiotic components.

2 - Here, we investigate to what extent biodiversity in lagoon ecosystems is affected by these different sources of heterogeneity and which are the implication of the different sources for biodiversity management at the local scale of each single lagoon.

3 - To this aim, we focused on benthic macro-invertebrates using two sources of data: literature data on a sample of 26 Italian lagoons, and synoptically collected data on a sample of 10 lagoons in Eastern Mediterranean and Black Sea. The first data set allowed inference on the among ecosystem heterogeneity and the second on the within ecosystem heterogeneity at the scale of habitat type. Therefore, a hierarchical scaling of biodiversity in lagoon ecosystem is globally addressed.

4 - Results show that the largest component of biodiversity in lagoon ecosystems is due to the differences among ecosystems. Dissimilarity among the taxonomic composition of macro-invertebrate guilds of the Italian lagoons was close to 90%. Difference in habitat type within lagoon ecosystems also affect biodiversity but less than among ecosystem differences; average dissimilarity among habitat types at the ecosystem level was 66.4±10.6 and within habitat types 49.67±6.0.

5 - The analysis suggest that most of biodiversity on benthic macro-invertebrate guilds in the Mediterranean and Black Sea is maintained at the Ecoregional scale, being realised only at a small extent at every local ecosystems. This finding stress the importance of a transnational governance of coastal ecosystem health in order to preserve biodiversity at any local scale within the EcoRegion.

6 - A role of land use management in lagoon watersheds was also emphasised and scaled up with respect to biological interactions acting at the very local scale.

Introduction

Transitional waters, which can be defined as “bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows” (EU-WFD 60/2000), are habitat islands in the coastal landscape. Transitional waters include a number of different habitat types: i.e. estuaries, deltas, lagoons, coastal lakes and ponds, brackish wetlands and salt-marshes. Enclosed bays receiving freshwater inflows and salterns can also be considered transitional waters. As habitat islands along the coastal landscape, lagoons have their biotic structure forced by immigration and emigration processes, which are characteristics island biogeography forces, habitat selectivity (Zobel, 1997) and coexistence relationships (Tilman, 2004). As habitat islands, lagoons are also ecotones among freshwater, marine and terrestrial biotopes, which abiotic structure is therefore forced by coastal geomorphological processes, hydrological processes, natural vegetation and land use in the watershed (Carrada *et al*., 1988; Rossi and Costantini, 2000). Due to their origin as ecotones lagoons are heterogeneous ecosystems with strong threshold of variation which were already expressed as confinement gradients (Guelorget and Perthuisot, 1983) or ergoclines (Legendre and Demers, 1993), both within and among ecosystems. Finally, due their origin as ecotones and to their geographic position along the coast, lagoons are ecosystems frequently stressed by different sources of anthropogenic pressures, such as eutrophication, chemical pollution, overfishing and clam farming, land reclamation and wrong management actions. Community and guild structure are known to be shaped by processes occurring at very different spatial and temporal scale: from speciation events and biogeography, to biotic small scale interactions, through diffusion processes and abiotic filtering (Zobel, 1997). Lagoons represent ideal study cases to evaluate the relevance of different potential drivers of community and guild structure at the local, ecosystem, level. On the one hand, they are known to be harsh ecosystems for both plants and animal guilds due to their strong gradients of salinity, temperature and dissolved oxygen in space and time. High flushing rates and high heterogeneity of deposition and erosion processes were additional limiting factors for many species. According to these two features, niche filtering can be expected to be very relevant in lagoon ecosystems, selecting very similar species according to few well known traits among which osmoregulation, resistance to hypoxia, temperature variability adaptation are the most studied. On the other hand, since physiographic and hydrologic factors are well know to differentiate lagoons into classes and to differentiate lagoon areas into habitat type according to geomorphology (Kjerfve, 1994), salinity (Battaglia, 1959) and degree of confinement (Guelorget and Perthuisot, 1983), a strong niche filtering could also be expected to result into some degree of heterogeneity of species composition both among lagoon and among the habitat types occurring in every lagoon. Moreover, at the ecosystem level tend to be characterised by relatively species-poor local guilds across a range of groups including micro-organisms, phytoplankton (Sabetta *et al*., 2008), benthic macroinvertebrates (Sabetta *et al*., 2007) and fish (Perez-Ruzafa *et al*., 2007), while at Eco-regional level an high diversity was recently observed for the macro-invertebrate guilds of a representative sample of Italian lagoons (Basset *et al*., 2007). However, the relative roles of factors determining homogeneity or heterogeneity of lagoon guilds and explaining the controversial evidences on local and ecoregional diversity of benthic macro-invertebrate guilds are still poorly investigated. Here, we have analysed the taxonomic composition of macro-invertebrate of Mediterranean lagoons searching for general patterns of guild composition according to abiotic (habitat) and biotic (species interactions) constraints. The analysis had two major aims: to evaluate components of Mediterranean lagoon biodiversity, in terms of among lagoon, among habitat, within habitat, biodiversity; and, to explore implications of a hierarchical scaling of macro-invertebrate biodiversity on the management and governance of biodiversity conservation at the local ecosystem scale. In fact, the local scale is the scale at which environmental issues are most commonly posed and at which socio-economic components of conservation are raised by local people. To these aim, we focused on benthic macro-invertebrates using two sources of data: literature data on a sample of 26 Italian lagoons (hereafter, Italian lagoon data-base) and synoptically collected data on a sample of 10 lagoons in Eastern Mediterranean and Black Sea (hereafter, Mediterranean/Black Sea data-base). The first data set al lowed inference on the among ecosystem heterogeneity and the second on the within ecosystem heterogeneity at the scale of habitat type. Therefore, a hierarchical scaling of biodiversity in lagoon ecosystem is globally addressed. Many published papers are based on these two data-bases (Basset *et al*., 2006; Basset *et al*., 2007; Sabetta *et al*., 2007; Basset *et al*., 2008) but they were not yet used to explore the potential scaling effects which are addressed in this study.

Materials and Methods

Italian lagoon data-base

The data used in the present study were gleaned from published sources, including international journals retrieved from electronic databases (*i.e., ASFA, WebSpirs, Biological Abstracts, Current Contents e Zoological Records*), Italian journals covering the fields of ecology and zoology (*i.e., Accademia Peloritana, Il naturalista siciliano, Oebalia, Rendiconti del Seminario della Facotà di Scienze dell'Università di Cagliari, Thalassia Salentina*) and proceedings of Italian scientific societies covering the field of aquatic ecology and zoology (*i.e., Associazione Italiana di Oceanografia e Limnologia, Società Italiana di Biologia Marina, Società Italiana di Ecologia, Società Sarda di Scienze Naturali*). The search was restricted to papers published in the last 25 years.

The electronic search was performed through a three-way factorial combination of the following groups of keywords: a) Italy, Italian; b) lagoon, coastal lake, coastal pond, saltmarsh, saltern, brackish; c) benthos, macrobenthos, macroinvertebrate, benthic invertebrates, benthic fauna.

Table 1 – Main structural abiotic features of the 26 lagoons considered for the study from the Italian lagoon data-base.

Lagoon		Abiotic factors								
ID	Name	A	B	C	D	E	F	G	H	I
1	Grado Marano	160	2	2	485.0	2732.6	0.596	17.05	27.5	15.85
2	Venezia	549	2	1.5	1635.0	8992.5	0.576	26.3	19.4	22.5
3	Sacca Canarin	8.9	1.5	1	365.0	871.6	0.411	14.5	29	14.9
4	Scardovari	38	1.3	1.5	318.0	1011.9	0.411	18.65	29.3	14
5	Nazioni	1	2.1	2	2655.2	8.3	0.411	25	12	16.65
6	Goro	32	1.6	1.5	483.0	1705.1	0.411	21.75	26.3	16.2
7	Comacchio	115	1.2	0.8	441.1	286.7	0.411	23.1	26.2	16
8	Pialassa Baiona	11.8	1.4	0.8	1984.5	132.3	0.411	23	26	16.5
9	Massaciuccoli	7	1.6	3	4276.0	117.2	0.204	8.7	14.6	17.5
10	Orbetello	25.5	2.3	1	1838.0	92.9	0.234	34.35	15.5	17.3
11	Lesina	51	2	0.8	985.0	34.0	0.156	22.5	23	16.5
12	Varano	64	1.2	4	450.1	30.0	0.156	24.86	26.2	19.15
13	Fogliano	4	1.8	0.9	356.0	57.0	0.261	33	30	20
14	Monaci	0.95	1	0.8	818.4	27.3	0.261	27.5	21	19
15	Caprolace	2.3	1	1	974.0	23.6	0.261	41.5	17	20
16	Sabaudia	3.7	3.9	4	980.0	15.2	0.261	22.25	21.5	16.2
17	Fondi	3.9	3.9	9	2349.5	76.9	0.261	20	14	19
18	Lungo	0.47	1.3	4	213.6	17.1	0.261	20	26	20.5
19	Fusaro	1	1.2	3	630.3	39.4	0.246	37.15	8.7	18.65
20	Torre Guaceto	1.2	1.6	0.4	10.0	0.4	0.195	19	28	16
21	Acquatina	0.45	2.94	1	66.8	267.1	0.195	25	30	18
22	Alimini	1.37	2.29	1.5	146.7	19.6	0.195	29	22	19
23	Oliveri-Tindari	0.19	2.7	3	0.0	0.0	0.124	25.5	21	21.15
24	Saline di Marsala	0.89	1.4	0.6	0.0	0.0	0.156	55	30	21
25	Stagnone Marsala	24	1.8	1	314.0	1794.6	0.156	39.3	12.4	19.77
26	Rada di Augusta	23.5	1.4	14.9	235.0	1512.7	0.187	38.15	0.1	2.77

A= surface (km2); **B**= sinuosity; **C**= mean depth (m); **D**= length outlet (m); **E**= width outlet (m); **F**= tidal range (m); **G**= mean salinity (PSU); **H**= range of salinity (PSU); **I**= mean water temperature (°C)

Paper retrieved were further screened according to three main criteria: a) taxonomic resolution (most taxa classified down to the genus or species level); b) taxonomic completeness (the taxonomic list of a lagoon, resulting from one or more papers, cannot be limited to a few selected phyla); c) sampling design (samplings carried out at a seasonal or higher resolution). Finally, 169 papers were selected for the analysis, referring to 26 lagoon ecosystems. A list of the considered ecosystems, reporting some key structural abiotic feature of every of them is presented in Table 1. In the dataset obtained by applying these criteria, the number of articles referring to each of the 26 transitional aquatic ecosystems ranges from 1 (*i.e.* Massaciuccoli coastal lake, Torre Guaceto brackish wetland, Marsala saltern and Piallassa Baiona lagoon) to 22 (*i.e.* Venice lagoon).

For each lagoon fifteen physiographic and hydrological parameters were collected from the published papers as well as from published satellite images and from the "Tide tables of Italy" (Istituto Idrografico della Marina, Genova 1999). The parameters are measures of surface area, perimeter and sinuosity of the water body, maximum axis and minimum axis, measures of length and width of its outlet(s) and their ratio (length/width), measures of mean depth, maximum and minimum tide, tidal range, maximum and minimum salinity and salinity range.

Data were organized into two matrices, a presence/absence matrix with benthic macroinvertebrate data was organized into 26 columns (*i.e.*, the selected lagoons) and 944 rows (*i.e.*, macroinvertebrate taxa); and a rectangular matrix with 26 rows (i.e., the selected lagoons) and 17 columns, with two columns describing the benthic macroinvertebrate guilds (*i.e.*, taxonomic richness and standard body length of the largest species), nine columns describing physiographic characteristics of the water bodies (*i.e.*, surface area, perimeter, sinuosity, length of min. axis, length of max. axis, outlet length, outlet width, outlet length/width ratio, average water depth), and three columns each describing the tidal regime (*i.e.*, minimum and maximum tides and tidal range) and the salinity regime (*i.e.*, minimum, maximum and range of salinity).

Multiple regression was used to evaluate the relative influence and the cumulative importance of surface area and other abiotic structural factors to macro-invertebrate taxonomic richness in the studied Italian lagoons. The taxonomic composition similarity between lagoon pairs was measured using the Jaccard similarity index.

Mediterranean/Black Sea data-base

Data on benthic macro-invertebrates colonizing different habitat types within lagoon ecosystems were originally collected in 10 transitional water ecosystems, located in 4 different countries (from West to East: Italy, Albania, Greece and Romania), as a part of the INTERREG IIIB Project known as TWReferenceNET. The ecosystems studied included micro- and non-tidal lagoons (following Basset *et al.*, 2006) salt pans and almost freshwater coastal wetlands (Table 2).

A hierarchical sampling design was adopted to investigate the seasonal and spatial variation of macroinvertebrate community structure within each considered ecosystem. Sampling design was based on the identification of different habitat types within every ecosystem according to two factors: substrate type [rock (average particle size larger than 2mm), sand (average particle size in the range comprised between 2mm and 0.5mm, and mud (average particle size smaller than 0.5mm)] and presence/absence of vegetation as seaweeds, seagresses and emergent macrophytes. According to these two criteria 12 habitat types (hereafter HT) were potentially identified as follows: HT1 rock without vegetation, HT2 rock with

Table 2 – Main structural abiotic features of the 10 lagoons considered for the study from the Mediterranean/ Black Sea data-base.

Site	Surface area (km^2)	Tidal range (m)	T °C	Salinity PPM	Dissolved oxygen mg/L	DIN µM	DIP µM	Organic matter %
Agiasma	3.20	0.50	23.71 ±*4.12*	27.74 ± *4.08*	7.13 ± *1.87*	5.62 ± *1.00*	1.92 ± *1.49*	2.15 ± *0.88*
Alimini	1.40	0.19	16.29 ± *1.73*	28.67 ± *2.63*	7.89 ± *0.79*	50.55 ± *8.48*	0.07 ± *0.01*	10.04 ± *8.54*
Cesine	0.70	0.15	17.28 ± *2.96*	5.45 ± *0.75*	8.69 ± *1.09*	3.29 ± *0.99*	0.11 ± *0.04*	15.38 ± *18.97*
Grado Marano	142.00	0.65	16.78 ± *6.65*	23.47 ± *4.65*	8.51 ± *1.55*	59.38 ± *11.47*	0.10 ± *0.04*	1.06 ± *0.46*
Karavasta	45.00	0.20	10.89 ± 3.15	42.20 ± *8.28*	9.59 ± *1.47*	19.28 ± *6.60*	0.09 ± *0.02*	11.03 ± *3.07*
Leahova	22.90	0.15	18.53 ± 0.85	0.20 ± *0.01*	8.30 ± *2.17*	18.08 ± *1.11*	0.14 ± *0.09*	3.63 ± *2.60*
Margherita di Savoia	12.00*	0.10	16.76 ± 4.95	60.98 ± 15.76	6.43 ± *2.46*	38.86 ± *32.91*	5.52 ±	13.48 ± *4.06*
Patok	7.10	0.30	12.27 ± 3.55	30.57 ± *5.31*	9.38 ± *1.46*	17.74 ± *6.26*	0.20 ± *0.01*	4.75 ± *3.23*
Sinoe	129.60	0.15	18.37 ± 0.74	0.22 ± *0.04*	8.83 ± *1.09*	16.63 ± *1.16*	0.12 ± *0.06*	2.69 ± *0.72*
Torre Guaceto	1.60	0.20	16.03 ± *4.21*	5.84 ± *0.84*	5.42 ± *2.51*	50.15 ± *44.15*	0.13 ± *0.08*	43.54 ± *29.86*

*The surface area of Margherita di Savoia reported here refers to areas not directly affected by productive uses.

seaweeds, HT3 rock with seagrasses, HT4 rock with emergent macrophytes, HT5 sand without vegetation, HT6 sand with seaweeds, HT7 sand with seagrasses, HT8 sand with emergent macrophytes, HT9 mud without vegetation, HT10 mud with seaweeds, HT11 mud with seagrasses, HT12 mud with emergent macrophytes. Not all twelve necessarily had to occur at every ecosystem or even in the overall sample of 10 ecosystems considered. In every ecosystems habitat types covering more than 25% of sediment surface were sampled and data were collected during Fall 2004 and Spring 2005, at 2 sampling stations for each habitat type in each ecosystem.

The samples were collected using a box-corer (0.03 m2). For each sampling point five replicates were collected . Each sample was sieved through a 0.5 mm mesh sieve and stored in 4% formalin solution. Abiotic water parameters (*i.e.*, dissolved oxygen, pH, water salinity and temperature) were monitored close to the bottom at each station during sampling activities at each site using a hand-held multi-probe meter (YSI 556). Samples of sediment from each sample site were collected for organic matter and heavy metal determination in the laboratory. Moreover, water samples were taken from the water column close to each station for the determination in laboratory of water nutrients (*i.e.*, ammonium, nitrite, nitrate and phosphate) as inorganic dissolved concentrations with standard techniques.

In the laboratory, the collected benthic macro-invertebrates were sorted and selected under a stereomicroscope. Animals were later identified to species level where possible and counted.

Results

Italian lagoon data-base

Overall, 944 taxa were reported to colonise the whole sample of lagoons considered in the data-base, nested into 343 families, 106 orders, 31 classes and 13 phyla. Mollusca, Anellida and Arthropoda were the three most represented phyla. Range size of the 944 taxa was extremely restricted. There were not taxa nor families recorded for all 26 lagoons. At the highest resolution, i.e., taxon level, more than 50% of taxa were recorded at a single lagoon and more than 95% of taxa were recorded at a maximum of 8 lagoons (Figure 1). At the level of family, more than 50% of families were recorded at a maximum of 2 lagoons and more than 95% of families at a maximum of 16 (Figure 1). Consequently, average similarity in the taxonomic composition

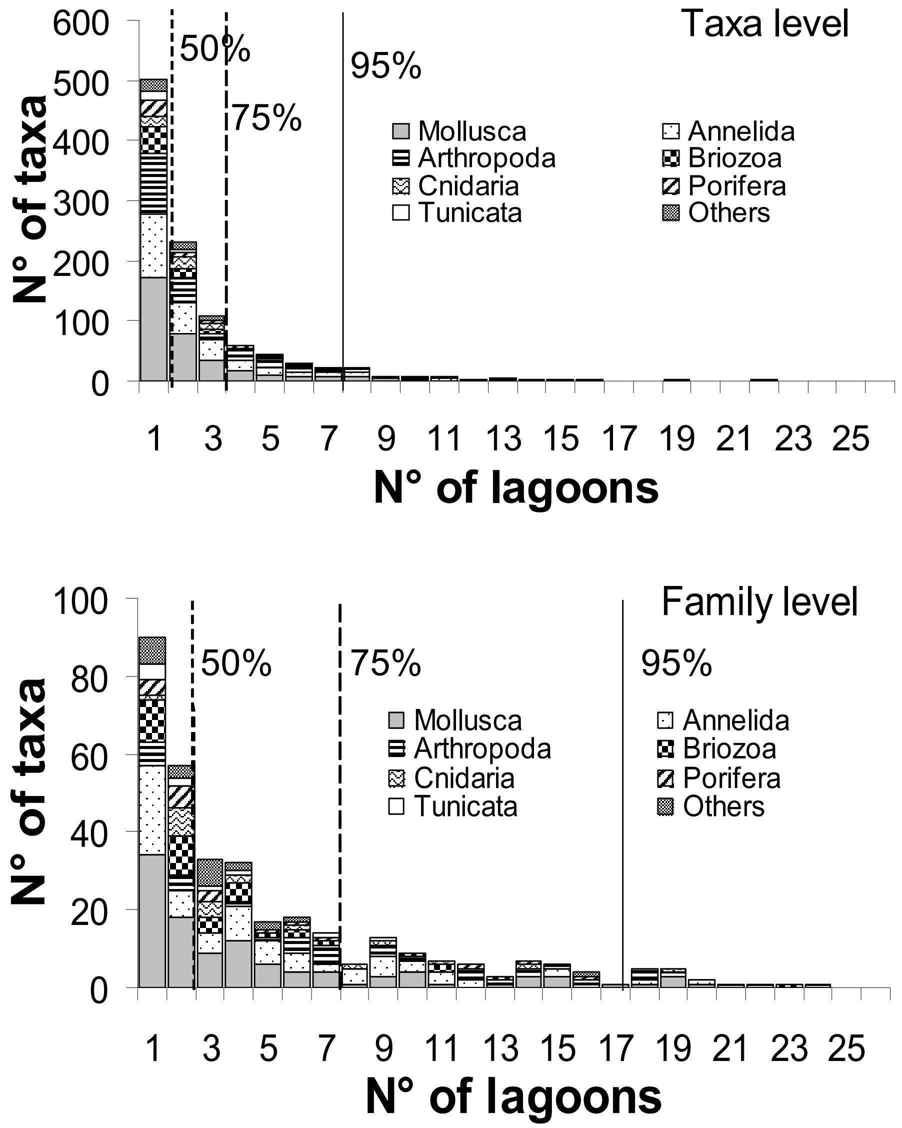

Figure 1. Species range for the benthic macro-invertebrate taxa recorded in the literature in the sample of 26 Italian lagoons considered. Data for two levels of taxonomic resolution are shown: taxa (A) and family (B) levels. For each level, the species ranges of the 50^{th}, 75^{th} and 95^{th} percentile of taxonomic richness are shown.

of benthic macroinvertebrate guilds was low between lagoons at every level of taxonomic resolution considered, being 0.105±0.008 at the taxon level (Figure 2) and 0.217±0.013 at the family level. Average similarity between lagoon pairs ranged from 0 to 0.345 at the taxon level, being the highest between the two spatially neighbouring Fogliano and Monaci lagoons; it ranged from 0 to 0.55 at the family level, being the highest between the two spatially neighbouring Goro and Sacca del Canarin lagoons. Spatially closed lagoons also had, on average, more similar taxonomic composition of macro-invertebrate guilds (Figure 2). At the taxon level, most of Adriatic lagoons are grouped together, even though into two distinct groups including Pialassa Baiona, Sacca of Scardovari and Lago Nazioni, the former and Lake Alimini Grande, Lake Acquatina, Lake Varano, Lesina Lagoon, Valle of Comacchio, Sacca of Goro, Sacca of Canarin and Venice Lagoon, the latter; nevertheless, the similarity on the taxonomic composition of benthic macro-invertebrate guilds even between the closest ecosystems was never higher than 0.300 (highest value between Sacca of Goro and Valle of Comacchio). Similarly, most of the Central Tyrrenian lagoons are grouped together into two distinct groups, including Lake Fusaro and Lake Caprolace, the former and Lake Fondi, Lake Lungo, Lake Sabaudia, Lake Monaci and Lake Fogliano, the latter.

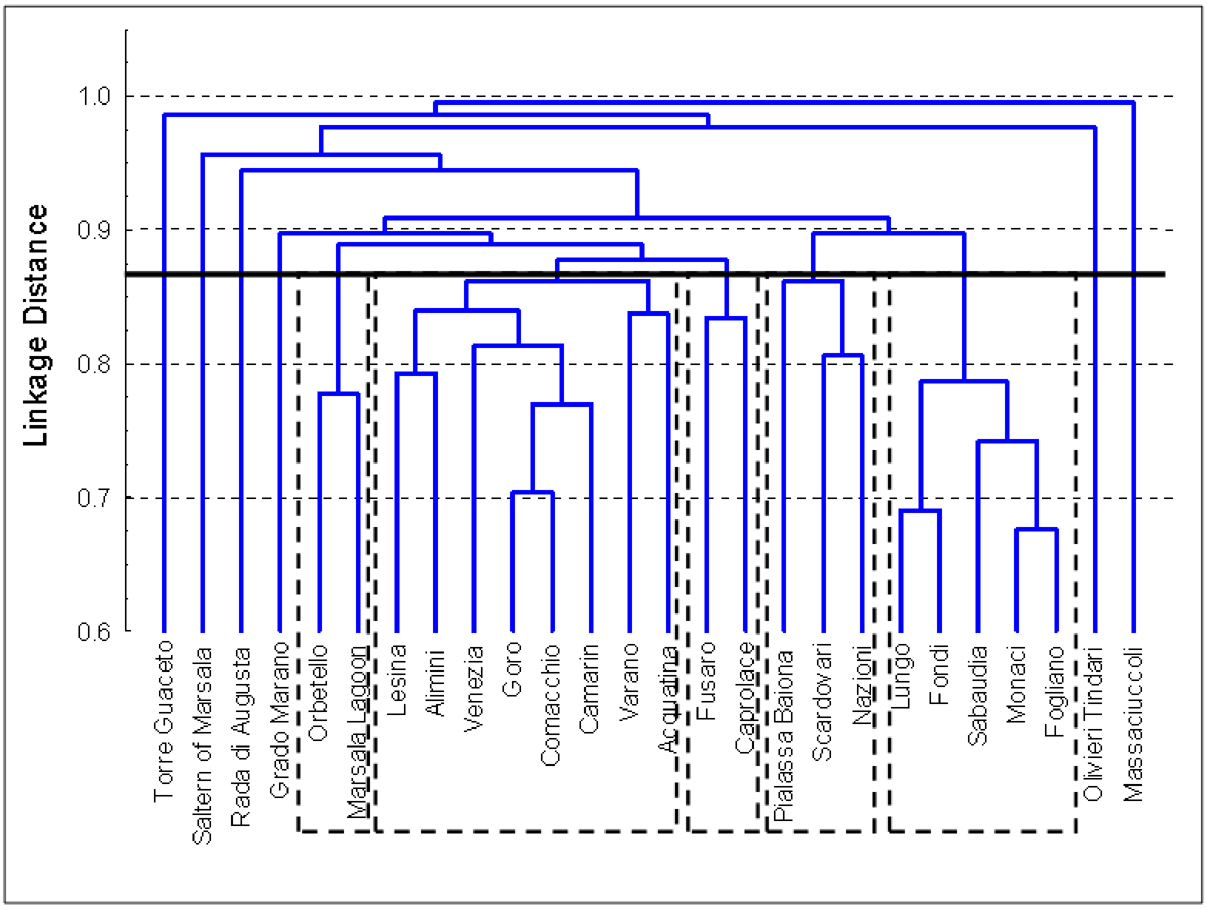

Figure 2. Average similarity of benthic macro-invertebrate guilds of the selected sample of Italian lagoons. UPMGA clustering was shown and post-hoc statistical test of group separation was performed. Groups are emphasized by the dashed lines.

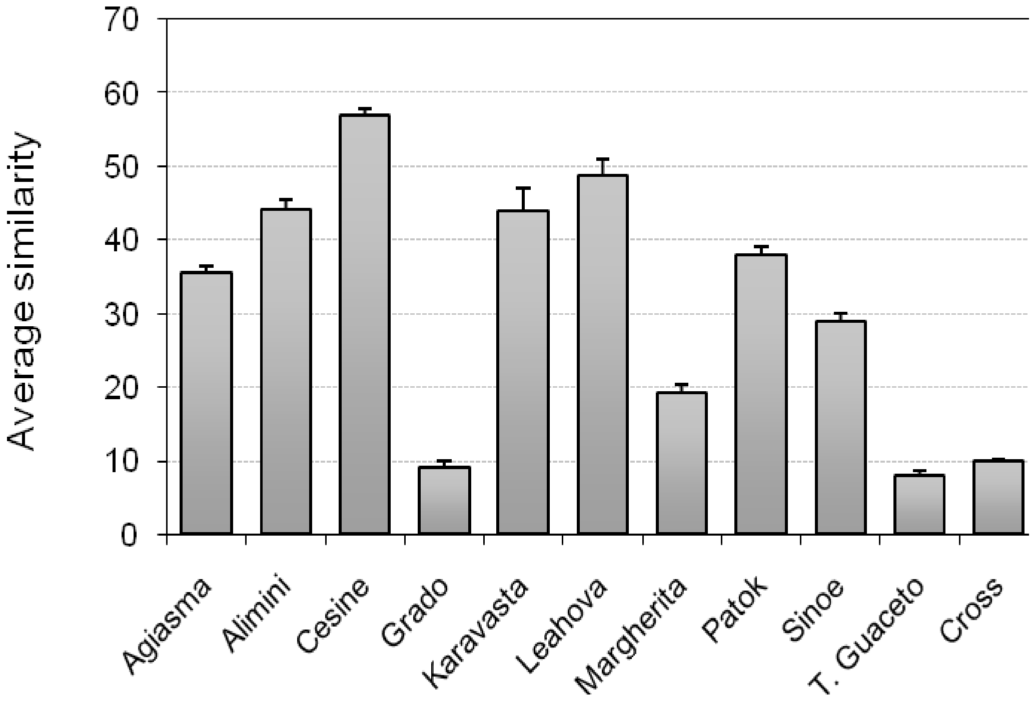

Figure 3. Average similarity of benthic macro-invertebrate guilds at the ecosystem level for the set of 10 ecosystems considered in the Mediterranean/Black Sea data-base. Similarity is among habitat types and stations. Vertical bars represent ± 1 SE.

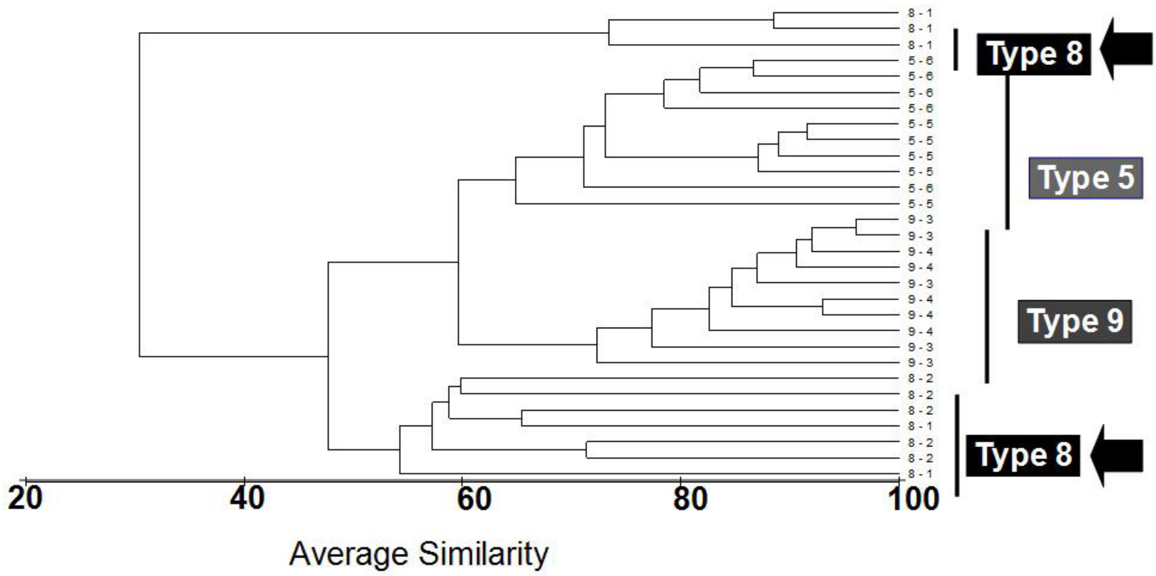

Figure 4. Hierarchical partitioning of taxonomic similarity among habitat types in Lake Alimini Grande. The three habitat types are clearly differentiated but for one of them (HT8) distinctions between stations also occur.

Mediterranean/Black Sea data-base

Globally, out of the 12 potential habitat types only 7 were actually found to cover at least 25% of the sediment surface at one of more of the studied ecosystems. Therefore only 7 habitat types were sampled at one or more ecosystems;

they include HT5, HT7, HT8, HT9, HT10, HT11, HT12. Substrate type with average particle size larger than 2mm was never found widespread at any ecosystem. Benthic invertebrate taxa showed a restricted range size also within ecosystems among typologies. 60.8% of sampled taxa were found specialized on a single habitat type, 25.9% were recorded from two habitat types and only the 0.5% of all taxa were collected from every habitat types. Consequently, differences among habitat types within lagoon ecosystems were also large; average dissimilarity among habitat types at the ecosystem level was 66.4±10.6 (Figure 3) and within habitat types 49.67±6.0. Differences among habitat types varied greatly among ecosystems being as large as 90% at Grado-Marano and Torre Guaceto lagoons and less than 50% at Le Cesine lagoon. Habitat types were clearly differentiated at every ecosystem except than at Lake Alimini Grande where differences also among stations at the habitat type 8, send with emergent macrophytes (Figure 4). However, at the other two habitat types dissimilarity between stations and among samplings at each station is on average lower than 30%, being 22.01%±1.66 at HT5 and 18.46%±1.42 at HT9 (Figure 4).

Discussion

The results of this study emphasise a hierarchical scaling of biodiversity in lagoon ecosystems. Local taxonomic diversity of macro-invertebrate guild was regularly found reduced while spatial differences within every transitional water ecosystem among habitat types and spatial differences at a larger spatial scale among ecosystems lead to an high EcoRegional biodiversity of macro-invertebrate guilds.

In particular the results of this study emphasise that most of biodiversity in transitional water macro-invertebrate guilds is maintained at the EcoRegional level, as it is shown by the extremely high dissimilarity of taxonomic composition of macro-invertebrate guilds among lagoons.

A large heterogeneity of taxonomic composition of macro-invertebrates in Italian lagoons was already shown (Basset *et al.*, 2007). In principle, the diversity of macro-invertebrate guilds could result from stochastic ecological and evolutionary processes on the local (e.g., community level) and regional (e.g., meta-community level) scale, or from dispersal and recruitment limitations on macro-invertebrate taxa, or from the structural heterogeneity of the transitional waters (Basset *et al.*, 2006) and the consequent selection of macro-invertebrate taxa according to their functional traits and niche requirements.

Decoding taxonomic heterogeneity of macro-invertebrate guilds into mechanisms of community assembly has already been addressed elsewhere (Basset *et al.*, 2007). Here, we want to focus on the implications of this finding for the governance of lagoon biodiversity. The large among ecosystem component of macro-invertebrate biodiversity outline the need of a co-ordinated governance at the EcoRegional level; governance at a lower, more restricted, spatial scale is not going to be effective on the process of biological conservation of lagoon integrity. In the Adriatic basin, where differences between North and South, West and East regions in term of socio-economic development and conservation effort, the need for an EcoRegional scale governance is even stronger in order to prevent on the Eastern and Southern coasts the same mistakes that were done in the past on the Northern and Western coasts. Due to the reduced redundancy in the macro-invertebrate fauna of different lagoons, local loss of biodiversity are likely to expand their influence at the entire EcoRegional scale threatening biodiversity even at local and protected ecosystems. In other words, conservation of biodiversity cannot be managed locally but requires a large scale, EcoRegional, process of governance.

The second relevant point raised by this paper is the quantification of internal patchiness of benthic macro-invertebrate guilds in lagoon ecosystems as related to habitat types. Changes in salinity, water level and oxygen concentration are known to be significant stresses which threaten taxonomic diversity in transitional water ecosystems (Guelorget and Perthuisot, 1983), determining low diversity within patches or within parameter levels along an environmental gradient (Chabrerie *et al.*, 2001), although the overall diversity may be high. Biodiversity in transitional water ecosystems was found to be severely threatened by pressures arising from human activities, such as eutrophication, chemical pollution and habitat loss or reduction of total area (Pérez-Ruzafa *et al.*, 2007). Temporal variations in benthic macro-invertebrate communities associated with eutrophication phenomena have been the subject of numerous studies (e.g., Tagliapietra *et al.*, 1998; Koutsoubas *et al.*, 2000; Lardicci *et al.*, 2001). Biodiversity in transitional water ecosystems was also found to be related directly to physiographic lagoon characteristic among which lagoon surface area (macro-invertebrate guilds, Basset *et al.*, 2006) and lagoon volume (fish guilds, Perez-Ruzafa *et al.*, 2007) seem to be the most important. The diversity/area diversity/volume found for different guilds were supposed to have a basis in the internal patchiness of lagoon ecosystems, which can be expected to be an increasing function of lagoon surface area and volume.

Therefore, the results reported here add some more to the existing knowledge. In fact, we showed that independently on existing gradients of salinity, water level and confinement, which were very likely to affect species composition of phytoplankton, seaweeds and sea grasses much more than the occurrence of seaweeds and, particularly, sea grass meadows, the internal patchiness into simple habitat type strongly affect taxonomic distribution of benthic macro-invertebrates and species diversity patterns. The selected habitat types actually respond to pressures, such as eutrophication, but they are strongly affected by the hydrology of the lagoon ecosystem and by the land use in the lagoon watershed. These two factors, directly dependent on human activities at the landscape level are likely to affect both the substrate conditions, determining the spatial distribution and the occurrence of erosion and depositional areas through qualitative and quantitative regulation of the freshwater flow, and the nutrient input to lagoon ecosystems, affecting the ecological succession of sea grasses, seaweeds and phytoplankton (Viaroli *et al.*, 2008). The finding that, focusing on the local scale, biodiversity of benthic macro-invertebrates in lagoon ecosystems largely depends on the internal patchiness outline the relevance of the landscape scale for the management of biodiversity within local lagoon ecosystems. Because of the effects of anthropogenic changes in land use and hydrologic water regime on the submerged landscape in lagoon ecosystems, determining the occurrence and extension of habitat patches, the watershed landscape scale management and the submerged landscape patchiness are strictly related.

In conclusion, the results of this study stress that addressing biodiversity conservation in lagoon ecosystems simply controlling chemical pollution at the local scale may be completely un-effective and is generally not adequate. Biodiversity in macro-invertebrate guilds is related to a hierarchical scaling of processes going from the local scale interaction with abiotic factors, including pollutants, and species interactions to a watershed scale, affecting habitat patchiness to an EcoRegional scale, determining the potential flux of immigrants on which local diversity seems to be based. Therefore, bottom up control of pollution pressures and landscape management have to be joined to EcoRegional scale governance of coastal land use and aquatic resource in order to achieve an actual conservation policy for these invaluable coastal landscape patches. In a closed basin, as the Adriatic Sea actually is, almost resembling an transnational internal salty lake, transnational governance of land use and aquatic resource is the only possible way to face with the actual problems and to prevent future threats potentially arising from the socio-economic development expected on the Adriatic coasts.

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