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A biological trait approach to assess the functional composition of subtidal benthic communities in an estuarine ecosystem

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ABSTRACT

Within transitional/estuarine environments ‘ecosystem functioning’ has been mostly investigated with “traditional” taxonomic analysis, based on the taxonomic composition of benthic invertebrate communities. However, ‘ecosystem functioning’ depends also greatly on the functional characteristics (biological traits) of organisms.

It was *a priori* suggested that the biological traits of the subtidal benthic invertebrate communities within an estuarine environment would respond to the high variability of environmental pressures (natural and human induced) within this type of ecosystem.

For this study, traditional taxonomic analysis (species richness, species density and Shannon–Wiener diversity) as well as biological trait analysis were used together for the first time to investigate the response of the subtidal benthic invertebrate communities to the environmental pressures within the Mondego estuary (Portugal).

Biological trait analysis, in addition to traditional taxonomic analysis provided a more comprehensive understanding of the functioning within this type of ecosystem. Some of the most important outcomes are: (i) the trait “salinity preference” was the most important trait that distributed the species along the estuary, (ii) the central part of the estuary appeared to be under higher environmental stress levels than the other areas, as suggested by a dominance of some “opportunistic” traits (*e.g.* small short-lived species), (iii) the ratio between functional diversity (FD) and Shannon–Wiener diversity (H′) indicated lower functional redundancy at the upper reaches of the estuary. Our results, suggest that the ratio (FD/H′) might be a helpful tool to visualize this functional attribute and could potentially be applied to different communities from distinct environments. Using the traditional taxonomic analysis alone, this last functional aspect would not be detectable. Therefore, the inclusion of biological traits analysis is recommendable for estuarine ecological studies.

1. Introduction

Human impacts have pushed estuarine ecosystems far from their historical baseline of rich, diverse, and productive ecosystems (Lotze et al., 2006). Centuries of overexploitation, habitat destruction and pollution have modified the rates of natural replacement and exchange of estuarine species, and increased species invasions and species extinctions (Loreau et al., 2001; Hooper et al., 2005; Lotze et al., 2006; Worm et al., 2006). These changes represent a great influence over natural balance and dynamics and have a strong potential to alter the functioning of estuarine ecosystems (Hooper et al., 2005; Lotze et al., 2006; Worm et al., 2006). Ecosystem functioning is a broad term, which includes ecosystem processes (*e.g.* nutrient cycling), the services that these processes provide to humanity (*e.g.* fisheries, nursery habitat and filtering capacity), as well as the resilience and resistance of these factors over time or in response to disturbance (Díaz and Cabido, 2001; Bremner, 2008).

Ecological experiments, observations and theoretical developments have shown that ecosystem functioning depends greatly on biodiversity in terms of the “functional characteristics” (biological traits) of organisms present in the ecosystem and on their distribution and abundance over space and time (Díaz and Cabido, 2001; Loreau et al., 2001; Hooper et al., 2005; Elliott and Quintino, 2007). Trait-based approaches provide clearer mechanistic links

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to ecosystem services since species traits are the main properties by which organisms influence ecosystem processes (Petchey and Gaston, 2006).

In transitional/estuarine environments, the assessment of ecosystem functioning has been mainly approached with "traditional" analysis based on the taxonomic composition of the communities (Mouillot et al., 2006; Elliott and Quintino, 2007). To our knowledge, traits-based analysis of benthic invertebrates has been mostly limited to feeding habits (*e.g.* Fano et al., 2003; Dolbeth et al., 2003; McLusky and Elliot, 2004) and size-structure (*e.g.* Warwick and Clarke, 1984; Basset et al., 2004; Mouillot et al., 2006; Reizopoulou and Nicolaidou, 2007). However, other traits that also refer to life strategy and behavioral characteristics have received far less attention, despite addressing important aspects of functioning.

Within this context, trying to overcome these limitations, a useful analytical approach had been developed to describe different aspects of functioning based on 'multiple' biological traits of aquatic invertebrates (*e.g.* mobility, feeding type, size, life span, and reproductive technique) (Bremner et al., 2003). This approach is commonly known as 'biological trait analysis' (BTA) and was largely developed in terrestrial and freshwater ecology (Bremner et al., 2003).

BTA has discriminated the effects of disturbances in freshwater ecosystems (*e.g.* Dolédec et al., 1999; Statzner and Bêche, 2010). In marine environments, BTA has been successfully applied to assess fishing effects on benthic fauna (*e.g.* Bremner et al., 2003; Tillin et al., 2006), and to investigate the effects of climate change (Neumann and Kröncke, 2010), as well as for management and conservation purposes (Bremner, 2008; Frid et al., 2008). In Mediterranean lagoons, this approach has been used to assess the relationship between biological functions and ecological quality (Marchini et al., 2008). Furthermore, BTA was used to assess functional diversity (FD) in different species assemblages (*e.g.* Bremner et al., 2003; Bady et al., 2005; Mermillod-Blondin et al., 2005; Schratzberger et al., 2007; Mouillot et al., 2007; Hewitt et al., 2008).

FD is the diversity of species traits in ecosystems (Díaz and Cabido, 2001). In contrast to taxonomic diversity, FD measures the distribution and the range of what organisms do in communities and ecosystems, and thus considers for example, the redundancy of co-occurring species (also known as functional redundancy) (Díaz and Cabido, 2001; Petchey and Gaston, 2006). Functional redundancy is an important property of ecosystem stability (Díaz and Cabido, 2001). The FD of a community approached through the measurements of traits is usually described by three kinds of indices which can be combined to calculate different facets of functional diversity (Mason et al., 2005; Villéger et al., 2008): functional richness, functional evenness and functional divergence. There are nine indices available in the literature to calculate FD on the basis of measured traits (Schleuter et al., 2010). For this study, the most common multivariate index to calculate FD (which includes all of the above facets) was used; the Rao's quadratic entropy (RQE) index (Rao, 1982; Champely and Chessel, 2002; Ricotta, 2005).

The main aim of this study was to investigate the biological trait response of the subtidal benthic invertebrate communities to the high variability of environmental conditions (natural and human induced) within an estuarine environment (the Mondego estuary, Portugal), by means of BTA. Moreover, the possibility of expressing functional redundancy of the benthic community using a ratio between taxonomic diversity (Shannon–Wiener diversity) and functional diversity was investigated. Thereby, this paper will contribute to a better understanding of the ecological functioning of these communities within this type of transitional ecosystem.

2. Materials and methods

2.1. Study area

The Mondego estuary (Fig. 1) is a relatively small warm-temperate polyhaline intertidal system (21 km long and 860 ha surface area), located on the NW coast of Portugal. The last 7 km, near the mouth, consist of two arms separated by Murraceira island.

The northern arm of the estuary is deeper (4–10 m during high tide) and is the most hydrological altered; it constitutes the main navigation channel and is the location for the Figueira da Foz harbor. The southern arm is shallower (2–4 m during high tide) and lies within a more 'natural environment'; 75% of its area are intertidal flats, where in some locations seagrass (*Zostera noltii*) meadows are present (Patrício et al., 2009). The hydraulic circulation in the South arm depends mostly on tides and on the connection with the North arm. The main human induced pressures in the Mondego estuary are the nutrient-loadings coming from agriculture (mainly corn and rice fields), harbor activities, fish farms located on Murraceira island and wastewater coming from Figueira da Foz and other upstream locations (Teixeira et al., 2009; Veríssimo et al., 2011).

2.2. Data collection

2.2.1. Biological data

Benthic samples were collected at five subtidal stations located in the estuary (Fig. 1), in two different seasons: summer 2009 (September) and winter 2010 (March). The two different seasons were chosen in order to investigate seasonal effects. The location of stations tried to encompass the variety of benthic communities that inhabit the Mondego estuarine gradient, from the most brackish reaches to marine-like conditions. St 3 ('st' is the abbreviation for station) and st 4 are located at the South arm of the estuary, st 12 at the North arm, st 16 at the center, and st 23 at the upper most part of the estuary. In each station, three sediment samples (replicates) were taken with a van Veen grab (0.1 m^2). Samples were stored in 4% buffered formalin solution and washed in the laboratory through 0.5, 1 and 2 mm mesh sieves. Afterwards, animals were sorted and preserved in 70% ethanol and, subsequently, identified and counted to the species level when possible, or to the lowest taxonomic level. The taxa density (individuals per 0.1 m^2) in each station was displayed in a numerical matrix (matrix 'taxa by stations').

2.2.2. Environmental data

During the collection of the sediment samples, salinity, temperature (°C), pH and dissolved oxygen (%) were measured *in situ* at the bottom of the water column where benthic invertebrates inhabit, using a Data Sonde Survey 4. In the laboratory, chlorophyll *a* (mg m^{-3}), N-NH_4 (mg L^{-1}), N-NO_3 (mg L^{-1}), N-NO_2 (mg L^{-1}), P-PO_4 (mg L^{-1}) and Si (mg L^{-1}) were analyzed following Parsons et al. (1985), Limnologisk Metokik (1992) and Strickland and Parsons (1972). TSS (total suspended solids, g L^{-1}) and granulometry data (%) for clay (<0.038 mm), silt (0.038–0.063 mm), fine sand (0.063–0.25 mm), medium sand (0.25–0.5 mm), coarse sand (0.5–2 mm) and gravel (>2 mm) were also measured.

2.3. Compilation of data matrices

Biological traits analysis (BTA) requires three different numerical matrices: (1) taxa density in each station (matrix 'taxa by stations'); (2) biological traits of the taxa (matrix 'taxa by traits'); and (3) a combination of the previous two, biological traits in each station (matrix 'traits by stations') (*e.g.* Bremner et al., 2003). In order to see the seasonal effects, these three matrices were built with summer and winter datasets. Data of taxa density in the