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Leatherback turtle after nesting, Pedra do Sal beach, Parnaíba Delta area, state of Piauí, Brazil, 2012. The red lights are warning lights on top of wind power turbines, plentiful in the region. See pages 6-11. Photo: Instituto Tartarugas do Delta.

W. M. de S. Magalhães et al. Regular nesting by leatherback sea turtles (*Dermochelys coriacea*) in the Parnaíba Delta area, northeastern Brazil.

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Regular Nesting by Leatherback Sea Turtles (*Dermochelys coriacea*) in the Parnaíba Delta Area, Northeastern Brazil

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In Brazil, leatherback sea turtles (*Dermochelys coriacea*) were known to nest regularly, in relatively small numbers, only in the northern part of the state of Espírito Santo, around latitude 19° S on the eastern Brazilian coast (Fig. 1; Colman *et al.* 2019). Occasional leatherback nestings have been documented in different years at several places along the country's coast (Barata & Fabiano 2002).

Since 2007, evidence has accumulated indicating the existence of a second regular leatherback nesting area in Brazil, located around the Parnaíba River delta, straddling the border between the states of Piauí and Maranhão in the country's northeastern region (Fig. 1). Loebmann *et al.* (2008) published a report about a single leatherback nest laid in 2004 in that area. Here, we provide a wider account of leatherback nesting in the Parnaíba Delta area, using data spanning 2007-2019 and satellite-tracking data from one nesting turtle. The data were gathered by Instituto Tartarugas do Delta (Delta's Turtle Institute), a non-governmental organization dedicated to sea turtle conservation in that region, created in 2006. Within the limitations of the available information, we attempt to place the Parnaíba Delta nesting area in a biogeographical context, and discuss some possible conservation implications of these new findings.

The nesting area comprises possibly the whole state of Piauí coast, which is approximately 66 km long, and also, immediately to the west, Poldros Island in the state of Maranhão, with about 23 km of oceanic coastline. This area falls entirely within the Parnaíba Delta Environmental Protection Area, a federal coastal protected area, created in 1996, located around the Parnaíba River delta (2.74 °S, 41.79 °W; Fig. 1), with a surface area of about 3100 km² and about 146 km of oceanic coastline, including beaches and the coastal sea up to a distance of three nautical miles (5.6 km) from the coast. The region is characterized by a relatively dry period in June-December, and a rainy period in January-May. Average monthly air temperature during the year is 26-28 °C; maximum temperature can be as high as 39 °C.

In Piauí, leatherback nests were recorded on the beaches Pedra do Sal (municipality of Parnaíba), Arrombado (municipality of Luís Correia), and Barra Grande (municipality of Cajueiro da Praia); these beaches have a combined length of about 25 km. To the west, in the municipality of Araisões in the state of Maranhão, there are reports by local fishermen of leatherback nests on Poldros Island, which has no regular human occupation. Beach patrols on that island by the Instituto Tartarugas do Delta's technical team have occurred sporadically during each nesting season, due to the difficulty of access; no leatherback nests were observed on Poldros Island by that team. Due to the multiple river branches that exist in the delta region, some beaches are difficult to access, and some are accessible only by boat.

Beach patrols were carried out each year from May to July, when most nests occur; there is only one report by local inhabitants of a leatherback nesting outside that period. The objective was to perform beach patrols at night, but the extent and regularity of patrolling were dependent mainly on the available funds. Pedra do Sal, the beach seemingly with the largest number of leatherback nests, was monitored daily, funds permitting, by means of a four-wheel drive vehicle. In Barra Grande and Arrombado, the patrols were performed once a week on foot. In 2015, for lack of proper funding, there was no regular fieldwork; only a few opportunistic beach patrols were performed in that year. In 2018, fieldwork was severely hindered or even prevented on many nights by quite heavy rains.

The location of nests and their monitoring during the incubation of eggs followed standard procedures established for leatherbacks in Espírito Santo by Projeto Tamar (Colman *et al.* 2019). If the nesting female was not observed, the species was determined by examining live hatchlings remaining in the nest, or even dead hatchlings or embryos; for nests without hatchlings or embryos, the species was determined by the size of eggs or the width of the tracks on the beach.

Females encountered while nesting were checked for the presence of flipper tags and, if none were found, were double tagged on the rear flippers with Inconel tags (National Band and Tag Co., USA; style 681). For lack of proper equipment, neither checks for passive integrated transponder (PIT) tags nor their application were performed.

Seven leatherbacks in 2014 and one equipped with a satellite transmitter in 2019 (see below) had their curved carapace length (CCL) measured with flexible plastic tapes. Although the goal was to measure CCL from the center of the nuchal notch to the posterior tip of the caudal peduncle, alongside the central dorsal ridge, we subsequently realized that there were errors and inconsistencies with data collection. For this reason, no CCL information will be presented in this note; training of the field team in relation to CCL measurement and data recording will be duly reviewed.

On 19 June 2019, on Pedra do Sal beach in Piauí (2.860111 °S, 41.659361 °W), a nesting leatherback was equipped with a satellite transmitter (SPOT-317A, Wildlife Computers, USA) linked to the Argos system; the transmitter was directly attached to the carapace (Colman 2019). Between deployment and 08 May 2020, 8558 location records were obtained; the transmitter was still functioning normally on that last date (Fig. 1).

The location data provided by Argos are of varying quality. Each location is classified by Argos into one of seven classes, 3, 2, 1, 0, A, B or Z; the class conveys some information on the location's accuracy (CLS/Argos 2016). For the analysis of the Argos data, we, in sequence, (1) discarded all records in class Z; locations in

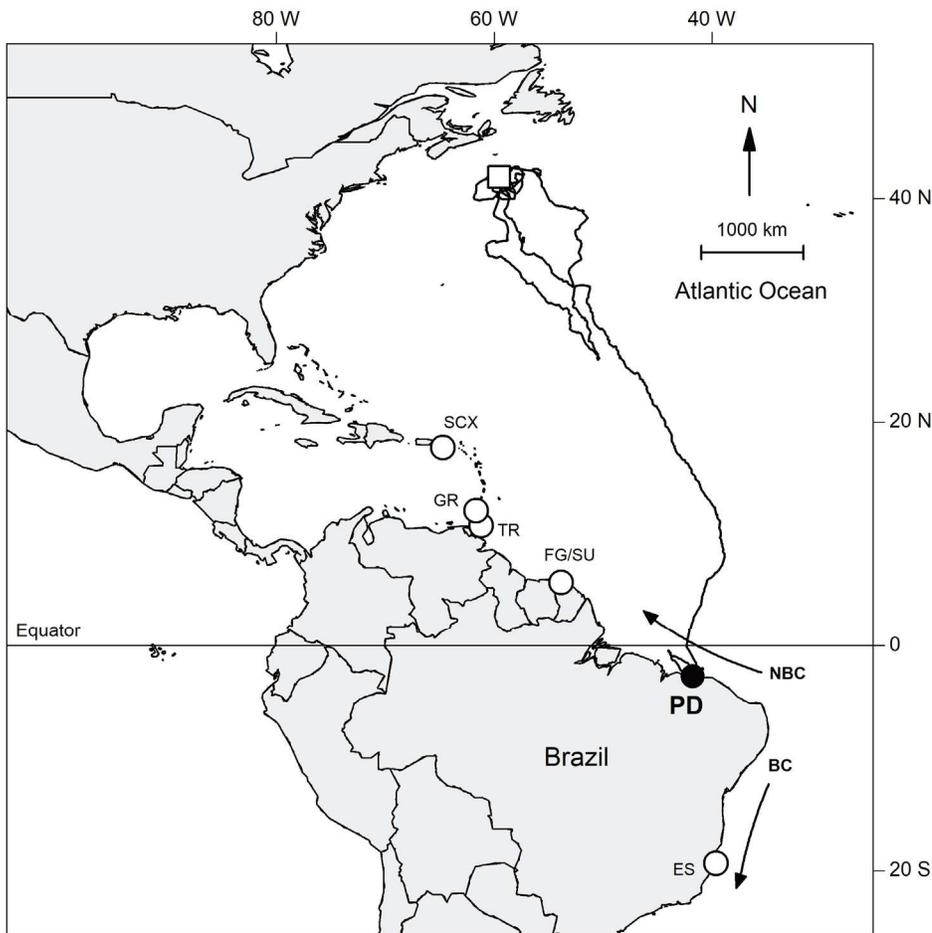


Figure 1. Map showing the leatherback nesting area around the Parnaíba Delta (PD; black circle), northeastern Brazil, and the route in the Western Atlantic taken by one nesting female satellite-tagged there on 19 June 2019; the white square marks the last position of this turtle on the map, obtained on 08 May 2020. The white circles indicate some regular leatherback nesting sites relatively close to the Parnaíba Delta area: Espirito Santo, eastern Brazil (ES), French Guiana/Suriname (FG/SU), Trinidad (TR), Grenada (GR) and Saint Croix, U.S. Virgin Islands (SCX). The curved ocean arrows indicate parts of the North Brazil Current (NBC) and of the Brazil Current (BC).

that class are considered invalid by Argos (CLS/Argos 2016); (2) discarded duplicate records in time and/or space (Shimada *et al.* 2016); (3) computed the apparent travel speed between consecutive locations, and discarded all pairs of consecutive locations for which that speed was > 10 km/h (Fossette *et al.* 2010); (4) repeated step 3 iteratively until no apparent travel speed > 10 km/h was obtained between two consecutive location points. The end result of this process was a data set with 1472 Argos locations. Data analysis and mapping were performed using the software R 4.0.2 (R Core Team 2020) and its package “maps”. Sea distances between the Parnaíba Delta and other leatherback nesting sites were estimated by means of the software Google Earth Pro (www.google.com/earth/versions).

We documented nesting activity nearly every year in our study (Fig. 2). A likely explanation for the absence of records in both 2015 and 2018 is the small amount of fieldwork performed in those years. Taking that into account, our data suggest that there is likely annual nesting activity in the study area. Given the wide differences in sampling effort that existed across the years, we have not attempted to estimate either the annual number of nests in the Parnaíba Delta area in each year or the temporal trend of the data presented in Fig. 2.

Although no estimates are available of either the average annual number of nests or population size, considering (1) the small number of nests either observed or inferred in each year (Fig. 2), (2) the relatively large extent of the monitored beaches in the state of Piauí, which comprise 38% of the state’s coast, (3) the duration of the annual fieldwork, which generally covered the entire leatherback

nesting season, and (4) the fact that, in the sporadic beach patrols by the Instituto Tartarugas do Delta’s technical team on Poldros Island in the state of Maranhão, no leatherback nestings have been observed there, we conclude that the Parnaíba Delta leatherback colony is relatively small in size, possibly no larger than the one nesting in Espirito Santo, Brazil, which had an average annual number of 90 nests in the five-year period 2013–2017, with 15–18 females estimated to nest each year in that period (Colman *et al.* 2019).

The leatherback nesting season in the Parnaíba Delta (May to July) overlaps with the nesting seasons in French Guiana and Suriname, Trinidad, Saint Croix (U.S. Virgin Islands) (Fig. 1) and other leatherback nesting sites in the northwestern Atlantic (Eckert *et al.* 2012). In French Guiana, where the main nesting season occurs in March–August, there is also some nesting between November and January, but in annual numbers about two to three orders of magnitude smaller than those in the main season; the reasons for this so-called “small” nesting season and its possible relationship with the main nesting season are poorly understood (Chevalier *et al.* 2000; Fossette *et al.* 2008). The nesting season for leatherbacks in the Parnaíba Delta is markedly different from the one in Espirito Santo, Brazil, where nesting occurs mainly between October and January (Colman *et al.* 2019). In Gabon and Congo, in the eastern Atlantic, a major leatherback nesting area located around the Equator but largely in the southern hemisphere, the nesting season goes mainly from December to February (Witt *et al.* 2009).

While nesting, seven leatherbacks were flipper-tagged in 2014, and one in 2019 (the turtle equipped with a satellite transmitter

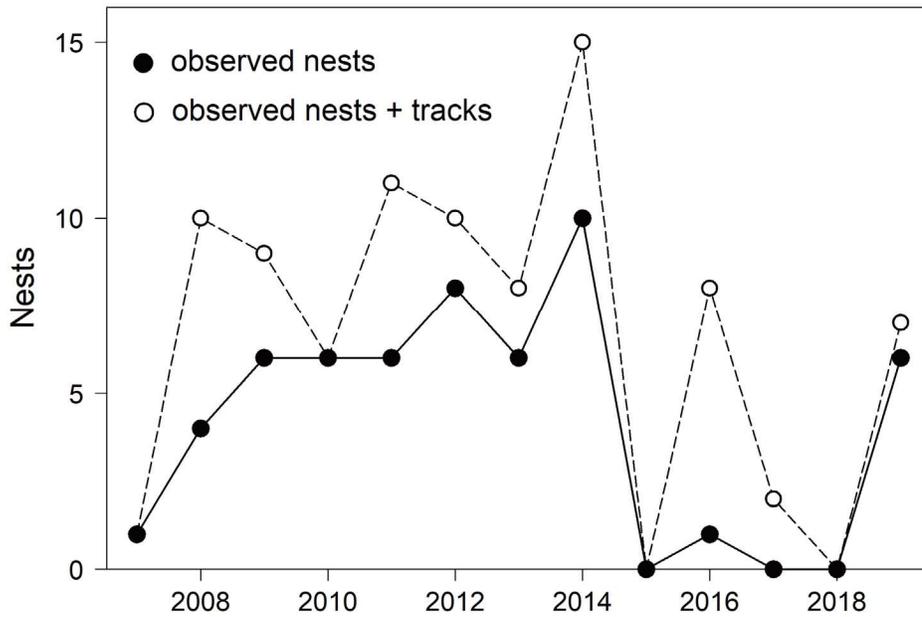


Figure 2. Leatherback nests by year, Parnaíba Delta area, northeastern Brazil. Black circles: number of observed nests by year. White circles: for each year, the number of observed nests plus the number of recorded tracks without confirmed nests; this provides an upper bound for the actual number of nests within the available records for the year.

in that season). Four renestings were recorded among that set of females, three in 2014 and one in 2019, but no remigration of tagged leatherbacks between different years was observed in the Parnaíba Delta area.

Considering only common metal flipper tags, widely applied on leatherbacks on nesting beaches and/or at sea at several places in the Atlantic (e.g., Stewart *et al.* 2013; Colman *et al.* 2019), no leatherbacks nesting in the Parnaíba Delta were ever found bearing tags applied elsewhere, and no leatherbacks tagged in the Parnaíba Delta have ever been reported either in nesting activity or incidentally captured or stranded elsewhere. The irregular fieldwork and the small number of females found on beaches and flipper-tagged in the Parnaíba Delta might at least in part explain these observations. Although leatherbacks nesting in the Parnaíba Delta were not checked for the presence of or equipped with PIT tags, these tags are used at several leatherback nesting sites or by at-sea research projects in the Atlantic (e.g., Fossette *et al.* 2008; Stewart *et al.* 2013). At the time of writing, PIT tags were used on nesting leatherbacks in Espírito Santo, Brazil, only in the 2019/2020 season (Colman, L., pers. comm. 2020).

Satellite transmitters, which could also help to establish connections between the Parnaíba Delta area and other leatherback nesting sites in the Atlantic, and with foraging areas (Hays & Hawkes 2018), have been attached to leatherbacks in the Atlantic either at sea (e.g., Dodge *et al.* 2014; Hamelin & James 2018) or on nesting sites (e.g., Almeida *et al.* 2011; Chambault *et al.* 2017), but no leatherback was found in the Parnaíba Delta bearing a satellite transmitter applied elsewhere.

The sole leatherback equipped with a satellite transmitter while nesting in the Parnaíba Delta area in 2019 followed a northward route, towards a region of the ocean relatively close to Nova Scotia in Canada (Fig. 1). That route was quite similar to those of some leatherbacks satellite-tagged on nesting beaches in French Guiana, Suriname and Grenada (Ferraro *et al.* 2004; Hays *et al.* 2006; Fossette *et al.* 2010; Chambault *et al.* 2017; Fig. 1). The northwestern Atlantic region off eastern Canada and northeastern United States is recognized as a key foraging area for leatherbacks

originating from multiple nesting sites in northern South America, in the Caribbean region and in southeastern United States (Stewart *et al.* 2013, 2016). The northward route taken by the turtle satellite-tagged in the Parnaíba Delta is completely distinct from the routes followed by leatherbacks (N = 4) satellite-tagged on nesting beaches in Espírito Santo, Brazil, which stayed entirely within the South Atlantic (Almeida *et al.* 2011; Colman 2019).

Satellite tracking studies have suggested the existence of a major south-north separation in the Atlantic in relation to geographical movements and use of foraging areas by leatherbacks, with leatherbacks nesting in the South Atlantic (Espírito Santo, Brazil, or Gabon, West Africa) remaining in the South Atlantic, while leatherbacks that nest in the Northwestern Atlantic appear to be restricted to the North Atlantic (Stewart *et al.* 2013; Fossette *et al.* 2014; Stewart *et al.* 2016). Although the Atlantic south-north separation might be followed in a general way, it may not be strictly maintained. A mixed-stock genetic analysis based on mitochondrial data, using samples from leatherbacks that were either stranded or incidentally captured in fisheries in southern Brazil and Argentina, found that while most of the turtles originated from West African populations, a small proportion of the animals could have originated from North Atlantic and other stocks (Vargas *et al.* 2019). These findings might be explained, at least in part, by the fact that some other West African leatherback populations, with their assortment of haplotypes, were not represented in the mixed-stock analysis, and/or by limitations in the resolution of analyses based on mitochondrial data (Fretey *et al.* 2007; Vargas *et al.* 2019).

A key difference in environmental conditions between the two leatherback nesting areas in Brazil, the Parnaíba Delta and Espírito Santo, is the direction of the major ocean surface current in each area; this might have significant implications for the dispersal patterns of hatchlings from each area into the sea (Gaspar *et al.* 2012). Off the Espírito Santo coast, the Brazil Current flows southwards (Fig. 1); it is a component of a counterclockwise subtropical gyre that exists in the South Atlantic between eastern South America and western Africa. In a contrasting mode, off the Parnaíba Delta area the North Brazil Current (NBC) flows in a northwesterly direction alongside

the northern Brazilian coast (Fig. 1). Further to the northwest, the NBC has quite a complex behavior, with seasonal variations in seawater flow including retroreflections and the formation of large-scale eddies; however, in any season at least a part of the NBC flows northwestwards to become the Guiana Current that goes along the northern South American coast towards the Lesser Antilles, to be continued from there by the Caribbean Current that goes towards the Gulf of Mexico (Richardson *et al.* 1994; Talley *et al.* 2011; Koszalka & Stramma 2019).

Regional mesoscale oceanographic conditions can differentially affect hatchling dispersion from different nesting beaches, and subsequently affect migration patterns of adults (Hays *et al.* 2010; Gaspar *et al.* 2012). The different oceanographic conditions between Espírito Santo and the Parnaíba Delta, which would presumably entail different dispersal patterns of hatchlings in each case, could lead to the use of distinct foraging areas later in their life. Under the assumption that the leatherback satellite-tracked from the Parnaíba Delta region had actually hatched there, the northwestward drift of the NBC, which would presumably define hatchlings' dispersal patterns, and the observed use by that turtle of a foraging area in the North Atlantic (Fig. 1) would seem to corroborate that hypothesis.

While in strict geographical terms the Parnaíba Delta area, located just below the Equator, belongs to the South Atlantic, three pieces of ecological information suggest that, in biogeographical terms, the Parnaíba Delta leatherback population might actually belong to the North Atlantic realm: (1) its nesting period, which agrees with those of Northwest Atlantic leatherback populations, (2) the northwestward direction of the major ocean surface current around the Parnaíba Delta, which may have a key role in the definition of the hatchlings's dispersion patterns, and (3) the northward route, up to an oceanic region close to Canada, taken by the one adult turtle satellite-tagged there. Further satellite-tracking data will be needed in order to obtain a clearer picture of the migratory patterns of the Parnaíba Delta population. Satellite-tracking of leatherbacks from French Guiana/Suriname and Grenada beaches showed the existence of a wide range of post-nesting migratory movements from these areas into the North Atlantic (Ferraroli *et al.* 2004; Hays *et al.* 2006; Chambault *et al.* 2017). The leatherback nesting area in the North Atlantic closest to the Parnaíba Delta, French Guiana/Suriname, is about 1700 km (sea distance) away from that Brazilian nesting site, while the closest one in the South Atlantic, Espírito Santo, Brazil, is about 2400 km (sea distance) away from the Parnaíba Delta.

At the time of writing, no genetic analyses have been performed of tissue samples already collected from leatherbacks nesting in the Parnaíba Delta. Genetic analyses, combined with the deployment of further satellite transmitters on nesting turtles, the ability to read and apply PIT tags, and stable isotope analyses of tissue samples (Haywood *et al.* 2019), should help increase our understanding of the ecology of the Parnaíba Delta leatherback population and of its possible connections with other leatherback populations and with foraging areas in the Atlantic, in particular with the large population that nests in French Guiana and Suriname. A regular schedule of beach patrols and turtle tagging in each nesting season would be a means of obtaining reliable estimates of the annual number of nests, clutch frequency, remigration period and other demographic parameters. These are matters of central importance in the establishment of conservation plans for the Parnaíba Delta population and for regional conservation purposes.

Globally, the leatherback sea turtle is currently classified by the IUCN Red List as Vulnerable (Wallace *et al.* 2013). However, in the 2013 Red List Assessment, the global leatherback population was divided into seven subpopulations, and each separately assessed. The Southwest Atlantic Ocean subpopulation, represented by a single nesting colony in Espírito Santo, Brazil (Fig. 1), is classified as Critically Endangered, while the Northwest Atlantic Ocean subpopulation, which includes French Guiana/Suriname, Trinidad, Saint Croix (U.S. Virgin Islands) (Fig. 1) and other nesting colonies, is classified as Endangered. As discussed previously, the available information suggests that the Parnaíba Delta leatherback population might belong, in biogeographical terms, to the North Atlantic. If this is confirmed in the future, this population should be included in the Northwest Atlantic Ocean subpopulation for regional assessment and conservation purposes.

In Brazil, leatherback turtles are currently classified as Critically Endangered, but this classification was determined solely on the basis of data from the population that nests in Espírito Santo, the only population in the country for which nesting data were previously available (ICMBio/MMA 2018). The different biogeographical characteristics that apparently exist between the leatherback populations of Espírito Santo and of the Parnaíba Delta will likely require that future status assessments in Brazil be separately performed for each of the two populations.

The conclusions here presented with respect to the Parnaíba Delta leatherback population are preliminary, some of them tentative. Clearly, a wider variety of data are needed to make it possible a more solid understanding of the demographical and biogeographical conditions of that population.

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