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Mediterranean lagoons revisited: weakness and efficiency of the rapid biodiversity assessment techniques in a severely fluctuating environment

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Abstract. The purpose of this paper is to test the performance of rapid biodiversity assessment techniques in the lagoonal environment at the pan-Mediterranean scale. The multivariate techniques can produce patterns of lagoonal biodiversity along the Mediterranean. Additionally, it is shown that the polychaete inventory can preferably be used rather than the aggregation of information at the family level for the purposes of rapid biodiversity assessment. These techniques, however, appear to be weak for the environmental assessment because they cannot detect differences between the naturally disturbed and the anthropogenically impacted lagoons. Both taxonomic distinctness indices are found to be robust in providing meaningful results for rapid biodiversity/environmental assessment when the crustacean inventory and the polychaete and molluscan ones are used for the estimation of the average taxonomic distinctness and of the variation in taxonomic distinctness values, correspondingly. Conversely, information on the distribution of the macrofaunal species to the Mediterranean lagoons appears to be inadequate for the needs of such rapid biodiversity assessment at a regional scale. It is suggested that information on ecological convergence of the macrofaunal species would probably provide biodiversity indices with additional power, at least in the lagoonal environment.

Introduction

The development and application of rapid biodiversity assessment techniques have recently been considered as an urgent need, caused by a variety of reasons such as: the habitat/biodiversity conservation, in compliance with the European and International treaties and conventions; the global decline of funding resources; the fast rates at which environmental managers and decision makers need biodiversity information.

The identification of optimum techniques for rapid biodiversity and environmental assessment has been discussed in a number of scientific works (Warwick 1988; Ferraro and Cole 1990, 1992, 1995; Warwick et al. 1990; Somerfield and Clarke 1995; Vanderklift et al. 1996; Oslgard et al. 1997;

Warwick and Clarke 1995, 1998, 2001; Clarke and Warwick 2001; Warwick and Light 2001; Féral et al. 2003). The fundamental question behind this tendency is whether the aggregated information to higher than species levels or a biodiversity index can provide the appropriate results for the biodiversity/ environmental assessment, with some degree of efficiency. The latter term refers to the taxonomic level necessary and sufficient to meet the objectives of an environmental monitoring study with the least possible cost (Kingston and Riddle 1989; Ferraro and Cole 1990, 1992). Two methodological approaches have been tried out in order to identify the indicator groups: (i) multivariate techniques performed on higher than species taxa (Warwick 1988; Ferraro and Cole 1990, 1992, 1995; Warwick et al. 1990; James et al. 1995; Somerfield and Clarke 1995; Vanderklift et al. 1996; Oslgard et al. 1997); (ii) recently developed sample-size, sample-effort free biodiversity indices (Warwick and Clarke 1995, 1998, 2001; Clarke and Warwick 2001).

Although the application of these techniques has provided meaningful results in a number of sublittoral soft bottom communities, they have never been applied to the lagoonal environment (Dounas et al. 1998). The major obstacle in applying rapid assessment techniques in this environment, and especially in the Mediterranean region, is that natural disturbances such as dystrophic episodes and anthropogenic activities (e.g. intensive resource exploitation, sewage discharges) often result in identical modifications in terms of community composition such as: low species diversity with almost complete dominance of a few tolerant species; dominance of the lower geometric size classes; intercrossed ABC curves, associated by near zero W-statistic values (e.g. Cognetti 1992; Reizopoulou et al. 1996).

It is, therefore, the purpose of this study to apply these rapid biodiversity techniques to the Mediterranean lagoonal environment and to explore whether or not they can provide meaningful results.

Methods

Data

An initial binary matrix (presence/absence, species-rows, lagoons-columns), including all macrofaunal species of the Mediterranean lagoons was constructed. Macrofaunal data were obtained from a total of fourteen coastal lagoons, throughout the Mediterranean: Prevost (Guelorget and Michel 1979a, b); Fogliano, Monaci, Caprolace, Fondi and Lungo (Gravina et al. 1989); Ghar el Melh (Romdhane and Chakroun 1986); Goro (both polluted and dredged areas), Tsopeli and Vivari (Reizopoulou et al. 1996); Gialova (Koutsoubas et al. 2000); Messologhi (Nikolaidou et al. 1988); Burollus (Samaan et al. 1989); Bardawil (Aboul-Ezz 1988).

The afore-mentioned lagoons have been subjected to at least seasonal sampling of their macrobenthic fauna. Most of them experience periodic aquaculture activities. Three of them (Carpolace, Ghar el Mehl and Gialova) host a relatively rich macrobenthic fauna, a fact which cannot been considered as indicative of severely impacted Mediterranean lagoons, according to the relevant literature (Romdhane and Chakroun 1986; Gravina et al. 1989; Koutsoubas et al. 2000). Comprehensive research methodology, such as diversity indices, multivariate analyses and graphical methods, which were applied to a number of these Mediterranean lagoons (Prevost, Carpolace, Fondi, Lungo, Fogliano, Monaci, Tsopeli, Messologhi, Gialova and Vivari) have demonstrated that all of them are naturally stressed ecosystems that are not experiencing severe anthropogenic impacts. No significant anthropogenic influx such as contaminants and organic material, which can cause alterations of their macrobenthic communities, have been reported in the relevant literature. Seasonal trends of their macrobenthic communities have been attributed to the naturally fluctuating environmental conditions (Guelorget and Michel 1979a,b; Gravina et al. 1989; Reizopoulou et al. 1996; Koutsoubas et al. 2000). Reizopoulou et al. (1996) also performed a variety of comprehensive uni-, multi-variate analyses as well as graphical methods on the datasets deriving from the Goro lagoon. Goro lagoon is formed at the Po River delta in the northern Adriatic. The most recent data on the water resources of the Po River show that they are exposed to a high level of anthropic pressure, 15% of which can be attributed to civil wastes, 52% to industrial wastes, and 33% to wastes produced by agricultural and animal production, as stated by the Po River Authority. A great part of this material is discharged in the Goro lagoon, where it causes anoxia, especially in those parts with limited circulation. The latter is reflected by the green alga *Ulva rigida*, which is abundant in the soft bottom of the lagoon, in the area characterized as 'Goro polluted' by Reizopoulou et al. (1996). The 'Goro dredged' area also receives the impact from the dredging for *Ruditapes philippinarum*, which is added to the previously mentioned anthropogenic drivers of stress. Reizopoulou et al. (1996) observed complete dominance of small size (biomass) classes in the two Goro areas and characterized these areas as severely impacted (both disturbed and stressed).

Analyses

The information included in the initial matrix was subsequently aggregated into the generic, family, order, class and phylum levels. Three additional subsets of the initial matrix, including the information on the distribution of the most abundant groups (polychaetes, molluscs and crustaceans), were also incorporated in the subsequent analyses.

One-way analysis of similarity (ANOSIM) randomization tests (Clarke 1993) were used to explore significant differences between the severely impacted lagoons (the two Goro areas) from the remaining ones. The multivariate patterns deriving from the previously mentioned matrices were compared by using the second stage as described by Somerfield and Clarke (1995). The overall multivariate biodiversity pattern was obtained from the initial matrix by using the technique (e.g. Clarke and Warwick 1994). Similarity matrices were derived from all binary matrices by using the Sørensen's similarity coefficient (review by Legendre and Legendre 1998). The goodness-of-fit of the resulting two-dimensional plots was measured using Kruskal's stress formula I (Clarke and Green 1988).

Both average taxonomic distinctness (AvTD) and variation in taxonomic distinctness (VarTD) were used to assess macrofaunal biodiversity of the Mediterranean lagoons. These indices were applied to the total macrofaunal lists as well as to the lists of the three most abundant groups. In all cases, both AvTD and VarTD statistics were calculated from the species lists of the lagoons considered and departures from expectation were determined by the corresponding simulation funnels, constructed from random subsets of species from the regional species pool (Warwick and Clarke 1998; Clarke and Warwick, 2001). Spearman's rank correlation coefficient was used to identify any correlation between AvTD and VarTD values.

Results

Faunal composition pattern

The overall Mediterranean lagoonal macrobenthic fauna, at least as derived from the frequently sampled lagoons, includes 282 species, belonging to 217 genera and 128 families. Polychaetes were the most numerous taxon accounting for 40.07% of the total number of macrofaunal species, followed by molluscs (31.92%) and crustaceans (28.01%). Percentages ranged from 12 (Ghar el Mehl) to 74% (Goro dredged) for polychaetes, from 13 (Goro dredged) to 67% (Fondi) for molluscs and from 11 (Vivari) to 64% (Ghar el Mehl) for crustaceans. The results of the ANOSIM test (global R: 0.174; $p \gg 0.05$) show no significant differences, in terms of species composition, between the two Goro areas (severely impacted) from the remaining Mediterranean lagoons.

The MDS ordination technique results in an ordination plot, showing separation of groups of the Mediterranean lagoons taken into account in this study (Figure 1). Four groups of lagoons can be seen on the plot, corresponding horizontally to the species numbers they host: the first group includes lagoons with lower species numbers (17–33 species), located in the Adriatic, Ionian and Aegean Seas (namely: the two Goro areas, Tsopeli and Vivari lagoons); the second group consists of lagoons with a higher number of species (34–63), located in the western Mediterranean basin: Fondi, Lungo, Fogliano, Monaci and Prevost; only lagoons with the highest species numbers (83–145), located in the Central basin and western Mediterranean, are included in the third group: Caprolace, Ghar el Melh and Gialova; all these lagoons included

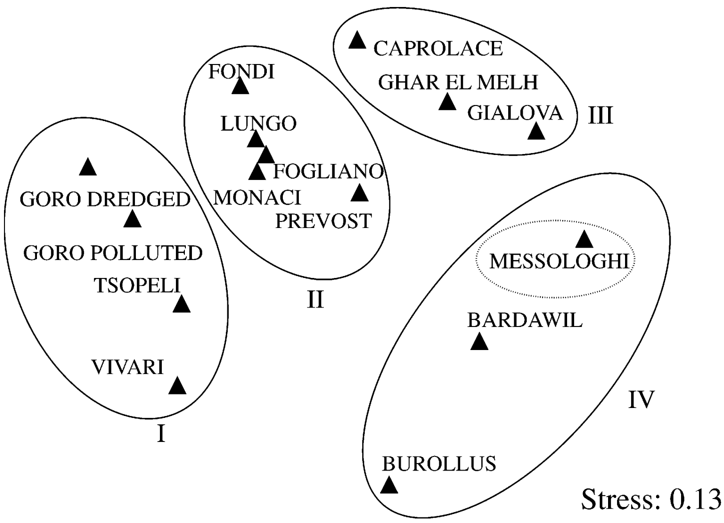

Figure 1. Non-metric multidimentional scaling plot showing the lagoonal biodiversity pattern along the Mediterranean. Latin letters refer to the groups of lagoons, as mentioned in the text.

in the fourth group are located in the Levantine basin of the eastern Mediterranean: Burollus and Brardawil; the number of species hosted in these lagoons ranges from 9 to 43 species.

Taxonomic categories versus most abundant groups

The performance of the second-stage MDS ordination on the matrices including information aggregated into the taxonomic categories (from species to phylum levels) and information from the most abundant groups (polychaetes, molluscs and crustaceans) resulted in the plot shown in Figure 2. When species information is aggregated to the level of the genus and family, there appear to be no significant change in the multivariate pattern; the same holds true for the matrices including information only on polychaetes and crustaceans. As the taxonomic level becomes higher (from order to phylum), the multivariate pattern is more divergent from the one derived from the species matrix; information deriving from molluscan fauna also reveals a pattern well distinguished from the one produced by the Mediterranean lagoonal species matrix.

Taxonomic distinctness: diversity information

The 95% funnels for the simulated distribution of average taxonomic distinctness (Δ^+) and variation in taxonomic distinctness (Λ^+) from random

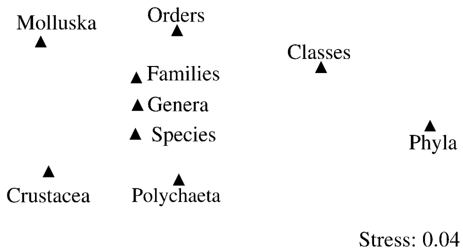

Figure 2. Second-stage ordination by nMDS of ranked intermatrix correlations. Matrices involved include information on species distribution, on species of the most abundant groups (polychaetes, molluscs and crustaceans), as well as aggregated information into higher than species level.

subsets of fixed species number from the Mediterranean lagoonal macrobenthic species pool are displayed in Figure 3. Superimposed on these funnels are the estimated Δ^+ and Λ^+ values resulting from the species list of the Mediterranean lagoons, considered in this study. Simulation procedure and calculation of the taxonomic distinctness indices are repeated for each of the most abundant groups, namely polychaetes, molluscs and crustaceans.

Most of the Mediterranean lagoons have Δ^+ values, as calculated for the total macrofaunal species they host, falling outside (lower than expected) from or being marginal to the funnel of the simulated values A(i). However, the picture is quite the opposite in the case of the corresponding Λ^+ funnel B(i), where most of the lagoons with lower than expected Δ^+ values now show higher than expected Λ^+ values, indicating an under-representation for some taxa and an over-representation of others.

When calculation of Δ^+ values is based on the polychaete and mollusc faunas of the Mediterranean lagoons none of them falls outside the corresponding funnels A(ii, iii). However, when Δ^+ values are calculated based on the crustacean fauna, only the two Goro areas are located in places by far lower than the remaining lagoons. These low values are produced by the presence of a few but closely related crustacean taxa: only a single species is present in the Goro dredged area (*Corophium orientale*) while four species are present in the Goro polluted area, of which three belong to the same genus (*Gammarus aequicauda*, *G. crinicornis*, *G. subtypicus*). In the case of the Λ^+ values B(ii, iii, iv), the two Goro areas show lower than expected values, only when these values are calculated from the polychaete and mollusc inventories, a fact which is considered as indicative of a severe under-representation of these particular groups, in relation to the species pool of polychaetes and molluscs inhabiting the Mediterranean lagoonal habitat. Less than 10% of the polychaete species pool and less than 5% of the molluscan species pool of the Mediterranean lagoonal habitat are present in the Goro polluted and Goro dredged areas (6 and 8 polychaete species and 2 and 1 mollusc species, correspondingly). Additionally, almost all of the polychaete and mollusc species,

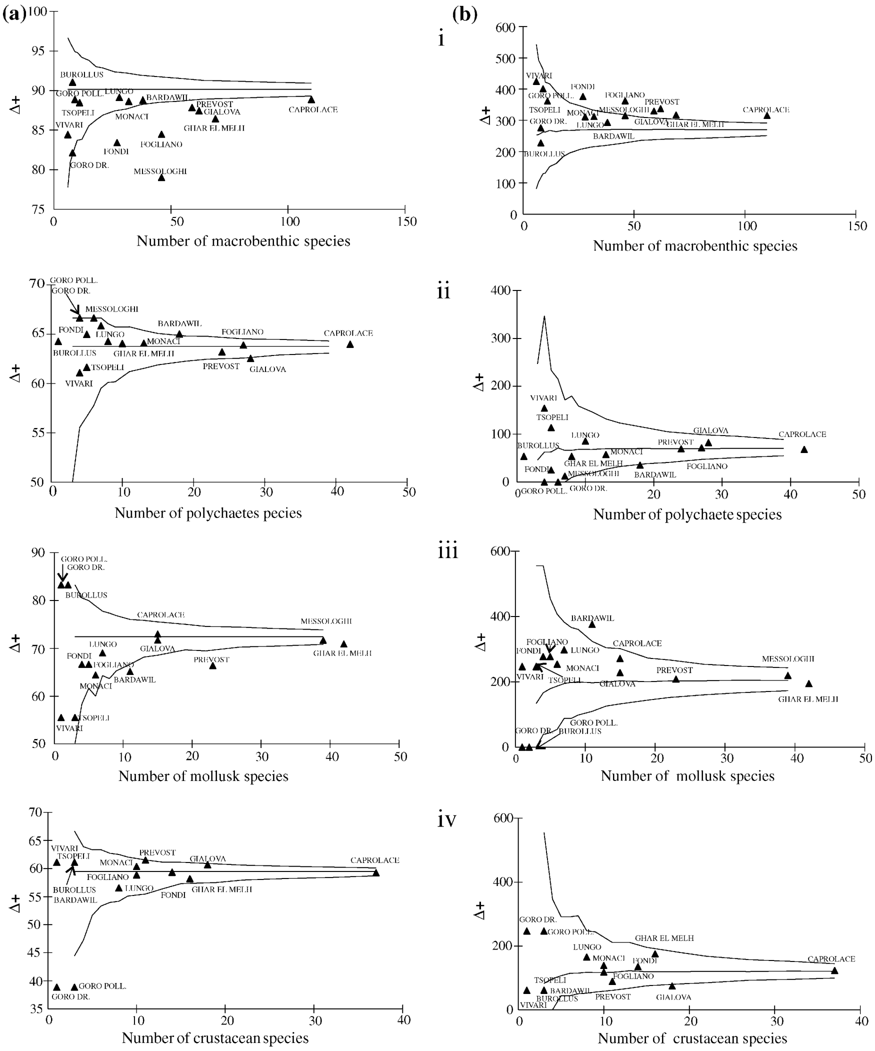

Figure 3. The 95% probability funnels for the average taxonomic distinctness (a) and for the variation in taxonomic distinctness (b). Expected average indicated by the straight line in the middle of the funnel. Funnels have been constructed based both on the entire macrofaunal inventory (i) and on the polychaete, mollusc and crustacean inventories (ii–iv) of the Mediterranean lagoons.

present in these two areas, belong to different families, a fact which contributes to the lower Λ^+ values derived from the inventories of the above two taxa.

In all cases, where lower than expected Δ^+ and Λ^+ values were calculated, there was also a significant departure at 2% level. Finally, Spearman's rank correlation test performed between the afore-mentioned sets of values gave no significant results (ρ values ranging from -0.3 to -0.5 ($p \gg 0.05$)) in the cases of the total macrobenthic and molluscan inventories. However, significant but negative ρ values were calculated in the cases of crustaceans ($\rho = -0.5, p < 0.05$) and of polychaetes ($\rho = -0.95; p \ll 0.01$). The above results indicate that the two indices are monotonically related and, perhaps, they should not be used simultaneously for the same purpose, in the case of molluscs and polychates.

Discussion

Multivariate pattern

The augmented number of higher than species taxa is indicative of a largely diversified fauna and must result from the adaptations that species have had to evolve in order to encounter the often extreme, severely fluctuating, lagoonal environmental conditions (e.g. Cognetti 1982, 1992; Giangrande et al. 1994).

The performance of the MDS technique produced a more detailed multivariate pattern than the previously existing one (Dounas et al. 1998). In this pattern, a broad differentiation of the lagoons located in the western from those of the eastern Mediterranean basins appears, when the number of species they host is low or intermediate. The only exception is the placement of Messologhi lagoon (dust framed) in the last group (IV), which is attributed to the absence of data on the crustacean fauna. However, the lagoonal habitat shows a unique multivariate pattern, in terms of faunal composition, throughout the Mediterranean when lagoons with a higher number of species are exclusively taken into account. This can be explained by the fact that when the species number surpasses a critical value (i.e. more than 30% of the total species number) then the probability of a lagoon to host unique species, and therefore showing a divergent faunal composition from the one of the remainder lagoons, from the total Mediterranean species pool, decreasing, thus leading to a homogeneity of the faunal composition. In other words, the more populated the lagoons are, the more species they share in common.

Weakness of the aggregated information in the lagoonal environment

The purpose of this approach is to save time by analyzing a substantially lower number of replicate sample units and by the coarser identification of the higher taxa, which have been often characterized as operational taxonomic units (OTUs) (Warwick et al. 1990). It has been suggested that anthropogenic activities modify community composition at a higher taxonomic level than natural environmental variables, which influence the fauna primarily by species replacement (e.g. Warwick 1988). The faunal analysis at the generic or at the family level has been proved to be meaningful, in a number of cases (e.g.

Warwick et al. 1990; Ferraro and Cole 1992, 1995). The results of this study show that in the lagoonal environment, the analysis of the polychaete taxo-communities as well as the aggregation of the community information to family level do not substantially alter the multivariate pattern observed at the pan-Mediterranean scale. The subsequent important question is whether the identification of the polychaete species is less time-consuming than the identification of the families of all macrobenthic taxa. In the case where both a polychaete specialist and a technician can identify equally easily the polychaete species and the macrofaunal families, correspondingly, then the technician has to deal with a number of taxa, which appears to be higher by 30% than the number of polychaete species in the Mediterranean lagoonal ecosystem. Also, the polychaete researcher has to concentrate only in these 90 species and to sort them directly out of the samples without paying any attention to the remaining macrofaunal taxa. Additionally, 90 species for a polychaetologist is a very low number of species as compared to the +1000 species occurring throughout the Mediterranean. Therefore, by assuming that the correct identification of 90 polychaete species appears to be much easier for a specialist than the identification of 128 macrofaunal families for a technician, it is suggested that the former alternative appears to be more advantageous than the latter.

However, the MDS technique does not succeed in discriminating those lagoons which are anthropogenically impacted, the two Goro areas, from the closest ones that are naturally disturbed, namely the Tsopeli and Vivari lagoons (Reizopoulou et al. 1996).

Effectiveness and paradox of the taxonomic distinctness

The second approach is based on the assumption that, under anthropogenic pressure the species that disappear first tend to be those representative of higher taxa, which are relatively poor (mono- or oligo-specific taxa). The two biodiversity indices of taxonomic distinctness suggested by Warwick and Clarke (1995, 1998) and Clarke and Warwick (2001) are measures of the degree to which species are taxonomically related to each other (i.e. the average taxonomic spread), and the degree to which taxa are over- and under-represented (i.e. the evenness of the distribution across the phylogenetic/taxonomic tree), correspondingly. The fundamental question behind this concept is whether the species list from a *sensu lato* sample is a random sample of the regional species pool.

At the pan-Mediterranean scale, the performance of the average taxonomic distinctness index is found to be potentially robust only in the case of the crustacean fauna, where the two Goro areas are sited in places much lower than the remaining Mediterranean lagoons, although the simulation funnel is not extended to this area of the plot. Provided that the crustacean species present in this lagoon are taxonomically very close to each other (they belong to the same genus), the extremely low Δ^+ values of this lagoon could be regarded as a result to be expected.

An unusual situation, however, appears in the case of the polychaete and mollusc taxocommunities of the Mediterranean lagoons, where the species are not closely related to each other. In the Goro areas, there appear 11 polychaete species, belonging to 11 genera, 9 families and 7 orders and only 3 molluscan species, belonging to 3 genera, 3 families and 3 orders. This explains the extremely high Δ^+ values of this lagoon, in the corresponding funnels. The aforementioned under-representation of the polychaete and molluscan species also results in the extremely low Λ^+ values for the Goro areas. In the case of the crustacean species, however, the Λ^+ values are highly ranked, a result that may occur in cases where a small number of species occur in the environment (Clarke and Warwick 2001). Finally, this over-representation of the crustacean species and the under-representation of the remaining abundant taxa is responsible for the high Λ^+ values that the Goro areas take in the funnels deriving from the total macrobenthic species. The paradox emerging from this environment is that the fragmented information on the species distribution of the most abundant groups gives meaningful results while the information on the entire macrofauna does not.

From 'what' and 'where' to 'why'

The previously discussed results provide the information needed in order to know what kind of biodiversity exists in which of the Mediterranean lagoons, based on macrofaunal species relatedness. The information on the regional species pool and the average taxonomic spread as well as the degree of the over- or under-representation of the taxa present in the lagoons across the phylogenetic/taxonomic tree, results in meaningful biodiversity/environmental assessments.

However, several genetic and life-history traits are responsible for the adaptation of the species in the unfavorable and severely fluctuating lagoonal environment, such as: (a) genotypes, which offer adaptation to the unpredictable lagoonal environment, and which result in low genetic diversity, locally (e.g. Abbiati 1989); (b) functional phenotypical flexibility, genetically controlled (Cognetti 1992); (c) incubation or deposition of the eggs within gelatinous masses; (d) direct development or benthic larvae with short larval phases with limited dispersal potential; (e) life-history of the k-strategy mode; (f) resting stages (e.g. Giangrande et al. 1995).

It is, therefore, not only the information on the phylogenetic/taxonomic relationship but also the information on the ecological convergence that explains why these species are present in the corresponding lagoonal communities. The latter would bring new information, especially at the genetic level, and would probably be more efficient in discriminating the naturally disturbed from the anthropogenically impacted lagoonal environments. Consequently, this information should be exploited for the calculation of biodiversity indices, a fact which requires information on the afore-mentioned traits, for all lagoonal species (e.g. Petchey and Gaston 2002).

Concluding remarks

The previously discussed results suggest that at the pan-Mediterranean scale (γ-diversity): (i) the multivariate techniques appear to be sufficient for producing biodiversity patterns of the lagoonal environments along the Mediterranean and that the polychaete inventory should preferably be used rather than the aggregation of information at the family level in order to produce these patterns; (ii) the same techniques, however, seem to be inadequate for environmental assessment since they cannot discriminate the naturally disturbed lagoons from the anthropogenically impacted ones; (iii) variation in taxonomic distinctness index has been found to be sufficient for rapid biodiversity/environmental assessment in the cases where the polychaete and molluscan inventories are used; (iv) information on ecological convergence of the species, present in the lagoonal environment, should be incorporated in the calculation of the biodiversity indices.

Finally, although the application of these rapid biodiversity assessment techniques has proved to be both useful and efficient, they should nevertheless be tested at lower biodiversity levels such as on macrofaunal inventories of different lagoons in smaller Mediterranean areas or on the macrofaunal inventory of the same lagoon in different seasons (β-diversity), before they are proposed for wider use.

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