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Assessement and management of environmental quality conditions in marine sandy beaches for its sustainable use—Virtues of the population based approach

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ABSTRACT

Sandy beaches constitute high natural value ecosystems which have been worldwide a target for growing human activities and ensuing pressures in the last decades, which caused ecological damages on these environments and led to its environmental quality decline. However, little is known about the responses of these ecosystems to distinct stressors and pressures, and holistic and integrated coastal management actions that protect beach environments and their ecological processes are yet to be developed. The aim of this *viewpoint* article is to present and discuss the utility of using a population approach to macrofaunal key species as a helpful tool for the assessment, management, and sustainable use of sandy beaches. The role of macrofaunal key species as indicators of environmental changes and of ecological quality condition is discussed and illustrated by some practical examples from the literature. The population is presented as a highly relevant ecological unit in management and one of the easiest ones to use, responding more rapidly to disturbances in the ecosystem than the most complex units. In this context, bio-ecology and population dynamics models are presented as tools and their potential, to improve the way we assess and manage ecological quality conditions of beach ecosystems aiming at its sustainable use, are discussed. Also, the advantages and drawbacks of the use of these tools in the population approach are evaluated. Monitoring, assessment and management practices focusing on beach key species bio-ecology as ecological indicator hold large potential in nowadays fast changing scenario, and should be encouraged as a function of their identifiable responses to manmade and natural disturbances.

1. Introduction

Sandy beaches are sensitive and dynamic coastal ecosystems with high natural value. They provide several important and often unique ecological functions, as for instance the filtration of large volumes of water and nutrients recycling, representing also crucial habitats for various species, besides offering a multitude of goods and services for humans (*e.g.* Defeo et al., 2009). Furthermore, their inherent aesthetical value, coupled with the assorted recreational possibilities that they offer to human society, have been attracting us for a long time.

In the last decades, sandy beaches worldwide have been a target for the development of human activities, suffering therefore the concomitant growing human pressures. Caffyn et al. (2002) state that approximately 50% to 70% of the world population lives within 60 km of the coast, a proportion that is actually increasing. This implies the development of several human activities and human infrastructures on coastal areas, ranging from urban and industrial developments to recreational and transportation facilities. Also, an enormous growth in beach tourism has occurred since the 1950s (Gormsen, 1997; Caffyn et al., 2002), conveying more and more tourists to these ecosystems every year. This development was only possible due to an escalating expansion of touristic and other recreational associated facilities. Hotels, resorts, jetties, service and parking areas, just to name a few, were often constructed in coastal areas without adequate spatial planning, and introduced an array of disturbances into beaches and coastal dunes' ecosystems. Ecological recovery of such types of disturbances may sometimes be almost impossible, and unfortunately, mass tourism in coastal areas is nowadays an undeniable reality in several parts of the globe.

Such intense human activities caused ecological damages in sandy beach habitats and led to an environmental quality decline of

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the beach environments (*e.g.* Lercari and Defeo, 2003; Davenport and Davenport, 2006; Schlacher et al., 2008; Bessa et al., 2014a; Nourisson et al., 2014). Furthermore, environmental problems related with climate change and sea level rise undeniably exacerbate this environmental quality decline, conducting for instance to beach erosion and beach narrowing (McLachlan and Brown, 2006; Doney et al., 2012). Coupled with higher sea and air temperatures, and subsequently the more frequent and intense storms that these temperature increases may promote (McLachlan and Brown, 2006), these phenomena can eventually, in the most extreme cases, translate into the disappearance of entire beaches and of their biotas. Thus, it should come as no surprise that sandy beaches are nowadays one of the most threatened worldwide ecosystems and face an uncertain future.

When compared to what is known regarding other marine coastal systems (*e.g.* rocky shores, estuaries), the scientific body of knowledge on sandy beach ecology is still somehow underdeveloped, and little is known about the responses of these ecosystems to their distinct stressors and pressures. Large efforts, however, have been done in the last 15–20 years, with important contributions and advances, namely on the understanding of the biological and ecological components of sandy beaches. Important information concerning the several types of threats and pressures imposed to beach ecosystems (namely derived from human activities) was gathered, and guidelines for coastal management actions and critical research directions that need to be urgently developed were defined and identified by several authors (see for instance Brown and McLachlan, 2002; Schlacher et al., 2007; Defeo et al., 2009; McLachlan et al., 2013).

Contrarily to what happens in coastal dunes where vegetation is the prevailing element, sandy beaches' biological communities are almost exclusively composed by faunal elements. In fact, in the vast majority of these systems, macrofauna, often dominated by crustaceans, molluscs and polychaetes (McLachlan and Brown, 2006), is a fundamental element in ecosystem structure and function. The presence of this biotic component in adequate numbers ensures the equilibrium of the system and allows marine sandy beaches to operate normally as ecosystems. Macrofauna contributes for wrack consumption and degradation and serves as prey for several top predators such as fishes or shorebirds, occupying a central position in beach food webs. Also, some faunal elements, like for instance sand hoppers in temperate beaches or ghost crabs in tropical and subtropical ones (*e.g.* Neves and Bemvenuti, 2006), exhibit abundant populations and may sometimes represent the bulk of the macrofaunal communities, functioning as key species (see for instance Gonçalves et al., 2009).

The objective of this *viewpoint* paper is to present, discuss and illustrate the utility of using a population approach to macrofaunal key species as a tool in the assessment and management of sandy beaches ecological conditions aiming at its sustainable use. We start by commenting on the crucial relevance of ecological resilience in the fast changing scenario that sandy beaches face today, and afterwards we enlighten the reasons justifying the selection and use of these key species populations as potential tools with regard to sandy beaches assessment and management practices. Several methodologies at the population ecological level of organization are presented and discussed. Finally, relevant recommendations regarding the assessment, management, and use of sandy beaches based on the population approach are provided.

2. Resilience of sandy beaches in a changing scenario

Ecological resilience is described as the amount of disturbance that an ecosystem in a given stability state can take in before it changes to an alternative state. It constitutes an inherent property of all ecosystems and, in other words, indicates the ecosystem's ability to absorb change against a background of the complexity and/or variability of the ecosystem (as reviewed in Elliot et al., 2007). The degree of resilience differs between ecosystems, and ecosystems that are naturally highly variable may absorb higher amounts of disturbance than less variable ecosystems (*e.g.* Elliott and Quintino, 2007).

With the exception of major engineering structures, that can have profound negative effects on the sediment supply and replace natural landscapes and habitats by artificial structures, sandy beaches are quite resilient to most human activities and are suited for recreational activities that do not involve the use of vehicles (McLachlan and Brown, 2006). Coastal dunes, however, are much more sensitive to human activities, mainly because of their vegetation which can be easily damaged even only by light trampling. Therefore, in coastal areas where sandy beaches are backed by coastal dunes, management practices should, in most cases, allow the access to the beach for recreational purposes but still restrict the disturbances to the adjacent dune environment by some sort of means.

Sandy beaches face presently a multitude of disturbances that, as previously mentioned, introduce several detrimental impacts and act like stressors, imposing uncertainty and rapidly changing scenarios. Understanding how these ecosystems respond to distinct disturbances is fundamental for their effective management and adequate use. Also, it represents a step forward on the comprehension of the amounts of change susceptible of altering their ecological stability state, helping to unveil their thresholds and their real degree of resilience.

In urbanized coasts where coastal dunes have often been intervened by artificial structures activities, such as the construction of urban and touristic facilities and mechanical and human trampling, occur directly in the supralittoral and intertidal zones of the beach. Environmental impacts associated to the ongoing climatic changes, like the rise of the sea level and the increase in storm occurrence and intensity, are also important stressors disturbing these zones. In this context, the supralittoral and the intertidal zones of the beach can be considered priority areas for intervention concerning management practices. Open oceanic sandy beaches, on the other hand, represent the largest proportion of the worlds' sandy shores (McLachlan and Brown, 2006), although physical aspects, like for instance the degree of exposure to wave action, may oscillate according to the local conditions and alter both the beach type and the species composition of macrofaunal benthic communities. The assumptions, that supralittoral and intertidal zones are priority areas for intervention and that open oceanic sandy beaches are the most abundant type of sandy beach worldwide, will consequently guide the rationale presented in the following sections of this *viewpoint* paper.

3. Methodologies available to evaluate the ecological condition of sandy beaches

The development of adequate indicators is a crucial step forward to understand and to evaluate the ecological condition of natural systems. In sandy beaches, management plans have been usually focused on protecting human infrastructures and stabilising the width of the beaches, by maintaining, sometimes through nourishment interventions, the volumes of sand on the system (Nordstrom and Mauriello, 2001; Nordstrom, 2008). However, besides these methodologies based on physical attributes of the system, other methodologies, mostly relying on biological and ecological attributes, are available to assess the ecological condition of these ecosystems (see Schlacher et al., 2014 for a more comprehensive background).