

1 **The efficiency of Taxonomic Sufficiency for identification of spatial patterns at**  
2 **different scales in transitional waters**

3  
4 Valentina Pitacco<sup>a</sup>, Michele Mistri<sup>a</sup>, Ida Floriana Aleffi<sup>b</sup>, Claudio Lardicci<sup>c</sup>, Susanna Prato<sup>d</sup>, Davide  
5 Tagliapietra<sup>e</sup>, Cristina Munari<sup>a</sup>

6 *<sup>a</sup>Department of Chemical and Pharmaceutical Sciences, University of Ferrara, Via Fossato di*  
7 *Mortara 17, 44121 Ferrara, Italy*

8 *<sup>b</sup>ARPA FVG, Osservatorio Alto Adriatico, Via La Marmora 13, 34139 Trieste, Italy*

9 *<sup>c</sup>Department of Biology, University of Pisa, Via Derna 1, 56126 Pisa, Italy*

10 *<sup>d</sup>ENEA, Via Anguillarese 301, 00123 Roma, Italy*

11 *<sup>e</sup>CNR-ISMAR, Arsenale di Venezia, Tesa 104, 30122 Venezia, Italy*

12  
13 *\*Corresponding author: [mism@unife.it](mailto:mism@unife.it) (M. Mistri)*

14 *Tel: +39 0532 455736; Fax: +39 0532 249761*

15

16 **Abstract**

17 Taxonomic Sufficiency (TS), the use of coarser taxonomic resolution in monitoring plans, has been  
18 receiving increasing attention in last years. A comprehensive dataset of macrobenthos from 18  
19 Italian lagoons in a range of different latitude, typology, salinity and surface area, was analysed in  
20 order to test the efficiency of TS, in terms of correlation between patterns at level of species and  
21 patterns resulting from different levels of taxonomic aggregation. First, TS was applied on a range  
22 of univariate indices, providing complementary information on macrobenthic community, in order  
23 to test the efficiency, in a contest of different taxonomic composition, and different number of  
24 lower taxa belonging to the same higher taxon in each lagoon. Then, TS was applied on multivariate  
25 analyses, in order to test whether the efficiency changes between two different scales: local  
26 (comparison of sites nested within each lagoon) and regional (comparison among lagoons), and  
27 with different data transformation. The patterns resulting from univariate indices and multivariate  
28 analyses, at both local and regional scales, were retained till family level, despite the different levels  
29 of taxonomic composition and different number of lower taxa belonging to the same higher taxon of  
30 different lagoons. Nevertheless, the correlation values among matrices and the effect of data  
31 transformation differed between regional and local scales. Our results support the efficiency of TS  
32 until family level, but at the same time underline the need of scale- and region-specific baseline  
33 knowledge prior application of TS in lagoons.

34

35 **Keywords:** Taxonomic Sufficiency, lagoons, benthic community, multi-scale patterns,

36 Mediterranean Sea

37

## 38 **1. Introduction**

39 Taxonomic Sufficiency (TS) has been receiving increasing attention in recent years, in view of  
40 avoiding long and difficult precise taxonomic identifications and saving time and costs in marine  
41 impact assessment and monitoring (Olsgard et al., 1998). The basic concept of TS (Ellis, 1985) is  
42 that the identification of taxa at taxonomic levels higher than species enables the detection of  
43 changes in assemblages exposed to environmental stressors without significant loss of information.  
44 The use of coarser taxonomic resolution was first suggested by Warwick (1988a, 1988b) who  
45 pointed out the theoretical advantages of conducting both multivariate and univariate analyses at  
46 various hierarchical levels of taxonomic aggregation in monitoring programmes. Furthermore, the  
47 identification of organisms at a higher taxonomic level allows the analysis of a larger number of  
48 replicates, increasing the spatial representativeness of the information. Studies supporting the  
49 efficiency of TS in marine systems were later performed worldwide in different habitat types, from  
50 soft bottom (e.g. Vanderklift et al., 1996, Włodarska-Kowalczyk and Kędra, 2007) to hard bottom  
51 (e.g. Mistri and Rossi, 2000, Terlizzi et al., 2002), focusing on strong pollution gradients (Dauvin et  
52 al., 2003), and on variation along natural gradients (Terlizzi et al., 2009). In coastal transitional  
53 ecosystems, TS has been mainly applied for the description of spatial patterns of macrobenthic  
54 community in response to heavy disturbance, such as oil spill (Dauvin et al., 2003), or to compare  
55 regions with different levels of anthropogenic disturbance (Mistri and Rossi, 2001; Arvanitidis et  
56 al., 2009), but it proved useful also for the discrimination of natural gradients in estuaries (Chainho  
57 et al., 2007).

58 Coastal lagoons represent important and fragile ecosystems in the coastal landscape in many places  
59 on the globe. They provide key ecosystem services such as water quality improvement, fisheries  
60 resources, habitat and food for migratory and resident animals, protection from storms and touristic  
61 appeal (Mitsch and Gosselink, 2000; Pérez-Ruzafa et al., 2011). At the same time they are also  
62 heavily affected worldwide by human-driven pressures (Newton et al., 2014), such as urban and  
63 industrial discharges, agricultural runoff (e.g. Bellucci et al., 2000; Lillebø et al., 2005; Paerl, 2006;  
64 Acquavita et al., 2014; Arienzo et al., 2013; Barhoumi et al., 2014; Pitacco et al., 2018a), fishery,  
65 aquaculture (e.g. Viaroli et al., 2003; Sladonja et al., 2011; Munari and Mistri, 2014), and climate  
66 change (e.g. Lloret et al., 2008; Anthony et al., 2009; Pitacco et al., 2018b). Given the ecological  
67 and economic importance of transitional environments, long-term monitoring is fundamental to  
68 understand the effect of anthropogenic stressors on macrobenthic community and thus to plan  
69 efficient management for ecosystem conservation and restoration. Since those projects usually  
70 benefit from a limited financial support, TS could be a useful tool for the improvement of  
71 cost/benefits ratio, allowing a more efficient use of available resources (Chapman, 1998).

72 Most studies have usually compared different levels of TS at a single spatial scale. Recent  
73 investigations pointed out the importance of including multi-scale designs. Since processes driving  
74 species distributions vary across multiple spatial scales (Underwood & Chapman, 1996; Hewitt et  
75 al., 2007) taxonomic surrogates are expected to depend on the same scale-dependent processes  
76 (Smale, 2010). To date works investigating the effects of TS on the spatial distribution patterns at  
77 multiple scales are still scant (Dethier and Schoch, 2006; Tataranni et al., 2009; Smale, 2010;  
78 Mueller et al., 2013).

79 This paper analysed datasets of macrobenthic communities obtained through research programmes  
80 carried out on 18 lagoons, representing a random subsampled of all Italian lagoons. Among those  
81 lagoons there were all main Adriatic and Tyrrhenian Italian lagoons, with different typologies, from  
82 mesohaline to hyperhaline, non-tidal to nano- and microtidal lagoons, subjected to different  
83 anthropogenic pressures and different levels of protections. The aim of the work was to test the  
84 efficiency of Taxonomic Sufficiency in detecting different components of univariate and  
85 multivariate variability of macrobenthic assemblages in transitional waters. The efficiency of TS  
86 was estimated in terms of correlation between patterns observed at level of species and patterns  
87 resulting from different levels of taxonomic aggregation. With univariate analyses the effect of  
88 taxonomic aggregation was tested in a contest of different taxonomic composition and number of  
89 lower taxa belonging to the same higher taxon in different lagoons. With multivariate analyses  
90 (MDS, cluster, PERMANOVA) the effect of taxonomic aggregation was tested in relation with two  
91 different spatial scales: regional (spatial variability among lagoons) and local (spatial variability  
92 among sites nested within each lagoon). The effect of different data transformations (row data,  
93 square root, logarithm, presence/absence) was considered, as well.

94

## 95 **2. Materials and methods**

96 The analysed dataset was gathered during several sampling campaigns carried out in eighteen  
97 Italian lagoons. Samples were collected repeatedly over time, from all main Adriatic and  
98 Tyrrhenian Italian lagoons: Baiona, Barbamarco, Caleri, Canarin, Comacchio, Goro, Grado-  
99 Marano, Lesina, Marinetta, Palude della Rosa (north easterly part of the Venice lagoon),  
100 Scardovari, and Vallona (Adriatic Sea), Caprolace, Feraxi, Fogliano, Orbetello, Porto Pino, and San  
101 Teodoro (Tyrrhenian Sea). This dataset comprises different typology of transitional waters, from  
102 large to small, from microtidal to non-tidal, hyperhaline to mesohaline ecosystems (see

103 Table 1). A total of 107 sites nested within the lagoons, 64 of which were located in Adriatic and 43  
104 in Tyrrhenian Sea (

105 Table 1), have been chosen as representative of the different habitats found within each transitional  
106 environment. Samples were collected at least in triplicates at each site, sieved on a 0.5 mm mesh-  
107 size sieve and retained macrobenthic fauna was fixed in 8% formalin. Animals were carefully  
108 sorted, and determined in laboratory with the combined use of a stereomicroscope and a  
109 microscope, according to basic taxonomic guides (e.g. Fauvel P., 1923; 1927; Ruffo, 1982-1998;) in  
110 combination with the most recent taxa-specific relevant publications (e.g. San Martin G., 2003;  
111 Viéitez et al., 2004). The identification was performed up to the species level in most cases  
112 (exceptions were due to the poor conditions of animals). All specimens were counted and average  
113 density values per m<sup>2</sup> was calculated.

114 For the analyses at the regional scale the averages of sampling sites were used as replicates in order  
115 to compare the different lagoons, while at local scale samples were used to compare different sites  
116 nested within each lagoon. Data were aggregated to genus, family, order, class and phylum.  
117 Taxonomic classification followed the World Register of Marine Species (WoRMS) (WoRMS  
118 Editorial Board, 2018).

119 For each of the 18 Italian lagoons 'Loss of information  $\alpha$ ' ( $\alpha$ ) was calculated according to Bacci et  
120 al. (2009), through the difference  $NT_x - NT_{x+1}$ , when  $NT$  expresses the number of taxa identified  
121 at the taxonomic level  $x$ , and  $x+1$  expresses the next higher taxonomic level compared to level  $x$ .  
122 ' $\alpha$ ' values describes the loss of information on the taxonomic structure of macrobenthic settlement  
123 which can be registered at the passage from a lower ( $x$ ) to a higher ( $x + 1$ ) taxonomic level (higher  
124 values correspond to a major 'loss of information' and vice versa). The ' $\alpha$ ' value was calculated  
125 step by step from the lowest to the highest taxonomic level considered (species-genus, genus-  
126 family, family-order, order-class, class-phylum). The percentage was then calculated as follows:  
127  $(NT_x - NT_{x+1})/NT_x * 100$ .

128 For each sample the following indices were calculated: expected taxa richness (ES) calculated with  
129 rarefaction method (for number of individuals  $n = 10000$ ), Simpson index ( $\lambda$ ), average taxonomic  
130 distinctness ( $\Delta^+$ ) calculated on presence/absence data, and variation in taxonomic distinctness ( $\lambda^+$ ).  
131 Those indices were chosen to provide complementary information on macrobenthic community,  
132 from richness (number of species, ES), to structure (combination of richness and abundances,  $\lambda$ ), to  
133 taxa identities (taxonomic distance,  $\Delta^+$  and  $\lambda^+$ ). All those indices are independent from sampling  
134 effort (Clarke and Warwick, 2001), and were calculated for matrices at different taxonomic levels,  
135 with PRIMER v6 + PERMANOVA software package (Anderson et al., 2008, Clarke and Gorley,  
136 2006). To test the consistency of univariate indices across different levels of taxonomic  
137 aggregation the Spearman's rank correlation coefficient ( $r_s$ ) was calculated for each index step by  
138 step from the lowest to the highest taxonomic level (species-genus, genus-family, family-order,

139 order-class, class-phylum). Those calculations were performed using R version 2.4.0 (R  
140 Development Core Team, 2008).

141 For regional scale analyses (differences among lagoons), an abundance matrix with average taxa  
142 density for each lagoon was produced for each of the six taxonomic levels (species, genus, family,  
143 order, class, and phylum), and for each of four different transformations (none, square-root,  
144 logarithm, and presence/absence). The affinities among lagoons were established using Bray–Curtis  
145 similarity and a second-stage non-metric Multi-Dimensional Scaling (MDS) ordination was plotted  
146 to visualize differences among similarity matrices at different levels of taxonomic aggregation and  
147 data transformation. As a measure of similarity between those resemblance matrices, Spearman’s  
148 rank correlation coefficient ( $r_s$ ) was calculated and tested using RELATE, a non-parametric  
149 analogue to the Mantel test, using 9999 permutations. The stress of the two-dimensional plot was  
150 calculated using Kruskal’s stress Formula 1 (Clarke and Green, 1988). Stress is a measure of the  
151 reliability of the representation, a value  $< 0.1$  is considered a good result (Clarke and Warwick,  
152 2001). In order to check the efficiency of MDS ordination in discriminating among lagoons,  
153 “Hierarchical Clustering Analysis” was performed on each of the six matrices based on average  
154 abundances for each lagoon: species, genus, family, order, class, and phylum matrix. Bray–Curtis  
155 similarity was calculated on untransformed data and group average was used as agglomeration  
156 method. In order to test the significance of variations in taxa-abundance matrices among the groups  
157 identified by cluster analysis, permutational multivariate analysis of variance, PERMANOVA  
158 (Anderson et al., 2008) was carried out on the six matrices corresponding to the different  
159 taxonomical levels. A single factor design (with number of levels corresponding to the number of  
160 cluster groups) and the “unrestricted permutation of row data” with 9999 permutations was chosen,  
161 as recommended in Anderson et al. (2008). A multivariate analogue of  $t$ -statistic was used for  
162 subsequent pairwise comparisons (Anderson et al., 2008). The same procedure was followed for  
163 each type of data transformations.

164 For the local scale analysis (differences among sites within lagoons), abundance matrices were  
165 produced separately for each lagoon, for each of the same six taxonomic levels, and for each of  
166 same four different transformations. The affinities among sites within each lagoon were established  
167 using Bray–Curtis similarity and for each data set, a second-stage matrix was created to visualize  
168 differences among different levels of taxonomic aggregation. Lagoons from Po river delta in Veneto  
169 region (Barbamarco, Caleri, Canarin, Marinetta, Scardovari and Vallona) were considered together  
170 (as DV), given the low number of sites for each lagoon (2-5). To test the consistency of the effect of  
171 different levels of aggregation across the studied lagoons, a third-stage resemblance matrix was  
172 built using second stage matrices constructed for each lagoon. Third-stage resemblance matrix is

173 defined as a second second-stage resemblance matrix constructed using rank correlations between  
174 corresponding elements in the set of second-stage matrices (following Arvanitidis et al., 2009). A  
175 third-stage resemblance matrix was built for each data transformation. Spearman's rank correlation  
176 coefficient ( $r_s$ ) was calculated between matrices, and the stress of the two-dimensional plot was  
177 calculated using Kruskal's stress Formula 1 (Clarke and Green, 1988). All those calculations were  
178 performed with PRIMER v6 + PERMANOVA software package (Anderson et al., 2008, Clarke and  
179 Gorley, 2006).

180 For all analyses a  $p < 0.05$  was chosen as significant threshold.

181

### 182 **3. Results**

183 The total 'loss of information  $\alpha$ ', from species to phylum level, did not showed a general pattern,  
184 but was highly variable among lagoons (Fig. 1), showing the highest value (120) at CA and the  
185 lowest (16) at VA. The highest percentage of loss ( $\alpha$ ) from species to genus level was observed at  
186 CO (19%), and the lowest at SC (2%). At MA, VA, BR, and CN, loss of information ( $\alpha$ ) at this  
187 level was null, because every genus was represented by only one species. Loss of information ( $\alpha$ )  
188 between genus and family levels was higher than zero in every lagoon, with percentages ranging  
189 from 5% at FE to 35% at GM, indicating the presence of families with more than one genus. Loss  
190 of information ( $\alpha$ ) was higher than zero also at family-order level (from 19% at CN and BA to 44%  
191 at FE), order-class level (from 13% at CO to 38% at PP), and class-phylum level (from 3% at GO,  
192 PR, CA and FE to 19% at CN). In most lagoons the highest percentage of loss was observed  
193 between family and order, with the exception of CA, FO and GM, showing the highest loss between  
194 genus and family, and of VA, CN, PP, and BA showing the highest loss between order and class  
195 levels.

196 The consistency of the pattern of variation across taxonomic levels varied among univariate indices  
197 (Fig. 2). Pairwise comparison between estimated taxa richness (ES) at different taxonomic levels  
198 showed very strong correlation up to the order level (species/genus, genus/family, and family/order,  
199  $r_s > 0.9$ ), and a progressive reduction of similarity between ES calculated at higher taxonomic levels  
200 (order/class and class/phylum, Fig. 2). Pairwise comparison between Simpson index ( $\lambda$ ) at different  
201 taxonomic levels showed very strong correlation ( $r_s > 0.9$ ) up to class levels (species/genus,  
202 genus/family, family/order, and order/class), and much weaker correlation between class and  
203 phylum level (Fig. 2). Conversely the pairwise comparison of indices based on taxonomic distance  
204 ( $\Delta^+$  and  $\lambda^+$ ) showed very strong correlation only between species and genus level ( $r_s > 0.9$ ). Average  
205 taxonomic distinctness ( $\Delta^+$ ) showed strong correlation ( $r_s > 0.7$ ) between genus and family, and  
206 between family and order, whereas correlation between  $\Delta^+$  at order and class level was weaker (Fig.



207 2). Variation in taxonomic distinctness ( $\lambda^+$ ) showed weaker but significant correlation between  
208 genus and family, and between family and order levels ( $r_s < 0.7$ ), and not significant correlation ( $p >$   
209  $0.05$ ) between order and class levels (Fig. 2).

210 From regional scale analyses (differences among lagoons) the similarity with the original matrix  
211 (species-level data) decreased with increasing taxonomic level (from genus to phylum) with all four  
212 transformations considered (Fig. 3). Similarity among matrices from species to genus, and from  
213 species to family increased with the strength of transformation (with the exception of  
214 presence/absence transformation from species to family level), whereas from species to higher  
215 levels (order to phylum), similarity decreased with increasing strength of the transformation. In  
216 particular correlations between ordination plots at species and genus levels ranged from  $r_s = 0.81$  for  
217 untransformed data to  $r_s = 0.93$  for presence/absence transformation; between species and family  
218 levels varied from  $r_s = 0.72$  for untransformed data to  $r_s = 0.79$  for logarithmic transformation,  
219 indicating a general lower loss of information with stronger transformation. Conversely correlation  
220 between similarity matrices at species and order levels varied from  $r_s = 0.60$  (presence/absence) to  $r_s$   
221  $= 0.63$  (untransformed and logarithm); between species and class aggregation matrices varied from  
222  $r_s = 0.44$  (square root) to  $r_s = 0.60$  (presence/absence); and between species and phylum aggregation  
223 varied from  $r_s = 0.18$  (presence/absence) to  $r_s = 0.50$  (untransformed), indicating higher loss of  
224 information with stronger transformation, in particular between class and phylum levels.

225 PERMANOVA highlighted significant differences ( $p < 0.05$ ) in macrobenthic assemblages among  
226 groups identified by ordination plot and cluster analysis at the species level with all four  
227 transformations (none, square root, logarithm and presence-absence), but the number of groups  
228 identified by the cluster analysis decreased with increasing strength of the transformation (Table 2),  
229 indicating increases of similarity among lagoons. For each of the four transformations, the  
230 differences among cluster groups were still significant at higher taxonomic levels, with the only  
231 exception of presence/absence data at the level of phylum (Table 2). Pair-wise comparisons  
232 revealed that not all possible pairwise combinations among cluster groups differed significantly, but  
233 the number of significant pairwise differences was consistent moving from species to higher  
234 taxonomic levels, with the only exception of the level of phylum (Table 2). Cluster plots are  
235 available as Supplementary material (Appendix 1-4).

236 From local scale analyses (differences among sites within each lagoon), the third-stage matrices  
237 (Supplementary material, Appendix 5) showed that the pattern of similarity among matrices with  
238 different levels of taxonomic aggregation varied among studied lagoon. Those differences, in  
239 general, were higher at higher taxonomic levels, and decreased with increasing strength of  
240 transformation (with the exception of few lagoons). Considering each lagoon separately, in most

241 cases the correlation with the original matrix decreased with increasing taxonomic level (from  
242 genus to phylum) with all four transformations considered (Fig. 4). Correlation between species  
243 matrices and matrices at higher taxonomic levels generally decreased with increasing strength of  
244 transformation, with two exceptions: ST lagoon, where  $r_s$  was more or less constant, and PP lagoon,  
245 where the opposite trend was observed. For untransformed data (Fig. 4A) the majority of lagoons  
246 showed very strong correlation among matrices (second-stage  $r_s \geq 0.9$ ) until family (GM), order  
247 (LE, DV, GO, FO, FE, CA, CO, OR, PR), or even class level (BA). At PP the matrix at species  
248 level showed strong correlation (second-stage  $r_s \geq 0.8$ ) with matrices up to order levels. At ST  
249 lagoon instead, matrices showed an extremely low loss of information until the class level (second-  
250 stage  $r_s = 1$ ). For square root-transformed data (Fig. 4B), all lagoons showed very strong correlation  
251 between matrices (second-stage  $r_s \geq 0.9$ ) until family (ST, FE, GM), order (CO, GO, PR, DV, LE,  
252 OR, CA, FO) or even class level (BA). At PP matrix at species level showed strong correlation  
253 (second-stage  $r_s \geq 0.8$ ) with matrices up to order levels. At ST lagoon it showed very strong  
254 correlation until class level (second-stage  $r_s = 1$ ), with the exception of correlation between species  
255 and order (second-stage  $r_s = 0.5$ ). For log-transformed data (Fig. 4C), most lagoons showed very  
256 strong correlation among matrices (second-stage  $r_s \geq 0.9$ ) until family level (GM, FO, GO, DV, FE,  
257 BA) or order level (PR, CA, OR, LE, OR). At PP species matrix showed strong correlation with  
258 matrices until order level (second-stage  $r_s \geq 0.8$ ). Species matrices at ST showed very strong  
259 correlation (second-stage  $r_s = 1$ ) even up to class level. For presence/absence data (Fig. 4D) lagoons  
260 showed very strong correlation between matrices (second-stage  $r_s \geq 0.9$ ) until the family level (FE,  
261 GO, GM, LE, OR, CA, PR, FO, CO, and DV). At BA species matrix showed very strong  
262 correlation ( $r_s \geq 0.9$ ) with the matrix at genus level, and strong correlation with family matrix ( $r_s \geq$   
263 0.7). ST showed a peculiar pattern, with correlation between species and family (second-stage  $r_s =$   
264 1) stronger than between species and genus (second-stage  $r_s = 0.87$ ).

265

#### 266 **4. Discussion**

267 The present work provides information on the applicability of TS in transitional waters at two  
268 different scales: regional scale (among lagoons), and local scales (among sites nested within the  
269 lagoons). The analysed data set comprises all main Adriatic and Tyrrhenian Italian lagoons. Along  
270 Italian coasts there are almost 170 lagoons, but only 30 of them have a surface area bigger than 10  
271 km<sup>2</sup>, and most of them (with some exceptions, like Orbetello Lagoon) are located along the Western  
272 Adriatic coasts (Mistri et al., 2018). Notwithstanding the recent proliferation of TS studies, present  
273 knowledge is still fragmented, and factors influencing the effectiveness of TS still require a great  
274 deal of clarification, in particular in relation to different spatial and temporal scales (Dethier and

275 Schoch, 2006; Smale, 2010; Bevilacqua et al., 2018). The use of a wide range of different lagoons,  
276 differing for typologies (non-tidal to microtidal), salinity (mesohaline to hyperhaline), and subjected  
277 to different anthropogenic pressures and different levels of protections, enabled us to obtain a more  
278 general picture of the effectiveness of TS, within and among lagoons, with a supra-local  
279 perspective. Macrobenthic communities were highly variables among (regional scale) and within  
280 the analysed lagoons (local scale), and those differences were observed both with univariate and  
281 multivariate analysis. It is known that lagoons exhibit different and peculiar characteristics  
282 depending on their geographical, hydrodynamic and ecological features (Tagliapietra et al., 2009).  
283 Natural gradients of salinity, marine water renewal, nutrients, turbidity and sediment structure,  
284 together with the pressures related with human activities, produce changes at levels of macrobenthic  
285 community. The present study showed that patterns of variation of macrobenthic community  
286 detected with univariate and multivariate analyses were consistent at different taxonomic levels.  
287 Notwithstanding the differential response of some analysed lagoons to TS, in general, those patterns  
288 were consistent until the family level, and the use of higher taxonomic levels lead to more relevant  
289 changes in observed spatial patterns, consistently with previous investigations (e.g. Mistri and  
290 Rossi, 2001; Dethier and Schoch, 2006).

291 Loss of information in terms of taxa richness, described by 'α' values, varied among the studied  
292 lagoons, but did not followed a clear pattern, suggesting a dependence on the specific character of  
293 each lagoon, resulting from a combined effect of different factors (e.g. size, salinity, tidal  
294 influence). In most lagoons the highest percentage of loss was observed between family and order,  
295 or at higher levels, consistently with the suitability of family as a proper taxonomic level for TS, but  
296 at CA, FO and GM the highest percentage of loss was observed between genus and family.  
297 Notwithstanding the different values of α in different lagoons, strong correlations between levels of  
298 taxonomic aggregation until family level, were observed, for both univariate indices and for the  
299 multivariate space, as already reported from different habitats (Bacci et al., 2009).

300 Considering univariate indices, estimated taxa richness (ES) and Simpson index ( $\lambda$ ) correlated well  
301 across the different levels of taxonomic aggregation at least until order level, confirming their  
302 suitability in view of analyses based on TS. As it was expected, indices based on taxonomic  
303 distance lost information more quickly moving to higher taxonomic levels, in particular the  
304 variation in taxonomic distinctness ( $\lambda^+$ ). Nevertheless, the correlation between species and family  
305 levels for both  $\Delta^+$  and  $\lambda^+$ , suggested a reasonably low loss of information at this taxonomic level.  
306 Their use is still not widespread as classical structural indices, but they could provide a more robust  
307 indication in case of biodiversity loss (Clarke and Warwick, 2001). Some attempts to use measures  
308 of taxonomic distance in transitional waters (Mistri et al., 2001; Salas et al., 2006; Munari et al.,

309 2009) confirmed that they can add complementary information to more classical measures of  
310 biodiversity (Munari et al., 2009). Nevertheless, being based on presence/absence data, they could  
311 experience reduced discrimination power when changes involve relative abundances of organisms.  
312 Therefore, the effectiveness of such measures is still unclear and require further investigations  
313 (Bevilacqua et al., 2011), despite Rosser (2017) suggested that better performance in using higher  
314 taxa should be expected (i) when the ratio of species to higher taxa is low, (ii) in communities with  
315 high evenness and high species turnover, and (iii) when niche conservation within higher taxa is  
316 preserved.

317 Considering multivariate analyses, our results confirmed that family-level identifications are  
318 sufficient to distinguish natural spatial patterns of variability both among sites within lagoons (local  
319 scale), and among Italian transitional water bodies (regional scale). The loss of information about  
320 the general structure of macrobenthic assemblages from species to family taxonomic level is  
321 limited, irrespective of the transformation used. In fact, correlations between matrices at species and  
322 at family levels were very high ( $r_s \geq 0.9$ ) or high (only one case  $r_s \geq 0.7$  for presence/absence data at  
323 BA) across all lagoons (local scale) and data transformations. Correlation was high ( $r_s \geq 0.7$ ) also  
324 among species and family matrices with average abundances for each lagoon (regional scale) across  
325 every data transformation. Our results are consistent with previous investigations proving that  
326 analyses based on family abundances were effective in detecting spatial patterns in transitional  
327 areas (Mistri and Rossi, 2001; De Biasi et al., 2003; Dethier and Schoch, 2006; Munari et al., 2009;  
328 Tataranni et al., 2009). Family level is usually also considered the best compromise between the  
329 loss of information and the time gained in sorting and identification at coarser levels than species  
330 (Mistri and Rossi, 2001; De Biasi et al., 2003). One of the given explanations for the efficiency of  
331 TS in transitional systems is that in brackish environments species are not particularly prone to  
332 speciation due to short evolutionary time allowed by the highly fluctuating environment; therefore,  
333 sympatric speciation pattern is often reduced or absent, and most families are represented by a  
334 single species (Giangrande et al., 2005). Nevertheless, the different values of  $\alpha$  (loss of information)  
335 observed in the present work suggested different levels of taxonomic heterogeneity, with different  
336 number of taxa belonging to the same higher taxon, among different lagoons. Those differences did  
337 not affect TS efficiency at family level. This result is consistent with investigations in different  
338 marine ecosystems (Bacci et al., 2009; Bevilacqua et al., 2009), demonstrating that even in presence  
339 of high taxonomic heterogeneity, a high number of species, genera and families can make the  
340 macrobenthic assemblage structure stable and diverse up to family level, compensating the loss of  
341 information at the passage to the higher taxonomic level. Warwick (1993), pointed out that families  
342 generally represent fairly homogeneous groups of organisms sharing basic functional traits.

343 However, the level of such intra-family functional redundancy could depend on the classification  
344 criteria adopted and on taxonomic traditions (Bertrand et al., 2006), which may be not consistent  
345 across phyla (Warwick and Somerfield, 2008), and could explain the differential response of  
346 different phyla to TS, reported from different habitats (Olsgard and Somerfield, 2000; Bevilacqua et  
347 al., 2009). Consequently, transitional waters should be particularly suitable for TS, since they are  
348 highly fluctuating environments, with macrobenthic community showing high levels of functional  
349 redundancy (e.g. Mistri et al., 2001; Munari et al., 2005; Pitacco et al., 2018b).

350 As already found elsewhere (e.g. Olsgard et al., 1998; Anderson et al., 2005; Włodarska-Kowalczyk  
351 and Kędra, 2007; Bevilacqua et al., 2009), this study showed that the choice of data transformation  
352 could influence the results of analyses as well as the level of taxonomic aggregation, or even more.  
353 For the analyses at local scale (differences among sites within lagoons), in most lagoons a reduction  
354 of similarity between matrices with different taxonomic levels was observed with increasing  
355 strength of data transformation, and the same was observed also at regional scale (differences  
356 among lagoons) for matrices at levels of order, class and phylum. A similar pattern has been  
357 observed in different habitats (e.g. Chapman, 1998; Clarke and Warwick, 2001; Anderson et al.,  
358 2005), suggesting untransformed or mildly transformed data as the best options for TS. Data  
359 transformation reduces the weight of the most abundant taxa. The structure of macrobenthic  
360 communities typical of lagoons is a numeric dominance of few species, so without data  
361 transformation this pattern of dominance could be easily transmitted to higher taxonomic levels,  
362 since dominant species are usually taxonomically distant (e.g. Marchini et al., 2008). Conversely  
363 with a strong transformation such as the conversion to presence/absence data, the dominance effect  
364 disappeared and taxonomic complexity, considering also rare and less frequent species prevailed. At  
365 the same time, analysing species, genus, and family matrices at regional scale (differences among  
366 lagoons), the similarity among lagoons increased with increasing strength of transformation,  
367 suggesting that in view of TS (with aggregation at family level) data transformation, even strong,  
368 should be the best choice. Those differential responses were most probably the results of complex  
369 interactions between the effect of taxonomic resolution and data transformation on macrobenthic  
370 community variability at different scales. Our results are consistent with a previous investigation in  
371 another habitat type: Anderson et al. (2005), showed that variability of benthic assemblages  
372 associated with kelp holdfast at species level was mainly “compositional” at larger scales, whereas  
373 it was driven by changes in relative abundance at medium or smaller scales, particularly by  
374 numerically dominant taxa. The relative importance of the two components (composition and  
375 abundance) across the different scales, changed at higher taxonomic levels (Anderson et al., 2005).  
376 Also considering the dataset analysed with the present study, the compositional aspect of the

377 community had a higher weight on variability at regional scale compared to local scale. Moreover,  
378 both the scale and the taxonomic level considered had a differential influence on the effect of data  
379 transformation. The traditional theory in the field of TS, suggested that in the absence of previous  
380 knowledge, untransformed data should be analysed, since is often difficult to recognize a priori how  
381 environmental variation will affect the structure of assemblages (Bevilacqua et al., 2009).  
382 Nevertheless, it was already pointed out that the choice of data transformation should result from  
383 biological questions, since it determines the relative contribution of quantitative and qualitative  
384 inter-sample differences in the final outcome of multivariate analyses (Tataranni et al., 2009). A  
385 weak transformation gives a narrow view of the community, deeply influenced by the most  
386 abundant taxa, whereas a strong transformation yields a wider view of the community, where all  
387 taxa have the same weight (Mistri and Rossi, 2001). Our results, together with other previous  
388 investigations (i.e. Anderson et al., 2005) suggested additional care in the choice of data  
389 transformation, since its effect could vary across different scales, and different taxonomic levels.  
390 Since the most frequent disturbance events (e.g. organic enrichment, eutrophication, chemical  
391 pollution) are likely related to changes in spatial patterns of assemblages (Warwick and Clarke,  
392 1993; Tataranni et al., 2009) TS may be usefully applied to monitoring programs of lagoon systems.  
393 TS application would make those programs more cost-effective, since the time necessary to process  
394 samples would be markedly reduced. Chapman (1998) estimated that in the same time that it takes  
395 to sort a given number of samples to the finest possible resolution, twice or more samples could be  
396 sorted to major groups. This improvement of the cost/benefit ratio would be particularly important  
397 in highly fluctuating habitat, such as transitional waters, where sampling frequency is particularly  
398 important. The use of TS in monitoring programs required by national laws, would consequently  
399 result in a consistent reduction of cost for Environmental Agencies.  
400 Our study provides evidences of the suitability of this technique at different scales, and in lagoons  
401 with different taxonomic complexity. Nevertheless, a different response to TS, at regional and local  
402 scales, suggested caution in generalising outcomes, and in the choice of data transformation.  
403 Moreover, prior to application of TS, region-specific baseline knowledge of each lagoon system,  
404 regarding macrobenthic community (at species level), main natural and anthropogenic stressors, and  
405 their effect on macrobenthic community, is fundamental. In addition, as suggested by previous  
406 investigations (e.g. Dethier and Schoch, 2006, Tataranni et al., 2009; Vieira et al., 2015), analyses at  
407 finer taxonomic level should be performed periodically and whenever a change in spatial pattern is  
408 detected or there are reasons to suspect that a given region is suffering from some new stressor, to  
409 which the response of the community is unknown, or when the effects of subtle environmental  
410 impacts may pass unnoticed with the use of low taxonomic resolution data.



412 **References**

- 413 Acquavita, A., Falomo, J., Predonzani, S., Tamberlich, F., Bettoso, N., Mattassi, G., 2014. The  
414 PAH level, distribution and composition in surface sediments from a Mediterranean Lagoon: the  
415 Marano and Grado Lagoon (Northern Adriatic Sea, Italy). *Mar. Pollut. Bull.* 81, 234-241.
- 416 Anderson, M.J., Connell, S.D., Gillanders, B.M., Diebel, C.E., Blom, W.M., Saunders, J.E.,  
417 Landers, T.J., 2005. Relationships between taxonomic resolution and spatial scales of  
418 multivariate variation. *J. Anim. Ecol.* 74, 636-646.
- 419 Anderson, M.J., Gorley, R.N., Clarke, K.R., 2008. PERMANOVA+ for PRIMER: Guide to  
420 Software and Statistical Methods. PRIMER-E, Plymouth, United Kingdom.
- 421 Anthony, A., Atwood, J., August, P., Byron, C., Cobb, S., Foster, C., Fry, C., Gold, A., Hagos, K.,  
422 Heffner, L., 2009. Coastal lagoons and climate change: ecological and social ramifications in US  
423 Atlantic and Gulf coast ecosystems. *Ecol. Soc.* 14, 8.
- 424 Arienzo, M., Masuccio, A., Ferrara, L., 2013. Evaluation of sediment contamination by heavy  
425 metals, organochlorinated pesticides, and polycyclic aromatic hydrocarbons in the Berre coastal  
426 lagoon (southeast France). *Arch. Environ. Contam. Toxicol.* 65, 396-406.
- 427 Arvanitidis, C., Somerfield, P.J., Chatzigeorgiou, G., Reizopoulou, S., Kevrekidis, T., Eleftheriou,  
428 A., 2009. Do multivariate analyses incorporating changes in pattern across taxonomic levels  
429 reveal anthropogenic stress in Mediterranean lagoons? *J. Exp. Mar. Biol. Ecol.* 369, 100-109.
- 430 Bacci, T., Trabucco, B., Marzialetti, S., Marusso, V., Lomiri, S., Vani, D., Virno Lamberti, C.,  
431 2009. Taxonomic sufficiency in two case studies: where does it work better? *Mar. Ecol.* 30, 13-  
432 19.
- 433 Barhoumi, B., LeMenach, K., Devier, M.-H., Ameer, W.B., Etcheber, H., Budzinski, H., Cachot, J.,  
434 Driss, M.R., 2014. Polycyclic aromatic hydrocarbons (PAHs) in surface sediments from the  
435 Bizerte Lagoon, Tunisia: levels, sources, and toxicological significance. *Environ. Monit. Assess.*  
436 186, 2653-2669.
- 437 Bellucci, L., Frignani, M., Raccanelli, S., Carraro, C., 2000. Polychlorinated dibenzo-p-dioxins and  
438 dibenzofurans in surficial sediments of the Venice Lagoon (Italy). *Mar. Pollut. Bull.* 40, 65-76.
- 439 Bertrand, Y., Pleijel, F., Rouse, G.W., 2006. Taxonomic surrogacy in biodiversity assessments, and  
440 the meaning of Linnaean ranks. *Syst. Biodivers.* 4, 149-159.
- 441 Bettoso, N., Aleffi, I.F., Faresi, L., Rossin, P., Mattassi, G., Crivellaro, P., 2010. Evaluation on the  
442 ecological status of the macrozoobenthic communities in the Marano and Grado Lagoon  
443 (northern Adriatic Sea). *Annales* 20, 193-206.
- 444 Bevilacqua, S., Frascchetti, S., Musco, L., Guarnieri, G., Terlizzi, A., 2011. Low sensitiveness of  
445 taxonomic distinctness indices to human impacts: evidences across marine benthic organisms  
446 and habitat types. *Ecological Indicators* 11, 448-455.
- 447 Bevilacqua, S., Frascchetti, S., Musco, L., Terlizzi, A., 2009. Taxonomic sufficiency in the detection  
448 of natural and human-induced changes in marine assemblages: a comparison of habitats and  
449 taxonomic groups. *Mar. Pollut. Bull.* 58, 1850-1859.
- 450 Bevilacqua, S., Mistri, M., Terlizzi, A., Munari, C., 2018. Assessing the effectiveness of surrogates  
451 for species over time: Evidence from decadal monitoring of a Mediterranean transitional water  
452 ecosystem. *Marine pollution bulletin*, 131, 507-514.
- 453 Bianchi, C.N., Morri, C., 1996. Ficopomatus 'Reefs' in the Po River Delta (Northern Adriatic):  
454 Their Constructional Dynamics, Biology, and Influences on the Brackish-water Biota. *Mar. Ecol.*  
455 17, 51-66.
- 456 Chainho, P., Lane, M., Chaves, M., Costa, J., Costa, M., Dauer, D., 2007. Taxonomic sufficiency as  
457 a useful tool for typology in a poikilohaline estuary. *Hydrobiologia* 587, 63-78.
- 458 Chapman, M., 1998. Relationships between spatial patterns of benthic assemblages in a mangrove  
459 forest using different levels of taxonomic resolution. *Mar. Ecol. Prog. Ser.* 162, 71-78.
- 460 Clarke, K., Green, R., 1988. Statistical design and analysis for a 'biological effects' study. *Mar. Ecol.*  
461 *Prog. Ser.* 46, 213-226.



462 Clarke, K., Warwick, R., 2001. Change in marine communities: an approach to statistical analysis  
463 and interpretation, PRIMER-E Ltd: Plymouth, United Kingdom.

464 Clarke, K.R., Gorley, R.N., 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth,  
465 United Kingdom.

466 Corbau, C., Munari, C., Mistri, M., Lovo, S., Simeoni, U., 2016. Application of the Principles of  
467 ICZM for Restoring the Goro Lagoon. *Coast. Manage.* 44, 350-365.

468 Dauvin, J., Gesteira, J.G., Fraga, M.S., 2003. Taxonomic sufficiency: an overview of its use in the  
469 monitoring of sublittoral benthic communities after oil spills. *Mar. Pollut. Bull.* 46, 552-555.

470 De Biasi, A.M., Bianchi, C.N., Morri, C., 2003. Analysis of macrobenthic communities at different  
471 taxonomic levels: an example from an estuarine environment in the Ligurian Sea (NW  
472 Mediterranean). *Estuar. Coast. Shelf S.* 58, 99-106.

473 Dethier, M.N., Schoch, G.C., 2006. Taxonomic sufficiency in distinguishing natural spatial patterns  
474 on an estuarine shoreline. *Mar. Ecol. Prog. Ser.* 306, 41-49.

475 Ellis, D., 1985. Taxonomic sufficiency in pollution assessment. *Mar. Pollut. Bull.* 16, 459.

476 Fauvel P., 1927. Faune de France. Paris, Polychètes sédentaires, Fédération Française des sociétés  
477 de sciences naturelles: 494 p.

478 Fauvel P., 1923. Faune de France. Paris, Polychètes errantes, Fédération Française des sociétés de  
479 sciences naturelles: 488 p.

480 Favero, N., Cattalini, F., Bertaggia, D., Albergoni, V., 1996. Metal accumulation in a biological  
481 indicator (*Ulva rigida*) from the lagoon of Venice (Italy). *Arch. Environ. Contam. Toxicol.* 31, 9-  
482 18.

483 Giangrande, A., Licciano, M., Musco, L., 2005. Polychaetes as environmental indicators revisited.  
484 *Mar. Pollut. Bull.* 50, 1153-1162.

485 Hewitt, J.E., Thrush, S.F., Dayton, P.K., Bonsdorff, E., 2007. The effect of spatial and temporal  
486 heterogeneity on the design and analysis of empirical studies of scale dependent systems. *The*  
487 *American Naturalist*, 169: 398-408.

488 Kruskal, W.H., Wallis, W.A., 1952. Use of ranks in one-criterion variance analysis. *Journal of*  
489 *American Statistical Association* 47, 583-621.

490 Lardicci, C., Rossi, F., Castelli, A., 1997. Analysis of macrozoobenthic structure after severe  
491 dystrophic crises in a Mediterranean coastal lagoons. *Mar. Poll. Bull.* 34, 536-547.

492 Lillebø, A.I., Neto, J.M., Martins, I., Verdelhos, T., Leston, S., Cardoso, P.G., Ferreira, S.M.,  
493 Marques, J.C., Pardal, M., 2005. Management of a shallow temperate estuary to control  
494 eutrophication: the effect of hydrodynamics on the system's nutrient loading. *Estuar. Coast.*  
495 *Shelf S.* 65, 697-707.

496 Lloret, J., Marín, A., Marín-Guirao, L., 2008. Is coastal lagoon eutrophication likely to be  
497 aggravated by global climate change? *Estuar. Coast. Shelf S.* 78, 403-412.

498 Marchini, A., Munari, C., Mistri, M., 2008. Functions and ecological status of eight Italian lagoons  
499 examined using biological traits analysis (BTA). *Mar. Pollut. Bull.* 56, 1076-1085.

500 San Martin G., 2003. Familia Syllidae. In: Anellida, Polychaeta II. *Fauna Iberica*. Vol. 21. Ramos,  
501 M.A., (ed.). Madrid, Museo Nacional de Ciencias Naturales, CSIC: 554 p.

502 Mistri, M., Borja, A., Aleffi, I.F., Lardicci, C., Tagliapietra, D., Munari, C., 2018. Assessing the  
503 ecological status of Italian lagoons using a biomass-based index. *Mar. Pollut. Bull.* 126, 600-605.

504 Mistri, M., Fano, E.A., Rossi, R., 2001. Redundancy of macrobenthos from lagoonal habitats in the  
505 Adriatic Sea. *Mar. Ecol. Prog. Ser.* 215, 289-296.

506 Mistri, M., Rossi, R., 2000. Levels of taxonomic resolution and choice of transformation sufficient  
507 to detect community gradients: An approach to hard-substrata benthic studies. *Ital. J. Zool.* 67,  
508 163-167.

509 Mistri, M., Rossi, R., 2001. Taxonomic sufficiency in lagoonal ecosystems. *J. mar. biol. Ass. UK*  
510 81, 339-340.

511 Mitsch, W.J., Gosselink, J.G., 2000. The value of wetlands: importance of scale and landscape  
512 setting. *Ecol. Econ.* 35, 25-33.

- 513 Mueller, M., Pander, J., & Geist, J. 2013. Taxonomic sufficiency in freshwater ecosystems: Effects  
514 of taxonomic resolution, functional traits, and data transformation. *Freshw. Sci.* 32, 762-778.
- 515 Munari, C., Mistri, M., 2007. Evaluation of the applicability of a fuzzy index of ecosystem integrity  
516 (FINE) to characterize the status of Tyrrhenian lagoons. *Mar. Environ. Res.* 64, 629-638.
- 517 Munari, C., Mistri, M., 2014. Traditional management of lagoons for fishery can be inconsistent  
518 with restoration purposes: the Valli di Comacchio study case. *Chem. Ecol.* 30, 653-665.
- 519 Munari, C., Rossi, R., Mistri, M., 2005. Temporal trends in macrobenthos community structure and  
520 redundancy in a shallow coastal lagoon (Valli di Comacchio, Northern Adriatic Sea).  
521 *Hydrobiologia* 550, 95-104.
- 522 Munari, C., Warwick, R.M., Mistri, M., 2009. Monitoring with benthic fauna in Italian coastal  
523 lagoons: new tools for new prospects. *Aquat. Conserv.: Mar. Freshwat. Ecosyst.* 19, 575-587.
- 524 Newton, A., Icely, J., Cristina, S., Brito, A., Cardoso, A.C., Colijn, F., Dalla Riva, S., Gertz, F.,  
525 Hansen, J.W., Holmer, M., 2014. An overview of ecological status, vulnerability and future  
526 perspectives of European large shallow, semi-enclosed coastal systems, lagoons and transitional  
527 waters. *Estuar. Coast. Shelf S.* 140, 95-122.
- 528 Olsford, F., Somerfield, P.J., 2000. Surrogates in marine benthic investigations-which taxonomic  
529 unit to target? *J. Aquat. Ecosyst. Stress Recovery* 7, 25-42.
- 530 Olsford, F., Somerfield, P.J., Carr, M.R., 1998. Relationships between taxonomic resolution,  
531 macrobenthic community patterns and disturbance. *Mar. Ecol. Prog. Ser.* 172, 25-36.
- 532 Paerl, H.W., 2006. Assessing and managing nutrient-enhanced eutrophication in estuarine and  
533 coastal waters: Interactive effects of human and climatic perturbations. *Ecol. Eng.* 26, 40-54.
- 534 Pérez-Ruzafa, A., Marcos, C., Pérez-Ruzafa, I.M., Pérez-Marcos, M., 2011. Coastal  
535 lagoons: "transitional ecosystems" between transitional and coastal waters. *J. Coast.*  
536 *Conservation* 15, 369-392.
- 537 Pitacco, V., Mistri, M., Ferrari, C.R., Munari, C., 2018a. Heavy metals, OCPs, PAHs, and PCDD/Fs  
538 contamination in surface sediments of a coastal lagoon (Valli di Comacchio, NW Adriatic, Italy):  
539 Long term trend (2002–2013) and effect on benthic community. *Mar. Pollut. Bull.* 135, 1221–  
540 1229.
- 541 Pitacco, V., Mistri, M., Munari, C., 2018b. Long-term variability of macrobenthic community in a  
542 shallow coastal lagoon (Valli di Comacchio, northern Adriatic): Is community resistant to  
543 climate changes? *Mar. Environ. Res.* 137, 73-87.
- 544 Ponti, M., Casselli, C., Abbiati, M., 2011. Anthropogenic disturbance and spatial heterogeneity of  
545 macrobenthic invertebrate assemblages in coastal lagoons: the study case of Pialassa Baiona  
546 (northern Adriatic Sea). *Helgol. Mar. Res.* 65, 25.
- 547 Prato, S., Morgana, J., La Valle, P., Finoia, M., Lattanzi, L., Nicoletti, L., Ardizzone, G., Izzo, G.,  
548 2009. Application of biotic and taxonomic distinctness indices in assessing the Ecological  
549 Quality Status of two coastal lakes: Caprolace and Fogliano lakes (Central Italy). *Ecological*  
550 *Indicators* 9, 568-583.
- 551 Ravera, O., Piva, A., Foltran, S., 2000. Chemical characteristics of the Palude della Rosa. *Man*  
552 *Biosph. Ser.* 25, 261-272.
- 553 RDevelopmentCoreTeam, 2008. R: A language and environment for statistical computing. R  
554 Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0.
- 555 Rosser, N., 2017. Shortcuts in biodiversity research: what determines the performance of higher  
556 taxa as surrogates for species? *Ecol. Evol.* 7, 2595-2603
- 557 Rossi, R., Cannas, A., 1984. Eel fishing management in a hypersaline lagoon of southern Sardinia.  
558 *Fisheries Research* 2, 285-298.
- 559 Ruffo, S., 1982-1998. The amphipoda of the Mediterranean. *Memoires de l'institut*  
560 *oceanographique de Monaco.* 13. Part.1-4. 959 p.
- 561 Sabil, N., Cherqui, A., Tagliapietra, D., Coletti-Previero, M.A., 1994 Immobilized enzymatic  
562 activity in the Venice Lagoon sediment. *Water Research* 28, 77-84.

563 Sannio, A., Lugliè, A., Sechi, N., 1997. Potentially toxic dinoflagellates in Sardinia. *Plant*  
564 *Biosystems-An International Journal Dealing with all Aspects of Plant Biology* 131, 73-78.

565 Sladonja, B., Bettoso, N., Zentilin, A., Tamberlich, F., Acquavita, A., 2011. Manila Clam (*Tapes*  
566 *philippinarum* Adams & Reeve, 1852) in the Lagoon of Marano and Grado (Northern Adriatic  
567 Sea, Italy): socio-economic and environmental pathway of a shell farm, Aquaculture and the  
568 Environment-A Shared Destiny. InTech.

569 Smale, D.A., 2010. Monitoring marine macroalgae: the influence of spatial scale on the usefulness  
570 of biodiversity surrogates. *Divers. Distrib.* 16(6), 985-995.

571 Spillman, C., Hamilton, D.P., Imberger, J., 2009. Management strategies to optimise sustainable  
572 clam (*Tapes philippinarum*) harvests in Barbamarco Lagoon, Italy. *Estuar. Coast. Shelf S.* 81,  
573 267-278.

574 Tagliapietra, D., Sigovini, M., Ghirardini, A.V., 2009. A review of terms and definitions to  
575 categorise estuaries, lagoons and associated environments. *Mar. Freshw. Res.* 60, 497-509.

576 Tataranni, M., Maltagliati, F., Floris, A., Castelli, A., Lardicci, C., 2009. Variance estimate and  
577 taxonomic resolution: an analysis of macrobenthic spatial patterns at different scales in a  
578 Western Mediterranean coastal lagoon. *Mar. Environ. Res.* 67, 219-229.

579 Terlizzi, A., Anderson, M.J., Bevilacqua, S., Frascchetti, S., Włodarska-Kowalczyk, M., Ellingsen,  
580 K.E., 2009. Beta diversity and taxonomic sufficiency: do higher-level taxa reflect heterogeneity  
581 in species composition? *Divers. Distrib.* 15, 450-458.

582 Terlizzi, A., Frascchetti, S., Guidetti, P., Boero, F., 2002. The effects of sewage discharge on shallow  
583 hard substrate sessile assemblages. *Mar. Pollut. Bull.* 44, 544-550.

584 Underwood, A.J., Chapman, M. G., 1996. Scales of spatial patterns of distribution of intertidal  
585 invertebrates. *Oecologia*, 107(2), 212-224.

586 Vanderklift, M., Ward, T.J., Jacoby, C., 1996. Effect of reducing taxonomic resolution on  
587 ordinations to detect pollution-induced gradients in macrobenthic infaunal assemblages. *Mar.*  
588 *Ecol. Prog. Ser.* 136, 137-145.

589 Viaroli, P., Bartoli, M., Giordani, G., Azzoni, R., Nizzoli, D., 2003. Short term changes of benthic  
590 fluxes during clam harvesting in a coastal lagoon (Sacca di Goro, Po river delta). *Chem. Ecol.*  
591 19, 189-206.

592 Vieira, L.C.G., Padial, A.A., Velho, L.F.M., Carvalho, P., Bini, L.M., 2015. Concordance among  
593 zooplankton groups in a near-pristine floodplain system. *Ecol. Ind.* 58, 375-381.

594 Viéitez J., Alis C., Parapar J., Besteiro C., Moreira J., Ninez J., Laborda A., san Martin G., 2004.  
595 Anellida, Polychaeta I. In: *Fauna Iberica*. Vol. 25. Ramos, M.A. (ed.). Madrid, Museo Nacional  
596 de Ciencias Naturales, CSIC: 530 p.

597 Warwick, R., 1988a. Analysis of community attributes of the macrobenthos of  
598 Frierfjord/Langesundfjord at taxonomic levels higher than species. *Mar. Ecol. Prog. Ser.* 46,  
599 167-170.

600 Warwick, R., 1988b. The level of taxonomic discrimination required to detect pollution effects on  
601 marine benthic communities. *Mar. Pollut. Bull.* 19, 259-268.

602 Warwick, R., Clarke, K., 1993. Comparing the severity of disturbance: a metaanalysis of marine  
603 macrobenthic community data. *Mar. Ecol. Prog. Ser.* 92, 221-231.

604 Warwick, R., Somerfield, P., 2008. All animals are equal, but some animals are more equal than  
605 others. *J. Exp. Mar. Biol. Ecol.* 366, 184-186.

606 Warwick, R.M., 1993. Environmental impact studies on marine communities: pragmatcal  
607 considerations. *Aust. J. Ecol.* 18, 63-80.

608 Włodarska-Kowalczyk, M., Kędra, M., 2007. Surrogacy in natural patterns of benthic distribution  
609 and diversity: selected taxa versus lower taxonomic resolution. *Mar. Ecol. Prog. Ser.* 351, 53-63.

610 WoRMS Editorial Board, 2018. World Register of Marine Species, Available from  
611 <http://www.marinespecies.org> at VLIZ. Accessed 2018-08-27. doi:10.14284/170  
612

613 Table 1 Characteristics of sampled lagoons and number of sampled sites.

Lagoon	Code	Coordinates	Area (km <sup>2</sup> )	Average depth (m)	Typology	Salinity	Sites	References
Venice (Palude della Rosa)	PR	45°31'N; 12°30'E	5.5	0.3-0.8	microtidal	poly/ euhaline	9	Sabil et al., 1994
Grado-Marano	GM	45°42'N; 13°20'E	160	1.5	microtidal	meso/poly/ euhaline	21	Bettoso et al., 2010
Caleri	CL	45.09°N; 12.31°E	11.5	2	microtidal	meso/ polyhaline	4	Mistri et al., 2018
Marinetta	MA	45°04'N; 12°22'E	10	0.8	microtidal	meso/ polyhaline	4	Mistri et al., 2018
Vallona	VA	45°02'N; 12°23'E	11.5	2	microtidal	meso/ polyhaline	2	Mistri et al., 2018
Barbamarco	BR	45°00'N; 12°46'E	8	0.8	microtidal	meso/ polyhaline	2	Spillman et al., 2009
Canarin	CN	44°92'N; 12°49'E	10.0	0.8	microtidal	meso/ polyhaline	3	Bianchi and Morri, 1996
Scardovari	SC	44°86'N; 12°42'E	32	1.5-2	microtidal	meso/ polyhaline	5	Marchini et al., 2008
Goro	GO	44°82'N; 12°31'E	26	1.2-1.5	microtidal	meso/ polyhaline	3	Corbau et al., 2016
Comacchio	CO	44°61'N; 12°17'E	100	0.5-1.5	non-tidal	euhaline	4	Munari et al., 2005
Baiona	BA	44°50'N; 12°25'E	10	1	microtidal	polyhaline	3	Ponti et al., 2011
Lesina	LE	41°53'N; 15°26'E	50	0.8	non-tidal	meso/ polyhaline	4	Marchini et al., 2008
Orbetello	OR	42°26'N; 11°12'E	27	0.5-1	non-tidal	polyhaline	11	Lardicci et al., 1997
Caprolace	CA	41°20'N; 12°58'E	2.26	1.3	non-tidal	euhaline	5	Prato et al., 2009
Fogliano	FO	41°24'N; 12°54'E	4.08	0.9	non-tidal	euhaline	4	Prato et al., 2009
San Teodoro	ST	40°48'N; 09°40'E	2.2	0.7	non-tidal	polyhaline	3	Munari and Mistri, 2007
Feraxi	FE	39°20'N; 09°35'E	0.4	NA	non-tidal	euhaline	10	Sannio et al., 1997
Porto Pino	PP	38°58'N; 08°36'E	4.4	NA	non tidal	hyperhaline	10	Rossi and Cannas, 1984

614 Table 2 Significance of cluster groups (PERMANOVA), and percentage of significant pairwise  
 615 combinations among those groups. Percentages are not shown for presence/absence data because of  
 616 low number of comparisons.

Data transformation	Cluster groups		Taxonomic resolution					
			Species	Genus	Family	Order	Class	Phylum
<b>None</b>	6	PERMANOVA p-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
		significant pairwise combinations	21%	21%	21%	21%	21%	14%
<b>Square root</b>	3	PERMANOVA p-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
		significant pairwise combinations	67%	67%	67%	67%	67%	67%
<b>Logarithm</b>	3	PERMANOVA p-value	0.0001	0.0002	0.0004	0.0005	0.0004	0.0191
		significant pairwise combinations	67%	67%	67%	67%	67%	33%
<b>Presence/absence</b>	2	PERMANOVA p-value	0.006	0.006	0.007	0.037	0.007	0.064

617

618 **Figure Legend**

619 Fig. 1 'Loss of information  $\alpha$ ' from lower to higher taxonomic levels (NT1-NT6) for the eighteen  
620 Italian lagoons (see

621 Table 1 for codes).

622 Fig. 2. Correlation between indices calculated at consecutive taxonomic levels (from species to  
623 phylum). ES = Estimated richness for N=10000;  $\lambda$  = Simpson index;  $\Delta^+$  = Taxonomic  
624 distinctness;  $\lambda^+$  = Variation of taxonomic distinctness.

625 Fig. 3. Second-stage inter-matrix rank correlations ( $r_s$ ) based on similarity matrices based on  
626 average taxa density for lagoon, at different taxonomic levels and calculated using different data  
627 transformation. Untr = untransformed, sqr = square root, log = logarithm, pa = presence/absence.

628 Fig. 4. Second-stage inter-matrix rank correlations ( $r_s$ ) based on similarity matrices based on  
629 average taxa density for site nested within lagoon, at different taxonomic levels and calculated  
630 using different data transformation: (A) untransformed data, (B) squared root, (C) logarithm, (D)  
631 presence/absence.