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Narrowing the gap: Phytoplankton functional diversity in two disturbed tropical estuaries

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ABSTRACT

The functional diversity of phytoplankton communities was studied in two tropical estuaries subjected to anthropogenic pressure, despite one being environmentally protected. We applied functional diversity indices, analysed the dominant morphology traits and explored morphology-based functional groups. The less disturbed estuary showed slightly higher diversity and functional redundancy, during a wet season (on average 1.3 higher). Functional groups including nuisance species were more abundant in the heavily disturbed estuary. During a dry season, results for both systems were similar. Overall, abundance and functional diversity were higher in the upstream areas, associated with the river runoff containing freshwater species and essential nutrients for algae development. In both systems, diatoms were dominant (> 75% of the community), however, the group included small and larger individuals, and freshwater to cosmopolitan species. This dominance and the change in traits were associated with sufficient nutrient supply, low light conditions, ressuspension and salinity changes, also associated with river runoff. Overall, the different functional diversity approaches enabled us to improve our understanding of the changes occurring in both systems.

1. Introduction

As transitional areas, estuaries are characterised by the mixing of turbid and nutrient enriched freshwaters with relatively clear and nutrient-poor ocean waters (McLusky and Elliott, 2004; Quinlan and Phlips, 2007). This mixing is responsible for different estuarine gradients that, overall, condition the availability of light, nutrients and salinity for the biota, among other factors (Cloern et al., 2014; McLusky and Elliott, 2004). The change in these chemical and physical gradients greatly influences the spatial and temporal distribution, abundance and functional characteristics of estuarine biological communities (McLusky and Elliott, 2004; Whitfield et al., 2012), which generally tend towards a functional trait convergence due to the highly dynamic nature of the estuarine environment (Dolbeth et al., 2016a; Veríssimo et al., 2017). This occurs because only one set of characteristics is able to cope with the habitat filtering imposed by the dynamic estuarine gradients. However, organisms thriving in estuaries may attain considerably high production values (Dolbeth et al., 2012), which place estuaries among the most productive aquatic ecosystems (Costanza et al., 2014). Besides the high productivity (e.g. provisioning services), estuaries provide other essential ecosystem services, such as bioremediation, flood protection, among several other processes (regulation and maintenance services), and recreational activities (cultural services), turning estuaries extremely valuable to mankind (Lillebø et al., 2016).

Phytoplankton communities are an important component of the estuarine biota (Cloern et al., 2014; Lancelot and Muylaert, 2011; McLusky and Elliott, 2004). These communities may be responsible for up to 50% of the estuarine primary production (Cloern et al., 2014; Soria-Píriz et al., 2017), and fuel a significant part of the estuarine food web, as they are a high-quality food source (Carstensen et al., 2015; Cloern et al., 2014). Nevertheless, the role of phytoplankton communities in estuarine dynamics is not as dominant as in rivers or the open ocean, due to environmental constraints such as turbidity, which controls light availability essential for phytoplankton growth (Cloern et al., 2014; Lancelot and Muylaert, 2011; McLusky and Elliott, 2004). Thus, phytoplankton production and species traits may differ considerably in response to the highly dynamic nature of the estuarine environment. Their response generally falls into two main categories (Cloern et al.,

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2014; Kruk and Segura, 2012; Lancelot and Muylaert, 2011): 1) resources for growth, mostly light and nutrients (and temperature, which regulates growth rate and photosynthetic efficiency), and 2) mortality avoidance, including grazing pressure, lysis by pathogens or osmotic stress, sedimentation, and washout from the system due to, for instance, river runoff.

Functional diversity approaches have been used more widely in aquatic ecosystems, to improve our knowledge on the response of the ecosystem to environmental disturbance or to better understand its functioning (Mouillot et al., 2013; Salmaso et al., 2014; Verberk et al., 2013). Regarding phytoplankton communities, attempts to classify and study their traits and functions have been made for some time (e.g. Margalef's r and K strategies (Margalef, 1978), morphological functional group approaches (Kruk et al., 2010a,b), and others (Salmaso et al., 2014)). There are several advantages to using this sort of approaches (Kruk et al., 2014; Kruk and Segura, 2012; Salmaso et al., 2014), including: 1) making comparisons between ecosystems around the world; 2) understanding phytoplankton responses to changing environmental conditions, thus improving our forecasting ability with regard to disturbance; 3) identifying the main driving processes in phytoplankton coexistence; 4) making generalisations about trophic webs and ecosystem energetics; and 5) measuring with greater ease than with taxonomic-based approaches.

Overall, trait-based approaches allow us to make generalisations about species performance with regard to environmental change, an essential step towards improving the quantification and prediction of its impacts on the system (Kruk et al., 2014; Kruk and Segura, 2012). This way, trait-based approaches may be important tools for more effective ecosystem management. In view of this potential, our goal was to characterise and explore the functional composition and diversity of the phytoplankton in two tropical estuaries in Brazil semi-arid region, while also bearing in mind the scarcity of trait-based and functional group studies in tropical estuaries (but see Costa et al., 2009). The Mamanguape and the Paraiba estuaries experience different intensities of anthropogenic pressure, as the Mamanguape is in an environmental protection framework, whereas the Paraiba is heavily disturbed (Alves et al., 2016; Dolbeth et al., 2016a; Vendel et al., 2017). Despite the different anthropogenic impacts, previous studies with other biological communities have shown that the ecological quality of both estuaries, assessed using integrative functional approaches, is not that different (e.g. Dolbeth et al., 2016a; van der Linden et al., 2017). Both systems showed consistent signs of disturbance in their faunal communities (Dolbeth et al., 2016a), with the Paraiba estuary presenting even greater resilience to this disturbance due to the higher functional redundancy of its fish communities (Dolbeth et al., 2016b). Taking these results of the higher trophic levels into consideration and bearing in mind that phytoplankton communities are among the basal resources in the food web, we were interested in understanding 1) what the functional characterisation of the phytoplankton communities from the two tropical ecosystems is, and 2) how phytoplankton communities respond to different levels of human impact.

2. Material and methods

2.1. Study area

The study was conducted in two tropical estuaries, the Paraiba (3012 ha) and the Mamanguape (690 ha) on the northeast coast of Brazil, a semi-arid region (Fig. 1). The climate type in these systems is equatorial with a dry summer (Alvares et al., 2013). In both estuaries, the rainy season lasts from February to August, with the highest rainfall occurring in June and the lowest in November. The Paraiba estuary has a wetter climate (1717 mm yr^{-1}) than the Mamanguape estuary (1392 mm yr^{-1}) (data from 1999 to 2014; Center for Weather Forecasting and Climate Research – CPTEC/INPE, www.cptec.inpe.br, accessed in December 2016).

The Paraiba River basin drains the driest region of Brazil, semi-arid region, with watersheds that drain directly into the Paraiba River covering approximately 38,472 ha. The Mamanguape River watersheds, which drain directly into the Mamanguape River, are approximately 25,055 ha in size. In addition, the Mamanguape has an 8.5 km long reef line parallel to the shoreline which creates a protected region at the mouth of the estuary. Both estuaries have mangrove areas that grow around the main channel and the intertidal creeks, as well as remnants of the Atlantic rainforest (de Almeida Ramos Campos et al., 2015).

Each system is subjected to different intensities of anthropogenic pressures, whose impacts have been studied for the zooplankton (de Moura et al., 2016; Veríssimo et al., 2017), invertebrates (van der Linden et al., 2017; Medeiros et al., 2016; Nóbrega-Silva et al., 2016), fish communities (Alves et al., 2016; Dolbeth et al., 2016a,b; Vendel et al., 2017) and fish parasites (Golzio et al., 2017). The Paraiba estuary is situated in a metropolitan area with approximately 1,100,000 inhabitants, i.e. João Pessoa, which is the capital of the state, and four other contiguous cities (± 9418 ha [24%] of land use; Z. Teixeira pers. comm). The estuary lies between extensive sugarcane plantations along the riverbanks land use and intensive shrimp aquaculture areas (± 14 618 ha [38%] and ± 468 ha [1.2%] of land use respectively; Z. Teixeira pers. comm). These activities have been leading to the overall environmental degradation of the estuary (Alves et al., 2016; Dolbeth et al., 2016a), with visible signs of anthropogenic impact (authors' personal observation). Such conditions are aggravated by the lack of surveillance and law enforcement, as well as the increasing trend in human population growth.

The Mamanguape estuary has been declared a conservation unit for sustainable use (Barra de Mamanguape environmental protection area, IUCN Protected Area Category V), due to the importance of its coastal habitats, with well-preserved mangrove areas, and as an area for the conservation of the marine manatee, which is a protected species. However, it also has extensive sugarcane fields and shrimp aquaculture beyond the mangrove area (± 14031 ha [56%] and ± 204 ha [0.8%] of land use, respectively; Z. Teixeira pers. comm.), contributing toward eutrophication and agrochemical pollution (Dolbeth et al., 2016a; Nóbrega et al., 2014). The nearby cities have a total of 66,000 inhabitants (± 519 ha [2%] land use).

2.2. Sampling and laboratory procedures

Samples were collected in November 2013 (dry season) and July 2014 (wet season) along the salinity gradient of the two estuaries (15 sites in the Paraiba estuary and 12 in the Mamanguape estuary). These sites were selected to cover the estuarine salinity gradient, from the upstream most freshwater/brackish reaches to downstream oceanic influenced conditions. In Paraiba, three additional sites were sampled, because the estuary downstream area divides into two arms (Fig. 1). Physicochemical parameters were measured *in situ* (surface water temperature, salinity, pH and turbidity with a multiparameter probe and water transparency with a Secchi disc). Water samples were collected for the analysis of nutrient content to infer the possible effects of organic enrichment from anthropogenic activities. Concentrations of ammonium (NH4-N, μg/L), nitrite, nitrate (NOx-N, μg/L) and total phosphorous (P, μg/L) were determined in the laboratory, following standard protocols (Strickland and Parsons, 1972; APHA, 2005).

Phytoplankton samples were collected at each site in the water subsurface and fixed in formalin and Lugol's iodine solution. The phytoplankton quantification was done with the Utermöhl method (1958), using an inverted microscope, and counting until reaching 400 individuals. These were identified to the lowest taxonomic resolution possible and their density evaluated as individuals per mL.