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Diversity and spatial distribution patterns of the soft-bottom macrofauna communities on the Portuguese continental shelf

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ABSTRACT

This study presents a comprehensive assessment of the diversity and spatial distribution of the soft-bottom benthic macrofauna communities along the Portuguese continental shelf and discusses the relationship between biological and environmental data. A total of 145 sites were sampled using a 0.1 m^2 Smith–McIntyre grab covering the whole west and south coast of Portugal, at depths ranging 13 and 195 m. More than 30,000 specimens were identified corresponding to 737 taxa, mostly annelids (43% of the total taxa). The most frequent species were *Ampharete finmarchica, Ampelisca* sp. and *Lumbrineris lusitanica* while the most abundant were *Mediomastus fragilis*, *Polygordius appendiculatus* and *Ampharete finmarchica*. Abundance ranged between 7 and 1307 specimens per 0.1 m^2 and *alpha* diversity reached a maximum of 96 taxa per 0.1 m^2. Gravel sediments, and shallow and sheltered areas presented higher diversity values than mud sediments and deeper sites. Six major benthic assemblages were identified: (a) Coarse sediments, mostly located on the western shelf, with *Protodorvillea kefersteini*, *Pisione remota*, *Angulus pygmaeus* and several other interstitial species; (b) near shore fine sands with *Magelona johnstoni*, *Urothoe pulchella* and *Angulus fabula*; (c) *Abra alba* community in northwestern deep muddy sands; (d) Southwestern very deep muddy sands characterized by *Galathowenia oculata, Lumbrinerides amoureuxi* and other burrowers and tubicolous polychaetes; (e) *Euchone rubrocincta, Nematonereis unicornis* and other warmer water species in muddy sands of the southern and sheltered shelf; and (f) muds dominated by *Sternaspis scutata*, *Heteromastus filiformis* and *Psammogammarus caecus.* Sediment grain-size, organic matter, depth and hydrodynamic regime were the variables best related to the macrofauna distribution patterns, highlighting the transitional characteristics of this northeastern Atlantic area, where northern and subtropical faunas can coexist.

1. Introduction

The identification, characterization and mapping of marine macrofauna benthic communities are important, for instance, to identify marine protected areas and to establish management tools for an overall better use of the marine environment (e.g. Gogina and Zettler, 2010). Past works have studied the spatial patterns of benthic communities and identified factors that affect them, namely sediment type and organic matter content, depth, latitudinal gradients and correlated variables, such as nutrients, pH or temperature (e.g. Hily et al., 2008). The macrofauna benthic communities from the Portuguese coast are well known, mainly in lagoons (e.g. Quintino et al., 1987, 1989; Rodrigues et al., 2012), estuaries (e.g. Rodrigues and Quintino, 1993; Rodrigues et al., 2006, 2011), sandy beaches (e.g. Dexter, 1988; Vale et al., 2010), intertidal rocky shores (e.g. Araújo et al., 2005; Pereira et al., 2006; Saldanha, 1995) and submarine canyons (e.g. Cunha et al., 2011; Cúrdia et al., 2004). In the continental shelf however, studies have focused on restricted areas (e.g. Carvalho et al., 2011; Freitas et al., 2003a,b, 2011; Marques, 1987; Marques and Bellan-Santini, 1993; Reis et al., 1982), unlike in other European shelves where broadscale and holistic soft-bottom macrofauna community studies were carried out in the past (e.g. Cabioch, 1968; Glémarec, 1973; Picard, 1965; Thorson, 1957). A more comprehensive biodiversity assessment of the Portuguese continental shelf was still lacking.

The Portuguese continental shelf, located in the Western Iberian coast, is a region of contact between colder waters from the North Atlantic and warmer waters from northern Africa and the Mediterranean Sea. The western Portuguese shelf is dominated by an extremely energetic regime of waves and tides and a complex current system, while the southern shelf is affected by warmer waters and is characterized by a lower energy hydrodynamic regime, where the Atlantic inflow imposes eastward-directed current patterns (Fiúza, 1983). In terms of hydrodynamic regime, the Portuguese coast has been divided in three areas: mesotidal exposed Atlantic coast, from the northern Portuguese border to Cape Carvoeiro west coast, mesotidal moderately exposed Atlantic coast, from Cape Carvoeiro to Ponta da Piedade south coast and mesotidal sheltered Atlantic coast, from Ponta da Piedade to Vila Real de Santo António, the remaining southern coast (Bettencourt et al., 2004). This different regime along the coast affects the sedimentary cover of the Portuguese shelf, where coarser sediments characterize the

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northwestern shelf, muddy sands dominate the remain western shelf and muds are mostly present in the sheltered southern shelf (Martins et al., 2012a). The Portuguese shelf is also fractured by submarine canyons, of which the most outstanding are Nazaré, Cascais/Lisboa, Setúbal, and S. Vicente, which cause morphological, sedimentary and hydrological boundaries (e.g. Oliveira et al., 2007).

The scope of the present study was to identify and characterize the macrofauna benthic communities on the Portuguese continental shelf, to discuss the relationship between biological and environmental data and to characterize and to map the soft-bottom benthic habitats.

2. Material and methods

2.1. Study area, sampling and laboratory procedures

The study area comprised the entire Portuguese continental shelf, from Caminha on the Northwest (41°51.8′N, 9°15.6′W) to Vila Real Santo António on the Southeast (36°56.1′N, 7°24.7′W). A total of 145 sites were distributed in perpendicular lines to the coastline, between 13 and 195 meter water depth (Fig. 1), being taken two sediment samples at each site, with a 0.1 m^2 Smith–McIntyre grab, one to study the macrofauna and the other for sedimentary analyses (grain-size and total organic matter content (TOM)). Macrofaunal sediment samples were sieved on board over 1 mm mesh size and the residue fixed in neutralized formalin (4%) stained with rose Bengal. The detailed results from grain-size analysis and the spatial distribution of superficial sediments are given in Martins et al. (2012a). The shallow and mid depth northwestern shelf and the areas located close to the major Portuguese submarine canyons are characterized by coarser sediments with low fines and organic matter content, the southwestern and the deep northwestern shelf are dominated by fine sands with moderate fines and organic matter content, the western part of the southern shelf is very heterogeneous and muds predominate off the major Portuguese rivers (the Tagus, in Lisbon, the Douro, in Porto, and the Guadiana, in Vila Real Santo António, on the southern coast). The total organic matter ranging below 1% to 10% of the total sediment, was well correlated with the sediment fines content (Spearman rho = 0.71). The highest TOM values were found in the southern shelf and in the Tagus mud patch (Martins et al., 2012a).

In the laboratory, the macrofaunal samples were abundantly rinsed with water through a 0.5 mm mesh sieve, hand sorted and the fauna preserved in ethyl alcohol (70%). Fauna were identified to species level, whenever possible.

2.2. Data analysis

Abundance, species richness and diversity measurements were calculated per sampling site and mean values were obtained per sediment type, depth classes (<30 m, 30–60 m, 60–100 m and >100 m), hydrodynamic regime areas (sheltered = 1; moderately exposed = 2; exposed = 3), latitudinal degree on the western shelf and longitudinal degree on the southern shelf, and major shelf areas (western, southern and entire shelf). *Alpha* diversity corresponds to the total quantity of species per sampling unit (0.1 m^2) and is often more simply referred to as species richness. *Beta* or turnover diversity corresponds to the extent of biotic change or species replacement along an environmental gradient (Gray, 2000; Whittaker, 1960), and was calculated for all the above categories, except per sampling site. It was obtained by dividing the mean *alpha* diversity per sample in a given category, by the total number of species found in that same category (Whittaker, 1960). As an example, *beta* diversity for the whole Portuguese shelf corresponds to the quotient between the mean a*lpha* diversity of the whole set of samples and the total number of species recorded in this study. Other diversity indices were also calculated per site, to complement and comprehend the spatial variation of the diversity along the Portuguese shelf, namely, Shannon–Wiener diversity (H′; $\log_2$), Margalef richness (d), Pielou evenness (J′), Simpson ($1 - \lambda'$) and Rarefaction indices (ES50) (Clarke and Gorley, 2006).

The data matrix with the macrofauna abundance per site was square root transformed and the Bray–Curtis similarity calculated between sites. The similarity matrix was analyzed using agglomerative hierarchical clustering, with the un-weighted pair-group mean average algorithm (UPGMA) and ordination analysis, with non-metric multidimensional scaling (NMDS). These techniques were used for the identification of the biological affinity groups, also named benthic assemblages thorough the text. The biological groups were characterized according to the mean abundance, species richness, *alpha* and *beta* diversity, Shannon–Wiener diversity ($\log_2$), Pielou evenness, Margalef richness, Simpson index, Rarefaction index, the sediment baseline data, the number of exclusive species and the characteristic species. The characteristic species of each assemblage were obtained following their constancy (C) and fidelity (F) in the assemblage. The constancy corresponds to a sampling frequency and is given by the number of sites where the species was sampled expressed as a percentage of the total number of sites in the assemblage (Dajoz, 1971). The fidelity corresponds to the quotient between the species constancy in a given assemblage and the sum of the constancies of the same species in all the assemblages where it exists (Retière, 1979). For constancy, species were classified into constant ($C > 50.0\%$), common ($50.0 \geq C > 25.0\%$), occasional ($25.0 \geq C > 12.5\%$) and rare ($C \leq 12.5\%$), and for fidelity into elective ($F > 90.0\%$), preferential ($90 \geq F > 66.6\%$), indifferent ($66.6 \geq F > 33.3\%$), accessory ($33.3 \geq F > 10.0\%$) and accidental ($F \leq 10.0\%$). The characteristic species per affinity group were selected following the highest product between the constancy and fidelity indices (e.g. Lourido et al., 2010). Using a one-way model in PERMANOVA + (Anderson et al., 2008), the null hypotheses (H_0) of no significant differences among the biological affinity groups were tested for the following fixed factors: (a) sediment descriptors (median grain-size, gravel (>2 mm), sand (2–0.063 mm), fines (<0.063 mm) content; H_01), total organic matter content (H_02), depth (H_03), hydrodynamic regime (H_04) and latitude (H_05). The significance in the main and pair-wise tests was obtained following unrestricted permutation of the raw data (9999 permutations) and the calculation of type III sums of squares. The null hypotheses were rejected at $p < 0.05$. The biological-environmental relationship was analyzed with the BIOENV procedure, in PRIMER v.6, using the Spearman correlation coefficient (Clarke and Gorley, 2006) and considering the environmental variables depth, median grain-size, gravel, sand, fines, biogenic fraction and TOM contents, hydrodynamic regime and latitude. The abundance, *alpha* diversity, Shannon–Wiener diversity and Pielou evenness per site, and the representation of the affinity groups were plotted with ArcGis 10.

3. Results

3.1. Abundance and diversity gradients

The spatial representation of the abundance, *alpha* diversity, Shannon–Wiener diversity and Pielou evenness per sampling site is shown in Fig. 2 (A–D). A total of 30,008 individuals were identified corresponding to 737 species. The complete faunal list, indicating the total abundance and number of occurrences per species, is given as Supplementary material. The most abundant taxa were the polychaetes, bivalves, nematodes, nemerteans and amphipods, with respectively, 19731, 1996, 1709, 1611 and 1413 specimens. The highest species richness was found within the polychaetes, with 319 species, followed by bivalves, amphipods, gastropods and decapods with 105, 99, 53 and 38 species, respectively. The abundance ranged from 7 to 1307 specimens per 0.1 m^{-2} with a mean value of 207 specimens per 0.1 m^{-2}. Abundance decreased from coarser to muddy sediments, from shallow to deep shelf, from exposed to sheltered shelf and from the north to the southern latitudes. Considering this, the highest macrofauna abundances of benthic fauna were obtained in gravel (479.0 ind. 0.1 m^{-2}), in the

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