Ecological Indicators 41 (2014) 49–57

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Temporal changes in macrofauna as response indicator to potential human pressures on sandy beaches

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ARTICLE INFO

Article history:
Received 1 November 2013
Received in revised form 11 January 2014
Accepted 14 January 2014

Keywords:
Sandy beaches
Macrofaunal assemblages
Temporal changes
Crustaceans
Human pressures
Coastal tourism

ABSTRACT

Sandy beaches are natural dynamic ecosystems, which are becoming worldwide increasingly disturbed by intensive human direct use, coastal development and erosive evolution. In this study, we have examined whether ten years of potential increased human pressures have resulted in significant changes in the macrofaunal assemblages' structure and composition of two mesotidal sandy beaches (Cabedelo – urban beach, and Quiaios – rural beach) on the European Atlantic coast (Portugal). Seasonal macrofauna collections were performed at both beaches in two different periods, one in 1999–2000 and another in 2010–2011. The physical variables did not change significantly in both beaches throughout the studied periods, however, the urban beach was subject to an increase of human pressures (tourism and shoreline modifications) over the 10-years interval considered when compared with the rural beach. The univariate community descriptors (total density, species richness and diversity) did not differ significantly among periods for the rural beach. In contrast, temporal differences were found at the most urbanised beach, principally regarding the abundances of the amphipod *Talitrus saltator* and the isopod *Tylos europaeus*, two of the most abundant species at both beaches. PERMANOVA tests enhanced these temporal variations and the SIMPER analysis attributed to these species the main differences found between periods in this beach. Since the physical environment was similar in both periods, the ecological changes were most likely attributed to the increased human pressures observed at the urban beach. Nevertheless, this study highlights the need of further robust and effective impact assessments and long-term studies to better discern between natural and human induced changes on sandy beaches.

1. Introduction

Human activities have been recognised to place heavy pressures on coastal ecosystems as the growth in both economies and populations continues (Halpern et al., 2008; Millenium Ecosystem Assessment, 2005). Exposed sandy beaches are not an exception and during the last decades, these ecosystems have been subjected to severe and increasing pressures in most countries, as a result of conflicting uses such as coastal development, environmental pollution, and intensive tourism, among other coastal disturbances (review in Defeo et al., 2009) as those documented in the Portuguese coast (Veloso-Gomes and Taveira-Pinto, 2003; Coelho et al., 2009).

In addition, on urbanised coasts (*sensu* Veloso et al., 2006), management practices such as nourishment and coastal armouring have been intensively used to counteract the erosive evolution of coasts, but the ecological implications of these actions are less considered (Defeo et al., 2009; Schlacher et al., 2006). Superimposed on these trends of coastal impacts is the predicted increase in the frequency and intensity of extreme natural phenomena (e.g. storms) due to the effects of global climate change that can dramatically affect the fauna and flora of ocean-exposed sandy beaches (Brown and McLachlan, 2002; Defeo et al., 2009; Dugan et al., 2010; Schlacher et al., 2007, 2008b).

Exposed sandy beaches are physically dynamic habitats where diverse assemblages of macroinvertebrates can occur (McLachlan and Brown, 2006), and since they are known to be structured mainly by physical factors (reviewed in Defeo and McLachlan, 2005),

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http://dx.doi.org/10.1016/j.ecolind.2014.01.023

documenting the biotic responses to particular modifications of the physical environment can be used for the assessment of the ecological conditions of beaches. To this regard, over the last years, several studies have been showing the negative effects to macrofaunal communities and/or individual species on beach-aeolian dune environments, when facing particular human disturbances caused by coastal management practices such as beach nourishment projects (e.g. Bessa et al., 2013; Fanini et al., 2009; Jones et al., 2008; Schlacher et al., 2012) and coastal armouring (Dugan and Hubbard, 2006; Dugan et al., 2008; Walker et al., 2008). Still, human recreational activities have been recognised to negatively affect beach fauna due to the intensive use of beaches (Schlacher and Thompson, 2012; Schlacher et al., 2011; Ugolini et al., 2008; Veloso et al., 2008) and to the impact of off-road vehicles (e.g. Schlacher et al., 2008a; Sheppard et al., 2009; Schlacher and Lucrezi, 2010; Walker and Schlacher, 2011).

Despite the long history of human activities on sandy beaches, little is known about their potential ecological implications over the course of time. When addressing this issue, the main difficulty for sandy beach ecologists is the fact that apart from the adverse effects of human activities, exposed sandy beaches show wide variations in the environmental conditions making it difficult to discern natural from human-induced changes. In addition, and regarding the European Atlantic coast, the knowledge about the ecological conditions of beaches before the increase of the above-mentioned human pressures is still scarce.

For instance, the mainland Atlantic coast of Portugal extends along more than 900 km, of which 60% are beaches and according to the last official European reports (Eurosion, 2004; GHK, 2006), 28% of this coast is facing severe problems of erosion. Over the last decades, in order to counteract the erosion process and the "coastal squeeze" phenomenon of this coastline, coastal management practices (in particular beach nourishment and breakwaters) have been applied on the mainland coast of Portugal (Veloso-Gomes and Taveira-Pinto, 2003), and were already proposed in the Plan of the Portuguese Environment Agency (PAPVL) for the period of 2012–2015.

On the other hand, the increase in the number of tourists recorded in the country (INE – National Institute of Statistics) in the last years has potentiated the improvement of sandy beaches' facilities to promote the aesthetic and economic value of beaches along the entire coast (Veloso-Gomes and Taveira-Pinto, 2003). However, the ecological implications of these actions were never assessed.

In 1999–2000, Gonçalves et al. (2009) identified three supralittoral crustaceans as key elements at two similar exposed sandy beaches in the central coast of Portugal and Gonçalves et al. (2013) proposed the use of the bioecology of these species as potential assessment tools to evaluate environmental disturbances.

Given the vital role of macroinvertebrates in the ecological functioning of sandy beaches the goals of this study were: (1) to investigate possible temporal variations in the structure and composition of the macrofaunal assemblages on two sandy beaches during two periods (1999–2000 and 2010–2011), and (2) to assess whether possible ecological changes reflect the effects of long-term human pressures. This assessment should be seen as a first step towards more comprehensive and robust evaluation of potential cumulative human pressures and their impact on sandy beaches.

2. Materials and methods

2.1. Study area

This study was conducted at two exposed sandy beaches, Cabedelo and Quiaios, in central Portugal, on the western coast of the Iberian Peninsula (Fig. 1). This coastal area presents a warm temperate Atlantic-Mediterranean climate and semidiurnal tides with maximum amplitude of about 3.5 m (Gonçalves et al., 2009). These beaches are affected by a wave regime that has an average significant wave height of 1.8 m (with wave directions of 242–297° N), reaching 5.0–6.5 m (1% of the total, with N262–282° directions) (Santos et al., 1991). The Cabedelo sandy beach is located in the vicinity of the Mondego estuary, while the Quiaios beach is located further north, about 8 km north from Cape Mondego (Fig. 1).

Regarding the morphodynamic state, both exposed beaches are of high-energy intermediate type, and present relatively similar conditions of exposure to wave actions: according to the rating scheme for assessing the degree of exposure in sandy beaches (McLachlan, 1980), Quiaios is classified as a very exposed beach (exposure rate: 16) and Cabedelo as exposed beach (exposure rate: 15). In addition, the littoral dynamics of this coastal sector and the historic beach evolution is provided by Cunha and Dinis (1998, 2002).

Cabedelo beach is widely recognised as an urban beach since it is closer to the important tourist centre town of Figueira da Foz, and have a high potential for recreational use. In this sense, in order to improve the human use of beaches, the entire urban area has been subjected to diverse transformation actions along time, i.e. improvement of touristic facilities and beach grooming (the removal of organic beach-cast material along the strandline that occurs in particular during the spring–summer seasons), and consequently leading to an increase of human use of the beach (e.g. recreational activities such as surf championships, in situ observations). The aeolian dunes immediately adjacent to this beach are also backed by infrastructures (boardwalks and parking areas, see Fig. 1b).

In addition, the coastal zone management plans approved for the entire coast of mainland Portugal to counteract the erosive evolution (Veloso-Gomes and Taveira-Pinto, 2003), has been also implemented for the Cabedelo beach, in particular, the extension of a breakwater (400 m) and related adjustment with rocks on the beach (in 2008 and 2010, source: local authorities). In contrast, at Quiaios beach, which is located in a rural area, the sampling point was chosen on an undisturbed zone, with limited access (no physical facilities placed on this zone on the beach, see Fig. 1a) and for this reason have a lower human beach use. This beach is about 3 km wide and rises to nearly 100 m and is backed by an extensive and well-developed dune sheet with varied vegetation and biota (more details in Gonçalves et al., 2009).

In the last years, the entire coast of mainland Portugal has received an increase in the touristic occupation, especially during the warmer spring and summer months (information provided by the national authorities of tourism – INE and Tourism of Portugal), in particular for the urban (city of Figueira da Foz) and rural (Quiaios) areas (Fig. 2). This data was used to obtain a quantification (a proxy) of the potential increase in the human use of these sandy beaches over the studied periods.

2.2. Sampling design

Between 1999 and 2000, Gonçalves et al. (2009) analysed the macrofaunal communities' structure at Quiaios and Cabedelo beaches. Quantitative samples were taken monthly, during low neap tides by using a wooden square of 0.25 m^2 to a depth of 20 cm and were sieved through a 1 mm mesh. The sampling design comprised 2 transects arranged at regular intervals (10 levels, 3 replicates per level) between the low-water mark and the foredune. For each transect, the first five sampling levels from the waterline to the high low tide watermark were considered the intertidal zone and the subsequent five levels until the base of the dunes, the supralittoral zone. The animals collected were separated in the laboratory and preserved in 70% alcohol for identification. Sediment samples were collected to determine the sediment grain