FORAGING AREAS AND MOVEMENTS OF ROYAL TERN *THALASSEUS MAXIMUS* BREEDING AT THE ISLES DERNIERES BARRIER ISLANDS REFUGE, LOUISIANA

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ABSTRACT

ROLLAND, V., NEPSHINSKY, M., WINDHOFFER, E.D., LIECHTY, J.S., MINOR, A.K. & PIERCE, A.R. 2020. Foraging areas and movements of Royal Tern *Thalasseus maximus* at the Isles Dernieres Barrier Islands Refuge, Louisiana. *Marine Ornithology* 48: 163–168.

The Isles Dernieres Barrier Island Refuge (IDBIR) in Louisiana constitutes a major colonial seabird breeding site but is also considered a high-risk marine area that is susceptible to both natural and anthropogenic disturbances that can be detrimental to breeding areas and food resources. The objective of this study was to track the movements of breeding Royal Terns *Thalasseus maximus* at the IDBIR to identify important foraging movement parameters and foraging areas. GPS loggers were attached to six Royal Terns during the 2014–2017 breeding seasons. Mean foraging trip distance was 28.8 km and the maximum distance traveled was 47.8 km. The overall mean foraging area (95% fixed kernel densities) was 1042.5 ± 526.1 km^2. There was individual variation among foraging area size and foraging habitats that included bays, offshore habitats, and marsh habitats. However, appreciable overlap in foraging areas included marsh habitats ~12 km north of the breeding colony and offshore areas south of the colony. Identifying seabird foraging areas is critical for understanding their resource needs in the Gulf of Mexico, the coast of which is undergoing rapid change, and to assess how major disasters, such as oil spills and hurricanes, may influence important foraging areas.

Key words: barrier islands, foraging areas, GPS tracking, Gulf of Mexico, movement patterns, Sternidae

INTRODUCTION

The northern Gulf of Mexico is considered a high-risk area susceptible to both natural and anthropogenic disturbances (Keim *et al*. 2007, Campagna *et al*. 2011, Trepanier *et al*. 2014). For one, coastal Louisiana is experiencing a rapid rate of erosion as a result of several factors, including subsidence, sea level rise, hydrologic alterations, saltwater intrusion, and erosion (Coastal Protection and Restoration Authority of Louisiana 2017, Khanna 2017). Louisiana's rapid coastal land loss threatens the continued existence of important habitats for seabirds. Secondly, seabirds in the Gulf of Mexico are threatened by major hurricanes (Raynor *et al*. 2013) and pollution, such as the 2010 BP Deepwater Horizon oil spill (Haney *et al*. 2014). Finally, seabirds may also interact with commercial fisheries through competition for forage fish, utilization of fisheries bycatch discards (Liechty *et al*. 2016), and potential mortality through gear entanglement (Phillips *et al*. 2010). Sensitivity to such diverse factors makes seabirds useful indicators of coastal ecosystem health, and they can provide information about the integrity of broader ecosystem processes.

Royal Terns *Thalasseus maximus* nest abundantly on barrier islands in the northern Gulf of Mexico. An estimated 26% of the global breeding Royal Tern population, approximately 50 000 individuals (Remsen *et al*. 2019), nests in coastal Louisiana. Despite previous studies in this region (Raynor *et al*. 2012, Owen & Pierce 2014, Liechty *et al*. 2016, Liechty *et al*. 2017), information about Royal Tern foraging areas is lacking.

The objective of this study was to track the movements of breeding Royal Terns using GPS trackers to identify important foraging patterns in coastal Louisiana. This information can identify important seabird foraging areas, help assess risks associated with major disasters (e.g., hurricanes, oil spills), and aid in the development of management plans for seabird conservation (Burger & Shaffer 2008).

METHODS

Study site

The Isles Dernieres Barrier Island Refuge (IDBIR) is a chain of barrier islands located off the coast of southeast Louisiana (Fig. 1) and is one of the most vulnerable areas to coastal erosion in the United States (Lindstedt 2005). Four islands, which span about 32.5 km, constitute the IDBIR chain (from east to west): Wine, Trinity, Whiskey, and Raccoon islands. Raccoon Island was split into two islands by a water inlet, and the two island sections are referred to as East Raccoon and West Raccoon. Large colonies of Royal Terns (~7000 breeding pairs) breed on East Raccoon Island (approximately 2.5 km in length) annually (Raynor *et al*. 2012, 2013, Windhoffer 2017).

Tracking of foraging terns

Foraging movements of Royal Terns were recorded using GPS loggers (earth&OCEAN Technologies, Kiel, Germany) that were programmed prior to deployment to start taking a GPS position every 15 min. In the event that GPS loggers could not locate enough satellites for an accurate position after 2 min, we set the loggers to attempt to search for a position again after 45 min in 2014 and after 15 min in 2015–2017. The batteries for the GPS loggers lasted between 72 and 46 h under the respective settings. The loggers also recorded a horizon dilution of precision (HDOP) for each position. The number of satellites accessed by the logger influenced the HDOP. An HDOP ≤ 2 is considered accurate, whereas an HDOP ≥ 10 has a larger positional discrepancy (Recio *et al*. 2011). A known point on the Nicholls State University campus (29°47'24.94610"N, 090°48'13.25795"W) was used to compare HDOP measurements and to determine the accuracy of the GPS loggers in meters. We found that a low HDOP (~2.0) had a high accuracy, detecting a position 8 m from the actual point, whereas a moderately higher HDOP (~8.0) detected a position 43 m from the actual point. Although this is not an exact translation of HDOP into meters of accuracy, it does provide context for the accuracy of logger-recorded positions of Royal Terns.

Seventeen Royal Terns captured on East Raccoon Island in 2014–2017 were banded and fitted with GPS loggers. Birds were captured using hand nets during May and June, near time of hatching when adults were most defensive of eggs and were easily captured. Thus, the foraging movement period that was monitored included egg incubation and chick rearing. Royal Terns were captured from colonies with 500–1500 breeding pairs to prevent disturbance and potential abandonment that might occur at smaller colonies. Captured adults were fitted with four bands: two colored bands on one leg and one colored band and one numbered aluminum band from the United States Geological Survey (USGS) on the opposite leg. We also fitted terns with a waterproof 10.5 g data logger, representing ≤ 3% of the bird's body weight. We attached the GPS loggers to the back of each bird using Tesa tape on three layers of feathers (Wilson & Wilson 1989, Wilson *et al*. 1997). This attachment method ensured that the logger would fall off if the bird was not recaptured and reduced the risk of any harmful effects from attachment, such as bill entanglement, disrupted foraging movements (Wanless *et al*. 1988), or reduced reproductive performance (Ackerman *et al*. 2004). Royal Terns were released after the devices were securely attached and, thereafter, were monitored using a spotting scope and binoculars until they were out of sight. We attempted to retrieve the GPS logger by recapturing the birds after three days to download the movement data. Blood samples were taken from recaptured birds for sex-determination (Nepshinsky 2017).

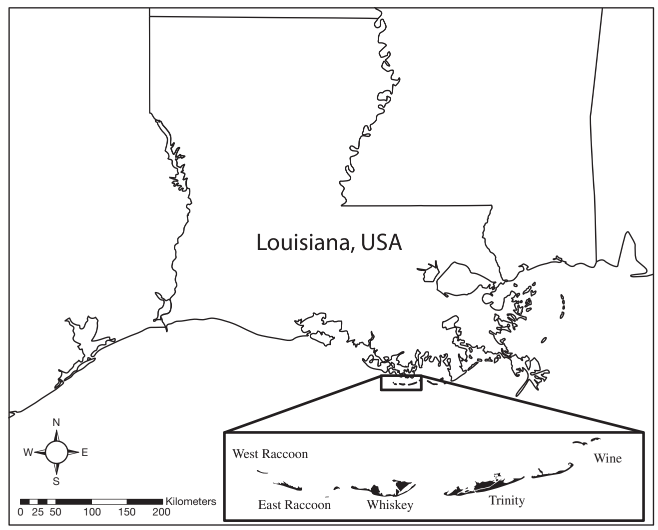

Fig. 1. Location of the Isles Dernieres Barrier Islands Refuge in south Louisiana, including (from east to west): Wine Island, Trinity Island, Whiskey Island, East Raccoon Island, and West Raccoon Island.

TABLE 1
Number of trips and mean (± SE) foraging movement parameters of six Royal Terns *Thalasseus maximus* breeding at the Isles Dernieres Barrier Islands Refuge in Louisiana in 2014–2017

Movement Parameters	GPS 367 (female, 2014)	GPS 353 (male, 2014)	GPS 354 (male, 2016)	GPS 370 (male, 2016)	GPS 379 (unsexed, 2017)	GPS 375 (unsexed, 2017)	Mean
No. trips	5	5[a]	4	10	2	3	4.8 ± 1.1
No. trips/day	1.25 ± 0.25	1.67 ± 0.12	2.00 ± 0.71	3.33 ± 1.02	1.00 ± 0.00	1.50 ± 0.41	1.88 ± 0.39
Mean trip duration (h)	4.1 ± 0.9	5.3 ± 2.2	2.5 ± 1.2	1.1 ± 0.9	4.2 ± 0.2	1.7 ± 0.8	2.8 ± 0.5
Mean trip distance (km)	52.0 ± 16.6	22.2 ± 9.8	37.2 ± 13.2	13.7 ± 3.3	67.0 ± 0.0	14.9 ± 5.3	28.8 ± 4.9
Max distance (km)	47.8	21.7	29.7	15.6	28.9	10.9	25.8 ± 5.3
Mean max distance[b] (km)	22.5 ± 6.9	8.5 ± 3.6	16.6 ± 5.6	6.6 ± 1.5	28.2 ± 0.6	6.8 ± 2.3	12.5 ± 2.1
Mean speed[c] (km/h)	35.9 ± 2.9	36.2 ± 1.0	33.6 ± 1.9	36.5 ± 1.6	32.2 ± 1.9	25.7 ± 4.3	35.6 ± 1.1
Approx. tracking time (h)	72	68	46	47	30	45	51.3 ± 6.4

[a] One trip contained a whole night on West Racoon Island, which increased the mean trip duration.
[b] Mean max distance is the average longest distance across trips.
[c] Mean speed only accounts for speeds > 10 km/h because speeds < 10 km/h were typically over land.

Foraging movement analyses

Once data were downloaded, GPS points were initially plotted on Google Earth. A location was defined as a foraging event if it occurred ≥ 15 m away from the island, based on land-based observations of Royal Tern foraging events (Erwin 1978). Additionally, we removed any locations deemed unrealistic based on average speed. Royal Terns travel at a mean speed of 47.5 km/h (Tucker & Schmidt-Koenig 1971) and up to 64.4 km/h (Schnell & Hellack 1979); therefore, we excluded four locations that an individual would have reached with a speed exceeding 64 km/h.

Although only foraging events were included for the home range analysis (see below), we retained the nest location for each bird to calculate the following parameters: mean maximum distance (km), mean maximum speed (km/h), mean speed (km/h), mean time to maximum distance (h), mean round trip (RT) distance (km), and mean RT time (h). These foraging movement parameters are presented as mean ± SE. We used the distm function with the Vincenty ellipsoid method (Vincenty 1975) from package "geosphere" (Hijmans 2016) in the computing program R (R Core Team 2018) to compute distances.

Using only foraging locations (i.e., between 15 and 36 locations per tracked bird), we estimated the size of core areas (50% locations) and foraging range (95% locations) of each individual using the fixed kernel density estimator (KDE) with the kernelUD function from package "adehabitatHR" (Calenge 2006) in program R. Many studies have selected the bandwidth parameter subjectively based on the distribution of points, but multiple techniques can be used to quantitatively calculate the bandwidth (Gitzen & Millspaugh 2003). We used the ad-hoc smoothing parameter to determine the bandwidth for the KDE (Horne & Garton 2006); the more popular Least Square Cross Validation algorithm did not converge for four of the six tracked birds. We also projected the 50% and 95% kernel density contours for each bird in ArcGIS version 10.3 (Environmental Systems Research Institute, Redlands, California).

RESULTS

Seventeen GPS loggers were deployed, but only six were recovered with data. Low GPS logger recovery rates were due to difficulty in recapturing individuals to obtain the loggers or loggers coming off during the deployment period. One female and one male were tracked in 2014, two males were tracked in 2016, and two individuals of unknown sex were tracked in 2017. During the 30-h to 72-h deployment period, each Royal Tern made 2–10 foraging trips, primarily during the day between 05h00 and 21h00 (Table 1). In late May/early June, when these data were collected, sunrise was at approximately 06h00 and sunset was at approximately 20h30. Royal Terns returned to roost for the night between 21h00 and 05h00. One tern roosted overnight at West Raccoon Island, whereas all others returned to East Raccoon Island. The mean HDOP among the four birds was 3.56 ± 0.07, which is in the range of accurate readings (Recio *et al*. 2011).

The maximum distance for each foraging trip ranged from 10.9–47.8 km, with the known female Royal Tern traveling the farthest. The mean maximum distance that all six birds traveled was 12.5 ± 2.1 km (Table 1), which is the approximate distance from the island to marsh habitats to the north of East Raccoon Island. The mean total distance for foraging movements of all six birds, at 28.8 ± 4.9 km, was more than double the mean maximum distance. The six birds traveled at an average speed of 35.6 ± 1.1 km/h and spent on average 1.3–5.3 h off the island per foraging trip (Table 1).

Although all birds showed variation in the direction and distance traveled away from their respective colonies, some areas overlapped to the north of the breeding colony. The KDE analysis revealed that all birds' foraging range (95% fixed kernel) included marsh habitat northeast of East Raccoon Island (Fig. 2). Another foraging area, shared by three birds, encompassed open water south of East Raccoon Island (Figs. 2, 3). The known female Royal Tern (GPS 367) had the largest foraging area at 3541 km^2 (Table 2); its foraging area stretched northwest to encompass additional marsh habitat, as well as to the east to include areas near shore to Whiskey, Trinity, and Timbalier islands (Fig. 2). One of the unsexed birds (GPS 375) tracked in 2017 had the smallest foraging area at 99.7 km^2 (Table 2), generally east of the colony (Fig. 2). Overall, the mean area (95% fixed kernels) that the six tracked Royal Terns used to forage was 1042.5 ± 526.1 km^2. The 50% fixed kernels revealed a mean potential "core" area size of 238.8 ± 116.6 km^2, which is roughly a quarter of the 95% fixed kernel mean area (Table 2; Fig. 3).

TABLE 2
Foraging areas generated for each tracked Royal Tern *Thalasseus maximus* breeding at the Isles Dernieres Barrier Islands Refuge in Louisiana in 2014–2017

GPS No.	No. locations	Tracking dates	Foraging area[a] (km^2)		Bandwidth
			50% FK	95% FK	
367	41	03–06 Jun 2014	772	3541	8254
353	38	06–09 Jun 2014	24.7	283	1943
370	25	29–31 May 2016	75.3	295	2389
354	17	29–31 May 2016	311	1150	4697
379	24	31 May–01 Jun 2017	224	886	4302
375	15	08–10 Jun 2017	25.8	99.7	1481
Mean	26.7		238.8 ± 116.6	1042.5 ± 526.1	
Overall	160		318	2095	4583

[a] Foraging areas were calculated with fixed kernel density (FK) estimator and the reference method to determine bandwidth.

DISCUSSION

Coastal Louisiana is an important breeding area for Royal Tern and is estimated to support 26% (50 000 breeding pairs) of the global breeding population (Remsen *et al*. 2019). The IDBIR is an important component of the species' breeding population in Louisiana, typically supporting 7000 breeding pairs (Raynor *et al*. 2013, Windhoffer 2017). This study provides the first information on Royal Tern foraging movements in this important breeding area. It also provides the first tangible evidence of the distance Royal Terns will travel for food, the size of their foraging range, and the habitats they will visit to access food resources.

The maximum distance traveled from the colony and mean trip duration varied among individuals. The known female Royal Tern travelled the farthest with a maximum distance of 47.8 km northeast of the island. One of the male Royal Terns travelled a maximum distance of 29.7 km, which was the second farthest distance. Similar movement distances were found for Royal Terns in Argentina using very high frequency (VHF) radio transmitters (Gatto *et al*. 2019). The number of trips per day and mean trip duration were also similar to the results from Gatto *et al*. (2019).

Royal Tern foraging areas ranged in size from 99.7–3541.0 km^2 (95% fixed kernels; Table 2) and included a variety of bay (nearshore), offshore, and marsh habitats. Additional research is needed to understand what may be driving this variation, such as environmental conditions, prey availability, or competition, among other factors. Interestingly, all foraging ranges overlapped over marsh habitats ~12 km to the north of the colony. Marsh habitats in this area are important for nekton and macrofaunal communities (Lowe & Peterson 2014) and are nurseries for small forage fish (Sheaves *et al*. 2015). These marsh communities include species such as brown shrimp *Farfantepenaeus aztecus* and Gulf menhaden *Brevoortia patronus*, two prey species that Royal Terns target in the IDBIR area (Liechty *et al*. 2016). Gatto *et al*. (2019) also determined that Royal Terns in Argentina primarily forage in coastal areas < 15 km offshore. Central-place foraging theory suggests that breeding seabirds should prefer prey items closer to the colony, and this theory has been supported by observations of the behaviors of other seabird species (Ballance *et al*. 2009). However, breeding colony size, prey availability, and prey quality likely affect Royal Tern foraging behavior, distance traveled by adults, and their time away from the nest. Nesting stage and body condition can also influence foraging movements, as seen in Brown

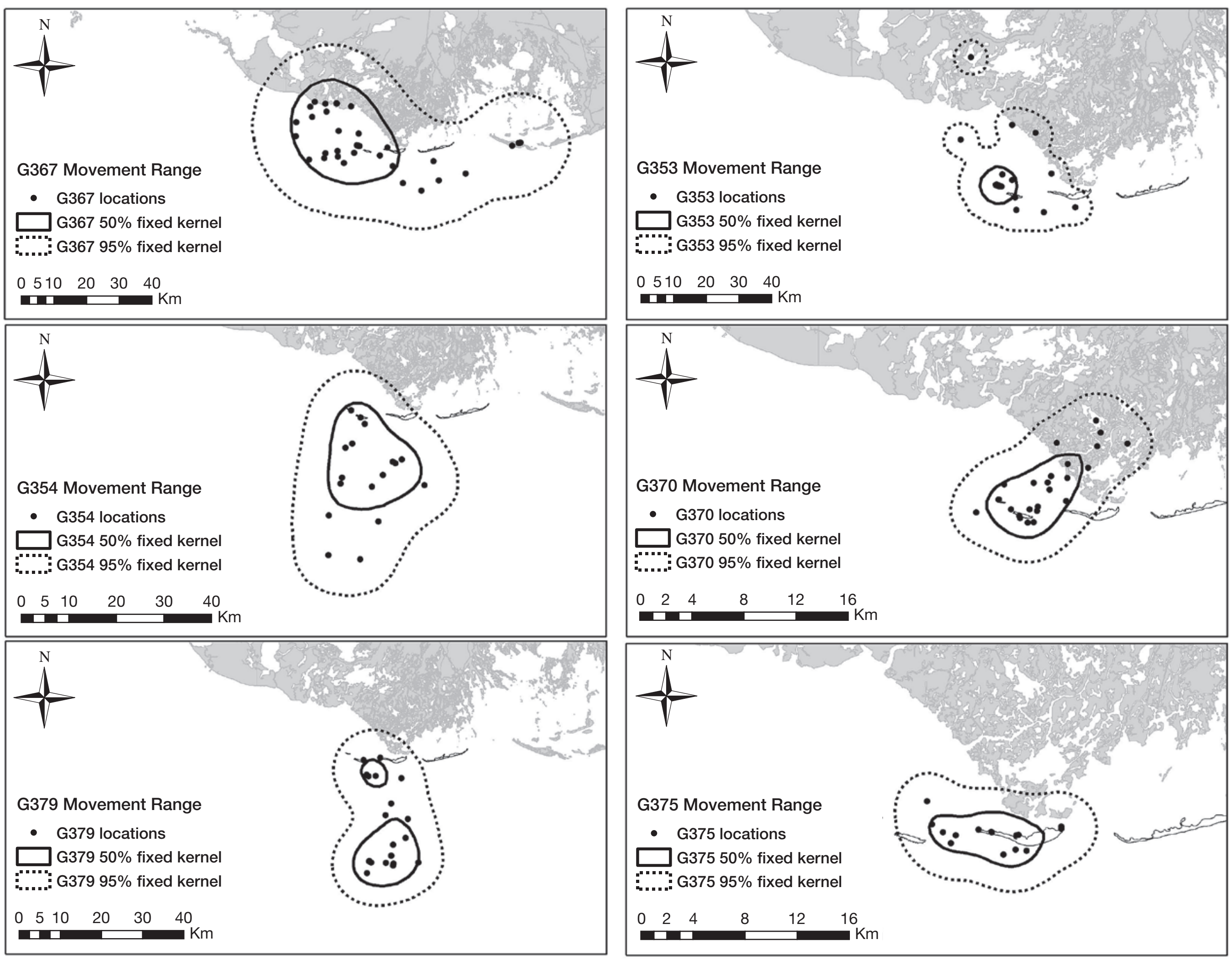

Fig. 2. Kernel density estimates of Royal Tern *Thalasseus maximus* foraging locations at the Isles Dernieres Barrier Islands Refuge in Louisiana.

Pelicans *Pelecanus occidentalis* tracked on the IDBIR (Water *et al*. 2014). We were not able to assess how these factors influence foraging in Royal Tern because deployments occurred within a restricted time period. Additional investigations on Royal Tern foraging movements are needed to refine our understanding of important foraging areas and the various factors (sex, nest stage, colony size, etc.) that influence their movements.

Recently, a Black Skimmer *Rynchops niger* was tracked to gain an understanding of the foraging areas and foraging movements of this species within the IDBIR (Rolland *et al*. 2019). Unlike Royal Terns, Black Skimmers forage primarily at night. The farthest that the Black Skimmer traveled was 16.4 km, which is only one-third of the maximum distance that Royal Terns traveled in our study. Black Skimmer foraging trip duration was similar to Royal Tern foraging duration; however, the Black Skimmer made more frequent trips (*n* = 14 trips; Rolland *et al*. 2019). Although there have been no recent diet composition studies of Black Skimmers in the Gulf, Black & Harris (1983) found that Black Skimmers off the Florida Gulf coast preferred marsh fishes such as killifish *Fundulus grandis*, and various shrimp species. Thus, Black Skimmers may also prefer foraging in marsh habitat, similar to Royal Terns. The Black Skimmer tracked on the IDBIR targeted the marsh areas to the northwest of the colony in Caillou Bay (Rolland *et al*. 2019), which overlapped with the Royal Tern foraging area (95% fixed kernels).

Overall, the identification of Royal Tern foraging areas may influence management decisions in the northern Gulf of Mexico. Productive marsh areas to the north of the IDBIR seem to be important foraging areas for both Royal Terns and Black Skimmers. These marshes are also vulnerable to erosion, subsidence, and pollution, all of which negatively affect important food resources found in these habitats (Denslow *et al*. 2015). Identifying these important seabird foraging areas is critical for understanding their resource needs in the Gulf of Mexico. This information can be used to help evaluate the benefits and costs of proposed restoration projects, such as freshwater diversions, marsh creation, shoreline protection, and barrier island restoration projects, which are critical components of the 2017 Louisiana Coastal Master Plan (Coastal Protection and Restoration Authority of Louisiana 2017). Additionally, seabird foraging movements and identified foraging areas can be useful for assessing damages associated with major disasters, such as oil spills and hurricanes, which may impact core foraging areas.

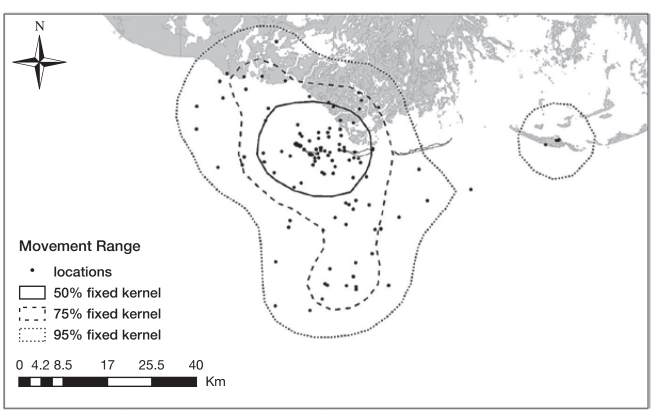

Fig. 3. Overall kernel density estimates of Royal Tern *Thalasseus maximus* foraging locations recorded during the 2014, 2016, and 2017 breeding seasons at the Isles Dernieres Barrier Islands Refuge in Louisiana.

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