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Long-term (1998–2010) large-scale comparison of the ecological quality status of gulf of lions (NW Mediterranean) benthic habitats

Alicia Romero-Ramirez [a,*], Paulo Bonifácio [a,b], Céline Labrune [b], Rafael Sardá [c], Jean Michel Amouroux [b], Gérard Bellan [d], Jean Claude Duchêne [a], Rachel Hermand [d], Ioannis Karakassis [e], Costas Dounas [f], Antoine Grémare [a]

[a] Université Bordeaux, CNRS, EPOC, UMR 5805, F-33120 Arcachon, France
[b] Université Paris 6, CNRS, LECOB, UMR 8222, F-66650 Banyuls-sur-Mer, France
[c] Centre d'Estudis Avançats de Blanes, Consejo Superior de Investigaciones Científicas, Carrer d'accés a la Cala Sant Francesc 14, F-17300 Blanes, Spain
[d] Université d'Aix-Marseille, OSU-Institut Pythéas IMBE Station marine d'Endoume, Chemin de la Batterie des Lions, F- 13007 Marseille, France
[e] Marine Ecology Laboratory, University of Crete, Vasilika Vouton, Heraklion 70013, Crete, Greece
[f] Hellenic Centre for Marine Research, Athens Sounio, Anavyssos Attiki 19013, Greece

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ABSTRACT

A comprehensive Mediterranean data set has been used to address 3 questions associated with the use of sensitivity/tolerance based biotic indices to infer the Ecological Quality status (EcoQs) of benthic habitats. Our results showed: (1) a significant effect of the reference database on derived sensitivity/tolerance measure (ES500.05) as well as associated Benthic Quality Index values and derived EcoQs; (2) a lack of correlation neither between BQI and AZTI Marine Biotic Index values nor between BQI and Multivariate-AZTI Marine Biotic Index values; (3) a lack of correlation between the values of the Benthic Habitat Quality Index (index derived from Sediment Profile Imagery) and those of either of the 3 tested biotic indices; and (4) a general agreement between the 3 tested biotic indices in describing the lack of global trend for the EcoQs of the Gulf of Lions despite the occurrence of significant changes in benthic macrofauna composition between 1998 and 2010.

1. Introduction

The assessment of the Ecological Quality Status (EcoQ) of European marine waters is of increasing interest due to recent policy requirements associated with the Water Framework Directive (WFD, 2000/60/EC) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC). In this context, the analysis of benthic macrofauna composition is sound although the exact modalities of its use in assessing the EcoQ of marine habitats are clearly still the subject of debates (Grémare et al., 2009). The three most widely used (either alone or in combination with other parameters) biotic indices within the WFD are the AZTI Marine Biotic Index (AMBI; Borja et al., 2000, http://ambi.azti.es), the Multivariate-AMBI (M-AMBI; Muxika et al., 2007) and the Benthic Quality Index (BQI; Rosenberg et al., 2004). They all refer to the sensitivity/tolerance concept and more specifically to Pearson and Rosenberg (1978) paradigm.

Several studies have compared the use of BQI and AMBI on the same benthic macrofauna data sets (Marín-Guirao et al., 2005; Labrune et al., 2006, 2012; Fleischer et al., 2007; Grémare et al., 2009; Dimitriou et al., 2012). Most of them have concluded to discrepancies largely resulting from differences in the sensitivity/tolerance levels attributed to dominant species (Labrune et al., 2006; Grémare et al., 2009). The sound assessment of species sensitivity/tolerance levels thus remains a clear challenge (Leonardsson et al., 2015). In AMBI and M-AMBI, this assessment is based on a synthesis of the literature/expert knowledge, which results in a regularly updated attribution of species to 5 ecological groups (EG)). Conversely, in BQI, species sensitivity/tolerance levels ($ES50_{0.05}$ and more recently $S_{0.05}$; Leonardsson et al., 2015) are derived from species richness of the stations at which the considered species tend to be present. Unless a sound regional list is available, assessing $ES50_{0.05}$ or ($S_{0.05}$) thus requires large data sets, which complicates the spread of the use of BQI. The magnitude of changes in $ES50_{0.05}$ due to changes in the characteristics (including size) of the data set they are computed from is still largely unknown (Leonardsson et al., 2009, 2015) although it may clearly contribute to discrepancies between AMBI and BQI.

In the case of major discrepancies in EcoQ assessments between biotic indices, an important question becomes: which index is providing the most satisfactory assessment? This question is difficult to tackle

* Corresponding author.
E-mail address: a.romero-ramirez@epoc.u-bordeaux1.fr (A. Romero-Ramirez).

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otherwise than qualitatively in the absence of independent quantitative information regarding the level of disturbance experimented by the stations to be characterized. In practice, this piece of information is most often lacking. A possibility consists in comparing the outputs derived from the use of biotic indices with those of an independent method of EcoQ assessment (Labrune et al., 2012). The use of Sediment Profile Images (SPIs; Rhoads and Young, 1970; Rhoads and Cande, 1971; Young and Rhoads, 1971; Rhoads and Germano, 1982; see Germano et al., 2011 for review) is especially valuable in this particular context (Nilsson and Rosenberg, 1997). A comparison between the values of the 3 above mentioned biotic indices and the Benthic Habitat Quality index (BHQ; Nilsson and Rosenberg, 1997) as a basis of SPI-based EcoQ assessment has already been achieved by Labrune et al. (2012) for a set of 16 stations located along a gradient of organic enrichment off the mouth of the Rhône River. These authors concluded that BQI correlated better with BHQ than AMBI and M-AMBI. There is however no reason to believe that this result necessarily holds for other geographic areas.

The first step of the transformation of a biotic index in an EcoQ is the computation of an Ecological Quality Ratio (EQR), which basically consists in dividing the value of the biotic index at the station, which is to be characterized by the value of the same index at a reference station within the same habitat, which is known to be in a High EcoQ (e.g., Rosenberg et al., 2004; Kennedy et al., 2011). It is nowadays extremely difficult to identify truly pristine areas, which could be used as references (Warwick et al., 2003). Historical data are thus often used as such (Pearson et al., 1985; Rosenberg et al., 1987; Grémare et al., 1998), which can prove hazardous when the studied communities exhibit long term natural changes, which may result in natural changes in the values of biotic indices and thus in derived EcoQ. This is apparently the case in the Gulf of Lions, where Grémare et al. (1998) and then Labrune et al. (2007a) have shown the occurrence of major changes in benthic macrofauna composition between 1967/1968, 1998 and 2003, which are likely related with periodic meteorological oscillations (Labrune et al., 2007a; Bonifácio, 2015) and result in drastic changes in the values of some biotic indices despite the apparent lack of major anthropogenic disturbances (Labrune et al., 2006). These last authors also provided the first large scale assessment of the EcoQ of benthic habitats in the Gulf of Lions based on a sampling of benthic macrofauna carried out in 1998.

Within this context, the present study aimed at: (1) comparing the $ES50_{0.05}$ provided by Grémare et al. (2009) for the Mediterranean Sea with those derived from a much larger data set including the Mediterranean component of the MacroBen database and the results of several new surveys carried out since then, and assessing the consequences of the use of this new list on BQI computation; (2) assessing the relationships between the values and the derived EcoQ of BHQ, AMBI, M-AMBI and BQI based on a set of stations sampled in 2010 (Bonifácio, 2015) and located in the open Gulf of Lions where, the natural disturbance gradient is much less marked than off the Rhône River (Labrune et al., 2012); and (3) carrying out a long-term and large-scale (1998–2010) comparison of the assessment of the EcoQ of the Gulf of Lions benthic habitats based on the re-sampling of the same set of stations and using the very same sampling gear and strategy as Labrune et al. (2007b, 2008).

2. Material and methods

2.1. $ES50_{0.05}$

The values of $ES50_{0.05}$ established by Grémare et al. (2009) based on the MacroBen database were compared with those derived from an updated database including new data from the Gulf of Lions, the Provencal coast and the Northern Mediterranean Spanish coast (see also the Results section) using a simple linear regression model. The same model was used to assess the relationships between the BQI computed for 3 subsets (based on the proportions of species with an attributed $ES50_{0.05}$, see below) of sampling events of the updated database using the Grémare et al. (2009) and the updated $ES50_{0.05}$ lists. The slopes and intercepts of the corresponding models were compared using covariance analysis (ANCOVA). Linear regression models were also used to assess the relatonships between: (1) $S_{0.05}$ (Leonardsson et al., 2015) and $ES50_{0.05}$ derived from our updated data base, and (2) $BQI_{ES500.05}$ and $BQI_{S0.05}$ of the stations sampled in 2010 (see below).

2.2. Biotic indices

2.2.1. Benthic macrofauna composition and sediment granulometry in 2010

Macrobentic fauna was sampled during a cruise carried out on board of the RV *Thetys* II in August 2010. Sampled stations, sampling gear and sample replication scheme were strictly identical to those used by Labrune et al. (2007b, 2008) during their 1998 sampling. Sampled stations were located along 21 inshore-offshore transects (A-U) between the Spanish border and the mouth of the Rhône River (Fig. 1). Almost all transects were sampled at 10, 20, 30, 40 and 50 m depths. Overall, 101 stations were sampled. Benthic macrofauna was collected using a 0.1 m^2 van Veen grab (3 replicates per site). Samples were sieved on a 1 mm mesh and fixed with 5% buffered formalin in seawater on board. Back at the laboratory, benthic macrofauna was manually sorted, identified to the lowest tractable taxa (i.e., most often species) and counted. Taxa lists were homogenized between sampling years to avoid discrepancies in taxonomic resolution between the two studies (Labrune et al., 2008). Synonyms of scientific names of species were updated using the World Register of Marine Species (WoRMS). Species with possible doubtful identifications were pooled to homogenize species lists and taxonomic resolutions between 1998 and 2010. This procedure allowed for a direct comparison (i.e., between 1998 and 2010) at 91 stations (Fig. 1). Univariate PERMANOVAs (Anderson, 2001; McArdle and Anderson, 2001) were used to assess changes in global descriptors (i.e., species richness and abundance) of benthic macrofauna with depth. An additional grab was collected at each station. The upper half centimetre of its sediment content was sampled, homogenized and frozen (−20 °C) on board. Back at the laboratory, sediment granulometry was assessed using a Malvern Mastersizer® 2000 laser microgranulometer. Here again, a univariate PERMANOVA (Anderson, 2001; McArdle and Anderson, 2001) was used to assess the effect of depth on sediment median diameter ($D_{0.5}$).

2.2.2. Computation of biotic indices

Macrofauna data were used to compute 3 biotic indices, namely: AMBI (Borja et al., 2000), M-AMBI (Muxika et al., 2007) and BQI (Rosenberg et al., 2004 later modified by Leonardsson et al., 2009).

As stated above, AMBI uses a single expert based classification of macrobenthic species in 5 EG corresponding to different sensitivity/tolerance levels. AMBI varies between 0 and 7. It does not compute any EQR and uses a single conversion scale into EcoQ. During the present study, AMBI was computed using the AMBI software (http://ambi.azti.es) and the October 2013 species EG classification. AMBI values were converted in EcoQ using the threshold values proposed by Borja (2004) (Table 1).

M-AMBI is based on a multivariate approach that integrates species richness (SR), the Shannon diversity index (H') and AMBI (Muxika et al., 2007). Besides the stations to be analyzed, M-AMBI also considers two hypothetical reference stations corresponding respectively to a high and a bad EcoQ within each community. M-AMBI ranges between 0 and 1 and basically corresponds to the orthogonal projection, in a reduced space, of each station along the straight line linking the bad and high hypothetical reference stations. M-AMBI therefore constitutes an EQR, which can later be converted in an EcoQ using a single conversion scale. During the present study, M-AMBI was computed using the AMBI software (http://ambi.azti.es) and the October 2013 EG classification list. M-AMBI values were converted in EcoQ using the threshold values proposed by Muxika et al. (2007) (Table 1).