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Differences in diversity and habitat use of avifauna in distinct mangrove areas in São Sebastião, São Paulo, Brazil

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ABSTRACT

Mangroves are an important ecosystem for many bird species for breeding, roosting and feeding, but habitat use depends on the area and vegetation structure. Avifaunal diversity studies are essential to establish baseline knowledge, identify impacts on communities, and for the effective management of ecosystems, especially in coastal areas under intense anthropogenic pressure. In this study, we: 1) characterized the mangrove vegetation structure on a former landfill (Ferry's site) from the expansion of São Sebastião Port, on the southeast coast of Brazil, 2) compared bird richness, abundance, and seasonal diversity of waterbirds and terrestrial birds at Ferry's site, with four sites located on natural land at Araçá Bay, a small semi-enclosed coastal bay, and 3) analyzed birds' habitat use. Ferry's site and Araçá Bay both border the port in the São Sebastião municipality. Overall, 52 bird species were detected in Ferry's site and 78 species in Araçá Bay. The waterbird community showed a higher average richness, abundance, and diversity in Ferry's site (A1) than in the Araçá sites (A2-A5). There were significant differences in these variables among sites, but not among seasons. For terrestrial birds, average richness and diversity were higher at Ferry's site, but average abundance was higher at Araçá Bay. These differences may be explained by habitat heterogeneity in the areas, however no pattern in these variables was found among A2-A5, because A5 has less human traffic and has more edge vegetation, which attracts birds. Ferry's site was used mainly for roosting throughout the year and as a breeding site for four heron species in summer, whereas Araçá Bay was used mainly as a foraging ground for waterbirds. Differences in habitat use were probably due to the higher density and maximum height of mangrove vegetation at Ferry's site, even though mangroves of Araçá Bay had a greater structural development. Furthermore, Araçá Bay has a large tidal plain, with high invertebrate diversity, which could explain why waterbirds used it mainly for foraging. This study highlights the importance of mangrove in the life cycle of several bird species and their aggregation. Therefore, protection of these coastal habitats should be prioritized in conservation measures.

1. Introduction

Mangroves are coastal ecosystems found between terrestrial and marine environments, subject to the tidal regime, in tropical and subtropical regions (Schaeffer-Novelli and Cintron, 1986). Brazil currently has approximately 7–9.4% of the world's mangrove forests, which equates to approximately 7600 km^2–9600 km^2 depending on the estimate, and it is among the top three largest mangrove areas in the world (FAO, 2007; Giri et al., 2011; Hamilton and Casey, 2016). Since 1980, about 20–35% of the world's mangroves have been destroyed due to anthropic pressures (FAO, 2007; Polidoro et al., 2010; Valiela et al., 2001). This is not different for Brazilian mangroves, where approximately 25% were destroyed or fragmented between 1985 and 2000 (Prates et al., 2012). Unfortunately, the decision-making processes favoring the degradation of mangroves during the last two decades were exclusively based on economic factors (Queiroz et al., 2017). The main causes of mangrove degradation in the world are conversion into shrimp farming, urban expansion, real estate speculation, port construction, and development of tourism areas (Duke et al., 2007; Hamilton, 2013; Leão and Dominguez, 2000).

Mangroves are widely known for their important ecosystem functions, such as retaining soil sediments, reducing contamination of

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beaches, and protecting coastal areas and communities from storms, waves, and typhoons (FAO, 2007). Additionally, mangroves account for 71% of all carbon storage in ocean sediments, and for more than 50% of the Earth's blue carbon sinks (Nellemann et al., 2009; Rovai et al., 2012). They are also recognized as biodigesters, and as providers of shelter and feeding grounds for a variety of mollusks, polychaetes, insects, crabs, shrimps, and fishes, including many commercially important species (Checon et al., 2017; Lacerda, 2009; Schaeffer-Novelli and Cintron, 1990).

Birds are also an important component of this ecosystem, due to their ecological role in the dynamics of mangroves (Acevedo and Aide, 2008; Mohd-Azlan et al., 2015). They can oxygenate the soil while feeding, and release nutrients into the water column through their feces and food waste (Navedo et al., 2015; Onuf et al., 1977). Birds use mangroves for feeding, roosting, resting and breeding purposes (Mestre et al., 2007; Nagelkerken et al., 2008; Olmos and Silva-e-Silva, 2001), but habitat use depends on the location and structure of the vegetation (Mohd-Azlan et al., 2015; Tews et al., 2004).

In a terrestrial landscape, bird diversity is related to habitat heterogeneity, which provides multiple niches for coexisting species (Mohd-Azlan et al., 2015; Weiher et al., 2011). Habitat heterogeneity is expected to increase with habitat size and microhabitat diversity (MacArthur and Wilson, 1967; Mohd-Azlan et al., 2015). In seascapes, mangroves bring complexity to the ecosystem, offering microhabitats and specialized niches for different species to occupy. Nevertheless, Ford (1982) recorded relatively low bird species richness in mangrove areas, limiting the possible number of coexisting species. Birds may also differ in their habitat use, depending on whether the mangrove meets their requirements for foraging, roosting, or nesting. The endangered Mangrove Finch (*Camarhynchus heliobates*), is known to nest in higher and older black mangrove trees (*Avicennia schaueriana*) (Fessl et al., 2011), whereas some species live almost exclusively in mangroves for their whole life cycle, e.g., Rufous Crab–hawk (*Buteogallus aequinoctialis*), Scarlet Ibis (*Eudocimus ruber*), and Yellow-crowned Night Heron (*Nyctanassa violacea*) (Bierregaard et al., 2017; Matheu et al., 2017; Martínez-Vilalta et al., 2017).

Habitat use by animals is defined by the range of resources they exploit (King et al., 2006; Walters et al., 2002), and also has key implications for wildlife conservation, as it can highlight factors affecting population dynamics and the impact of human activities on the distribution and abundance of species (Larson et al., 2004; Schrott et al., 2005). Migratory birds, for example, need to obtain appropriate resources at multiple sites throughout their annual cycle, including wintering, breeding and stopover sites (Harrison et al., 2011).

In the coastal zone of São Paulo, bird surveys have mainly been conducted in the southern area (Barbieri and Mendonca, 2005; Barbieri and Paes, 2008; Campos et al., 2004; Olmos and Silva-e-Silva, 2001; Silva-e-Silva and Olmos, 2007). There is scarce information on birds in coastal and mangrove areas under intense anthropogenic pressure, such as the São Sebastião municipality, which holds one of the last remnants of mangroves on the northern coast of São Paulo State (Amaral et al., 2010, 2016; Lamparelli et al., 1998). The construction of the São Sebastião Port (1934–1955), modified the coastline, induced hydrological changes, and led to silting of the beaches and intertidal zone, which resulted in changes to the mangroves in São Sebastião (Schaeffer-Novelli et al., 2016, 2017).

Araçá Bay belongs to the Marine Environmental Protection Area of the North Coast (Decree State No. 53.525/2008) and the Municipal Environmental Protection Area of Alcatrazes (Decree 848/1992; Amaral et al., 2016). Both documents recognize the bay's high biodiversity and socioeconomic importance, as mentioned in previous studies (Ávila-da-Silva et al., 2015; Gorman et al., 2015; Lamas et al., 2016; Mancini et al., 2017; Turra et al., 2015). Despite all these attributes, the bay has been severely affected over the past century by various activities, including the occupation of a substantial area of land for port infrastructure expansions, and the increase in urbanization of nearby areas (Amaral et al., 2010; 2016). In the near future, even more severe impacts are predicted if the São Sebastião Port expansion plan, including the expansion of its backyard, covering Araçá Bay, goes ahead (CPEA, 2011). This expansion is heavily debated, due to the severe habitat modifications it would cause (Amaral et al., 2010, 2016; CPEA, 2011).

Conversely, mangrove vegetation has naturally grown over landfill close to the São Sebastião Port since the late 1990s, and is identified as “Ferry's site” in this study. Detailed information on this area is presented in the results section, where the mangrove vegetation was characterized. Ferry's site is inside a restricted access area in the DERSA (Desenvolvimento Rodoviário S/A – Road Development) parking lot, opposite Araçá Bay which is a free access site. Information on avifaunal composition, abundance, and habitat use in coastal areas is essential to establish a baseline knowledge for monitoring and identification of possible impacts on communities, as birds and mangroves are good indicators of habitat quality and both can be used for long-term monitoring studies (Cavarzere et al., 2013; Mestre et al., 2007; Somenzari et al., 2011). As Ferry's site provides a new mangrove habitat near the São Sebastião Channel, it is important to study the properties of the mangrove, and record the structure of the bird community which benefits from this area.

The present study aims to: 1) characterize the mangrove environment in a landfill area (Ferry's site), 2) compare bird diversity in Ferry's site and Araçá Bay (natural land), and 3) analyze birds' habitat use. Furthermore, the following hypotheses are tested: 1) the diversity in bird species differs among areas due to heterogeneity of habitats, and 2) the habitat use among waterbirds in mangroves differs according to vegetation structure.

2. Material and methods

2.1. Study areas

Ferry's site and Araçá Bay are located in the São Sebastião municipality, on the northern coast of São Paulo State (Fig. 1). Ferry's site (**A1**), approximately 900 m north of Araçá Bay, adjacent to São Sebastião Channel, originated from several landfills of São Sebastião Port; it reached its final form in the late 1990s, covering 26,600 m^2. Subsidence of soil material in the fringe allowed the tide to enter, carrying mangrove propagules which colonized the site (Adriano Truffi de Lima, Personal communication), and mangrove vegetation has grown naturally over the landfill for the last two decades (CPEA, 2011).

Araçá Bay is a small, artificial, semi-enclosed coastal bay, covering approximately 500,000 m^2, adjacent to São Sebastião Channel; it is bordered by rocky shores, and contains four beaches, two islets, an extensive tidal flat that is exposed entirely during periods of low tide due to syzygy, and six overwashed mangrove core areas (Schaeffer-Novelli et al., 2016, 2017; Fig. 1). The total area occupied by mangrove forests corresponds to 3,644 m^2 (0,6% of the bay area), and the total basal area of living trees corresponds to 238 m^2 where we find typical plant species: black mangrove (*Avicennia schaueriana*), white mangrove (*Laguncularia racemosa*), and red mangrove (*Rhizophora mangle*). The black and white mangrove trees have the heights and trunk diameters of mature forest trees, and are estimated to be over 60 years old (Schaeffer-Novelli et al., 2016, 2017). The Araça Bay site **A2** (25 400 m^2) is characterized by 2,515 m^2 of mangrove vegetation, with the diameter at breast height (DBH) of adult mangrove trees ranging from 8 to 44 cm, and a maximum canopy height of 10 m (Table 1); site **A3** (29 600 m^2) is characterized by 915 m^2 of mangrove vegetation, with the DBH of adult mangrove trees ranging from 7 to 31 cm, and a maximum canopy height of 6 m; site **A4** (34,700 m^2) is characterized by 214 m^2 of mangrove vegetation, with the DBH of adult mangrove trees ranging from 6 to 23 cm, and a maximum canopy height of 3 m; and site **A5** (26,000 m^2) is characterized by 284 m of rocky shores, without mangroves. In summary, both study areas are composed of a mosaic of