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Spatial distribution of intertidal sandy beach polychaeta along an estuarine and morphodynamic gradient in an eutrophic tropical bay

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ABSTRACT

The spatial distribution of polychaeta along pollution gradients often reflects different degrees of disturbance. In order to evaluate polychaeta fauna of an organically polluted tropical bay, 20 sandy beaches distributed in five areas were sampled. The relationship between community structure, slope, beach index, exposure, sediment and water quality parameters were analysed. Multivariate analysis of variance (PERMANOVA) showed differences among areas and beaches. *Scolelepis chilensis* dominated at mouth of bay beaches whereas *Streblospio gynobranchiata* and *Capitella capitata* complex, at inner beaches. Highest polychaete density was recorded at areas 3 and 5 with the dominance of *Saccocirrus* sp. and the organic indicator species *C. capitata* complex and *Polydora* sp. The most important factors obtained from canonical analysis were sorting, slope, mud and organic matter percentage. Marine biotic index (AMBI) showed that areas 3 and 5 were highly affected by anthropogenic factors, given that a poor polychaeta fauna, dominated by opportunistic species, were found. Polychaete assemblages were affected by eutrophication along an estuarine gradient as well as by morphodynamic condition of the beaches.

1. Introduction

Estuaries and shallow bays are among the coastal ecosystems most threatened by anthropogenic activities, organic and inorganic pollutants and habitat changes (McLuski and Elliot, 2006). They have for long been depositories of effluent from industrial processes and domestic waste or areas of industrial or urban development. Several anthropogenic activities promote organic matter accumulation in bottom sediments, which is believed to play an important role on benthic communities influencing its trophic structure and biomass. Organic enrichment influences community composition, reducing diversity by exclusion of low-tolerance species and increasing the biomass associated with the dominance of a few opportunistic species (Pearson and Rosenberg, 1978; Bigot et al., 2006; Diaz-Castaneda and Harris, 2004; Lardicci et al., 1993). Many studies have been using macrobenthic organisms as bioindicators of ecological quality in marine environment (Borja et al., 2000; Rosenberg et al., 2004). Macrofauna species are sedentary, have a relatively long life span, consist of different species that exhibit different tolerances to stress, thus they can integrate conditions over a period of time rather than reflecting conditions only at the time of sampling (Dauer, 1983). This property makes them more useful in assessing local effects in monitoring programs than classical approaches such as physico-chemical analyses of sediment. The AZTI's marine biotic index (AMBI), largely used in the European coast, is based essentially upon the distribution of five ecological groups of soft-bottom macrofauna in relation to their sensitivity to an increasing stress gradient (Grall and Glemarec, 1997; Borja et al., 2000).

Macrofauna of shallow estuarine bays and lagoons have been focus of many studies about the effect of anthropogenic impacts on coastal areas (Carvalho et al., 2005; Ferrando and Mendez, 2011; Lardicci and Rossi, 1998). However, in estuarine areas, major shifts in the physico-chemical water parameters mask the pollution effects on macrobenthic assemblages (Rakocinski et al., 1997). In a typical estuarine gradient, macrofauna density and diversity increases from inner to inlet areas (Lardicci and Rossi, 1998). This general pattern can be altered by many anthropogenic factors such as the discharge of sewage effluents, man-made alterations of the channel or coast line, fish farms and aquaculture (Ferrando and Mendez, 2011; Nalesso et al., 2005). An opposite pattern, with higher macrofauna density and species richness at the inner estuarine area was also recorded (Cardoso et al., 2012; Carvalho et al., 2005; Taurusman, 2010). Sheltered habitats and organic rich muddy sediments that cover inner areas of these systems might be a favorable condition to macrofaunal colonization, especially deposit feeding polychaetes (Carvalho et al., 2005).

Polychaetes are excellent indicators of organic pollution due to their high abundance and sensitivity to different contents of organic matter in sediments. Some species have a strong dominance in disturbed environments, caused mainly by urban sewage (Pearson

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and Rosenberg, 1978; Hily and Glémarec, 1990; Olsgard and Somerfield, 2000). The capitellid polychaetes, specially the *Capitella capitat*a "complex", are classified as r-strategists, having the ability to colonize new habitats quickly (Tsutsumi, 1990). In undisturbed conditions these r-strategist species are replaced by k-strategist ones which, with rare exception, numerically dominate the community. Also some studies suggest the use of polychaetes as a representative taxa in environmental monitoring programs as they closely follows the whole macrofaunal community distribution patterns (Del-Pilar-Ruso et al., 2009; Papageorgiou et al., 2006).

Several recent studies have focused on the impact of human activities on community composition and structure of the macrofaunal communities at sandy beaches. The influence of freshwater effluent was evident on Uruguayan beaches where salinity, coupled with slope and beach/swash zone, were the main environmental variables that induced changes in the macrobenthic community (Lercari and Defeo, 2003). A loss of more than two thirds of the total species richness after an oil spill was recorded on Galician sandy beaches, in which polychaetes were among the most affected taxonomic group (Junoy et al., 2005). A negative relationship between human recreational activities (e.g., trampling) and density of macroinfaunal species was observed on Brazilian exposed beaches (Veloso et al., 2006). A lower polychaete diversity and occurrence of some indicator species on a sandy beach could be related to the influence of organic enrichment from domestic input and to salinity variation (Rizzo and Amaral, 2001).

Guanabara Bay is a tropical estuarine system that has undergone intense degradation, mainly due to pollution by untreated domestic sewage (Mayr et al., 1989). The general pattern of macrobenthic species distribution along the bay reflects a negative gradient of diversity and biomass towards the inner parts of the bay and sheltered areas (Lavrado et al., 2000; Van Der Ven et al., 2006; Santi and Tavares, 2009). Three zones can be depicted by analyzing the polychaeta sublittoral fauna: the mouth-of-the-bay zone with high polychaete diversity, the middle-bay zone with low diversity and high biomass, and the inner-bay zone, a very poor polychaete assemblage, sometimes azoic (Santi and Tavares, 2009). Similar results were found for crustaceans, where the absence of fauna was recorded at hypoxic sediments from inner sectors, suggesting harmful effects on the local fauna (Van Der Ven et al., 2006). The depletion of oxygen is one of the effects of the eutrophication impact, preventing the survival of aerobic organisms (Diaz and Rosenberg, 1995). It has been suggested that hypoxic conditions combined with slow water renewal in the inner bay seemed to play a key role in the polychaete diversity and biomass (Santi and Tavares, 2009). However, in spite of the intense habitat degradation and the reduced number of species of commercial value, Guanabara Bay still supports an important fishery (Jablonsky et al., 2006).

This study aims to evaluate how polychaeta assemblage is responding to eutrophication along an estuarine gradient and natural factors such as morphodynamic condition in 20 sandy beaches.

2. Materials and methods

2.1. Study area

Guanabara Bay is an estuary of 384 km^2 located in the center of the metropolitan region of Rio de Janeiro city (22°44'–22°57′S and 42°33′–43°19′W). A sub-tropical climate prevails in summer between December and April with 2500 and 1500 mm of rainfall respectively. The mean annual air temperature is between 20 and 25 °C (Nimer, 1989).

Guanabara Bay receives the discharge from a drainage basin impacted by over 7.8 million inhabitants, in which organic pollution and trace metal contamination of sediments have been evident in the last few decades (Carreira et al., 2002; Kjerfve et al., 1997; Machado et al., 2008). Concentrations of coprostanol in sediments as high as 40 μg g^{-1} indicate areas of severe sewage contamination (Carreira et al., 2004). For more than 20 years, land reclaims on the margins of the bay have been increasing sediment deposition, bathymetric reduction and alteration of tidal induced currents (Amador, 1997). Water quality data show an eutrophic gradient (e.g., ammonium and phosphate concentrations) in Guanabara Bay waters from the eastern area, close to the environmental protection area of Guapimirim (EPAG) to the western area of the bay, at the estuary of São João de Merití River, by 1–2 orders of magnitude. This is due to a greater sewage runoff and less efficient water renewal on the western margin than on the eastern one (Kjerfve et al., 1997; Mayr et al., 1989). The greater eutrophication in western estuaries is supported also by total coliforms and faecal coliforms in sediment (Silva et al., 2008) and by the isotopic composition of particulate matter collected in Iguaçu and São João de Merití Rivers which presented sewage-enriched particulate organic matter (Carreira et al., 2002, 2004).

According to the hydrological characteristics of Guanabara Bay, Mayr et al. (1989) suggested a classification into different sections in which natural and anthropogenic factors act in distinct manners: area 1: the central channel; area 2: the margins at the mouth of the bay; area 3: the area around Governador Island; area 4: the northeastern section, within the Guapimirim environmental protection area (EPAG); and area 5: the western area. Greater inputs of urban and industrial effluents are recorded at areas 3 and 5.

2.2. Field sampling and laboratory procedures

We sampled at 20 sandy beaches (sites) located in different areas of the bay: as indicated in Mayr et al. (1989) (Fig. 1): Paquetá Island (area 1), mouth of the bay area (area 2), Governador Island (area 3), inner bay (area 4) and western area (area 5). Sampling was undertaken during low neap tides on three occasions: dry season (September 2005 and October 2006) and wet season (March 2006) and consisted of three transects arranged from the low tide watermark to the mean high water neap tide mark at each beach. In each transect, we collected three replicates in each one of the three different intertidal levels (low, middle and high) using a core of 0.2 m^2, making a total of 27 samples in each beach. Samples were washed in seawater and sieved with 0.5 mm mesh screens and the organisms anesthetized with magnesium chloride, fixed in 4% formaldehyde, and later preserved in 70% ethanol. For the analyses of granulometry and organic matter concentration, three samples along each transect were collected. Sediments were processed following the methodology described by Suguio (1973) and Wentworth scale was used for grain classification (mm). Organic content of dry sediment was estimated as the loss of weight after ashing. The carbonate percentage was calculated by weighing a fraction of the sediment before and after it was treated with chloridic acid (Suguio, 1973).

We used a method proposed by Emery (1961) for estimating slope profile of each transect. The total length of the beach and its distance from the mouth of the bay were also estimated. The beach index (BI) (McLachlan and Dorvlo, 2005) was calculated for each beach as a measure of its morphodynamic state, BI = (mean grain size × tide)/slope. The exposure index proposed by McLachlan (1980) was used to categorize the beaches in relation to wave energy.

A set of water quality parameters was measured to evaluate possible relationships between polychaete assemblage and their environment: temperature, salinity, transparency, ammonia, nitrite, nitrate, total phosphorus, chlorophyll *a*, dissolved oxygen and dissolved organic carbon. For water quality parameters a