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Performance of biotic indices in naturally stressed estuarine environments on the Southwestern Atlantic coast (Uruguay): A multiple scale approach

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ABSTRACT

Biotic indices based on benthic communities have become an important tool in the assessment and monitoring of marine pollution. These communities vary at several spatial and temporal scales giving rise to scale-dependent patterns of distribution, being of particular importance because results from the application of ecological indices, and the subsequent classification of communities, could reflect these variations at several scales. We test some of the most widely applied indices for the evaluation of coastal benthic communities, using a hierarchical spatio-temporal sampling design, within two sets of estuarine habitats in the Atlantic coastal zone of Uruguay. Results showed that ecological indices can vary at different spatial scales, with important variation at small scales. So, independently from the used index, an appropriate sampling design should be taken into account considering different scales (both spatial and temporal). At some of the scales studied, indices appear to reflect natural variations in disturbance through currents rather than variation in anthropogenic effects. At the large scale, variation is low consistent with a preliminary classification of sites according to the putative levels of human activity. The low level of similarity between all indices could be denoting some degree of inconsistency in the assignment of the categories to an ecological status.

1. Introduction

The use of biotic indices has become an important tool in the assessment and monitoring of the biological effects of marine pollution. Various studies have demonstrated that benthic organisms are useful indicators of environmental status, as they respond predictably to several types of natural and anthropogenic disturbances (Grall and Glémarec, 1997; Borja et al., 2000; Gómez-Gesteira and Dauvin, 2000; Simboura and Zenetos, 2002; Rosenberg et al., 2004). Although a number of indices are available for marine/estuarine coastal environments, there is a lack of consensus about which is the most appropriate. A major concern about their applicability is that they ought to respond differently to natural and man-induced changes in communities. Another important issue is that selecting different indices may result in different classifications of ecological status, as shown by several recent papers in this topic (Borja et al., 2007 and references therein).

The hydrodynamics at coastal areas can be considered as a source of natural disturbance for soft sediment communities (Levin and DiBacco, 1995; Roth and Wilson, 1998; Hewitt et al., 2003). Sediment characteristics are the result of near-bed flow conditions, which influence grain size, sedimentary organic matter content, pore-water chemistry, microbial content and larval supply (Gray and Elliot, 2009). These variables can directly or indirectly influence the benthic species distribution (Gray and Elliot, 2009) therefore influencing, in a general way, community structure and functioning.

Hydrodynamic forces and other factors operate on benthic communities at several spatial and temporal scales giving rise to scale-dependent patterns of distribution (Thrush et al., 1997, 2003; Giménez and Yannicelli, 2000; Ysebaert and Herman, 2002; Giménez et al., 2005, 2006). These are of particular importance because results from the application of ecological indices, and the subsequent classification of communities, could reflect variations in hydrodynamics at several spatial scales. Patterns of variability may be more evident at some scales than others; therefore, evaluation of ecological status of natural communities must consider the scale-dependent nature of their structure. Few studies have been done to explore the performance of biotic indices considering the natural spatial and temporal variability of macrobenthic communities (Reiss and Kröncke, 2005; Labrune et al., 2006; Quintino et al.,

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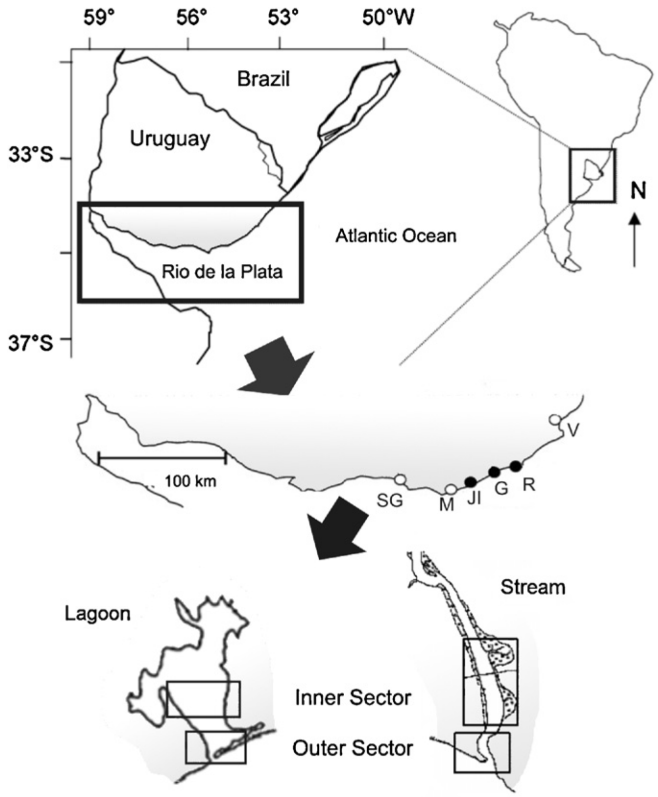

Fig. 1. Map of the study area. Black points indicate the sampled lagoons and white ones the streams. At bottom part, the diagram indicates the inner and outer sector of stream (right) and lagoon (left). Where SG: Solís Grande, M: Maldonado, V: Valizas, JI: José Ignacio, G: Garzón and R: Rocha. Land is represented by the shaded areas.

2006) and yet less effort have been done using a detailed nested sampling design to obtain estimates of variation according to the scale of observation (Tataranni and Lardicci, 2010).

In this paper, we test some of the most widely applied indices for the evaluation of coastal and/or estuarine benthic communities, using a hierarchical spatio-temporal sampling design, within two sets of estuarine habitats, coastal lagoons (intermittently open/closed sites) and streams in the Atlantic coastal zone of Uruguay. In particular, we tested indices based on different attributes (taxonomic, trophic and ecological indicator units): the Shannon-Wiener diversity (H'), the AZTI marine biotic index (AMBI), the BENTIX biotic index and the infaunal trophic index (ITI), most of them widely used in the last years for quality assessment of benthic ecosystems (de Paz et al., 2008 and references therein). We used a multiple scale approach to evaluate the spatial and temporal variability of these indices in response to estuarine habitat type, lagoons vs. streams, considering the mouth and the inner sector of each habitat.

2. Materials and methods

2.1. Study area

The six estuaries included in the present study are located on the eastern Atlantic coast of Uruguay. These are three lagoons: José Ignacio (34°50′S, 54°40′W), Garzón (34°48′S, 54°34′W) and Rocha (34°40′S, 54°16′W) and three streams: Solís Grande (34°47′S, 55°23′W), Maldonado (34°54′S, 54°52′W) and Valizas (34°20′S, 53°47′W) (Fig. 1). José Ignacio, Garzón and Rocha have a water body of 13 km^2, 18 km^2 and 72 km^2 respectively and are characterized by a high frequency of connection to the ocean, resulting from the alternation of natural and artificial openings of the sand bar (Conde and Rodríguez-Gallego, 2002). These lagoons show an incipient growing urbanization without sanitation that may be considered as a potential source of deterioration. On the other hand, the streams are tending to be connected to the ocean through all the year. Solís Grande stream, with 70 km length and a catchment area of 1409 km^2, shows low urban development. Maldonado stream, with a basin that covers an area of 1437 km^2 and a length of 60 km, shows a high urban and touristic development. Valizas stream with a catchment area of 1561 km^2 and a length of 18 km, only receives influence of forestry activities (Defeo et al., 2009).

2.2. Sampling design

Both types of study habitats (coastal lagoons and streams) are considered natural experiments (*sensu* Diamond and Case, 1986). Such "experiments" are naturally replicated, because the Uruguayan coast has several lagoons and streams flowing directly into the coastal zone. A hierarchical sampling design was adopted to estimate the spatial variability, using different spatial scales: 2 habitats (lagoons and streams), six sites (3 lagoons and 3 streams), 2 sectors (outer and inner) at each site and 3 transects in each sector (see Fig. 1).

Sectors were defined as follows: (1) Outer Sector: from the mouth of the stream or lagoon to the line of dunes, (2) Inner Sector: from the dune line toward the inner portion of the lagoon or stream. The definition of sectors is based on previous information (Giménez et al., 2006), suggesting that outer sectors are characterized by sandy sediments and high hydrodynamics, while the inner sectors, more sheltered, are dominated by muddy-sand sediments. These two sectors were sampled always at a mean depth of 1–2 m on the portion of the system closer to the sea, where salinity can range between 5 and 25, according to the patterns of water exchange between the lagoon/stream and the sea.

Each sector was divided into 20 transverse transects, 50 m long and bounded by the margins of each stream or lagoon. Through random selection, we chose three of these transects to be sampled (considered as replicates of each sector). The random selection of transects and the geographical position, was made previous to the first sampling, using satellite image. The sampling procedure was repeated five times, always at the same transects initially selected, in January, April, May, July and October of 2008.

We obtained 36 samples of shallow subtidal benthic macrofauna per survey giving a total of 180 samples. Each macrobenthic sample was composed of three PVC corers (22.5 cm of diameter buried to 20 cm depth) taken randomly within each transect. Our sampling effort can be therefore considered as "intensive" given the number of samples taken per site as compared with other studies (2–4 stations per 10 km: see Tataranni and Lardicci, 2010 for discussion) while also attempting to cover an extensive area. This approach follows those of Muniz et al. (2005) and it is consistent with the idea that optimizing sampling effort, and disentangling variations occurring at several scales and due to differences in habitat characteristics.

The samples were sieved through a 0.5 mm. The use of larger sieves (1 mm) has been considered as a better option in order to avoid temporal variation, large number of juvenile stages that may later disappear in subsequent samplings. However, there are important arguments against this approach (Tataranni and Lardicci, 2010): (1) larger meshes may not retain small species, fragmented individuals, or those characterized by reduced width; (2) large mesh size would imply "unacceptable underestimation of the abundance of ecologically relevant species".

The samples were preserved in 4% formaldehyde; in the laboratory, all organisms were identified to the lowest possible taxonomic level (generally at specific level) and counted.