MOVEMENTS BY AN ADULT MALE MAGNIFICENT FRIGATEBIRD *FREGATA MAGNIFICENS* CONNECT PROTECTED AREAS IN WATERS OFF NORTHEASTERN SOUTH AMERICA

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ABSTRACT

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The Magnificent Frigatebird *Fregata magnificens* has a broad range throughout the tropical Atlantic. Here, we report the movements of an adult male fitted with a GPS satellite transmitter starting from Fernando de Noronha Archipelago in northeastern Brazil. The bird covered 5,153 km in 34 days, ranging first over the northern Brazilian seamounts then over coastal-estuarine sites, which included 10 different protected areas from northeastern Brazil to French Guiana, before contact was lost in eastern Suriname. By standardizing locations with nearest-neighbor distances, we were able to check 13 stopovers, notably in remote oceanic regions and protected sites in the Delta do Parnaíba Environmental Protected Area (Brazil), Cabo Orange National Park (Brazil), and the Grand-Connétable National Nature Reserve (French Guiana), all areas of high productivity. Our results confirm the connection between Fernando de Noronha and Grand-Connétable frigatebird populations, which has already been suggested by genetic data. Additionally, we highlight the importance of protected areas as an effective conservation strategy for wide-ranging species.

Key words: coastal management, marine environments, seabird movement, seamounts, South Atlantic, spatial connectivity, stopovers

INTRODUCTION

Seabirds are among the most wide-ranging vertebrates. They employ various flight modes to exploit resources over a broad spatial scale, which enable them to forage and migrate across vast areas and to colonize different habitats (Lovette & Fitzpatrick, 2016; Ruaux et al., 2020). This has become more evident with the development and increased availability of technologies from geolocators to satellite tracking (Brooke, 2018). Therefore, it is now possible to document the routes by which seabirds move between nesting and feeding areas, including in remote regions (Davies et al., 2021; Hedd et al., 2012). Critical areas used as stopovers or connecting sites can be identified and, eventually, be justified properly as protected areas (Davies et al., 2021; Gray et al., 2016; Ronconi et al., 2012).

Several seabird species occur in waters off northern South America, hailing from colonies in the Caribbean, North Atlantic, and South Atlantic (Carlos, 2009; Daudt et al., 2019; Willems et al., 2017). One Important Bird Area (BR234; Devenish et al., 2009) is the Fernando de Noronha Archipelago (03°52′S, 032°25′W), a volcanic cluster of 18.4 km^2 that rises from > 4,000 m below sea level to 323 m above sea level and is located 345 km from the Brazilian coast (Almeida, 1955; Teixeira et al., 2003). Islets with nesting colonies of ~400 Magnificent Frigatebirds *Fregata magnificens* (hereafter frigatebirds or frigates; Mancini et al., 2016; Silva e Silva, 2008) occur within this portion of the Brazilian Exclusive Economic Zone (EEZ), as well as in two marine protected areas: the Fernando de Noronha Environmental Protection Area (Área de Proteção Ambiental Fernando de Noronha, hereafter APAFN; Instituto Chico Mendes de Conservação da Biodiversidade, 2017) and the Fernando de Noronha National Marine Park (Parque Nacional Marinho de Fernando de Noronha, hereafter PNMFN; Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, 1990). The degree to which frigatebirds use these areas remains to be determined.

Frigatebirds (order: Suliformes) are large seabirds with broad wings (wingspan: 175–240 cm) that are adapted for low-energy soaring flight. This allows them to travel thousands of kilometers from their breeding areas, despite being unable to land on the water (Schreiber & Burger, 2001; Weimerskirch et al., 2003, 2006;

Diamond & Schreiber, 2020). One of these species, the Magnificent Frigatebird, nests at several sites in the western North and South Atlantic oceans—from southeastern USA to southeastern Brazil, including those sites mentioned above—and they range widely from these sites (Diamond & Schreiber, 2020; Martins et al., 2022; Weimerskirch et al., 2006).

In this study, we report the movements of an adult male Magnificent Frigatebird tracked from Fernando de Noronha, showing the use of previously unrecorded dispersal areas and links with other regions, including protected areas.

METHODS

On 29 October 2021, we captured one adult-plumaged male Magnificent Frigatebird at Boldró Beach in the APAFN (03°50′46″S, 032°25′52″W) by attracting a flock of frigates habituated to fishing discards using small fish and throwing a weighted line to entangle it amid the feeding frenzy (Sistema de Autorização e Informação em Biodiversidade (SISBIO) Authorized Protocol no. 75073/24381). Although its breeding status was unknown, specimen morphology indicated a non-breeding bird, based mainly on its undeveloped gular sac. The individual was fitted with a solar-powered satellite transmitter (GPS Pinpoint Iridium 850), backpacked with a nylon strap; the tag represented 4.1% of his body mass (1,360 g). After the equipment was attached, the bird was marked with a metal ring (Centro Nacional de Pesquisa e Conservação de Aves Silvestres (CEMAVE) no. U62001) and released. Transmitter signals containing data on location, date, time, altitude (negative values were corrected to 0 m), and air temperature were automatically uploaded. The data points were initially recorded every 30 minutes from 04h00 to 19h00 between 29 October and 06 November 2021. Despite the equipment reconfiguring itself to record every three hours and the transmission gaps after 06 November 2021, it was possible to map the bird's continuous route until 01 December 2021.

Movement was assessed for the entire sampled period using geoprocessing tools (SIRGAS 2000 Polyconic UTM Datum; QGis v3.34). We overlaid raster images with the location points to get the range (km) and duration (h) of the bird's flight. This allowed us to estimate 1) point-to-point speed (km/h), 2) total relief of marine and terrestrial topography (Diretoria de Hidrografia e Navegação da Marinha do Brasil, 2021; European Space Agency, 2024), 3) average distance between the mainland coastline and the Brazilian EEZ (as a representation of offshore coverage), 4) use of protected areas (Ministério do Meio Ambiente e da Mudança do Clima, 2025; World Database on Protected Areas, 2025), and 5) use of habitat classes. Habitats were categorized into four classes: offshore (≥ 2,500 m isobath), inshore (2,500 to 0 m isobath), freshwater (≥ 0 m over rivers), and terrestrial (≥ 0 m over land). In addition, seamounts were considered as delimited elevations rising from depths > 4,000 m in offshore regions (see Almeida, 2006).

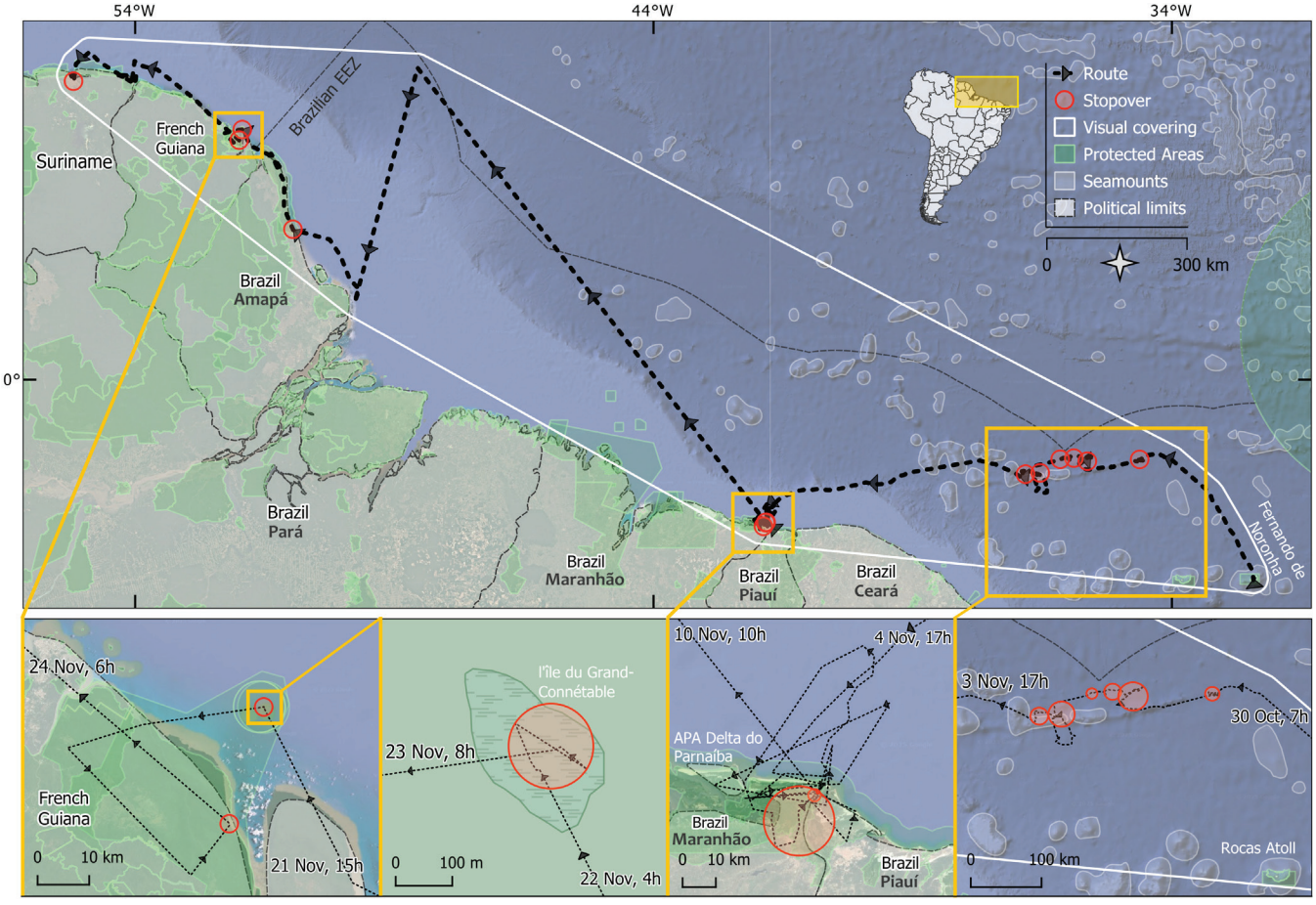

Fig. 1. Overview of adult male Magnificent Frigatebird *Fregata magnificens* tracked from 29 October until 01 December 2021 in offshore and coastal waters of the tropical South Atlantic Ocean, including the Fernando de Noronha Archipelago (where the transmitter was installed) and several sites in northeastern South America.

We defined stopovers as groupings of sequential points that had a nearest-neighbor distance (NND) of ≤ 6 km for a period of ≥ 180 min (adapted from Pollet et al., 2019). We assessed NND points and used Generalized Linear Mixed Models to test whether the bird's route was related to habitat class (using all data) and to protected areas along the coastline (using data from 06 November 2021). Vertical movements were investigated by using Spearman's coefficient to correlate flight altitude with relief and Levene's test followed by Kruskal-Wallis H test to check whether the flight altitude varied between hour-long classes. Statistical procedures were performed using RStudio v.2024.09.1 ($\alpha = 0.05$).

RESULTS

The Magnificent Frigatebird was tracked ($n = 293$ locations) between 29 October 2021 and 01 December 2021, until the transmitter stopped in inland Suriname (05°52′40″N, 055°14′22″N; Fig. 1), 2,754.1 km from the starting point. The total distance travelled during this period was 5,153.44 km over 34 days, with signals totaling 734 hours. Point-to-point speed averaged 11.0 ± 9.6 km/h (min: 0, max: 45.5), and air temperature measured 18.2 ± 3.4 °C (min: 11.0, max: 33.5). Vertical movement often achieved 163.0 ± 217.8 m, though a few points were above 500 m ($n = 13$); maximum height was 2,217 m. Flight altitude was not related significantly with time of day (H test $\chi^2 = 24.50$, $p = .056$), although higher elevations occurred mostly during 10h00 to 14h00 ($F = 0.73$; $p = .751$; Fig. 2A). Furthermore, flight altitude was not correlated with whether the bird was flying over water or land (Spearman's $\rho = -0.06$; $p = .272$), despite evidence of greater variation in offshore waters and along the mainland coastline (Fig. 2B).

Before heading towards the mainland (04 November 2021), the frigatebird remained in waters beyond the continental shelf for six days, averaging 362.6 ± 58.4 km away from the mainland during this period (Fig. 2C). The bird's path reached a maximum distance of 454.7 km (81.4% distant) from shore on 30 October 2021 (just after being tagged). On 18 November 2021, the transmitter displayed a new offshore data point located 364.1 km from the Brazilian coastline, which was ~95% of the distance between mainland and EEZ. The bird returned to the mainland the following day.

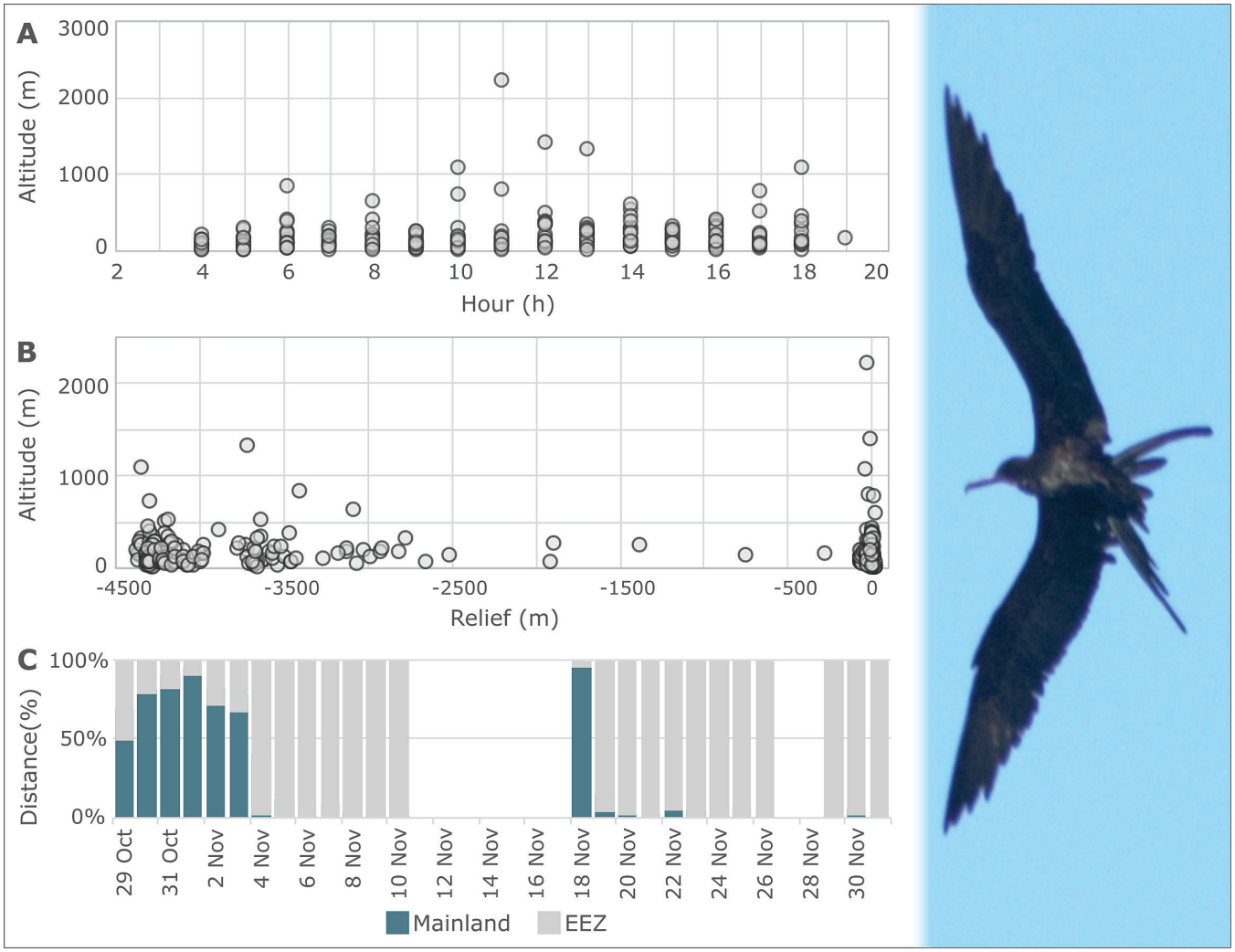

Fig. 2. Movement patterns of an adult male Magnificent Frigatebird *Fregata magnificens* during a flight from the Fernando de Noronha Archipelago to Suriname in 2021, showing the A) flight altitude (m) by time of day (02h00 to 20h00); B) flight altitude (m) related to surface relief, marine to inland topography (m); and C) distance as a percentage from the Mainland coast (0%) to the limit of the Brazilian Exclusive Economic Zone (EEZ, 100%; as a representation of offshore coverage). Blank columns indicate transmission gaps.

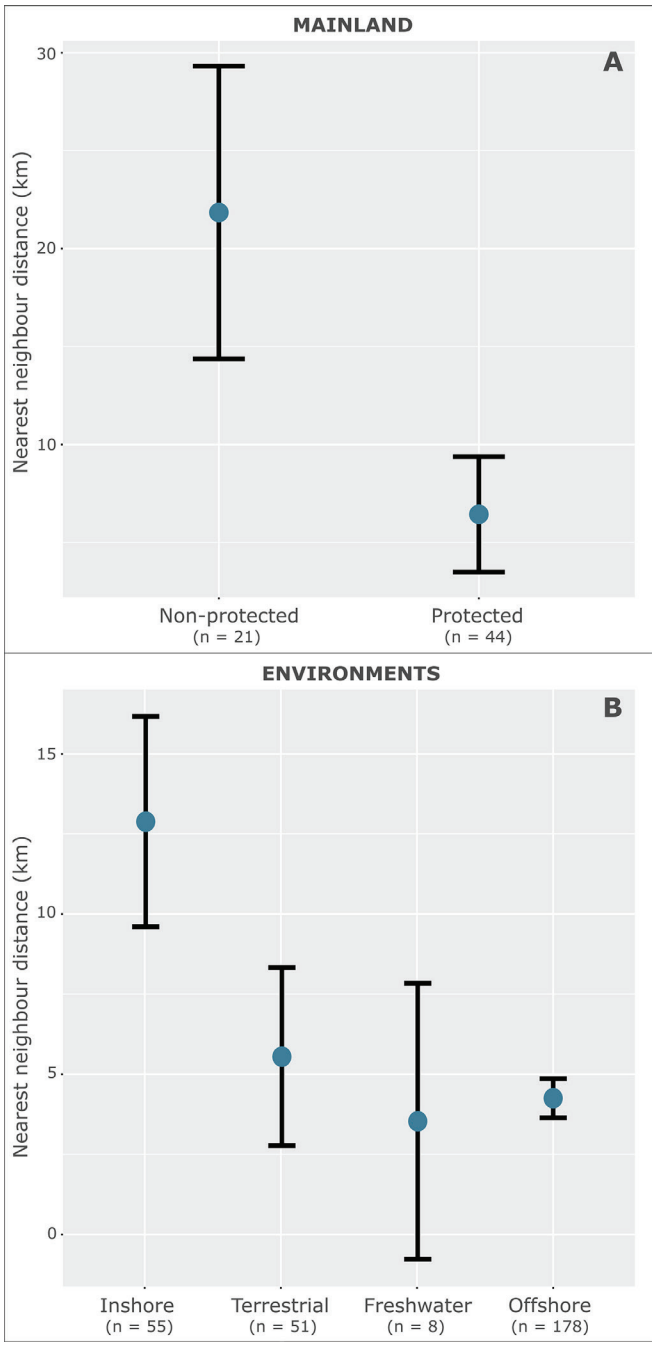

Fig. 3. Average nearest-neighbor distances (NND; blue circles) and standard deviation (black whiskers) of a single Magnificent Frigatebird *Fregata magnificens* tracked from 29 October until 01 December 2021 off northeastern South America. Positions are associated with A) non-protected and protected areas (standard data points from 06 November 2021), and with B) inshore, terrestrial, freshwater and offshore habitats.

The bird's occurrence was significantly clustered in protected areas, showing NND points that were ~15 km closer together than in non-protected areas ($\beta = -15.41$; $F = 22.56$; $p < .001$; Fig 3A). Also, the frigatebird was more associated with offshore (NND 4.2 ± 4.1 km), freshwater (3.5 ± 5.1 km), and terrestrial (5.6 ± 9.9 km) habitats compared to inshore habitats (NND 12.9 ± 12.1 km; $\beta_0 = 12.50$; $F = 19.19$; $p < .001$; Fig. 3B). Considering the total time spent, we observed similar durations of closest (≤ 6 km; 385.2 h) and furthest (> 6 km; 358.6 h) NND points, suggesting a balanced movement pattern between short and long distances along the flight path.

Along its route, the frigatebird visited 10 different protected areas and made 13 stopovers (time spent: 229 h; distance flown: 778.4 km), which included six offshore sites over two seamounts northeast of Fernando de Noronha (Table 1). Notably, the Delta do Parnaíba Environmental Protected Area (Área de Proteção Ambiental Delta do Parnaíba, APADP) in Piauí, Brazil, had three different stopovers, totaling 113.8 h and 341.4 km flown. Further north, other stopover sites (frequented once each) included Cabo Orange National Park (Parque Nacional do Cabo Orange, PNCO, Brazil), the Grand-Connétable National Nature Reserve (GCNNR, French Guiana), and the Marais De Kaw-Roura National Nature Reserve (MKRNR, French Guiana).

DISCUSSION

This is the first report of a Magnificent Frigatebird tracked from Brazilian oceanic islands and showing fast long-distance movements. Different environments were visited during the journey, mostly in marine habitats but also in mangroves, coastal scrub ("restinga"), and saltworks (Instituto Brasileiro de Geografia e Estatística, 2004). The bird flew over forest, rocky islets, and estuaries, which is not surprising, given that frigatebirds are known to be attracted to wetlands and coastal lagoons (Diamond & Schreiber, 2020; Silva e Silva, 2008). The eastern coast of northern South America has a great diversity of oceanic and coastal habitats, including seamounts and estuaries important to marine life, and this frigatebird substantiated this (see de Boer et al., 2014; Mannocci et al., 2013; Pusineri et al., 2022).

Information on movement patterns and use of resources by seabirds is important, even if the studies include just a few individuals (Soanes et al., 2013). Averaging ~150 km/d, displacement and stopover patterns by the bird in our study were similar to those observed in other studies of frigatebirds (Oppel et al., 2017; Weimerskirch et al., 2017; Zaluski et al., 2019), with flight time balanced between longer and shorter distances. This suggests continuous foraging throughout the route, as detected by inland and at-sea stopovers. In addition, behavior in oceanic waters indicated concentrated feeding during stopovers, while the use of terrestrial and freshwater environments was likely for roosting, as supported by field observations of this species.

Stopover sites may offer higher environmental quality, especially in protected areas that maintain biodiversity and conserve natural resources (Gray et al., 2016). Non-protected areas made up most of the stopovers in offshore regions, with only one occasion in a terrestrial environment. For instance, seamounts are known to attract seabirds because they create upwellings and concentrate marine life, such as predatory fish that drive bait fish to the surface (de Souza et al., 2013; Longhurst & Pauly, 1987; Morato et al., 2008). Our data add to the evidence that seamounts should be included in marine protected areas (Mincarone et al., 2022; Santos et al., 2024; Thompson et al., 2024). Other feeding sites used by the frigatebird were in other highly productive areas, for example, those associated with discharges from the Parnaíba and Amazon rivers and extensive mangrove systems, especially in APADP and PNCO.

Gaps in the data points caused by faulty satellite signals may have been related to signal interference or equipment damage (see Hays et al., 2007; Justicia et al., 2018). There are surprisingly few records

TABLE 1
A summary of duration (h) and flight range (km) of the adult male Magnificent Frigatebird *Fregata magnificens* when visiting various habitats, as well as protected vs. non-protected areas

Locations	Habitats								TOTAL		
	Offshore		Inshore		Terrestrial		Freshwater				
	Duration[b]	Range	Duration	Range	Duration	Range	Duration	Range	Duration	Range	Stopovers
Protected[a]	**3.0**	**19.9**	**57.0**	**236.4**	**182.3** [6]	**626.4**	**31.5**	**94.8**	**273.8**	**977.5**	**6**
APAFRP	0.0	0.00	0.0	0.00	1.0	14.4	0.0	0.00	1.0	14.4	0
APADP	0.0	0.00	19.0	34.1	66.3 [3]	236.2	28.5	71.1	113.8	341.4	3
APAFN	3.0	19.9	0.0	0.00	0.0	0.00	0.0	0.00	3.0	19.9	0
GCNNR	0.0	0.00	0.0	0.00	41.0 [1]	38.4	0.0	0.00	41.0	38.4	1
GNNR	0.0	0.00	16.0	52.3	24.0	6.2	0.0	0.00	40.0	58.5	0
GRNP	0.0	0.00	0.0	0.00	3.0	15.2	0.0	0.00	3.0	15.2	0
MKRNR	0.0	0.00	0.0	0.00	19.0 [1]	47.0	3.0	23.7	22.0	70.7	1
NCMA	0.0	0.00	3.0	38.9	0.0	0.0	0.0	0.00	3.0	38.9	0
PNCO	0.0	0.00	19.0	111.1	25.0 [1]	226.3	0.0	0.00	44.0	337.4	1
WWNR	0.0	0.00	0.0	0.00	3.0	42.7	0.0	0.00	3.0	42.7	0
Non-protected	**342.5** [6]	**2,578.0**	**99.5**	**1,428.8**	**28.0** [1]	**169.2**	**0.0**	**0.00**	**470.0**	**4,176.0**	**7**
Seamounts	20.8 [2]	122.6	–	–	–	–	–	–	20.8	122.6	2
TOTAL	**345.5** [6]	**2,597.9**	**156.5**	**1,665.2**	**210.3** [7]	**795.6**	**31.5**	**94.8**	**743.8**	**5,153.4**	**13**

[a] APAFRP = Área de Proteção Ambiental da Foz do Rio das Preguiças (Foz do Rio das Preguiças Environment Protected Area); APADP = Área de Proteção Ambiental Delta do Parnaíba (Delta do Parnaíba Environment Protected Area); APAFN = Área de Proteção Ambiental Fernando de Noronha (Fernando de Noronha Environment Protected Area); GCNNR = Grand-Connétable National Nature Reserve; GNNR = Galibi National Nature Reserve; GRNP = Guyane Regional Nature Park; MKRNR = Marais De Kaw-Roura National Nature Reserve; NCMA = North Commewijne Marowijne Multiple Use Management Area; PNCO = Parque Nacional Do Cabo Orange (Cabo Orange National Park); WWNR = Wia-Wia National Nature Reserve.

[b] Superscript numbers in duration fields represent the stopover frequencies.

of Magnificent Frigatebirds from waters off the northern coast of Brazil in citizen-science platforms (eBird, 2025; WikiAves, 2025). More tracking studies that include other species nesting both in the Fernando de Noronha Archipelago (as a whole, not only APAFN; e.g., Roy et al., 2021; Santos et al., 2019) and at other oceanic islands in the tropical South Atlantic are needed to integrate conservation actions in offshore and coastal areas. This is especially important for the careful prevention of the negative impacts by the oil industry off the coast of northeastern Brazil (Soares et al., 2020).

Our results provide evidence that frigates from the Fernando de Noronha Archipelago do move to French Guiana and that their range overlaps with GCNNR, which supports this nature reserve as a key link for the species. Observations of the birds of Grand-Connétable also suggest the use of large areas along the coast of South America as well as regular gene flow between different populations (e.g., Caribbean and Fernando de Noronha; Martins et al., 2022; Weimerskirch et al., 2006). Therefore, the present study provides evidence of similar movement among sites 3,600 km apart and the potential connectivity over thousands of kilometers by this species.

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AUTHOR CONTRIBUTIONS

LPSS: Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing

CL: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

HLN: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Software, Resources, Visualization, Writing – review & editing

RK: Investigation, Methodology, Validation, Visualization

JK: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Software, Resources, Supervision, Validation, Visualization, Writing – review & editing

LSTC: Data curation, Methodology, Resources, Supervision, Validation, Visualization, Writing – review & editing

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FO: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

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