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Effects of hydrocarbon pollution in the structure of macrobenthic assemblages from two large estuaries in Brazil

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ABSTRACT

Changes in the structure of benthic macrofauna and its relationship with hydrocarbon contamination were determined at different spatial scales in sublittoral sediments of two large estuaries in Brazil. Guanabara Bay (GB) is a heavily polluted estuary due to the presence of a large industrial complex and high demographic density. Laranjeiras Bay (LB) lies in an Environmental Protection Area and can still be considered as preserved from human activities. Despite some spatial differences within each bay, the PAHs concentrations were significantly and consistently higher in GB, with values generally above the threshold effect levels. No signs of hydrocarbon contamination were observed in LB. Macrofauna abundance, diversity and overall assemblage structure were largely different between bays. Canonical analysis of principal coordinates (CAP), used to model the relationship between macrofauna and PAHs levels, indicated that this class of hydrocarbons is the main structuring factor of soft-bottom assemblages in both bays.

1. Introduction

Estuaries and shallow bays act as sinks for sediment and associated particle-reactive contaminants (Wang et al., 2012) and, therefore, are among the coastal ecosystems most threatened by anthropogenic activities (McLuski and Elliot, 2006). Aliphatic and polycyclic aromatic hydrocarbons are ubiquitous contaminants in estuaries, particularly those characterized by high urban and industrial development (Colombo et al., 2005; Chen et al., 2013; Dudhagara et al., 2016).

Aliphatic hydrocarbons (AHs) have several sources, which include biogenic and man-induced inputs. Although they may be synthesized by marine organisms, higher plants, bacteria, phytoplankton and zooplankton, AHs are also part of petroleum-related products (Wang et al., 2009). On the other hand, polycyclic aromatic hydrocarbons (PAHs) are predominantly derived from anthropogenic sources, including the incomplete combustion of fossil fuels, coal and plant biomass, in addition to crude oil and its derivatives (Liu et al., 2009).

Due to their hydrophobic characteristics, oil-derived hydrocarbons tend to adsorb on to particulate material and settle to sediments, where they may affect important ecosystem functions such as decomposition rates, oxygen dynamics and nutrient recycling (Law and Biscaya, 1994; Venturini et al., 2008; Cibic et al., 2012). Petroleum by-products are also known to cause adverse effects at different levels of biological organization, from antioxidant defense responses and cellular damage (Morales-Caselles et al., 2008; Sureda et al., 2011; Marques et al., 2014; Sandrini-Neto et al., 2016) to changes in assemblage structure over large spatial scales (Andersen et al., 2008; Ocon et al., 2008; Yu et al., 2013). Soft-bottom macroinvertebrates are frequently used as indicators of pollution because they form abundant and diverse assemblages of species that exhibit different tolerances to stress (Dauvin et al., 2010). Moreover, benthic organisms are relatively sedentary and live in close association with sediments, where contaminants tend to accumulate (Hyland et al., 2005).

Guanabara Bay (GB) is a large estuary located in the Rio de Janeiro metropolitan region (southeastern Brazil) widely known for its high pollution degree (e.g., Carreira et al., 2002; Wagener et al., 2012; Soares-Gomes et al., 2016). GB is an example of a tropical system under long and severe environmental pressure, with practically all its extension showing relatively high concentrations of petroleum-related hydrocarbons (Wagener et al., 2012). On the other hand, Laranjeiras Bay (LB) lies in an extensive Environmental Protection Area on the coast of Paraná state (south Brazil). In general, concentrations of aliphatic and aromatic hydrocarbons in LB sediments are below the threshold effect levels used in environmental monitoring (Martins et al., 2012).

In this work, we evaluated changes in the concentration of hydrocarbons and the structure of benthic macrofauna at different spatial

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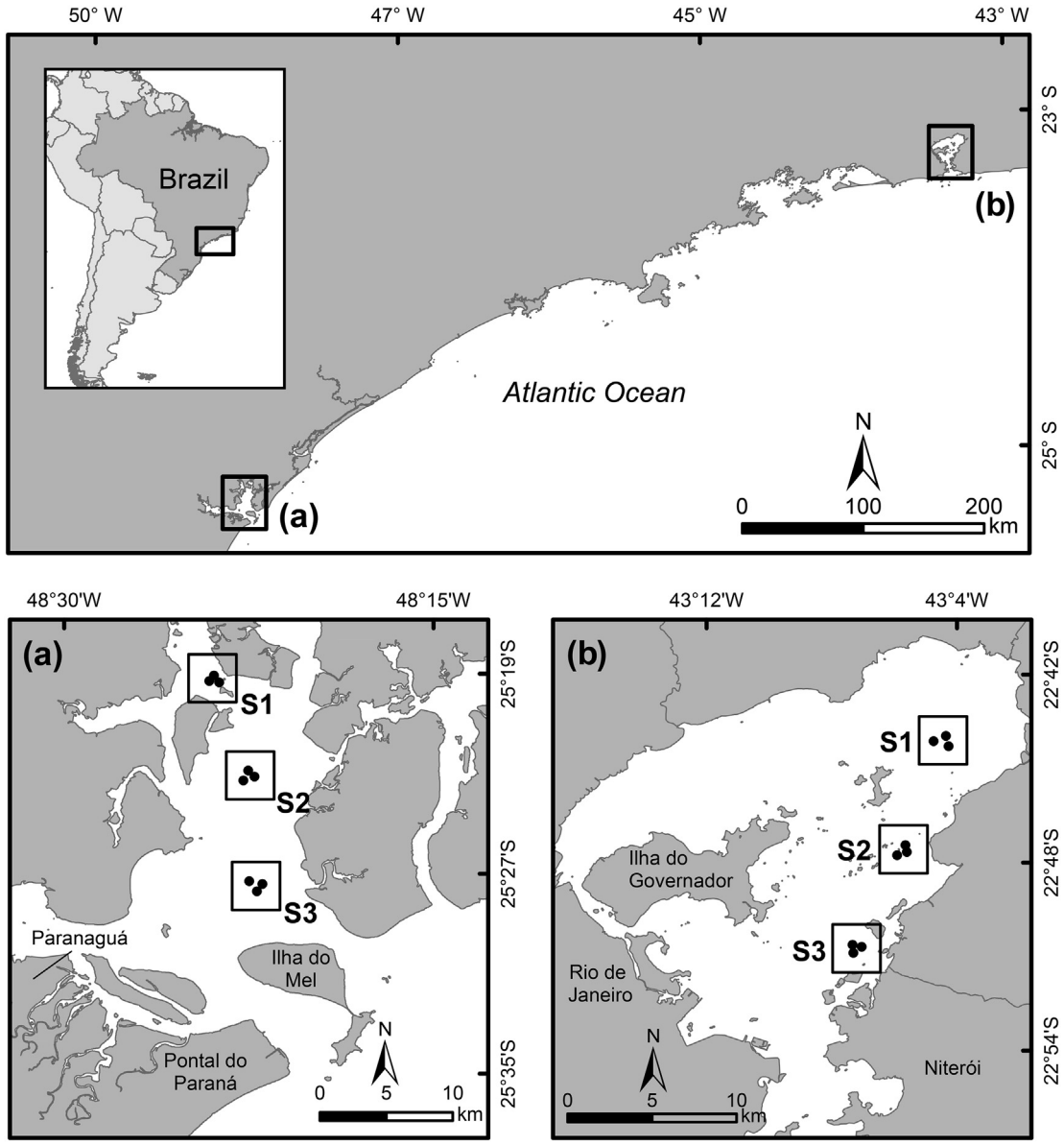

Fig. 1. Map of the study area showing sectors and locations within (a) Laranjeiras Bay and (b) Guanabara Bay. S1 = inner sector; S2 = intermediate sector; S3 = external sector.

scales in sublittoral sediments of GB and LB using a hierarchical sampling design. The incorporation of multiple sources of spatial variation is crucial to detect and measure human impacts on benthic assemblages (Underwood, 2000), mainly in estuaries, which are characterized by high environmental variability (Dauvin and Ruellet, 2009). Moreover, we modelled the relationship between soft-sediment benthic fauna and the concentration of PAHs in sediments of both bays, using canonical analysis of principal coordinates according to Anderson (2008). We hypothesized that the largest proportion of total variation in macrofauna density, diversity and overall assemblage structure would occur at the larger spatial scale, hundreds of kilometers between bays. We also expect a strong relationship between changes in assemblage structure and the PAH contamination gradient.

2. Material and methods

2.1. Study area

Guanabara Bay (GB; Fig. 1b), located in the Rio de Janeiro metropolitan region (22°80′S, 43°15′W), is a large coastal bay (384 km^2) with great economic, social, cultural and ecological relevance (Soares-Gomes et al., 2016). The bay harbors the second largest industrial complex of Brazil, an oil refinery and many oil terminals, two commercial ports and is surrounded by the largest coastal urban settlement in the country, with > 11 million inhabitants. Consequently, the bay receives a large load of inorganic and organic contaminants delivery by fluvial input, atmospheric deposition and urban runoff, making it one of the most impacted estuaries in the Brazilian coast (e.g., Kjerfve et al., 1997; Carreira et al., 2004; Baptista Neto et al., 2006; Wagener et al., 2012; Fistarol et al., 2015). High concentrations of hydrocarbons are usually found in the northwest portion of GB, close to the port region and oil refinery (Meniconi et al., 2002; Wagener et al., 2012). On the other hand, the northeast portion, which includes the environmental protection area, has significantly lower concentrations, being one of the few locations of GB where severe contamination by hydrocarbons is not observed (Mauad et al., 2015).

Laranjeiras Bay (LB; Fig. 1a), located in the north-south axis of the Paranaguá Estuarine Complex (612 km^2) in Paraná state (25°40′S, 48°37′W), is a semi-closed bay (240 km^2) bordered by extensive tidal flats, mangroves and saltmarshes. This region presents a great diversity