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Original Article

Reproductive and ecological similarity between *Caretta caretta* (Linnaeus, 1758) and *Eretmochelys imbricata* (Linnaeus, 1766) in southern Bahia (Brazil)

Semelhança reprodutiva e ecológica entre *Caretta caretta* (Linnaeus, 1758) e *Eretmochelys imbricata* (Linnaeus, 1766) no sul da Bahia (Brasil)

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Abstract

This study evaluates the reproductive and ecological similarity between loggerhead sea turtle (*Caretta caretta*) and Hawksbill sea turtle (*Eretmochelys imbricata*) two species of sea turtles on the southern coast of Bahia (Brazil) during two breeding seasons (October to April 2013 to 2015). The study covers a 10-km area composed of three beaches, Pompilho, Itacarezinho and Patizeiro beach, which are 5, 3, and 2 km long, respectively. Daily field surveys were performed for 102 days to assess patterns between the studied species, using the non-metric multidimensional scaling order and the Spearman correlation analysis to obtain the oviposition pattern of the two species. Moreover, Kruskall-Wallys tests were performed to review the differences in the number of hatchlings on the three beaches. The NMDS proved the species are very similar from an ecological perspective since as there were three clear groupings in terms of the number of hatchlings on the three beaches. With reference to the number of nests, a negative correlation was observed in the two species. Regarding the hatching activity of both species on the three beaches studied, a larger amount of *C. caretta* and *E. imbricata* hatchlings was found on Pompilho beach, followed by Patizeiro and Itacarézinho. These findings influence management strategies to reduce anthropogenic impact and contribute to the conservation of these two endangered sea turtle species.

Keywords: sea turtles, conservation, reproductive similarity, three beaches, northeastern Brazil.

Resumo

Este estudo avalia a semelhança reprodutiva e ecológica entre a tartaruga cabeçuda (*Caretta caretta*) e a tartaruga-de-pente (*Eretmochelys imbricata*) duas espécies de tartarugas marinhas no litoral sul da Bahia (Brasil) durante duas estações reprodutivas (outubro a abril de 2013 a 2015) . O estudo abrange uma área de 10 km composta por três praias, Pompilho, Itacarezinho e praia do Patizeiro, com 5, 3 e 2 km de extensão, respectivamente. Foram realizados levantamentos diários de campo durante 102 dias para avaliar padrões entre as espécies estudadas, utilizando a ordem de escala multidimensional não métrica e a análise de correlação de Spearman para obter o padrão de oviposição das duas espécies. Além disso, testes de Kruskall-Wallys foram realizados para revisar as diferenças no número de filhotes nas três praias. O NMDS provou que as espécies são muito semelhantes do ponto de vista ecológico, pois havia três agrupamentos claros em termos do número de filhotes nas três praias. Com relação ao número de ninhos, foi observada correlação negativa nas duas espécies. Em relação à atividade de eclosão de ambas as espécies nas três praias estudadas, uma maior quantidade de filhotes de *C. caretta* e *E. imbricata* foi encontrada na praia do Pompilho, seguida de Patizeiro e Itacarézinho. Esses achados influenciam as estratégias de manejo para reduzir o impacto antropogênico e contribuir para a conservação dessas duas espécies de tartarugas marinhas ameaçadas de extinção.

Palavras-chave: tartarugas marinhas, conservação, similaridade reprodutiva, três praias, nordeste do Brasil.

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1. Introduction

Sea turtles are widely distributed on the planet, regularly migrating between feeding and nesting areas (Nichols et al., 2000; Ferreira-Junior et al., 2011; Monteiro et al., 2016). In general, they reach maturity later and have a long lifecycle (Chaloupka and Limpus, 1997; Meylan and Donnely, 1999; Ferreira-Junior et al., 2011), fulfilling their entire lifecycle at sea, with the exception of nesting activity, when females return to the same nesting beaches where they were born to lay eggs. As these species do not receive parental care, the nest's success is heavily reliant on the suitability of the site selected by the female (Kamel and Mrosovsky, 2005) for egg-laying.

There's a lower intensity of nesting activity in the secondary nesting sites, but nevertheless sea turtles use these sites regularly. Considering the different reproductive degrees of isolation (Wallace et al., 2010) of the Management Units of the species on the Brazilian coast, as well as egg laying in secondary nesting grounds (Camillo et al., 2009; Souza et al., 2015; Siqueira-Silva et al., 2020), two extreme isolation situations are presented. In the case of *E. imbricata*, the nesting populations from the Brazilian coast overlap with populations found in the East Atlantic Regional Management Unit; therefore, it is a less reproductively isolated species (Wallace et al., 2010). On the other hand, *C. caretta* has the highest reproductive isolation behavior, making it the species of greater concern with regard to secondary nesting sites as there is no genetic variability contribution from other populations (Wallace et al., 2010).

On the Brazilian coast, the nesting period of the species occurs between September and April (spring – summer in the southern hemisphere; Marcovaldi et al., 2011) and in the oceanic islands, from December to June (summer – autumn; Almeida et al., 2011). Priority areas for *C. caretta* egg laying are located on the north coast of the states of Bahia, Espírito Santo, north of Rio de Janeiro and Sergipe (Marcovaldi and Chaloupka, 2007). As for *E. imbricata*, the most important areas are the northern coast of Bahia, Sergipe and southern Rio Grande do Norte (Marcovaldi et al., 2007), however, there are several secondary beaches, including some sites on the southern coast of Bahia (Camillo et al., 2009; Siqueira-Silva et al., 2020).

Thus, considering the current biodiversity crisis, the reproductive dynamics associated with the temporal and spatial overlap of two sea turtle species must be understood. Considering that nesting sites may suffer anthropic interventions, which can further reduce populations, management strategies have now become an urgent issue (Mrosovsky, 2006). Consequently, assuming that *C. caretta* and *E. imbricata* compete for nesting sites, the present research, focusing on species conservation actions, shows evidence of ecological and reproductive overlap of the two species on beaches on the southern coast of Bahia.

2. Material and Methods

2.1. Study area

The study was carried out in the Área de Proteção Ambiental - APA Costa de Itacaré – Serra Grande (UICN Category V) located on the southern coast of the State of Bahia. In this APA, the egg laying of the species was monitored on three beaches, Pompilho beach (POMP; -14.45561S/-39.02486W), Patizeiro beach (PAT; -14.402667S/-39.014050W) and Itacarézinho beach (ITC; -14.38253S/ 39.01003W) (Figure 1). The total length of the three beaches is approximately 10 km (Lavenére-Wanderley et al., 2005), with morphodynamic characteristics changing gradually in the dissipative-reflective continuum from North to South.

At approximately 5 km long, Pompilho beach is the longest, bordered to the south by rocky shores and to the north by the Tijuípe River mouth, while Patizeiro beach, 2 km long, is bordered to the south by the Tijuípe River mouth and to the north by rocky shores (Lavenére-Wanderley et al., 2005).

Itacarézinho, which is 3 km long, is bordered to the north and south by rocky shores. Compared to the other two beaches, it has the highest movement of tourists, with resort developments, restaurants and summer houses along the entire length of the coast.

2.2. Data collection

Field surveys were carried out in the mornings on foot, between 6:30 am and 11 a.m., during the 102 days of sampling, from October to April in the nesting seasons of 2013/2014 and 2014/2015. After locating the egg chamber, the nests were marked with standardized stakes and monitored until hatchling emergence.

Each nest was opened after hatchling emergence and eggshells were counted to estimate the number of live, stillborn and unhatched hatchlings (Miller, 1997). When hatchling sand tracks were not visible, the nest was opened after 60 days of incubation for data collection.

During the present study, the identification of the species belonging to the nest was only possible due to the presence of hatchling stragglers retained in the nest, stillborn, unhatched eggs with embryos in the third stage of development (small juvenile state), or when hatchlings were spotted heading towards the sea. The morphological identification observed external characteristics such as the head plate pattern, jaw shape, number of plates in/of

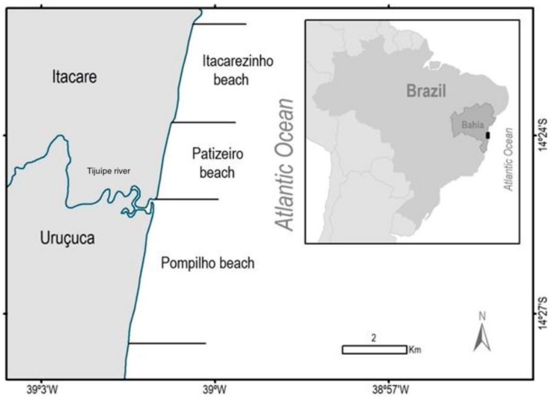

Figure 1. Location of the study area on the Brazilian coast. The river mouth corresponds to the Tijuípe River (Bahia, Brazil).

the plastron, and especially, the anteroposterior count of lateral plates of the turtle's carapace (Wyneken, 2001).

2.3. Data analysis

2.3.1. Similarity patterns and correlation between the two species

An NMDS ordering analysis was used to determine if *C. caretta* and *E. imbricata* presented a similar oviposition hatching pattern in the seasons sampled for the three beaches. For this purpose, the Euclidean distance was used, establishing an ordination maximum stress value of 0.3. Stress is a statistical measure that reflects how good a rank order is; the smaller the stress values, the better the NMDS configuration. Ideally, stress should be less than 10% and not exceed 30% to properly present the original data (Kindt and Coe, 2005).

The Shapiro-Wilk normality test was performed, followed by Spearman's correlation ($p < 0.05$), to prove the hypothesis that the specie' oviposition pattern was correlated. Also, two Kruskall-Wallis tests were carried out to: a) verify the difference in the number of hatchlings among the beaches of Pompilho, Itacarézinho and Patizeiro, and b) demonstrate whether there was a difference in the number of hatchlings between the species on each beach. Accordingly, it was assumed that the beaches' extensions are different and are subject to different anthropogenic interference. To verify if one species built more nests than another, the non-parametric Mann-Whitney test was performed.

Abiotic factors are important limiting factors for the species, thus, reproductive period, monthly temperature and precipitation data were obtained through public data (Instituto Nacional de Pesquisas Espaciais – INPE). For both species; the collection period defined for meteorological data considered the first day of oviposition as the starting date, and the last day of hatching as the end date. This procedure was performed separately for each species considering two aspects: 1) number of hatched hatchlings (Table 1) and 2) number of oviposed nests in each month.

Temperature and precipitation data were related to the number of hatchlings and nests using the accumulated abundance data per month. To demonstrate the possible influence of precipitation or temperature on the number of nests or hatchlings, the normality test was performed followed by a Pearson correlation ($p<0.05$). All tests were performed using the PAST© program, version 4.1 (Hammer et al., 2001) and a test version of the statistical program (Vers.10).

3. Results

The NMDS showed ecological similaritie between *C. caretta* and *E. imbricata* on the three beaches as there are three clear groupings in terms of the number of hatchlings (Figure 2). The stress level was 0.09 which is a suitable ordination to express the similarity between the number of hatchlings for the two species. Regarding the number of nests, the two species were negatively correlated (Figure 2), and despite these species being ecologically similar (Figure 3), the number of nests of one species increased as the number of nests of the other species decreased ($R=0.51$; $p<0.05$). This pattern is shown as resource partitioning because species have avoided interspecific competition for nesting sites along the beaches. This ecological effect resulted in the maximization of hatching, with 11,034 *C. caretta* hatchlings, and 11,251 *E. imbricata* hatchlings, considering the 2013/2014 and 2014/2015 seasons for both species.

Regarding the hatching of both species on the three beaches studied, a larger number of *C. caretta* and *E. imbricata* hatchlings (5,715) was observed on Pompilho beach, followed by Patizeiro (4,261) and Itacarézinho (1,953), ($p<0.001$) (Figure 4). Furthermore, the number of

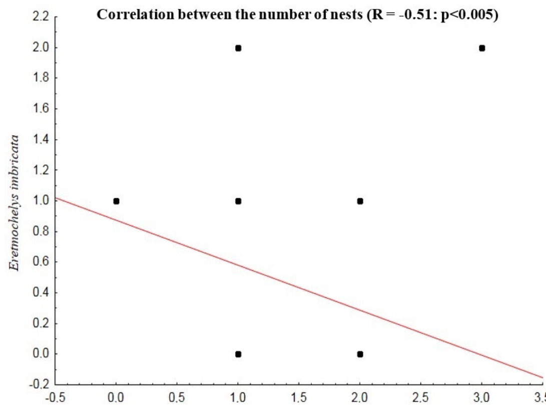

Figure 2. Correlation between the number of nests observed for the *Caretta caretta* and *Eretmochelys imbricata*. The descending line shows the correlation pattern. The number of nests ranged from 0 to 3 for each sample (n=102).

Table 1. Number of hatched hatchlings of *Caretta caretta* and *Eretmochelys imbricata* in three nesting beaches between 2013 and 2015.

	2013/2014			2014/2015		
	Itacarezinho	**Patizeiro**	**Pompilho**	**Itacarezinho**	**Patizeiro**	**Pompilho**
Caretta caretta	493	944	870	5	14	15
Eretmochelys imbricata	644	1181	1036	9	16	12
Lepidochelys olivacea	104	-	-	1	-	-
NI				4	4	4

NI **= "**unidentified".

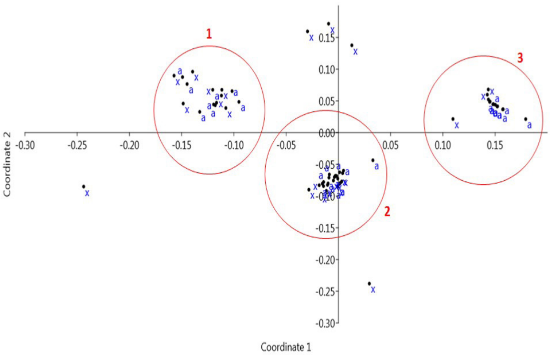

Figure 3. Similarity of hatchlings between species. a = *Caretta caretta* and x = *Eretmochelys imbricata*. The numbers and red circles highlight the three groups of ecological similarity among hatchlings.

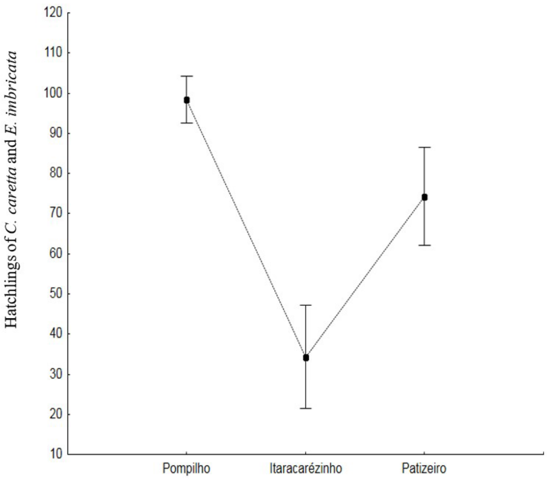

Figure 4. Comparison between the number of hatchlings for both species on the three beaches (p < 0.001).

nests built by the two species is statistically equal (p=0.35), hence, the numerical difference observed (61 for *C. caretta* and 52 for *E. imbricata*) could have happened by chance.

Furthermore, it was demonstrated that the number of hatchlings was equal in both species (Figure 5) on each beach, which may evidence co-occurrence and coexistence of the two species in the beaches in similar nesting seasons, and their response to similar ecological factors. Also, among the two ecological factors tested, temperature proved to most influence hatching activity because it was positively correlated with the number of hatched hatchlings for both species (Figure 6). On the other hand, precipitation and temperature did not influence the number of nests of the species (p=0.63 for *E. imbricata* and p=0.74 for *Caretta caretta*). Temperature ranges between the two species compared were equal (p=0.74), which means that the species not only responded similarly, but also under the same range of environmental conditions (temperatures mean 25.07ºC ± 0.69 *C. caretta*/25.15 °C ± 0.62 *E. imbricata*). This can be corroborated by the hatching peak of both species, which occurred at an interval of 26 °C.

Considering the species-area relationship, the presence (weak or intense) of human pressure on each beach (e.g., presence of summer houses, tourist activities and artificial lighting) and the number of hatchlings successfully hatched, the extension of Pompilho beach can have positively influenced their reproductive sites. That is, the extension of the beach may have mitigated the impact of human activities on the nests. On the other hand, even though Patizeiro is three kilometers shorter than Pompilho, it has little anthropogenic interference, and when compared to Itacarézinho (with intense anthropogenic activity) the number of reproductive sites and the number of hatched hatchlings was higher.

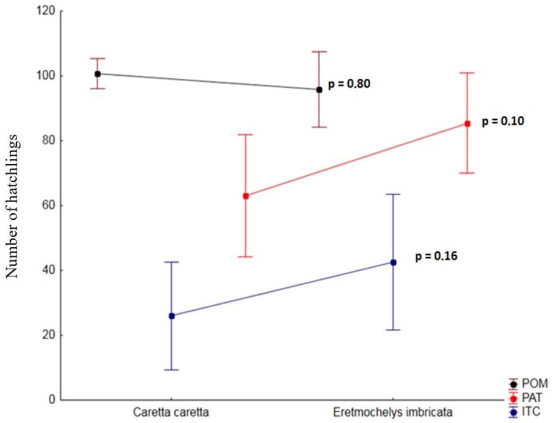

Figure 5. Comparison between the number of hatchlings of both species.

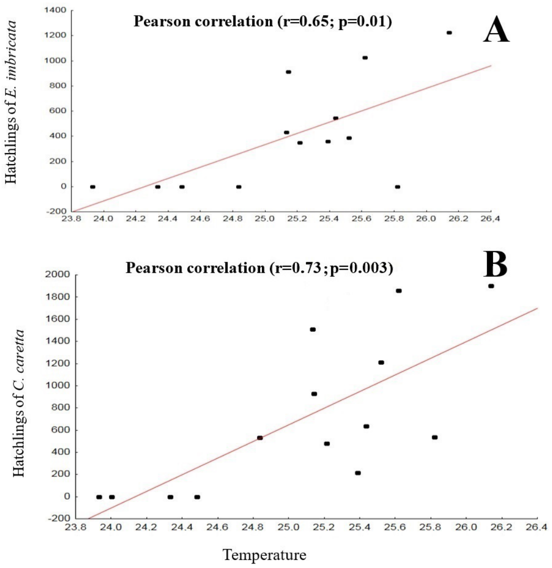

Figure 6. Correlation between the hatch response of (A) *Eretmochelys imbricata* and (B) *Caretta caretta* and temperature.

4. Discussion

During the two nesting seasons, ecological similarities between *C. caretta* and *E. imbricata* were found in terms of oviposition pattern over the sampled periods, number of hatchlings, as well as in the responses to temperature of both species measured by nest success. Furthermore, considering the negative correlation between oviposition, it is clear that there is a co-occurrence between the two species on nesting sites, especially since co-occurrence can be measured at intervals in which the number of eggs laid by a species decreases, providing more sites. of oviposition and favoring the increase of the oviposition of the other species. Therefore, by reducing the density of the other species, more nesting sites are available for the other, favoring co-occurrence between them (Chase et al., 2002). This pattern may have occurred since in the first season studied, it was empirically observed that several nests documented as NI (short for "unidentified" and therefore not included in the statistical analyses) were the target of predation by the crab-eating-fox (*Cerdocyon thous*). Based on direct observation, literature review and footprint records, this species was considered one of the main predators of the northern coast of Bahia (Longo et al., 2009). The results of this study showed similar patterns as the study from (Antworth et al., 2006) demonstrating no correlation between the number of nests for *C. caretta* with temperature or precipitation. Moreover, in the same study, the researchers highlighted that the *C. caretta* nesting season reached its peak in the hottest years. The present study confirmed a similar ecological pattern between *E. imbricata* and *C. caretta*, since the increase in the number of hatchlings is correlated with the increase in temperatures. This hypothesis is supported by (Camillo, 2008), who verified the sediment deposition processes in the three studied beaches. The author proved that said variables had no influence on nesting sites or beach selection of *C. caretta* or *E. imbricata*. In this sense, temperature, precipitation and sediment deposition have already been tested and none of the biotic variables have influenced the nesting of the species.

Historically, *C. caretta* and *E. imbricata* are species considered abundant on the coast of Bahia, and hence, they have been widely studied for a long time. (Marcovaldi and Laurent, 1996) monitored the reproductive season of the two species from 1987 to 1993. The present study, in a shorter temporal scale, has demonstrated negative correlation between the number of nests of both species, which is consistent with the pattern observed by the cited authors. That is, although the number of *C. caretta* nests was much greater in Praia do Forte (Bahia), the number of *E. imbricata* nests also started to increase from December onwards, when the oviposition growth curve for *C. caretta* began to decline after peak nesting (Marcovaldi and Laurent, 1996). As the results of this study show patterns for three beaches, the density of *C. caretta* nests may have been influenced by the extension of the studied area if it is compared to the pattern found by (Marcovaldi and Laurent, 1996). This occurrence may be explained due to the larger area and habitats available, less nest overlaps, and more nesting sites opportunities, along with interference from the predator *C. thous*, balancing the proportion of nestlings per season, and maintaining co-occurrence of the species (Chase et al., 2002). Mazaris et al. (2006) state that various environmental factors at different stages of the nesting process balance the energy cost in the search for the nest site versus the benefits of choosing a favorable location. The absence of egg laying in the northern part of Pompilho beach and in the southern part of Patizeiro beach was also observed by Camillo (2008). The author explains absences due to rock and sandstone barriers in the foreshore region limiting the access of the female turtles, corroborating data from the study carried out by Marcovaldi and Laurent (1996).

Based on an evolutionary perspective, (Camillo et al., 2009; Tomas, 2016) suggest a greater production of male hatchlings on the north coast of Bahia. Therefore, Pompilho, Itacarézinho and Patizeiro beaches become important secondary nesting areas, maintaining a balanced supply of hatchlings, mainly because the region could favor demographic maintenance of *C. caretta* and *E. imbricata* populations reproducing in Brazil. Considering *C. caretta* reproductively more isolated than *E. imbricata,* which is probably why there is no contribution of genetic variation from other subpopulations (Wallace et al., 2010), this study reinforces the importance of secondary nesting areas, which can contribute genetically by producing more male hatchlings. The former has been demonstrated in sea turtle populations laying eggs in Brazil that are characterized by a high incidence of hybrids, in addition to a significant genetic differentiation from other turtle populations (Vilaça et al., 2013; Proietti et al., 2014) highlighted that the spatial and temporal overlap in nesting sites of *C. caretta* and *E. imbricata* can result in hybrid individuals. Furthermore, in Brazil the nesting groups of *C. caretta* and *E. imbricata* have exceptionally high hybridization rates (Lara-Ruiz et al., 2006). It is interesting that these hybrids are reproductively viable, possibly due to a continuous introgressive hybridization process (Lara-Ruiz et al., 2006; Vilaça et al., 2012). According to (Soares et al., 2017), most hybridization events in the north of Bahia are recent, approximately 30 years, coinciding with the largest population decline of both species in Brazil. Finally, the APA Costa de Itacaré – Serra Grande region is an area that has been undergoing an anthropization process, especially after the construction of the BA-001 highway (Artaza-Barrios and Schiavetti, 2007). The presence of sea turtle nesting sites in this area should be used as a reference encouraging sea turtle conservation efforts in the region. Thus, if the ecological and reproductive similarities of *C. caretta* and *E. imbricata* demonstrated in this research are considered, both species may have the same reliable selecting pattern of nesting sites on Itacarézinho, Pompilho, and Itacaré beaches. On the other hand, populations of both species can be affected by the anthropic impact on each of these beaches.

5. Conclusions

The two species have similar spatiotemporal reproductive periods and respond ecologically to temperature. On the other hand, the co-occurrence of the two species can be explained by the action of predators, as they may decrease interspecific competition which is evidenced by the negative correlation between oviposition. Additionally, this co-existence raises an important issue about the possible hybridization between the two species at these nesting sites. These patterns are decisive in the design of management strategies to reduce anthropogenic impact and contribute to the conservation of these two endangered species.

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