Oceanological and Hydrobiological Studies

International Journal of Oceanography and Hydrobiology

Volume 52, No. 3 September 2023
pages (287-298)

sciendo

ISSN 1730-413X
eISSN 1897-3191

Effect of touristic activities on seabirds' habitat selection on sandy beaches

by

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DOI: **https://doi.org/10.26881/oahs-2023.3.03**
Category: **Original research paper**
Received: **February 24, 2023**
Accepted: **June 12, 2023**

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Abstract

Seabirds are biological models for habitat selection studies at different spatial scales. In general, seabirds select areas with a higher availability of prey, but human disturbances can modify their spatial and temporal foraging patterns in urban coastal ecosystems. Here we tested the hypothesis that human activities prevent seabirds foraging on beach sectors that are impacted by urbanization and recreational activities. Seabirds were counted while foraging at the interface between the surf zone and foreshore in three sectors with different levels of urbanization in southeastern Brazil. Physical variables, prey abundance, and human stressors, such as the number of people and dogs, were also measured. The brown booby *Sula leucogaster* foraged mainly in the least impacted sector, despite the lower abundance of prey and harsher physical conditions. The number of individuals of this species was negatively related to the number of people, indicating a human-induced avoidance behaviour. In turn, the kelp gull *Larus dominicanus,* a synatropic species, was more abundant in the high impact sector. Our results have implications for the management and conservation of sandy beaches, especially regarding the zoning and selection of priority areas for environmental protection and nature-based ecotourism activities.

Key words: Coastal birds; ecotourism; spatial distribution; anthropogenic impact

1. Introduction

The distribution of species at different spatial scales is the result of environmental filters and habitat selection, which is defined by an active choice for environments with optimal conditions within a range of ecological tolerance and by factors that meet species-specific demands for resources (Miller 1942, Jones, 2001, Fauchald, 2009). The selection of feeding habitats is controlled mainly by the trade-off between the availability of resources and antagonistic ecological interactions (Miller 1942, Skórka et al. 2009). According to the optimal foraging theory, behaviours that maximize energy intake and minimize the risk of predation perpetuate more frequently in birds' populations (Pyke 1984, Skórka et al. 2009). Thus, in a heterogenous landscape, experienced individuals tend to select habitat patches with greater intrinsic quality, i.e., those that offer a higher abundance of resources (Matsumura et al. 2011), although young birds can be unfamiliar with habitat quality (Skórka et al. 2016). However, ideal free distribution theory (IFD) predicts that patches with lower intrinsic quality but with lower population density and competition may be selected because the availability of resources per capita is higher (Fretwell 1969; Matsumura et al. 2011). Patches with lower quality can also be selected when either environmental or human factors inadequately signal a lower risk of predation and a higher availability of food, thus consisting in ecological traps (Sherley et al. 2017).

Seabirds represent model biological groups for the study of movement and habitat selection in marine ecosystems. They are among the most vulnerable groups of marine vertebrates, with metapopulations of more than 150 species currently showing declines globally (Paleczny et al. 2015). The selection of feeding habitats by seabirds is naturally controlled by the abundance of prey (Vilchis et al. 2006, Waggitt et al. 2018) but also comprises a mosaic of abiotic variables (Becker and Beissinger 2003; Meager et al. 2012). Human disturbances also affect the habitat selection of seabirds, especially because human activities are perceived as an additional risk of predation (Frid and Dill 2002). If critical habitats are disturbed to the point of limiting the use of that habitat for feeding and other activities, populations can decline due to losses in individual performance (Mallord et al. 2007).

Sandy beaches are coastal ecosystems that hold metacommunities formed by the association of resident species, mostly invertebrates and transient vertebrates (McLachlan and Defeo 2018). The oceanic limit of this ecosystem includes what is called the surf zone, which is an area where wave energy is dissipated and that is used especially by juvenile fish for shelter and feeding (Lasiak 1986; Olds et al. 2018). Beaches with more gentle hydrodynamics have a greater abundance and richness of practically all biological groups, including fish (Defeo et al. 2017; Olds et al. 2018; Esmaeili et al. 2021). Thus, organisms that prey on invertebrates and fish, such as seabirds, may also select beaches with lower wave action and a gentle swash regime to feed, taking on a bottom-up trophic control (Dugan et al. 2003; Lunardi et al. 2012). Similarly, human disturbances have depleted food resources and driven seabirds away, making the ecosystem inadequate for foraging (Meager et al. 2012).

The aim of this work was to identify the response of seabirds to human disturbances on sandy beaches – in southeastern Brazil. We tested the hypothesis that human disturbances prevent seabirds foraging in sectors impacted by recreational activities, regardless of the physical conditions and food availability.

2. Materials and methods

2.1. Study area

The study was carried out in three sectors (~ 500 m each) with different levels of urbanization and recreational activities in Praia Grande beach (-22.973209°S, -42.032621°W), the municipality of Arraial do Cabo, Rio de Janeiro, southeastern Brazil (Fig. 1). Praia Grande is recognized as one of the main tourist destinations in the region, receiving almost 500,000 tourists annually during the summer (Suciu et al. 2018). The beach also harbours a large amount of transient marine species, especially because it is directly influenced by a coastal upwelling and, consequently, has high levels of primary production (Tavares et al. 2016a).

The state of Rio de Janeiro has at least seven coastal islands where seabirds nest, including Ilha dos Franceses in Arraial do Cabo (Tavares et al. 2016a). This island has a high density level of brown booby *Sula leucogaster* (Boddaert, 1783) nests and is located 1,000 m away from the most urbanized sector of Praia Grande (Fig. 1) (Tavares et al., 2016b). Thus, the brown booby is the most abundant species in Praia Grande, followed by the kelp gull *Larus dominicanus* Lichtenstein, 1823, the frigatebird *Fregata magnificens* Mathews, 1914, the South American tern *Sterna hirundinacea* Lesson, 1831, and the neotropic cormorant *Nannopterum brasilianus* (Gmelin, 1789) (Rangel et al. 2020).

Along the beach arch, the high impact sector (HI) is characterized by a supply of tourism infrastructure,

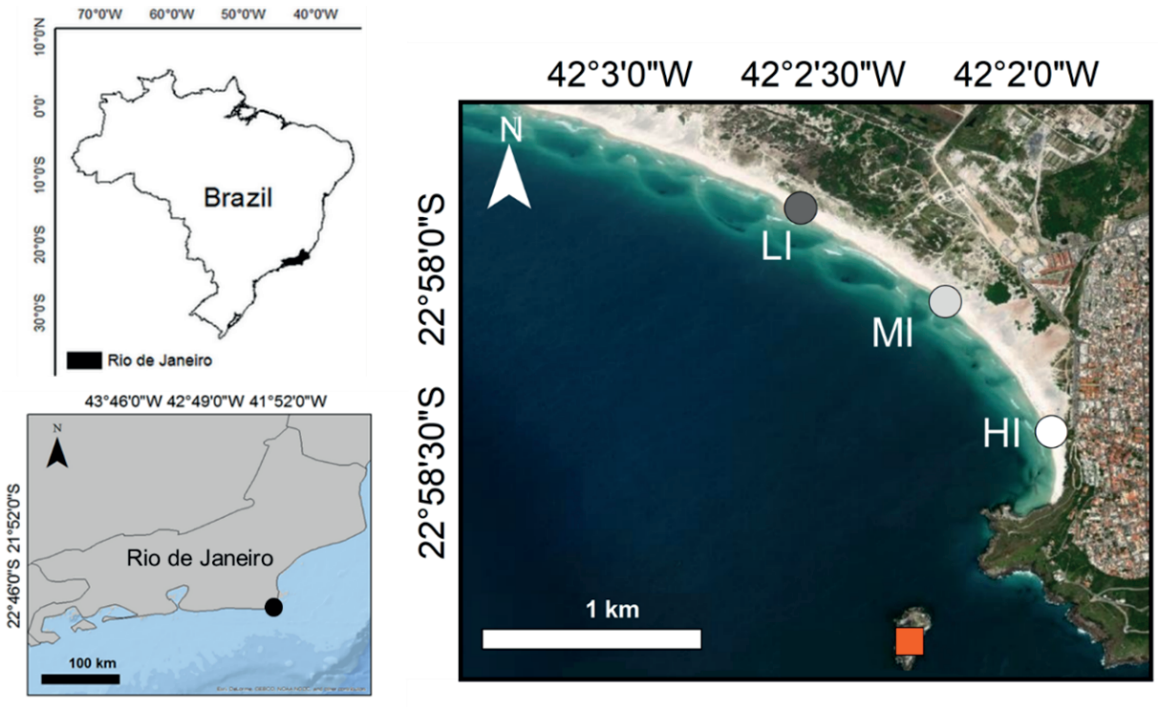

Figure 1

Map of the study area showing the high impact (HI), moderate impact (MI), and low impact (LI) sectors in Praia Grande, southeastern Brazil. The Ilha dos Franceses island (red square) is a nesting area for the brown booby *Sula leucogaster.*

easy access, a paved backshore, and disturbed dune vegetation (Costa et al. 2017b). Moreover, there is a high density of people (reported maximum of 625 people in 100 m^{-1} along the shoreface) and marine litter (reported maximum of 8 items m^{-2}) during the summer (Suciu et al. 2017). In turn, the low impact sector (LI) is of difficult access and there is no tourism infrastructure, while dune vegetation is well preserved and there are few people (reported maximum of 2 people in 100 m^{-1} along the shoreface) and low density of marine litter (~ 1 item m^{-2}) (Suciu et al. 2017). The moderate impact sector (MI) is located at the transition between the areas that have high and low impacts from urbanization and tourist activities (Suciu et al. 2017) (Fig. 1). All the sectors were sampled three times during the low tourist season (June to September 2015) and twice during the high season (January to March 2016).

2.2. Abiotic variables

The swash regime was determined considering the distance between the maximum reach and the water line (Sw = swash width) and by the time interval between the formation and end of each swash (St = swash time) (McArdle and McLachlan 1992). Wave height was estimated considering the distance between the ocean surface and the crest of the wave (Alves and Pezzuto 2009), using a person of known height as a visual reference (Costa et al. 2019). Water temperature was measured using a Horiba U-50 portable multiparameter device. Wind speed was determined in situ using an anemometer (AD-250, Instrutherm). A total of 10 samples were obtained for the variables mentioned in each sampling campaign.

2.3. Prey availability

Fish were collected from the surf zone (up to 1.5 m in depth) using trawls parallel to the water line that were standardized regarding their duration (Costa et al. 2017a). The trawls were carried out during the day and with a flood tide, using a beach trawl net measuring 25 m in length, 2.5 m in height, and with a mesh of 10 mm. The fish were fixed in 10% formalin, counted and identified using specific identification keys (Figueiredo and Menezes, 1978; Menezes and Figueiredo, 1980, 1985).

2.4. Seabirds

Seabirds were counted along the three sectors of different levels of urbanization and recreational activities during three days in a row (6:00 a.m. - 11:00

a.m.) over August, October, and November 2015, and in January and February 2016, totaling 15 reports. Three observation stations (50 m distant from each other) were sampled in each beach sector (HI, MI and LI) (600 m distant from each other) to estimate the abundance of foraging seabirds (Furnes and Monaghan, 1987; Bibby et al. 2000, Tavares et al. 2015). Ten minutes after the last station was sampled, a new sampling took place in the same stations but in the reverse direction. The seabirds were counted for three minutes at each station to avoid re-counting (Bibby et al. 2000). Only seabirds present between the surf zone (starting at where the wave crests began) and the swash zone at an angle of 90° and with foraging behaviour (visual search, diving, and swooping) were counted (Tasker et al. 1964).

2.5. Data analysis

The characterization of the HI, MI, and LI sectors regarding their abiotic, biotic, and human predictor variables was carried out using Principal Component Analysis (PCA). In this analysis, we opted to use the mean values and standard deviation for all variables per sector and sampling campaign, avoiding distortions to the scale of those with a variation in the number of observations.

The abundance of seabird species foraging between the surf zone and shoreface was compared between the sectors with different levels of human disturbance using linear mixed models. In these, the day of counting (survey = 5 levels) was included as a random variable. Linearity, homoscedasticity, and normality were tested in the models by the visual inspection of residuals. When the residuals presented a normal distribution, an Analysis of Variance (ANOVA) was applied. Only models adjusted for the brown booby and kelp gull had residuals with normal distribution; for the other species, Generalized Linear Mixed Models (GLMMs) with Poisson distribution were used.

The relationship between the abundance of foraging seabirds on the beach and abiotic, biotic, and human variables was tested using multiple linear regression models. In these, we opted to use the mean values for all variables per sector and sampling campaign, controlling the temporal autocorrelation of the number of birds foraging (dependent variable) and distortion of the scale of predictor variables. The collinearity between independent variables (swash width, swash time, wave height, water temperature, wind speed and fish abundance) was controlled using a Variance Inflation Factor (VIF); predictor variables with VIF > 3 were gradually removed from the models. The selection of the most parsimonious model based on a global model, with no collinearity detected through the VIF, was based on the Akaike information criterion for all possible combinations of the predictor variables (Appendix 1). Linearity, homoscedasticity, and normality were confirmed through the visual inspection of the models' residuals; an empirical transformation of the response variable was carried out when necessary to meet the assumptions of the linear regression.

3. Results

3.1. Abiotic characterization

All data are presented as the mean± standard deviation. The sector with high impact from urbanization and recreational activities was characterized by a lower wave height (42 ± 26 cm), longer swash time (10 ± 8 s) and swash width (9 ± 6 m), compared to the moderate impact sector (44 ± 19 cm, 5 ± 1 s, and 8 ± 2 m, respectively) and the low impact sector (54 ± 25 cm, 5 ± 1 s, and 7 ± 2 m, respectively) (Fig. 2). In the high impact sector, there was a greater number of domestic dogs (10 ± 8 per day) and people (120 ± 57 per day), compared to the moderate impact sector (8 ± 4 dogs and 21 ± 9 people per day) and the low impact sector (0 ± 1 dog and 11 ± 12 people per day) (Fig. 2).

3.2. Prey availability

The abundance (22 ± 35 individuals per trawl) and richness (3 ± 2 species per trawl) of fish in the surf zone were higher in the high impact sector, compared to the moderate impact sector (7 ± 16 individuals and 1 ± 1 species per trawl) and the low impact sector (4 ± 8 individuals and 2 ± 2 species per trawl) (Fig. 3).

3.3. Seabirds

Among the species of seabirds most frequently found in the surf zone, the brown booby was at least twice as abundant in the low impact sector (5 ± 4 individuals per count) in comparison with the high impact sector (2 ± 1 individuals per count) (Fig. 4A) (F_{ANOVA} = 21.419; $p < 0.001$). The same pattern was found for the South American tern occurring in flocks (see outliers Fig. 4D), though with no statistical support according to the Poisson GLM (*Chisq* = 3.079; $p = 0.214$). In turn, the kelp gull was significantly more abundant in the high impact sector, compared to the low impact sector (F_{ANOVA}= 8.734; $p < 0.001$). The frigatebird and

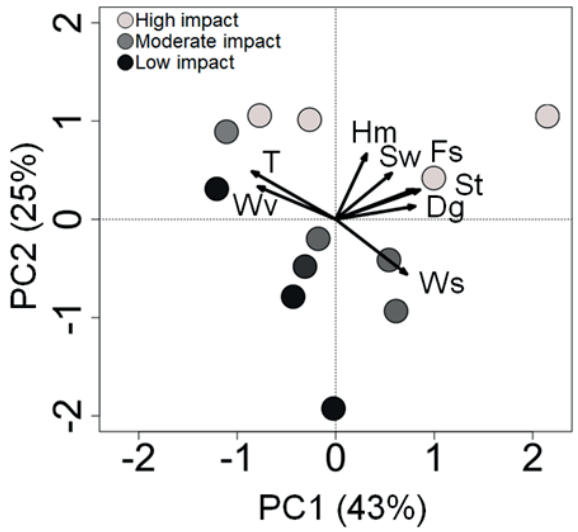

Figure 2

Principal Component Analysis (PCA) showing the abiotic and biotic characterization of the high, moderate, and low impact sectors in Praia Grande, southeastern Brazil. Wv = wave height; T = water temperature; Hm = number of people; Sw = swash width; St = swash time; Fs = abundance of fish in the surf zone; Dg = number of domestic dogs; Ws = wind speed.

the neotropic cormorant were infrequent and their abundance did not vary significantly among the sectors.

Multiple linear regression models were adjusted to test the effect of the biotic, abiotic, and anthropic variables on the number of individuals of the two most abundant species, the brown booby and the kelp gull, foraging on the beach. There were fewer brown boobies foraging in the presence of more people on the beach (t = -2.963; p = 0.018; $R2$ = 0.343; Fig. 5A) and in sampling campaigns with higher wind speeds (t = -2.231; p = 0.056; $R2$ = 0.252; Fig. 5B). The most parsimonious model including the abundance of the kelp gull as the response variable, resulted in having only the width of the swash zone as a predictor variable (t = 2.328; p = 0.044; $R2$ = 0.306). The larger the swash zone, the higher the number of individuals of this species foraging (Fig. 5C).

4. Discussion

The sector with the high impact from urbanization and recreational activities in Praia Grande has characteristics that theoretically make it a patch of higher quality for seabird foraging than the other sectors. There, the interface between the surf zone and

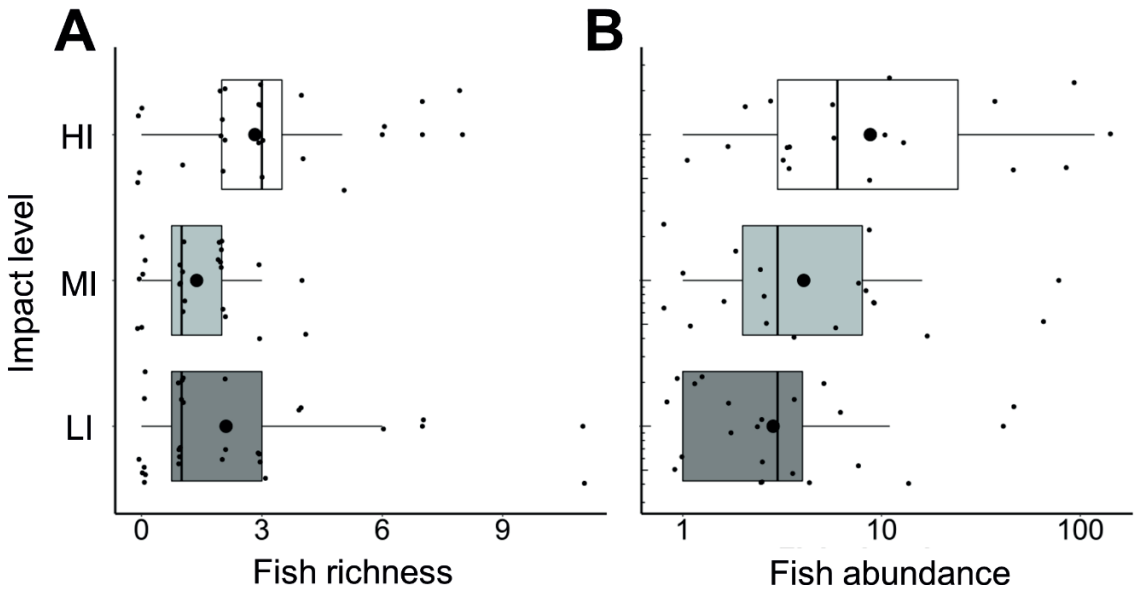

Figure 3

Number of species (A) and abundance of fish (B) in the surf zone of the high impact (HI), moderate impact (MI), and low impact (LI) sectors in Praia Grande, southeastern Brazil. The dispersed points represent trawls carried out twice during the high tourist season and twice again during the low season; the larger point within the box represents the mean values; the line within the box represents the median; the box represents the interquartile intervals.

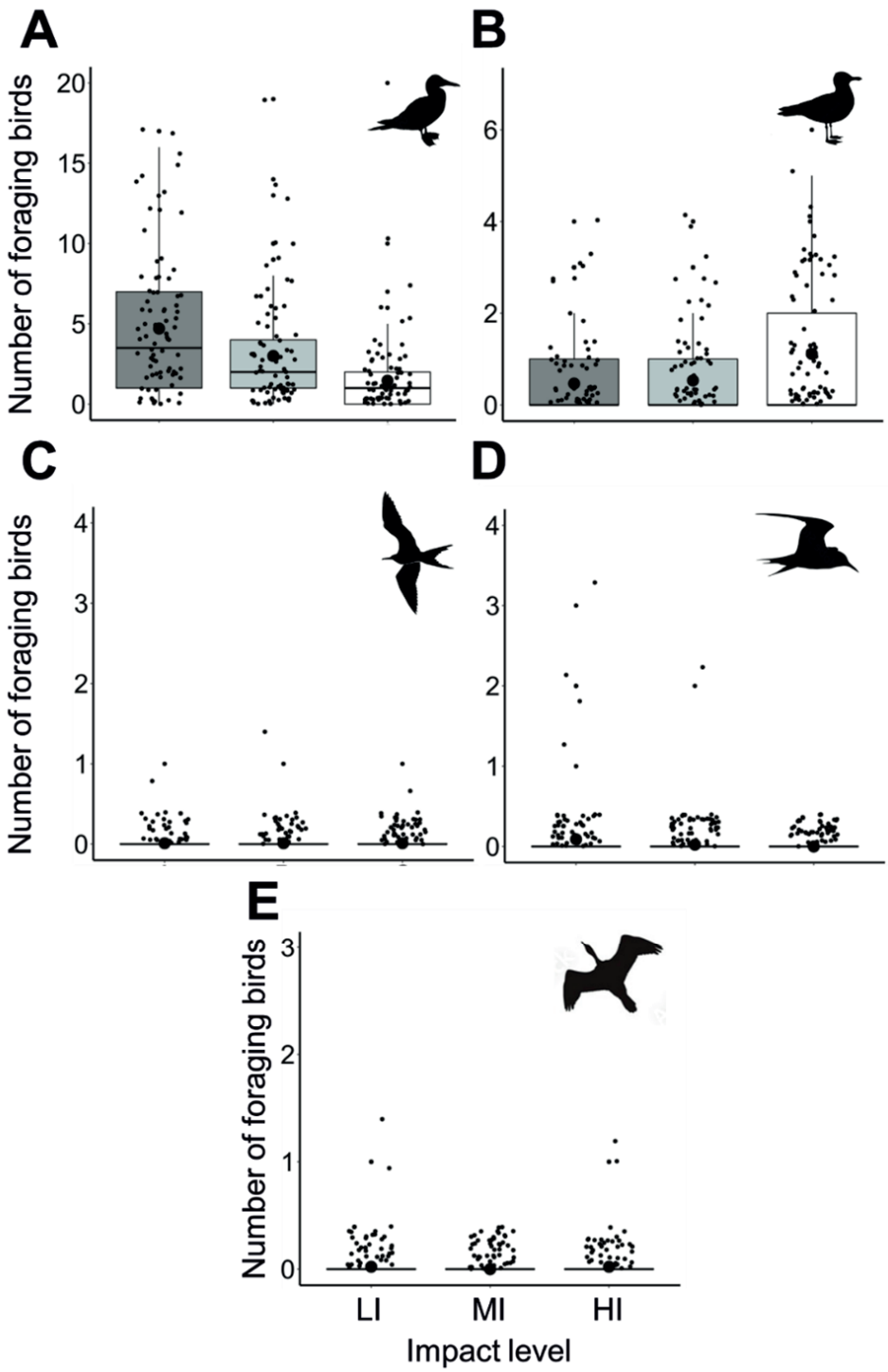

Figure 4

Number of foraging birds in the high impact (HI), moderate impact (MI), and low impact (LI) sectors in Praia Grande, southeastern Brazil. A: *Sula leucogaster*; B: *Larus dominicanus*; C: *Fregata magnificens*; D: *Sterna hirundinacea*; E: *Nannopterum brasilianus*. The dispersed points represent approximated values of the counting of birds with foraging behaviours; the larger point within the box represents the mean values per sampling day; the line within the box represents the median; the box represents the interquartile intervals.

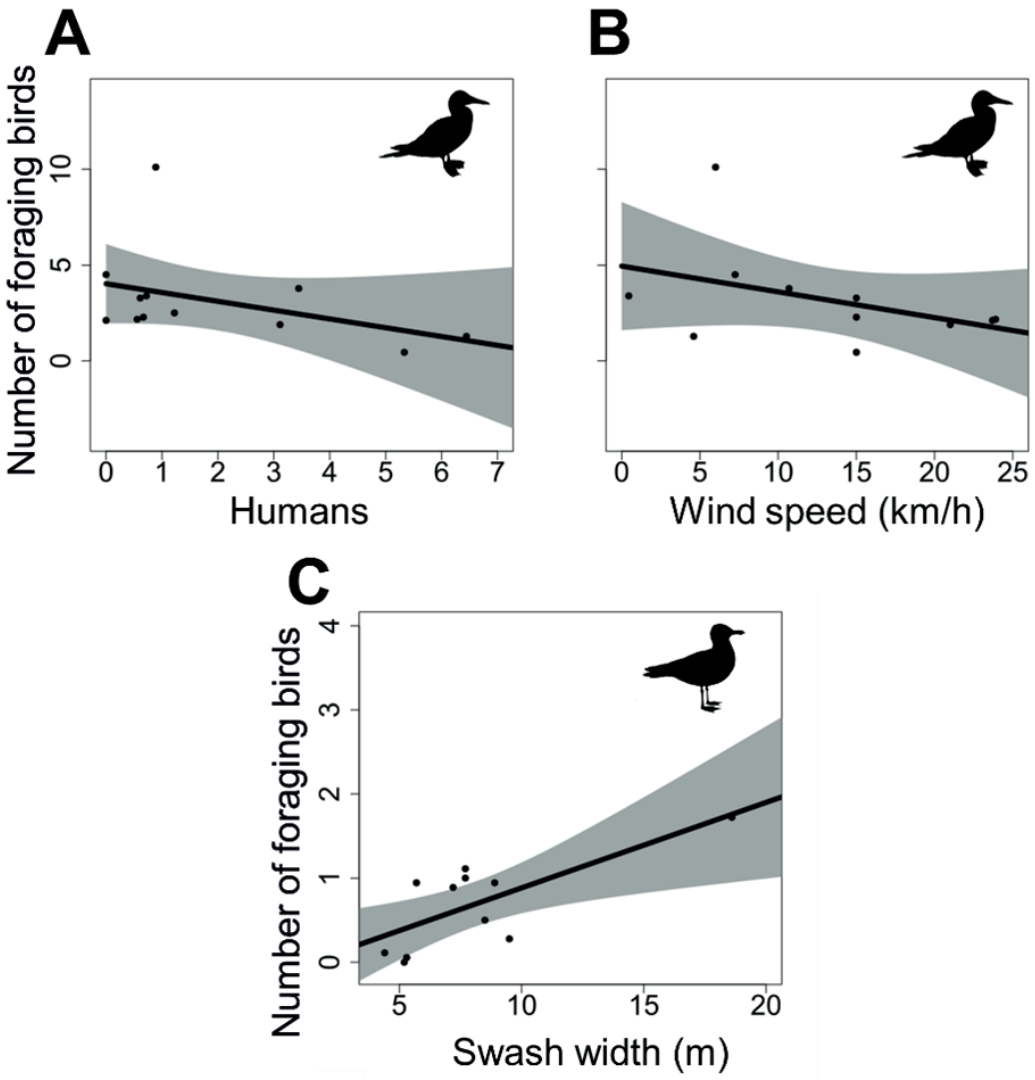

Figure 5

Relationship between the number of birds foraging in Praia Grande, southeastern Brazil, and predictor variables. A: *Sula leucogaster* and humans; B: *Sula leucogaster* and wind speed; C: *Larus dominicanus* and swash width (m). The points represent the mean values per sampling campaign and sector (high impact, moderate impact, and low impact).

shoreface is less physically harsh, due to the nearby rocky outcrops, thus presenting a lower wave action and a more gentle swash, for which reason there is a greater availability of food for piscivorous birds such as terns and the brown booby (Costa et al. 2017b). Our results suggest a chronic use of the habitat in sectors with lower resource abundance and further from nesting islands, especially by the brown booby. Thus, the results for this species corroborate the hypothesis that human disturbances regulate the use of the habitat by seabirds at fine scales.

The greater effort to search for prey in patches with less availability of resources and further away from brown booby colonies seem to contradict the optimal foraging theory. Moreover, the increased number of people on the beach showed a linear negative relationship with the foraging activity of the species, evidencing an avoidance behaviour. Similarly, Velando and Munilla (2011) observed that an increase in boat traffic around islands of the Iberian Peninsula resulted in a substantial decrease in the foraging activity of the European shag *Phalacrocorax aristotelis* (Linnaeus, 1761), excluding individuals from optimal feeding grounds. This higher use of energy may result in decreased body condition among reproductive females and lower success rates among offspring

(Graña et al. 2018). Even subtle variations in fecundity and in the success of the offspring can trigger a long-term reduction in the size of populations (Chastel et al. 1995).

The aggregation of individuals in areas with lower availability of resources per capita, though with less human disturbance, may produce a negative density dependence due to the competition in areas with lower carrying capacity. This demands an even greater displacement of birds to other habitat patches that are further away from the colony (Weimerskirch et al. 2007). This displacement that depends on either the density or level of human disturbance into the lower-quality patches is similar to the premise of the ideal free distribution theory (IFD), as proposed by Velando and Munilla (2011). Seabirds are mobile and freely select habitats, which makes them interesting study models for the IFD, especially on beaches that are apparently homogeneous systems. However, studies that measure individual fitness and energetic balance are needed to confirm if the cost-benefit of the selection of areas with different intrinsic qualities is comparable, corroborating the IFD. In addition, the chronic avoidance of urban coastal environments with high food availability can represent a typical ecological trap (a low-quality habitat that animals prefer over other available habitats of higher quality) (Battin 2004).

The implications of seabird species selecting lower quality habitat at a fine scale are, nevertheless, controversial. The species are highly mobile, which could make the choice for feeding grounds that are located a few kilometers away from their nesting islands irrelevant for their body condition (Weimerskirch 1998). Moreover, the availability of fish in the low impact sectors, including in areas other than the surf zone, may be sufficient to meet the caloric needs of the birds and compensate their displacement. However, brown boobies foraging on sandy beaches do not seem to meet their preference for larger pelagic prey (Branco et al. 2005), since the surf zone is inhabited mostly by small juvenile fish (Lasiak 1986). Thus, it is possible that fish from the surf zone near the nesting islands are in fact captured to feed chicks (Lewis et al. 2004). According to Lewis et al. (2004), the distance, frequency, and duration of the displacement of brown boobies in search of food are strong indicators of the age of their offspring. As their young grow, solitary displacement becomes more frequent and long-lasting, due to a perceived lower risk of chick predation (Lewis et al. 2004). Thus, Praia Grande seems to be a decisive habitat for the recruitment success of the brown booby. The search for scarcer food in more distant areas from the colony, induced by human pressure, can therefore result in a cascading loss in body condition among the reproductive pairs responsible for parental care and among their offspring, thus also affecting their future reproductive success (Lewis et al. 2004).

Temporal variation in the use of beaches, near the colony, for seabird feeding can thus be closely linked to periods of nesting, recruitment, and feeding offspring. In tropical regions, the tendency is that metapopulations show a similar contribution of offspring and reproductive adults throughout the year, suppressing possible temporal variations in foraging for this reason. Here we observed that fine-scale temporal variation of habitat selection was related to the wind speed. The higher the wind speed, the lower the number of brown booby individuals foraging on the beach. The brown booby has relatively low wing loading; thus, flight stability and prey detection are hindered by strong winds, leading to lower foraging rates on the beach (Yamamoto et al. 2017). This individual attribute probably makes boobies more susceptible to climate change, since an increase in the frequency and intensity of extreme events has been observed globally (Harley et al. 2006).

Refuting the hypothesis that human disturbances negatively affect the foraging of seabirds on the beach, the kelp gull was generally more abundant in the sector with higher impact from urbanization and recreational activities. This species is known to be synanthropic, tolerating human presence, besides feeding opportunistically on human food subsidies (Duhem et al. 2003; Maciusik et al. 2010). Studies across the globe have observed for decades an increase in the population size of gulls in urban areas due to the higher availability of human food (Goutner 1992; Bosch et al. 1994; Vidal et al. 1998; Spelt et al. 2021). On the other hand, negative effects in fecundity, reproductive success, and behaviour among gulls, which may become reliant on the trophic subsidies from beach visitors, have also been reported (Bosch et al. 1994; Orams 2002; Ramos et al. 2009). Moreover, species that are sensitive to human presence and that coexist with gulls may be competitively excluded from areas with a high availability of human food (Ramos et al. 2009). In the region, feeding seabirds on purpose is considered a relevant tourism activity, with gulls seeking food from visitors' hands, which also justifies the aggregation of these birds on urban beaches. The socioecological implications of this practice are controversial and need to be better studied, seeking adequate management (Orams 2002; Newsome and Rodger 2008).

The number of kelp gulls foraging on the beach was positively related to the size of the swash. In fact, the high impact sector was characterized by gentler

physical conditions, which, added to urbanization, could favour habitat selection in the case of this synanthropic species. The close relationship between biotic systems and physical conditions determines the classical ecological hypothesis and theories of sandy beaches (McLachlan and Defeo 2018). In general, a higher richness of bird communities and size of populations on beaches are attributed to a gentler swash regime, which acts as an environmental filter for habitat harshness (McLachlan and Defeo 2018; Costa et al. 2022b). Under more severe physical conditions, species with low tolerance levels are excluded and, those that establish populations, tend to be less abundant and more sensitive to human disturbances due to the individual energy budget that is directed for survival to the detriment of growth and reproduction (Mclachlan et al. 1993; Defeo et al. 2003; Costa et al. 2022a). These relationships have been tested through observational studies, mainly with sedentary invertebrates, while studies on the active selection of habitats by birds are still incipient (Rangel et al. 2022).

The present study offers an important baseline for investigations on a larger spatial scale regarding the use of beaches and habitat selection by transient species, particularly when beaches are near to seabird breeding islands. Regardless of the limited spatial scale and absence of replicas of urbanization levels, our results have numerous implications for the management and conservation of sandy beaches at local and regional scales. First, birds have a higher conservation appeal than invertebrates (Miralles et al. 2019), which despite these biological groups being more studied and abundant on beaches, does not gain so much interest from the population (Schlacher et al. 2008; Harris et al. 2014). Thus, the choice of priority areas for conservation and beach zoning based on bird habitat selection data, including species that are endangered and considered charismatic, will certainly receive greater support from the general public and decision makers (Maguire et al. 2011). Moreover, controlled ecotourism activities in urban areas, such as birdwatching, can surely contribute to the development of a biocentric behaviour and to the support of local environmental education projects, in addition to enabling opportunities for local economic activities and citizen science (Veríssimo et al. 2009; Fanini et al. 2021). Obviously, activities such as birdwatching and even feeding of synanthropic birds must be supported by previous studies that evaluate their ecological implications on individuals and ecosystems (Newsome and Rodger 2008.

In conclusion, the fine scale habitat selection carried out by the most abundant seabirds in the study area was regulated mainly according to the impact of urbanization and recreational activities. Human disturbance suppresses the brown booby's use of the habitat patches with more food resources and that are closer to nesting islands. In turn, synanthropic species such as kelp gulls aggregate in areas with greater human presence, benefitting from gentler hydrodynamics. Here we suggest the use of seabirds as study models for the classical hypotheses that determine sandy beach ecology and habitat selection. This recommendation is based on the potential of these birds to support conservation projects and gain community support through environmental education actions, ecotourism, and citizen science. This can be a viable solution for the development of a biocentric perspective on sandy beaches, going beyond the delivery of ecosystem services related exclusively to recreation.

Acknowledgments

We thank Dr. Davi Castro Tavares who assisted in the experimental design and data collection of seabirds. LLC is supported by Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro — FAPERJ (E-26/200.620/2022 and E-26/210.384/2022). IRZ is supported by FAPERJ (259920/2021) and the Brazilian Agency for Research Development — CNPq (301203/2019-9).

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