Habitat use of Common and Roseate terns tracked with satellite transmitters in northeast Brazil

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Introduction

We used satellite telemetry to investigate movements of Common Terns (*Sterna hirundo)* and Roseate Terns (*Sterna dougallii*) tagged in Galinhos, Brazil. This study was part of a broader project to assess, monitor, and minimize collisions of *Sterna* terns with power lines along a barrier beach that is used as a nocturnal roost site. The satellite telemetry components described herein aimed to collect new information on space-use of *Sterna* terns relative to natural and human-altered habitat features in northeastern Brazil.

Galinhos is part of the northern coast of Rio Grande do Norte and is in the Potiguar Basin, a geomorphologically classified area that includes the northern coast of Rio Grande do Norte and the south coast of Ceará. The Potiguar Basin is documented as a stopover area in the Brazilian northeast for both Common and Roseate Terns. However, relatively few stopover sites have been identified for Roseate Terns in this area (Azevedo Júnior et al. 2001, Larrazábal et al 2002, Macedo Mestre et al. 2010, Mendonça et al. 2015, Mestre 2007). Galinhos is a peninsula-shaped barrier beach with sand formations (e.g., dunes and sandbanks) and coastal heath vegetation (Diniz et al. 2015). Within Galinhos, *Sterna* terns roost nocturnally in sand formations along the beach, at the edge of the peninsula, and on nearshore sand banks that are surrounded by water.

A field team from Projeto Cetáceos da Costa Branca (PCCB, Costa Branca Cetacean Project), with the Universidade do Estado do Rio Grande do Norte (UERN, the University of the State of Rio Grande do Norte) surveys the beach in Galinhos for marine fauna (cetaceans, manatees, sea turtles, and seabirds) impacted by exploration of petroleum and gas as an environmental requirement by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). Each year since 2010, the field team has documented injured *Sterna* terns that were recovered after colliding with a power distribution line that extends above the beach and runs along the entire length (USFWS 2020; Ventura et al. 2020, Revorêdo 2021). The number of tern collisions appears to have increased following installation of a coastal wind power facility on a neighboring beach in 2014. The increase in tern collisions led to collaborations between institutions in Brazil and the USA to help reduce and mitigate the power lines' impacts to Roseate Terns in Galinhos. In Brazil, the mitigation activities started in 2022, including marking and monitoring the power line, and have been led by Centro de Estudos e Monitoramento Ambiental (CEMAM).

Inshore of the barrier beach in Galinhos are large areas of mangrove habitat. Most mangroves in Galinhos have been modified by the salt industry, including large areas of salt concentration ponds, as well as the shrimp farming industry. This habitat is used by *Sterna* terns and other local tern species (*Thalasseus acuflavidus eurygnathus, Gelochelidon nilotica, Sternula antillarum, Sternula superciliaris*) to feed and roost on sandbanks inside of the ponds (Valente et al. 2011; Diniz et al. 2015).

There has been little previous work researching *Sterna* tern use in marine habitats offshore of Galinhos, although research has been conducted elsewhere in Brazil that has documented offshore feeding areas and roosting on oil platforms (Hays 2003, Lima et al. *in prep*). This information is especially important due to recent plans for the development of industrial-scale offshore wind farms in Brazil, including off the coast of Galinhos, and for existing activities related to oil and gas exploration that are ongoing.

In 2022, we initiated a pilot satellite telemetry study to better understand use of natural and human-altered habitat features by *Sterna* terns in the Galinhos region. The main objectives were to: 1) use miniaturized satellite transmitters to track movements of *Sterna* terns tagged in Galinhos; 2) map diurnal and nocturnal home ranges of satellite-tagged *Sterna* terns; and 3) assess onshore and offshore habitat use of *Sterna* terns near the staging area in Galinhos relative to industrial activities: the power distribution line along the beach in Galinhos, onshore wind turbines, salt production facilities, shrimp ponds, offshore petroleum activities, and planning areas for offshore wind turbines.

Methods:

Transmitter specifications

We tracked terns using satellite transmitters ('Sunbird Solar Argos Transmitters', Lotek Wireless, Ontario CN), hereafter 'tag'. Each tag body measured 27 mm x 15 mm x 8 mm and had a custom-fit attachment tube (inner diameter 1 mm) at the anterior and posterior end, and a 23-cm whip antenna extending posteriorly.

Trapping and tagging

Dr. Pedro Lima, DVM, led the capture effort and held all required permits for capture and marking activities. From February 25 to March 2, 2022, *Sterna* terns were captured using mist nets set up near nocturnal roosting areas in Galinhos, Brazil (location: -5.0932, -36.2957). Mist nets were 12 m long, 2.5 m high with 10 mm mesh. The nets were set up along the high tide line for approximately 12 hours each night (17:30 to 05:30 hrs BST) and checked hourly.

Captured birds were placed in cloth holding bags for processing. Morphometric data collected from each bird included bill length (mm), head length (mm), wing length (mm) and body mass (g). If birds were not already banded, a standard metal Brazilian band was applied to the tarsus. For *S. dougallii*, a yellow plastic field-readable band with a black three-digit alphanumeric code was applied to the opposite tarsus (Fig. 1).

Three *S. hirundo* and 12 *S. dougallii* were selected for tag attachment. Tags were attached to the dorsal inter-scapular region using cyanoacrylate adhesive and two sutures (Prolene: 45-cm length, 4.0, BB taper point needle, catalog # 8581H) inserted subcutaneously and secured to the end-tubes of the tag. Total weight of each tag, attachment materials, and bands comprised < 2% of the body mass of the tagged bird. After tagging, all birds were released near the capture location.

Figure. 1. Roseate Tern with satellite tag, metal leg band (left) and yellow plastic field readable band (right). Photo: Pedro Lima.

Location data collection and processing

The tags collected doppler location data and tag diagnostic data with global coverage using the Argos satellite system (Argos 2023). Number of positions collected per day varied with the available sunlight, tag power, geometry of satellites overhead and latitude of the tag. If the battery voltage became too low, the tags switched to a low-power mode to recharge. The tags were programmed to resume operation if the battery was recharged via solar to a sufficient level.

Location accuracy varied with the geometrical satellites, the stability of the transmitter oscillator, the number of messages collected and their distribution in the pass (Argos 2023). Miniaturized transmitters, such as the tags used in this study, tend to be less stable and have less accurate location estimates relative to larger transmitters. Location accuracy was estimated for the following classes, where values correspond to one standard deviation of the radial distance of the isotropic error: class 3 (<250 m), class 2 (<500 m), class 1 (<1,500 m), and class 0 (>1,500 m). Location classes A, B, and Z do not have associated error estimates (Argos 2023). Class A and B locations may be useful for analysis, but the error is unknown due to an insufficient number of satellite messages needed to calculate error. Possible validity of locations with unknown error was assessed using filtering algorithms.

Tag diagnostic data analysis

Tag diagnostic data were transmitted with a subset of messages and included the following information from on-board sensors: temperature (degrees C), transmit current (mA) and battery voltage (V). We obtained tag diagnostic data from Lotek Argos Web Service (2023). Transmit current values measure how much current (mV) each transmission is consuming. Values between 90-125 mV indicate good tag health (D. Phoenix, Lotek Wireless, pers comm). Battery voltage measures the charge of the cell, where values between 3.6 V and 4.0 V indicate good tag health (D. Phoenix, Lotek Wireless, pers comm). Voltage values fluctuate up and down as the cell uses its power and is recharged during the day. If the voltage on the cell drops as low as 3.3 V, the tag goes into a low-power mode and recharges.

Tags may cease to transmit if the battery voltage drops below threshold and is unable to charge (e.g. shading of the solar panel, damaged electronics, etc.). For each tag, we plotted transmit current and battery voltage over time, to visually assess tag health for all locations transmitted in Brazil, including pre-deployment testing data and post-deployment data collected from tagged birds.

We used all post-deployment data to calculate each tag's total transmission duration (in days) from tag deployment date through the last transmitted location. In addition, we mapped all post-deployment data to visually assess the movements of each bird prior to tag failure. This information is presented as maps of movement data for each bird with locations recorded within the final 24-hours of tag data collection highlighted. We summed the Euclidean distance of tag locations within final 24 hours of data transmission and report summary statistics across all tagged birds.

Movement data management and analysis

We managed tag location data in Movebank (www.movebank.org), a free online database of animal tracking data. All tags were set to live-feed into Movebank, enabling automatic data streaming from Argos to Movebank every six hours. The data are managed under the Movebank study titled 'Sterna - Galinhos, Brazil'.

To flag and remove outliers, we applied the Douglas-Argos 'Best Hybrid' filter in Movebank using default parameters (Fig. 2), except for 'keep lc', which we changed to 'keep lc=2' to remove additional outlier locations that were being retained with the less conservative default setting of keep 'lc=1'. For more information, see Movebank (2023). We used the dataset processed by the Douglas-Argos filter for all subsequent analyses.

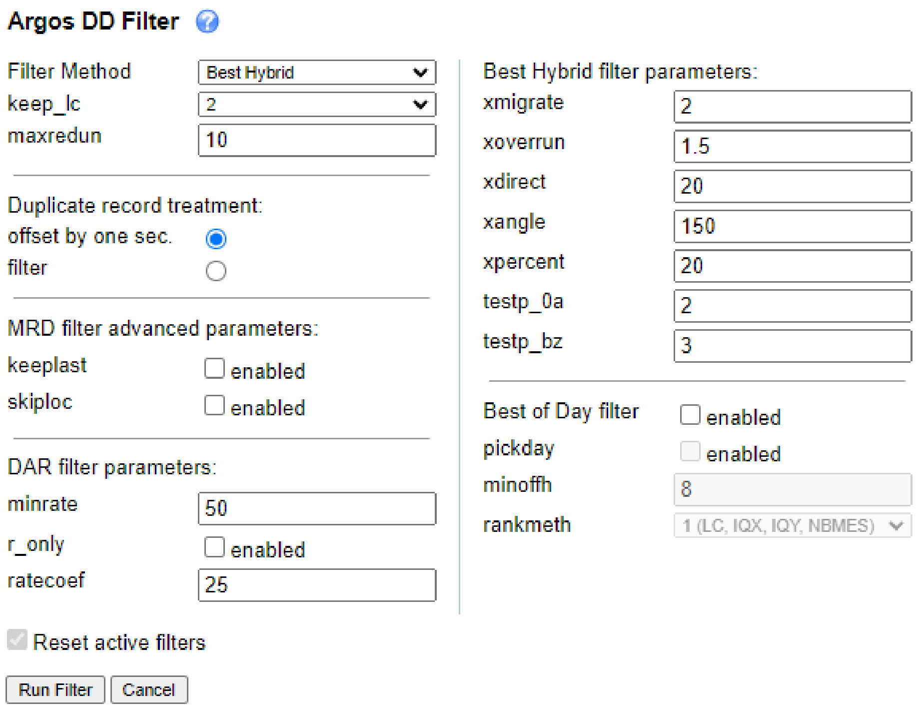

Figure 2. Default parameter settings for Douglas-Argos "Best Hybrid" filter in Movebank.

We analyzed movement data using Program R (R Core Team 2022). We used the 'move' package (Kranstauber et al. 2022) to download the dataset processed by the Douglas-Argos directly into R. We converted all time stamps from the default UTC time zone into the study's local time zone (America/Belem, UTC-3). We used the 'maptools' package (Bivand and Lewin-Koh 2022) to calculate the solar elevation for each point. We used solar elevation values to categorize points as occurring during day versus night, where elevations < -6 degrees below the horizon were classified as night (Smolla et al. 2022).

We then used the 'move' package to calculate several metrics of the tracking data set, including time (min) and distance (m) between subsequent locations. For each bird, we summarized the number of days tracked and distance traveled during the final 24 hours of data collection to help provide information on bird behavior during the final day of tag transmission. We generated individual maps of each birds tracking data and highlighted points within the final 24 hours of data collection to aid in visual interpretation of the tracking data for diagnostic purposes.

Spatial data on industrial activities

We assessed exposure of terns to industrial activities in onshore and offshore habitats near the staging area in Galinhos using GIS data. Onshore data were digitized by R. Revorêdo in QGIS using GPS data collected in the field and satellite imagery. Onshore data consisted of the power distribution line along the beach in Galinhos, locations of onshore wind turbines in Galinhos and Guamaré, salt ponds in Galinhos and Guamaré, and shrimp ponds in Galinhos and Guamaré. Offshore data consisted of petroleum production areas (ANP 2022), petroleum areas in process of concession (ANP 2022), petroleum exploratory areas (ANP 2022), and planning areas for offshore wind energy (IBAMA 2022).

Exposure analysis

For birds with sufficient location data (≥ 5 days tracked), we evaluated exposure to industrial activities by summarizing overlap of each layer with bird location data at two scales: 1) using locations buffered by accuracy class and 2) using core-use areas within utilization distributions generated from location data classified as "day" or "night".

The first method directly estimates exposure at points in time when the tag transmitted location data that met our accuracy criteria (< 1,500 m). For this method, we subset all locations retained by the Argos filter that were classified as LC3, LC2, or LC1 to retain locations with estimated error <1,500 m. We mapped those locations with a buffer corresponding to the accuracy radius estimated by Argos.

For the analysis using utilization distributions, we started with all locations retained by the Douglas-Argos filter for each bird and removed consecutive locations within 120 min to address temporal autocorrelation. We used the package 'adehabitatHR' (Calenge 2006) to calculate kernel utilization distributions with a smoothing parameter generated using the least square cross validation (LSCV) function. The LSCV function, which is built in to the adehabitatHR package, was selected because it calculates and automatically applies the optimal smoothing parameter for each utilization distribution (Calenge 2015). We then calculated "day" and "night" kernel utilization distributions for each bird and generated 50% isopleths from each utilization distribution. These 50% isopleths represent core-use areas for each bird. We then estimated daytime and nighttime exposure to industrial activities by intersecting core-use areas (50% isopleths) with GIS layers described above.

Results

Tag diagnostics and bird recoveries

We used a combination of tracking duration, tag sensor data, movement data, and tag recoveries to assess tag diagnostics and bird health. Of 15 tags deployed, one failed to collect valid location data tag ID # 225584). The remaining 14 tags transmitted for a mean of 9 days (SD 10 days, range 0.84 to 27 days). Six of these tags transmitted for < 24 hours prior to release. Therefore, only 8 tags collected data over a period spanning > 24 hours (Table 1).

Sensor and movement data

Tag sensor data includes tag voltage (V) and tag transmit current (mA). The tag manufacturer provides information on the operational range of values for each sensor (3.6-4.0 V and 90-125 mV) indicating good tag health. We summarized the voltage and transmit-current values of each tag's final location relative to the healthy operational range to assess if these values can provide information on why the tags ceased to transmit.

Overall, 36% of tags (n=5 of 14 tags) showed voltage values outside of the healthy range during their final transmission (Figure 3). The mean voltage during final transmission was 3.68 V (SD 0.27 V, range 2.85 to 3.95 V). Overall, 36% of tags (n=5 of 14 tags) showed current values outside of the healthy range during their final transmission (Figure 4). The mean current during final transmission was 103.04 mV (SD 28.44 mV, range 50 to 170 mV). Three of the 14 tags (21%) showed both voltage and current values outside of the healthy range during the final transmission.

In addition to tag sensor data, we calculated and mapped the distance birds traveled in the final 24-hours of transmission for the eight tags collected data for > 24 hours (Figures 5 to 18). The mean distance traveled during the final 24-hours of transmission was 64.88 km (SD 87.84 km, range 3 to 266 km).

Tag recoveries

Two tagged birds were recovered during the monitoring efforts. On March 2, a Common Tern (tag ID #225579) was recovered live by monitors beneath the powerlines in Galinhos with head injuries consistent with a powerline collision. It was taken to a rehabilitation center and died the same day. The tag was not working upon recovery and last transmitted on March 1 with final tag diagnostic values (voltage and current) in the healthy range (Table 1). The tag was removed from the bird and placed in a sunny location for testing. It did not resume operation. This bird was tagged on March 1 and tracked for <24 hours.

The second recovery was a Roseate Tern (tag ID #225577) discovered by PCCB-UERN monitors on a beach in the State of Ceará, about 120 km northwest of Galinhos. The bird was found dead in a decayed condition on March 11. The tag had last transmitted on March 9 with tag diagnostic values (voltage and current) in the healthy range (Table 1). The tag was removed from the bird and placed in a sunny location for testing. It resumed operation on March 14 with voltage values below the healthy range and transmit current (mA) values in the healthy range. Tracking data indicate that this bird traveled 78 km during the 24 hours preceding its final transmission on March 9. Therefore, the bird likely died shortly after its last tag transmission on March 9 due to apparent movement on March 8 and the decayed state it was found in on March 11.

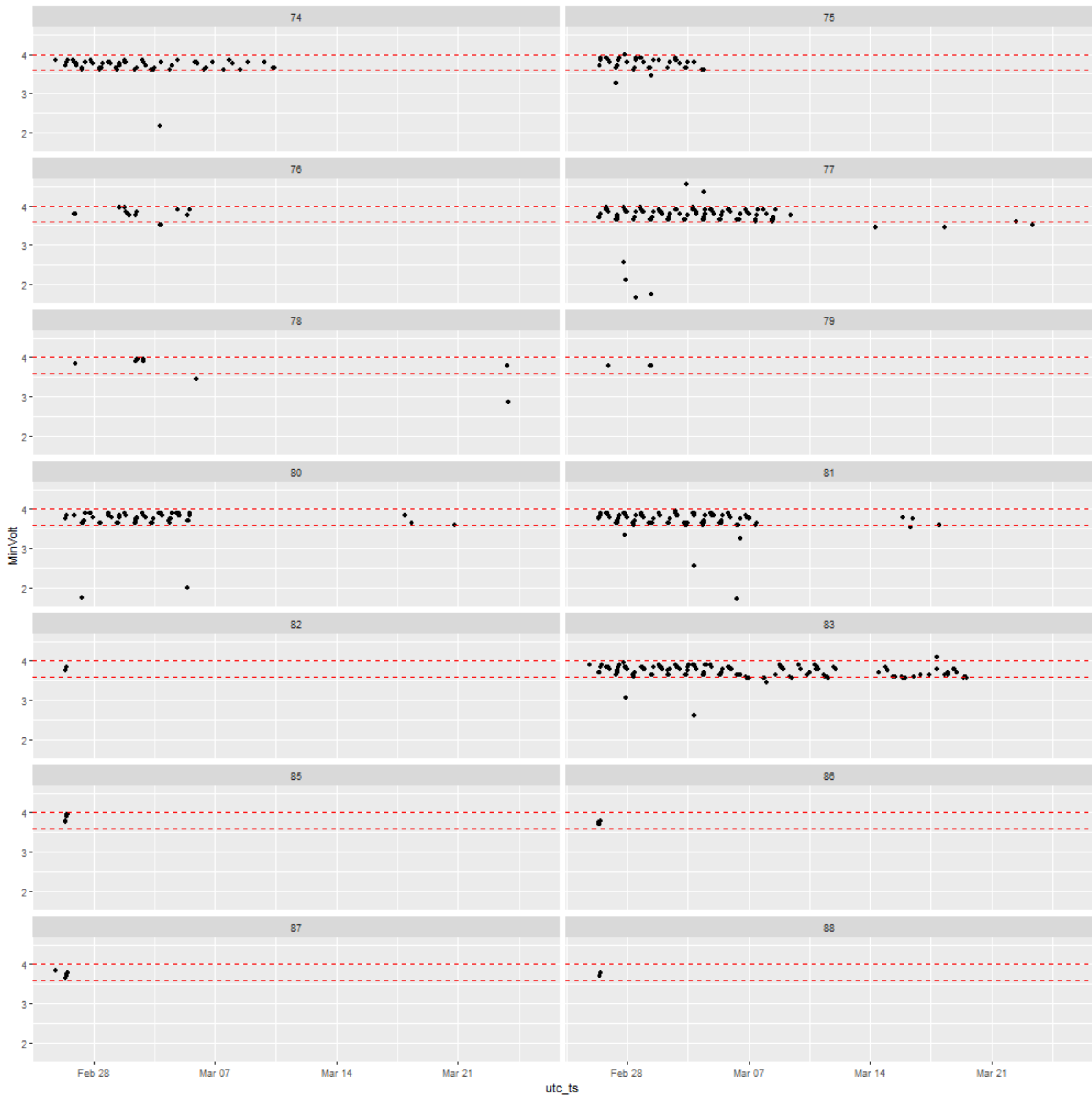

Figure 3. Plots of tag battery voltage (V) values over time for all data collected following tag deployment. Red dashed lines show values in healthy range.

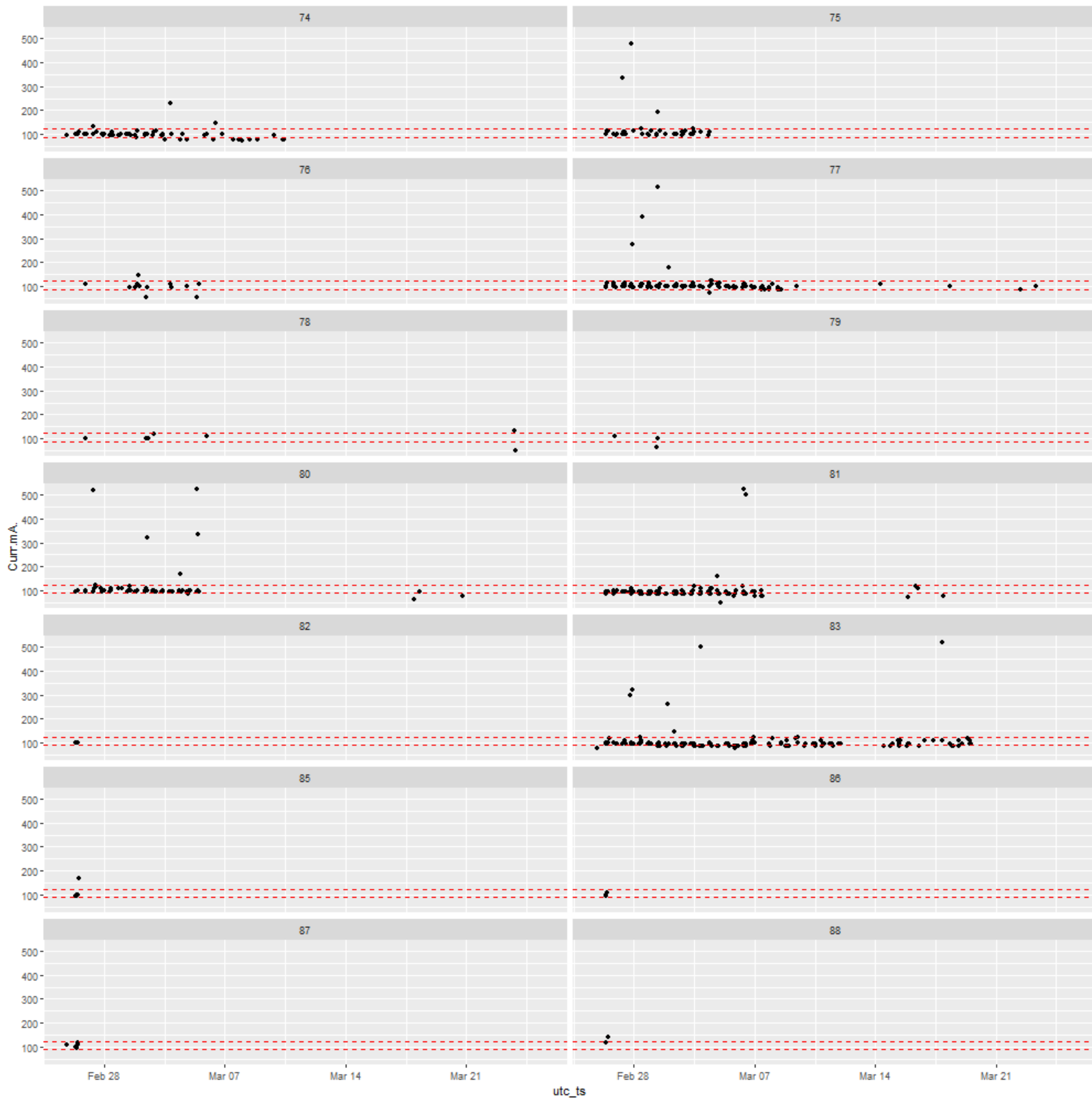

Figure 4. Plots of tag transmit current (mA) values over time for all data collected following tag deployment. Red dashed lines show values in healthy range.

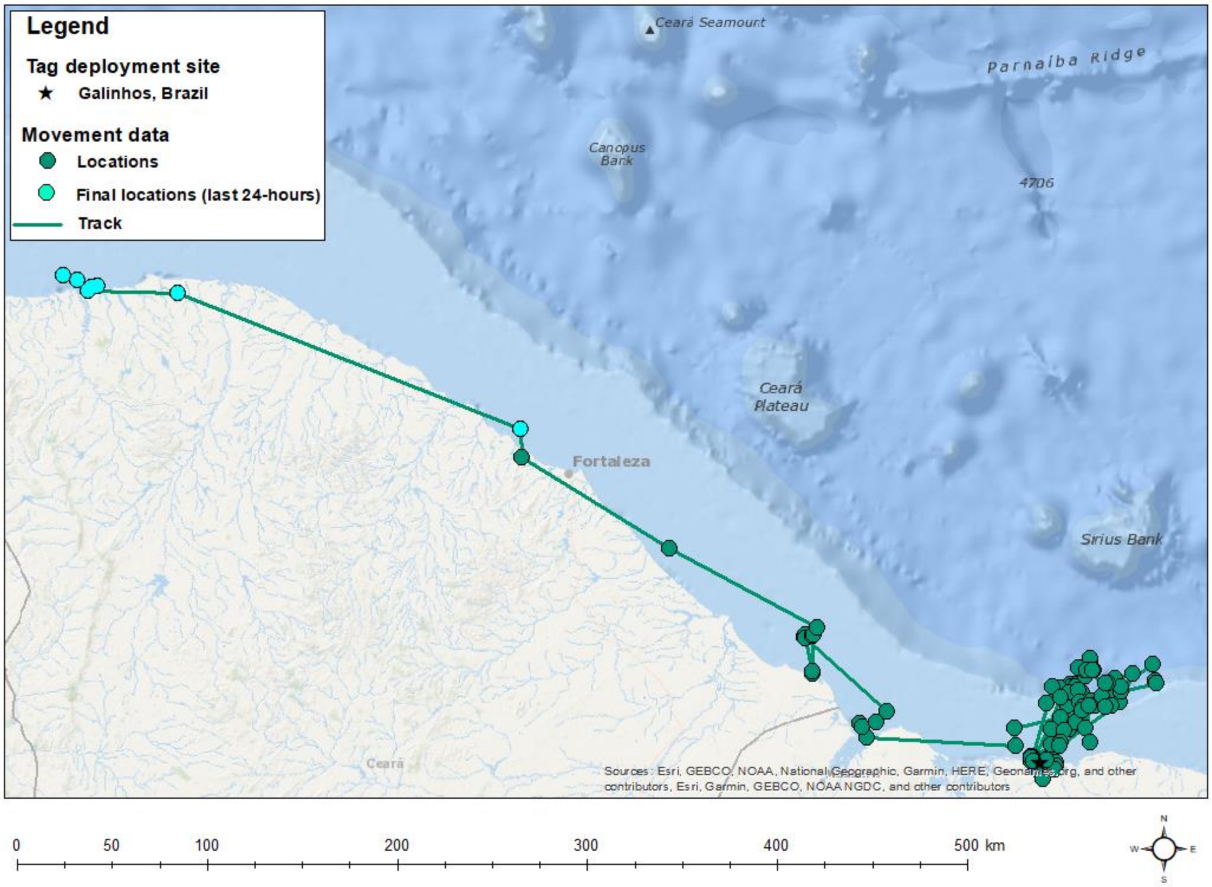

Figure 5. Map of location data from tag ID # 225574. Final tag locations recorded during last 24 hours of data collection are highlighted in blue. Total distance traveled within final 24 hours of data collection was 266 km (n=6 points).

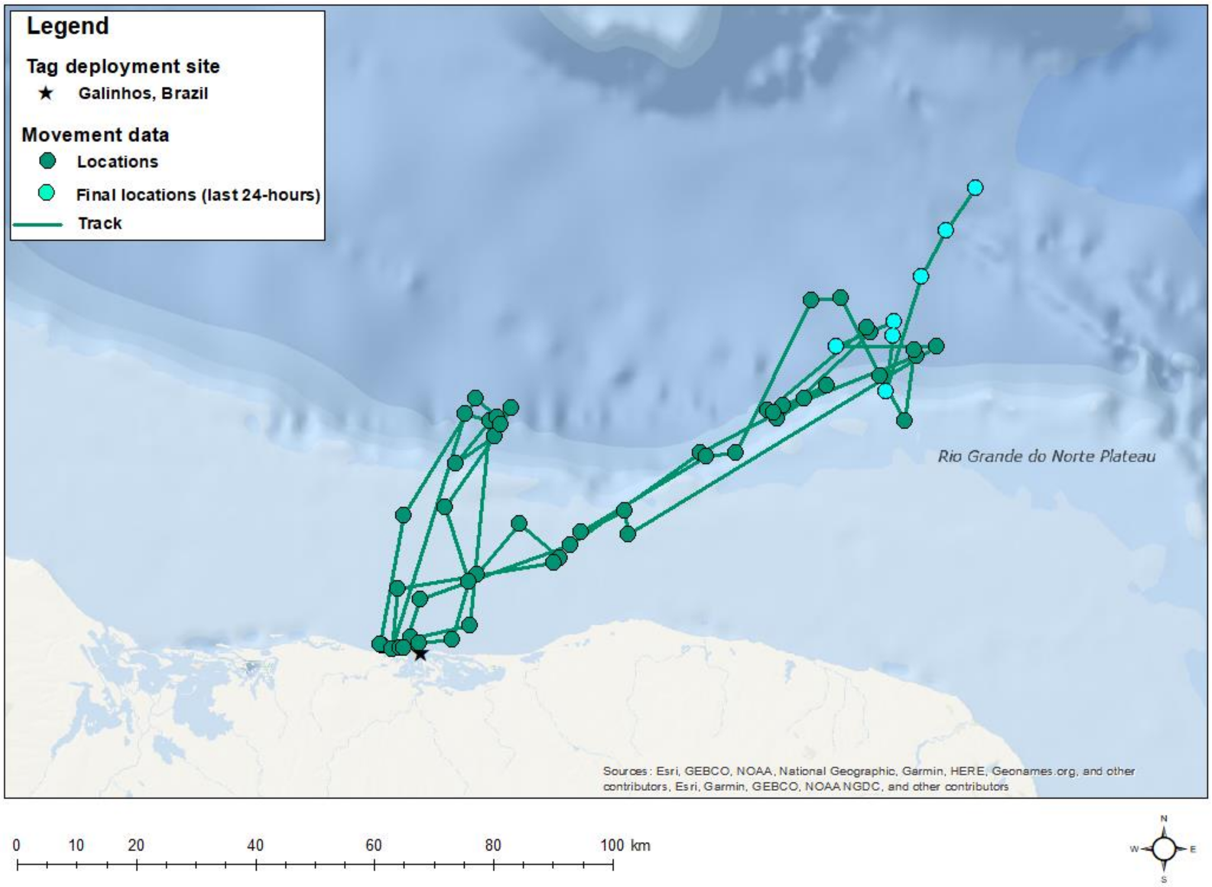

Figure 6. Map of location data from tag ID # 225575. Final tag locations recorded during last 24 hours of data collection are highlighted in blue. Total distance traveled within final 24 hours of data collection was 60 km (n=7 points).

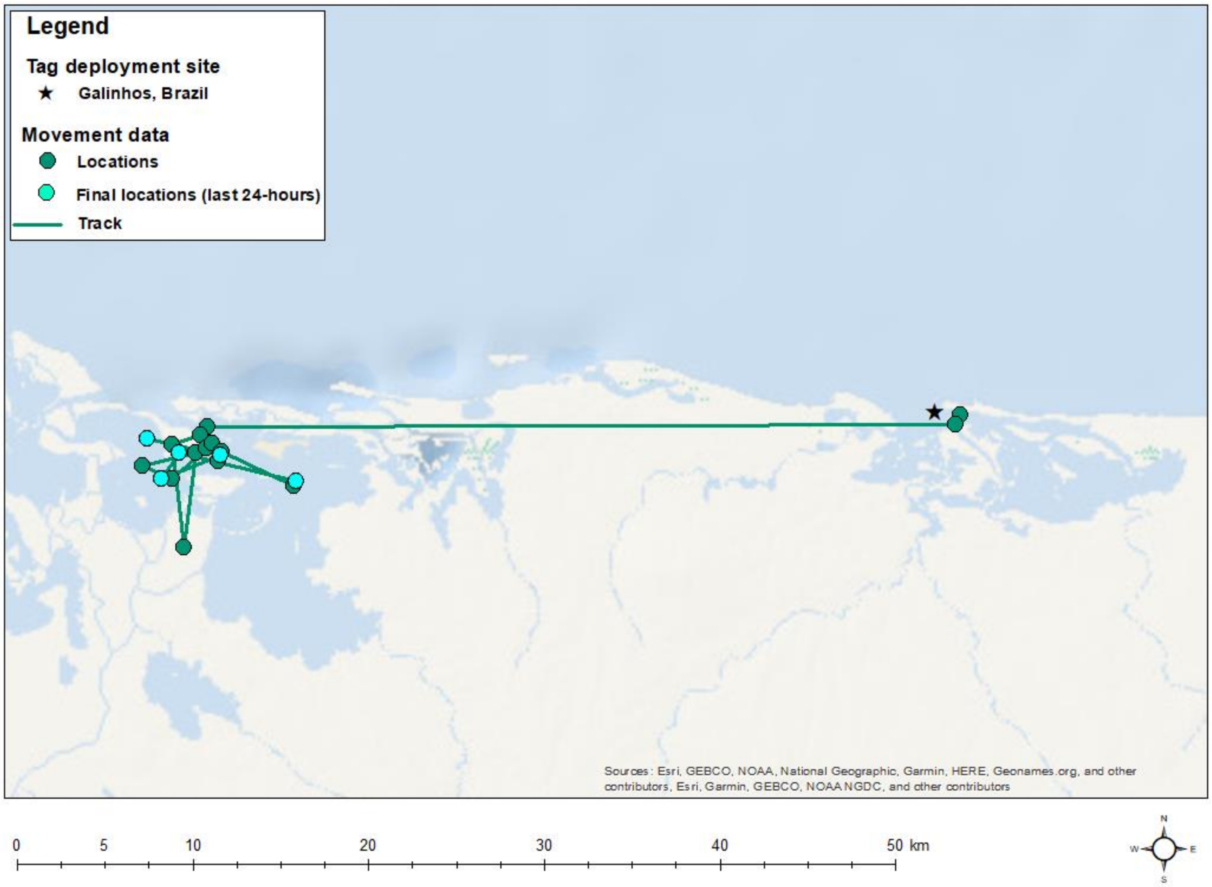

Figure 7. Map of location data from tag ID # 225576. Final tag locations recorded during last 24 hours of data collection are highlighted in blue. Total distance traveled within final 24 hours of data collection was 16 km (n=5 points).

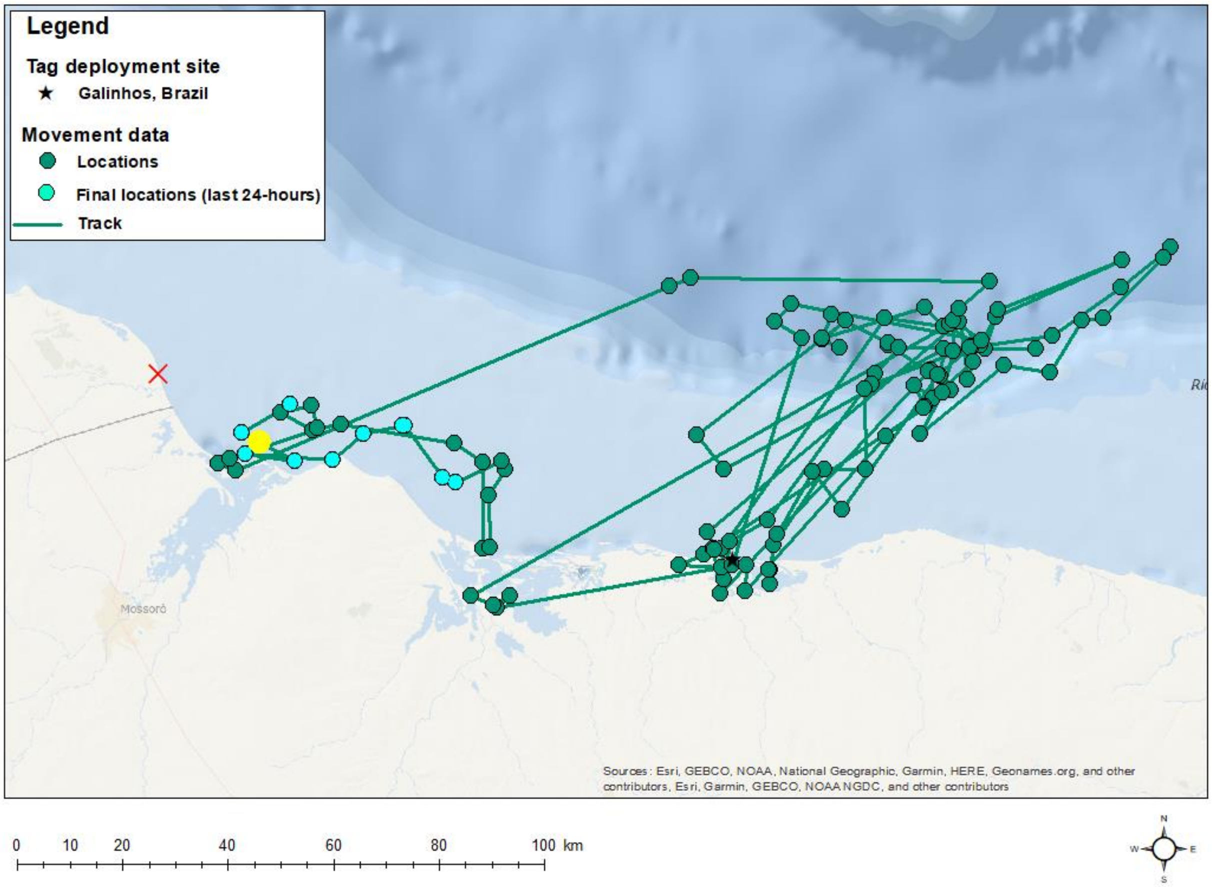

Figure 8. Map of location data from tag ID # 225577. Final tag locations recorded during last 24 hours of data collection are highlighted in blue. Total distance traveled within final 24 hours of data collection was 78 km (n=11 points). The final tag location is highlighted in yellow and occurred on March 9, 2022 at 07:51:46 BST. The bird was found in a decayed state by monitors on March 11, 2022 at the location marked with red X.

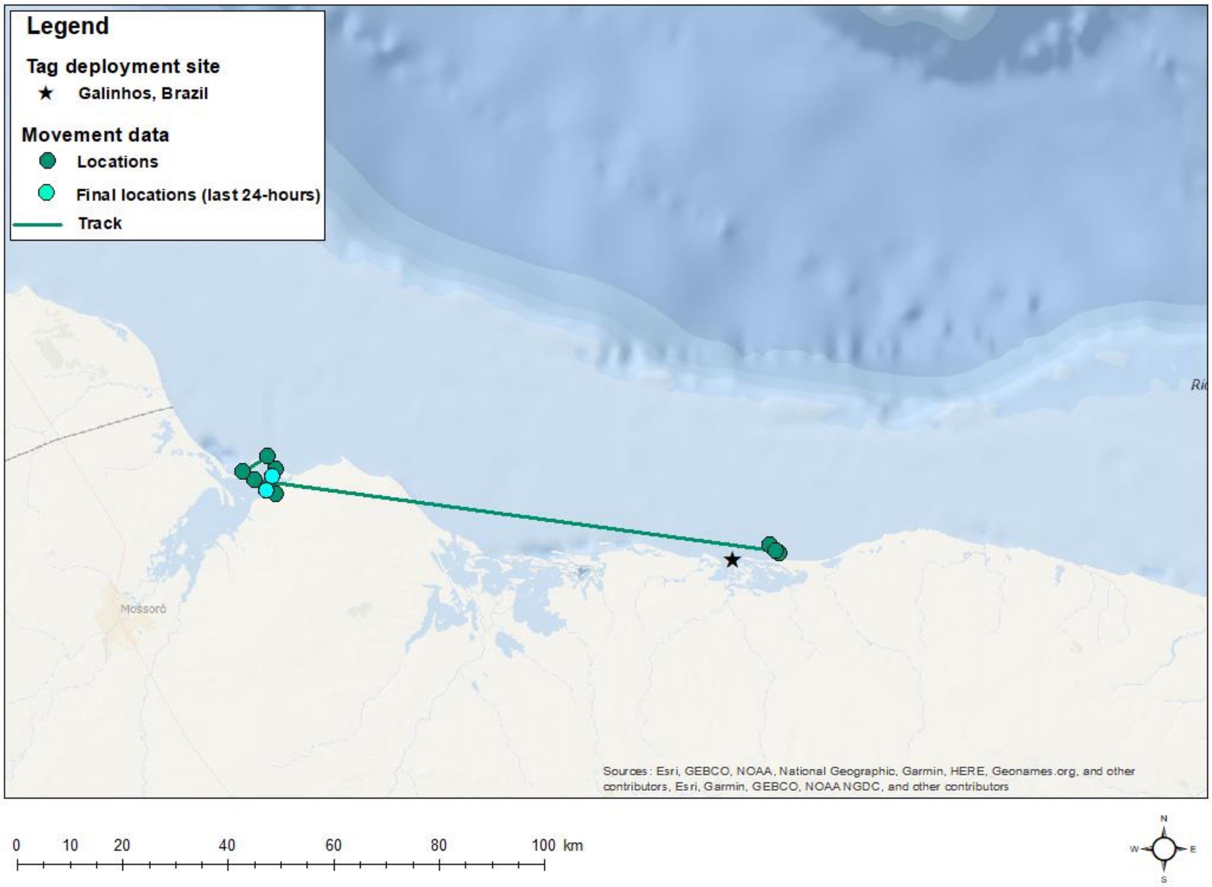

Figure 9. Map of location data from tag ID # 225578. Final tag locations recorded during last 24 hours of data collection are highlighted in blue. Total distance traveled within final 24 hours of data collection was 3 km (n=2 points).

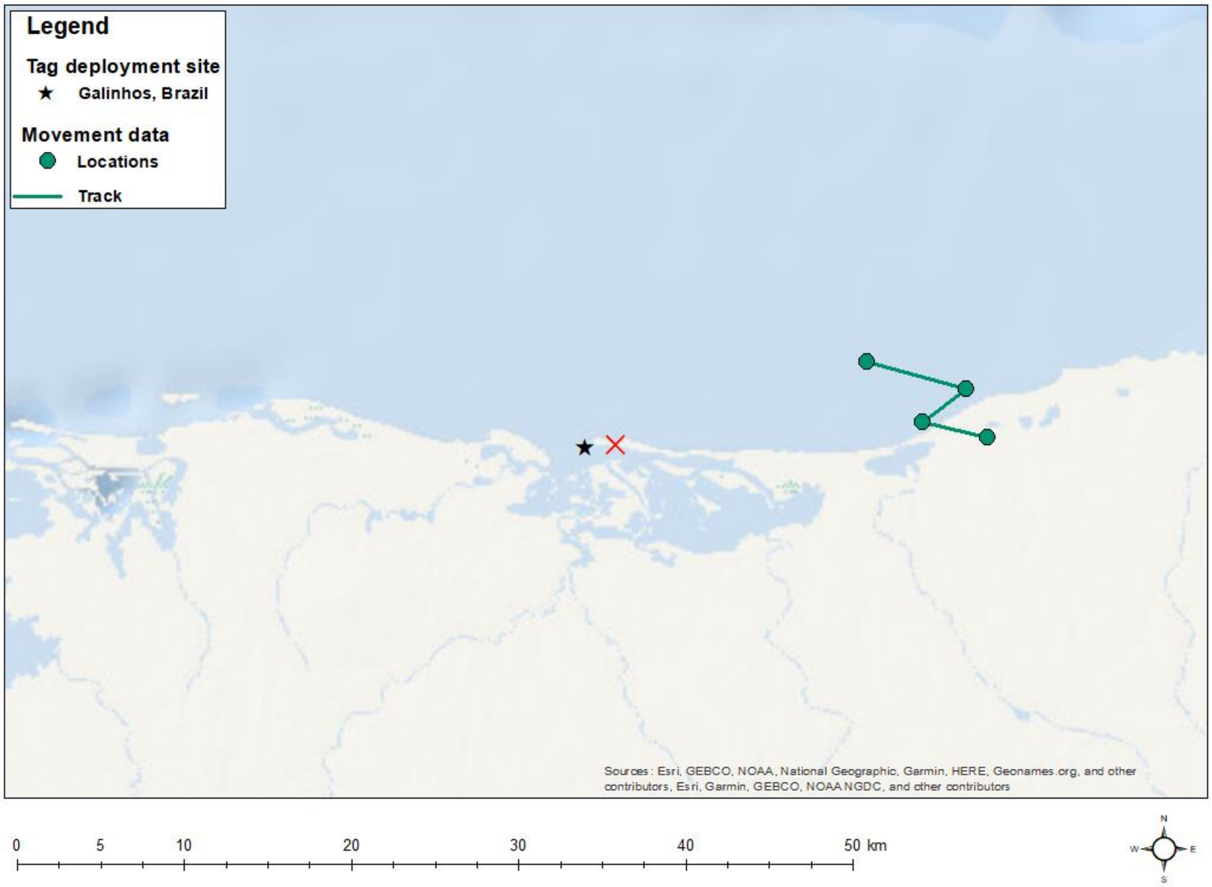

Figure 10. Map of location data from tag ID # 225579. Total transmission time was < 24 hours. The bird was recovered in powerline monitoring area in Galinhos (red X) on March 2nd with head injuries and non-functioning tag. The bird was taken to a rehabilitation facility and died.

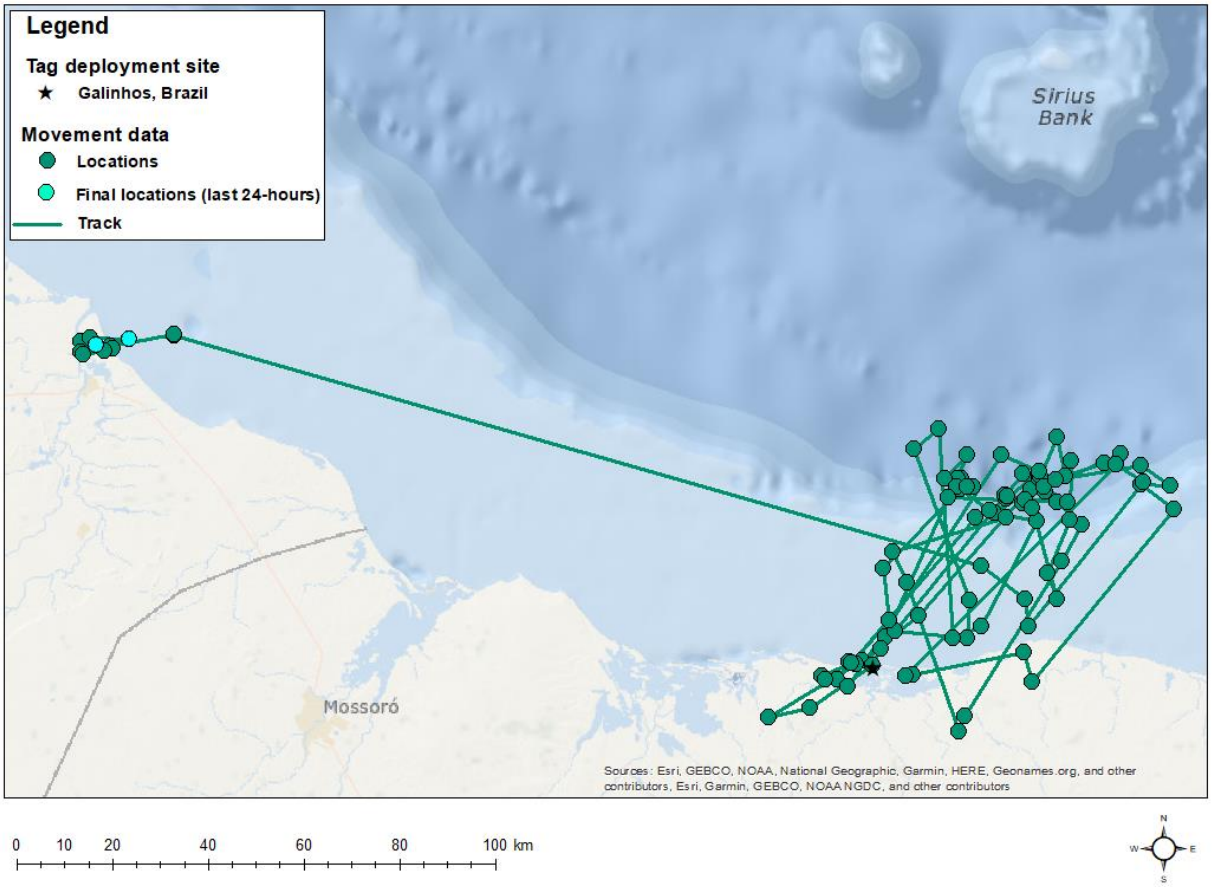

Figure 11. Map of location data from tag ID # 225580. Final tag locations recorded during last 24 hours of data collection are highlighted in blue. Total distance traveled within final 24 hours of data collection was 7 km (n=2 points).

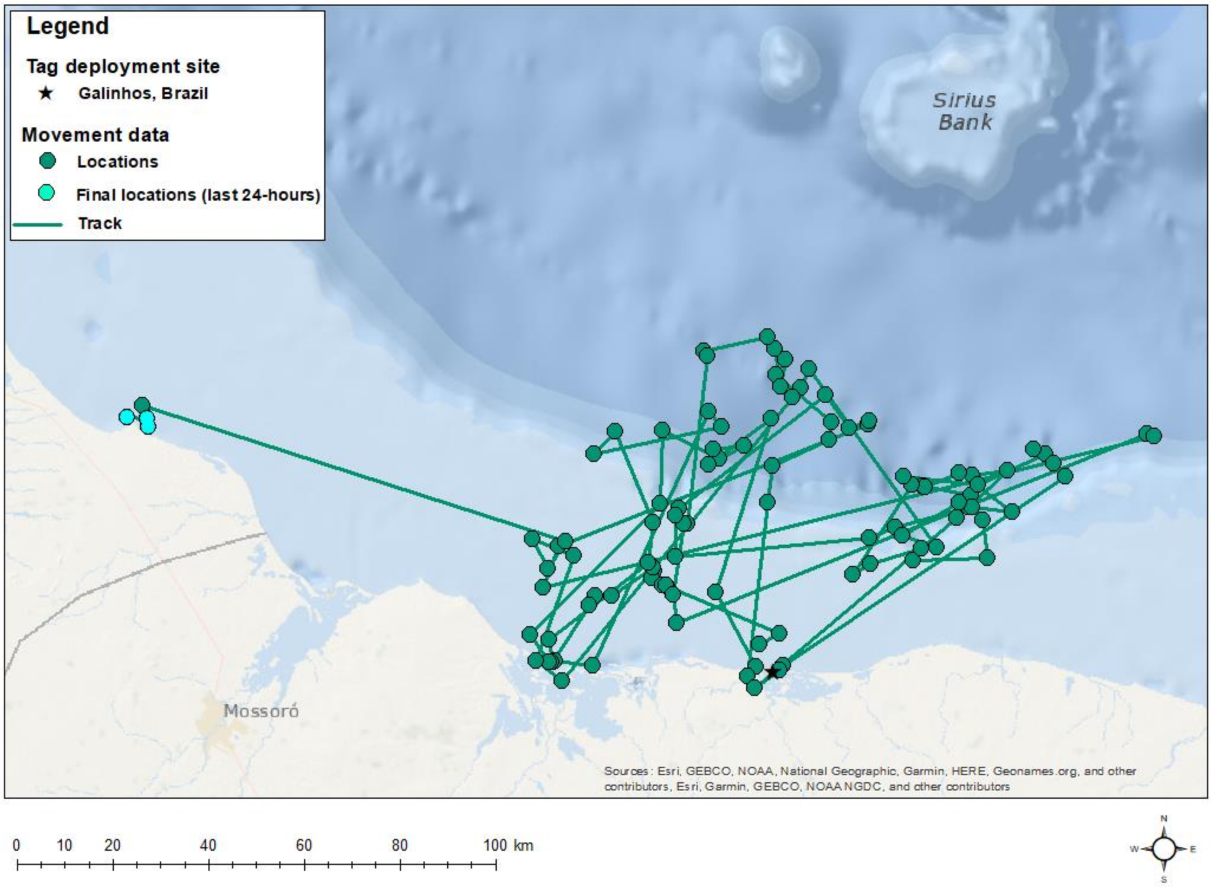

Figure 12. Map of location data from tag ID # 225581. Final tag locations recorded during last 24 hours of data collection are highlighted in blue. Total distance traveled within final 24 hours of data collection was 6 km (n=3 points).

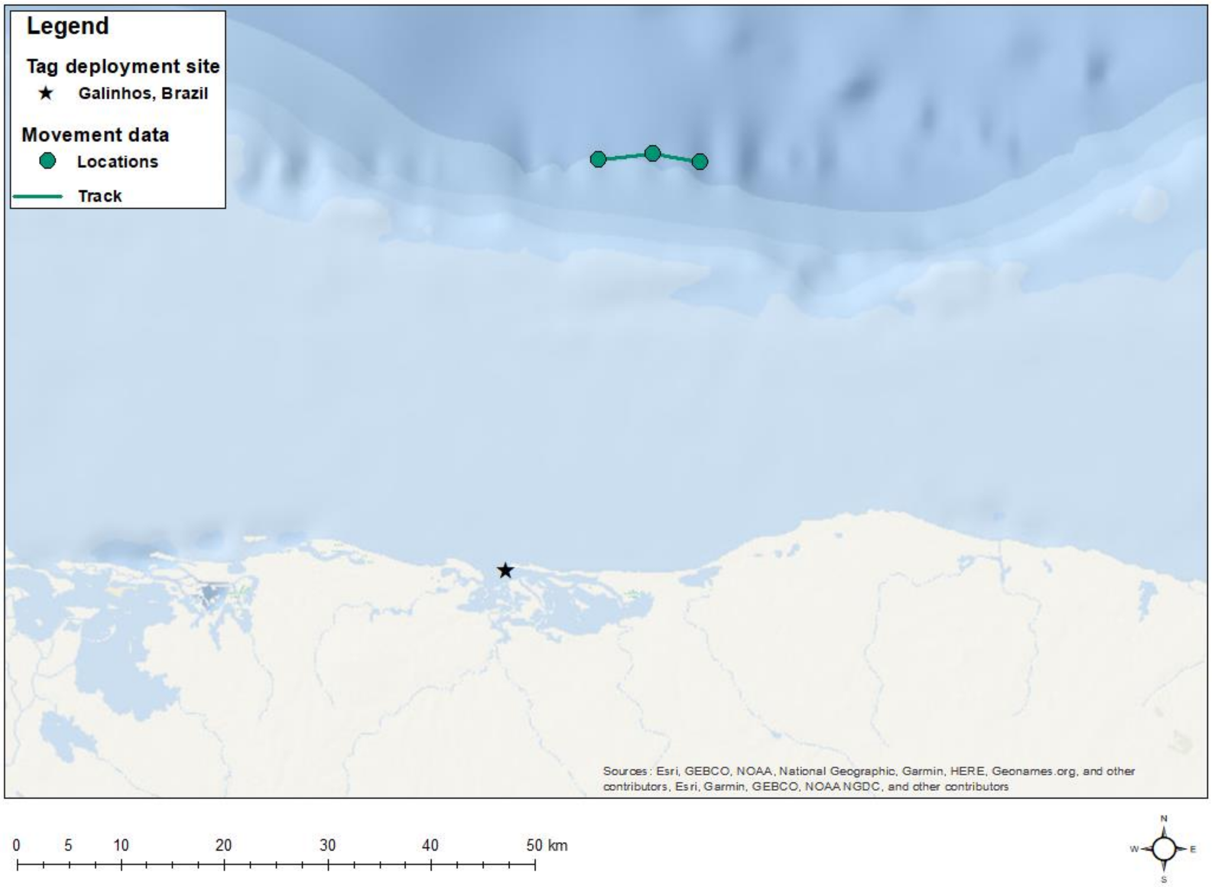

Figure 13. Map of location data from tag ID # 225582. Total transmission time was < 24 hours.

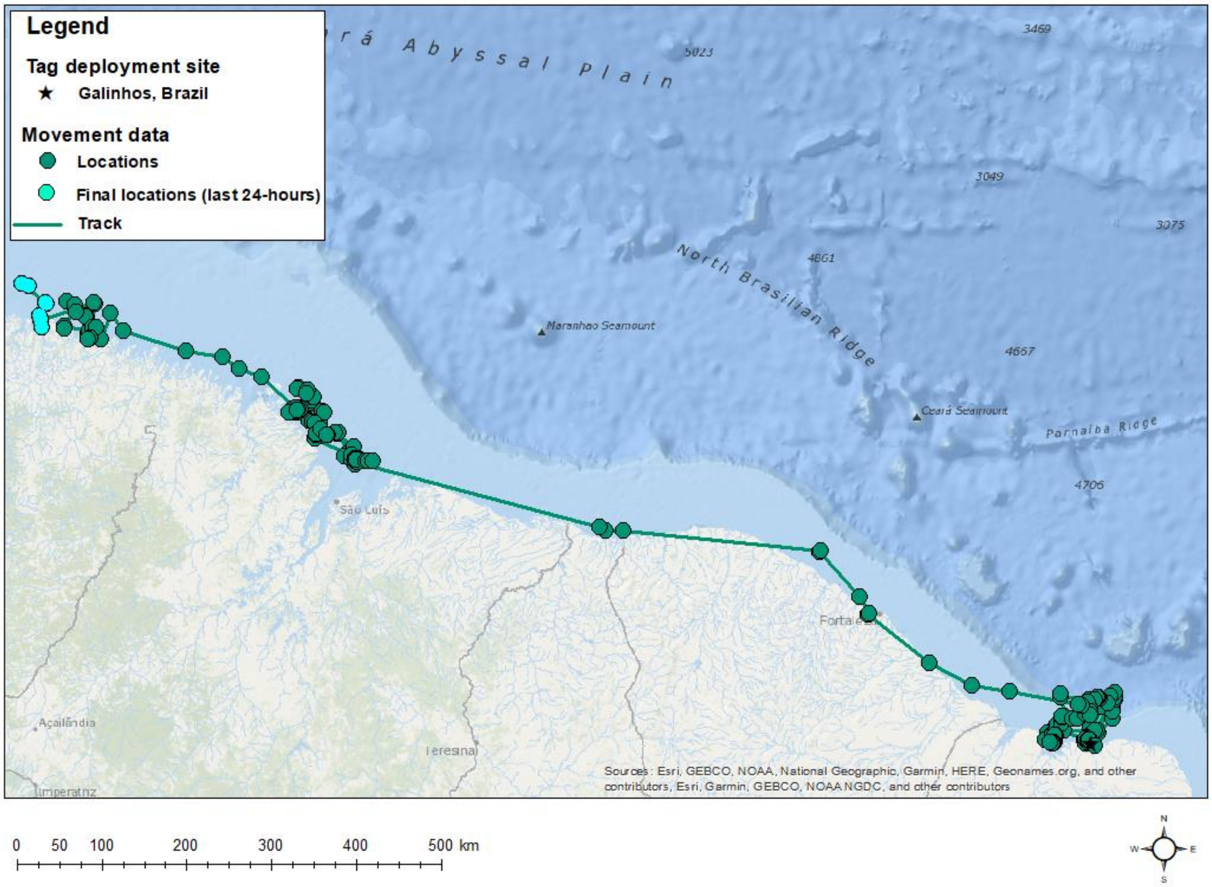

Figure 14. Map of location data from tag ID # 225583. Final tag locations recorded during last 24 hours of data collection are highlighted in blue. Total distance traveled within final 24 hours of data collection was 83 km (n=8 points).

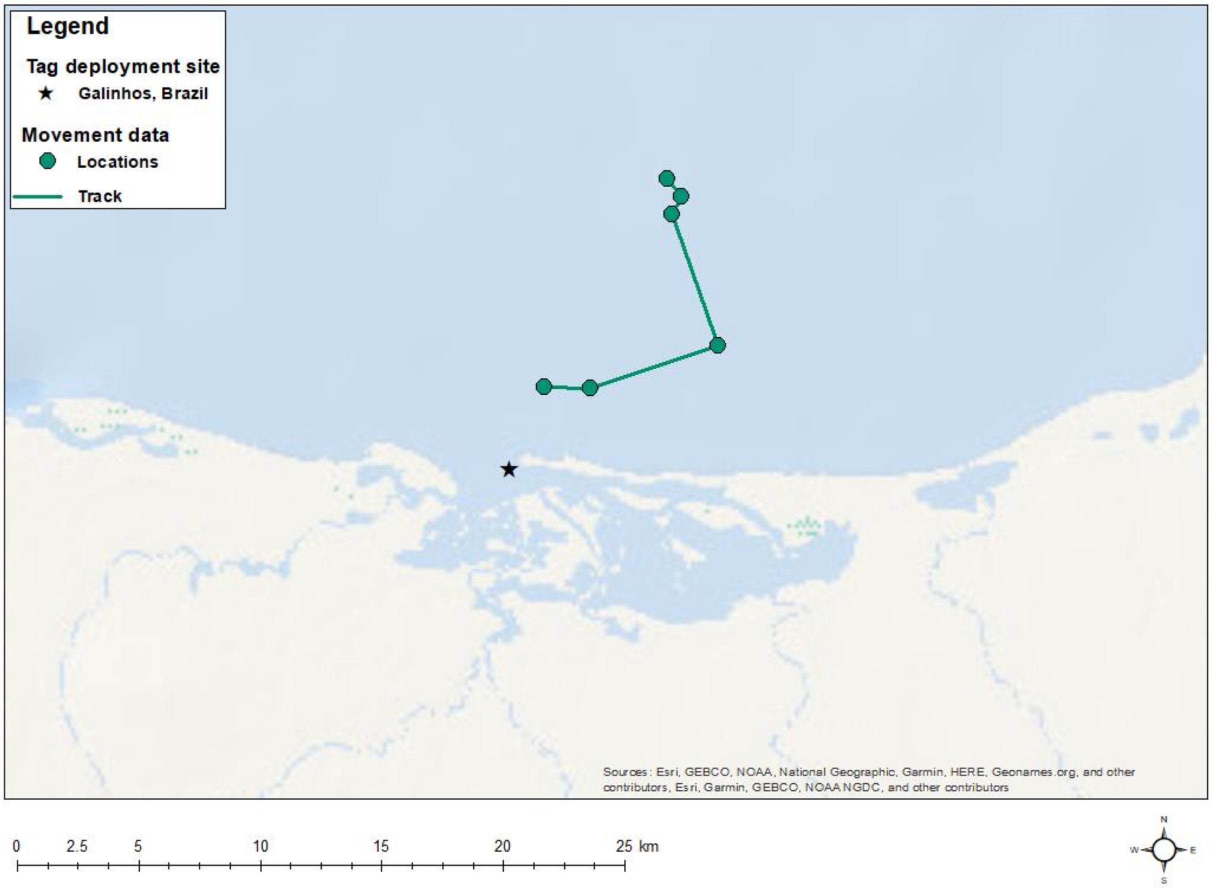

Figure 15. Map of location data from tag ID # 225585. Total transmission time was < 24 hours.

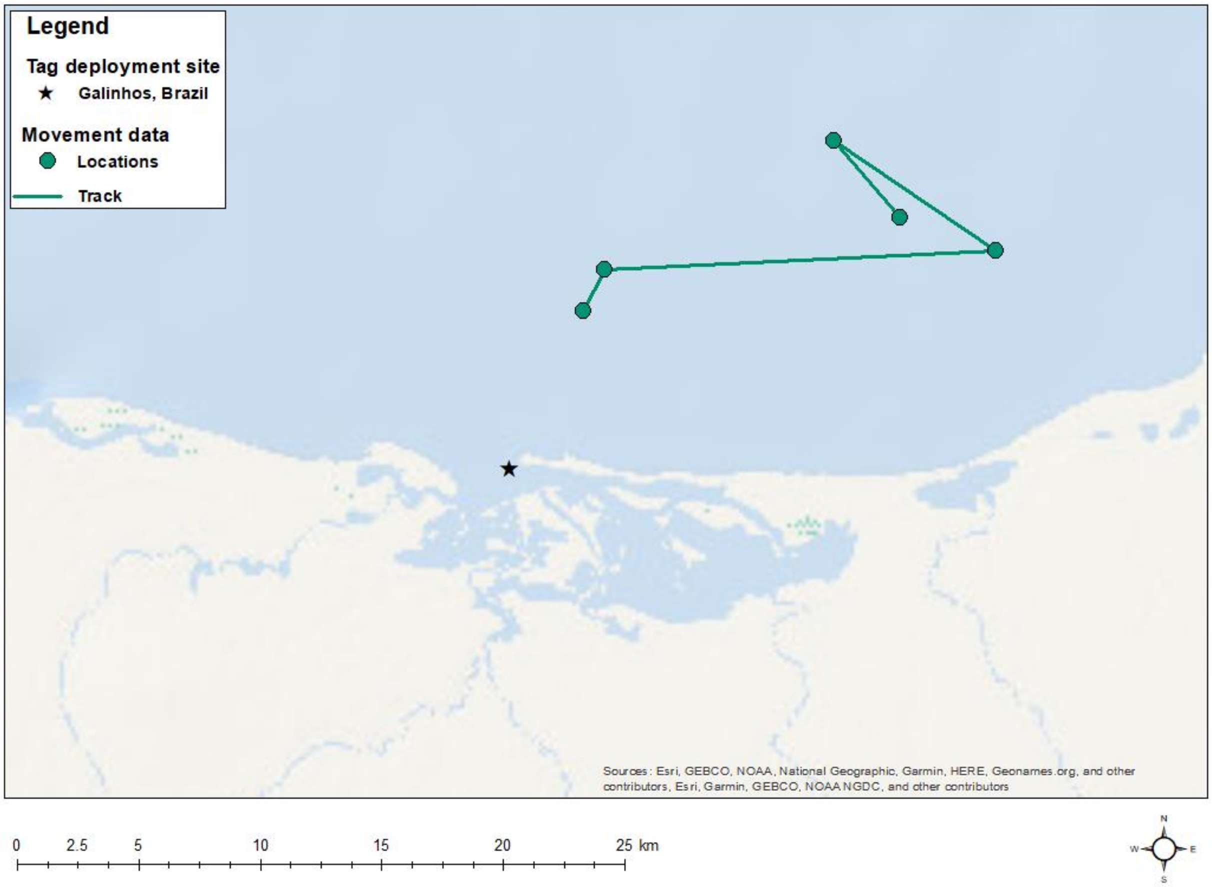

Figure 16. Map of location data from tag ID # 225586. Total transmission time was < 24 hours.

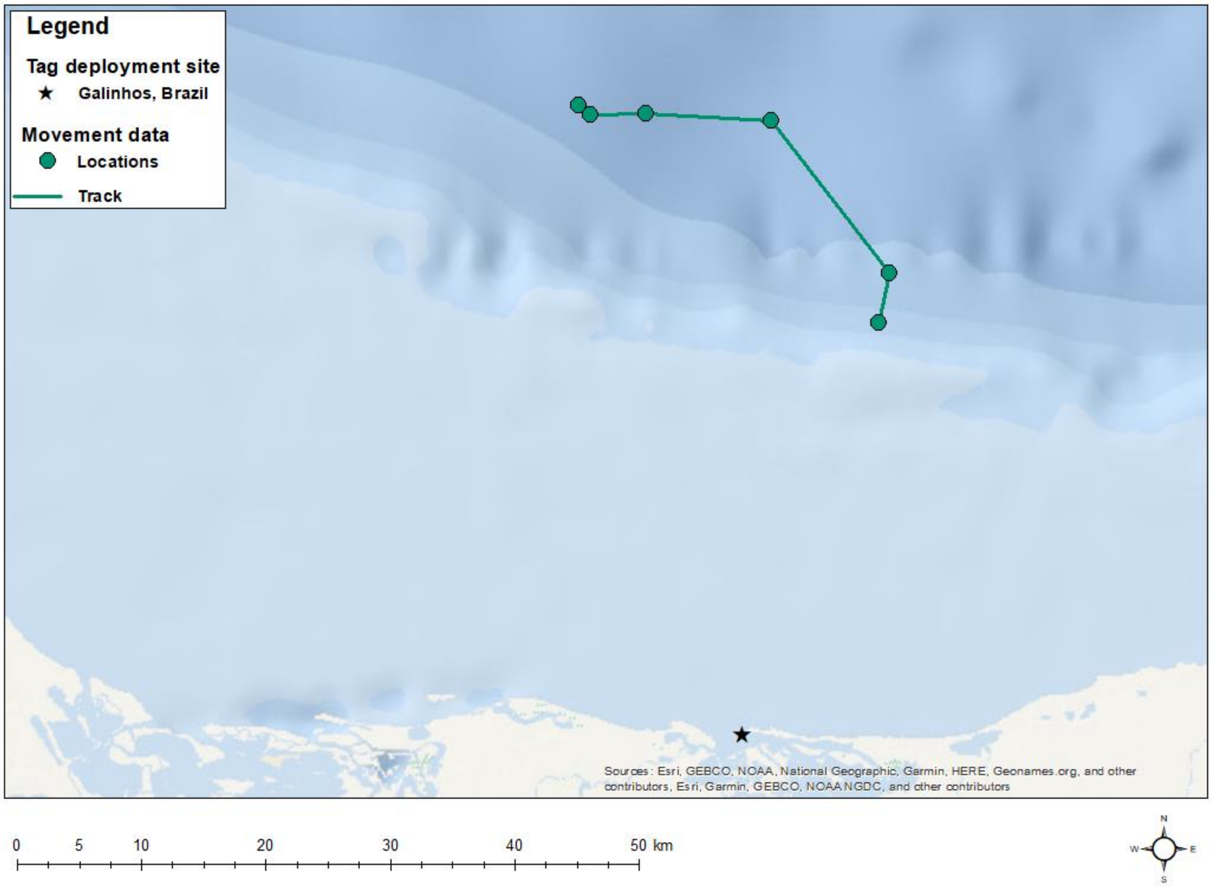

Figure 17. Map of location data from tag ID # 225587. Total transmission time was < 24 hours.

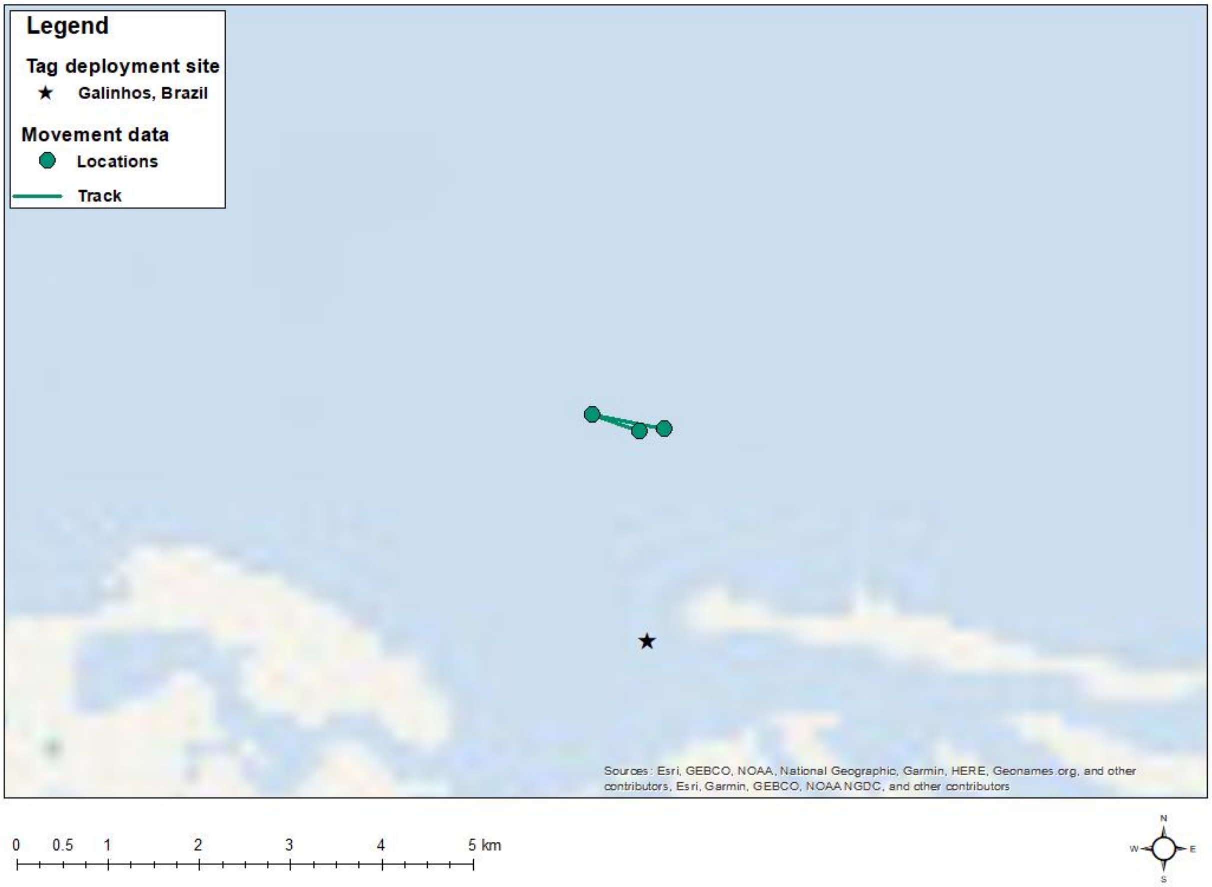

Figure 18. Map of location data from tag ID # 225588. Total transmission time was < 24 hours.

Table 1. Banding and satellite tag diagnostic data from two Common Terns (*S. hirundo*) and 12 Roseate Terns (*S. douglaii*) tagged in Galinhos Brazil from February 25 to March 2, 2022. Final tag voltage (V) and current (mA) values in red indicate values outside the healthy tag operational range. Days tracked indicates the time in days between the first and last location. Distance traveled final 24-hours sums the Euclidian distance (km) between all successive points within 24 hours of the last recorded location.

Tag ID	Tag Datetime (BST)	Species	Band	PFR Band	First location (BST)	Last location (BST)	N locs	Days tracked	Final tag voltage (V)	Final tag current (mA)	Distance traveled (km) final 24-hours
225574	2/26/22 1:16	S. dougallii	H924 43	ye(JR1)	2/26/22 5:41	3/10/22 9:15	97	12.15	3.65	80.0	266
225575	2/25/22 23:14	S. dougallii	H102 565	ye(JR0)	2/26/22 6:23	3/4/22 9:40	57	6.14	3.60	110.0	60
225576	3/1/22 3:33	S. hirundo	H103 197		3/1/22 8:59	3/5/22 9:19	19	4.01	3.90	110.0	16
225577 *	2/25/22 22:31	S. dougallii	Brazil recap H108 406	ye(JP6)	2/26/2022 8:23	3/9/22 7:51	113	10.98	3.75	102.5	78
225578	3/2/22 4:00	S. hirundo	H103 187		3/2/22 4:42	3/25/22 9:04	10	23.18	2.85	50.0	3
225579 **	3/1/22 2:38	S. hirundo	H103 192		3/1/22 5:41	3/1/22 8:59	4	< 1	3.80	102.5	NA
225580	2/26/22 1:28	S. dougallii	H924 39	ye(JR2)	2/26/22 5:40	3/25/22 9:03	177	27.14	3.60	80.0	7
225581	2/26/22 1:41	S. dougallii	H924 28	ye(JR3)	2/26/22 5:40	3/18/22 17:10	104	20.48	3.60	80.0	6

225582	2/25/22 23:08	S. dougallii	H924 05	ye(JP8)	2/26/22 6:16	2/26/22 8:17	3	< 1	3.85	102.5	NA
225583	2/25/22 23:22	S. dougallii	U.S. recap 1382-1392 6	ye(JP9)	2/26/22 5:41	3/19/22 11:04	178	21.22	3.55	95.0	83
225584	2/25/22 22:10	S. dougallii	H924 41	ye(JP5)	NA	NA	0	NA	NA	NA	NA
225585	2/26/22 23:02	S. dougallii	U.S. recap 1332-5199 3	rd(K93)	2/26/22 5:39	2/26/2022 9:08	6	< 1	3.95	170.0	NA
225586	2/26/22 00:39	S. dougallii	U.S. recap 1402-1974 2	bl(JJ6)	2/26/22 5:44	2/26/22 8:19	5	< 1	3.80	110.0	NA
225587	2/25/22 21:35	S. dougallii	H103 184	ye(JP4)	2/26/22 5:40	2/26/22 9:07	6	< 1	3.80	110.0	NA
225588	2/25/22 22:49	S. dougallii	H924 34	ye(JP7)	2/26/22 5:44	2/26/22 8:23	3	< 1	3.80	140.0	NA

* Carcass recovered 120 km away by PMP monitors in decayed state on 3/11/2022. Location found: -4.77709, -37.27356
** Bird recovered on March 2 after colliding with the powerline in Galihos and was sent to rehabilitation center. It died in the rehabilitation center on March 2.

Exposure to industrial activities

The Argos filter retained 782 locations as valid after processing. Mean number of locations per bird (n=15) retained by the filter was 52 locations (SD 52, range 0 to 178 locations; Table 1). Of the 15 birds tagged, six Roseate Terns had sufficient data (≥ 5 days tracked) to be included in the exposure analysis. Results of the exposure analysis are described below.

Location data

For the location-scale exposure analysis, we used all LC3,2,1 locations retained by Argos filter (n=177 locations). The resulting dataset for each bird (n=6) had a mean of 28 locations (SD 9, range 10 to 39 locations). We buffered each location by its Argos error radius (mean 918 m, SD 374 m, range 122 to 1,499 m) and overlayed the buffered locations on GIS layers representing industrial activities (Fig. 19)

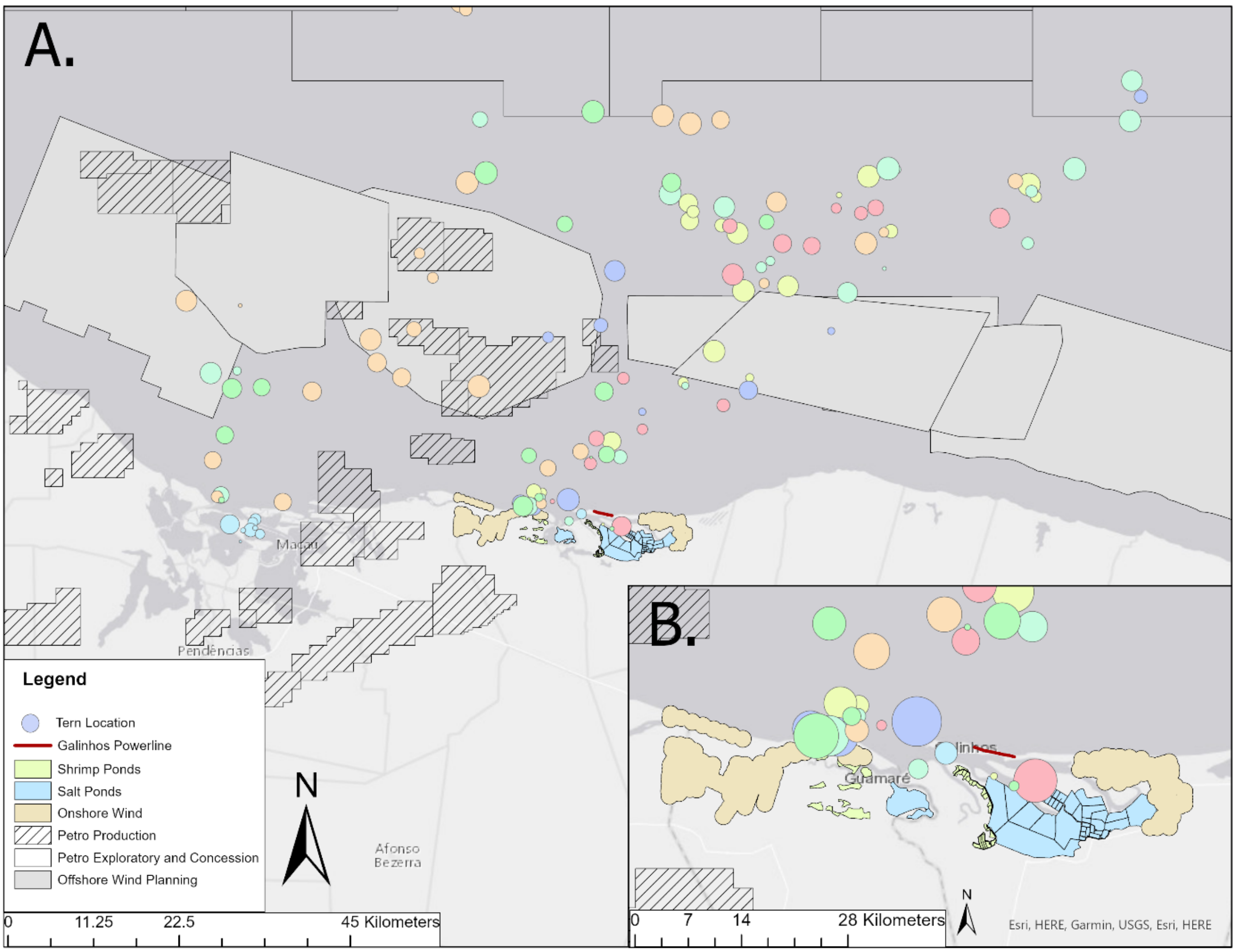

Figure 19: Roseate Tern locations in the study area. Circles representing tern locations are symbolized by bird ID (color) and estimated error radius of the Argos location (size). Map A shows tern locations in Galinhos and Guamaré and offshore. Map B shows tern locations onshore.

Overlap of location data and industrial activities

Overlap between locations and industrial activities was highest for offshore wind energy, with 83% of birds (n=5 of 6) occurring in the planning areas (Table 2). Most birds (67%, n=4 of 6) using offshore habitats also overlapped with exploratory petroleum layers. Overlap with petroleum production occurred to a lesser extent (33%, n=2 of 6 birds). For each tern, we calculated minimum, maximum, and mean distances between offshore tag detections and the coast (Table 3). Offshore locations were a mean distance of 20.73 km (SD 5.53, range 0.05 to 63.97 km) from the coastline. Onshore overlap was highest (67%, n=4 of 6 birds) with onshore wind energy facilities and salt ponds, followed by shrimp ponds (50%, n=3 of 6 birds).

Table 2. Filtered Argos locations (error radius <1,500 m) of Roseate Terns that overlapped industrial activities in Galinhos and Guamaré. Table shows number of locations per bird used in analysis (N) and the number of locations with exposure to each industrial activity type.

Bird ID	N	Galinhos powerline	Shrimp ponds	Salt ponds	Onshore Wind	Petro production	Petro concession	Petro exploratory	Offshore wind planning
225574	26	0	0	1	2	0	0	0	4
225575	10	0	1	0	2	2	0	1	4
225577	26	0	1	1	1	0	0	2	2
225580	39	0	0	1	0	0	0	0	0
225581	28	0	0	0	0	3	0	3	9
225583	36	0	1	1	1	0	0	1	2
Total		0	3	4	6	5	0	7	21

Table 3: Filtered Argos locations (error radius <1,500 m) of Roseate Terns relative to distance to shore. Table shows number of offshore locations per bird (N) and summary statistics of the distance (km) between offshore locations and the coastline.

Bird ID	N	Max	Min	Mean	SD
225574	23	41.19	0.46	22.39	14.60
225575	9	55.61	0.47	19.95	16.76
225577	24	57.21	0.05	26.72	17.43
225580	25	36.47	0.08	13.16	14.38
225581	28	63.97	0.47	26.37	18.30
225583	35	52.08	0.07	15.79	14.96
Total	144	63.97	0.05	20.12	16.71

Core-use areas

For the core-use area exposure analysis, we used all locations retained by Argos filter and subset those data to remove points that were within 120 min to address temporal autocorrelation. The resulting dataset for each bird (n=6) had a mean of 34 locations (SD 20, range 13-66 locations). The mean number of locations per bird used to generate daytime utilization distributions was 18 locations (SD 8, range 8-34 locations). The mean number of locations per bird used to generate nighttime utilization distributions was 16 locations (SD 10, range 5-32 locations).

Overall, exposure to offshore industrial activities was highest during the day, and exposure to onshore industrial activities was highest at night (Fig 20). During the day, most birds (83%, n=5 of 6) had core-use areas that overlapped with offshore wind planning areas, exploratory petroleum areas, and petroleum production areas (Table 4).

During the night, most birds (83%, n=5 of 6) had core-use areas that overlapped with onshore wind energy areas, salt ponds, and shrimp ponds (Table 4). Exposure to offshore wind planning areas and petroleum production areas also occurred during the night (67%, n=4 of 6 birds). Half of the birds (50%, n=3 of 6) had overlap between night core-use areas and the Galinhos powerline.

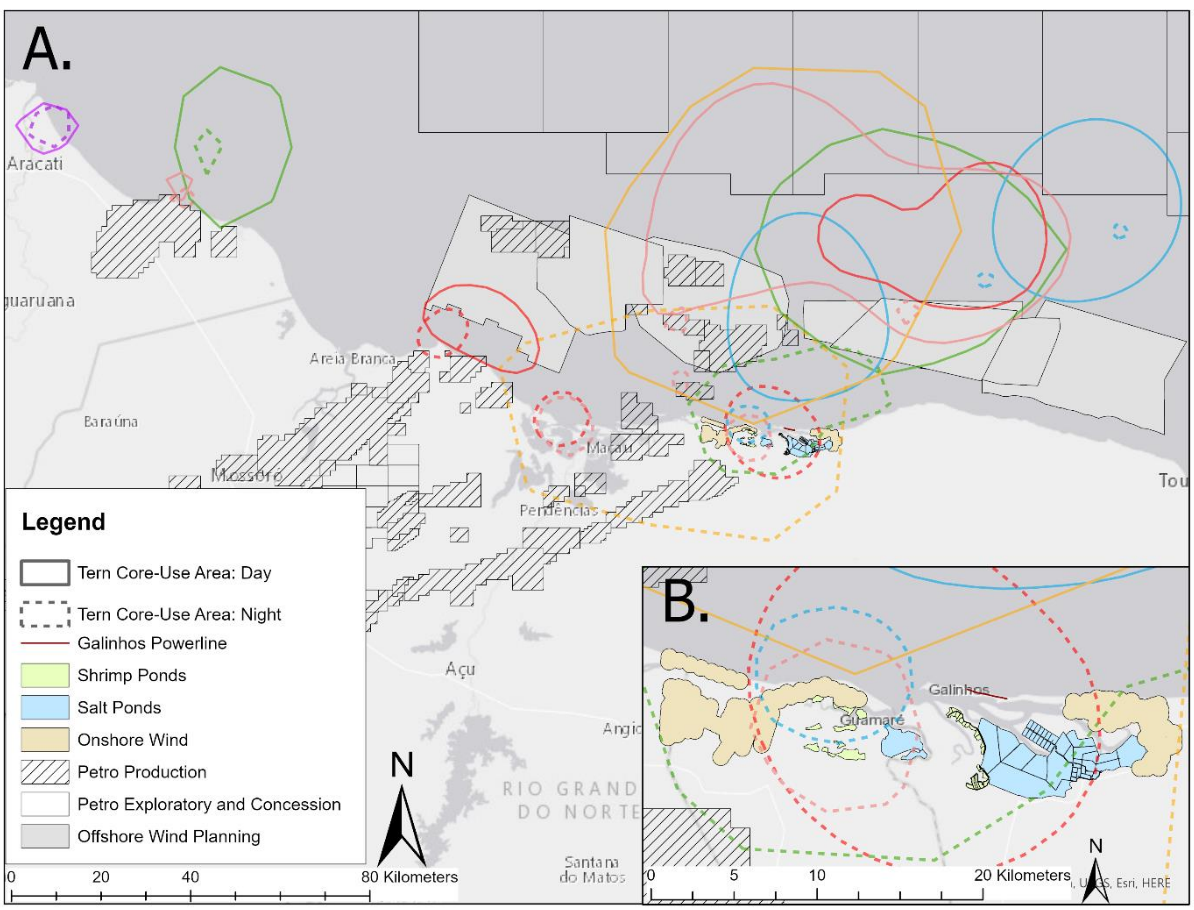

Figure 20: Day and night core-use areas of Roseate Terns in the study area. Core-use area boundaries are symbolized by bird ID (color). Solid outlines represent day core-use areas, while dashed lines represent night core use areas. Map A shows all core-use areas and map B shows core-use areas onshore.

Table 4 Day and night core-use areas of Roseate Terns relative to industrial activities in Galinhos and Guamaré. Values of 1 indicate where core-use areas overlapped with industrial activities.

	Galinhos powerline	Shrimp ponds	Salt ponds	Onshore Wind	Petro production	Petro concession	Petro exploratory	Offshore wind planning
Bird ID (PTT)								
Day core-use area								
225574	0	0	0	0	1	0	1	1
225575	0	0	0	0	1	0	1	1
225577	0	0	0	0	1	0	1	1
225580	0	0	0	0	0	0	0	0
225581	0	0	0	0	1	0	1	1
225583	0	0	0	0	1	1	1	1
Total (day)	**0**	**0**	**0**	**0**	**5**	**1**	**5**	**5**
Night core-use area								
225574	1	1	1	1	1	0	0	1
225575	0	1	1	1	0	0	0	0
225577	1	1	1	1	1	0	0	1
225580	0	0	0	0	0	0	0	0
225581	0	1	1	1	1	0	0	1
225583	1	1	1	1	1	0	0	1
Total (night)	3	5	5	5	4	0	0	4

Discussion

This study used newly available 2-g satellite transmitters to track movements of *Sterna* terns in a spring migratory staging area in northeastern Brazil. The main objectives of the study were to assess onshore and offshore habitat use relative to some of the primary industrial activities overlapping with tern habitat within the region. However, miniaturized satellite tracking technology for tracking small-bodied terns is relatively new. Several of the transmitters ceased to collect data within 24 hours of deployment, and the remaining transmitters collected data for up to one month.

Due the variability in data collected per bird and small sample sizes overall, results from this study should be considered preliminary and in the context of a pilot effort. Despite these limitations, we documented new information on technological considerations for tracking *Sterna* terns and habitat use of *Sterna* terns along the northern coast of Brazil. We also provide some recommendations for future studies to build on these efforts.

Tag diagnostics

According to specifications from the tag manufacturer, the tags used in this study can operate indefinitely, unless limited by charge capabilities of the solar panel or excessive wear and tear on the electronics. In this study, all tags stopped transmitting within one month of deployment. Reasons for tag failure could include shading of the solar panel (e.g. from feathers), or partial to complete obstruction of the solar panel resulting from bird death or tag loss. Tags may also cease to transmit due to wear and tear (e.g. saltwater intrusion of electronics), which is a likely factor for tags deployed on marine taxa such as *Sterna* terns that feed by plunge diving.

We attempted to infer the fate of each tagged bird by examining tag diagnostic data and movement data prior to tag failure, but the results were inconclusive. Tag sensor data can be used to determine if voltage and transmit current values are in the healthy operational range. However, most tags showed healthy diagnostic values through their final transmissions.

Two of the tagged birds were recovered by monitors. One bird was found in a decayed state 120 km away from the tagging site, and the second was found in a critically injured state after colliding with the powerlines in Galinhos within 24 hours of tagging. Given that these two recovered tags transmitted with final tag diagnostic data (current and voltage) in the healthy range indicates that tag diagnostic values are not always a reliable indicator of tag health or bird health. Therefore, reasons for premature tag malfunction and data loss in this study remain inconclusive.

Beyond electronical failure, additional factors may include tag loss associated with the temporary attachment method (glue and sutures). We used the glue and suture attachment method because it has been used to track large numbers of Common and Roseate terns successfully in previous efforts, without apparent adverse effects (Loring et al. 2019). However, these previous efforts used smaller tags (1 g radio-transmitters) relative to the larger (2 g) satellite tags used in this effort. Previous efforts tracked terns during the nesting period and estimated a mean (±SE) retention time of 48 days (± 2 days, range 22 to 90 days; Loring et al. 2016). Therefore, it is possible that the larger tags used in this study may have a shorter retention time due to the increased drag and stress to tag attachment points. It is also possible that the electronics in the radio tags used in previous studies were more robust to environmental conditions relative to the satellite tags. The radio tags had an internal battery, were encased in resin for water resistance, and were less technologically complex relative to satellite tags that are charged with an external solar panel. The combination of a lighter tag (with less stress to attachment points), more robust waterproofing, and less complex technology may have all contributed to higher duration of data collection from radio tags (in previous studies) relative to the satellite tags (in the present study).

It is also possible that tags failed to collect data due to bird mortality associated with tag attachment. Roseate Terns are known to be especially sensitive to tag attachment methods (Mostello et al. 2014, Paton et al. 2022). There are documented issues with attaching satellite transmitters to Roseate Terns using backpack harnesses, including lethargic behavior following release and multiple observations of birds with their bill stuck in the harness material, leading to direct mortality in at least one occurrence (Paton et al. 2020). These issues with using harnesses on Roseate Terns were the main deciding factor for using the glue and suture method for this study. However, it is possible that the Roseate Terns were more sensitive to the tag attachment during this study due to the larger tags used or the time of year that the tags were deployed. Therefore, we recommend that additional precautions be used in future tracking studies of Roseate Terns including: 1) minimizing handling time; 2) minimizing tag size and weight; 3) minimizing sample size of tagged birds; 4) tagging Common Terns to provide information on *Sterna* terns that could be generalized to Roseate Terns where appropriate; and 5) conducting target efforts to observe tagged terns following release, including band resighting efforts near tagging locations and coordinated band resighting and colonies and staging areas throughout the annual cycle.

Habitat-use analysis

Results from the habitat use analysis should be interpreted as preliminary and in the context of data limitations. These limitations include variability in number of locations per bird, variation in number of days tracked per bird, and a limited number of locations and birds tracked overall. To address these limitations, we used two methods to assess habitat-use in an exploratory context.

The first method used overlap of individual locations with habitat areas. For this method, we retained only locations with known accuracy (<1,500 m) which further limited the sample size. However, it allowed us to directly assess habitat use during the times that birds were relocated, with a known degree of spatial accuracy. The limitations of this method are that it does not make use of lesser-quality location data or estimate where birds may have occurred between periods of data collection.

To address these limitations, we also used kernel-density estimation to assess habitat use. This method uses known locations for a tracked individual to calculate the probability that the individual could be found in surrounding areas (Worton 1989). We used locations categorized by “day” and “night” to generate diurnal and nocturnal utilization distributions for each bird. We calculated 50% isopleths to represent core-use areas for each tagged individual. These core-use areas can be used to estimate habitat use within the overall distribution of location data points (Boitani and Fuller 2000). However, the size and shape of core-use areas generated from location data is largely influenced by number of points in dataset and the length of time between successive relocations (Seaman et. al. 1999). We attempted to address potential biases in core-use area estimates by subsampling locations that were > 120 min apart and birds that were tracked for at least 5 days, but we had limited data to work with overall.

Due to the various limitations of the data and analysis methods, absence of location data or core-use area overlap with industrial activities should not be interpreted as lack of exposure. We present results of the habitat-use analysis in a presence-only context and did not attempt to quantify the extent of spatial overlap, time spent in different habitats, or the proportion of individual locations per habitat type due data limitations.

Offshore habitat use

Both analysis methods showed highest overlap of terns with offshore wind energy planning areas and with exploratory petroleum areas. Exposure to these areas occurred mostly during day and to a lesser extent during night. During the non-breeding period, terns generally occur offshore and feed during the day, come to shore at night to roost, and may use multiple roosting sites within a season (Hays et al. 1999, Lima et al. 2003, 2004, 2005, Lima, 2006).

Currently (April 2023), the Potiguar basin has 15 offshore oil fields with a total of 430 wells. The platforms are distributed in a large area from the continental shelf, and new fields have been prospected on the slope region (ANP 2023). Offshore activities related to oil exploration and production along the Rio Grande do Norte coast may be impacting *Sterna* terns and other species that occur offshore. These impacts are difficult to monitor because of the location of structures, but have been associated with interactions such as collisions, incineration, exposure to oil, exhaustion, starvation, roosting and resting, and displacement from habitat (Ronconi et al. 2015). *S. hirundo* and *S. dougalli* have been observed using oil platforms on the coast of the State of Sergipe as a perching site when foraging (Pedro Lima, pers. comm). The birds land on the platform structures to rest and observe the schools of fish (Figure 21).

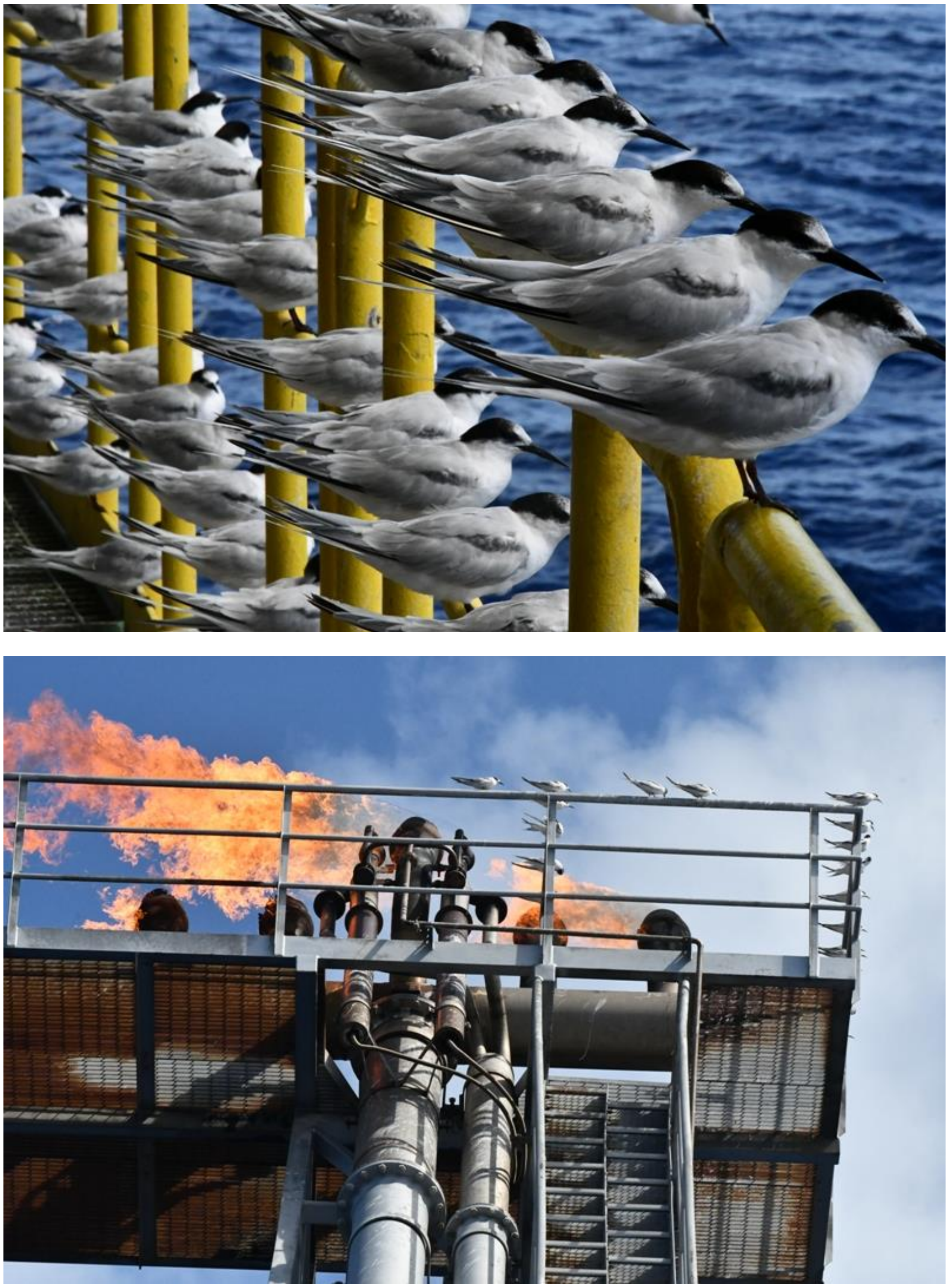

Figure 21. ***Sterna*** **terns using an oil platform on the coast of Northeast Brazil. Photo credit: Pedro Lima.**

The Potiguar basin is also one of the three largest areas for offshore wind power in Brazil and already has environmental license requests for 10 different projects that sum to almost 18,000 MW (CEMAVE/ICMBIO 2022; IBAMA 2023). We found high overlap between offshore tern locations and the offshore planning areas for wind energy development. Risks to birds from offshore wind turbines include: 1) acting as barriers to movement (e.g. between foraging and roosting sites, along migration routes); 2) destruction, modification, or displacement of habitat; and 3) direct mortality from collisions with infrastructure (Exo et al. 2003; Drewitt and Langston 2006; Fox et al. 2006)

Similar to oil platforms, offshore wind turbine foundations may create artificial reef effects that concentrate fish and provide roosting sites (Marques *et al.* 2014). However, perching and foraging behavior around offshore wind turbines has been associated with increased collision risk (Marques et al. 2014). Therefore, it will be important to monitor the movements and behavior of *Sterna* terns and other species in the offshore planning areas as development advances. The mitigation hierarchy (avoid, minimize, mitigate) should be used to address risks using the best available information in an adaptive framework (Arlidge et al. 2018).

Onshore habitat use

In this study, overlap with onshore industrial activities such as onshore wind energy facilities, salt ponds, and shrimp ponds occurred primarily at night, as birds come ashore to roost. Previous observational studies and monitoring of terns and shorebirds in Galinhos have documented daytime habitat use within mangrove wetland habitats and coastal barrier beaches (Azevedo Júnior et al. 2001, Larrazábal et al 2002, Macedo Mestre et al. 2010, Mendonça et al. 2015, Mestre 2007). Therefore, our tracking data provided an incomplete picture of habitat use relative to what has been documented by other studies.

Monitoring use of terns in shrimp and salt ponds is an important component of assessing onshore risks. These industrial activities are associated with environmental impacts such as contamination of water bodies and prey items, alteration and removal of mangrove habitats, loss of biodiversity, changes in the morphology of coastal environments and dune fields, and degradation and suppression of natural wetland systems (Diniz et al. 2015). The shrimp ponds also influence the feeding behavior of many bird species, especially terns and shorebirds, which are attracted to high densities of prey (Silva-Júnior et al., 2020). However, in Galinhos, the community reported that the shrimp industry uses guns and fireworks to scare away the birds, sometimes resulting in escape flights towards power lines culminating in collisions, injuries, and mortality (R. Reveredo, pers. comm.).

Future directions

This study used relatively coarse satellite telemetry data to document presence of terns relative to industrialized habitat in a study area in northeastern Brazil. More detailed information is needed to assess foraging, roosting, and staging habitat use and risk factors, and to identify and manage high-value habitat for terns in onshore and offshore areas. The scale of information provided by Argos-satellite tracking technology was sufficient for larger-scale exposure analyses (e.g. offshore wind and petroleum areas), but too coarse for measuring fine-scale habitat use such as movements around the powerline area, despite one of our tagged birds actually colliding with the powerline. This further highlights the importance of the in-person monitoring efforts that have occurred in Galinhos since 2010 (Revorêdo 2021).

We recommend that future tagging studies aim for more robust sample size and integrate monitoring methods to allow for use of more detailed analysis on exposure and risk (e.g. duration of exposure, magnitude of risk associated with each activity). Future studies could focus on collecting data to better understand threats associated with industrial activities, including: use of salt ponds and shrimp farms by feeding and roosting terns, flights between salt ponds and shrimp farms relative to overhead powerlines, risk of vehicle collisions of terns flying through mangrove habitat intersected by roads, and use of offshore oil platforms by roosting terns. Additional biological data to help inform risk assessments include detailed flight height data of terns flying over land (in vicinity of powerlines) and offshore (within offshore wind planning areas), and more detailed information on flight paths of terns in areas with collision hazards. Such data could be obtained from a radar study or possibly by using newly available miniaturized GPS tracking technology. Future study designs should carefully consider information needs (e.g., flight height data, detailed movements) relative to technological limitations (e.g., size, weight, cost, data transfer methods, and sensitivity of electronics to marine environments, successful use in previous efforts). In this study, we selected Argos satellite tags due to their light weight (2 g), remote data acquisition/transfer via satellite, ability to acquire consistent locations (6-8 per day) when tag has sufficient battery power, and successful deployments on Common Terns in previous pilot efforts (Loring et al. 2019). However, limitations of this technology include coarse location error estimates (optimally 250 m to 1500 m), variable time gaps between locations depending on solar charge and satellite passes overhead, and tag longevity limited by sensitivity of electronics to wear and tear which can be challenging for light-weight tags in marine environments (e.g. waterproofing adds weight). Thus, this technology is best suited for larger-scale exposure analyses of space-use in remote environments (e.g., offshore wind and petroleum areas) where direct observation is more challenging. Future studies of habitat use in onshore areas should employ a combination of observational and tracking methods to obtain more detailed information where possible.

More complete assessments of onshore risks would require regional scale GIS layers on industrial uses (e.g., powerlines, onshore wind farms, salt production ponds, shrimp farms) obtained from industry or digitized if not available. Additional habitat layers (e.g., undeveloped mangrove wetlands, barrier beach, inlets) would support conservation efforts and could be digitized from satellite imagery as needed. These industrial and habitat GIS data could be used to inform risk assessments across a broader portion of the non-breeding range and would be highly valuable for informing plans for energy development and mitigation strategies.

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Loring P.H., T.M. Kuras, R.A. Revorêdo, D.S.D. Farias, F.J.L. Silva, P.C. Lima, S. von Oettingen, J. Walsh. 2023. Habitat use of Common and Roseate terns tracked with satellite transmitters in northeast Brazil. U.S. Department of the Interior, U.S. Fish and Wildlife Service. State of the Birds Program. 38 p.

References

Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP), Ministério de Minas e Energia, Brasil. 2023. Acervo de Dados: Dados de Poços. URL: <https://www.gov.br/anp/pt-br/assuntos/exploracao-e-producao-de-oleo-e-gas/dados-tecnicos/acervo-de-dados>. Accessed 27 April 2023.

Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP), Ministério de Minas e Energia, Brasil. 2022. Shapefile de Dados. URL: < https://www.gov.br/anp/pt-br/assuntos/exploracao-e-producao-de-oleo-e-gas/dados-tecnicos/shapefile-de-dados >. Accessed April 2022.

Arlidge W.N.S, J.W. Bull, P.F.E Addison, M.J. Burgass, D. Gianuca, T.M. Gorham, C. Jacob, N. Shumway, S.P. Sinclair, J.E.M. Watson, C. Wilcox, E.J. Milner-Gulland. 2018. A Global Mitigation Hierarchy for Nature Conservation. BioScience 68(5): 336-347.

Argos. 2023. FAQ localisation Argos. URL: <https://www.argos-system.org/support-and-help/faq-localisation-argos/>Accessed 30 April 2023.

Azevedo Júnior, S. M., Dias, M. M., Larrazábal, M. E. de, Telino Júnior, W. R., Lyra-Neves, R. M., & Fernandes, C. J. G. (2001). Recapturas e recuperações de aves migratórias no litoral de Pernambuco, Brasil. Ararajuba, 9(1), 33–42.

Bivand, R. and N. Lewin-Koh. 2022. maptools: Tools for Handling Spatial Objects. R package version 1.1-4. URL: <https://CRAN.R-project.org/package=maptools>

Boitani, L. and T. Fuller. 2000. Research Techniques in Animal Ecology: Controversies and Consequences. Columbia University Press.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling, 197, 516-519.

Calenge, C. 2015. Home range estimation in R: the adehabitatHR package. Office national de la classe et de la faune sauvage Saint Benoist, Auffargis. URL: <https://mran.microsoft.com/snapshot/2016-08-05/web/packages/adehabitatHR/vignettes/adehabitatHR.pdf>. Accessed 30 April 2023.

Centro Nacional de Pesquisa e Conservação de Aves Silvestres (CEMAVE), & Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio). 2022. Relatório de áreas de concentração de aves migratórias no Brasil. URL: <https://cemave-sede.github.io/relatorio_aves/> Accessed 30 April 2023.

Diniz, M., Souza Ferreira, A., & Macêdo de Maria, G. K. (2015). Análise integrada da paisagem e formas de uso do solo no litoral de Galinhos/RN: subsídios à gestão integrada da zona costeira. *Caderno de Geografia*, *25*(44), 49–69.

Kranstauber, B, M. Smolla and A.K. Scharf. 2022. move: Visualizing and Analyzing Animal Track Data. R package version 4.1.8. URL: <https://CRAN.R-project.org/package=move> Accessed 30 April 2023.

Hays, H., Lima, P., Monteiro, L., DiCostanzo, J., Cormons, G., Nisbet, I. C. T., Saliva, J. E., Spendelow, J. A., Burger, J., Pierce, J., & Gochfeld, M. 1999. A Nonbreeding Concentration of Roseate and Common Terns in Bahia, Brazil (Concentración de Individuos de Sterna dougallii y de S. hirundo en Bahia, Brazil). Journal of Field Ornithology, 70(4), 455–464.

Hays, H., Neves, V., & Lima, P. 2002. Banded Roseate Terns from different continents trapped in the Azores. Journal of Field Ornithology, 73(2), 180–184.

Hays, H., Cormons, T., Lima, P. C., Bremer, R., Cormons, G. 2003. Following radio-tagged terns off Brazil and Argentina. In: XXVII Annual Meeting of the Waterbird Society. Cuiabá, MT. Annual Meeting of the Waterbird Society, p. 49-49.

Instituto Brasileiro do Meio Ambiente e dos Recursos (IBAMA). 2023. Mapas de projetos em licenciamento - Complexos Eólicos Offshore. URL: <https://www.gov.br/ibama/pt-br/assuntos/laf/consultas/arquivos/20230328_Usinas_Eolicas_Offshore_reduzido.pdf> Accessed 30 April 2023.

Instituto Brasileiro do Meio Ambiente e dos Recursos (IBAMA). 2022. Mapas de projetos em licenciamento - Complexos Eólicos Offshore. URL: < https://www.gov.br/ibama/pt-br/assuntos/laf/consultas/mapas-de-projetos-em-licenciamento-complexos-eolicos-offshore> Accessed July 2022.

Larrazábal, M. E. de, Azevedo Júnior, S. M. de, and O. Pena. 2002. Monitoramento de aves limícolas na Salina Diamante Branco, Galinhos, Rio Grande do Norte, Brasil. Revista Brasileira de Zoologia, 19(4), 1081–1089.

Lima, P. C., Dicostanzo, J., and H. Hays. 2003. Concentrations of non-breeding common and roseate terns along the coast of Bahia, Brasil. In: XXVII Annual Meeting of the Waterbird Society, 2003, Cuiabá, MT. XXVII Annual Meeting of the Waterbird Society, p. 51-51.

Lima, P.C., Hays, H., Lima, R.C.F.R., Cormons, T., Cormons, G., Dicostanzo, J., and S. S. Santos. 2004. Recuperações de Sterna dougallii (Montagu, 1831) na Bahia, Brasil. Ararajuba 12: 147-149.

Lima, P.C., Hays, H., Rocha, R.D., Cormons, T., Cormons, G., & Sampaio, S. 2005. Recuperações de Sterna hirundo (Linnaeus, 1758) na Bahia, Brasil, entre 1995 e 2004.

Lima, P. C. 2006. Aves Do Litoral Norte Da Bahia. 1st ed. Atualidades Ornitologicas. v1. 616 p.

Loring, P.H. 2016. Evaluating Digital VHF Technology to Monitor Shorebird and Seabird Use of Offshore Wind Energy Areas in the Western North Atlantic. Doctoral Dissertation, University of Massachusetts Amherst. URL: <https://scholarworks.umass.edu/dissertations_2/761> Accessed 30 April 2023.

Loring P.H., P. W. C. Paton, J. D. McLaren, H Bai, R. Janaswamy, H. F. Goyert and P. R. Sievert. 2019. Tracking offshore occurrence of Common Terns, endangered Roseate Terns, and threatened Piping Plovers with VHF Arrays. U.S. Department of the Interior, Bureau of Ocean Energy Management, Sterling, Virginia.

Lotek Argos Web Service. 2023. URL <https://data.sirtrack.com/>. Accessed 30 April 2023.

Macedo Mestre, L. A., Mestre, L. A. M., Roos, A. L., Nunes, M. F. C., and L. A. Macedo Mestre. (2010). Análise das recuperações no Brasil de aves anilhadas no exterior entre 1927 e 2006. *Ornithologia*, *4*(1), 15–35.

Marques, AT, H Batalha, and J Bermandino. 2021. Bird Displacement by Wind Turbines: Assessing Current Knowledge and Recommendations for Future Studies. Birds 2021(2):460-475.

Mestre, L. A. M. 2007. Registros das migrações de trinta-réis-boreal Sterna hirundo: análise das recuperações de indivíduos marcados na América do Norte (1928-2005) e Brasil (1983-2005). In *Ornithologia* (Vol. 2, Issue 2).

Mostello, C. S., I. C. T. Nisbet, S. A. Oswald and J. W. Fox. 2014. Non-breeding season movements of six North American Roseate Terns Sterna dougallii tracked with geolocators. Seabird 27: 1-21.

Movebank. 2023. URL: <https://www.movebank.org/cms/movebank-content/argos-data-filters>. Accessed 30 April 2023.

Paton, P.W.C, P.H. Loring, G.D. Cormons, K.D. Meyer, S. Williams, L.J. Welch. 2020. Fate of Common (*Sterna hirundo*) and Roseate Terns (*S. dougallii*) with satellite transmitters attached with backpack harnesses. Waterbirds 43(3-4): 342-347.

Neves, V. C., Nava, C. P., Cormons, M., Bremer, E., Castresana, G., Lima, P., Junior, S. M. A., Phillips, R. A., Magalhães, M. C., and Santos, R. S. 2015. Migration routes and non-breeding areas of Common Terns (*Sterna hirundo*) from the Azores. *Emu - Austral Ornithology*, *115*(2), 158–167.

Seaman, D. E., Millspaugh, J.J., Kernohan, B. J., Brundige, G. C., Raedeke, K. J., and Gitzen, R. A. 1999. Effects of Sample Size on Kernel Home Range Estimates. The Journal of Wildlife Management, 63(2): 739–747.

Silva-Júnior, J. J., Nicacio, G., & Rodrigues, G. G. 2020. A CARCINICULTURA NOS MANGUEZAIS DO NORDESTE BRASILEIRO: PROBLEMÁTICAS SOCIOAMBIENTAIS NAS COMUNIDADES TRADICIONAIS. Revista Movimentos Sociais e Dinâmicas Espaciais. 9: 70–84.

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: <https://www.R-project.org/>. Accessed 30 April 2023.

Revorêdo, R. Â. 2021. Colisão de aves marinhas migratórias em linha de energia no Nordeste brasileiro: avaliação espaço-temporal e descrição da histologia gonadal em áreas não reprodutivas com fins de conservação. 74 p. Thesis (Master's degree) - Curso de Biologia Estrutural e Funcional, Departamento de Morfologia, Universidade Federal do Rio Grande do Norte, Natal, 2022.

Ronconi, R. A., Allard, K. A., & Taylor, P. D. 2015. Bird interactions with offshore oil and gas platforms: Review of impacts and monitoring techniques. Journal of Environmental Management. 147: 34-45.

Smolla, M., B. Kranstauber and A. Scharf. (2022). Using the move package. URL: <https://cran.r-project.org/web/packages/move/vignettes/move.html>. Accessed 30 April 2023.

U.S. Fish and Wildlife Service (USFWS). 2020. Roseate Tern Northeastern North American Population (*Sterna dougallii dougallii*)- 5-Year Review: Summary and Evaluation. URL <https://ecos.fws.gov/docs/tess/species_nonpublish/3063.pdf>. Accessed 30 April 2023.

Valente, R. de M., Silva, J. M. C. da, Straube, F. C., & Nascimento, J. L. X. do. 2011. *Conservação de Aves Migratórias Neárticas no Brasil*. URL:

<https://ppbio.inpa.gov.br/sites/default/files/Livro_Aves_migratorias_nearticas_no_brasil_Conservation_International.pdf>. Accessed 30 April 2023.

Ventura, A. C. B., Farias, D. S. D., Silva, F. J. de L. (2020). Nota Técnica Conjuta PCCB-UERN/CEMAM Nº 01/20. Natal: PCCB-UERN e CEMAM. 7p. URL < https://www.gov.br/icmbio/pt-br/assuntos/biodiversidade/pan/pan/pan-aves-marinhas/1-ciclo/produtos/2020-pan-aves-marinhas-nt-mortalidade-de-aves-galinhos-rn.pdf>.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70(1): 164–168.