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Performance of some biotic indices in the real variable world: A case study at different spatial scales in North-Western Mediterranean Sea

Mariella Tataranni*, Claudio Lardicci

Università di Pisa, Dipartimento di Biologia, Via Derna 1, 56126 Pisa, Italy

How heterogeneous distribution of macrobenthos can affect the performance of some biotic indices.

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ABSTRACT

The aim of this study was to analyse the variability of four different benthic biotic indices (AMBI, BENTIX, H′, M-AMBI) in two marine coastal areas of the North-Western Mediterranean Sea. In each coastal area, 36 replicates were randomly selected according to a hierarchical sampling design, which allowed estimating the variance components of the indices associated with four different spatial scales (ranging from metres to kilometres). All the analyses were performed at two different sampling periods in order to evaluate if the observed trends were consistent over the time. The variance components of the four indices revealed complex trends and different patterns in the two sampling periods. These results highlighted that independently from the employed index, a rigorous and appropriate sampling design taking into account different scales should always be used in order to avoid erroneous classifications and to develop effective monitoring programs.

1. Introduction

Soft bottom marine environments are usually characterized by a wide diversity of macrobenthic invertebrates that are directly involved in many key ecosystem processes at the water/sediment interface (Snelgrove, 1998; Austen et al., 2002). Moreover, macrobenthic species are considered highly suitable to assess environmental quality and to detect several kinds of natural and anthropogenic stresses. Their life-history traits (low motility, long life cycles, etc.) do not allow avoiding adverse environmental conditions, many species show different tolerances to stress events and their response, mainly to organic enrichment, has been widely described (Pearson and Rosenberg, 1978; Gray, 1981, 1997; Hily, 1984; Dauer, 1993; Dauer and Alden, 1995; Lardicci and Rossi, 1998). The employment of biological components to assess the ecological quality status (EcoQ) of marine environments is also directly claimed by the European Water Framework Directive (WFD; 2000/60/EC), which represents the legislative basis for the management and protection of all water bodies in Europe. Among other things, each member state is required to value the EcoQ of all coastal areas and to determine reference or control conditions being comparable in monitoring programs. In particular, the WFD recommends the study of benthic macrofaunal species composition and abundance as well as the identification of groups of species according to their sensibility (or tolerance) to disturbance events (Vincent et al., 2002).

The implementation of the WFD has led to a development of tools and methods in order to assess the EcoQ of marine water bodies through macrobenthic community analysis. Univariate diversity indices, such as the Shannon–Wiener (H′), have been commonly used in the past, while most of the recently developed biotic indices rely on the model of organic enrichment by Pearson and Rosenberg (1978). These indices analyse environmental quality comparing the proportion of species tolerant or favoured by pollution to species representative of unpolluted conditions, such as the Benthic Index (Grall and Glémarec, 1997), the Azti Marine Biotic Index (AMBI) (Borja et al., 2000), the BENTIX (Simboura and Zenetos, 2002), the Benthic Quality Index (BQI) (Rosenberg et al., 2004) and the Benthic Opportunistic Polychaetes Amphipods Index (BOPA) (Dauvin and Ruellet, 2007). Since the WFD suggests macrobenthic communities should be investigated analysing diversity and species richness as well as the presence/absence of indicator species, multivariate biotic indices combining results from different metrics have also been proposed like the Benthic Index of Biotic Integrity (B-IBI) (Weisberg et al., 1997), the Ecological Quality Ratio (EQR) (Quintino et al., 2006) and the Multivariate-AMBI (M-AMBI) (Muxika et al., 2007). The applicability of such different methods of EcoQ assessment has been tested in several geographical areas (i.a. Salas et al., 2004; Muniz et al., 2005; Simboura et al., 2005; Labrune et al., 2006; Quintino et al., 2006; Bigot et al., 2008) and for

* Corresponding author. Tel.: +39 050 2211445; fax: +39 050 2211410.
E-mail address: mtataranni@biologia.unipi.it (M. Tataranni).

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a large variety of disturbance sources (i.a. Marin-Guirao et al., 2005; Muxika et al., 2005; Simboura et al., 2007). The majority of papers considered two or more biotic approaches to assess whether the different indices displayed similar tendency in the classification of stations (Reiss and Kroncke, 2005; Albayrak et al., 2006; Labrune et al., 2006; Fleischer et al., 2007), while the objective of other studies was to modify the thresholds values in order to obtain an exact intercalibration of different biotic indices (Borja et al., 2007; Ruellet and Dauvin, 2007).

Natural communities often show differences in species composition and structural parameters in marine sediments at a variety of spatial scales (Andrew and Mapstone, 1987; Levin, 1992; Koenig, 1999) and the extent of such variability is highly related to the spatial and/or temporal scale of observation (Levin, 1992; Morrisey et al., 1992; Fraschetti et al., 2005). Patterns of variability could be more evident at some scales being quite absent at others and, therefore, analyses of the community features at multiple scales are crucial in order to avoid a misleading generalization of results obtained for a peculiar scale. In particular, hierarchical sampling designs have been repeatedly suggested as the most appropriate method to evaluate the proportion of variability at each examined spatial scale (Underwood, 1997; Hewitt et al., 1998; Underwood et al., 2000). Unfortunately, at present very few studies have investigated the performance of biotic indices with regard to the natural spatial and temporal variability of macrobenthic communities (Reiss and Kroncke, 2005; Labrune et al., 2006; Quintino et al., 2006) and none of them have used a detailed nested sampling design to obtain estimates of variability associated with each examined scale of observation.

The EcoQ judgement obtained through any biotic index is expected to be scarcely variable, if the homogeneity of the study area is assumed both in terms of natural environmental features and/or anthropogenic disturbances. In fact in this kind of areas, spatial differences in specific composition of macrobenthic assemblages are most probably associated with the variability of their distribution patterns whereas they might hardly be ascribed to a real change of environmental quality. Moreover, decreasing of the spatial scale of observation would enhance the probability that environmental conditions within the considered area are homogenous and therefore biotic indices' values should even be less variable. On this basis, in environmental monitoring studies, every station employed for the EcoQ assessment is considered representative for the whole extent of the referential spatial scale, thus implicitly supposing that at smaller spatial scales the index value (and its associated EcoQ class) is not affected by possible natural differences in benthic assemblages.

In order to investigate these assumptions and since the spatial scales of patchiness in the variables being measured are not often known before sampling is done, the present work analyse the spatial variability of benthic assemblages at four different spatial scales (ranging from m to thousands of m) in two sandy coastal areas of the North-Western Mediterranean Sea using a hierarchical sampling design. Both these areas can be reasonably considered as homogenous environments, within which the estimated EcoQ should be scarcely variable independently from the absolute value of any employed index.

In particular, the aims of this study were to: (i) evaluate the agreement of four different biotic indices (H′, AMBI, BENTIX and M-AMBI) in terms of estimated EcoQ values at each station and relationships among stations; (ii) examine whether and how the spatial variability of benthic assemblages could influence the variability of the four biotic indices and the assessment of the EcoQ classes at the considered spatial scales. All the analyses were performed at two different sampling periods in order to evaluate if the observed trends were consistent over the time.

2. Material and methods

2.1. Study areas

This study was conducted in two marine coastal areas of the Tuscany; both areas are about 10 km long and they are almost 120 km distant (Fig. 1a). Environmental conditions can be reasonably considered scarcely variable within each of the study areas. In particular, Pisa coastal area is located in the part of Tuscany more subjected to urbanization and industrialization, although great urban and industrial centres are absent along such coastal stretch. The estuary of the Arno River, whose prevalent northward drift can influence coastal macrobenthic communities through freshwater, organic and nutrient inputs, characterizes this area. Grosseto coastal area is in the southern part of Tuscany, which is characterized by a low anthropogenic pressure, comparing to other western Italian sandy coasts. Along this part there are only few small tourist centres and some marinas, moreover there is also a wide terrestrial natural park. To our knowledge, no peculiar acute disturbances caused by anthropogenic impacts occurred at the investigated stations during the elapsed sampling period. Therefore in this study, possible changes in macrobenthic community structure should reflect the "natural" temporal variability of analysed soft bottom communities.

A hierarchical sampling design (Fig. 1b) was adopted to estimate the spatial variability at four scales. Inside the two coastal areas, three random localities

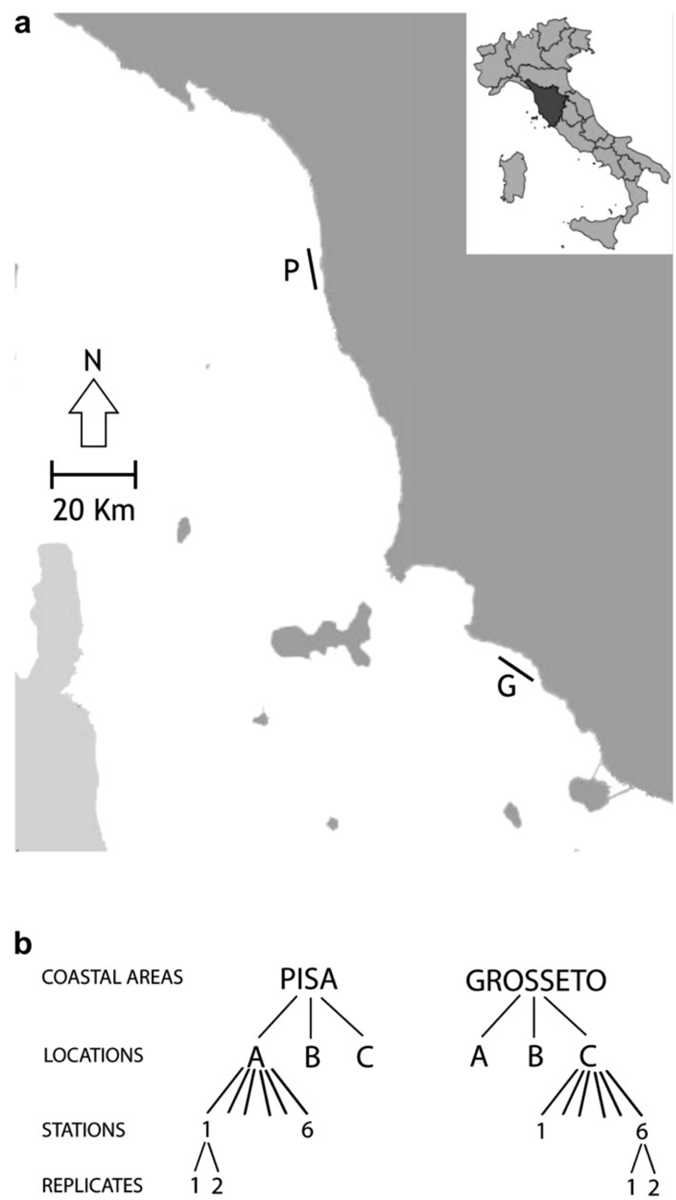

Fig. 1. (a) Map of the study area. Black lines indicate the two coastal areas investigated. (b) Hierarchical sampling design used in this study.