AVIFAUNA ASSOCIATED WITH AN OTTER-TRAWL FISHERY IN A TROPICAL ESTUARY

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ABSTRACT

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Otter trawls are commonly used in fisheries for benthic fishes, and they provide a source of food to many marine birds. This study aimed to quantify the response of birds, by species, attracted to forage at fishing vessels in Ribeira Bay, Angra dos Reis, Rio de Janeiro, Brazil. Sampling was conducted every two months in 2006 at five stations, for a total of 30 trawls; fish were collected for 20 minutes per trawl. Bird counts were recorded just before the trawling started, when it began, 10 minutes after trawling began, and 10 minutes after it stopped. After trawling, 10 fresh dead fish were released into the water, and we recorded the number of successful and unsuccessful attacks. Our 224 observations included eight bird species; three species—Magnificent Frigatebird *Fregata magnificens*, Neotropic Cormorant *Phalacrocorax brasilianus*, and Great Egret *Ardea alba*—accounted for 68.3%, 10.7%, and 5.8% of the records, respectively. Scoring highest in a Frequency of Occurrence Index were the Magnificant Frigatebird, South American Tern *Sterna hirundinacea,* and Brown Booby *Sula leucogaster*, with 75%, 30%, and 25%, respectively. When trawling started, 21% of the eventually recorded birds approached the boat, but after 10 minutes, they dispersed. After trawling stopped, 77% of the eventually recorded birds approached. Most attacks on discarded fish were performed by frigatebirds (79%), which were also the most efficient in getting fish (83%). Our results emphasize the important association of frigatebirds with trawling, in accord with its kleptoparasitic mode of foraging.

Key words: aquatic birds, Brazil, fishing offal, frigatebird, Neotropic Cormorant, trawling

INTRODUCTION

Otter trawls are used worldwide (McHugh *et al.* 2017, Currie *et al.* 2019, Wang *et al.* 2020), landing millions of tons of fish each year (Amoroso *et al.* 2018). While it captures the target fish, trawling also captures non-target species, which are discarded as waste. Several seabird species eat the discarded bycatch (Cianchetti-Benedetti *et al.* 2018), including benthic or demersal fishes that are not otherwise available (Karris *et al.* 2018). This kind of human activity may influence marine avifauna in several ways, such as increasing competition for food among species, increasing their diet spectrum, and influencing seabird populations via the low nutritional value of the discarded fish (Hudson & Furness 1989, Benemann *et al.* 2016). The increase in food resources may be an important factor in the distribution and abundance of seabirds in some areas (Real *et al.* 2017).

Several taxonomic families have been recorded following trawl vessels (Branco 2001, Branco *et al.* 2006, Grémillet *et al.* 2008, Benemann *et al.* 2016, Karris *et al.* 2018), most commonly Laridae, Fregatidae, Phalacrocoracidae, and Sulidae (Branco *et al.* 2006). Several species of fregatids, which are regularly kleptoparasitic and feed directly on pelagic schooling prey (Austin *et al.* 2019), are often seen feeding on fishing waste (Branco *et al.* 2006). Other seabirds also forage on fishery waste, especially those that do not dive in search of prey (García *et al.* 2020). However, there are no reports that quantify the efficiency of discarded fish capture by birds or that identify which species are most successful in foraging for discarded fish during or after trawling. The objective of our study was to assess these aspects of avian association with an otter trawl fishery.

METHODS

Study site

We conducted our experiments in Ribeira Bay, located at Angra dos Reis in southern Rio de Janeiro, between 22°55′S and 23°02′S and between 044°18′W and 044°26′W. Sampling was conducted at five sites: (1) Japuíba Cove, northeastern Ribeira Bay with surrounding mangrove vegetation, maximum depth 7 m; (2) Ariró and Imbu coves near Caierira and Comprida islands, maximum depth 10 m; (3) Bracuí Cove, maximum depth 6 m with inflow from five rivers, and including Palmeira, Comprida, and Cunhambebe Grande islands; (4) Saco Piraquara de Fora, where waters that cool the reactors of the Almirante Álvaro Alberto thermonuclear plant (on Angra Island) are discharged, maximum depth 11 m; and (5) the entrance channel to the bay, near the Ponta Grossa, Tucum, Brandão, and Pau a Pino islands, maximum depth 23 m (Fig. 1).

Trawling is forbidden in Ribeira Bay (Joventino & Johnsson 2018), but illegal industrial fishing occurs (Joventino *et al.* 2013). Besides illegal fishing, other fishing gear is used by traditional people, like gill nets, beach seines, and boat seines (Joventino & Johnsson 2018).

Bird observations

Our study was conducted during 2006 in alternate months. We eventually sampled during six months with one trawl conducted per study site, acquiring 30 samples. Trawling lasted 20 minutes per sample, for a total of 600 minutes. Fish were caught using a fishing boat (9.30 m in length) with an otter trawl (body panel mesh: 20 mm; cod end mesh: 15 mm) at a speed of 2 kts (~3.7 km/h, see Andreata *et al.* 1994). Birds were counted by eye and binoculars (8×40) from the stern of the vessel within a ~200 m radius. Records were made in 10-minute bins: before trawling began, at the beginning of trawling, during trawling, and after trawling stopped.

Foraging success experiments

After counting birds, we experimentally discarded 10 fresh dead fish of the species *Diapterus rhombeus* (juveniles, ~100 mm total length) and recorded the number of avian attempts to secure the fish, as well as success or failure, over 10 minutes. This fish species has been recorded as prey of the Pelagic Cormorant *Phalacrocorax pelagicus*, a small cormorant species, indicating suitability even for small birds. We chose *D. rhombeus* because it is a species that is frequently discarded in shrimp fisheries (Vianna *et al.* 2004) and because it is abundant in Ribeira Bay (Andreata *et al.* 2002). Counts were made in calm conditions (0–2 Beaufort scale) and without other vessels around. The same boat was used throughout the study.

Results related to variation in bird abundance before, during, and after trawling were analyzed via Kruskal-Wallis test (one-way ANOVA) and Dunn's Multiple Comparisons test to check for significant differences between all possible pairs. A Frequency of Occurrence Index was calculated to determine species prevalence. A Foraging Success Index (FSI; Garthe & Hüppop 1998) was used to identify which bird species were most associated with discarded fish; this index was calculated according to

$$\log\left[\frac{\textit{percent of all fish swallowed by a species}}{\textit{percent of all birds of this species that followed the boat}}\right]+1$$

Fish attack success was analyzed by the number of attempts made by a bird to secure a fish divided by the number of fish swallowed. Rarefaction analysis was used to compare sites. The α was 0.05, and data were expressed by percentage or mean ± standard deviation.

RESULTS

We conducted 30 trawls and noted eight aquatic bird species in a total of 224 records. The maximum number of records during a given trawl was 56 individuals, which included several species. The bird species recorded during trawling were Magnificent Frigatebird *Fregata magnificens*, Neotropic Cormorant *Phalacrocorax brasilianus*, Snowy Egret *Egretta thula*, Great Egret *Ardea alba*, South American Tern *Sterna hirundinacea*, Royal Tern *Thalasseus maximus*, Brown Booby *Sula leucogaster*, and

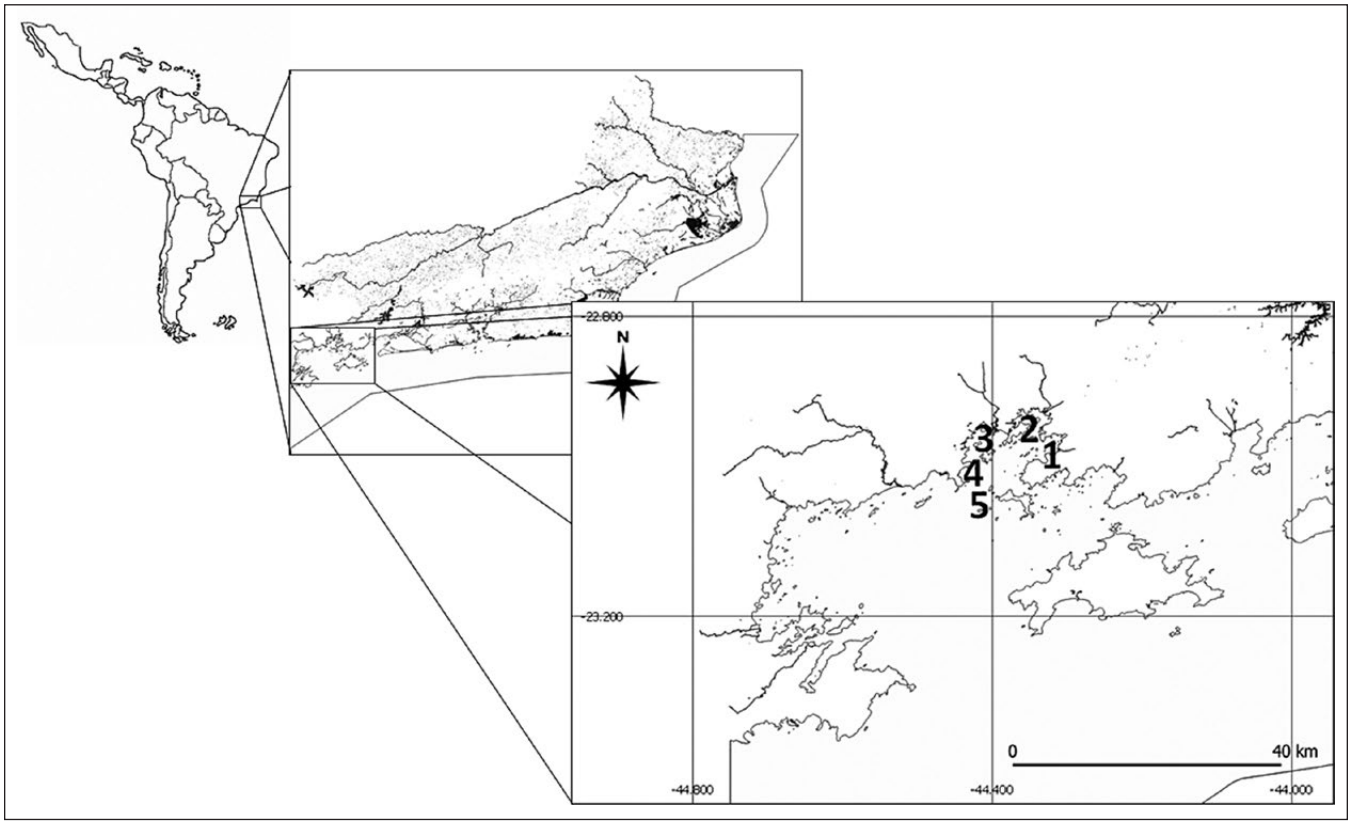

Fig. 1. Study sites in Ribeira Bay, Angra dos Reis, Rio de Janeiro, Brazil: 1) Japuíba Cove, 2) Ariró Cove, 3) Bracuí Cove, 4) Saco Piraquara de Fora, 5) entrance of the bay.

Kelp Gull *Larus dominicanus*. Among these species, Magnificent Frigatebird was the most often observed (68.3%, *n* = 153), followed by Neotropic Cormorant (10.7%, *n* = 24) and Great Egret (5.8%, *n* = 13). Remaining species made up less than 5% of observations. The species with the largest Frequency of Occurrence Index was Magnificent Frigatebird at 75%, followed by South American Tern at 30% and Brown Booby at 25%. The frequency of the remaining species together was ~5% (Table 1).

The site with the greatest species richness associated with trawling was Site 2 with six species, followed by Site 5 with five species; only two species were observed at each of the other sites. The site with the largest abundance was Site 5 with a mean of 19 ± 5 individuals, followed by Site 2 (18 ± 7 individuals) and Site 4 (10 ± 6 individuals). Site 3 had the smallest mean abundance with 2 ± 1 individuals (Table 2).

Before trawling started, no bird was seen following the vessel. When the net was deployed, birds approached, representing 21% (*n* = 62) of individuals observed during each trawl (3.26 ± 7.74). Only two species occurred during deployment: Magnificent Frigatebird was the most frequent (65%, *n* = 19) and the most abundant (90%, *n* = 39), while Brown Booby represented 10% (*n* = 6) of the birds and was rare (10%, *n* = 3). After the first 10 minutes, Brown Boobies dispersed (relative abundance: 2%, *n* = 6; 0.31 ± 0.94) and only Magnificent Frigatebirds followed the vessel during two of the trawls, with 3 individuals per trawl. By the end of the trawling, when fish were brought to the boat, relative abundance of all birds rose to 77% (*n* = 224, 11.78 ± 18.12 individuals; Fig. 2). Magnificent Frigatebird and Brown Booby were again the only species present at this stage of the trawl, with the same frequency but different abundance: Magnificent Frigatebird at 79% (*n* = 121) and Brown Booby at 21% (*n* = 46). Differences were statistically significant between the four observation periods (KW = 35.641; *df* = 59; *P* < 0.001). According to Dunn's test, significant differences were noticed between the following pairs: before × beginning, before × after, and during × after (Table 3).

Magnificent Frigatebird made the most attempts to secure fish, representing 79% (*n* = 46) of the total attacks with a success rate of 83% (*n* = 38). Brown Booby and South American Tern each executed 7% (*n* = 4) of the total attacks with a success rate of 0% (*n* = 0) and 50% (*n* = 2), respectively. Snowy Egret represented 5% (*n* = 3) of attacks with no success (0%; *n* = 0) and Great Egret represented 2% (*n* = 1) of attacks with success of 100% (*n* = 1). The Foraging Success Index also pointed to frigatebirds as being

TABLE 1
Relative abundance, frequency of occurrence, and total number of individual seabirds recorded as associated with trawling in Ribeira Bay, Angra dos Reis, Rio de Janeiro, Brazil

Species	Relative abundance (%)	Frequency of occurrence (%)	Total (*n*)
Fregata magnificens (Magnificent Frigatebird)	68.3	75	153
Phalacrocorax brasilianus (Neotropic Cormorant)	10.7	5	24
Egretta thula (Snowy Egret)	2.7	5	6
Ardea alba (Great Egret)	5.8	5	13
Sterna hirundinacea (South American Tern)	5.4	30	12
Thalasseus maximus (Royal Tern)	1.8	15	4
Sula leucogaster (Brown Booby)	4.9	25	11
Larus dominicanus (Kelp Gull)	0.4	5	1

TABLE 2
Mean, maximums and minimum species richness and abundance of seabirds related to trawling in Ribeira Bay, Angra dos Reis, Rio de Janeiro, Brazil

Sampling site	Mean richness (max,min)	Mean abundance (max,min)
Site 1	1 (2,0)	5 (6,0)
Site 2	2 (6,0)	18 (24,0)
Site 3	1 (2,0)	2 (3,0)
Site 4	1 (2,0)	11 (21,0)
Site 5	3 (4,2)	19 (30,1)

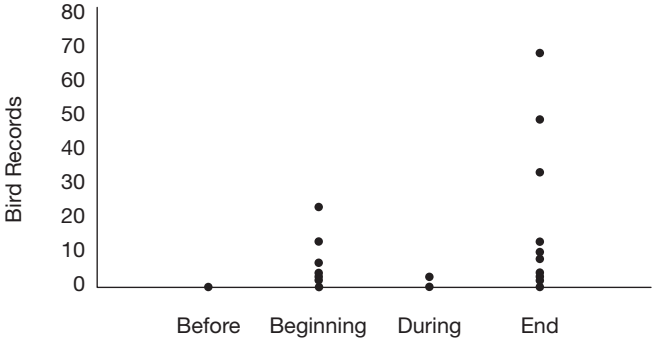

Fig. 2. Number of birds associated with the fishing boat before trawling began (Before), immediately after trawling began (Beginning), 10 minutes after trawling began (During), and 10 minutes after the trawl ended (End) in Ribeira Bay, Angra dos Reis, Rio de Janeiro, Brazil.

TABLE 3
Dunn's Multiple Comparisons Test applied to different periods in the experiments: before the beginning of trawling (Before), at the beginning of trawling (Beginning), during trawling (During), and after the end of trawling (End) in Ribeira Bay, Angra dos Reis, Rio de Janeiro, Brazil

Periods compared	*P*
Before × Beginning	< 0.001*
Before × During	> 0.05
Before × End	< 0.001*
Beginning × During	> 0.05
Beginning × End	> 0.05
During × End	< 0.001*

the most successful species (FSI = 1.989), followed by Neotropic Cormorant (FSI = 1.184), Great Egret (FSI = 0.918), South American Tern (FSI = 0.883), Brown Booby (FSI = 0.846), Snowy Egret (FSI = 0.582), and Royal Tern (FSI = 0.406). Kelp Gull had a negative Foraging Success Index (FSI = –0.195). All the attacks were observed on fish floating on the surface; no fish sank during our observations.

DISCUSSION

Birds observed in the present study exhibited conditioned behaviors associated with otter trawl fishing. A total of eight species were recorded, aligning with studies by Wickliffe & Jodice (2010) in South Carolina, USA, and Branco (2001) in Santa Catarina, Brazil, who also recorded eight species each. Other studies recorded more species, such as reported by Branco *et al.* (2006) with 14 in Santa Catarina and Blaber *et al.* (1995) with 12 species at Australia's Great Barrier Reef. The species number may vary according to year, season, and region, since bird abundance and occurrence is usually related to the life cycle, season, population size, and year (Branco *et al.* 2001).

The greatest species richness (6) was reported at Site 2, near the mangroves. Mangroves shelter several bird species and some of them may be opportunistic feeders, such as the Great Egret, Snowy Egret, and Neotropic Cormorant (Mancini *et al.* 2018). Site 5 at the bay entrance also had many species associated with trawling. Many seabirds nest on islands in this area, with the avifauna of neighboring bays also contributing. However, there are records of only Kelp Gull (Ornellas & Ornellas 2011) and Magnificent Frigatebird (Alves *et al.* 2004, Ornellas & Ornellas 2011) nesting in the islands of Ilha Grande Bay.

The increase in the abundance of birds when nets were deployed indicates a highly conditioned behavior associating otter trawls with easy food (Krull 2004, Louzao *et al.* 2006). The high abundance of Magnificent Frigatebird is in accord with its surface and kleptoparasitic foraging style. The intense association of this species with otter trawl fisheries has also been recorded by Barbieri (2010) off the coast of São Paulo. This species executed complex maneuvers, gliding or even descending quickly with synchronized movements between wings and tail to obtain fish (Diamond & Schreiber 2002).

The association of aquatic birds and otter trawl fishing is common, and there are several reports of birds being caught accidentally in the nets (Williams 1996, Pierre *et al.* 2010). Croxall (2008) estimated an annual mortality of 31 000 marine birds related to otter trawl fishing. The present study showed that Magnificent Frigatebird was the most efficient species in terms of prey capture, and therefore the bird with the largest associated risk. But it has no diving capacity, which reduces its probability of being caught. During our study, no bird got stuck in the net or was hurt. Although the association between avifauna and trawling has been frequent and intense in the sampling sites, and with birds conditioned to approach during net release and recovery, risks should not be high.

While obtaining bycatch might represent a smaller risk for the Magnificent Frigatebird, there are other issues to consider. The fishery waste is an alternative food source and seabirds might benefit from its provision. Theoretically, birds could feed on fishery waste and spend less energy, but Grémillet *et al.* (2008) reported that not all birds experience benefits. The low nutritional food provided by discarded bycatch might be beneficial for non-breeding Cape Gannet *Morus capensis*, as noted by those authors, but breeding animals must feed their chicks high-quality prey. If high-quality resources are scarce, they fail to sufficiently provision their chicks. Therefore, the association of seabirds with fisheries should continue to be studied in more detail.

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