# Biodiversity partitioning for transitional water ecosystems

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***Abstract.*** *Biodiversity partitioning means that the biodiversity of all individuals in a given meta-community may be split into the diversity within and between local communities. In this work we adopt diversity measures based on the deformed exponential transformation of the Tsallis entropy to analyze biodiversity partitioning in the Po River Delta. Several measures are investigated with varying importance given to rare species. Mixed effects models are then used to investigate the variation of diversity measures with fixed effects such as vegetation cover and sediment type and random effects ruled by nested sources of variability.*

***Keywords.*** *Shannon entropy; Biodiversity decomposition; Mixed effects models*

## 1 Introduction

Lagoon ecosystems are highly heterogenous and often characterized by patchiness due to chemical, physical, morphological, hydrodynamic or functional factors. In the last few years increasing attention has been granted to changes in the biodiversity of the benthic macroinvertebrate community within these environments, acknowledging the economic importance of lagoons through their provision of ecosystem services such as nutrient cycling, flood control, shoreline stabilization, water quality improvement, fish-

eries resources, habitat and food for migratory and resident animals and recreational areas for humans ([3], [1]).
As phytoplankton and rooted aquatic macrophytes are being replaced by floating macro algae and human pressures (i.e. clams breeding, navigation, etc.) modify shore environments that used to be rich in *Phragmites*, the role of vegetation modifications in lagoon macrobenthic diversity assessment is increasingly investigated. It is known that the annual life course of floating macro algae has two main phases corresponding to the warm and cold season and that different key macrobenthic species respond to both microhabitat and seasonal differences, adding complexity to the variability of lagoon ecosystems. From a conservational point of view several questions arise. What is the importance of the biodiversity of a single microhabitat with respect to the entire lagoon ecosystem? Which microhabitats contribute more to the entire ecosystem biodiversity? Is it possible to maintain lagoon biodiversity preserving only the most diverse microhabitat or should we care more about the conservation of ecosystem peculiarities? In conclusion should we consider a lagoon as a combination of microhabitats and can we identify a microhabitat more representative than others?
The first fundamental step in trying to answer the above questions is the choice of a biodiversity measure and an appropriate definition of the aggregation level or local community (monitoring station, microhabitat, lagoon, system of lagoons). Many biodiversity measures, including the number of species and Simpson and Shannon indices, can be viewed in a unified framework as special cases of the Tsallis entropy. Given a discrete set of probabilities $\{p_i\}$ and any real number $q$, the Tsallis entropy of order $q$ is defined as

$$H_q(p) = \frac{1}{q-1}\left(1 - \sum_i p_i^q\right).$$

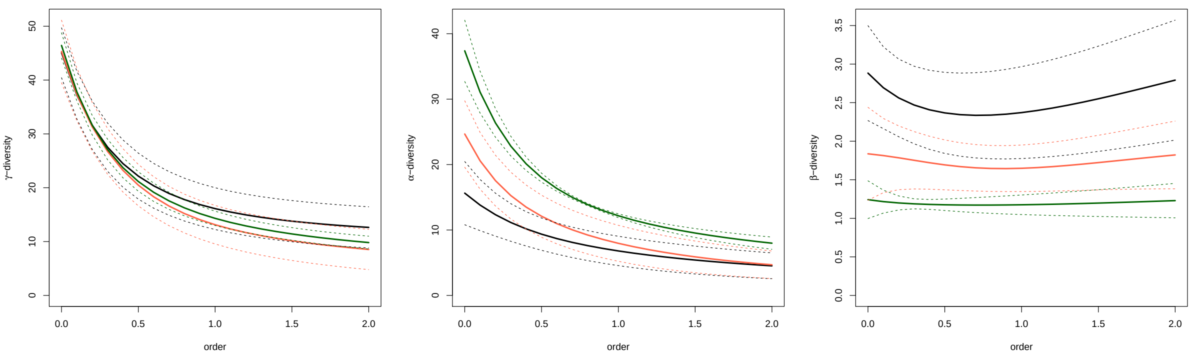
The number of species is the Tsallis entropy of order $q = 0$, while Shannon's and Simpson's indices respectively correspond to $q = 1$ and $q = 2$, then the importance given to rare species decreases continuously with $q$. Diversity is obtained taking the *deformed exponential* transformation of the entropy: $D_q(p) = e_q(H_q)$. For $x < \frac{1}{q-1}$ the deformed exponential transformation of order $q$ is defined as

$$e_q(x) = [1 + (1-q)x]^{\frac{1}{1-q}}$$

with the standard exponential obtained as a special case when $q = 1$.
Diversity measures are traditionally partitioned into *gamma* ($\gamma$), *alpha* ($\alpha$) and *beta* ($\beta$) diversity [5], where $\gamma = \alpha \times \beta$. Biodiversity partitioning means that the gamma biodiversity of all individuals in a given meta-community may be split into alpha and beta biodiversity, that respectively reflect the diversity within and between local communities. The mathematical equivalence of the multiplicative partition of a generalized biodiversity measure to the additive decomposition of the Tsallis entropy is given in [4], where the authors define beta entropy as the average generalized Kullback-Leibler divergence between local communities and their average distribution. They also propose estimation bias corrections that can be applied to the Tsallis entropy to obtain, after deformed exponential transformation, easy-to-interpret components of biodiversity.
The present study is part of a larger investigation involving two areas on the Eastern Italian coasts: the Po River Delta and four lagoons in the Apulia region. In this work we first analyze biodiversity partitioning in the Po River Delta with the order of the generalized diversity measure varying in a specified range and for alternative definitions of the local communities. The variation of biodiversity indices corresponding to a set of selected orders is then analyzed by mixed effects models properly accounting for fixed and nested sources of variability. In the following we only report results for the Po Delta database, while the same approach will be adopted to analyze the Apulian lagoons in future works.

## 2 Data and Results

Data on benthic macroinvertebrates were originally collected from three systems of lagoons, (Goro, Fattibello and Comacchio) in the Po River Delta area (Northern Adriatic Sea) and from four lagoons in the Apulian region (Southern Adriatic Sea). The selected lagoons present from one to three dominant habitat types defined by a factorial classification of sediment granulometry (sand, mud) and vegetation cover/type (without vegetation, submerged macrophyte, emerged macrophytes and macroalgae) as in [2]. Here, we only consider the data of the Po Delta area. In every lagoon field sampling campaigns were performed with one to three sampling stations per habitat type. Three replicates per monitoring station were sampled in the period 1997-2000 with a van Veen grab (area 0.06 m2). In the laboratory, benthic samples were sorted under a stereomicroscope, identified to the lowest possible taxonomic level and counted. To summarize, the Delta database includes 3 replicates at each of 21 monitoring stations divided in 9 lagoons belonging to 3 systems. Diversity indices are computed at every monitoring station distinguishing several situations characterized by different combinations of month/season, vegetation cover and sediment type of the relative monitoring station. In Fig. 1 we report the partitioning of the gamma biodiversity into alpha and beta biodiversity for a range of values of the index order and 3 alternative definitions of the local communities: monitoring station, lagoon and system of lagoons. 95% bootstrap confidence intervals are also included in the plots. As expected gamma biodiversity does




(a) (b) (c)

Figure 1: Biodiversity indices (solid) and their bootstrap 95% confidence intervals (dashed) for alternative definitions of the local communities (black - monitoring station, light red - lagoon, dark green - system of lagoons): (a) gamma diversity, (b) average alpha diversity and (c) beta diversity

not change according to the definition of the local communities and both gamma and alpha biodiversity increase with the importance given to rare species. Alpha biodiversity is obviously larger for larger local communities (system) while the opposite holds for beta biodiversity. Beta biodiversity reaches a minimum for $q \in (0.5, 0.9)$ and increases for extreme values of $q$ i.e. when the importance given to rare species is very high or minimal. This effect is more evident when local communities are small (station). An interesting feature of the beta index is that the magnitude of its value decreases with the increasing size of the local community suggesting that the largest the community the smallest the differences among them. This same feature is reflected in the random effects evaluation in the models estimated below. A further investigation of biodiversity within microhabitats identified by vegetation and sediment focusing on $\alpha$ diversity characterized by vegetation and by sediment type at the monitoring station level shows that sediment type is not a discriminant factor, while two situations are identified by the vegetation factor:

presence of macro algae versus all other type of vegetation. The first corresponding to larger values of the $\alpha$ diversity for all values of $q$. These exploratory results suggest to consider at least two different characterization of monitoring stations with respect to vegetation in models evaluations: one including all vegetation types and a dichotomous one opposing the presence of macro algae to all other situations.

### 2.1 A multilevel mixed effects model for the Delta data

The variation of biodiversity indices corresponding to a set of selected order levels is analyzed by multi-level mixed effects models accounting for fixed and nested sources of variability:

$$y_{rmls} = \mu + \beta_1 x_{1,rmls} + \beta_2 x_{2,mls} + \beta_3 x_{3,mls} + b_s + b_{ls} + b_{mls} + \varepsilon_{rmls} \quad (1)$$

where $y_{rmls}$ is the value of the biodiversity index, with $r = 1,\ldots,12$ for months, $m = 1,\ldots,21$ for monitoring stations, $l = 1,\ldots,10$ for lagoons and $s = 1,2,3$ for systems of lagoons. The previous model accounts for the fixed effect of the season (factor $x_1$), of the presence of macroalgae ($x_2$) and of two sediment types ($x_3$). Random effects of the system of lagoons ($b_s$), of the lagoon ($b_{ls}$) and of the monitoring station ($b_{mls}$) reflect the nested grouping structure of the local communities. Model comparison shows the general relevance of macroalgae and sediment type in determining the biodiversity variation. In particular when rare species are taken into account ($q = 0$) the sediment type seems to be relevant, while higher order indices seems less sensitive this factor.
In conclusion we observe that microhabitats are in general properly defined in terms of the presence of macroalgae. Sediment only appears to be influential for the presence and abundance of rare species. We adopt the Shannon index for further investigation as customary when analyzing biodiversity in a conservational perspective. Fitting model (1) with $q = 1$ we obtain that the most relevant random effect is at the system level and the smallest at the lagoon level, suggesting relevance of two different spatial scales to explain biodiversity variation in the Po Delta area: the monitoring stations i.e. the local microhabitats and the aggregation of lagoons into systems.

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