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Investigating heavy metal bioaccumulation by macrofauna species from different feeding guilds from sandy beaches in Rio de Janeiro, Brazil

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ABSTRACT

The relationship between metal accumulation and feeding behavior of macrofauna species is a key concept to understand the bioavailability of different metals in the marine environment. We examined and compared the concentrations of eight heavy metals (Cr, Zn, Pb, Ni, Cu, Cd, Co and V) in different feeding guilds of macrofauna species, from a data set including 68 sandy beaches along the Rio de Janeiro coast. For this purpose, macrofauna species were classified in five feeding guild categories: carnivorous, herbivorous, detritivorous, suspensivorous and filter feeders. The coast of Rio de Janeiro was divided into seven regions according to environmental characteristics and historical human activities. For each region, generalized linear models were adjusted to test for differences between feeding guild abundances. Redundancy Analysis was performed to explore the relationship among the feeding guilds composition and the environmental variables. We found high variability in abundance and composition among feeding guilds, linked with environmental heterogeneity. In general, carnivorous species showed a higher heavy metal concentrations compared **to** other trophic guilds evaluated. However, bioaccumulation across the feeding guild was not the rule and patterns varied across regions. Our hypothesis is that variations are probably related to the different magnitudes of metal contamination along the coast as also in to the trophic structure found in each beach. This data highlighted the crucial role of the relationship between variability of environmental drivers and bioaccumulation in macrofauna species in sandy beaches ecosystem.

1. Introduction

Industrial and urban discharges in the last 50 years have drastically increased, besides the input of heavy metals to the sea with harmful effects to the marine biota and human health, metal pollution is now considered a major chronic environmental problem worldwide (Wells and Sheppard, 2007; Zhou et al., 2008). Heavy metal concentrations in marine species depend not only on environmental contamination, but also on several ecological factors, such as the physiological role of each element, elemental chemical speciation, diet and trophic position of the species (Das et al., 2004). In this sense, the relationship between metal accumulation and the feeding behavior of a species reflects the crucial role of bioavailability of different metals in the aquatic environment and the trophic transfer to the food web (Monperrus et al., 2005).

The largest problem in this regard is heavy metal bioaccumulation in tissues of animals from the upper levels of the trophic pyramid (Fang et al., 2006). Metal bioaccumulation in different species depends on a multitude of factors, but diet shows the greatest influence (Jakimska et al., 2011a). Bioaccumulation is a complex process, requiring the simultaneous examination of metal levels in animal tissues from at least two adjacent trophic levels (Jakimska et al., 2011a). However, very limited information regarding the relationship of feeding guilds and heavy metal bioaccumulation in macrofauna is available, especially considering invertebrate species from sandy beaches.

Sandy beaches are the most common coastal environment around the world and harbor a diverse and specialized biota (Defeo and

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McLachlan, 2005). These ecosystems are transitions between continental and marine zones where physical variables regulate the abundance and distribution of the resident macrofauna (Defeo and McLachlan, 2005). More than half of world's human population lives in coastal zones, and it is expected that this number could rise to three quarters until the year 2020 (UNCED, 1992). With a high socio-economic value and intrinsically related with human culture, beaches are more often 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 regarding the socio-economic and ecological impacts, such as exploitation of natural resources, habitat destruction and pollution, contrasting with the vital role they play in modern society (Defeo and McLachlan, 2005; Schlacher et al., 2007).

The macroscopic food chain of sandy beaches includes suspensivorous, filter-feeders, herbivorous, detritivorous and carnivorous organisms (Inglis, 1989; Colombini et al., 2011), playing an important role in energy transfer (Takahashi et al., 1999). In relation to morphodynamic type and feeding guilds, Defeo and McLachlan (2011) performed a meta-analysis, where sandy beach communities were deconstructed, and detected increased richness and abundance from reflective to dissipative conditions for filter-feeders and detritivores.

Since physical variables control the presence and abundance of species with suitable functional morphologies (McLachlan and Brown, 2006; Lercari et al., 2010), analyses concerning the feeding guild structure of macrofauna communities may also provide indirect information about the environment. Macrofauna feeding behavior is related, to some degree, to the physical characteristics of the substrata (Arruda et al., 2003). However, very few attempts have been dedicated to evaluate how the functional composition of macrofauna communities changes across environmental conditions and spatial scales regarding contamination levels. In this way, using a dataset from 68 sandy beaches from Rio de Janeiro our investigation aimed to: (i) assess and investigate heavy metal bioaccumulation across different macrofauna feeding guilds (ii) investigate the physical environmental role in structuring species composition of macrofauna feeding guilds.

2. Material and methods

2.1. Study area

Sixty-eight sandy beaches along the Rio de Janeiro state were sampled, comprising a total length of 636 km and covering the entire state's coastal region (Fig. 1). The Rio de Janeiro coast was divided into seven regions, according to environmental characteristics and historical urbanization/industrialization processes, comprising beaches with a wide range of coastal development, contamination sources and morphodynamic features: South (5 beaches), Ilha Grande Bay (21 beaches), Sepetiba Bay (11 beaches), Metropolitan (4 beaches), Oceanic (14 beaches), Lakes (8 beaches) and North (5 beaches).

The morphodynamic environment plays a crucial role in macrofauna composition on sandy beaches. Exposed beaches are generally composed of coarse sand and characterized by steep slopes, representing a more severe environment for macrofauna, which **results** in low species richness. This type of beach comprises most of the beaches within the study area (Supporting Appendix 1). At the other extreme, protected beaches are composed of fine sand, with a marked presence of silt and clay and a gentle slope. The variations of physical factors are more limited in these environments (McLachlan and Brown, 2006). The low or absent wave action provides a benign environment for species, which present high species richness, abundance and biomass (Dexter, 1992). All beaches classified as protected are located in Ilha Grande and Sepetiba Bays (Supporting Appendix 1). Usually, crustaceans are the dominant organisms on exposed beaches, more generalist and adapted for living in harsh reflective beaches. In contrast, polychaetes and mollusks are specialists, and may be delicate forms and / or slow burrowers, and tend to dominate benign environments, such as protected beaches (McLachlan and Brown, 2006). For more information about the physical variables and morphodynamic characteristics of the sampled beaches, see Supporting Appendix1.

Located on the Southern coast of the Rio de Janeiro state, Paraty Bay has a total area of 925 km^2 and a relatively pristine natural ecosystem, including five government-protected areas (Wanick et al., 2012). Ilha Grande Bay, named after the sixth largest Brazilian island, has been reported as a reference area due to low levels of metals present in water, biota and sediments, despite the presence of potential pollution sources, such as two nuclear power plants, an oil terminal and shipyards (Cardoso et al., 2001; Cabrini et al., 2017). On the south coast of Rio de Janeiro, Sepetiba Bay is a semi-closed coastal lagoon, and has suffered considerable urban and industrial development in the last decades, with approximately 400 surrounding industries, releasing waste rich in metals and potentially toxic substances directly in the bay (Cunha et al., 2009; Gomes et al., 2009). In the Oceanic region, sampling was carried out in beaches displaying a wide range of coastal development, different distances to urban centers and, consequently, different levels of human usage and variable morphodynamic features (for more details see Cardoso et al., 2016) and contaminants, including heavy metals, from industrial and urbanized areas are discharged by disposal systems located in beaches within this region (Fistarol et al., 2015). Beaches located near the central region of the cities of Rio de Janeiro and Niteroi are directly subjected to the influence of Guanabara

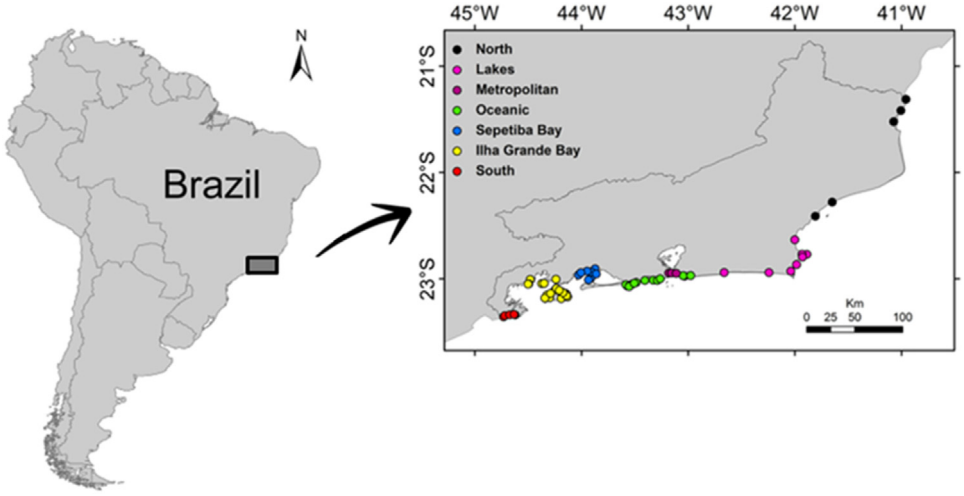

Fig. 1. South America and locations of the 68 sampled beaches along the Rio de Janeiro state.