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Functional diversity of fish communities in two tropical estuaries subjected to anthropogenic disturbance

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ABSTRACT

The functional diversity of fish communities was studied along the salinity gradient of two estuaries in Northeast Brazil subjected to different anthropogenic pressures, to gain a better understanding of the response of fish communities to disturbance. We evaluated functional complementarity indices, redundancy and analysed functional composition through functional groups based on combinations of different traits. The fish communities in both estuaries share similar functions performed by few functional groups. The upstream areas had generally lower taxonomic, functional diversity and lower redundancy, suggesting greater vulnerability to impacts caused by human activities. Biomass was slightly more evenly distributed among functional groups in the less disturbed estuary, but total biomass and redundancy were lower in comparison to the urbanized estuary. The present findings lend strength to the notion that the less disturbed estuary may be more susceptible to anthropogenic impacts, underscoring the need for more effective conservation measures directed at this estuary.

1. Introduction

Coastal and estuarine ecosystems are often home to a variety of human activities and constitute an important source of wealth for populations around the world (Costanza et al., 2014). In recent decades, anthropogenic stress has intensified in tropical estuarine ecosystems due to urban and industry effluents, agriculture, aquiculture, overfishing and poaching activities (Barletta et al., 2010; Blaber, 2013; Diegues, 1999). Undisturbed or nearly pristine tropical systems are now rare (Blaber, 2013). Efforts have been made for the conservation of such aquatic ecosystems locally, nationally or internationally through management plans as well as the establishment of Ramsar sites and world heritage sites. However, many tropical regions continue to suffer from human activities that lead to environmental degradation stemming from inadequate management, unenforced laws, poverty and over-population (Barletta et al., 2010; Diegues, 1999).

Northeast Brazil exemplifies the conflicting uses of estuarine areas. Human activities flourish in estuaries in the region, which is home to sugarcane production, intensive shrimp aquaculture (97% of the national production) and fishing activities, together with high degrees of urbanization and the dumping of untreated solid waste and effluents (Barletta et al., 2010; Lacerda, 2006; Sá et al., 2013). Such activities have been leading to the general impoverishment of aquatic communities.

Despite protection actions from both governmental and non-governmental organizations in recent years (Diegues, 1999), environmental degradation continues and has the potential to intensify in the near future. The largest estuaries of the state of Paraiba (Northeast Brazil) are the Paraiba and Mamanguape estuaries, which have distinct intensity profiles with regard to anthropogenic pressures. The Paraiba estuary is a highly impacted system, with anthropogenic pressures from several sources, while the Mamanguape estuary has been declared a conservation unit by the IUCN (category V), despite also having some anthropogenic pressure on the system. Human activities in both estuaries have considerable economic importance in the region for different end-users (Alves et al., 2005; Sá et al., 2013). Thus, any management program must take into account the multiple and often conflicting uses of the estuary without compromising its ecological quality and overall functioning. For such, one needs to gain an understanding of the responses of biological communities to anthropogenic disturbances in order to gather information on ecological quality and the capacity of a system to recover from such disturbances.

As species do not contribute equally to the functioning of an ecosystem, it is important to understand the way these organisms use the system and how they cope with environmental changes (Stuart-Smith et al., 2013). The evidence suggests that the determination of functional

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diversity provides a way to understand the responses of a community to disturbances in a more integrated approach (Mouillot et al., 2013) and to gain a better understanding of the functioning of an ecosystem (Dolbeth et al., 2015; Strong et al., 2015). Functional diversity is generally described as the functional component of biodiversity that is measured by the traits of species (Violle et al., 2007). Traits reflect the mechanisms underlying species-environment relationships and may provide considerable insight into the responses of a community (e.g., Mouillot et al. 2013). However, functional diversity encompasses different components, which may all be important to revealing the impacts of disturbances, and several methods have been proposed to quantify this aspect (Carmona et al., 2016; van der Linden et al., 2016; Villéger et al., 2008).

The aim of the present study was to characterize and explore functional composition and diversity in the Mamanguape and Paraiba estuaries, assuming that the two ecosystems experience distinct degrees of anthropogenic pressure. However, since different facets of functional diversity are important to revealing the impact of disturbances (Mouillot et al., 2013; Villéger et al., 2008, 2010), two different approaches were employed to evaluate functional diversity: 1) based on a functional complementarity effect (i.e., evaluating mean trait dissimilarity using different functional indices and evaluating functional redundancy); and 2) based on a functional identity effect. To study functional identity and understand how it could help in explaining the community response to disturbances, the concept of functional groups was employed rather than analysing each trait separately. Recent studies have shown that a particular combination of traits may reflect stability in the presence of environmental disturbance better than each trait alone (Dolbeth et al., 2015; Verberk et al., 2013; Winemiller et al., 2015). The goal was to broaden knowledge on how tropical systems function and understand what characteristics allow fish communities to recover better from environmental disturbances. Ultimately, we want to test whether the analysis of the functional diversity of fish communities is a useful tool for the assessment of the effectiveness of environmental protection practices.

2. Materials and methods

2.1. Study area

This study was conducted in two tropical estuaries located on the coast of Northeast Brazil (Fig. 1): the Paraiba estuary (3012 ha) and the Mamanguape estuary (690 ha). According to the Köppen-Geiger classification, the climate in the two estuaries is "As", i.e., equatorial with a dry summer (Alvares et al., 2013). In both estuaries, the rainy season extends from February to August, with the greatest rainfall occurring in June and the lowest in November. The Paraiba estuary has a wetter climate (1717 mm/year) than the Mamanguape estuary (1392 mm/year) (data from 1999 to 2014; CPTEC/INPE 2015).

The Paraiba River valley drains the driest region of Brazil (the Borborema plateau). Most rainfall is retained in reservoirs, except during wetter years. During the study period, freshwater entering the Paraiba estuary originated on the humid coastal plains (Executive Agency for the Management of Waters in the State of Paraiba [AESA]; accessed in August 2015). The watersheds that drain directly into the Paraiba River have approximately 38,472 ha. The Mamanguape River valley drains areas that are less dry, including a humid range, leading to frequent water spill over onto the coastal plains (AESA 2015). The watersheds that drain directly into the Mamanguape River have approximately 25,055 ha. Moreover, the Mamanguape estuary has a reef line 8.5 km in length running parallel to the shoreline that creates a protected region at the mouth of the estuary. Both estuaries have mangroves that grow around the main channel and intertidal creeks, along with remnants of the Atlantic rainforest (Campos et al., 2015).

Both systems are subjected to different intensities of anthropogenic pressures. The Paraiba estuary is situated in a metropolitan area with

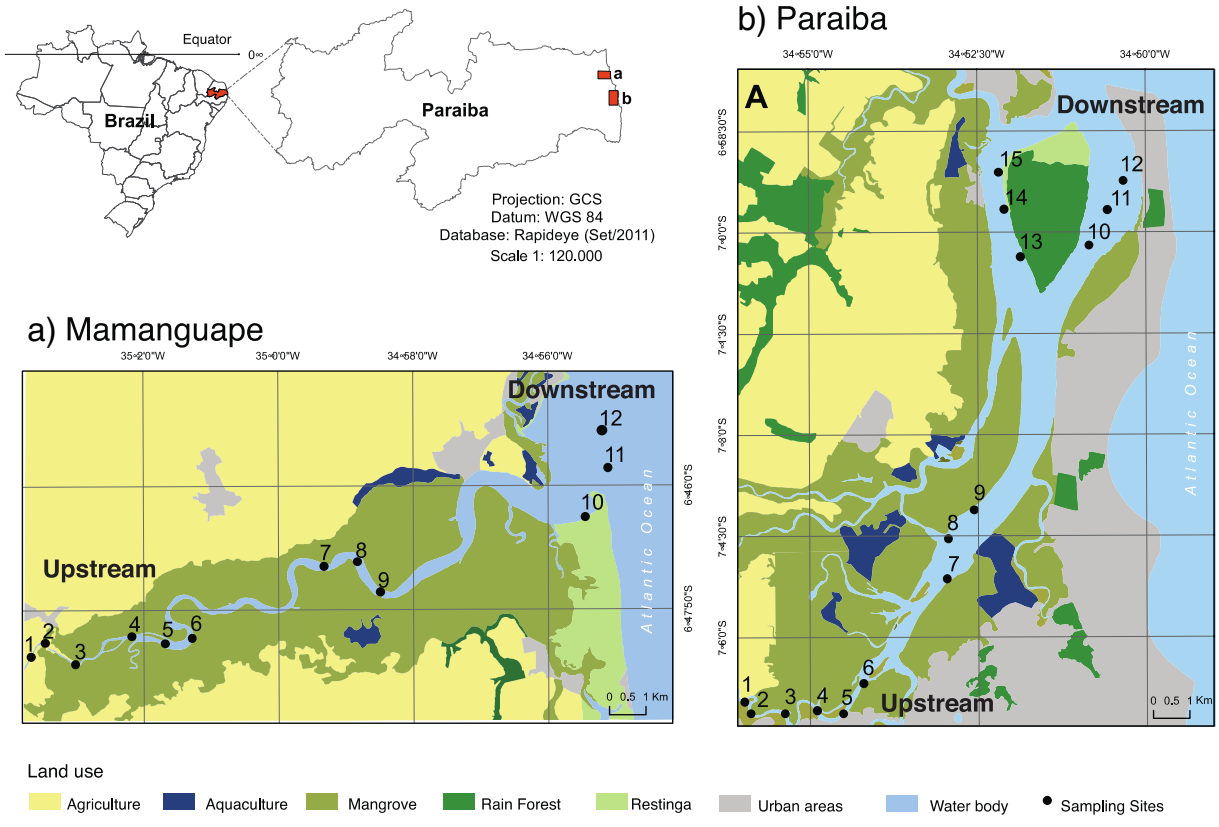

Fig. 1. Location of estuaries in Northeast Brazil, sampling sites and main land uses.

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