Trabajo

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Breeding success and conservation of *Eretmochelys imbricata* in the Delta do Parnaíba Environmental Protection Area, northeastern Brazil

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ABSTRACT

Sea turtles are one the most threatened group worldwide mainly due to environmental disturbances caused by anthropogenic actions. Herein, we aimed to investigate the breeding success of hawksbill turtles in two beaches of Piauí state, contained within the Delta do Parnaíba Environmental Protection Area. Turtle nests were monitored according to the methodology proposed by Projeto TAMAR-ICMBio. A multi-model inference approach using Akaike's Information Criterion (AICc) obtained through the Generalized linear models (GLM) was used to investigate what are the best predictors of hawksbill turtles' breeding success. We observed that vegetation distance is the main driver of its breeding success (each nest survival rate), reinforcing the needed to preserve the natural vegetation cover existing in coastal environments. With our constant monitoring of nests avoiding predatory attacks, it was allowed the protection of almost four thousand eggs and the consequent liberation of more than three thousand live hatchlings. Therefore, we think that studies, as presented here, are important for the maintenance and conservation of marine turtle populations and, in particular, to subsidize the protection and conservation of hawksbill turtles in the Parnaíba River Delta.

Key Words: Hawksbill turtle; Breeding success; Parnaíba River Delta; Piauí; Sea turtles.

Introduction

Five of the seven species of sea turtles visit the Brazilian coast (Costa and Bérnils, 2018), being both considered threatened species (IUCN, 2021), in which, human-induced mortality is also the main cause to explain decline of sea turtle populations. It includes sea pollution; reproductive habitat destruction; incidental capture; and human hunting (National Research Council, 1990; Mcclenachan *et al*., 2006; Marcovaldi *et al*., 2011).

Among these sea turtles, *Eretmochelys imbricata* (Linnaeus, 1766), commonly known as hawksbill turtle, is classified as critically endangered and its population decreases worldwide (Mortimer and Donnelly, 2008; IUCN, 2021), despite being widely distributed in the Brazilian coastal zone (Valls *et a*l., 2011; Brito *et al*., 2015; Costa and Bérnils, 2018). This species usually tends to nest in or near vegetation, mainly in heterogeneous environments (Diamond, 1976; Kamel and Mrosovsky, 2005), nevertheless, there is some lack of information about what are the best predictors for hawksbill turtles' nests choice and the nests sites in the Brazilian coast. For instance, we believed for a long time, that hawksbill turtle Brazilian spawning areas were distributed from Espirito Santo to Ceará states, with hatchlings occurring in the north-northeast Brazilian coast (Marcovaldi *et*

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al., 2011), however, it was found nests of hawksbill turtles also in the Delta do Parnaíba Environmental Protection Area, Piauí state (Santana *et al.*, 2009).

Studies dealing with the breeding biology of hawksbill turtles date from the seventies (Diamond, 1976), henceforth, several studies have been development worldwide. For instance, Kamel (2013) observed that vegetation cover predicts temperature in nests of the hawksbill sea turtle, for consequence, influencing the offspring sex ratios. At Guadeloupe, French West Indies, it was reported a significant repeatability of nest site choice, suggesting a heritable behavior in hawksbill turtles (Kamel and Mrosovsky, 2005). With respect to Brazilian coast, most studies were focusing on hatching success, mainly concentered in the coastal zone of Bahia, Pernambuco, and Rio Grande do Norte states, northeastern Brazil (e.g., Marcovaldi *et al.*, 1999; Serafini *et al.*, 2009; Santos *et al.*, 2010; Moura *et al.*, 2012), being scant studies in the north-northeast Brazilian coast.

Although in Brazilian beaches the spawning peak of most sea turtle species occurs in spring and summer months, from September to March (Marcovaldi and Marcovaldi, 1999), little is known about the reproductive biology of hawksbill turtles in the coastal zone of Piauí state. Therefore, herein (i) we report key data about the spawning peak and breeding success of *Eretmochelys imbricata*, (ii) investigate what are the best predictors of hawksbill turtles' breeding success in the Delta do Parnaíba Environmental Protection Area, and (iii) discuss the importance of this area for preservation and conservation of the species.

Materials and methods

Study area

The present study was carried out in two beaches from the Delta do Parnaíba Environmental Protection Area (EPA): Praia do Coqueiro (02°54'10" S, 041°33'51" W) and Praia do Arrombado (02°54'10" S, 041°32'50" W), both in Luís Correia municipality, Piauí state, northeastern Brazil (Fig. 1). The EPA Delta do Parnaíba was created by a Federal Decree

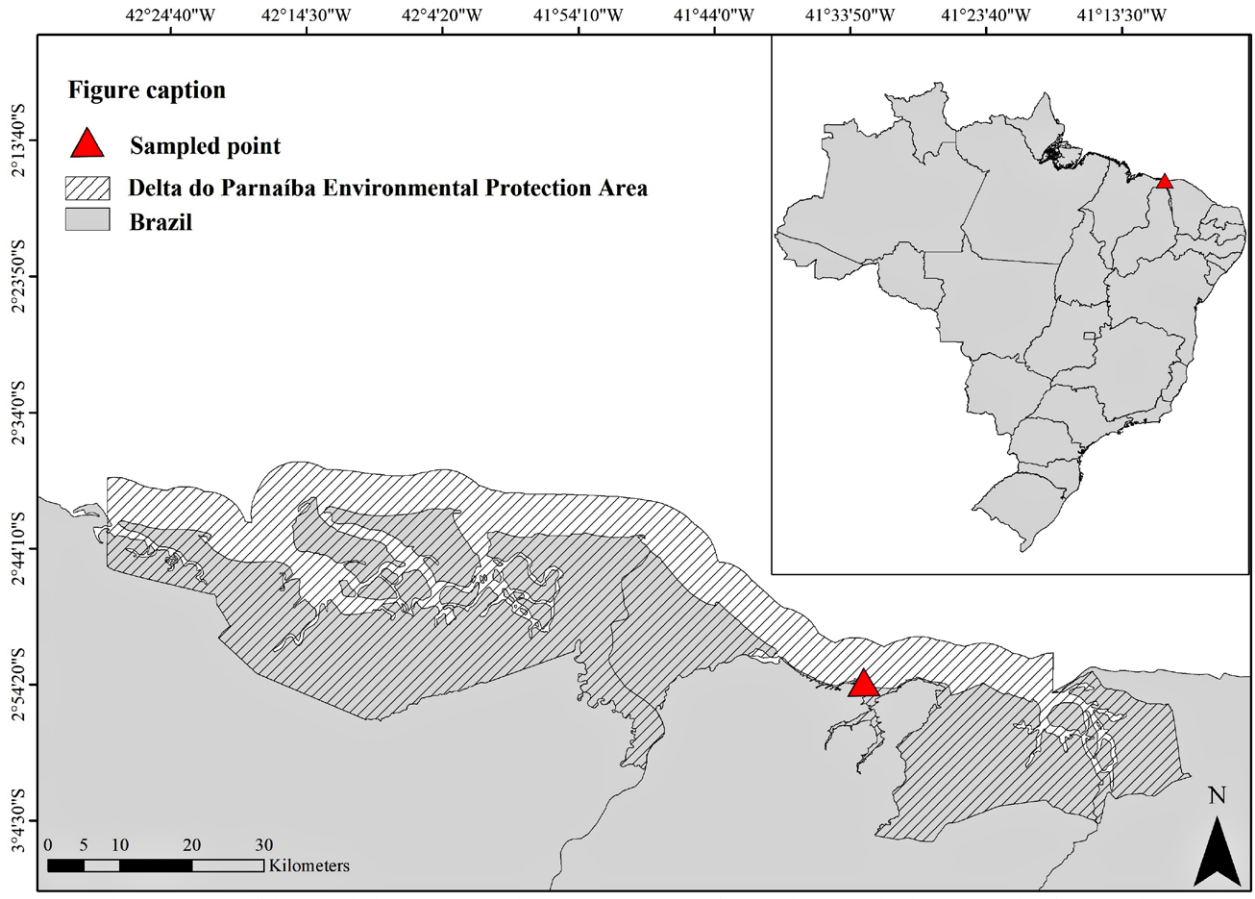

Figure 1. Schematic map of the sampled area in Praia do Coqueiro (LC) and Praia do Arrombado (AT), Delta do Parnaíba Environmental Protection Area (EPADP), Piauí state, northeastern Brazil.

on 28 August 1996 and involves 313.809 ha in three states (Maranhão, Piauí and Ceará) with a perimeter of 460.812 m, including the maritime area (IBAMA, 1998).

Sampling

Sea turtles breeding sampling was taken according to the Projeto TAMAR-ICMBio (Marcovaldi and Marcovaldi, 1999) between summer and autumn months (December 2011 to May 2012). We monitored the hawksbill turtle (Fig. 2) nests along a 12 km straight line between the two sampled beaches during night hours. Nests were localized either according to presence of females or by detecting their crawls. Once a nest was detected it was immediately marked with PVC pipe to facilitate monitoring and isolated with wood stakes to avoid anthropic disturbances (Pritchard and Mortimer, 1999). Monitoring was made periodically every 24 hours since egg-laying to hatching. Once most hatchlings have emerged, we excavated nests within the posterior 24 hours in order to known clutch size by counting eggshells and unhatched eggs (Miller, 1997). A hatchling voucher specimen was deposited in the Zoological Collection of the Universidade Federal do Delta do Parnaíba – UFDpar (Voucher: CZDP (J1) 0003).

Statistical analyzes

To measure the hawksbill turtle breeding success, we used the apparent reproductive success (number of successful clutches/total of clutches), live hatchlings percentage (number of hatchlings that entered into the ocean/clutch size) x 100 (Skutch, 1985), and the Mayfield method (Mayfield, 1975) to obtain the survival probability estimate considering the nests incubation mean period (60 days).

Through the live hatchlings percentage, we calculated the survival rate (SR) of each one of the 27 hawksbill turtle nests, thenceforth, we did a multi-model inference approach using the Akaike's Information Criterion (AICc) (Burnham and Anderson, 2002) to measure the direction and relative importance of the predictor variable (SR) on the response variables (nest distance from the Restinga vegetation, nest distance to ocean, clutch size, and incubation period). The model with the lowest value

Figure 2. Adult female of *Eretmochelys imbricata* (hawksbill turtle) in Delta do Parnaíba Environmental Protection Area (EPADP), Piauí state, northeastern Brazil.

of AICc was considered further adjusted (Burnham and Anderson, 1998). We ran these statistical models as generalized linear models (GLMs) with Poisson error structure and log-link function. In addition, we used the VIF values to test for potential collinearity between our explanatory variables, and we used the Spearman's rank test (rho) to show graphically the most correlated variables.

Statistical analyses were performed in R software (R Core Team, 2021), using Corrplot (Wei and Simko, 2017), MuMIn (Barton, 2009), RColorBrewer (Harrower and Brewer, 2003), USDM (Naimi *et al.*, 2014), and Vegan packages (Oksanen *et al.*, 2016).

Results

We found 27 well-successful clutches of *Eretmochelys imbricata* during the breeding period that began on 24 December 2011 and end on 01 May 2012 with a peak of nests observed in February and March (32% and 39%, respectively). These clutches involve 3.870 eggs that were protected and conduct to let out in ocean 3.148 live hatchlings. Clutch size varied from 97 to 221 eggs-laying in the nests, with a mean of 142.7 eggs/nest (Fig. 3).

The apparent reproductive success and survival probability estimate was 93% and 91.8%, respectively, while the eggs hatching success was 81.3%. The model selection results indicate that nest distance from the Restinga vegetation is the most important predictor for the hawksbill turtle breeding success, which means, nests closest to natural vegetation tend to present a higher nest survival rate. In addition, the clutch size has also an important influence on the predictor variable (Fig. 4, Table 1). No variable from the 5 input variables has collinearity problem (VIF values ranged from 1.087662 to 2.076622).

Discussion

Previous studies recorded a hatching success varying from 58.3% (eleven nests registered/ one breeding season) in Costa Rica (Bjorndal *et al.*, 1985), 65.6% (350 nests registered/ three breeding seasons) in Ipojuca municipality, Pernambuco state (Moura *et al.*, 2012), 73.3% (141 nests registered/ four breeding seasons) on Cousine Island, Seychelles (Hitchins *et al.*, 2004), 78.3% (38 nests registered/ three breeding seasons) in Itacaré and Uruçuca municipalities, Bahia state (Camillo *et al.*, 2009), to 79.8% (41 nests registered/ one breeding season) in João Pessoa and Cabedelo municipalities (Mascarenhas *et al.*, 2003). Indeed, we found a high hatching success percentage (81.3%, 27 nests registered/ one breeding season), but we also suggest more studies should be undertaken in the Parnaíba River Delta aiming to investigate how this hatching success rate might vary according to the nesting seasons.

As important as describing the aspects of spawning peak and breeding success is to investigate what are the best predictors of hawksbill turtles' breeding success in the Delta do Parnaíba Environmental

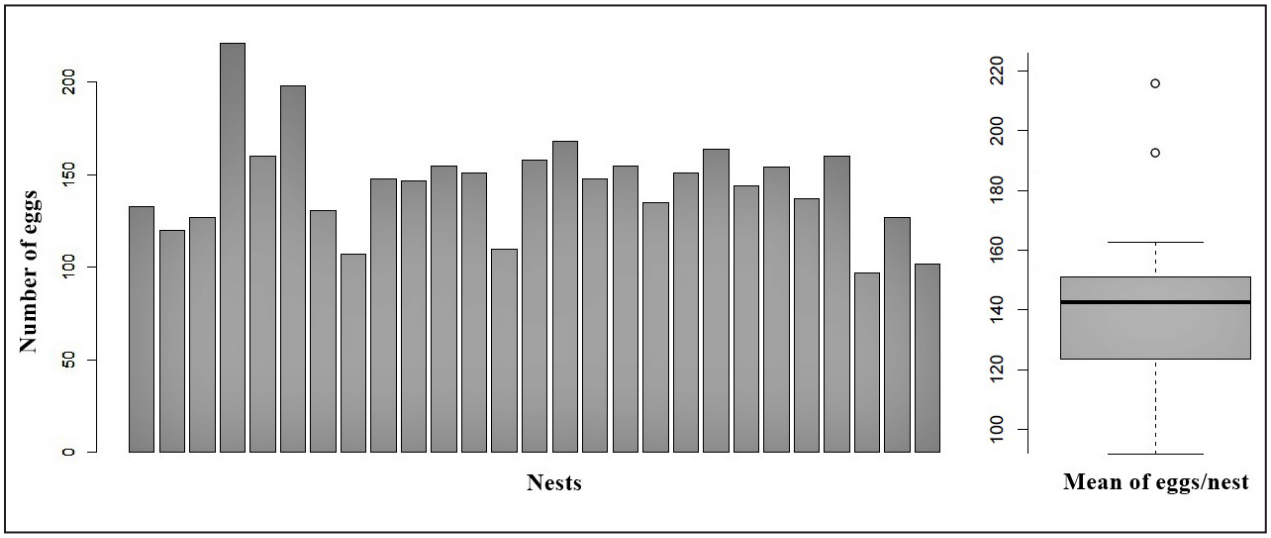

Figure 3. Number of eggs in each one of the 27 nests (left) and mean of eggs/nest (right) of Eretmochelys imbricata in Delta do Parnaíba Environmental Protection Area (EPADP), Piauí state, northeastern Brazil.

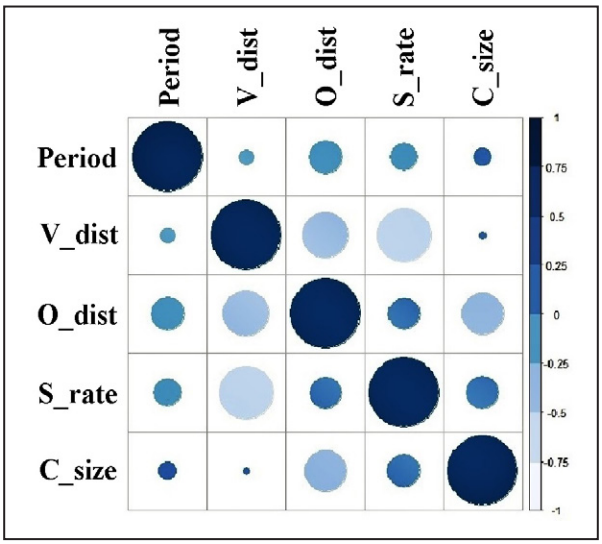

Figure 4. Correlation between the variables nests survival rates (S_rate), incubation period (Period), clutches sizes (C_size), nest distance from the ocean (O_dist), and Restinga vegetation (V_dist). As larger the circles more correlated are the variables and the blue tones variation indicates the positive or negative correlation sign.do Parnaíba Environmental Protection Area (EPADP), Piauí state, northeastern Brazil.

Protection Area. Although hatch success is a complex process, involving multiple environmental and individual variables, it was observed the vegetation is an important component of hawksbill nesting habitat in eastern Caribbean (Ditmer and Stapleton, 2012). Likewise, Horrocks and Scott (1991) found that hatching success of hawksbill nests was higher in the vegetation zone in Barbados, also in Caribbean, and Kamel and Mrosovsky (2005) associated the hatching success with the vegetated zone in Guadeloupe, French West Indies. Our results corroborate these above-cited studies once we observed the most important predictor for the hawksbill turtle nests survival rates, consequently breeding success, was the natural vegetation cover proximity.

In addition, preserving natural vegetation cover at hawksbill nesting beaches is crucial in order to maintain the thermal diversity of nesting sites and, potentially, mitigate the impacts of increasing global temperatures (Kamel, 2013). Therefore, we also underscore the needed to maintain healthy these Restinga environments and to investigate how beaches' environmental characteristics as sand structure, Restinga physiognomies, illumination, and pollution influence the nest choice and survival, and the consequent breeding success of the Sea turtles along the Parnaíba River Delta.

Regarding the clutch size, we observed an average of 142.7 eggs/nest, being similar to the mean fecundity registered in Ipojuca municipality, Pernambuco state (Moura *et al.*, 2012), in Itacaré and Uruçuca municipalities, Bahia state (Camillo *et al.*, 2009), in João Pessoa and Cabedelo municipalities (Mascarenhas *et al.*, 2003), in Guadeloupe, French West Indies (Kamel and Mrosovsky, 2005), and in Costa Rica (Bjorndal *et al.*, 1985). In addition, it is important to point out that clutches size was an important driver for nest survival, consequently the hawksbill turtle breeding success in this area.

Furthermore, nest predation may be considered one the main reasons of failure on the life cycle of sea turtles (Spencer, 2002). Predation of nests depends of environmental nest characteristics and the number of predators in the area (Tinkle *et al.*, 1981). Likewise, nesting site choice has also an important influence on sea turtle reproductive success (Kamel and Mrosovsky, 2005). Indeed, we observed potential nest predators in the study sites but in reason nests were exhaustively monitored predation was avoided, allowing also a high breeding success of *Eretmochelys imbricata*.

We found three nests / km² an average value similar to thōse registered in Porto de Galinhas and Maracaípe beaches, Pernambuco state (Moura *et al.*, 2012), but lower than the reported for other sites along the Brazilian northeastern coastline (Mascarenhas*et al.*, 2003; Camillo *et al.*, 2009; Moura *et al.*, 2012). We think that beach characteristics as coral reefs, artificial light, and high tourist flow, mainly in Praia do Coqueiro, might have inhibited nests choice by hawksbill turtles in the coastal zone of Piauí state. Thus, it should be crucial to preserve beaches into which this threatened turtle choice to nest and the Parnaíba River Delta as an important spawning area for hawksbill turtles.

The environmental monitoring of *Eretmochelys imbricata* in the Delta do Parnaíba Environmental Protection Area, northeastern Brazil provided observation of important biological aspects and describe details of this sea turtle breeding period in the Piauí state coastline, besides underscore and reinforce the importance of the Restinga environments for hawksbill turtles' breeding success. Overall, we protected and let out more than three thousand live hatchlings of hawksbill turtles, thus, our study is important for maintenance and conservation, besides being able to subsidize actions aimed at the protection and conservation of hawksbill turtles in the Parnaíba River Delta.

Table 1. Delta AICc and associated measures from all possible models predicting the nests survival rates of *Eretmochelys imbricata* in Parnaíba River Delta

Model	K	AICc	ΔAICc	Weight	LogLik
V_dist	3	223.3	0.00	0.262	-108.151
C_size + V_dist	4	223.4	0.07	0.253	-106.798
O_dist + V_dist	4	224.2	0.86	0.171	-107.193
Period + V_dist	4	225.7	2.40	0.079	-107.966
C_size + O_dist + V_dist	5	225.8	2.48	0.076	-106.486
C_size + Period + V_dist	5	225.9	2.52	0.074	-106.506
Period + O_dist + V_dist	5	226.3	2.99	0.059	-106.739
C_size + Period + O_dist + V_dist	6	228.3	4.91	0.022	-106.030
C_size	3	234.0	10.66	0.001	-113.484
Null	2	235.1	11.75	0.001	-115.300
C_size + O_dist	4	236.4	13.06	0.000	-113.293
C_size + Period	4	236.6	13.27	0.000	-113.400
Period	3	237.6	14.24	0.000	-115.274
O_dist	3	237.6	14.28	0.000	-115.294
C_size + Period + O_dist	5	239.3	16.00	0.000	-113.244
Period + O_dist	4	240.3	17.00	0.000	-115.262

Abbreviations: incubation period (Period), clutches sizes (C_size), nest distance from the ocean (O_dist), and Restinga vegetation (V_dist).

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