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Urban vs. extra-urban environments: Scales of variation of intertidal benthic assemblages in north Portugal

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ABSTRACT

Littoral areas are subject to severe and increasing pressures resulting from human activities occurring along or next to the coast. In this study, patterns of variability in the structure of rocky intertidal benthic assemblages and in the abundance of individual taxa were compared between locations close to the coastal cities of Porto and Vila Nova de Gaia (north Portugal) and reference locations far from it in much less urbanized conditions over a temporal scale of fourteen months and multiple spatial scales. Present findings indicated that assemblages were more heterogeneously distributed in the urban than in the extra-urban condition. The total number of taxa and several individual taxa displayed, in general, this same pattern of variability. This could be interpreted as the beginning of a habitat deterioration process with largely unpredictable consequences. The adopted sampling design supports the need for simultaneously including a range of temporal and spatial scales when evaluating responses of coastal marine biodiversity to anthropogenic disturbances.

1. Introduction

Littoral areas are subject to severe pressures resulting from activities of the large proportion (i.e. more than 60%) of the human population living in coastal areas. This proportion is predicted to increase up to 75% in the next decades due to further demographic growth and to the tendency to move to coastal zones (Vitousek et al. 1997; Airoldi and Beck, 2007). This urban development typically modifies original habitats, causing impacts on local animals and plants, which are often replaced by non-native species (Lindegarth and Hoskins, 2001; Magura et al. 2009). In general, anthropogenic pressures are not easy to unequivocally identify and quantify as they interact in complex ways with natural processes and can be produced by a wide range of activities, including chemical pollution, sewage discharges, fishing and aquaculture (e.g. Fraschetti et al. 2011). Nevertheless, there is evidence that they can affect local, regional and even global patterns of distribution, abundance and diversity of benthic organisms, from individuals and populations to the ecosystem level (Lotze et al. 2006; Halpern et al. 2008; Fraschetti et al. 2011; Martins et al. 2012).

It has been frequently addressed (Olden and Rooney, 2006; Bevilacqua et al. 2012; Guarnieri et al. 2012; Tamburello et al. 2011) that a major result of anthropogenic pressures is a reduction of species diversity and evenness, as rare and more sensitive species are replaced by more resistant ones, leading to assemblages including less taxa, each represented by a relatively larger number of individuals. This can also lead to a homogenization of the spatial distribution, in terms of composition and abundance of species, among sites, i.e. the beta diversity (e.g. Balata et al. 2007a). Empirical tests of such expectation, however, have documented inconsistent findings. In particular, homogenization could occur in heavily disturbed systems (Archambault et al. 2001; McKinney, 2008), while in moderately disturbed ones the results varied considerably. In fact, several authors reported that human disturbances could modify local assemblages towards increases of their heterogeneity (e.g. Caswell and Cohen, 1991; Warwick and Clarke, 1993; Fraschetti et al. 2001), for example through the addition of non-native species that replace native species faster than these are lost (McKinney, 2002, 2006). Therefore, formally testing whether local anthropogenic disturbances drive a homogenization or a larger heterogeneity of populations and assemblages is extremely important to detect actual impacts of human activities in previously

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unstudied systems and to provide a basis for their possible mitigation (e.g. Elmqvist et al. 2003). An overwhelmingly relevant issue in such assessments concerns the scale at which a certain human impact is examined (Fraschetti et al. 2001, 2005; Menconi et al. 1999; Tamburello et al. 2011), as different processes can generate variability at different scales (Underwood and Chapman, 1996). In such a context, the use of hierarchical sampling designs able to capture variability over a range of scales has been widely proposed as a key tool to identify the extent of an impact (e.g. Vanderklift and Lavery, 2000; Piazzi et al. 2004; Pardi et al. 2006; Balata et al. 2007b, 2008) and to ensure that comparisons between disturbed and reference locations are done over scales appropriate to detect the actual impacts in an unconfounded way (Underwood, 1993, 1994; Glasby and Underwood, 1996; Bishop et al. 2002).

In this study, patterns of variability in the structure of rocky intertidal benthic assemblages and in the abundance of individual taxa were compared between urban (i.e. close to large coastal cities on the NW Portuguese coast) and reference (i.e. far from large coastal cities, in less urbanized areas) locations over a temporal scale of fourteen months and multiple spatial scales, ranging from 10s cm to 10s km. The hypothesis was that temporal and spatial patterns of distribution and abundance of whole assemblages and individual taxa were significantly affected by urbanization. The direction of such change towards a reduced or increased homogenization, however, could not be anticipated in detail as such issues had not been previously addressed in the present system despite the obvious local human pressure due to its proximity to the largest cities, commercial and industrial activities occurring along the Portuguese shore.

2. Materials and methods

2.1. Study site

The study took place between February 2012 and April 2013 at four rocky locations (100s m long) interspersed along about 30 km of coast in NW Portugal: Praia da Aguda (41° 2.71′N, 8° 39.20′W), Lavadores (41° 7′52.31″N, 8°40′12.31″W), Castelo do Queijo (41°10′4.82″N, 8°41′25.96″W) and Mindelo (41°18′36.19″N, 8°44′32.77″W). Lavadores and Castelo do Queijo are adjacent to highly urbanized areas (Vila Nova de Gaia and Porto, located next to the south and north side of Douro River's estuary, respectively). A map of the study system is reported in Fig. 1. Resource limitation prevented to include a larger number of replicate locations in each condition, which would have allowed a more accurate estimation of patterns of variability at each scale. However, our design was aimed at assuring that possible sources of uncontrolled variability, particularly those related to the geographical positioning of the sampled units relatively to the urban areas were equally distributed between the urban and the reference condition. Praia da Aguda and Mindelo occur in areas with small resident population lacking large commercial and industrial plants and are located south and north of Lavadores and Castelo do Queijo, from which they are separated by about 10–15 km of sandy beach. The shore at all locations is gently sloping, with a typical granitic substratum, analogous exposure to prevalent wind and waves, similar accessibility and a semi-diurnal tidal regime with maximum range of spring tides of 3.5–4 m. At each location, sampling was carried out in the mid intertidal habitat, i.e. about 1–2 m above Chart Datum. Assemblages at this shore level are dominated by mussels (*Mytilus galloprovincialis* Lamarck) in association with several algal species, commonly including encrusting (e.g. *Lithophyllum* spp.) and articulated corallines (e.g. *Corallina* spp.), other erect red algae such as *Gelidium* spp., *Chondracanthus teedei* (Mertens ex Roth) Kützing and *Chondracanthus acicularis* (Roth) Fredericq, green foliose species of the genus *Ulva* and the brown tuning fork weed *Bifurcaria bifurcata* R. Ross (Araújo et al. 2005). Grazing gastropods such as *Patella* spp. and *Gibbula* spp. are also very common.

2.2. Experimental design and data collection

At each of the two urbanized and reference locations, we randomly selected two sites (about 100 m long, about 50 m apart), with two 10 m areas (about 10 m long, 3–5 m apart) in each site and 15 quadrates (20 × 20 cm, 10s cm apart) in each area. The same sampling was repeated at each of four dates, established at random over a scale of 14 months: February 2012, May 2012, November 2012 and April 2013. New sets of independent sites, areas and quadrates were established at random at each sampling date.

At each date, organisms in each replicate quadrate were sampled visually utilizing a 20 × 20 cm frame, divided into twenty-five 4 × 4 cm sub-quadrates. The abundance of sessile organisms in

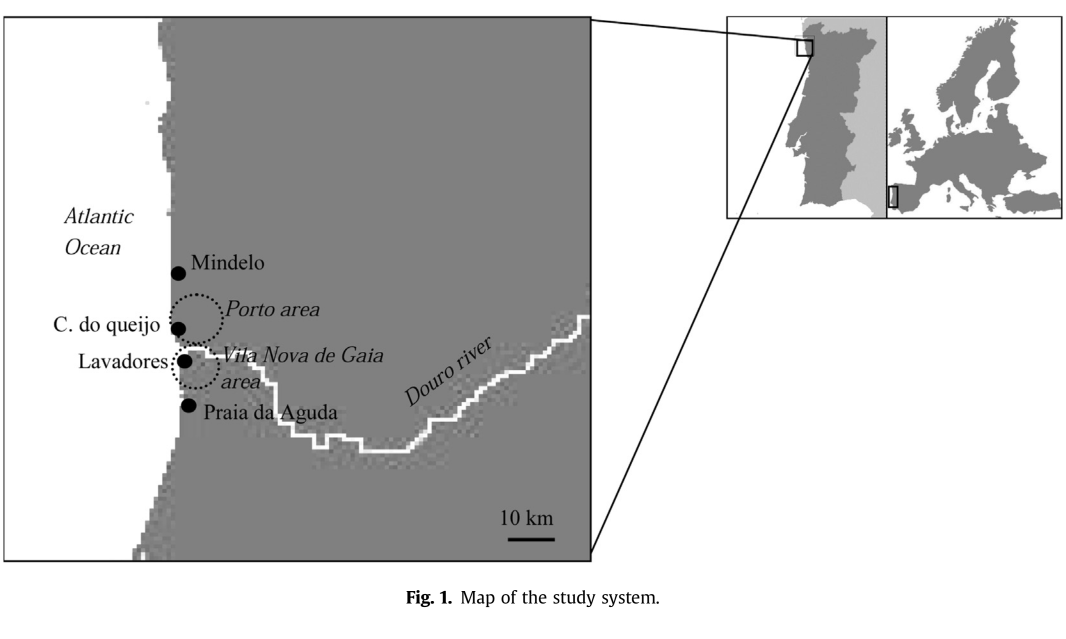

Fig. 1. Map of the study system.