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Fish assemblages in tropical estuaries of northeast Brazil: A multi-component diversity approach

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ABSTRACT

Biodiversity in estuarine ecosystems suffers from the impact of environmental changes and human activities. This mainly involves changes in temperature, salinity, pollution, habitat degradation or loss and fishing activities. The diversity of species communities is traditionally assessed on the basis of their species richness and composition. However, there is growing interest in taking into account complementary components dealing with species differences (e.g. taxonomic relatedness). In spite of their social, ecological and economic importance, the diversity of tropical estuarine fish assemblages has rarely been monitored by means of a multi-component approach under different human pressure and environmental conditions. We analysed the diversity of exploited fish communities (both target and non-target species) sampled during scientific surveys within four estuarine complexes in the state of Pernambuco, Brazil: Itapissuma, Suape, Sirinhaém, and Rio Formoso. A total of 122 species were collected within 34 samples. Overall, diversity indices and species models fitting dominance-evenness profiles mainly revealed differences between assemblages from Itapissuma, being the largest estuary with wide areas of mangrove, and the other estuaries. While assemblages from Itapissuma generally encompassed more species and individuals than the other estuaries, species were more closely related from a taxonomic point of view. In addition, a Double Principal Coordinate Analysis (DPCoA) established a typology of assemblages, useful for management purposes, and linked to particular fish families: it highlighted differences between Itapissuma, Suape, Sirinhaém and Rio Formoso. This method combines matrices of species abundances and differences (here taxonomic distances according to the Linnean classification). It was particularly accurate with a first factorial plane explaining 73% of the total inertia, while only 17% was achieved by a traditional Principal Component Analysis (PCA). Overall, this study provides an assessment of the state of fish assemblage diversity in Pernambuco estuaries where contrasted human and environmental conditions occur. It underscores the accuracy of using a multi-component diversity approach, with a multivariate analysis that is not yet widely used, for monitoring the diversity of estuaries for ecosystem-based fisheries management purposes.

1. Introduction

Estuaries, interfaces between land and sea, are the site of a range of hydrological (e.g. river discharge), oceanographic and anthropogenic processes. These complex processes create habitats with intense thermal and salinity gradients and variable nutrient and pollutant concentrations (Wolanski, 2007). They notably drive fish patterns of distribution in space and time, and shape the diversity of assemblages (Elliott et al., 2007; Potter et al., 2015). Estuaries are ecologically essential as feeding and breeding grounds, providing appropriate habitats for different stages of the fish life cycle. In addition, they are a migratory pathway for both anadromous and catadromous species (Elliott et al., 2007; Potter et al., 2015).

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Furthermore, the high socio-economic value of their products, especially as a source of income and food, is widely recognized (Glaser and Diele, 2004; Isaac et al., 2009). However, global environmental change and direct human pressures impact the water quality and biodiversity of estuarine ecosystems (Garcia et al., 2003; Halpern et al., 2008; Borja et al., 2010; Li and de Jonge, 2015). Notably, major changes in fish diversity from the effects of mangrove removal, shrimp farming and agricultural development have been recently documented for estuaries worldwide in terms of assemblage composition, decrease in number of species, feeding groups and larger fishes (Blaber, 2008, 2009, 2013; Weerts and Cyrus, 2002; Singkran and Sudara, 2005; Oribhabor and Ogbeibu, 2010; Viana et al., 2010, 2012).

Aquatic resources are of fundamental importance for human food and for the development of Brazil, which has one of the longest coastlines in the world (9th longest worldwide) (Burke et al., 2001). Recently, Pinheiro et al. (2015) stated that the Brazilian aquatic biodiversity is in peril, notably with regard to fishes, in many cases due to habitat degradation. However, it is widely acknowledged that the success of many fisheries resources is dependent on the quantity and quality of the habitat (Lindall and Thayer, 1982; Auster et al., 1996). The northeast is one of the most densely populated coastal regions in Brazil. In Pernambuco state, the degradation of coastal ecosystems is most severe around the main urban centre, Recife, mainly due to domestic pollution, industrial activity and habitat degradation and loss. These coastal ecosystems are also threatened by fishing (Elfes et al., 2014) because of the impact on the habitat (Turner et al., 1999) and/or fishes at the top of the trophic networks (e.g. trophic downgrading, Estes et al., 2011). Along the Pernambuco coast are located 34 fishing communities, with ca. 12 000 fishermen (Lessa et al., 2006). To supply food and satisfy economic needs, aquatic resources are intensively exploited using multiple techniques and multispecies artisanal fisheries (Frédou et al., 2006, 2009a, b). The majority of stocks are either fully or over-exploited, and there is little room for expansion into new fisheries (MMA, 2006). Despite all these threats, the degree of dependency on and use of estuarine ecosystems, even in urban areas, remains very high (MMA, 2002).

The diversity of the threats and their intensification in the Pernambuco estuaries (Lira et al., 2010a, b) highlight the need to monitor fish biodiversity for management and sustainable use purposes. While several studies dedicated to the diversity of fish assemblages have been carried out in this area (Paiva et al., 2009; Paiva and Araújo, 2010), there is still a need to assess and quantify their state in the main estuaries subjected to contrasting human pressure and environmental conditions. For this purpose, the diversity of fish assemblages can be monitored more exhaustively by a multi-component diversity approach (e.g. Wilsey et al., 2005; Mérigot et al., 2007; Gaertner et al., 2010; Lefcheck et al., 2014). This approach consists in assessing different components, or facets, such as species number and evenness, and also components that explicitly take into account the degree of difference among species. This reflects the taxonomic relatedness between species, on the basis of which diversity indices can be more sensitive to environmental and/or human drivers (Clarke and Warwick, 1998). Monitoring a single diversity component using one or few diversity indices leads to an incomplete description of the diversity of assemblages, and in turn important responses in the face of environmental and/or human drivers could be missed (e.g. Stuart-Smith et al., 2013; D'agata et al., 2014).

In this context, the aim of this work is to investigate the fish diversity assemblages on the basis of a multi-component approach, comparing tropical estuaries subjected to contrasting environmental conditions and human pressure. Firstly, complementary diversity indices were quantified for each estuary. Secondly, the typology of fish assemblages among these estuaries was characterized using a recent multivariate analysis, the Double Principal Coordinates Analysis (DPCoA), that explicitly takes into account species differences (here, taxonomic relatedness). Overall, this study provides an assessment of the state of assemblages among the studied tropical estuaries of northeast Brazil, and demonstrates that a multi-component approach of this kind can be useful for ecosystem-based fishery management in estuarine ecosystems.

2. Materials and methods

2.1. Study area

Four estuaries located along the coast of Pernambuco State were studied: Itapissuma, Suape, Sirinhaém and Rio Formoso (Fig. 1). The estuarine complex of Itapissuma is located to the north of and closest to the Recife and Olinda urban centres, and is the most strongly influenced by landscape alterations, industrial discharges, shrimp farming and high fishing pressure (CPRH, 2003; Lira et al., 2010a; Gondim, 2015). The other three estuaries are located south of Recife: the Suape estuary has suffered the high impact of deforestation and land reclamation due to the construction of a large industrial port complex (chemical, shipping and logistics companies), with predictable effects on both the biodiversity and fisheries productivity (Paiva and Araújo, 2010). Sirinhaém and Rio Formoso are located in the southernmost area, and although located within an environmental protected area (APA Guadalupe), they are also impacted by agricultural pollution (mainly sugar cane), shrimp farming and fishing (Lira and Fonseca, 1980). Rio Formoso is also a popular tourism destination (Lira et al., 2010b).

2.2. Sampling design

Fish were sampled from the end of 2012–2014 (see Table S1 in Supplementary Material for sampling dates). A total of 34 samples were obtained using block net and beach seine (seine) gear: 17 in Itapissuma, 9 in Sirinhaém, 4 in Rio Formoso and 4 in Suape. These types of fishing gear were selected as, together, they can cover most fish habitats present in the studied estuaries: shallow coastal areas and sand/mud banks (beach seine), and flooded mangrove and channels (block net). The number of samples per estuary varied according to the characteristics of each type of gear, the influence on tidal variation, and the gear setting time. Beach seine nets measured 80–180 m long, 5 m high with a mesh size of 20 mm. The operation lasted no more than 20 min and was repeated several times. Block nets were set along the mangrove forest and channels and measured 70–90 m long, 2.5 m high with a mesh size of 50 mm. At low tide, the net was anchored to the bottom. At slack high-water, the net was deployed and attached to stakes and pulled taut so that it was above the water, enclosing the mangrove area. Blocking was initiated at the end of the high tide and continued throughout the entire ebb tide cycle (approximately 6 h).

2.3. Statistical analyses

Firstly, we computed a species accumulation curve to assess whether the fish community in the study area was exhaustively sampled, with the gear used (Gotelli and Colwell, 2001). We used a randomized method without replacement. It enables calculation of a mean number of species for a given number of samples, with a 95% confidence interval, as well as obtaining the total number of species caught for the total number of samples considered. We also computed the Chao2 index (Chao, 1987), which extrapolates, from the occurrence of rare species, the total expected number of species in the area, for the given sampling gear. In addition, because the

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