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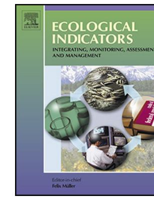

Original article

Macrofaunal community abundance and diversity and talitrid orientation as potential indicators of ecological long-term effects of a sand-dune recovery intervention

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A B S T R A C T

In the last decades the increasing urban development on coastal areas have produced extensive modifications on shores all over the world, making critical the active management of pressures on sandy beaches. The use of engineering solutions to counteract beach erosion has been significantly increasing; the ecological indicators used to monitor these interventions generally focus on short- and medium-term effects, while little is known on their effectiveness on long-term temporal scales. The following ecological indicators have been tested in the present study: (a) macrofaunal community abundance and diversity and (b) orientation behaviour of *Talitrus saltator*, a talitrid amphipod widespread on Mediterranean and European Atlantic sandy beaches. Two sites were considered on a sandy beach of the Portuguese Atlantic coast, one located in front of a natural dune and the other at about 500 m of distance, where the dune had been rebuilt between 2000 and 2008 using geotextile tubes. In 2011 and 2012, macrofauna sampling and orientation experiments on *T. saltator* were performed at both sites in spring and autumn; contemporaneously the main environmental variables were registered. Macrofaunal data were analysed through multivariate statistical tests, and for the orientation distributions the circular statistics were calculated and multivariate analyses for angular data were performed. Geotextiles appeared to be successful in stabilising the recovered dunes; accordingly, the diversity of the macrofaunal communities and the orientation performances of *T. saltator* showed no differences between the altered and control sites. Significant reductions were nevertheless observed in the artificial-dune site regarding the abundance of *T. saltator* and, to a lesser extent, macrofaunal densities, likely ascribable to the presence of geotextiles instead of a vegetated natural dune, preventing invertebrates to burrow into the sand. These results, complementing a more comprehensive study on these two sites, indicate the abundance of *T. saltator* as the best indicator to follow long-term effects of this kind of soft-engineering intervention. The use of this bioindicator may be recommended for the late phases of monitoring procedures in dune-recovery processes.

1. Introduction

Sandy beaches are among the most important environments for human activities (Schlacher et al., 2008), being intensively exploited especially in the last two centuries (Nordstrom, 2000). In the coming decades about three quarter of the world's population will live within 60 km of the shoreline (Povh, 2000) intensifying human pressures both as direct and indirect impacts. Sandy beaches will be squeezed between rising sea level and coastal erosion on the marine side and expanding human populations and development on the landward side (Schlacher et al., 2008; van der Weide et al., 2001). To slow down this trend, an active management has become necessary for most coastal zones. Currently, managers involved in coastal defence tend to focus on physical and geomorphological features (James, 2000; Micallef and Williams, 2002), despite more and more evidences have been accumulated of ecological change in beach ecosystems due to human interventions (Brown and McLachlan, 2002; Defeo et al., 2009; Dugan et al., 2010; Jones et al., 2007; Schlacher et al., 2007, 2008). Sandy beaches are dynamic habitats, with specialised living communities structured mainly by physical forces (Defeo and McLachlan, 2005; McLachlan and Brown, 2006). A deep knowledge of biotic responses to modifications of the physical environment is therefore a critical step, and the effects of interventions on local communities should be always considered when planning management, conservation, or restoration strategies.

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The use of geosynthetic containers was initiated more than 50 years ago in the USA, The Netherlands and Germany (Saathoff et al., 2007), and has become increasingly popular. Although this intervention impedes the natural morphodynamics of the coast by preventing erosion, so that a static shoreline may develop, geosynthetic containers are considered a soft solution because, if an unforeseen environmental impact ensues, they can easily be sliced open and removed, spilling sand back onto the beach (Corbella and Stretch, 2012). Moreover, the use of geotextile tubes to create artificial dunes reduces costs, time and environmental damage, with the advantage of being adaptable to the morphology of the dune system and using locally available sand (Oumeraci et al., 2003; Stokes et al., 2012). Recent examples of successful application of geotextile tubes come from the coastal zones of USA (Harris and Sample, 2009), Australia (Jackson et al., 2004) and the Republic of Korea (Shin and Oh, 2007), where positive outcomes were obtained in terms of coastal protection. However, very little is known on the effects of dune recovery with geotextiles on biotic communities, if compared to the several studies on the ecological impacts of both beach nourishments (reviewed in Goldberg, 1988; Peterson et al., 2006; Speybroeck et al., 2006) and hard-engineering interventions (Bertasi et al., 2007; Dugan et al., 2008; Martin et al., 2005; Sobocinski, 2003). Negative nourishing effects were observed at the population, community and ecosystem levels on all the biotic components (Bishop et al., 2006; Fanini et al., 2009; Speybroeck et al., 2006). Generally, if the interventions were carefully planned, they may represent short-term, pulse disturbance (Peterson et al., 2006) and a rapid ecological recovery may occur after few months, as sandy-beach species are adapted to severe physical disturbances (Hall, 1994). On the other side, hard-engineering interventions often promote erosion by the development of rip currents (Hsu et al., 2007; Martin et al., 2005; Phillips and Jones, 2005), altering the hydrodynamic regimes of the coastal zone, which in turn drive the composition of benthic macrofaunal assemblages (Defeo and McLachlan, 2005; McLachlan and Brown, 2006). Substantial changes to the system ecology were generally observed after these interventions (Brown and McLachlan, 2002; Chapman and Bulleri, 2003; James, 2000; Speybroeck et al., 2006). Frequently, as eroding beaches tend to become narrower, the reduced habitat disposability directly impacts diversity and abundance of biota in the upper intertidal zone, with consequences at all the trophic levels, thus engendering long-term ecological effects on the whole community (Bertasi et al., 2007; Dugan et al., 2008; Martin et al., 2005; Sobocinski, 2003). To monitor the effects of dune-recovery using geotextiles, managers need effective ecological indicators. Furthermore, being the ecological effects of such interventions relatively unknown, various indicators should be considered to obtain indications fitted to different ecological compartments or functional roles, depending on the impacts to be assessed (Dale and Beyeler, 2001; Niemerijer and de Groot, 2008; Pinto et al., 2009; Salas et al., 2006).

The diversity and the structure of the macrofaunal community are considered representative bioindicators of impacts on sandy beaches (Fanini et al., 2009; Lercari and Defeo, 2003; Peterson et al., 2000; Schoeman et al., 2000). Intertidal invertebrates are at the basis of the food chain (Audisio, 2002; McLachlan and Brown, 2006), thus representing a key-component of the beach ecosystem. Arthropods in particular, well adapted to harsh climatic conditions and involved in the processing of nutrients from both sea and land, have been recognised as reliable bioindicators of ecosystem stability and recommended for use in conservation planning of sandy beaches (Colombini et al., 2003; Finnamore, 1996; Mattoni et al., 2000). However, a relatively little attention was given to the long-term effects of human-induced disturbances on the macrofaunal community structure of beaches (Bessa et al., 2013a; Lercari and Defeo, 2003; Schoeman et al., 2000).

Another potential indicator of shoreline changes is the behaviour of the invertebrates dwelling sandy beaches, which may represent a first response to changes in their life-environment. Almost all beach arthropods display common adaptive behaviours, such as digging attitudes, rhythmic activity patterns, and orientation abilities to quickly recover the safest zone on the littoral (Audisio, 2002; Schlacher et al., 2008). Several behavioural studies were carried out on the sandhopper *Talitrus saltator*, a widespread talitrid amphipod that often dominates (in term of abundance) sandy beach communities at temperate northern latitudes on Mediterranean and Atlantic coasts (Scapini, 2006). One of the most interesting behavioural aspects shown by this and related talitrid species is zonal recovery, namely the ability to come back to the intertidal beach zone after spontaneous or accidental displacements, searching for the right moisture conditions to burrow into avoiding dehydration risk (Pardi and Ercolini, 1986). The correct orientation is ensured by a redundancy of mechanisms, both heritable (sun-compass, beach slope) and learned (landscape features, reviewed by Scapini, 2006); orientation can also be modified according to the immediate climatic and ecological beach characteristics, adapting to an increasing risk of dehydration or submersion. Populations of *T. saltator* exhibit a higher seaward concentration on beaches that are stable in time and result more scattered if changes frequently occur (Borgioli et al., 1999a; ElGtari et al., 2000; Scapini et al., 1995). For this reason talitrid sun orientation was proposed as an indicator of human-impact on shoreline stability (Fanini et al., 2007; Scapini et al., 2005). Since the species' life-span in the Mediterranean area ranges from 6 to 9 months (Marques et al., 2003), orientation is expected to reflect the response to quite recent changes, while little is known about the effects on the populations' orientation over longer periods.

In this paper, the diversity and abundance of the macrofaunal community and the orientation behaviour of *T. saltator* were analysed on a sandy beach, where a dune-recovery intervention was carried out three years before. Two sites were defined, having the same physical conditions, to highlight eventual impacts ascribable to the intervention: (a) a control site, where no relevant alterations have been observed over the last two decades and (b) a site in front of the artificial dune. We aimed to assess which long-term impacts are susceptible of being detected by the selected indicators, assuming that three years represent a reasonably long temporal range in very dynamic and changeable environments such as sandy beaches (Dugan et al., 2008; Martin et al., 2005; McLachlan and Brown, 2006; Sobocinski, 2003). This study represented an extension of two previous studies in the same sites; the first one analysed the macrofaunal community features to detect eventual effects of the dune-recovery intervention (Bessa et al., 2013a), while the second represented a first assessment of behavioural adaptations in *T. Saltator* sub-populations on the same rehabilitated sandy shore (Bessa et al., 2013b). Here the same features were studied in parallel and the two sites were compared, to assess whether and which bioindicator may be proposed for long-term monitoring of dune-recovery with geotextiles.

2. Materials and methods

2.1. The study-site

The Leirosa beach (40° 02′ 57.33″ N, 08° 53′ 35.01″ W) is located to the south of Figueira da Foz, midway along the Portuguese Atlantic coast (Fig. 1a). The beach is mesotidal with semidiurnal tides, and waves frequently reach amplitudes of about 3 m. The well-developed sand dune system is about 10 km long, and protects two cellulose pulp and paper factories located behind it. In 1995 a submarine pipeline was built to discharge the industrial