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Satellite-tracking reveals multiple foraging strategies and threats for olive ridley turtles in Brazil

Augusto C. C. D. da Silva[1,*], Erik A. P. dos Santos[1], Fábio L. das C. Oliveira[2], Marilda I. Weber[2], Jamyle A. F. Batista[2], Thiago Z. Serafini[3], Jaqueline C. de Castilhos[2]

[1]Centro Nacional de Conservação, Pesquisa e Manejo das Tartarugas Marinhas, ReBio Santa Isabel, 49190-000, Pirambu, SE, Brazil

[2]Fundação Centro Brasileiro de Proteção e Pesquisa das Tartarugas Marinhas, 49035-485, Aracaju, SE, Brazil

[3]Programa de Pós-Graduação em Meio Ambiente e Desenvolvimento - MADE, Universidade Federal do Paraná — UFPR, 80035-050, Curitiba, PR, Brazil

ABSTRACT: The state of Sergipe in northeastern Brazil is the largest nesting area for olive ridley turtles along this nation's coast, and constitutes a major rookery in the western Atlantic as well. Conservation efforts with a focus on nesting activities have been implemented there since 1982, but little is known about other aspects of the life cycle, specifically post-nesting movements of females and the locations of foraging grounds. To address this issue, satellite transmitters were deployed on 10 females that nested between February and April 2006. The turtles were monitored for an average of 113 d (range: 14 to 297 d), and an average movement of 1669 km (range: 407 to 4265 km) was recorded. Of the 10 turtles monitored, 6 moved along the Brazilian continental shelf to neritic foraging areas. Five of these turtles utilized foraging areas along the northern and northeastern coasts of Brazil, while one foraged along the southeastern coastline. Two females were tracked to equatorial oceanic waters, with one first moving to an inshore foraging site where she remained for 34 d before migrating to oceanic waters off the Brazilian coast. Signal transmission of 3 of the 10 turtles tracked ceased during their post-nesting migrations, preventing identification of their feeding areas. Olive ridley turtles nesting on the coast of Sergipe displayed a range of post-nesting movements including to coastal sites along the continental shelf as well as offshore oceanic areas. Inter-nesting habitats, migration routes and foraging grounds showed great overlap with a variety of coastal fisheries, as well as with longline fishing in oceanic waters, a key consideration for developing conservation strategies for this species in the western Atlantic.

KEY WORDS: Satellite tracking · Inter-nesting · Migration · Foraging grounds · *Lepidochelys olivacea* · Conservation · Brazil

INTRODUCTION

The olive ridley *Lepidochelys olivacea* is considered to be the most abundant sea turtle species and is distributed throughout tropical and subtropical ocean basins worldwide (Pritchard 1997). Despite this relative abundance, olive ridleys are classified as globally vulnerable in the IUCN Red List (Abreu-Grobois & Plotkin 2008).All sea turtles hatch from eggs on nesting beaches and then enter the ocean. The life history of olive ridleys is not well known, and their life cycle may include neritic and/or oceanic stages for juveniles and adults, depending on differences in resource availability between regions (Bolten 2003). North Pacific olive ridley juveniles, for example, are associated with warmer oceanic waters in the center of the subtropical gyre (Polovina et al. 2004). In contrast, in the eastern tropical Pacific, where large juveniles and adults are relatively abundant (Eguchi et al. 2007), post-nesting females pre-

*Email: cesar@tamar.org.br

sent nomadic oceanic migratory behaviors characterized by non-directional movements and highly flexible responses to changing environmental conditions (Swimmer et al. 2009, Plotkin 2010). Moreover, in Australia, olive ridley turtles do not undertake extensive migrations, remaining instead in coastal neritic waters close to their nesting grounds (McMahon et al. 2007, Whiting et al. 2007).

In the Atlantic Ocean, nesting grounds of the olive ridley turtles are found in the western hemisphere mainly in northeastern Brazil, Suriname and French Guiana (Fretey 1999, da Silva et al. 2007), whereas along the African coast they are located between Guinea Bissau and Angola (Fretey 2001). Behavioral differences and a lack of tag recoveries among the different nesting areas support the distinctiveness of the Brazilian rookery from others in the Atlantic (Godfrey & Chevalier 2004), although the Brazilian population shares mitochondrial DNA markers with those in Surinam and Guinea Bissau, and Brazil and Surinam are not currently distinguishable genetically (Bowen et al. 1998, A. Torres Hahn pers. comm.).

In Brazil, conservation efforts have been undertaken since 1982, starting with protection and monitoring of nesting beaches, then extending to feeding grounds (Marcovaldi & dei Marcovaldi 1999) and monitoring and mitigation of fishery interactions (Marcovaldi et al. 2002). The main olive ridley nesting beaches in Brazil are found along a 340 km continuous span of coastline in the states of Sergipe and northern Bahia, where annual nest numbers have been increasing since 1991 (da Silva et al. 2007). Despite these nesting increases, juvenile and adult olive ridley turtles have been captured by coastal (da Silva et al. 2002, Thomé et al. 2002) and oceanic (Sales et al. 2008) fisheries, constituting a major threat to the turtle population and underscoring the need for effective conservation strategies.

Little is known about post-nesting behavior, female habitat usage and the location of olive ridley foraging grounds in Brazil and regionally, hindering the development of informed management plans. The aim of this study was therefore to investigate the behavior of female olive ridley turtles nesting in northeastern Brazil, with respect to post-nesting movements, migratory routes and foraging grounds. By reporting data on olive ridley movements revealed by satellite telemetry in the Atlantic Ocean basin, this study provides information that is key for the conservation of olive ridley turtles and their habitats in the Western Atlantic, and for better understanding the variable life history patterns of this vulnerable species.

MATERIALS AND METHODS

The study took place along 21 km of sandy beaches in northern coastal Sergipe, an important nesting area for olive ridley turtles in Brazil, between 1 February and 4 April 2006 (Fig. 1; 10.7° S, 36.7° to 36.8° W; for detailed site descriptions see da Silva et al. 2007). Satellite transmitters were attached to 10 female olive ridley turtles (model KiwiSat 101, Sirtrack). Nesting females were located and, following complete oviposition, each turtle was placed in an open wooden box to facilitate transmitter attachment. The second and third medial scutes on the carapace were cleaned, and a satellite tag was attached with Tubolit® epoxy (Mitchell 1998). The attachment was then painted with Micron Premium® anti-fouling paint (International Yatch Paint) and allowed to dry for 45 min, after which turtles were released from the boxes and allowed to crawl into the ocean. Inconel tags (National

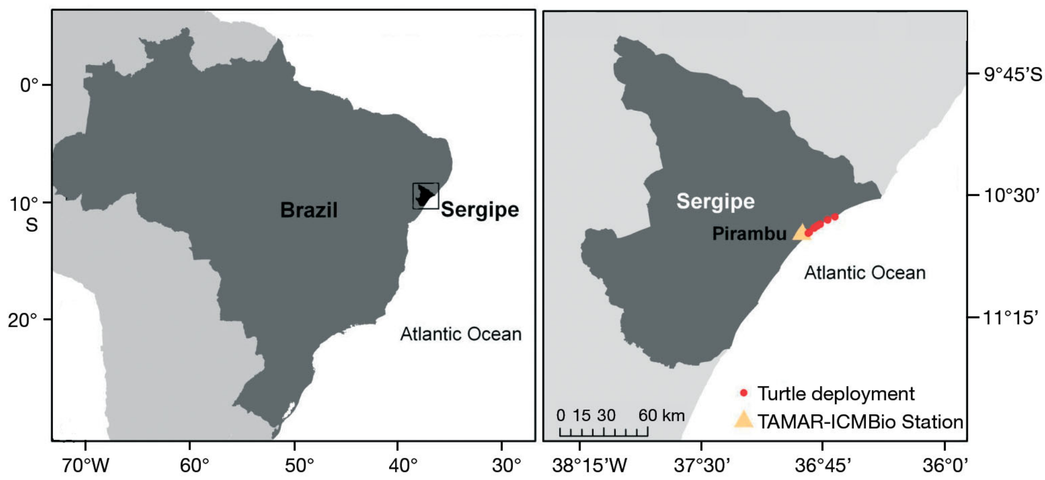

Fig. 1. Study area and locations of transmitter deployment on olive ridley turtles at Pirambu Beach in Sergipe, Brazil. Also shown is the location of the TAMAR-ICMBio conservation research station

Band and Tag Co.) were also attached to the trailing edge of each front flipper (following Balazs 1999), and curved carapace length (CCL) was measured in cm (Bolten 1999). Transmitters were powered by 2 D-size lithium batteries (0.5 W output), and were configured to work continuously during the first 60 d, and then for 24 h on/48 h off.

Data were collected via the Argos system (http://argosinc.com), which assigned location classes (LC) to each transmission as an estimate of accuracy. The location classes were: LC 3 (accurate to ±150 m), LC 2 (±350 m), LC 1 (±1000 m), LC 0 (accurate to >1000 m), and LCs A, B and Z (of unknown accuracy). The tracking information was automatically downloaded and sorted into fields from the Argos databank using the Satellite Tracking and Analysis Tool (STAT; Coyne & Godley 2005), which additionally provided information about seafloor depth and distance from the coast to the turtles' locations.

The location classes known to be most accurate (LCs 3, 2, 1 and A; Hays et al. 2001) were used for reconstructing migration routes and estimating distances traveled. We also included LC A, since according to Hays et al. (2001), it has similar accuracy to LC 1. LCs 0, B and Z, and positions requiring turtles to move at speeds in excess of 5 km h^{-1} were excluded from this analysis. To achieve a better estimate of area usage and avoid excessive data filtration, broader-scale foraging and inter-nesting habitat characterization also relied on LCs B and 0 data, in addition to data from LCs 3, 2, 1 and A. We filtered locations for water depth >0.5 m, speed <5 km h^{-1} and angles <25°.

Inter-nesting habitats were identified based on transmitter signals from turtles that remained in the vicinity of the nesting beach for at least 16 d after transmitter deployment. Post-nesting migrations were considered complete when movement no longer appeared to be directed for at least 3 consecutive days (Zbinden et al. 2008). Foraging grounds were identified as those areas where turtles showed restricted movements (multidirectional and back-tracked over previous tracks) following post-nesting migrations, which continued until transmissions ceased or turtles engaged in new return migrations (Troëng et al. 2005). These areas were defined solely based on turtle movements as it was not possible to verify foraging behavior.

Geographic information systems software (ArcGIS 9.1, Environmental Systems Research Institute) was used to map turtle movements and calculate high-use areas and movement pathways. To define important habitats for each turtle, home ranges based on fixed kernel density estimators were calculated using Hawth's analysis tools for ArcGIS (Beyer 2004). The minimum convex polygon (MCP) was calculated to determine the total size of foraging and inter-nesting grounds. Core activity areas were defined using 50% kernel home range estimates (KHREs). Individual and joined core habitat use areas were identified using a single parameter smoothing factor of 0.05 calculated following Silverman (1986). Also calculated were 75% and 90% KHREs. The polygonal shapes were measured in km^2. Bathymetry was determined by plotting the tracks against nautical charts from the Brazilian Navy (DHN 2009). The tracks were combined with available data on incidental longline fishery captures provided by Sales et al. (2008). Pelagic fishing effort was represented as the total number of hooks in each 5° × 5° quadrant measured in 2006. In order to identify potential threats within inter-nesting areas, the turtle's home range and core areas were superimposed with shrimp otter trawl data obtained during TAMAR's monitoring efforts in Sergipe.

RESULTS

Inter-nesting habitat

Of the 10 turtles tracked, 6 females (Turtles C, D, F, H, I and J) remained at the nesting grounds for 35.3 ± 28.2 d (mean ± SD; range: 20 to 84 d) before starting post-nesting migrations, while the remaining 4 females (Turtles A, B, E and G) left the area immediately following nesting and transmitter deployment (Table 1). The MCP analyses revealed that the total area occupied by the turtles that remained at the nesting ground was 5223.8 km^2. The core of this area, in which 50% (KHRE) of the signals were observed, covered 490.9 km^2, corresponding to 9.3% of the total inter-nesting habitat (Fig. 2). The inter-nesting area delineated by the analysis comprised almost all of coastal Sergipe. Most of the signals were transmitted from areas in the vicinity of the capture beach and release location, but signals were also received from both further north and south of this site (Fig. 2). The mean distance from the coast of the turtles tracked during the inter-nesting period was 7 ± 5.6 km (range: 1 to 36 km), and water depths were on average 19.8 ± 45.7 m (range: 1 to 420 m). The deeper areas were associated with submarine canyons typical of the Sergipe coast. Individual variation in distance and water depth is presented in Table 1.

Of the turtles remaining at the nesting grounds following transmitter attachment, Turtle H was observed again 20 d after transmitter attachment during

Table 1. *Lepidochelys olivacea*. Transmission data obtained from the 10 olive ridley turtles tracked in this study with respect to their inter-nesting habitat. CCL: curved carapace length. (–): no data (turtles did not nest again)

	Transmission data					Inter-nesting area		
Turtle	CCL (cm)	Deployment date (dd/mm/yy)	Last location (dd/mm/yy)	Days tracked	Total non-linear distance tracked (km)	Residence time (d)	Distance from coast (km) mean ± SD (range)	Depth (m) mean ± SD (range)
A	71.0	01/02/06	15/02/06	14	407	–	–	–
B	74.5	03/02/06	05/03/06	30	430	–	–	–
C	70.0	04/02/06	28/11/06	297	2789	84	5.6 ± 5.5 (1–23)	17.3 ± 35.9 (1–208)
D	69.0	05/02/06	08/07/06	153	1137	21	8.5 ± 2.6 (3–15)	18.5 ± 8.5 (7–46)
E	67.5	06/02/06	16/04/06	69	2402	–	–	–
F	71.5	08/02/06	30/04/06	81	604	65	5.3 ± 3.2 (1–18)	14.6 ± 43.8 (2–376)
G	68.5	11/02/06	05/07/06	144	4265	–	–	–
H	69.0	15/02/06	11/07/06	146	1645	22	5.9 ± 3.9 (1–14)	13.2 ± 8 (3–27)
I	71.0	18/02/06	30/05/06	74	612	31	13.9 ± 6.2 (3–30)	50.1 ± 91.2 (1–420)
J	75.5	03/04/06	12/08/06	131	2400	18	5 ± 2.3 (2–9)	8 ± 3.6 (1–13)

a second nesting event on 6 March 2006. According to the telemetry results, Turtles C, F and J probably also nested again in intervals of 20, 17 and 18 d, respectively, after the first recorded nesting event and transmitter attachment, but were not recaptured. Monitoring of shrimping vessels within the identified inter-nesting habitat (n = 413 hauls) revealed that there is a significant overlap between fishing grounds and core turtle inter-nesting habitats (Fig. 2). The trawl fleet operates in areas up to 30 m depth, between 3 and 15 km from shore.

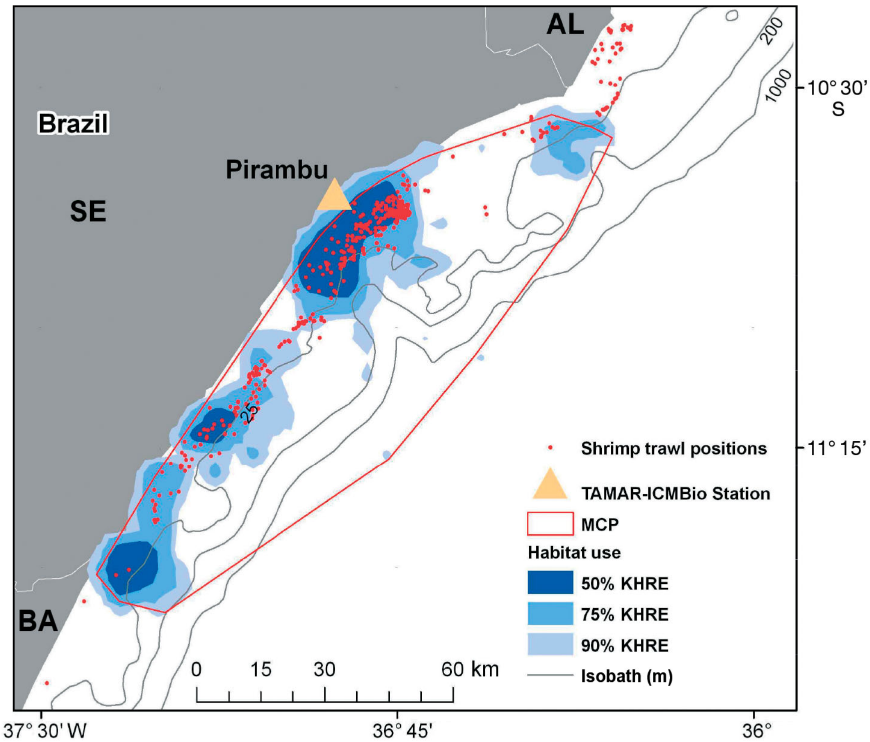

Fig. 2. *Lepidochelys olivacea*. Inter-nesting positions for olive ridley turtles (n = 6) nesting at Pirambu Beach (Sergipe, Brazil), with respect to locations of monitored shrimp trawls, isobaths, kernel home range estimates (KHREs; 90 %, 75 % and 50 %) and the minimum convex polygon (MCP). Abbreviations for Brazilian states are as follows: AL, Alagoas; SE, Sergipe; and BA, Bahia

Post-nesting migration

The turtles left the inter-nesting habitat after all nesting activity was concluded, and moved to neritic areas mainly within the limits of the continental shelf, with only 2 turtles (E and G) migrating to oceanic areas. Eight turtles (A, B, C, D, F, I, J and H) migrated to neritic areas located in northern, northeastern and southeastern Brazil. Of the 2 turtles that traveled to oceanic areas, one (Turtle E) departed the neritic zone from coastal Alagoas (9.985° S, 35.681° W), whereas the other (Turtle G) departed from the Paraiba coast (7.459° S, 34.455° W; Fig. 3, Table 2).

The distance from the nesting beach to neritic foraging grounds averaged 1172.1 ± 916.7 km (range: 222 to 2300 km). The migration time to foraging areas ranged from 16 to 78 d, with a mean of 40 ± 25.7 d (Table 2). Migratory routes were largely restricted to the northeast coast of Brazil, which is characterized by a narrow continental shelf (Fig. 3). The mean seafloor depth during the turtle's migration was 78 ± 175.6 m.

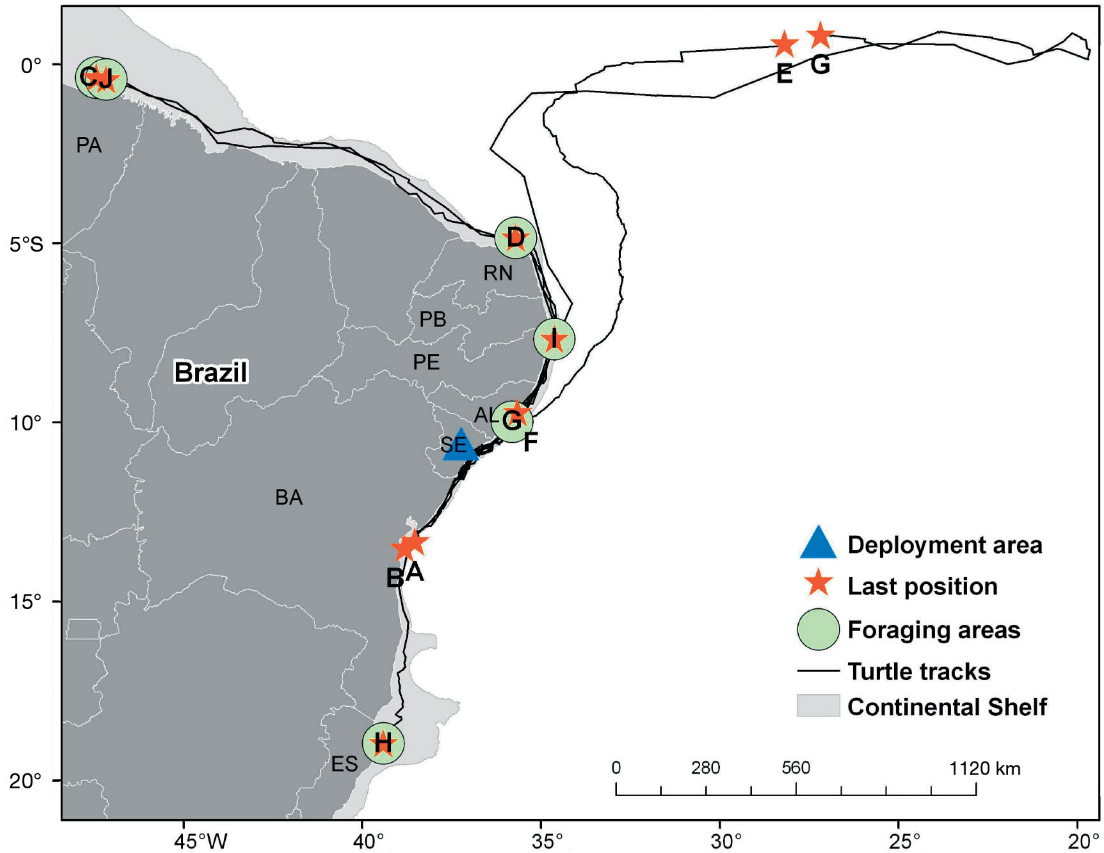

Fig. 3. *Lepidochelys olivacea*. Post-nesting movements of olive ridley turtles satellite-tracked from their nesting grounds in Sergipe (n = 10). Stars indicate last position of turtles before signal transmission ceased. Abbreviations for Brazilian states are as follows: PA, Pará; RN, Rio Grande do Norte; PB, Paraíba; PE, Pernambuco; AL, Alagoas; SE, Sergipe; BA, Bahia; ES, Espírito Santo

Table 2. *Lepidochelys olivacea*. Post-nesting migration and foraging ground residency data collected from satellite-tracked olive ridley turtles (n = 10). Abbreviations for Brazilian states are as follows: PA, Pará; RN, Rio Grande do Norte; PE, Pernambuco; AL, Alagoas; ES, Espírito Santo. (–): missing data or premature signal termination

	Post-nesting migration			Neritic foraging grounds						
Turtle	Departure from nesting area (dd/mm/yy)	Post-nesting migration (d)	Distance traveled (km)	Foraging ground location	Arrival at foraging ground (dd/mm/yy)	Distance from nesting grounds (km)	Residency (d)	50% kernel density estimates (km^2)	Distance (km) from coast mean ± SD (range)	Depth (m) mean ± SD (range)
A	08/02/06	14	407	–	–	–	–	–	–	–
B	03/02/06	30	425	–	–	–	–	–	–	–
C	29/04/06	78	2293	PA	16/07/06	2293	135	270.61	24.4 ± 3.1 (17–31)	18 ± 2.3 (13–21)
D	26/02/06	26	761	RN	24/03/06	761	106	164.84	31.3 ± 3.2 (22–37)	51.6 ± 41.4 (33–259)
E	06/02/06	69[a]	2402	–	–	–	–	–	–	–
F	18/04/06	16	264	–	–	–	–	–	–	–
G	11/02/06	21[b], 89[c]	4212	AL	04/03/06	222[a]	34	35.18	10.6 ± 2.3 (4–13)	15.3 ± 2.3 (9–18)
H	09/03/06	33	1051	ES	11/04/06	1051	91	273.61	41.0 ± 10.1 (29–72)	31.9 ± 6.1 (21–44)
I	21/03/06	16	406	PE	06/04/06	406	27	114.64	21.9 ± 4.0 (17–31)	42.2 ± 9.2 (33–72)
J	21/04/06	66	2300	PA	26/06/06	2300	47	184.15	23.4 ± 3.7 (18–29)	19.6 ± 1.2 (16–21)

[a]Post-nesting migration to oceanic waters
[b]Post-nesting migration to foraging sites
[c]Subsequent migration to oceanic waters from foraging site