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Evaluation of environmental quality of sandy beaches in southeastern Brazil

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ABSTRACT

The effect of urbanization on the environmental quality of two sandy beaches was evaluated using metrics such as pH, dissolved oxygen, coliforms and solid waste. Urbanization effects on physicochemical metrics (pH and dissolved oxygen) were not significant. The coliforms concentration was below the established limit for primary contact, but it was significantly higher on beaches with highest recreational potential. Similarly, the abundance of solid waste was significantly higher in urbanized areas (~4.5 items/m^2), and it was higher than what was found for 106 beaches worldwide. Plastic represented 84% of the total number of items and recreational activities were the main sources of debris (80%). Therefore, a balance between recreation and conservation actions, based on short-term (e.g. fines) and long-term measures (e.g. educational policies) is recommended. We demonstrate that the use of multiple metrics provides more robust estimates of the environmental quality of sandy beaches than a single impact metric.

1. Introduction

Coastal environments provide several ecosystem services to humanity, including food, recreational activities and buffering the impact of extreme events (Cardinale et al., 2012; Gonçalves et al., 2013). Sandy beaches are notable among these ecosystems for being affected by human practices associated with tourism and rapid demographic growth (Weslawski et al., 2000; Gheskiere et al., 2005; Bessa et al., 2014). Rapid urban occupation and development reduce the environmental quality of sandy beaches and their touristic value (Kline and Swallow, 1998; Peterson et al., 2000; Defeo et al., 2009). The economy of many coastal cities depends on beach tourism; therefore, there is a need to collect information about the quality and conservation status of these environments (Barbier et al., 2011; Rao, 2014).

The location of beaches near urban centers is a decisive factor for the loss of environmental quality (Aragonés et al., 2016). The accumulation of solid waste in coastal environments is a growing problem worldwide that is injuring and killing many marine organisms, including invertebrates and megafauna (Derraik, 2002; Gall and Thompson, 2015; Gil and Pfaller, 2016). Nowadays, the socioeconomic impact of marine debris on human health and biodiversity is a major challenge (Browne et al., 2015; Rochman et al., 2015; Tavares et al., 2016).

Pollutants are generally derived from human settlements, resource use and interventions, such as construction, agricultural activities and urbanization (Islam and Tanaka, 2004). Sewage from industrial, domestic waste and fecal material is also considered one of the main pollutants in coastal waters (Barile, 2004; Islam and Tanaka, 2004). As a consequence of coastal development, beaches receive large amounts of domestic and industrial sewage, with the proliferation of bacteria and reduction of dissolved oxygen near the shore, which impacts the structure and function of aquatic communities (Valiela et al., 1990, 1992). Urban beaches are also exposed to numerous tourists and domestic animals, such as dogs and pigeons (Abdelzaher et al., 2010), which can contaminate the environment with feces hosting some pathogens (i.e., *Escherichia coli* and *Enterococcus*) (Aragonés et al., 2016). Tourism associated with recreational activities is one of the main sources of disturbance in Brazilian sandy beaches, particularly in the Southeast, where development and landfills have transformed the coastal landscape (Amaral et al., 2016).

Most studies about the environmental quality of sandy beaches have used a single measure to evaluate the impact, focusing on biological information or contamination by solid waste (Cardoso et al., 2016; Munari et al., 2016). Beaches are subject to diverse human pressures; thus, the use of only one metric to evaluate the ecosystem quality may not indicate the actual effects of urbanization, and different indicators can better support planning and monitoring environmental pollution. The objectives of this study was (1) to evaluate the environmental quality of two beaches under different levels of urbanization using distinct metrics, including pH and dissolved oxygen of the water surface, the amount of sediment coliform and solid waste; (2) to determine the indicators that reflect differences in levels of urbanization. We test the hypothesis that sandy beaches with highest recreational potential and lowest conservation value have highest coliform concentrations and solid waste abundance, indicating environmental

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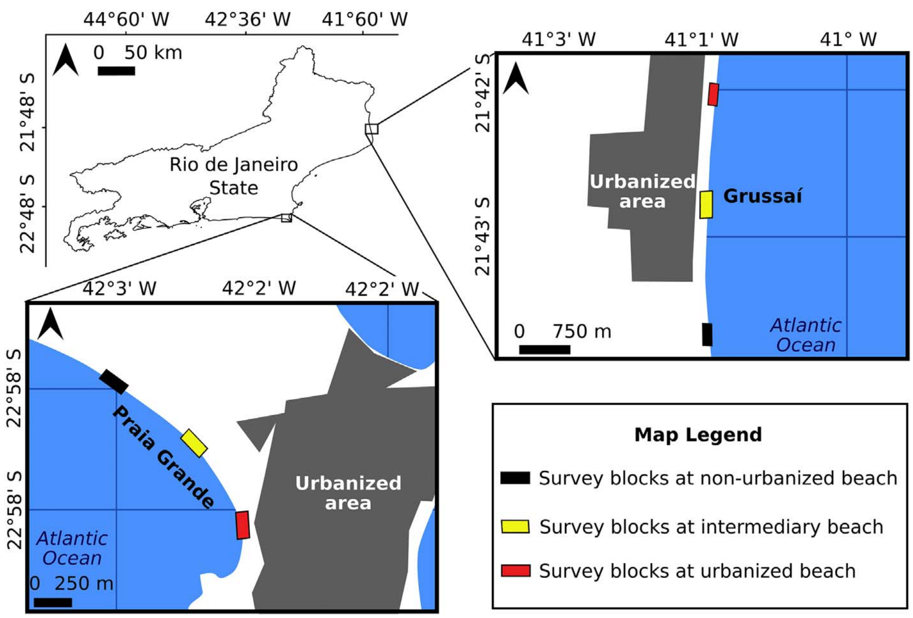

Fig. 1. Map of the study areas, including the urbanized, intermediate and non-urbanized sectors on Praia Grande Beach and Grussaí Beach.

quality reduction in urbanized areas.

2. Material and methods

2.1. Study area

The study was conducted on Praia Grande Beach (21°41′57.82″S 41°1′25.91″W), in the municipality of Arraial do Cabo on the central coast of Rio de Janeiro State, and Grussaí Beach (21°41′57.82″S 41°1′25.91″W), in the municipality of São João da Barra in the northern Rio de Janeiro State (Fig. 1).

Praia Grande and Grussaí beaches display an impact gradient of tourism along the coast, including high impacted areas with two tourists/m^2 and areas with a lower presence of humans due to a reduced access. Praia Grande Beach is heavily visited and includes facilities such as kiosks, a paved waterfront, parking lots, streets, stores, restaurants and residences. According to municipal authorities, the city of Arraial do Cabo has a national tourism value and receives 400,000 visitors annually during the summer. The municipality of São João da Barra receives 150,000 tourists during the summer, mostly on Grussaí Beach, which has a regional touristic value and offers leisure activities, food, inns, and shows.

On both beaches three sectors, 2 km apart from each other, were selected representing an urbanization gradient based on the following criteria: number of visitors, infrastructure, and access to the beach and dune vegetation (Fig. 1). The urbanized sectors (U) have tourism infrastructure, easy access to transportation, a large number of visitors and scarce vegetation. The non-urbanized sectors (NU) are preserved, with dune vegetation and few visitors. The intermediate sectors (I) are in transition zones between the U and NU sectors and it shares characteristics of urbanized (e.g. easy access to beach) and non-urbanized beaches (e.g. dune vegetation preservation). In general, intermediate sectors receive higher number of visitors than non-urbanized sector, but it is not used by tourists as observed in the urbanized sectors (Costa et al., 2017).

Sampling was conducted twice during the low tourist period and twice during the high tourist period (winter 2015 and summer 2016, respectively), for each sector on each beach, totaling 24 sampling campaigns.

2.2. Recreational potential (RP), conservation index (CI) and urbanization index (UI)

The conservation, recreation potential and urbanization indexes for each sector were calculated by summing the scores attributed to the ecological and socioeconomic features. The original conservation index proposed by McLachlan et al. (2013) included the number of threatened and iconic species (0 to 3), macrofauna richness and abundance (0 to 2) and considered the dune system (0 to 5) as the main ecological characteristic; however, in the present study we chose the characterization of the dune vegetation as an adequate indicator of conservation. The recreation potential index considered infrastructure (0 to 5), safety for swimming and health (0 to 3), and the physical extension of the beaches (0 to 2). The urbanization index, adapted from González et al. (2014), was estimated by the scores (0–5) of six variables: (1) distance from urban centers, (2) buildings on the sand, (3) cleanliness of the beach, (4) solid waste in the sand, (5) vehicle traffic on the sand, and (6) frequency of visitors. The urbanization levels were estimated by field observation (variables 1, 2, 3, 5 and 6), and sampling (variable 4). This index was calculated following the method of Gover, $X' = ((\Sigma X - X_{\min}) / (\Sigma X_{\max} - X_{\min}))$ (Legendre and Legendre, 1998), which reduce the indicator values to a range result, where ΣX is the sum of the values attributed to each of the six variables and $X_{\min} - X_{\max}$ corresponds to the extreme values (0–5, in this case). Values near "0" indicate low anthropogenic intervention and those near "1" indicate high anthropogenic intervention (González et al., 2014).

2.3. Environmental quality indicators

The indicators used to determine the environmental quality of the beaches were the following: pH and dissolved oxygen (DO) of surface water; concentration of total and fecal coliform in the sediment; composition, abundance and source of solid waste.

2.3.1. pH and dissolved oxygen (DO) content of surface water

The pH and DO of the surface water was measured with a Horiba U-50 Multiparameter Water Quality Meter. During each sampling period the water quality for primary contact was evaluated following the recommendations of the Brazilian National Council of the Environment (CONAMA) (Resolution 357/2005) (www.mma.gov.br), where salt water should have a DO not lower than 6 mg and pH between 6.5