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Relationship between structure of macrobenthic assemblages and environmental variables in shallow sublittoral soft bottoms

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ABSTRACT

We establish baseline knowledge of abundance, diversity and multivariate structure of macrobenthos from shallow sublitoral soft bottoms in the North Portuguese coast and elucidate main environmental factors that shape their spatial patterns. In this area distribution of soft bottoms is patchy, surrounded by boulders and rocky substrates. This particular landscape and the lack of significant anthropogenic disturbances are values for the conservation of this habitat. Sediment and physicochemical properties of the water column were studied to provide models for each studied macrobenthic variable. Our models highlighted that most of variation (59%–72%) in macrobenthic spatial patterns was explained by the studied environmental variables. Sedimentary variables were more relevant that those of the water column. Therefore, disturbances affecting sedimentary environment could cause dramatic changes in macrobenthic assemblages because of the limited availability of soft bottoms in the area. In this way, results are useful to adopt right management and conservation strategies.

1. Introduction

Coastal ecosystems provide valuable goods and services to humans but anthropogenic use has also altered the oceans through direct and indirect means (Halpern et al., 2008). Particularly, in recent decades, worldwide marine ecosystems are suffering the synergistic effects of multiple stressors derived from anthropogenic activities such as overfishing, invasive species or pollution (Claudet and Fraschetti, 2010). These stressors act as major drivers of ecosystems altering the structure and functioning of their assemblages with consequences to human well-being (Worm et al., 2006). In this scenario, there is an imperative need for adopting management and conservation strategies in marine systems that will be crucial for the sustainable use of resources (Desroy et al., 2002; Claudet and Fraschetti, 2010). However, the major constrains to implement conservation strategies in marine ecosystems are the general lack of baseline data prior to impacts and substantial gaps in the current knowledge of natural patterns of variability of their assemblages, which are intrinsically variable (Claudet and Fraschetti, 2010; Schückel et al., 2015).

Soft bottom macrobenthos plays an important role in marine ecosystem processes such as nutrient cycling, pollutant metabolism or secondary production (Snelgrove, 1998; Pratt et al., 2014). Most of macrobenthic species display a sedentary lifestyle, intermediate trophic level positions, relatively long life-span and varying responses to changes in environmental stress that make macrobenthos an effective and useful indicator for the assessment of coastal system quality (Dauvin, 2007). Over the past few decades, macrobenthos has been a key element of many monitoring programmes; in this way, upgrading our knowledge about its biodiversity is useful, particularly in marine soft-bottoms (Ellingsen, 2002; Veiga et al., 2016). Although soft-bottoms are the largest ecosystem on Earth in terms of area coverage, only a small percentage of their macrobenthos has been studied and most of its species are still undescribed (Snelgrove, 1998). Within soft-bottom

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ecosystems, sublittoral macrobenthic assemblages have been less studied that those from the intertidal and remaining largely unknown (Desroy et al., 2002; Schückel et al., 2015). Spatial distribution of these assemblages is heterogeneous (Mann and Lazier, 2006) and sediment features (e.g. grain size, organic matter content and food availability) have been identified as responsible for spatial patterns of macrobenthos (Ellingsen, 2002; Van Hoey et al., 2004; Hily et al., 2008; Ramey and Bodnar, 2008). Moreover, at greater spatial scales, physicochemical characteristics of the water column and hydrodynamics, seem to control directly or indirectly abundance and distribution of macrobenthos by influencing food availability, bottom-water oxygenation and larval dispersion (Dauvin et al., 2004; Blanchet et al., 2005; Schückel et al., 2015).

Spatial models such as multiple regression or canonical correspondence analyses have revealed that the percentage of the variation in assemblage structure from soft-bottom habitats explained by environmental factors is very variable (i.e. between 10% and 90%) (e.g. Veiga et al., 2009; Olsson et al., 2013; Schückel et al., 2015). These previous studies were done in subtidal areas where soft bottoms are the dominant habitat and cover wide extensions. However, in some regions like north Portuguese coast, soft bottoms at shallow sublittoral are restricted to patches surrounded by large extensions of boulders and rocky substrates, the latter being the predominant habitat (Rodríguez et al., 2011). Moreover, on the one hand, the north Portuguese coast is still an area characterized by relatively low levels of anthropogenic pressure, deserving attention for its conservation. Previous investigations showed that concentrations of nutrients, PAHs and trace metals were near background values (e.g. Reis, 2012; Reis et al., 2014; Rubal et al., 2014), indicating that North Portuguese coast is not subjected to severe eutrophication or pollution by industrialization and urbanization of the surrounding areas. On the other hand, benthic studies done in this area have been focused on intertidal assemblages from rocky shores (e.g. Araújo et al., 2006; Rubal et al., 2011; Veiga et al., 2013) and soft bottoms (Veiga et al., 2014). However, there is a gap in knowledge about the structure of assemblages from subtidal soft-bottoms. As proof of this, new species of macro- and meiobenthos have been recently described from shallow subtidal sediments of the North Portuguese coast (Esquete et al., 2015; Rubal et al., 2017), indicating that this system may be also of high value for conservation.

The study of spatial patterns in macrobenthic assemblages in this area will let us establish baseline knowledge, mandatory to detect future potential changes in species distribution and helpful for monitoring and management issues (Desroy et al., 2002; Claudet and Fraschetti, 2010; Dutertre et al., 2013; Schückel et al., 2015). Moreover, elucidating main natural environmental factors that shape spatial patterns of macrobenthic assemblages from subtidal soft-bottom will help to discriminate between natural and anthropogenic changes (Glockzin and Zettler, 2008; Dutertre et al., 2013). Therefore, the aims of this study were to determine the natural environmental variables that shape the structure of macrobenthic assemblages in shallow sublittoral soft bottoms in the North Portuguese coast and providing baseline information for assessing the quality of this system in the future, which will be crucial for adopting right management and conservation strategies. To achieve these aims first, spatial patterns of sediment features, physicochemical properties of the water column and macrobenthic assemblages were described. Then, the relationship between spatial distribution patterns of macrobenthos and those of environmental factors were investigated using multivariate statistical approaches. This will allow identifying useful predictor variables and generating simple models to explain natural spatial variability in macrobenthic assemblages.

2. Material and methods

2.1. Study area

The study was carried out on shallow subtidal soft bottoms in the North of Portugal, encompassing over 22 km of coast between 41°51′10.01″N; 8°52′54.00″W and 41°39′39.72″N; 8°50′24.42″W (Table 1 and Fig. S1). This subtidal area is predominantly covered by rocky shores that constituting the 69%, whereas soft bottoms are the second most abundant habitat (21%) followed by boulders (10%) (Rodríguez et al., 2011). The coast in this area is north-to-south oriented, exposed to prevailing northwest oceanic swell. Moreover, this coastal area is subjected to the influence of river plumes, being Miño and Lima the most important rivers regarding flow and to upwelling events (Lemos and Pires, 2004).

2.2. Sampling design

Sampling was conducted in May 2012 at four shallow subtidal soft bottom localities (Table 1, Fig. S1). A two-factor sampling design was used to assess the spatial patterns of macrobenthic assemblages and their relationship with sedimentary and water column environment. The largest spatial scale was that of locality, which included four levels: Moledo, Âncora, Gelfa and Lima, spaced kms from one another. At each locality, three sites, approximately 100s of ms apart, were randomly established within each soft bottom patch. Localities and sites were selected considering the availability of soft bottoms (Fig. S1) based on a previous work that had characterised main habitats of the study area including bathymetric and geomorphologic analyses (Rodríguez et al., 2011). Sediment samples within each site were randomly collected, about 10s of ms apart, using a Van Veen grab (sampling surface of 0.12 m^2) to a mean depth of 12 m (between 9.5 and 15 m) (Table 1). At each site, a total of seven grabs were collected, five to the study of macrobenthos and the remaining two to study the sedimentary environment (i.e. grain size and organic matter). Macrobenthic samples were immediately washed on board over a 0.5-mm mesh sieve. The retained macrofauna was then preserved in 4% neutralised formaldehyde solution with Rose Bengal in labelled plastic bags until its posterior study. Samples to sedimentary study were frozen. To characterise the water column environment, three independent measures of oxygen concentration, salinity and temperature were obtained at each locality by means of a CTD SBE25. Moreover, three independent water column samples of 250 ml were collected at each site and locality for nutrient analyses: nitrate (NO_3), phosphorus (PO_4) and ammonium (NH_3) as close to the bottom as possible avoiding sediment resuspension.

2.3. Sampling processing

Macrobenthos was sorted, identified to the lowest possible taxon (usually species level) and counted. The organic matter content was calculated by measuring the loss of weight on ignition in a furnace at 450 °C for 4 h. In order to study the sediment grain size, samples were dried and then sieved. The following sedimentary fractions were considered: coarse gravel (>4 mm), fine gravel (2–4 mm), very coarse sand (1–2 mm), coarse sand (0.5–1 mm), medium sand (0.25–0.5 mm), fine sand (0.125–0.25 mm), very fine sand (0.063–0.125 mm) and silt/clay (<0.063 mm). Then, the median particle size (Md; Bale and Kenny, 2005) and sorting coefficient of the sediment (QDΦ; Yamanaka et al., 2012) were calculated. Nutrient analyses were done directly in filtered seawater samples by Molecular Absorption Spectrometry using a segmented flux autoanalyser (San Plus System, Skalar). The concentrations of NO_3, PO_4 and NH_3 were determined according to Skalar methods M461-