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Ability of taxonomic diversity indices to discriminate coastal lagoon environments based on macrophyte communities

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Abstract

Lagoons are highly productive areas representing more than 50% of the coastline area in Languedoc-Roussillon (South of France, Mediterranean sea). These lagoons are very different in their environmental conditions, human influences, eutrophication levels and aquaculture intensity. Based on macrophyte communities associated with soft substrates, two indices of taxonomic diversity (the “average taxonomic distinctness” (Δ^+) and the “variation in taxonomic distinctness” (Δ^+)) were used to discriminate four of these lagoons (Thau, Salse-Leucate, Bages-Sigean and Mauguio). Bages-Sigean presented a significant higher average taxonomic distinctness ($p < 0.05$) and Salse-Leucate had a significant higher variation in taxonomic distinctness ($p < 0.05$) without considering exotic species. The index values were neither influenced by sample size nor by presence of exotic species. Thus, the “average taxonomic distinctness” was related to human activities and eutrophication level whereas the “variation in taxonomic distinctness” was more related to the environmental variability, associated with the prime stressor of salinity in brackish coastal lagoons.

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1. Introduction

Worldwide, lagoon systems represent 13% of the coastal line (Knoppers, 1994) and with the other coastal ecosystems constitute a large part of the

ecological richness of the biosphere (Costanza et al., 1997). Due to their location between the continent and the sea (interface area with freshwater inputs from the watershed and marine influence from the sea through the channel), and their shallow depths, lagoons are very productive ecosystems (on average of $300 \text{ g C m}^{-2} \text{ y}^{-1}$, Knoppers, 1994), but also very sensitive to both climatic and human activities.

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Lagoons are distributed all over the world coastline, but are not equally widespread on the different coastal areas. In the northwestern part of the Mediterranean sea, lagoons are numerous. In the Languedoc-Roussillon area, they constitute 50% of the coastal line. They are subjected to many anthropogenic impacts, mainly due to permanent and seasonal population density increases, tourism activities expansion, aquaculture and agriculture. One of the urgent needs is to evaluate human influences on the structure and functioning of coastal lagoons, which was one of the goals of the “National Research Programme on Coastal Environment” (PNEC). In the context of this program, specific site studies were initiated in 1993 with a special interest in the macrophytic community, the composition and structure of which are known to be good indicators of environmental changes (Bachellet et al., 2000; Kunii and Minamoto, 2000; Sfriso et al., 2001). Moreover, numerous studies highlighted the functional impact of macrophytes on lagoon ecosystems by its effect on epifaunal assemblages (Parker et al., 2001), sediment microbial processes (Hansen et al., 2000), or on benthic fluxes of oxygen, sulphide and nutrients (Viaroli et al., 1996; Plante-Cuny et al., 1998; Dhargalkar and Shaikh, 2000).

To summarize a community composition, the more widely used parameter is the number of species or the specific diversity measured in samples (α -diversity) (Magurran, 1988; Gaston, 1996). However, this observed taxonomic richness is an underestimation of the true taxonomic richness (the real number of species living on the studied site) and the error involved will depend on sampling effort (Gaston, 1996; Griffiths, 1997). Furthermore, this specific diversity or richness is difficult to relate to the ecosystem productivity or disturbance because the diversity-productivity relationship remains controversial and is not always monotonic (Grace, 1999; Waide et al., 1999; Mackey and Currie, 2001; Mittelbach et al., 2001). For these reasons, the community richness does not seem to be a useful indicator of disturbance in applied ecology (Drobner et al., 1998).

As early as 1949, Simpson suggested that the number of species only represented an aspect of species diversity, noting that the diversity of a given community also depends on the quantitative equilibrium between the species, which we term the evenness. To take into account the structure of the

community, numerous diversity or evenness indices have been proposed such as the Shannon and Weaver (1949) index and its associated evenness or the Simpson (1949) index, for the most famous ones. These diversity indices are classically used in ecology to assess the environmental impacts on ecosystems (Coleman et al., 1997; Cusson and Bourget, 1997; McRae et al., 1998; Chiarucci et al., 1999; Weiher and Keddy, 1999; Pires et al., 2000). Nevertheless, some authors criticized the limited ability of these indices to discriminate between communities or to detect change within a given community (Cairns and Pratt, 1993; Cao et al., 1996; Burel et al., 1998; Gray, 2000; Lydy et al., 2000; Rice, 2000). Moreover, these indices do not take into account functional or taxonomic differences between species whereas some authors pointed out the necessity of including these differences between species to assess diversity (Purvis and Hector, 2000; Shimatani, 2001).

Since 1995, Warwick and Clarke (1995, 1998) and Clarke and Warwick (1998, 1999, 2001) proposed four indices of taxonomic diversity that take into account the “weighted” taxonomic differences between species. The first two, termed taxonomic diversity (Δ) and taxonomic distinctness (Δ^*), are natural extensions of Simpson diversity and use abundance of species. The two last ones measure average and variation in taxonomic distinctness (Δ^+ and Δ^{+*} , respectively) with presence/absence data. Thus, the combination of the two last indices is supposed to provide a statistically robust summary of taxonomic relatedness patterns within an assemblage (Warwick and Clarke, 2001). These four indices are intended to be independent of sample size, unbiased, related to functional diversity and to environmental impact (Clarke and Warwick, 1998, 2001; Rogers et al., 1999; Warwick and Clarke, 2001; Warwick et al., 2002; Warwick and Light, 2002). Nevertheless, using Δ and Δ^* , Somerfield et al. (1997) found no consistent pattern of decreasing taxonomic diversity of marine macrofaunal assemblages with increasing environmental impact and, following Hall and Greenstreet (1998), indices incorporating taxonomic distinctness showed identical time trends to conventional diversity measures with fish communities.

Undeniably, these indices need further investigation concerning their ability to assess environmental impact. Moreover, they have not been widely used in

ecology because one must know all the members of the community theoretically present on each site, and these methods are heavily dependent upon calculations, especially for the associated randomisation test.

In this study, we focus on the ability of two new weighted taxonomic diversity indices (Δ^+ and Λ^+), based on presence/absence data, to discriminate coastal lagoon environments. To this aim, we use a database on macrophytic communities sampled in four coastal lagoons of the Languedoc-Roussillon (France, Mediterranean sea) with high contrast in their environmental conditions such as eutrophication level. Then we discuss a lagoon classification based on taxonomic diversity of macrophytic communities.

2. Material and methods

2.1. Study areas

During the “National Research Program on Coastal Environment” (PNEC), four coastal lagoons located in the Languedoc-Roussillon area were sampled between 1998 and 1999: Bages-Sigean, Mauguio, Salse-Leucate and Thau Lagoon (Fig. 1). Two of them, Salse-Leucate and Thau Lagoon, harbour shellfish aquaculture activities (mainly oyster aquaculture). As the breeding of oysters is not of a level to allow the collection of larva in the Mediterranean sea, production is wholly dependent on the importation of adults or spat. Since 1961, professionals have imported Portuguese oysters and, from 1976, Japanese oysters (*Crassostrea gigas*). These importations caused numerous accidental marine species introductions.

Main chemical and physical characteristics and the eutrophication level of each lagoon are summarized in Table 1 (RSL, 2001). Eutrophication levels are estimated using parameters from the water column such as oxygen, turbidity, chlorophyll, pheopigments and some chemicals (P, N, NH_4^+ and $\text{NO}_2^-/\text{NO}_3^-$) (RSL, 2001). Environmental features and human activities differ according to the lagoon:

- *Bages-Sigean*. This lagoon is the least influenced by human activities because of a low population density on the watershed. Water exchanges with the sea take place in the middle and south of the lagoon.

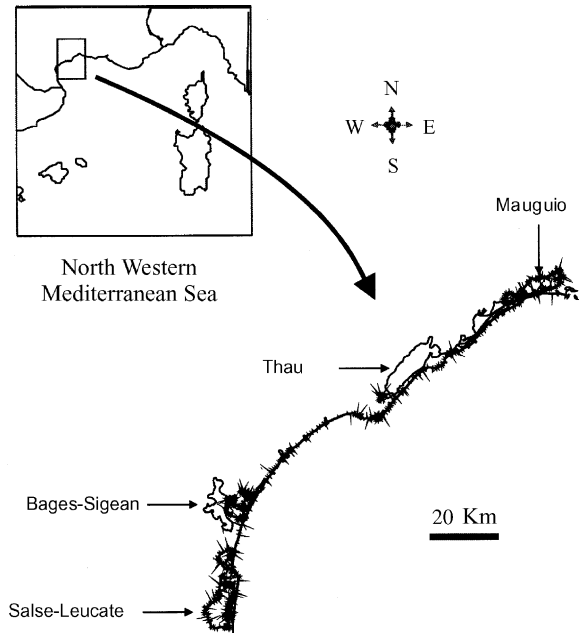


Fig. 1. Lagoons location (Languedoc-Roussillon region, France).

- *Mauguio*. All around this lagoon, human activities and urbanization have rapidly increased during the last thirty years because of development and the vicinity of the largest city of the region (Montpellier; 400 000 inhabitants within agglomeration in 2001). Industrial and commercial buildings are built along this lagoon and agricultural activities occupy a part of the watershed. Communication with the sea takes place through a channel (“grau”), but several gates hamper the water exchanges, increasing eutrophication processes.
- *Salse-Leucate*. This lagoon is not highly impacted by human activities or by eutrophication. However, aquaculture activities are present (1000 tonnes of shellfish per year), and constitute an important source of accidental species introduction (Sauriau, 1991; RSL, 2001).
- *Thau lagoon*. This lagoon is usually lightly impacted by eutrophication (RSL, 2001) but it is the leading site of shellfish aquaculture in the Mediterranean sea (about 15 000 tonnes of shellfish of which 12–13 000 tonnes of oysters are produced per year). These activities influence the biochemical composition of the water column (Souchu et al., 2001). Thau lagoon is one of the major hot spots of

Table 1
Environmental characteristics of the four studied lagoons

Lagoon	Surface (ha)	Eutrophication level	Salinity (PSU)	Organic matter (%)	Watershed surface (ha)
Bages-Sigean	3800	2	32.4 (±2.6)	4 (±1.7)	3800
Mauguio	3170	5	17.3 (±3.7)	7.7 (±2)	31 300
Salse-Leucate	6500	1	33.8 (±1.5)	5.4 (±4)	3170
Thau	7000	2	35.3 (±0.7)	7.2 (±4.8)	35 000

Mean values are given ± standard deviation; organic matter is given as a percentage of dry sediment. Eutrophication level is estimated using parameters from the water column (RSL, 2001) and varies between 1 (lowest eutrophication) and 5 (highest eutrophication).

accidental marine species introduction, especially of marine algae (Verlaque, 2001).

2.2. Sampling

Macrophytic communities on soft substrates were sampled using a regular grid for each lagoon in the spring period depending on the studied community. Each sample represented a randomly distributed 2500 cm²–1 m² quadrat in which the macrophytes were sampled by hand. Material was directly analysed or preserved in 4% Formalin/seawater before identification to the laboratory. The number of quadrats was proportional to the surface area of the lagoon and we obtained, respectively 57, 52, 32 and 32 samples for Thau, Salse-Leucate, Bages-Sigean and Mauguio lagoons.

A bibliographical analysis on the four Languedoc-Roussillon lagoons yielded 202 species of aquatic macrophytes, of which 43 are introduced (Verlaque, 2000, 2001) (see Appendix A). These 202 species were assumed to represent the list of species potentially present in the region. The hierarchical tree was constructed partially based on the taxonomic classification found in the world-wide web electronic publication: <http://www.algaebase.com/> (Guiry and Nic Dhonncha, 2003).

2.3. Taxonomic diversity indices

The first diversity index based on the taxonomic relationship between species proposed by Warwick and Clarke (1995), the taxonomic diversity index (Δ), can be seen as a generalization of the Simpson diversity index incorporating an element of taxonomic relatedness whereas the second is a measure of taxonomic distinctness (Δ^*). Both can include abundances of species.

When data are only presence/absence of species, Δ and Δ^* converge to the average taxonomic distinctness (Δ^+) (Clarke and Warwick, 1998; Warwick and Clarke, 2001) with the formula:

$$\Delta^+ = 2 \frac{\sum \sum_{i < j} \omega_{ij}}{S(S-1)}$$

where S is the species richness and ω_{ij} is the “distinctness weight” given to the path length linking species i and j in the hierarchical classification.

Recently, Clarke and Warwick (2001) proposed a new index based on the evenness of the distribution of taxa across the hierarchical taxonomic tree. This “variation in taxonomic distinctness” can be expressed by:

$$\Lambda^+ = 2 \frac{\sum \sum_{i < j} (\omega_{ij} - \bar{\omega})^2}{S(S-1)} = 2 \frac{\sum \sum_{i < j} \omega_{ij}^2}{S(S-1)} - \bar{\omega}^2,$$

$$\text{where } \bar{\omega} = 2 \frac{\sum \sum_{i < j} \omega_{ij}}{S(S-1)}$$

When species are placed within a taxonomic hierarchy, based on the Linnean classification into phylum, class, order, family, genus and species (Appendix A), the average taxonomic distinctness, Δ^+ , is simply the mean number of steps up the hierarchy that must be taken to reach a taxonomic rank common to two species, computed across all possible pairs of species in an assemblage (Clarke and Warwick, 1998, 1999; Warwick and Clarke, 2001). Thus, if two species are congeneric, one step (species-to-genus) is necessary to reach a common node in the taxonomic tree; if the two species belong to different genera but the same family, two steps will be necessary (species-to-genus, and genus-to-family); and so on, with these numbers of steps averaged across all species pairs. Step lengths are standardized so that the distinctness of two species connected at the highest

taxonomic level is set equal to 100 (Clarke and Warwick, 1999); Δ^+ being between 0 and 100 and Λ^+ being positive. If Δ^+ is the mean path length through the taxonomic tree connecting each pair of species, Λ^+ is simply the variance of these pairwise path lengths and could be seen as an index of the “complexity” of the hierarchical tree.

These two last indices Δ^+ and Λ^+ , used in our study, are explained in more detail in the synthesis of Warwick and Clarke (2001) and in Fig. 2.

2.4. Estimation and randomisation tests

Warwick and Clarke (1998) developed a method to test each index based on the deviance from the null hypothesis: deviance between the index obtained for one locality and that calculated from the whole flora, i.e., for the present study, samples from one lagoon are regarded as random samples from the whole Languedoc-Roussillon macrophytic flora. To test the null hypothesis, we selected randomly from the species list (202 species), 10 000 subsamples of a fixed number of species. We estimated both indices Δ^+ and Λ^+ on each subsample to obtain a distribution of 10 000 index values for each richness level between 10 and 200

species with a regular increase of 10 species. Then, we constructed a “funnel” representing the 95% confidence intervals for the null hypothesis. We compared the observed indices to these distributions to obtain a p -value to reject or accept the null hypothesis. If the species list established for one lagoon is assumed to be a random sample of the total species list, indices should fall within the confidence funnel (with 5% type I error).

For 200 000 simulated communities (10 000 simulated replicates \times 20 sample sizes) and for each lagoon community, we calculated Δ^+ and Λ^+ using a computer program developed using borland C++ Builder 5.0. To use this program, the complete hierarchical tree for each lagoon must be known from the species to the reign level.

3. Results

Species richness of soft substrate macrophytic communities is, respectively 41, 23, 8 and 7 for Thau, Salse-Leucate, Bages-Sigean and Mauguio Lagoons. Fifteen species for Thau, three for Salse-Leucate and one for Bages-Sigean are exotic taxa from Asia (Appendix A).

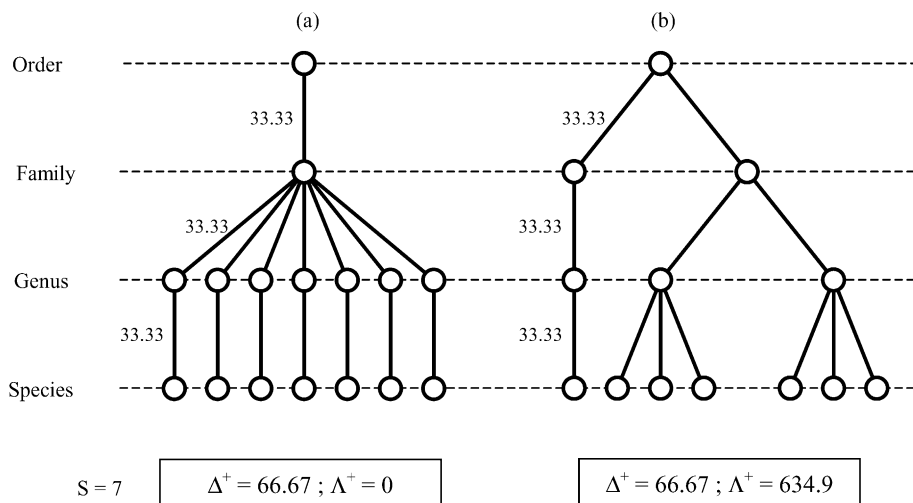


Fig. 2. Two theoretical trees (a and b) with the same richness (seven species) but with a different taxonomy. The mean path length between species is the same for the two trees and thus Δ^+ is identical. The tree structure has a greater unevenness or variability in (b) compared to (a), thus the variation in taxonomic distinctness (Λ^+) is higher for (b). According to Clarke and Warwick (2001), the “distinctness weight” given to the path length between each taxonomic level is 33.33 with a total of four levels.

Table 2

Taxonomic diversity indices and species richness for the whole potential community of macrophytes (regional pool) in Languedoc-Roussillon lagoons and for the four sampled lagoons

Community	Species considered	Number of species	Average taxonomic distinctness (Δ^+)	Variation in taxonomic distinctness (Δ^+)
Regional pool	All	202	85.10	408.97
	Exotic	43	82.37	445.66
	Without exotic	159	85.74	409.51
Thau	All	41	87.05	378.10
	Without exotic	26	88.15	421.21
Salse-Leucate	All	23	83.4	525.91
	Without exotic	20	84.56	556.97(+)
Bages-Sigean	All	8	91.67(+)	505.95
	Without exotic	7	90.48	623.58
Mauguio	All	7	81.11	698.77

When one index is significantly higher (5% type I error) than expected (null hypothesis of random sample in the whole community) the sign + is added.

Taxonomic diversity indices are given in Table 2 for each lagoon, for the whole species list and for only exotic species or non-exotic species of this list. The 95% confidence funnel was constructed for Δ^+ (Fig. 3). We can notice that Thau, Salse-Leucate and Mauguio lagoons show no departure from the expected Δ^+ under the null hypothesis, i.e., each lagoon is a random subsample of the whole macrophytic flora. Bages-Sigean presents a significant higher average taxonomic distinctness ($p < 0.05$). Even though few species were observed (eight), four different phyla with two species each were represented

in this lagoon (see Appendix A): Magnoliophyta (*Zostera marina* and *Z. noltii*), Rhodophyta (*Gracilaria bursa-pastoris* and *G. gracilis*), Chlorophyta (*Ulva rigida* and *Cladophora* sp.) and Heterokontophyta (*Sargassum muticum* and *Cladostephus spongiosus*). This pattern suggests high path length between species through the tree and a high Δ^+ . Without the exotic species *S. muticum* the significant higher average taxonomic distinctness for Bages-Sigean lagoon disappears. The lowest Δ^+ value is obtained for Mauguio lagoon with only two phyla, two families having 4 species (total of 7) leading to one

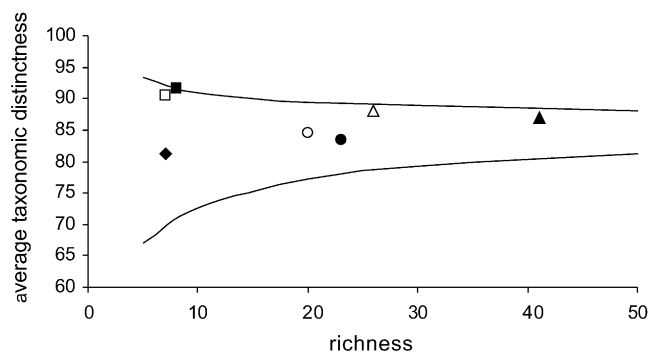


Fig. 3. Values of the average taxonomic diversity (Δ^+) for the macrophyte communities in Thau, Salse-Leucate, Bages-Sigean and Mauguio lagoons, plotted against the number of species on the 95% confidence funnel (see estimation and randomisation test). Triangles, circles, squares and diamonds are for Thau, Salse-Leucate, Bages-Sigean and Mauguio lagoons, open marks are for macrophyte communities without exotic species, respectively.

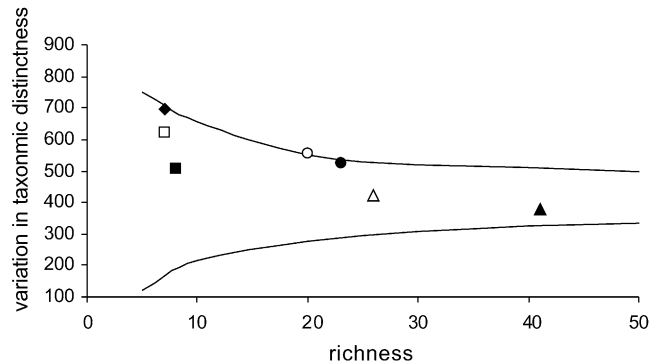


Fig. 4. Values of the variation in taxonomic diversity (Δ^+) for the macrophyte communities in Thau, Salse-Leucate, Bages-Sigean and Mauguio lagoons, plotted against the number of species on the 95% confidence funnel (see estimation and randomisation test). Triangles, circles, squares and diamonds are for Thau, Salse-Leucate, Bages-Sigean and Mauguio lagoons, open marks are for macrophyte communities without exotic species, respectively.

relative low path length between species (Table 2, Fig. 2 and Appendix A).

Results for Δ^+ are shown in Fig. 4 and Table 2. Thau, Bages-Sigean, Mauguio and Salse-Leucate lagoon show no significant values for variation in taxonomic distinctness ($p > 0.05$). If exotic species are removed from Salse-Leucate, Bages-Sigean and Thau lagoons, Δ^+ remains not significant for Thau and Bages-Sigean lagoons whereas Δ^+ becomes significant for Salse-Leucate (Table 2). For this last lagoon 9 out of 12 orders sampled have only 1 species and, at the same time, 3 families (Cladophoraceae, Ceramiaceae, Rhodomelaceae) represent 11 species (about half of the total) leading to a high variation in the taxonomic tree (see Appendix A).

4. Discussion

First of all, by simulating various sample sizes or species richness from the whole species list, we can assess whether both indices are independent of sample size (Figs. 3–4) as indicated by the authors in previous studies (Clarke and Warwick, 1998; Warwick and Clarke, 2001). When diversity indices are used to assess impact on communities, the major problems are the dependence on sample size (number of species sampled) and the ability to detect environmental influences. For the usual diversity indices and species richness, the relationship between diversity values and

sample size was emphasized in the literature (Rice, 2000). This kind of relation prevents any comparison between communities with different species richness. This is not the case with the indices used in the present paper.

Secondly, it appears that taxonomic diversity indices are weakly influenced by the presence of exotic species. Indeed, values of these indices vary little whether we consider the presence of exotic species, of non-exotic species or both (Table 2). This result is surprising because exotic species are supposed to add taxonomic diversity with new phyla, but the taxonomic diversity of macrophyte assemblages seems very robust. For example, Thau has been shown to be a “hot spot” for the accidental introduction of exotic species because of aquaculture activities (Verlaque, 2001). In this lagoon, the 15 exotic species present in the samples add 5 new families (Rhodymeniaceae, Areschougiaceae, Dasyaceae, Chordaceae, Monostromataceae) and one new order (Laminariales), but the taxonomic index and the variance are not significantly different from the null hypothesis for this lagoon. This result could be related to the index values for the whole community of macrophytes in Languedoc-Roussillon lagoons. When we consider only exotic species or only non-exotic species in Table 2, we observe that Δ^+ and Δ are very similar to the whole community values. For the Salse-Leucate lagoon, we have the same evidence: Δ^+ is not positively influenced by exotic species (Fig. 4). This

result is in total accordance with the study of Enquist et al. (2002) suggesting that the processes which structure the taxonomic diversity of woody plant communities, operate in a regular manner over millions of years and across broad geographical gradients. Diversity might be more strongly regulated by local ecological and evolutionary rules, and only weakly influenced by environmental or historical factors such as dispersal barriers or speciation (Gotelli, 2002). In other words, the taxonomic diversity or the structure of the taxonomic tree is about the same for exotic or non-exotic species (results for the whole community in Table 2).

In many studies, diversity indices failed to assess environmental impact. For example, Cao et al. (1996); Karydis and Tsirtsis (1996); Lydy et al. (2000) showed the inefficiency of diversity indices in detecting polluted communities. According to Danilov and Ekelund (1999), all of the diversity indices calculated (Hurlbert's, Margalef's, Menhinick's, Shannon's, Simpson's, McNaughton's and Species number) failed to distinguish between different levels of eutrophication. Likewise, Fortin et al. (1999) were unable to discriminate between post-fire successional gradient sites using only Simpson and Shannon diversity indices. Using taxonomic diversity as indicators, Somerfield et al. (1997) did not detect any influence of pollution impact when these indices are supposed to assess environmental changes (Warwick and Clarke, 1998; Rogers et al., 1999). In the present study, even if the four lagoons considered are very different in their environmental conditions, we observed only two weak significant results, i.e., departure from the null hypothesis (Table 2). We observe a narrow range for Δ^+ values (81.11–91.67) and a range of 378.10–698.77 for Λ^+ values.

Mauguio lagoon, the most depressed one in our study, presents the lowest Δ^+ value (81.11) whereas the highest Δ^+ value was observed for the less human impacted lagoon (low eutrophication, no aquaculture, low agriculture activity and low population density on the watershed) (Table 1). A significant highest Δ^+ value for Bages-Sigean suggests large ecological niches are available with low environmental stress allowing macrophyte species with a high taxonomic diversity and different biological requirements to be established. For example, we found two Heterokontophyta species in Bages-Sigean (*Sargassum muticum* and *C. spongio-*

sus) whereas this phylum is absent in soft-substrate communities of Salse-Leucate and Mauguio lagoons (Appendix A). We noted the presence of *S. muticum* in Bages-Sigean lagoon, which is an invasive species in Europe (Rueness, 1989), where no aquaculture activity is present. In contrast, we can hypothesize that environmental constraints in the Mauguio lagoon limit the taxonomic diversity of macrophyte community. For example, more than half of the species are from two families (Gracilariaceae and Ulvaceae) with species able to live in such impacted environments. Salse-Leucate and Thau lagoons with low eutrophication level but human impact through aquaculture (Souchu et al., 2001) were not discriminated from the regional pool with medium Δ^+ values.

The only significant result for Λ^+ was obtained for the Salse-Leucate macrophyte community when exotic species were not considered. In this case the taxonomic tree is more irregular than the ones obtained under the null model. The highest level of Δ^+ , i.e., the most irregular observed taxonomic tree, was found for Mauguio lagoon (Fig. 4, Table 2) which had the highest eutrophication level and the lowest salinity level compared to the other three lagoons considered (Table 1). Nevertheless this trend was not observed when we consider the four lagoons of the study. More sampled lagoons are thus necessary to recommend Λ^+ as a good indicator for the eutrophication level. Λ^+ seems more related to the salinity coefficient of variation (ratio of the standard deviation to the mean) in our study. This coefficient varies from 2% for Thau lagoon to 21% for Mauguio with medium values for Bages-Sigean (8%) and Salse-Leucate (4.5%) lagoons. The relationship between the salinity coefficient of variation (environmental variability) and Λ^+ is significant and positive ($p < 0.05$). The distribution of organisms and diversity within estuaries had already been supposed to be influenced more highly by variation than by absolute salinity regimes (Attrill, 2002). The environmental variability, associated with the prime stressor of salinity in brackish coastal lagoons, would therefore, seem to influence the variation in taxonomic distinctness of macrophyte communities. We summarize all these tendencies in Fig. 5 and speculate about a classification for coastal lagoon environments based on macrophyte communities, a classification independent of sample size, species richness or exotic invasion. We need certainly

		Average taxonomic distinctness		
		Low	Medium	High
Variation in taxonomic distinctness	Low	Low environmental variability Human impact Eutrophication	Low environmental variability Medium human impact No eutrophication (Thau)	Low environmental variability No human impact No eutrophication
	Medium		Medium environmental variability Medium human impact No eutrophication (Salse-Leucate)	Medium environmental variability No human impact No eutrophication (Bages-Sigean)
	High	High environmental variability Human impact Eutrophication (Maugio)		High environmental variability No human impact No eutrophication

Fig. 5. Classification of Languedoc-Roussillon lagoons based on taxonomic diversity indices. Environmental variability is related to the variation of environmental factors such as salinity or temperature.

more lagoons to validate this classification more particularly those with high environmental variability but low human impact.

Research on summarizing information from a community is still useful in applied ecology, even if “biodiversity can never be fully captured by a single number” (Purvis and Hector, 2000). Here, we applied for the first time, two new taxonomic indices based on presence/absence data to macrophyte communities sampled from four Mediterranean lagoons. A significant highest average taxonomic distinctness was estimated for the less human impacted lagoon (low eutrophication and no aquaculture) whereas other lagoons were not discriminated from the regional pool. Thus, proposing diversity indices that include differences between species is certainly an important step in ecology. These differences could be estimated through genetic data to obtain a phylogenetic diversity (Clarke and Warwick, 2001) but interpretation of these differences is still unclear. These differences could be functional. Recently, Petchey and Gaston (2002) used a new functional diversity estimation based on

morphological characters of species. We can expect some advances on this topic because functional diversity indices could be more relevant in environmental impact assessment or in ecosystem functioning studies.

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Appendix A

Taxonomic tree for macrophyte community in Languedoc-Roussillon lagoons (Verlaque, 2000, 2001; Guiry and Nic Dhonncha, 2003), exotic species having a star. In the last column, the names of the lagoon where they were sampled: B, M, S and T for, respectively, Bages-Sigean, Mauguio, Salse-Leucate and Thau lagoons

Phylum	Class	Order	Family	Genus	Species	Lagoon			
Magnoliophyta	Liliopsida	Najadales	Ruppiales	<i>Ruppia</i>	<i>cirrosa</i>	S			
		Potamogetonales	Potamogetonaceae	<i>Potamogeton</i>	<i>pectinatus</i>	M			
			Zosteraceae	<i>Zostera</i>	<i>marina</i> <i>noltii</i>	BST BST			
Charophyta	Charophyceae	Charales	Characeae	<i>Lamprothamnium</i>	<i>papulosum</i>	S			
				<i>Chara</i>	<i>aspera</i>				
Chlorophyta	Chlorophyceae	Bryopsidales	Bryopsidaceae	<i>Bryopsis</i>	<i>plumosa</i>	T			
				Blastophysa	<i>rhizopus</i>				
				Chaetosiphonaceae	<i>Chaetosiphon</i>	<i>moniliformis</i>			
				Codiaceae	<i>Codium</i>	<i>bursa</i> <i>fragile*</i>	T		
			Chaetophorales	Derbesiaceae	<i>Derbesia</i>	<i>rhizophora*</i>			
					Chaetophoraceae	<i>Bolbocoleon</i>	<i>piliferum</i>		
					<i>Entocladia</i>	<i>leptochaete</i> <i>viridis</i>			
				Chroolepidaceae	<i>Pilinia</i>	sp.			
					Cladophorales	Cladophoraceae	<i>Chaetomorpha</i>	<i>aerea</i> <i>linum</i> <i>mediterranea</i>	S MST
							<i>Cladophora</i>	sp.	BST
		<i>Rhizoclonium</i>	<i>riparium</i>						
		Dasycladales	Polyphysaceae	<i>Acetabularia</i>	<i>acetabulum</i>	T			
		Phaeophilales	Phaeophilaceae	<i>Phaeophila</i>	<i>dendroides</i>	S			
		Siphonocladales	Valoniaceae	<i>Valonia</i>	<i>aegagropila</i>	S			
		Ulotrichales	Ulotrichaceae	<i>Eugomontia</i>	<i>sacculata</i>				
				<i>Ulothrix</i>	sp.				
				Ulvales	Monostromataceae	<i>Monostroma</i>	<i>obscurum*</i>	T	
		Ulvaceae	<i>Enteromorpha</i>		<i>clathrata</i> <i>compressa</i> <i>flexuosa</i> <i>intestinalis</i> <i>prolifera</i>	MT S			

Appendix A (Continued)

Phylum	Class	Order	Family	Genus	Species	Lagoon
				<i>Ulva</i>	<i>fasciate</i> [*] <i>lactuca</i> <i>pertusa</i> [*] <i>rigida</i>	BMT
			Ulvellaceae	<i>Acrochaete</i>	<i>inflata</i>	
Heterokontophyta	Phaeophyceae	Cutleriales	Cutleriaceae	<i>Aglaozonia</i>	<i>parvula</i>	
				<i>Cutleria</i>	<i>multifida</i>	T
		Desmarestiales	Desmarestiaceae	<i>Desmarestia</i>	<i>viridis</i> [*]	
		Dictyotales	Dictyotaceae	<i>Dictyota</i>	<i>dichotoma</i> <i>fasciola</i> <i>linearis</i>	T
				<i>Padina</i>	<i>pavonica</i>	
		Ectocarpales	Ectocarpaceae	<i>Acinetospora</i>	<i>crinita</i>	
				<i>Feldmannia</i>	sp.	
				<i>Strebloema</i>	sp.	
				<i>Hinksia</i>	<i>fuscata</i> <i>granulosa</i> <i>mitchellae</i> <i>sandriana</i>	
				<i>Ectocarpus</i>	<i>fasciculatus</i> <i>siliculosus</i>	
				<i>Kuetzingiella</i>	sp.	
				<i>Kuckuckia</i>	<i>spinosa</i>	
			Pylaiellaceae	<i>Pilayella</i>	<i>littoralis</i> [*]	
		Chordariales	Chordariaceae	<i>Cladosiphon</i>	<i>cylindricus</i> <i>mediterraneus</i> <i>zosteriae</i> [*]	T
				<i>Sphaerotrichia</i>	<i>firma</i> [*]	T
			Corynophlaeaceae	<i>Myriactula</i>	sp.	
				<i>Leathesia</i>	<i>difformis</i> [*]	
				<i>Cylindrocarpus</i>	<i>microscopicus</i>	
			Acrotrichaceae	<i>Acrotrix</i>	<i>gracilis</i> [*]	
			Elachistaceae	<i>Elachista</i>	<i>stellaris</i>	
				<i>Halothrix</i>	<i>lumbricalis</i> [*]	
			Myrionemataceae	<i>Myrionema</i>	<i>orbiculare</i> <i>strangulans</i>	

Appendix A (Continued)

Phylum	Class	Order	Family	Genus	Species	Lagoon
			Spermatocnaceae	<i>Stilophora</i>	<i>rhizodes</i>	
		Dictyosiphonales	Punctariaceae	<i>Punctaria</i>	<i>latifolia</i> <i>tenuissima</i>	
			Giraudiaceae	<i>Giraudia</i>	<i>sphacelarioides</i>	
			Striariaceae	<i>Stictyosiphon</i> <i>Colpomenia</i>	<i>adriaticus</i> <i>peregrina</i> <i>sinuosa</i>	T T
		Scytosiphonales	Scytosiphonaceae	<i>Petalonia</i> <i>Scytosiphon</i>	<i>fascia</i> <i>dotvi</i> [*] <i>lomentaria</i>	T
		Fucales	Cystoseiraceae	<i>Cystoseira</i>	<i>barbata</i> <i>schiffneri</i>	T
			Sargassaceae	<i>Sargassum</i>	<i>muticum</i> [*]	BT
		Laminariales	Alariaceae	<i>Undaria</i>	<i>pinnatifida</i> [*]	
			Chordaceae	<i>Chorda</i>	<i>filum</i> [*]	T
			Laminariaceae	<i>Laminaria</i> <i>Cladostephus</i>	<i>iaponica</i> [*] <i>spongiosus</i>	BT
		Sphacelariales	Sphacelariaceae		<i>cirrosa</i> <i>fusca</i> <i>rigudula</i> <i>sp.</i>	
			Stypocaulaceae	<i>Halopteris</i>	<i>scoparium</i> <i>dichotoma</i>	
	Xanthophyceae	Vaucheriales	Vaucheriaceae	<i>Vaucheria</i>	<i>sescuplicaria</i> <i>synandra</i>	
Rhodophyta	Rhodophyceae	Acrochaetiales	Acrochaetiaceae	<i>Acrochaetium</i>	<i>daviesii</i> <i>leptonema</i> <i>mediterraneum</i> <i>reductum</i> <i>savianum</i> <i>secundatum</i> <i>virgatulum</i>	
		Bangiales	Bangiaceae	<i>Bangia</i> <i>Porphyra</i>	<i>atropurpurea</i> <i>leucosticta</i> <i>yezoensis</i> [*]	
		Ceramiales	Ceramiaceae	<i>Aglaothamnion</i> <i>Antithamnion</i> <i>Callithamnion</i>	<i>byssoides</i> <i>cruciatum</i> <i>nipponicum</i> [*] <i>corymbosum</i> <i>tetragonum</i>	

Appendix A (Continued)

Phylum	Class	Order	Family	Genus	Species	Lagoon
				<i>Centroceras</i>	<i>clavulatum</i>	
				<i>Ceramium</i>	<i>ciliatum</i> <i>codii</i> <i>diaphanum</i> <i>flaccidum</i> <i>petitii</i> <i>secundatum</i> <i>siliquosum</i> <i>strictum</i> <i>tenerrimum</i>	S M
				<i>Griffithsia</i>	<i>corallinoides</i> *	ST
				<i>Pterothamnion</i>	<i>plumule</i>	
				<i>Seirospora</i>	<i>giraudyi</i>	
				<i>Spyridia</i>	<i>filamentosa</i>	S
			Dasyaceae	<i>Dasya</i>	<i>sessilis</i> *	T
				<i>Dasysiphonia</i>	sp.*	
			Delesseriaceae	<i>Acrosorium</i>	<i>venulosum</i>	ST
				<i>Nitophyllum</i>	<i>punctatum</i>	
				<i>Radicilingua</i>	<i>reptans</i> <i>thyzanorhizans</i>	ST
			Rhodomelaceae	<i>Alsidium</i>	<i>corallinum</i>	T
				<i>Chondria</i>	<i>capillaris</i> <i>coerulescens</i> * <i>dasyphylla</i>	S S
				<i>Halopithys</i>	<i>incurva</i>	ST
				<i>Herposiphonia</i>	<i>parca</i> *	
				<i>Laurencia</i>	<i>microcladia</i> <i>okamurae</i> *	T
				<i>Lophosiphonia</i>	<i>obscura</i>	
				<i>Osmundea</i>	<i>truncata</i>	S
				<i>Polysiphonia</i>	<i>atlantica</i> <i>brodiei</i> <i>denudate</i> <i>elongata</i> <i>furcellata</i> <i>harveyi</i> * <i>morrowii</i> * <i>opaca</i> <i>paniculata</i> * <i>sertularioides</i>	T S

Appendix A (Continued)

Phylum	Class	Order	Family	Genus	Species	Lagoon
					<i>setigera</i>	
					<i>subulate</i>	
				<i>Pterosiphonia</i>	<i>pennata</i>	
					<i>tanakae</i> *	T
				<i>Rytiphloea</i>	<i>tinctorial</i>	T
		Corallinales	Corallinaceae	<i>Corallina</i>	<i>elongata</i>	
				<i>Hydrolithon</i>	<i>farinosum</i>	
				<i>Jania</i>	<i>rubens</i>	
				<i>Lithophyllum</i>	<i>yessoense</i> *	
				<i>Lithothamnion</i>	sp.	
				<i>Phymatolithon</i>	<i>lenormandii</i>	
				<i>Pneophyllum</i>	<i>confervicola</i>	
					<i>fragile</i>	
				<i>Titanoderma</i>	<i>pustulatum</i>	
		Erythropeltidales	Erythropeltidaceae	<i>Erythrotrichia</i>	<i>carnea</i>	
					<i>investiens</i>	
					<i>simplex</i>	
				<i>Sahlingia</i>	<i>subintegra</i>	
		Gelidiales	Gelidiaceae	<i>Gelidium</i>	<i>crinale</i>	
					<i>pusillum</i>	
				<i>Pterocladia</i>	<i>capillacea</i>	
					<i>melanoidea</i>	
		Gigartinales	Areschougiaceae	<i>Agardhiella</i>	<i>subulata</i> *	ST
				<i>Solieria</i>	<i>filiformis</i> *	
			Gigartinaceae	<i>Chondracanthus</i>	<i>acicularis</i>	
				<i>Chondrus</i>	<i>giganteus</i> *	T
			Hypneaceae	<i>Hypnea</i>	<i>musciiformis</i>	
					<i>valientae</i> *	T
			Peyssonneliaceae	<i>Peyssonnelia</i>	<i>dubyi</i>	
			Phylloporaceae	<i>Ahnfeltiopsis</i>	<i>flabelliformis</i> *	T
				<i>Gymnogongrus</i>	<i>griffithsiae</i>	
		Goniotrichales	Goniotricaceae	<i>Chroodactylon</i>	<i>ornatum</i>	S
				<i>Stylonema</i>	<i>alsidii</i>	
		Gracilariales	Gracilariaceae	<i>Gracilaria</i>	<i>bursa-pastoris</i>	BST
					<i>dura</i>	T
					<i>gracilis</i>	BMT
					sp.	M
				<i>Gracilariopsis</i>	<i>longissima</i>	T

Appendix A (Continued)

Phylum	Class	Order	Family	Genus	Species	Lagoon
		Halymeniales	Halymeniaceae	<i>Grateloupia</i>	<i>turuturu</i> [*] <i>filicina</i> <i>lanceolata</i> [*] <i>asiatica</i> [*]	T
				<i>Halymenia</i> <i>Prionitis</i>	<i>floresia</i> <i>patens</i> [*]	T
		Nemaliales	Liagoraceae	<i>Nemalion</i>	<i>helminthoides</i>	
		Palmariales	Rhodophysemataceae Rhodothamniellaceae	<i>Rhodophysema</i> <i>Rhodothamniella</i>	<i>georgii</i> [*] <i>codicola</i> [*]	
		Plocamiales	Plocamiaceae	<i>Plocamium</i>	<i>cartilagineum</i>	
		Rhodymeniales	Champiaceae	<i>Champia</i> <i>Chylocladia</i> <i>Gastroclonium</i>	<i>parvula</i> <i>verticillata</i> <i>clavatum</i>	
			Lomentariaceae	<i>Lomentaria</i>	<i>clavellosa</i> <i>hakodatensis</i> [*]	
			Rhodymeniaceae	<i>Chrysymenia</i>	<i>wrightii</i> [*]	ST

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