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Environmental and anthropogenic factors structuring waterbird habitats of tropical coastal lagoons: Implications for management

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ABSTRACT

Tropical coastal lagoons are among the most threatened ecosystems on Earth due to multiple factors. The loss and degradation of coastal lagoons can adversely affect waterbirds, which depend crucially on wetland habitats. This study investigates the effects of a number of environmental variables on waterbird habitat use. Specifically, we assessed the abundances of six waterbird guilds in relation to hydrochemical, structural, and anthropogenic factors in 351 survey blocks of 22 tropical coastal lagoons of southeastern Brazil. Patterns of habitat use were analyzed using generalized mixed models. We found that water depth was the most important variable influencing the waterbird assemblage. Increasing water depth reduced the abundance of small and large wading birds, dabbling ducks, and diving birds. Extreme values of salinity negatively affected diving birds and large wading birds. Vegetation height influenced shorebirds negatively, while it influenced vegetation gleaners positively. Anthropogenic factors played an important role in structuring the habitat of small wading birds, dabbling ducks, diving birds and fishing birds. Our study indicates that the various guilds showed specific responses to different habitat variables. We conclude that the maintenance of water depths in the range of 0–20 cm, the preservation of a mosaic of vegetation heights, and the reduction of livestock grazing pressure are among the most important aspects for supporting high avian abundance and biodiversity in tropical coastal lagoons. Management strategies should therefore address a specific number of structural and hydrochemical attributes of coastal lagoons and should carefully consider the effects of land use practices.

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1. Introduction

Tropical coastal lagoons are shallow aquatic ecosystems located at the boundary between terrestrial and marine environments. They are intermittently connected to the sea by restricted inlets and exhibit marked variations in their hydrological features due to rainfall and other environmental factors (Kjerfve, 1994). These ecosystems occupy 13% of coastal areas in the world (Barnes, 1980) and support a range of highly valued ecological services (Anthony et al., 2009). In addition, they are among the most biologically productive environments of our planet and harbor a rich and unique biodiversity of species (Esteves et al., 2008; Whitfield et al., 2008). The high environmental heterogeneity of coastal lagoons, in both temporal and spatial scales, provides habitats for aquatic bird species with different ecological needs (Ntiamoa-Baidu et al., 1998; Paracuellos and Tellería, 2004; Tavares and Siciliano, 2013a). However, tropical coastal lagoons are among the most threatened ecosystems on Earth due to multiple disturbances, including habitat alterations (Bulleri and Chapman, 2010), climate change (Anthony et al., 2009; Clausen and Clausen, 2014) and different forms of anthropogenic perturbations (McKinney et al., 2010). For example, they are vulnerable to artificial sandbar opening and drainage canals building, which could promotes arid conditions and salinization (Esteves et al., 2008). Previous studies have documented the sensitivity of waterbirds to habitat alterations (Alexander and Hepp, 2014; Ma et al., 2010) and have highlighted the importance of management strategies, especially under the current context of rapid environmental change (IPCC, 2014) and biodiversity loss (Monastersky, 2014).

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However, understanding the effects of habitat alterations on waterbirds is a difficult task that requires first an insight into how environmental factors influence habitat use. Most environmental and anthropogenic perturbations have contrasting effects on different waterbird guilds. For example, alteration in spatial attributes may cause the loss of certain species due to area and isolation effects (Guadagnin and Maltchik, 2007), but may favor other species that use human-created habitats or resources (Pérez-García et al., 2014). Also, hydrological and hydrochemical alterations can have opposite consequences to waterbirds. High water levels, for example, can make it difficult for small birds to land, rest and find food, while this same condition may provide advantages to diving birds (Navedo et al., 2012). High salinities may negatively affect growth and survival of some waterbird guilds due to problems associated with osmoregulation and feather damage (Rubega and Oring, 2004), although other guilds may be favoured by increased abundance of resources (Takekawa et al., 2006). High vegetation can have negative effects for wading birds and gulls by impairing prey detectability and site selection (Butler and Gillings, 2004; Tavares et al., 2013), but it constitutes a suitable habitat for other groups such rallids and ciconids (Jedlikowski et al., 2014; Tavares and Siciliano, 2013b). Finally, a clear positive relationship has been observed between wetland size, habitat heterogeneity and waterbird species richness and abundance (Elmberg et al., 1994; Rosselli and Stiles, 2012; Sebastián-González and Green, 2014).

Here we investigated the effects that a number of important environmental variables have on waterbird habitat use in tropical coastal lagoons. Since waterbird abundance represents a recognized metric for habitat use (Baschuk et al., 2012; Lunardi et al., 2012; Paracuellos and Tellería, 2004), we assessed the effects of hydrochemical, structural and anthropogenic factors on the abundance of different guilds. Specifically, we tested the expectation that different guilds should show specific responses to variations in water depth, vegetation height, lagoon size, water salinity, water pH, grazing pressure, and distance from human settlements (Cumming et al., 2012; Guadagnin and Maltchik, 2007; Pérez-Crespo et al., 2013; Sebastián-González and Green, 2014). Knowledge regarding the use of habitats by waterbirds is particularly poor in tropical and subtropical coastal systems, which harbor complex arrays of habitats and unique bird communities (Gianuca et al., 2014; Lunardi et al., 2012; Tavares and Siciliano, 2014a). Furthermore, we provided an evaluation of suitable habitat conditions, which may find useful applications for management purposes.

2. Materials and methods

2.1. Study site

This study was conducted in a chain of 22 tropical coastal lagoons, located along the coastline of northern Rio de Janeiro, southeastern Brazil (22°11′44″S, 41°26″03′W, Fig. 1A). The Restinga de Jurubatiba National Park includes eleven of the surveyed coastal lagoons (Caris et al., 2013). Almost all lagoons are characterized by shallow waters, average depth = 0.82 cm, and are relatively small in size, average size = 0.94 km^2 (Caliman et al., 2010). When considered together, they form a heterogeneous ecosystem with contrasting hydrochemical and structural attributes both in the spatial and temporal dimensions (Macedo-Soares et al., 2010; Tavares and Siciliano, 2013a). For example, two lagoons separated by a 300 m sandbar can have, respectively, salinity values of 15 ppt and 130 ppt during a severe dry period. This heterogeneity allowed us to account for a wide range of habitat variables. Note, however, that the orientation of the lagoons parallel to the coastline makes such variables relatively uniform within each lagoon (Di Dario et al., 2013; Kjerfve, 1994). These systems operate like intermittently open estuaries, remaining most of the time closed off from the sea, especially during low rainfall regimes (Whitfield et al., 2008). Such condition together with their small sizes, makes the lagoons particularly vulnerable to anthropogenic influences (Ortega-Cisneros et al., 2014). Two principal kinds of management activities are erratically conducted by local authorities and farmers in the study site (Caris et al., 2013): (1) sandbar opening to mitigate overflow and (2) drainage canals building to claim land for agriculture and pasture. Such activities cause broad shifts in the hydrochemical, structural, and spatial characteristics of the lagoons (Esteves and Suzuki, 2008; Santos et al., 2006).

2.2. Waterbird survey

We carried out point counts along the coastal lagoons, every month, between May 2012 and April 2013. Counts were performed every 1 km in the center of survey blocks. We considered 34 survey blocks distributed along a transect oriented linearly with the beachline (Bibby et al., 2000, Fig. 1B). Each block covered a semicircular visual field with 300 m fixed radius and the counting lasted no more than 5 min in order to reduce the probability of bird recount (Gregory et al., 2004). The data were collected always by the same ornithologist by means of spotting scope (20–60 × 80), binoculars (8 × 42), and rangefinder. The small size of the survey blocks and the low vegetation cover (average height = 0.13 m) reduced the survey error. Rails and Bitterns were not considered due to their low detectability with the adopted survey method (Conway and Gibs, 2005).

2.3. Waterbirds guilds

Waterbirds were grouped into guilds reflecting species' foraging habits and morphology, according to Tavares and Siciliano (2014b) and following the guild concept proposed by Blondel (2003). We identified six guilds: diving birds (grebes), dabbling ducks (belonging to the genera *Dendrocygna* and *Anas*), large wading birds (herons, egrets and storks), vegetation gleaners (jacanas and gallinules), fishing birds (gulls and terns) and small wading birds – also called shorebirds (mostly sandpipers and yellowlegs). The species observed within each guild and basic statistics are reported in Appendix A.

2.4. Habitat variables

We collected data on seven habitat variables at the end of each waterbird survey and for each sampling block. These variables were classified into three groups: (1) structural, i.e. vegetation height, lagoon size and water depth; (2) hydrochemical, i.e. water salinity and pH; (3) anthropogenic, i.e. livestock grazing pressure and distance from human settlement.

Vegetation height was estimated at each survey block using graduated sticks in three random locations. Mean values were considered for each survey block. The southern cattail (*Typha domingensis* Pers.) is the dominant plant species with height above 1 m. The effect of lagoon size on bird abundance was investigated using LandSat® imagery (available online at http://landsatlook.usgs.gov). Lagoon size was measured only for water covered surface, yielding a metric corrected by water availability (Sebastián-González and Green, 2014). Water depth was estimated as the mean between minimum water depth and maximum water depth, measured by means of fixed graduated sticks at, respectively, 1 m and 300 m from the lagoon shore.

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