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Sea turtle strandings along a semiarid coast in the western equatorial Atlantic

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Abstract

For decades, the Brazilian north-east coast has been a recognized feeding area for five sea turtle species. However, it still lacks information about stranding patterns. A decade of a beach monitoring programme (from 2010–2019) provided information on the composition, abundance and spatio-temporal distribution of stranded sea turtle species along a semiarid coast in the western equatorial Atlantic. A total of 905 individuals of four species were recorded in a route of ∼130 km. The most stranded group was the juvenile green turtles (*Chelonia mydas*), followed by *Lepidochelys olivacea*, *Eretmochelys imbricata* and *Caretta caretta*. The strandings present a seasonal and geographic pattern, and therefore any conservation measure to be implemented must consider these patterns. Also, the possible occurrence of fibropapillomatosis tumours calls for additional studies to understand its causes. Lastly, stranded sea turtles eventually show marks of fishery interaction, which indicate the need for environmental education programmes with fishing communities.

Introduction

Successful conservation programmes are built on a broad range of knowledge about an aimed target and its major threats to set assertive conservation measurements (Godley *et al.*, 2003; Flint *et al*, 2017). However, such programmes are particularly challenging for sea turtles because they spend most of their lives underwater (Godley *et al.*, 2020; Machovsky-Capuskaa *et al.*, 2020). Therefore, even after long-term efforts, there is still a lack of information following the turtles' complete life cycle (Gibons & Lovich, 2019; Godley *et al.*, 2020). This framework of difficult-to-assess habitat coupled with biological features such as long migration periods, late reproductive maturation, and low offspring success make sea turtle conservation a pressing and challenging matter (Marcovaldi *et al.*, 2012; Poli *et al.*, 2014; Gibons & Lovich, 2019). Six of the seven known sea turtle species are considered vulnerable (N = 3), endangered (N = 1) or critically endangered (N = 2) by the International Red List of the IUCN (Seminoff, 2004; Abreu-Grobois & Plotkin, 2008; Mortimer & Donnelly, 2008; Wallace *et al.*, 2013; Casale & Tucker, 2017). Fishery and bycatch are the major threats for sea turtles worldwide, significantly decreasing populations (Snape *et al.*, 2013). In addition, rubbish in the oceans, diseases and disasters also negatively impact sea turtle populations globally (Poli *et al.*, 2014).

Several approaches to characterize these threats and obtain information concerning sea turtle ecological and life-history patterns are available, including beach monitoring. Beach monitoring programmes (BMPs) are widely used to study sea turtle populations (Poli *et al.*, 2014), improving not only the available data on possible threats but also the size of the local population, nesting incubation periods, anthropogenic interactions, spatial distribution, species use of an area, and other valuable parameters for determining conservation priorities. However, data obtained through BMPs represent only a fraction of what is effectively happening to any given population (Hart *et al.*, 2006; Wallace *et al.*, 2010). Despite this limitation, BPMs are an important research tool once they can be performed from land and adapted for different personnel realities and availability of low- to high-cost tools. In Brazil, companies often sponsor long-term BMPs as a form of compensation demanded by law due to polluting activities.

The Brazilian coastal zone and oceanic islands are well-known habitats for sea turtles. These animals can be found foraging, reproducing or passing through the migration corridors. Five species occur in the area: the green turtle (*Chelonia mydas* Linnaeus, 1758), the olive turtle (*Lepidochelys olivacea* Eschscholtz, 1829), the hawksbill turtle (*Eretmochelys imbricata* Linnaeus, 1766), the loggerhead turtle (*Caretta caretta* Linnaeus, 1758) and the leatherback turtle (*Dermochelys coriacea* Vandelli, 1761) (Marcovaldi & Marcovaldi, 1999). Sea turtles have been nationally protected in Brazil since the 1980s with measures implemented by law alongside projects such as the TAMAR national project (Marcovaldi & Marcovaldi, 1999) and many others acting locally. However, despite best efforts, all five species occurring in Brazilian waters are still considered endangered by Brazilian law (MMA, 2014).

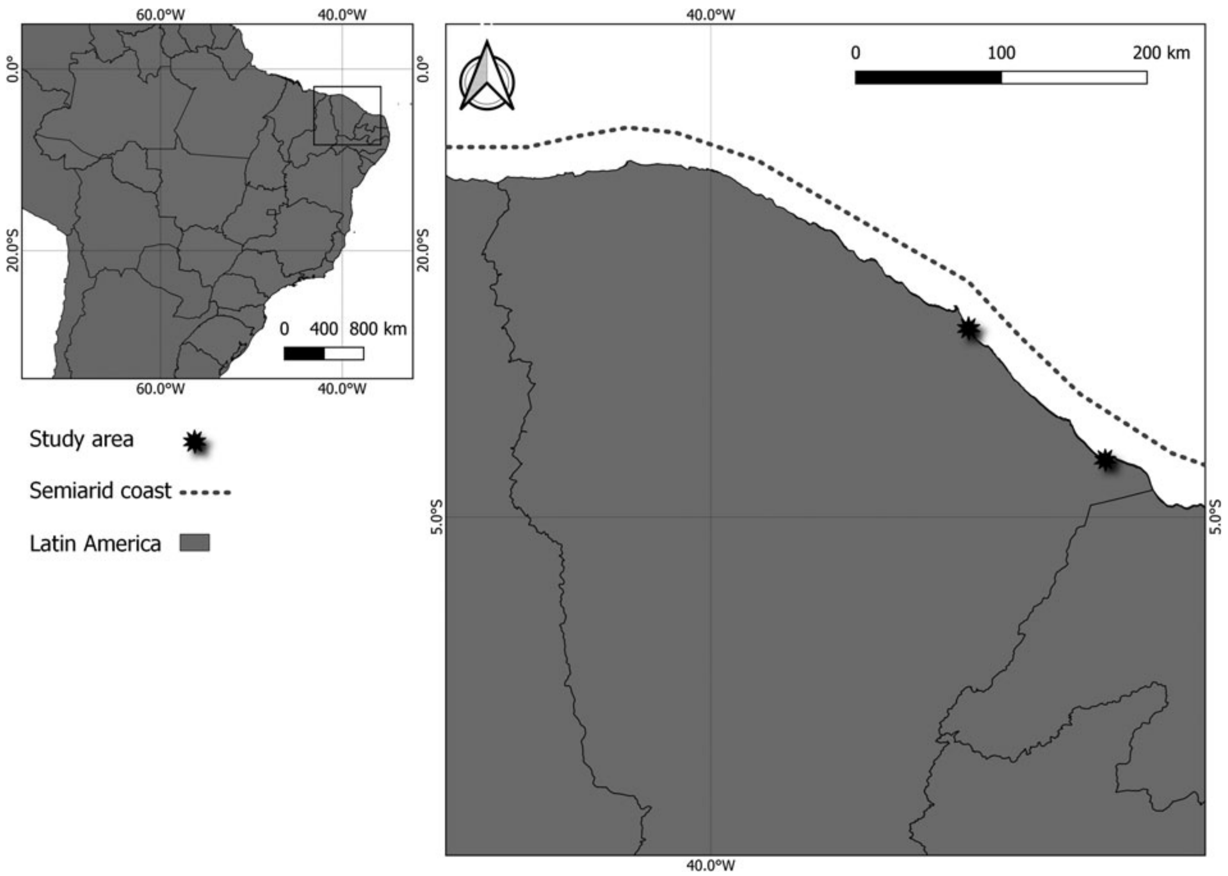

Fig. 1. Map of Brazil showing the location of Ceará state and the beach survey route used for monitoring sea turtle strandings between 2010 and 2019 along a semiarid coast in the western equatorial Atlantic, eastern Ceará state (from Aquiraz to Aracati), north-eastern Brazil.

Sea turtle strandings were recently described for an easternmost stretch of north-eastern Brazil's semiarid coast in the western equatorial Atlantic (Farias *et al*., 2019). However, the sea turtles stranding west of this point (Ceará coastline) is still poorly documented, even though the region is considered a migration corridor and foraging ground for sea turtles (Lima *et al*., 2013). Within this context, the present study aimed to identify the species and the relative abundance of sea turtle strandings alongside the coast; to determine the maturation stage of these turtles; to test if stranding patterns follow a seasonal or geographic pattern; and to characterize any sign of fibropapillomatosis (FB) or anthropogenic interaction.

Materials and methods

Study area

A total of 151 beach surveys were conducted on the east coast of Ceará, north-eastern Brazil, from February 2010 to July 2019 by the Associação de Pesquisa e Preservação de Ecossistemas Aquáticos (NGO Aquasis; under licence ABIO number 1080/2019), through their BMP (Figure 1). The route started from the east side of Pacoti River in Aquiraz and ended in Aracati, both in Ceará (Figure 1). The coastline route was ∼130 km long. The monitoring team was composed of at least two people. A 4 × 4 pickup truck was used during surveys, which usually lasted around 8 h. The interval between surveys was 20 days, on average. During a survey, when a high tide precluded the route, a ferry was used, or the team waited for the low tide to continue the survey. In cases where none of these options was available, the team would continue the survey the following day. Another alternative used was to split the team in two, where the first group was driving on the road while the second would walk the shore.

Ceará has semiarid weather characterized by two main seasons: rainy (first semester) and windy (second semester). The first semester concentrates almost 91% of yearly rain, with low-speed winds; on the other hand, the second semester is dry and with relatively high-speed winds (Morais *et al*., 2006). For this work, we considered only the two main seasons of the study area. Its coastline presents 573 km and suffers significantly from erosion due to anthropogenic and natural causes (Morais *et al*., 2006). The state's economy is strongly associated with tourism. It was the fifth capital of Brazil in the number of international tourists between January and April 2019, presenting a strong relationship with artisanal fishing linked with economic implications. The Brazilian northern and north-east regions represent Brazil's most substantial producers of marine fish (Neto *et al*., 2021).

Individuals

Species identification followed Reis & Goldberg (2017). One character considered for species identification was the number of coastal scutes. The shape of scutes and colour nuances were used to confirm green and hawksbill turtles because they present no differences in the number of scutes. Animals without carapace (removed) or in an advanced state of decomposition were recorded as 'not identified', and the turtle's head was not used for identification.

The curved carapace length (CCL) was measured with flexible tape. The CCL was taken from the nuchal notch mid-line to the supracaudals tip (Bolten, 1999). The following additional data were recorded: (1) date; (2) geolocation and municipality; (3) external evidence of disease; and (4) external evidence of negative anthropic interaction. Each individual was photographed.

Data analysis

The CCL was used to determine the maturation stage for each individual according to values established in the literature for

Table 1. Records of sea turtle strandings between 2010 and 2019 along a semiarid coast in the Western equatorial Atlantic, eastern Ceará state, north-eastern Brazil

Year	*Chelonia mydas*	*Lepidochelys olivacea*	*Eretmochelys imbricata*	*Caretta caretta*	Not identified	Total
2010	106	1	1	0	7	115
2011	73	1	4	1	0	79
2012	92	3	3	0	0	98
2013	101	5	5	2	0	113
2014	111	7	4	1	0	123
2015	82	3	2	1	0	88
2016	93	3	0	0	0	96
2017	56	0	0	0	0	56
2018	71	5	2	0	0	78
2019	56	2	0	0	1	59
Total	841	30	21	5	8	905

Table 2. Maturation stage and size of sea turtle strandings between 2010 and 2019 along a semiarid coast in the Western Equatorial Atlantic, eastern Ceará state, north-eastern Brazil

Species	N	Juvenile	Adult	Min–Max CCL (cm)	Mean (SD) (cm)
Chelonia mydas	841*	730	107	27–126	60,2 (21,4)
Lepidochelys olivacea	30	12	18	39–92	63,83 (8,64)
Eretmochelys imbricata	21**	17	3	34–100	55,94 (21,5)
Caretta caretta	5	1	4	47–107	88 (23,6)

CCL, curved carapace length.
*Four individuals without CCL measured. **One individual without CCL measured.

sea turtles in Brazil. Sea turtles with the following CCL values were considered adults: (1) green turtle, CCL ≥ 90 cm (Almeida *et al*., 2011); (2) olive turtle, ≥ 65.3 cm (Da Silva *et al*., 2007); (3) hawksbill turtle, ≥ 83 cm (Santos *et al*., 2010); (4) loggerhead turtle, ≥ 86.5 cm (Lima *et al*., 2012). Individuals with smaller CCL values were considered juveniles.

We used Generalized Linear Mixed Models (GLMM) to quantify the changes between the turtle strandings as a function of the season (first and second semester), size of the coast (considering the length of the four study area's municipalities), species (loggerhead, olive, hawksbill and green) and age (juveniles and adults). GLMMs combine the mixed linear models' properties, which incorporate random effects to quantify the variation between sample units, and generalized linear models, which use 'link' functions and exponential distributions families to deal with non-normally distributed data (Bolker *et al*., 2009). Because we were analysing non-negative metrics, we considered a Gaussian distribution with a logarithmic link function to generate the models.

We considered the year and municipality as added random effects. We compared results in terms of small sample Akaike's Information Criterion (AICc) for each metric. AICc accommodates the sample size influence to measure the quality of the model fit (Sugiura, 1978; Hurvich & Tsai, 1991). We examined all models to understand the influence and significance of model factors on turtle strandings and calculated the relative weights for the preferred models. GLMM calculations were performed in the software R (R Core Team, 2020) through the packages lme4 (Bates *et al*., 2015) and AICcmodavg (Mazerolle, 2020).

Results

We recorded 905 stranded sea turtles belonging to four species. The most stranded species was the green turtle, *C. mydas* (93% of recorded individuals), followed by the olive turtle, *L. olivacea* (3%), hawksbill turtle, *E. imbricata* (2%), and loggerhead turtle, *C. caretta* (0.6%). Another eight sea turtles recorded were not identified at the species level due to damaged carapace (Table 1).

The green turtle was the only species recorded throughout all years. The olive turtle was recorded in nine years, and hawksbill in seven years. Finally, the loggerhead was recorded in four years (Table 1). As for the sea turtle life stage, juveniles stranded significantly more than adults (N = 762; $P < 0.01$) compared with adults and were present in all species recorded (Table 2).

Sea turtle strandings differed by season ($P < 0.01$), considering the local division of rain (first semester) and wind (second semester) seasons, with the higher number of strandings during the wind season. Only green, olive and hawksbill turtles were recorded throughout the year. Strandings were significantly higher in more extensive coastlines ($P < 0.01$). Thus, it is likely that the number of sea turtles stranding fluctuates according to the available area.

Stranded sea turtles showed external evidence of disease and negative anthropogenic interaction. First, tumours commonly associated with FB were found in 17 individuals (1.8%). Second, entangled flippers with fishing nets, amputation and turtles trapped in a lobster device (*manzuá*) were recorded for 37 individuals (4%). Unfortunately, no information on internal injuries of anthropogenic origin, for example, foreign body ingestion, was obtained because necropsies were not performed.

Discussion

This study represents the most comprehensive dataset on sea turtle strandings in north-eastern Brazil (a decade-length). Sea turtles have been primarily studied in the western (Projeto TAMAR) and central (Instituto Verdeluz) coastal portion of the Ceará state. The present study fills this gap by bringing comprehensive

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information for a larger extension of the state and building a profile of the stranding sea turtles in the region.

Ceará's coastal zone is an important site of sea turtle feeding (Lima *et al.*, 2013) and a migration path (Naro-Maciel *et al.*, 2006) for the five species occurring on the Brazilian coast. The green turtle was the most recorded species (93%) in the present study, corroborating the pattern observed in other studies alongside the Brazilian coast. *Chelonia mydas* strandings represent 81% of the occurrences in the Brazilian north-east (Farias *et al.*, 2019) and 89.9% in the Brazilian south-east (Tagliolatto *et al.*, 2019). The highest number of strandings for the green turtle also occur in other parts of the world, including the Mediterranean (Sönmez, 2018) and Oceania (Flint *et al.*, 2017). Overall, the largest record of *C. mydas* is perhaps due to the species' foraging strategy, which is mainly concentrated in shallow waters (Campos & Cadorna, 2020).

The other species' strandings in the area presented considerably lower frequencies than *C. mydas*. The second most abundant species in strandings was the olive turtle, *L. olivacea*, which uses Ceará as a foraging area (juveniles and adults) and a migratory corridor for reproduction (adult females) in French Guiana and Surinam (Da Silva *et al.*, 2011). The hawksbill turtle, *E. imbricata*, was the third species in strandings. It migrates to Ceará after the nesting season in Bahia (north-eastern Brazil; Marcovaldi *et al.*, 2012) and also uses Ceará's coast as a feeding ground (Lima *et al.*, 2013). At last, the loggerhead turtle, *C. caretta*, was the less frequently stranded species, although it also uses Ceará as a foraging area (Lima *et al.*, 2013). This species is abundant in the northernmost part of its distribution range in the western Atlantic (USA; Lamont *et al.*, 2014), potentially explaining its relatively rare occurrence in the region. The leatherback turtle (*D. coriacea*) is Brazil's only sea turtle species with no strand recorded in the studied area.

The sea turtles' juvenile individuals represented 84% of the recorded strandings. The species found in the present study complete their ontogeny in neritic environments with higher food availability, justifying the high incidence of juvenile turtle strandings (Bolten, 2003; Poli *et al.*, 2014).

The strandings trend for the second semester, during the strongest winds, may be explained by the increased chance of the carcass landing on the shore. Also, for a sea turtle to run aground onshore, it usually dies close by; otherwise, it would simply decompose in the sea. Hart *et al.* (2006) estimate a 20 km approximate distance from a beach line for sea turtles dying to shore, and the wind is a considered factor. Similar findings were obtained in the following Brazilian states: Rio Grande do Norte (Farias *et al.*, 2019), Rio de Janeiro (Tagliolatto *et al.*, 2019) and Rio Grande do Sul (Monteiro *et al.*, 2016). The relationship between the coastal size and the number of strands indicates another important management pattern, suggesting that the second half of the year and longer beaches should be the primary choice for monitoring and mitigation efforts. However, as sea turtles could easily move a few kilometres on each side, the efforts should consider the whole length and, if possible, the whole year.

Furthermore, coastal areas are heavily affected by human impacts such as fishing, pollution and contamination, exposing sea turtles and other marine animals to these threats. The presence of anthropogenic interaction related to fishing (e.g. sea turtles trapped in *manzuás*) is a sensitive topic to the region. North-east Brazil is one of the country's leading producers of marine fishing, and most of it is artisanal fishing (Neto *et al.*, 2021). Creating awareness programmes for local fishermen and their community is essential in this context, considering their role in sea turtle conservation and economic importance (Awabdi *et al.*, 2018).

In addition to the dangers caused by fishing activities, we highlight in this study the general health conditions of sea turtles prior to dying and stranding. The presence of fibropapillomatosis in 17 of 905 turtles examined indicates that these animals were already debilitated before death. Tumours can appear during periods of stress and impair sea turtles' vision, swimming and feeding skills (Herbest, 1994; Zwarg *et al.*, 2014; Jones *et al.*, 2015). Other Brazilian states from the east semiarid coast held similar investigations. In Rio Grande do Norte, 22.7% of the sea turtles stranded had tumours associated with FB (Silva-Junior *et al.*, 2019), and in Paraíba, this presence was seen in 28.5% of the cases (Poli *et al.*, 2014).

Furthermore, the presence of this disease may be indicative of overall poor water quality in the marine ecosystem (Herbest, 1994; Jones *et al.*, 2015). Its occurrence has been increasing in tourist sites (e.g. in the USA; Foley *et al.*, 2005) as well as in environments with bad quality indexes (e.g. Espírito Santo, Brazil; Santos *et al.*, 2010).

In conclusion, our results provide relevant data on sea turtle strandings from the Ceará coast for the last decade, with juvenile *C. mydas* as the group with the greatest strandings. We also indicate a seasonal and geographic pattern in strandings. We described the anthropogenic interactions found and the presence of tumours in some individuals. Finally, since the coast of Ceará is an important feeding area and migration route for sea turtles, this study can contribute to mitigating measurements and encourage marine ecosystem conservation with a focus on environmental education.

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