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Crustaceans as ecological indicators of metropolitan sandy beaches health

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ABSTRACT

We have investigated how indices of beach health perform in predicting the abundances of the crustaceans *Emerita brasiliensis* and *Atlantorchestoidea brasiliensis* from 22 metropolitan beaches in the cities of Rio de Janeiro and Niterói. Urbanization, Recreation and Conservation indices were used to assess sandy beaches health. Grain size and beach slope were used as morphodynamics indicators. Diagram from the principal component analysis clearly separated beaches with different urbanization and conservation levels. Generalized additive models (GAM's) were adjusted for species abundance using the indices and morphodynamic parameters as explanatory variables. Lower abundances were predicted for beaches with high levels of urbanization, whereas predictions of higher abundances occurred on beaches with high conservation levels. Using theoretic inference we showed that the urbanization index was the most important predictor for abundance of *A. brasiliensis* and the conservation index was the most important predictor for *E. brasiliensis*, reflecting different responses by upper tidal and intertidal species. *A. brasiliensis* occupies the intermediate and upper beach zones and *E. brasiliensis* is a swash zone filter-feeder that is more abundant in pristine beaches. Both species are highly subject to the impact of bathers and coastal modification. Unexpected, the recreation index did not show a negative effect on abundance predictions. Urbanization and conservation indices can be suitable metrics to measure anthropogenic effects on macrobenthic species. Moreover, mole crabs and sandhoppers species can be easily monitored. Coastal urbanization is a global phenomenon and we used the diagram of urbanization and conservation levels to expose possible directions for management strategies of metropolitan sandy beaches.

1. Introduction

Sandy beaches are the most common coastal environment around the world and harbor a diverse and specialized biota (Defeo and McLachlan, 2005), including numerous endangered species such as birds and turtles (Burger, 1991; Rumbold et al., 2001). Having high socio-economic value and being intrinsic related with human culture, beaches are more frequented by people than any other type of shoreline (Klein et al., 2004; Schlacher et al., 2007). However, sandy beaches have been neglected in most assessments of the socio-economic and ecological impacts, contrasting with the vital role that beaches play in modern society (Defeo and McLachlan, 2005; Schlacher et al., 2007). 'Coastal urbanization' resulted in widespread changing of sandy beach ecosystems (Defeo et al., 2009), modifying beaches' morphodynamic characteristics, nutrient flux, habitat features, community structure and species richness (Schlacher et al., 2007; Bessa et al., 2013; Hubbard et al., 2013; Nourisson et al., 2014). Massive coastal development across the globe is expected to be intensified over the coming decades (Brown et al., 2008). Therefore, more sandy beaches are becoming mechanically cleaned and used for recreation by increasing numbers of residents and tourists (Schlacher and Thompson, 2012).

Accurately determine the ecological effects caused by beach use is a critical step (Dale and Beyeler, 2001; Niemeijer and de Groot, 2008; Williams and Micallef, 2009) and presents complex management and conservation challenges (Schlacher and Thompson, 2012; Schlacher et al., 2014a,b). In this context, indices for assessing "beaches health" have been proposed in order to offer metrics that can be more easily implemented by managers. For example, McLachlan et al. (2013) developed a Conservation Index based on dune state of health, the presence of iconic species and macrobenthic species richness; and a Recreation Index based on the extent of infrastructure, the level of safety/health of the beach and

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its physical carrying capacity. González et al. (2014) proposed an Urbanization Index scoring the proximity to urban centers, building on the sand, beach cleaning, solid waste on the sand, vehicle traffic on the sand, quality of the night sky and frequency of visitors.

The macrobenthic invertebrate fauna of sandy beaches primarily comprises crustaceans, mollusks and polychaete worms, with a highly diverse fauna inhabiting the intertidal area (Defeo et al., 2009). The diversity and structure of the macrofaunal community are considered suitable ecological indicators of sandy beaches 'health', since human disturbances affect the distribution and life-history traits of the resident species (Peterson et al., 2000; Schoeman et al., 2000; Lercari and Defeo, 2003; Fanini et al., 2009; Schlacher and Thompson, 2012). As reliable indicators of ecosystem stability (Wenner, 1988; Peterson et al., 2000), crustaceans have already been used as monitoring tools for coastal management of beaches and dunes (Colombini et al., 2003; Fanini et al., 2009; Noriega et al., 2012; Gonçalves et al., 2013; Bessa et al., 2014; Nourisson et al., 2014). Among them, the talitrid amphipods and the hippids have received special attention as bioindicators because they are the dominant faunal species in terms of abundance, exhibit a variety of responses to human disturbances and have a high plasticity on their life-history characteristics (Wenner, 1988; Contreras et al., 1999; Lercari and Defeo, 1999; Peterson et al., 2000; Powell et al., 2002; Fanini et al., 2005; Barca-Bravo et al., 2008; Sauco et al., 2010; Boere et al., 2011). The sandhopper *Atlantorchestoidea brasiliensis* (Dana, 1853) is capable of maintaining populations from the supralittoral zone to the upper midlittoral zone across the entire morphodynamic spectrum on exposed sandy beaches (Cardoso and Veloso, 2001; Veloso et al., 2003; Gómez et al., 2013). The mole crab *Emerita brasiliensis* (Schmitt, 1935) is a suspension feeder commonly found in the intertidal zone of reflective and dissipative sandy beaches (Veloso and Cardoso, 1999, 2001; Celentano et al., 2010).

During the second half of the last century, an overall process of urbanization of the cities of Rio de Janeiro and Niterói resulted on a massive coastal modification and an increase in beach use (Barickman, 2014). For example, Copacabana and Ipanema beaches are crowded by bathers and receive a big number of entertainment events during almost all year long. These beaches have efficient public transportation and recreational facilities where many restaurants, bars and hotels are located. Rio de Janeiro also experienced a massive increment in the number of tourist visiting the city and attending the beaches, that is expected to increase in the next years. Although urbanization and tourism are placing 'escalating pressures' on sandy beaches at never experienced scales (Schlacher et al., 2007), studies on modifications caused by landfills, recreation and cleaning are still rare (Veloso et al., 2006). In this context, we investigated how Urbanization, Conservation and Recreation indices perform in predicting the abundance of two very common crustacean species, the hippid decapod *E. brasiliensis* and the talitrid amphipod *A. brasiliensis*, along 22 sandy metropolitan beaches of Rio de Janeiro and Niterói cities. Both species are generally common in the exposed sandy beaches along the shoreline of the study area and were previously pointed as sensitive species to human disturbance effects (Veloso et al., 2006, 2008). Therefore, we tested the hypotheses that the abundances of both crustaceans species are negatively affected by urbanization levels and recreation facilities, where higher abundances should occur on beaches with high conservation levels.

2. Material and methods

2.1. Study area

We sampled 22 sandy beaches along the shorelines of Rio de Janeiro (18 beaches) and Niterói (4 beaches) cities, comprising a total length of 63 km. The study area included beaches with a wide range of coastal development, proximity to urban centers, morphodynamic features, levels of human usage and cleaning (Table 1).

Table 1 Physical characteristics and the number of citizens from each local neighborhood of the 22 beaches sampled in the state of Rio de Janeiro. Exposure following McLachlan (1980). Beaches as a form of recreation have a long history in Rio, dating back at least to the early nineteenth century (Barickman, 2014). As the country's former capital, Rio de Janeiro received special attention from the national government, particularly from 1902 to 1906, when federal authorities carried out a massive program to remodel the city center (Barickman, 2014). This explains why beaches near the downtown, such as Flamengo, and Urca (Fig. 1), with historically better facilities for transportation and commercial activities, were the first locations to be used by citizens as recreation sites (Barickman, 2014). Beaches located near the central region of Rio de Janeiro and Niterói are also subjected to the influence of Guanabara Bay, that has 384 km^2 and is located in the center of the metropolitan region that separates the cities. This bay receives the discharge from a drainage basin impacted by over 11 million inhabitants, in which organic pollution and trace metal contamination of sediments have been evident in the last few decades (Kjerfve et al., 1997; Carreira et al., 2002; Machado et al., 2008). Beaches located in the southern zone of Rio, such as Copacabana, Ipanema and Leblon, some of the most expensive neighborhoods in South America, are very near to urban centers, are crowded by citizens and tourists during the whole year and have innumerous recreational facilities such restaurants, bars and hotels. Beaches in the western zone, far from the central region, such as Barra de Guaratiba, Grumari and Macumba (Fig. 1), have experienced slighter and more recent coastal development and have been subject to lower human pressures. However, previous studies have shown very clear negative relationships between urbanization facilities/human recreational activities (e.g., trampling) and the density of macrobenthic species on Barra da Tijuca, located in the western zone of Rio (Veloso et al., 2006, 2008).

2.2. Sampling procedures and morphodynamic measures

Sampling was carried out during spring low tides in summer to reduce biotic and abiotic inter-annual variability linked to the seasonal cycle (Defeo and Rueda, 2002). Eighteen beaches were sampled during the summer of 2011–2012, three sampled during the summer of 2013 and a single one sampled on summer of 2015. A total of 82% of the beaches was sampled on the same summer precluding effects of temporal variability on abundances. Therefore, we did not consider changes between years, as we focused only on spatial analysis. Biological samples were taken along five equally spaced transects settled perpendicularly to the shoreline. On each transect, 10 sampling units equally spaced were established, where: stratum 1 on waterline and stratum 10 on supralittoral. One sample was taken with a 0.04 m^2 quadrat sampler to a depth of 25 cm from each sampling units. The collected sediment was sieved through a 0.50 mm mesh and the retained material was taken to the laboratory organisms were sorted by species, counted and fixed in 5% buffered formalin.

Sediment samples for particle size analysis were collected with a 3.5 cm diameter corer to a depth of 15 cm at all strata of central transects of each sandy beach. Sediment texture was assessed by sieving for coarse fractions (Suguio, 1973), and by using a laser granulometer for fine fractions. Sediment parameters were estimated according to Folk and Ward (1957). The beach face slope was determined by the height difference (Emery, 1961) between the supra littoral and the waterline on the central transect. Beach Index (BI) (McLachlan and Dorvlo, 2005) was calculated for each beach as a measure of its morphodynamic state. The rating system proposed