



Foraging habitats of roseate and common terns in the South American wintering grounds[☆]

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ABSTRACT

The roseate (*Sterna dougallii*) and common (*S. hirundo*) terns are transhemispheric migratory seabirds with wide global distribution. North American populations migrate to South America, but their ecology during the wintering period has been poorly understood, particularly for the threatened roseate tern. In this study, we investigate the movement ecology from roosting sites to feeding grounds of roseate terns in northeastern Brazil and common terns in Argentina, during the non-breeding period. In total, 53 roseate and 51 common terns captured and radio-tagged with VHF transmitters from 2001 to 2003 were aerial tracked with a high wing Cessna 172 airplane equipped with two Advanced Telemetry System antennas. During aerial tracking flights, radio tagged terns were observed in flocks of up to at least one thousand individuals feeding offshore. Birds were also observed using oil platforms and interacting with fishing vessels. Tracking results revealed contrasting offshore foraging areas between common terns in Argentina and roseate terns in Brazil, with terns in Argentina predominantly detected nearshore, mostly within 10 km of the coast and over the 20 m isobath. In contrast, roseate terns in Brazil were detected at distances considerably farther from shore (20–50 km) and predominantly occupied deeper offshore waters beyond the 1000 m isobath. Information obtained in this study fills important gaps in knowledge about non-breeding season foraging movements for roseate and common terns. Despite the impossibility of a direct spatial or interspecific comparison, these ecological differences emphasize the need for species and region-specific monitoring programs to inform conservation planning and impact assessments.

1. Introduction

Understanding the patterns of habitat use by organisms is fundamental to the development of effective conservation strategies (Harrison et al., 2018; Karp et al., 2025; Robinson et al., 2017). For migratory seabirds research efforts traditionally focused on studies during the breeding periods, where generally the predictability of birds' presence and concentration in colonies facilitates capture, sampling and monitoring (e.g. Gianuca et al., 2019; Hughes et al., 2017). In contrast, during the wintering period, seabirds tend to be more dispersed across vast marine areas and have received comparatively less attention (Arneill et al., 2019; Davies et al., 2021; Frederiksen et al., 2012). This imbalance results in large gaps of knowledge regarding biological

requirements of migratory marine birds during the non-breeding season (Barrett et al., 2007; Carneiro et al., 2020; Croxall et al., 2012) even for seabird species extensively studied in the Northern Hemisphere. Importantly, conditions during wintering can potentially impose carry-over effects, and influence survival and reproductive success in subsequent breeding seasons, reinforcing the need for studies and conservation efforts that consider the population's year-round distribution (e.g. Catry et al., 2013; Sorensen et al., 2009).

Common (*Sterna hirundo*) and roseate (*S. dougallii*) terns breed sympatrically in the Northern Hemisphere (Arnold et al., 2020; Burger and Gochfeld, 1991). Both are migratory seabirds with wide distribution across the globe and similar ecological requirements. A portion of the North American common tern populations, estimated at around

[☆] This paper is dedicated to the late Helen Hays, chair of the Great Gull Island Project for over fifty years. Her vision inspired this research; her leadership made it happen.

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100,000 pairs on the Atlantic Coast (Arnold et al., 2020), migrates along the north and east coasts of South America, wintering in large numbers with thousands of individuals reported in southern Brazil (Bugoni and Vooren, 2004; Resende and Leeuwenberg, 1987) and Argentina (Hays et al., 1997; Lima et al., 2005; Mauco et al., 2001). On the wintering grounds, almost all juvenile common terns stay in northeastern Brazil, or in northern areas (Daudt et al., 2019), including Suriname and Guyana (Blokpoel et al., 1982, 1984; Hays et al., 1999), while many adults go on to southern Brazil and Argentina (Hays et al., 1997). Common terns start arriving on southern wintering grounds by late August and early September and some do not depart until early May (Bracey et al., 2024; Bugoni and Vooren, 2005). During the non-breeding period, common terns roost on the coast near foraging grounds, and have fish-based diets (e.g. Bugoni and Vooren, 2004; Mauco and Favero, 2005). Off the coast of Brazil, common terns primarily feed on demersal sciaenid fish, which are chased to the surface by large predatory fish. In Argentina, the primary diet of the species consists of the Argentine anchovy, *Engraulis anchoita* (Mauco et al., 2001; Mauco and Favero, 2005).

The North American population of roseate terns are comparatively small, estimated at ~3200 pairs (Gochfeld and Burger, 2020), and the US population was declared 'Endangered' in 1987. Roseate terns have been intensively studied on the marine islands where they breed (e.g. Cormons, 2023; USFWS, 2010). During post-breeding migration, birds fly south over the Caribbean Sea and the North Atlantic Ocean to the north and east coasts of South America. Some remain in northern Brazil, while most go on to northeastern Brazil, never reaching southern Brazil and Argentina (Hays and Lima, 1997; Hays et al., 1999; Lima et al., 2004). During wintering, roseate terns had been poorly studied, with virtually no information on ecological requirements during this period (but see Hays et al., 1999). Aiming to overcome this knowledge gap, prospective expeditions started in 1995 (described in Hays et al., 1999) to investigate the critical wintering period of roseate and common terns along the Bahia coast in Brazil, mainly Cacha Pregos and Mangue Seco, where they roost at night; and in parallel with common terns at Punta Rasa in Argentina, where roseate terns did not reach. Tracking at sea started in both countries, with efforts directed at roseate terns in Bahia. Valuable information was gathered, despite the fact that the data obtained do not allow for comparative analysis between species or locations.

The limited information about terns at sea on wintering grounds is based on the description of foraging areas of common terns roosting on the Lagoa do Peixe, in Rio Grande do Sul state, in southern Brazil (Bugoni et al., 2005). This study described the movements of terns based on radio-tracking and demonstrated that they feed twice a day in waters up to 20 m depth isobath and move along the coast (Bugoni et al., 2005). In another study, several terns, including common terns, were associated with Argentine anchovy schools detected by acoustic methods in neritic waters of southern Brazil during the austral late winter/early spring (Costa et al., 2020). This shortage of wintering information is of special concern given the increasing anthropogenic pressures seabirds suffer at sea, such as oil and gas extraction, contamination by trace elements, organic contaminants and plastics, interaction with fisheries, and the emerging development of offshore wind farms (Bugoni et al., 2022; Croxall et al., 2012; Nunes et al., 2022; Wiese and Robertson, 2004; Wilcox et al., 2015).

In this context, we use aerial VHF telemetry to provide a descriptive analysis of movement patterns of roseate and common terns between roosting and foraging grounds during the wintering period in South America. Although direct interspecies or interannual comparisons are limited, our findings contribute to critical baseline knowledge on wintering area use. This information is essential for evaluating current and future threats and inform conservation planning and impact assessments.

2. Methods

2.1. Study area

The study was carried out in two key wintering grounds for terns in South America: Punta Rasa (36°17'S, 56°46'W), in Samborombón Bay, Argentina, and in the northeastern coast of Brazil, on the beaches of Cacha Pregos (13°8'S, 38°47'W) and Mangue Seco (11°27'S, 37°21'W) in Bahia state (Fig. S1). Punta Rasa is a sand spit located in the southern portion of Samborombón Bay – a Ramsar site of international importance defined as a strategic place for several bird species, including common terns that winter in the area (Martínez-Curci et al., 2015; Neves et al., 2002; Sapoznikow et al., 2002). The area is located between the estuary of Plata River and the Atlantic Ocean, and is characterized by large mudflat zones influenced by semidiurnal <1.5 m tides along the estuarine coast, and small intertidal areas on the oceanic beaches, with temperate climate (Bertola and Morosi, 1997).

In contrast, the coastal portion of northeastern Brazil is characterized by a humid tropical climate, with an absence of summer rain and a rainy season during winter (Golfari et al., 1978). Mangue Seco and Cacha Pregos are estuarine regions located in the mouths of the Real and Jaguaripe Rivers, respectively. Wide sandbars are used as roosting sites for several tern species, such as yellow-billed (*Sternula supercilialis*) and least (*S. antillarum*) terns during the day, and common tern and roseate tern for nocturnal roosting sites (Hays et al., 1999; Lima et al., 2004, 2005). The sandbars vary in size from year to year, ranging from 1 to 2.5 ha. At Mangue Seco, previous monitoring identified concentrations of approximately 10,000 individuals from nine tern species – predominantly roseate and common terns (Hays et al., 1999). This represents the largest known concentration of roseate terns on the Atlantic South American coast (Hays et al., 1999; Lima et al., 2004, 2005). The importance of these sites is highlighted by documentation of their use by terns from other continents. Two roseate terns banded in England have been recovered at Mangue Seco (Lima et al., 2005), and a roseate banded at Mangue Seco was trapped on a nest in the Azores (Hays et al., 2002). Common terns banded in the Azores were first netted at Mangue Seco in 1996 (Hays et al., 1999), and have been regularly recovered there since (P. Lima, pers. obs.). Similarly, a study found three common terns tracked with geolocators from the Azores spending time along the coast of Brazil. One of the three spent nearly two months on the coast of Bahia, at Mangue Seco, Cacha Pregos and Corumbau (Neves et al., 2015).

2.2. Bird captures and monitoring

During the austral summers of 2001 to 2003, birds were captured at the roosting areas with 10-mm mesh size mist-nets installed in the sand 2 m above the high tide line. This mesh size, despite being smaller than that widely used for terns or other birds of similar size, poses less risk, particularly for the wings. In Argentina, where roseate terns do not occur, a total of 53 common terns were captured and tagged in 2001, 25 in 2002 and 15 in 2003. In Brazil, where roseate terns were prioritized due to conservation concerns, 71 were captured and tagged in 2001, and 22 in 2002. Terns were measured (wing chord, body, tarsus and exposed culmen length) with a Vernier caliper (± 0.02 mm) and their body mass was measured with a Pesola® spring scale with precision of 1 g to assess whether they could receive a transmitter. Each bird was radio tagged with a Very High Frequency (VHF) transmitter (Holohil Systems Ltd., Ontario, Canada) equipped with a lithium battery expected to last about three weeks and a 14 cm long whip omni-directional antenna. Each transmitter had a unique frequency to allow individual differentiation. Transmitters operated at a frequency of 172.072 to 173.541 MHz, at a range up to 5 km (Bugoni et al., 2005). Transmitters were glued to metal leg rings with US Bird Banding Lab (BBL) individual numbers. The transmitter and band weighed ~1.2 g, corresponding to approximately 1% and 1.1% of mean body mass of common and roseate terns captured, respectively (P. Lima and E. Bremer, unpublished data), well below the

2% threshold specified in applicable banding permits. According to the manufacturer, the transmitter antenna and adhesive attachment were expected to degrade and detach from the band after the study period. After banding, birds were temporarily held in a soft holding enclosure and visually monitored by a veterinarian with expertise on bird rehabilitation procedures, and were released after showing normal posture and no obvious signs of distress. Importantly, prior to the main field deployments, a pilot trial was conducted at Mangue Seco, Brazil, in February 1999 on six VHF-tagged common terns. After release, birds were observed among offshore feeding flocks and at the nocturnal roosts with no signs of abnormality. This provided a preliminary field assessment of transmitter attachment and short-term post-release behavior before the fieldwork. All roseate tern field procedures for tagging were carried out by, or under supervision of, a veterinarian.

VHF monitoring was performed using two one-directional 4-element Yagi antennas, one attached on each side of a Cessna 172 high wing aircraft, the standard for aerial tracking (Marzluff et al., 1994). Flights were conducted on days with good visibility and weather conditions (i.e. minimal cloud cover and light wind). Flight altitude ranged from 600 to 900 m, occasionally descending to 300 m for photography or ascending to 1400 m when required to do so by air traffic restrictions; usually between 100 and 130 kph. A Lotek (Ontario, Canada) STR 1000 receiver was programmed to scan bird frequencies. Once a frequency was detected, researchers noted which antenna that detected the signal, the intensity, and the time of detection. The location of a bird was determined using a switch box to switch between the right and left antennas. The plane circled the location endeavoring to obtain three points around each signal to increase the accuracy of birds' location, and the corresponding coordinates were taken using a hand-held Garmin GPS device (Bugoni et al., 2005).

Two approaches were used in aerial monitoring. The first involved arriving at roosting sites in the early morning to circle the area and follow the birds with the strongest signals. The second method employed flights parallel to the coast to look for signals to follow. In addition to the detection of tagged birds, when flocks of feeding terns were observed opportunistically, estimates of flock size, position and the time were recorded. Also, in 2000 and 2001, land tracking was performed at the two different roosting sites along the Bahia coast. Two observers checked for signals of tagged birds using a hand-held antenna between 09:00 PM and 6:00 AM during six nights at each site in 2000, and three nights at each roosting site in 2001. One person used a hand-held antenna and preprogrammed receiver, while the other recorded what signals were received. Locations of these detections were compared with where the individuals had been tagged.

2.3. Data analysis

To investigate terns and the use of foraging areas, tracking data were analyzed in the R programming environment v. 4.3.2 (R Core Team, 2020). All detection coordinates were projected using the WGS84 datum with high-resolution of the national boundaries of Brazil and Argentina. The linear distance from each tern detection to the nearest coastline was determined in "sf" package (Pebesma, 2018). Bathymetric information was assigned to each detection point by extracting depth values from GEBCO's global bathymetry raster using "marmap" package (Pante and Simon-Bouhet, 2013). Each detection was classified into one of three bathymetric zones: (1) shelf waters (0–20 m and 20–40 m), (2) slope (40–100 m), and (3) shelf break and deep pelagic waters (100–500 m; 500–1000 m and > 1000 m).

To identify high-use offshore areas used by terns, kernel density estimation (KDE) was performed on the detection data using "mass" package (Ripley and Venables, 2009). KDEs were computed at a resolution of 400×400 grid cells. The spatial extent of the KDEs was defined by the bounding box of all detection points with an added buffer ($\pm 0.3^\circ$). KDEs were calculated separately by year and country. To quantify space use across years, center of gravity (weighted mean

coordinates), maximum and mean density values, and the core use area – defined as the cumulative area enclosing the top 50% of the KDE density distribution – were also calculated.

To evaluate movements of roseate terns between nocturnal roosting sites in northeastern Brazil, a 30 km radius buffer – maximum estimated foraging range of common terns (Thaxter et al., 2012) – was applied around central coordinates of each area. Aerial detections were filtered to only include records within these buffers to determine which individuals had been detected in both areas.

3. Results

A total of five tracking flights (one on 25 February 2001; two on 21 and 22 January 2002; two on 04 and 16 February 2003) were conducted in Argentina, and 13 flights in Brazil (eight between 09 and 20 February 2001; and five between 10 and 15 January 2002). Mean tracking flights lasted 3 h 18 min in Argentina and 3 h 24 min in Brazil (Table S1). Daily detections ranged from 4 to 220 (mean 71 ± 58). Pooling all years, a total of 51 common terns (out of 94 radio-tagged) and 53 roseate terns (out of 93 tagged) were detected in aerial tracking between 2001 and 2003. Common terns were detected from 1 to 163 times each, and roseate terns from 1 to 178 times (Table 1 and S2, Fig. S2). Repeated detections of tagged birds after release indicated that tagged individuals continued to move between roosting and foraging areas during the monitoring period, exhibiting expected normal behavior.

3.1. Foraging area use patterns of common terns in Argentina

Common terns usually left the roosting areas in Argentina between 7:30 and 8:40 AM, but in 2002 birds departed around 9:30 AM, and three individuals were observed returning to the continent around 12:00 PM, prior to returning to sea. Most birds used shelf waters, mainly in the isobaths of 20 m, with 78% of records, followed by 40 m (16% of detections). The returns to roosting sites occurred mainly up to two hours before sunset (5:30–6:30 PM).

Birds were detected up to 114 km from the coastline, but most birds were detected between 0 and 10 km (41%), followed by 20–50 km (26.6%, Fig. 1A). Interannual differences in the pattern of common terns in coastal Argentina were observed. Birds tended to occur closest to the coastline in 2002 (mean 6.0 ± 4.5 km) in comparison to 2001 (25.1 ± 15.4 km) and 2003 (48.8 ± 37.1 km; Fig. 2). Kernel density analysis also revealed different patterns of common tern use in Argentina, with the core use area varying from 599 km² in 2001 to 390 km² in 2002 and to 1111 km² in 2003 (Fig. 1B). The center of gravity of detections shifted eastward mostly between 2002 and 2003, by approximately 0.5 degrees in longitude (~ 45 km).

3.2. Foraging area use patterns of roseate terns in Brazil

Departure of the terns from roosting sites in the morning usually occurred soon after sunrise, from 5:00 to 6:00 AM, and the return to roosting sites always occurred after sunset, usually just past nautical twilight, between 6:30–7:00 PM. Roseate terns were detected up to 55 km from the coastline, and most birds were recorded within 50 km from the coast (Fig. 3A). Most detections were between 20 and 50 km (56.0%), followed by 10–20 km (26.5%). In relation to bathymetry, most roseate terns were detected over deep waters beyond the isobaths of 100 m, with 29% of records beyond 1000 m. In contrast to common terns in Argentina, only 14% of detections in Brazil were in shelf waters as far out as the 20 m isobath.

In addition to tagged birds, aerial monitoring allowed the visual observation of 14 flocks (6 in 2001 and 8 in 2002) of feeding terns up to 1000 individuals, composed of both common and roseate terns, but due to distance, it was not possible to differentiate them. Flocks were observed between 19 and 55 km from the coast (Fig. S3). Feeding activities were observed on different days, ranging in time from 08:43 AM

Table 1
Number of individuals and detections of roseate (*Sterna dougallii*) and common (*Sterna hirundo*) terns tracked in northeastern Brazil and Argentina during 2001–2003. SD = standard deviation, Min = minimum number of individual detections; Max – maximum number of individual detections.

Year	Country	Species	Number of individuals tagged	Number of individuals detected	Total number of detections	Mean (± SD) number of detections	Range (Min. – Max.)
2001	Argentina	Common	54	26	220	8.46 ± 31.6	1–163
2001	Brazil	Roseate	71	29	306	10.6 ± 13.7	1–56
2002	Argentina	Common	25	19	199	9.95 ± 7.46	1–26
2002	Brazil	Roseate	22	22	419	17.5 ± 35.6	1–178
2003	Argentina	Common	15	6	144	24 ± 47.2	1–120

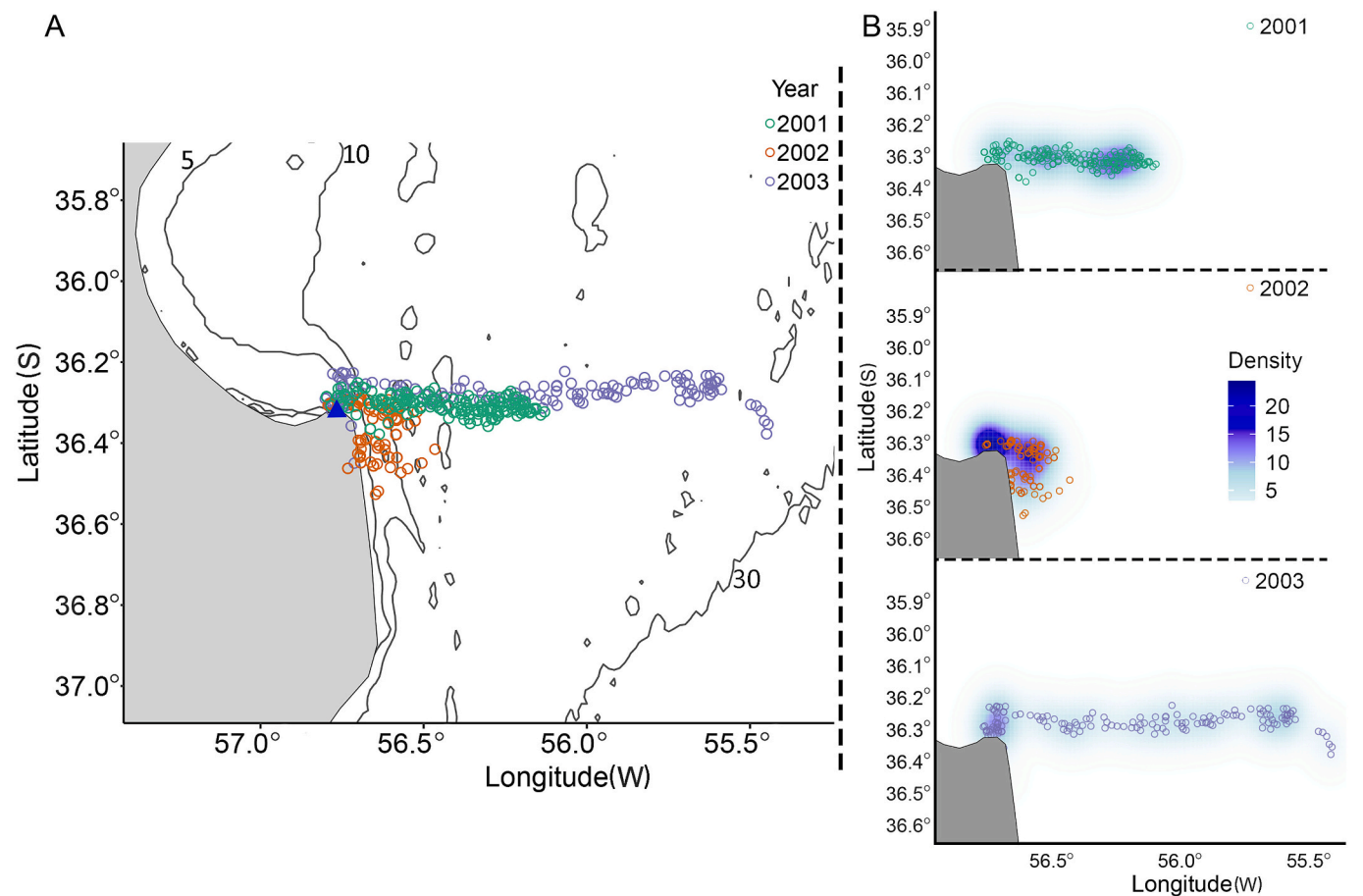


Fig. 1. (A). Patterns of aerial detections of common terns (*Sterna hirundo*) VHF tagged in coastal Argentina during wintering periods 2001 to 2003. Values near isobath lines indicate depth (in meters) below the sea surface. (B). Kernel Density Estimation (KDE) distribution of aerial detections in coastal Argentina during wintering periods 2001 to 2003.

to 18:59 PM. Most observations (57.1%) were located on isobaths <1000 m, and we observed differences in distance from coast of flocks observed in 2001 in comparison to 2002 (Fig. S3). During aerial monitoring, terns were observed interacting with artisanal fisheries (i.e. landing near the boats and feeding on discards/bycatch), especially shrimp trawler vessels near the coast.

In contrast to the results obtained for common terns in Argentina, the detections of roseate terns in northeastern Brazil presented interannual consistency, with no differences in distance to coastline observed between 2001 and 2002 (mean in 2001 = 21.9 ± 7.2 km and in 2002 = 22.8 ± 14.2 km; Fig. 4). However, KDEs revealed an expansion in core area used by roseate terns, varying from 1367 km² in 2001 to 9098 km² in 2002. The center of gravity of detections shifted northeastward by approximately 94 km, reflecting broader and more dispersed (maximum kernel density decreasing from 7.7 to 1.19) space used in 2002 (Fig. 3B).

Regarding movements between roosting areas, five individuals were detected through aerial monitoring at both of the sites monitored in

Bahia (two individuals were detected both at Mangue Seco and at Cacha Pregos in 2001, and three were present at both sites in 2002, e.g. Fig. S4). Additionally, 17 individuals tagged at one roosting site were detected at another roosting site during five days of nocturnal monitoring in 2001.

4. Discussion

The current study reveals foraging area use of common terns in Argentina and roseate terns in Brazil during the non-breeding season. Roseate terns monitored used and fed over deeper waters in comparison to common terns monitored in Argentina. However, the major documented differences could be related to characteristics of the feeding habitat (Argentina vs. Bahia, Brazil) rather than to species differences, although inherent species preferences could not be ruled out. Differences in patterns of foraging of these species were observed during breeding and non-breeding periods in mixed colonies (e.g. Goyert, 2014;

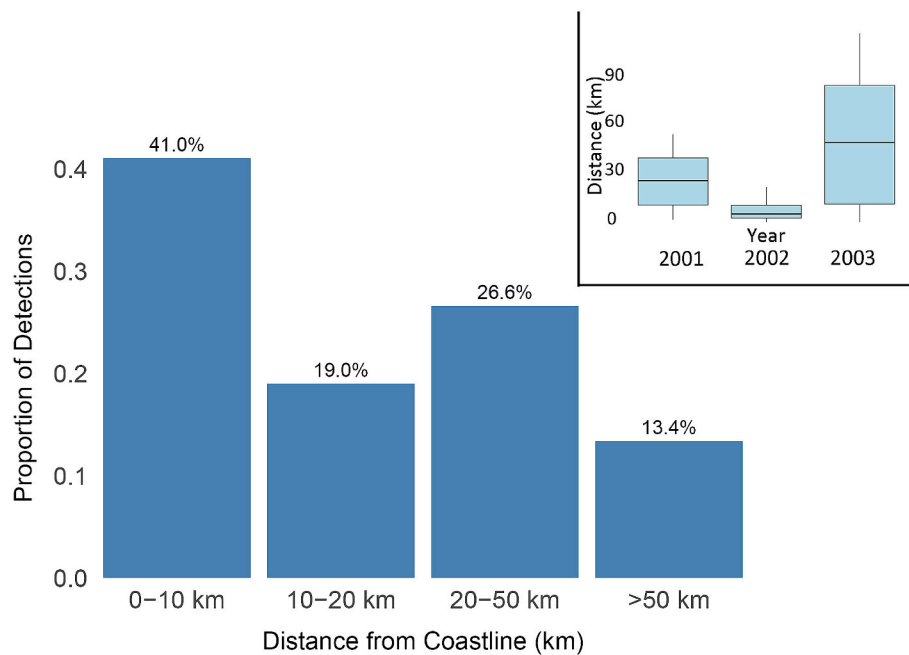


Fig. 2. Proportion of detections and interannual differences related to coastline distance of common terns (*Sterna hirundo*) monitored in Argentina during wintering periods in 2001, 2002 and 2003.

Monticelli et al., 2006).

Common terns largely foraged in continental shelf waters in Argentina. This result is similar to those of other studies during the non-breeding period in South America (Bugoni et al., 2005; Mauco and Favero, 2005), evidencing species use of inner shelf neritic environments for foraging. Despite limitations inherent to the number of surveys conducted and differences in effort (i.e. number and duration of flights), interannual shifting of core areas and differences in distances from shore were observed. This potential variation can reflect differences in prey availability and coastal dynamics in foraging areas of the species, influenced by estuarine dynamics and changes in oceanographic and weather conditions (Mauco and Favero, 2005).

Roseate terns monitored in Brazil were consistently observed in offshore areas in both study years. Birds tracked from roosting sites in Bahia frequently reached the shelf break and offshore areas, where the association with large pelagic fish chasing small fish to the surface could play a role. This phenomenon was documented from a boat (T. Cormons, pers. obs.), where ~400 terns were feeding aggressively over large fish predators approximately 32 km from the coastline of Bahia state.

Our study finds that roseate terns in Bahia, and probably also common terns, are doing most of their feeding far out by the shelf break. Apparently, they seem to stay out there all day, either feeding or resting on the water, only returning to the roosting sites at dusk. This contrasts strongly with the behavior described earlier of common terns in southern Brazil (Bugoni et al., 2005), where terns take shorter fishing trips and come back to land during the day. In southern Brazil, common terns perform two foraging trips each day, returning to roost on beaches where egested pellets were found in two periods during the day (Bugoni and Vooren, 2004, 2005).

The documented shift by individuals from one roosting site to another (Mangue Seco to Cacha Pregos and vice versa) suggests that the roseate terns go in to roost at whichever site is closer to where they have been foraging. This movement between roosting sites had also been documented in radio-tracked common terns in southern Brazil (Bugoni et al., 2005). Such flexibility seems advantageous, suggesting that terns may need different roosting areas close to fishing areas where schools are found. However, it highlights a conservation concern, as urban development and human activities on the beaches (e.g. the strong

touristic activity in Bahia) needs to be restricted to maintain undisturbed areas as roosting sites for terns.

Foraging areas identified in the current study overlapped with other anthropogenic activities. Direct observations support this co-occurrence, documenting predation of fish discards that fishermen use as bait, such as dwarf goatfish *Upeneus parvus* (P. Lima, pers. obs.). The aerial monitoring in Argentina did not detect interactions, but common terns were observed interacting with small-scale fisheries in southern Brazil (Carniel and Krul, 2012) and both species do so in the Caribbean Sea (Blokpoel et al., 1984).

The interaction with artificial structures raises concern for seabird species conservation worldwide (e.g. Coleman et al., 2022; Goldberg et al., 2024). In addition to fisheries, roseate and common terns were also observed using oil platforms, both to rest and to feed in adjacent areas, as in Sergipe state just north of Bahia waters (P. Lima, pers. obs.). This phenomenon was also observed at other wintering sites, with common and roseate terns feeding around oil platforms in Central America (Erwin et al., 1986). This behavior raises concerns for both human and birds' health. The presence of wild birds, feathers and feces can expose the crew to pathogens, including high pathogenic avian influenza H5N1 – already documented in terns and with recent outbreaks in Brazil (Araújo et al., 2024; Przymencki et al., 2024). Additionally, birds using these structures are clearly exposed to collisions and oil contamination. Erwin et al. (1986) found oil on 50% of common terns captured in Trinidad, Caribe. Recently, oil spills – probably mostly illegal spills from cargo ships on international routes – are increasing on the Brazilian coast. For example, one recently occurred in northeast Brazil that deposited hundreds of tons of crude oil over >3000 km of mangroves, beaches and coastal waters, impacting several species and small-scale fisheries (Zacharias et al., 2024). In coastal areas, terns are also exposed to contaminant runoff from rivers, including metals (Nunes et al., 2022) or microplastics ingested through food webs, as shown in terns and their food in Argentina (Carrillo et al., 2025). Recently, mortality of both common and roseate terns was documented due to collisions with powerlines and onshore windfarms in northeastern Brazil (Revorêdo et al., 2025).

Finally, the foraging distribution of the endangered roseate tern overlaps with offshore windfarm (OWF) areas targeted in Brazil. Two

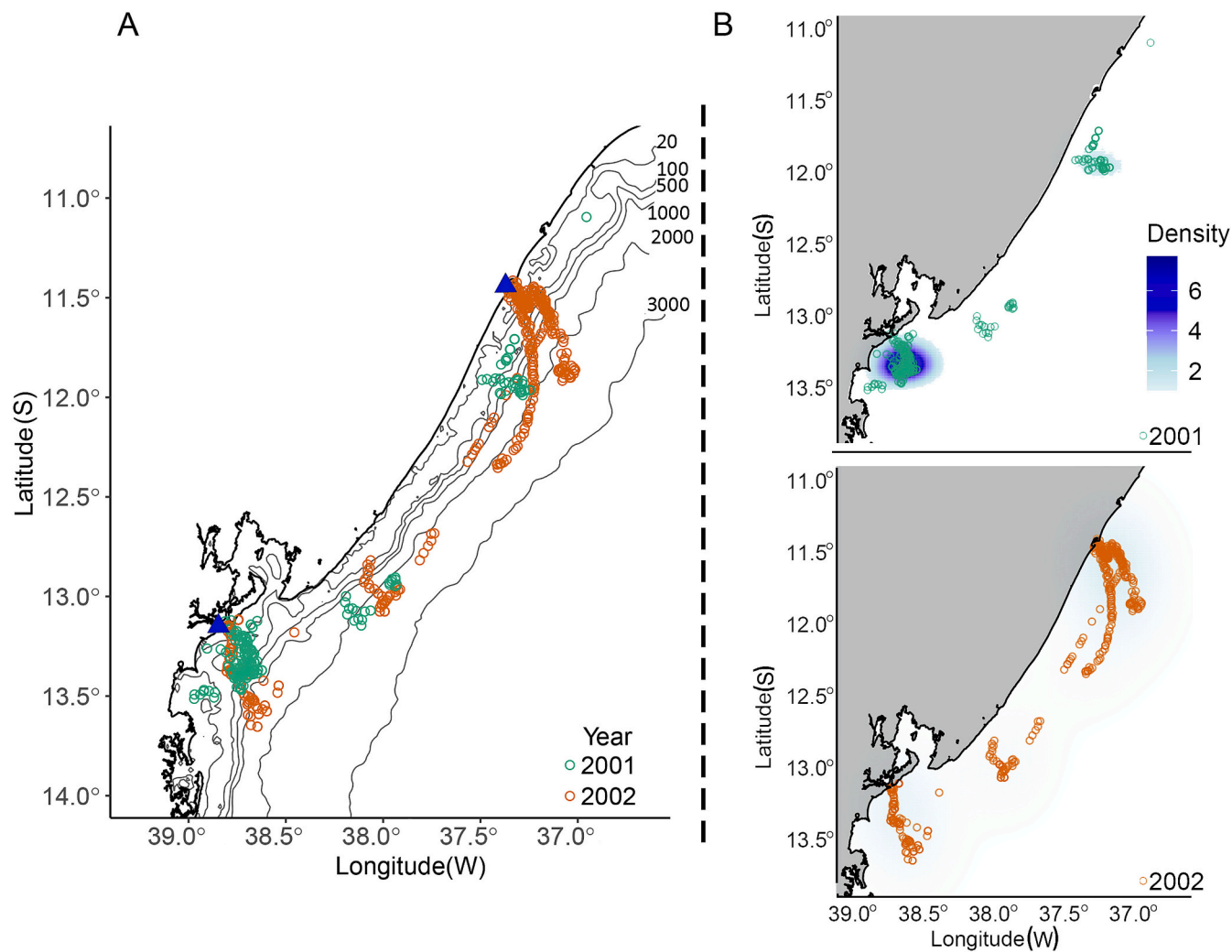


Fig. 3. (A). Patterns of aerial detections and (B) Kernel Density Estimation (KDE) distribution of roseate terns (*Sterna dougallii*) VHF tagged in northeastern Brazilian coast during wintering periods of 2001 and 2002. Values close to lines indicate isobaths.

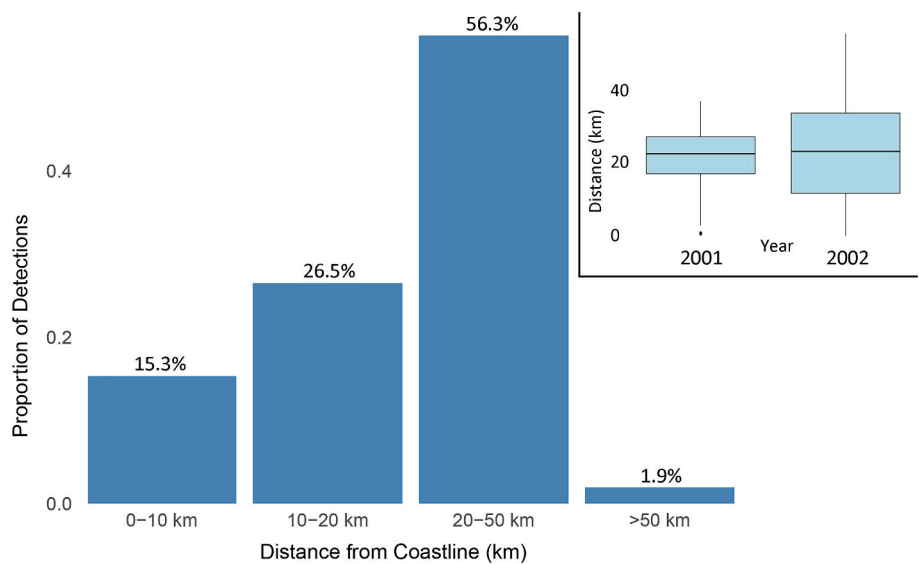


Fig. 4. Proportion of detections and interannual differences related to coastline distance of roseate terns (*Sterna dougallii*) monitored in northeastern Brazil during wintering periods in 2001 and 2002.

out of the three areas with strong winds in Brazil, suitable for OWF, are important wintering areas: along the Rio Grande do Sul coast used by common terns; and in northeast Brazil, from Rio Grande do Norte to Ceará state coasts, where both common and roseate terns stay during the wintering period (Hays et al., 1997; Loring et al., 2023; Nisbet et al., 2011). Currently, there are no OWFs in the country, but 105 projects are currently in development (<https://www.gov.br/ibama/pt-br/assuntos/laf/consultas/mapas-de-projetos-em-licenciamento-complexos-eolicos-offshore>). Towers are proposed to be installed on average 18 km from the coastline, mostly in isobaths ≤ 50 m in northeastern, southeastern and southern Brazil (Bugoni et al., 2022). None of the actual OWFs projects overlap with the study area in Brazil, but this scenario already occurs in other portions of the Brazilian northeastern coast (Loring et al., 2023).

Tagging small seabirds with radio-transmitters attached to leg rings and following birds at sea by plane was the only feasible approach to identify at sea foraging areas of common and roseate terns during early 2000s (Bugoni et al., 2005; this study). At the time of our fieldwork, leg-band-mounted VHF transmitters had already been tested in common terns, with no measurable effects on brood attendance or chick-feeding rates, and were considered advantageous because of their light mass, rapid attachment, and loss of antennae after battery exhaustion (Morris and Burness, 1992). Despite limitations (e.g. active monitoring dependency, relatively low range detection and associated individual bias; weather conditions and costs), this Lagrangian perspective complemented at sea counts (i.e. the Eulerian perspective) by providing successive locations of individual birds (e.g. Ballance, 2007; Phillips et al., 2019). Seabird identification and counts at sea also have difficulties and limitations, including the high costs of vessels and dedicated observers, in addition to species identification, which is difficult for some species including small terns which frequently is kept at genus level (e.g. Costa et al., 2020; Dault et al., 2019).

Tracking technologies, however, have advanced substantially during the last decades, including now a range of options and extensive miniaturization, which provide opportunities for tracking small birds for longer periods and with more locations than aerial tracking and radio transmitters used here (Holton et al., 2021). Additional studies published after our fieldwork have demonstrated that tracking devices can affect avian behavior, breeding performance, and return rates, depending on device type, attachment method, deployment duration, and species seasonal context (Barron et al., 2010). With regard to terns specifically, negative effects were observed in roseate terns fitted with leg-mounted geolocators tracked over a year (Mostello et al., 2014) and with satellite transmitters attached using backpack harnesses (Paton et al., 2020). These cases are important cautionary examples, although they involved devices and attachment methods different from those used in this study. Repeated detections of tagged birds among offshore feeding flocks and at nocturnal roosts on the beach, together with the use of leg-band attachments designed to detach shortly after the study period, and the recapture of one previously tagged roseate tern detected nesting in the Azores, three months after banding in Brazil (Hays et al., 2002), suggest that major disruption to movement, foraging, and behavior was unlikely.

In the current study, direct comparison between species is not possible since roseate terns do not occur in Argentina, while in Bahia state tracking had prioritized roseate terns due to conservation concerns. Similarly, because aerial tracking detections were obtained through non-random search and tracking procedures, KDEs should be interpreted as descriptive visual summaries of where VHF detections were concentrated, rather than as unbiased estimates of population-level space use. Notwithstanding, tracking more than 100 individuals in successive years allowed the identification of foraging areas, movement dynamics along the coast, i.e. between foraging grounds and indicated potential inter-annual differences in foraging grounds for common terns in Argentina. Further studies using miniaturized GPS or satellite tags would result in more refined tracks of wintering terns. Continued monitoring of habitat

use and foraging sites is crucial for gathering information for marine spatial planning and conservation (Augé et al., 2018; Hindell et al., 2020; Ronconi et al., 2012). Considering the development of OWFs, it would be useful to obtain accurate flight altitude, both during foraging in wintering periods and during migration, as a way to infer collision risks with towers and blades, and area displacements (Kelsey et al., 2018; Stienen et al., 2024).

Results obtained here elucidate previously undescribed foraging patterns of two tern species wintering in South America, providing useful data for monitoring programs to inform conservation planning and impact assessments evaluation. The use of new technologies and lighter devices will allow advances in other ecological aspects of species habitat use, such as fine scale movement (e.g. Catlin et al., 2024; McKellar and Clements, 2023), long-term/autonomous monitoring (e.g. Yu et al., 2022) and flight altitude (e.g. Hedenström and Åkesson, 2016) to inform stakeholders and encourage economic development based on scientific knowledge and committed to conservation.

5. Conclusion

We provide new insights into the wintering ecology and foraging area use of two long-distance migratory seabirds—roseate and common terns—across key non-breeding areas in South America. Using aerial VHF tracking, we reveal differences in movements, with roseate terns in northeastern Brazil regularly using deep pelagic waters beyond the continental shelf, while common terns in Argentina predominantly forage in nearshore, shelf waters.

Our findings are particularly relevant in light of accelerating offshore energy development, especially in Brazil where numerous OWF projects are proposed near key wintering areas. Recognizing the technical limitations of early 2000s VHF telemetry, our study nonetheless lays a robust baseline for future work. With the continuous development of autonomous tracking devices, future studies can refine spatiotemporal resolution and behavioral classifications, incorporating fine-scale movement and flight altitude. This is critical for improving collision risk models and displacement estimates associated with OWFs. Continued long-term monitoring, integrated with environmental covariates and technological advances in biologging, is essential for evidence-based conservation planning that addresses both current threats and emerging pressures.

Permits

The study was carried out in accordance with Brazilian legislation at the time of the study, as well as US Fish and Wildlife Service Bird Banding Lab requirements. Banding and radio tagging were conducted under banding and auxiliary markers permits from SISBIO (No. 33203), granted to P. Lima. US bands and transmitters were used on the terns under Helen Hays' permit No. 09772 from the Bird Banding Lab, United States Fish and Wildlife Service. Bird handling was carried out or supervised by a veterinarian and in accordance with Brazilian legislation.

CRediT authorship contribution statement

Fernando Faria: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Grace Cormons:** Writing – review & editing, Methodology, Funding acquisition, Data curation. **Tom Cormons:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Pedro Lima:** Methodology, Data curation. **Leandro Bugoni:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jmarsys.2026.104303>.

Data availability

Data will be made available on request.

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