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Patterns and spatial distribution of sea turtle strandings in Alagoas, Brazil

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ABSTRACT

This study makes a descriptive analysis of necropsied sea turtles registered in the Biota Conservation Institute database between May 2018 and May 2022 on the coast of Alagoas, Brazil. During this period, 79 animals of four species were necropsied: 87.4 % (69) *Chelonia mydas*, 6.3 % (5) *Caretta caretta*, 3.8 % (3) *Lepidochelys olivacea* and 2.5 % (2) *Eretmochelys imbricata*. *C. mydas* was the most frequent species, mainly juvenile females. In 29.1 % (23/79) evidence of anthropogenic interactions was found (e.g., fishing net marks, plastic waste in the digestive tract, trauma from collisions with boats). Cutaneous tumors suggestive of fibropapillomatosis in 35.4 % (28/79), in *C. mydas* and *E. imbricata*, half were in an area of high eutrophication, close to the capital. Endoparasites were found in 46.8 % (37/79) individuals. Information on strandings in the region is essential for understanding the use of the area and the impacts to which these animals are exposed.

1. Introduction

Sea turtles exhibit migratory behavior, occupying different marine environments according to their life stages (Márquez, 1990; Marcovaldi and Filippini, 1991; Meylan and Meylan, 1999). Due to these characteristics, sea turtle species are vulnerable to various natural and anthropogenic impacts, which threaten their populations to the point that all species are in the IUCN Red List of endangered animals (International Union for Conservation of Nature, 2023) and almost all in the Official List of Brazilian Fauna Threatened with Extinction (MMA, 2022).

The coastline of the state of Alagoas, Northeast region of Brazil, is 230 km long, with regular reproductive records of three species: *Eretmochelys imbricata* (hawksbill), *Caretta caretta* (loggerhead) and *Lepidochelys olivacea* (olive ridley), in addition to being a feeding area for juvenile *Chelonia mydas* (green turtle) (Stefanis et al., 2016).

In general, the impacts of human activities can directly or indirectly affect the conservation of sea turtles. Among the threats with the greatest impact are incidental capture in fisheries and pollution of coastal and marine environments (Aguilar-González et al., 2014; Vasconcelos et al., 2019). Fisheries bycatch is responsible for a large proportion of strandings and deaths of healthy turtles, which get entangled in nets or trapped by hooks and, unable to free themselves, drown or later die as a result of injuries (Canabarro et al., 2018; Botterell et al., 2020). In addition to drowning and direct injuries from fishing gear, gas embolism, resulting from decompression syndrome (García-Párraga et al., 2014; Parga et al., 2020), as respiratory infections (Work and Balazs, 2010) secondary to drowning, the physiological changes resulting from stress (e.g., metabolic acidosis) (Miguel et al., 2020) and capture myopathy (Phillips et al., 2015), are important causes of late mortality resulting from this interaction. There are also other threats that negatively affect sea turtle populations, such as: collisions with boats (Fuentes et al., 2021), oil and gas exploration with the risk of spills (Asif et al., 2022; Wallace et al., 2020), unsustainable tourism activities (Dias et al., 2014) and accelerated urban expansion in the coastal environment (Lopez et al., 2015).

Negative human interference contributes to the occurrence of diseases such as fibropapillomatosis (FP), related to *Chelonid herpesvirus* 5 (ChHV5), which is more prevalent in green turtles and more common in polluted areas (Zwarg et al., 2014; Rossi et al., 2015; Koproski et al., 2017; Origlia et al., 2023). FP is a debilitating disease characterized by the presence of tumors on the skin and, in severe cases, on internal

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organs, affecting the survival of individuals (Baptistotte, 2007; Zwarg et al., 2014). The drop in immunity caused by the virus favors the proliferation of the parasitic fauna that infects sea turtles. In these cases, the exacerbated proliferation of parasites can worsen anemia, which is commonly seen in animals with tumors (Zwarg et al., 2014). This association therefore constitutes another important cause of morbidity and mortality related to strandings of these animals (Werneck, 2011).

Beach monitoring activities, with systematic data collection along the Brazilian coast, have shown high rates of sea turtle strandings (Lopes-Souza et al., 2015; Tagliolatto et al., 2019; Cantor et al., 2020). In Rio Grande do Sul, 6285 strandings were recorded in an area of approximately 620 km between 1995 and 2014 (Monteiro et al., 2016). In the state of Rio de Janeiro, 12,162 strandings were reported, over approximately 1251 km, between 2010 and 2017 (Tagliolatto et al., 2019). In the Northeast, 124 strandings were recorded between 2009 and 2010 on a 15 km stretch of urban beaches in Paraíba (Poli et al., 2014) and 418 strandings on a 12 km stretch in the state of Pernambuco between 2008 and 2016 (Silva et al., 2019).

Understanding the causes of strandings is a huge challenge, since the animal's illness or death can be caused by several factors acting concomitantly on it. For dead animals, necroscopic analysis is an important tool for evaluating organs and tissues, making it possible in many cases to diagnose the cause of death. The information generated by this analysis can help us understand the impacts and devise mitigation strategies to prevent other animals from stranding. In view of this, this study carries out a descriptive analysis of sea turtle strandings recorded in the Biota Conservation Institute database, evaluating the relevant macroscopic findings observed during the necropsy of the animals.

2. Material and methods

2.1. Study area

The study area is located in the state of Alagoas, in the northeast of Brazil. The collection of specimens included fourteen municipalities along the state's coastline (Maragogi, Japaratinga, Porto de Pedras, São Miguel dos Milagres, Passo de Camaragibe, Barra de Santo Antônio, Paripueira, Maceió, Marechal Deodoro, Barra de São Miguel, Roteiro, Jequiá da Praia, Coruripe and Feliz Deserto), S-8. 913868/W-35.153251, on the border between the municipality of Maragogi and the state of Pernambuco, and to the south, S-10.363003/W-36.304599, on the border between Feliz Deserto and Piaçabuçu. In total, the region consists of 225 km of straight coastline. The municipality of Piaçabuçu was not included, as it is part of an environmental condition for the exploration and production of gas and oil belonging to the SE/AL Basin Beach Monitoring Project carried out by another institution.

The coast of Northeast Brazil intercepts the South Equatorial Current, diverting it to the south and north, and the sea surface temperature in Alagoas is around 25 to 27.5 °C throughout the year (Sperling, 2012). The state's coastline has a diverse geography with many lagoons and rivers that flow into the ocean, as well as a barrier reef that stretches for 130 km, from Maceió to Maragogi, belonging to the Costa dos Corais Environmental Protection Area, and some reef banks in the other municipalities (Alagoas, n.d.; ICMBio, 2021). To the south of the area is the Lagoa do Jequiá Marine Extractive Reserve located in the municipalities of Jequiá da Praia and the northern part of Coruripe (ICMBio, 2023).

2.2. Sampling

Strandings were assessed using the Biota Conservation Institute's database, which comes from regular monitoring of the beaches and drives. Animals classified as Code 2 were selected, according to an adaptation of the classification proposed by Geraci and Lounsbury (1993) for aquatic mammals (Table 1).

In order to handle and collect biological material from these animals, SISBIO (Biodiversity Authorization and Information System) authorization was required from IBAMA, which is renewed periodically (SISBIO/28187).

Table 1
Classification of decomposition stages adapted for sea turtles.

Classification	Stage of decomposition
Code 1	Live animal.
Code 2	Recent death. Intact integument, normohydrated eyeballs and mucous membranes, absence of odor and gas accumulation.
Code 3	Moderate stage of decomposition. Hypohydrated eyeballs and mucous membranes, foul odor, accumulation of gases and altered color and consistency of internal organs.
Code 4	Advanced decomposition. Severe alteration of the integument, detachment of the keratin plates from the carapace and plastron, putrid smell and exterminated organs.
Code 5	Mummified carcass. No organs, only skeleton left.

Geraci and Lounsbury (1993), adapted.

2.3. Identification, biometrics, life stage and gender

The species were identified based on descriptions by Wyneken (2001) and Márquez (1990). The curved carapace length (CCL - cm) and the curved carapace width (CCW - cm) were determined, as it is the Biota Institute's routine procedure for estimating the developmental stage of animals. Considering the CCL for adult individuals greater than 90 cm for *C. mydas* (Almeida et al., 2011), 83 cm for *C. caretta* (Baptistotte et al., 2003), 62.5 cm for *L. olivacea* (Da Silva et al., 2007) and 86 cm for *E. imbricata* (Marcovaldi and Marcovaldi, 1999). Sex was determined by macroscopic observation of the gonads during necropsy by veterinarians of Biota Conservation Institute.

2.4. Necroscopic examination

The necroscopic examinations of the animals were carried out by the veterinary team of Biota Institute. The necropsy technique was carried out as described by Wyneken (2001) and Matushima (2007), consisting initially of an external examination to integrity of the skin, the existence of tumors, the absence of limbs or other parts of the body, the existence of characteristic marks from fishing gear. The body score was classified according to the visual assessment of the plastron as bad (concave), regular (flat) or good (convex), as proposed by Thomson et al. (2009). The oral cavity, cloaca, presence of epibionts, ectoparasites and lesions or any alterations suggestive of anthropic interactions were checked. The plastron was then removed and the pectoral and pelvic muscles were assessed. The topography and possible alterations in the organs in situ were observed, in order to assess the surface, color, size, shape, location, consistency and texture, as well as the existence of gas in the large vessels that irrigate the main organs. In the digestive tract, the presence of food and fecal content was checked, as well as endoparasites and anthropogenic waste and their respective locations. Endoparasites were classified only according to their presence or not in the digestive tract or other organs. As for anthropogenic residues, these were observed macroscopically and only separated when originating from fisheries. After removing the digestive tract, it was possible to check the gonads (ovaries or testicles) to confirm sex.

2.5. Data analysis

The stranding site of each animal was recorded by GPS and photographed, with subsequent map generation and evaluation comparing necropsy findings and sea turtle stranding sites. Occurrences were described by absolute (*fi*) and relative (%) frequencies (Fig. 1) for total number, sex, stage of development, anthropogenic interactions, skin tumors and presence of endoparasites.

The area of influence of stranding events was determined using the

Absolute frequency $fi = f1 + f2 + f3 \ldots (n)$

Relative frequency (%) $fri = \frac{fi}{n} \times 100$

Fig. 1. Formulas for calculating absolute frequency (*fi*) and relative frequency (*fri*) expressed as a percentage (%): *f*1, *f*2, *f*3 numbers of events that occurred; *n* is the total number of occurrences.

adaptive radius algorithm in the TerraView 5.6.1 program (Instituto Nacional de Pesquisas Espaciais - INPE). As for the pixel size of the maps generated in this study, their grids were 15 m by 15 m and, when grouped together using red coloring, they highlighted the "hot points" in the cartographic products produced. The kernel density analysis raster image was processed in the Terraview 5.6.1 program and the descriptive maps of occurrences were produced in the Qgis 3.28.9 software (Open Source Geospatial Foundation - OSGeo).

3. Results

Between May 2018 and May 2022, 79 sea turtles were necropsied, 69 specimens of which were *C. mydas* (87.4 %), five specimens of *C. caretta* (6.3 %), three specimens of L. *olivacea* (3.8 %) and two specimens of *E. imbricata* (2.5 %), distributed along the fourteen coastal municipalities of Alagoas. The hotspots of turtle mortality in the state showed a spatial pattern of concentration near the municipality of Maceió and its surroundings, with dispersal to the south and north of the state (Fig. 2). We found that 77.3 % (61/79) of the sea turtles were identified as females and 22.7 % (18/79) as males (Fig. 3).

In the classification by developmental stage, 82.3 % (65/79) were observed in the juvenile phase, all belonging to the species *C. mydas* and *C. caretta*, with a predominance of females (84.3 %; 54/65); followed by 17.7 % (14/79) of individuals in the adult stage of the four species (Table 2). A total of 69.6 % (55/79) specimens were recorded in the Costa dos Corais Environmental Protection Area, with 39.2 % (31/79) only in the region around the capital, Maceió. During the period in which the study was carried out, around 5000 sea turtle strandings were recorded on the coast of Alagoas, through beach monitoring (data from an unpublished study by the Biota Conservation Institute).

In the *C. mydas* group, 88.4 % (61/69) were juveniles and 49.2 % (30/61) of which had bad body condition.

In 29.1 % (23/79) of the sea turtles, evidence of anthropogenic interactions was found, such as fishing net marks, plastic waste and trauma from collisions with boats or wounds from sharp objects (Table 3). It was observed that 15.2 % (12/79) showed marks of interaction with fishery, possibly by nets. Plastic fragments were found in the digestive tract of 13.9 % (11/79). Of these, 81.8 % (9/11) were *C. mydas* and 18.2 % (2/11) were *C. caretta*. In 54.5 % (6/11) of the animals with solid waste, lesions were observed in the digestive tract, such as ulcers and obstructions, with the formation of fecalomas. Animals with trauma, such as cuts or mutilations, accounted for 10.1 % (8/79) of the occurrences. Concurrent situations were observed in 7.6 % (6/79), that is, individuals affected by more than one anthropogenic event, with interaction with fisheries and with plastic waste being the most common, 66.6 % (4/6).

Skin tumors suggestive of FP were found in 35.4 % (28/79) of the turtles, 96.4 % (27/28) in juvenile *C. mydas* and 3.6 % (1/28) in adult *E. imbricata*, the latter confirmed by histopathological examination. A higher prevalence zone was observed in the surroundings of the state capital, Maceió, where 42.8 % (12/28) of the animals exhibited this condition (Fig. 4). Of the juvenile *C. mydas* with tumors, 92.6 % (25/27) were females and 7.4 % (2/27) were males. Endoparasites were also found in 55.5 % (15/28) of the animals with skin tumors and 52 % (13/

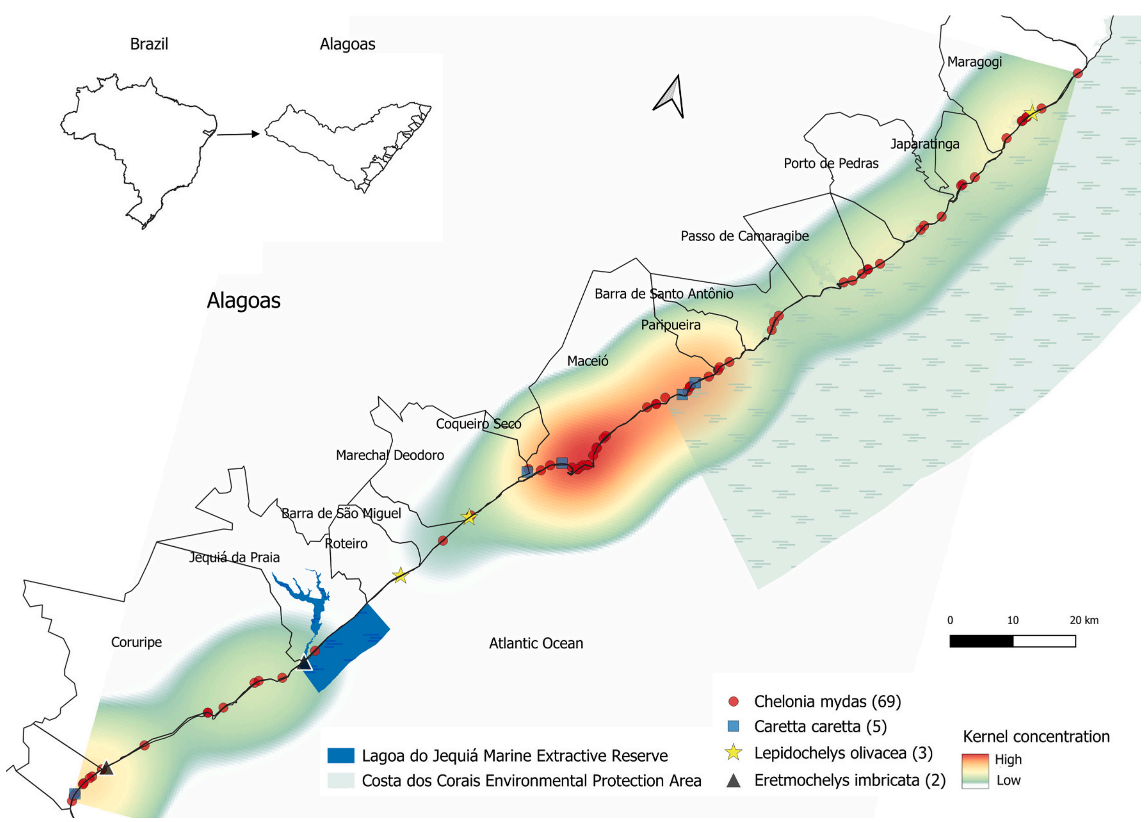

Fig. 2. Spatial distribution and Kernel density analysis of the 79 necropsied sea turtles of the species *C. mydas*, *C. caretta*, *L. olivacea* and *E. imbricata* on the coast of Alagoas between May 2018 and May 2022.

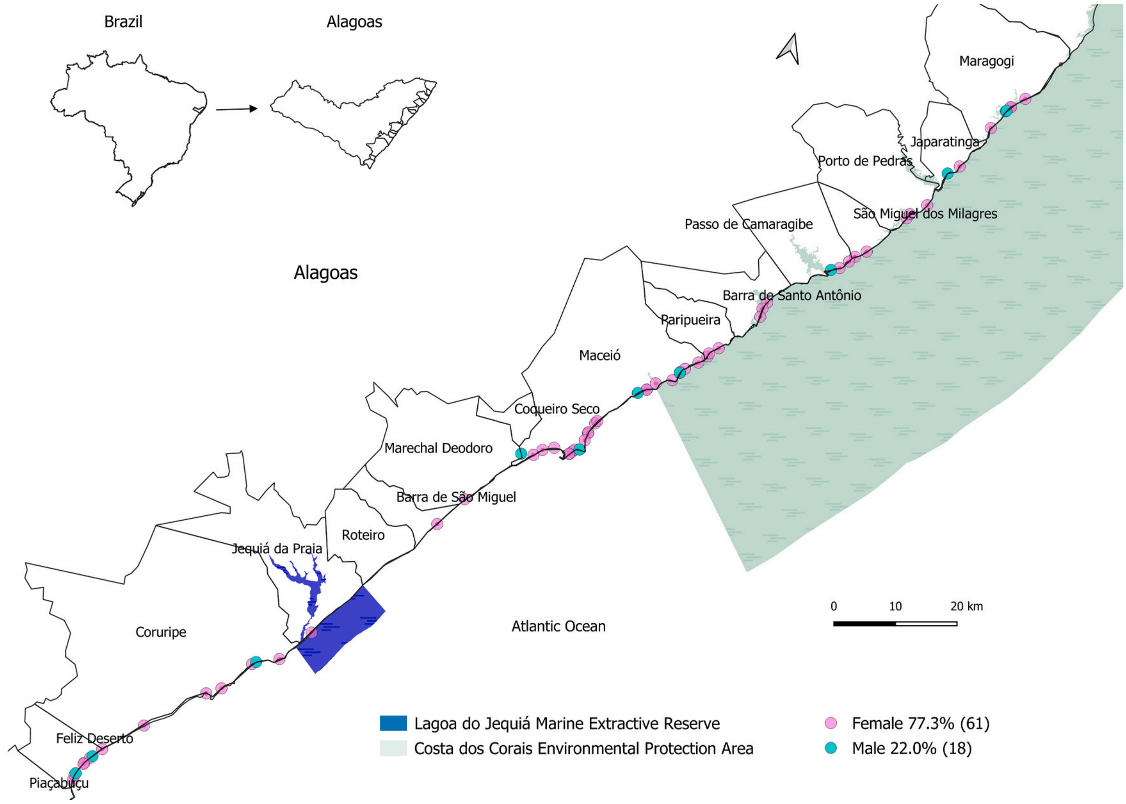

Fig. 3. Distribution of male and female sea turtles necropsied between May 2018 and May 2022 on the coast of Alagoas.

Table 2
Identification and quantification of sea turtles necropsied in Alagoas between 2018 and 2022, divided by species, sex, life stage and body condition expressed as relative frequency (%) and absolute frequency (fi).

Species	% (f_i)	*C. mydas*	*C. caretta*	*L. olivacea*	*E. imbricata*	Total
		87.4 % (69)	6.3 % (5)	3.8 % (3)	2.5 % (2)	100.0 % (79)
Sex	Female	82.6 % (57)	80.0 % (4)	–	–	77.3 % (61)
	Male	17.4 % (12)	20.0 % (1)	100.0 % (3)	100.0 % (2)	22.0 % (18)
Life stage	Juvenile	88.4 % (61)	80.0 % (4)	–	–	82.3 % (65)
	Adult	11.6 % (8)	20.0 % (1)	100.0 % (3)	100.0 % (2)	17.7 % (14)
Body condition	Good	23.1 % (16)	20.0 % (1)	20.0 % (1)	–	22.7 % (18)
	Regular	28.9 % (19)	40.0 % (2)	–	50.0 % (1)	29.1 % (22)
	Bad	47.8 % (34)	40.0 % (2)	80.0 % (2)	50.0 % (1)	48.1 % (39)

Table 3
Sea turtles necropsied with evidence of anthropogenic interaction in Alagoas between 2018 and 2022. Values expressed as relative frequency (%) and absolute frequency (fi).

Species	Fishery		Plastic waste		Trauma	
	%	f_i	%	f_i	%	f_i
C. mydas	83.3 %	10	81.8 %	9	87.5 %	7
C. caretta	16.7 %	2	18.2 %	2	12.5 %	1
L. olivacea	–		–		–	
E. imbricata	–		–		–	
Overall total	15.2 %	(12/79)	13.9 %	(11/79)	10.1 %	(8/79)

28) had bad body condition.

Endoparasites were found in 46.8 % (37/79) of the sea turtles, present in all four species identified in this study. Among these animals, 51.3 % (19/37) had endoparasites in more than one anatomical location, such as the digestive tract, circulatory system, urinary system and biliary tract. It was observed that 56.7 % (21/37) had bad body condition.

4. Discussion

The distribution of strandings along the coast of Alagoas during the studied period shows the occurrence of the four species in the region, *C. mydas*, *C. caretta*, *L. olivacea* and *E. imbricata*, as already reported by Stefanis et al. (2016) in Alagoas and by Silva et al. (2019) in Pernambuco. In this survey, we can see that there are strandings of *C. mydas*, *C. caretta* and *L. olivacea* on the Costa dos Corais Environmental Protection Area. Andrade dos Santos et al. (2022) pointed out that telemetry monitoring in this Conservation Unit showed a recurrence of overlapping use by *L. olivacea* and *E. imbricata*. Silva (2023), on the other hand, in his study of drone monitoring in the Costa dos Corais Environmental Protection Area, in the three-month period between 2019 and 2020, estimated a density of 6.65 turtles/km^2. We emphasize that the region has a large coral bank, serving as an important feeding area, bringing together a rich biodiversity, as reported in the area's management plan by ICMBio (2021).

The predominance of *C. mydas* strandings (87.4 %) may be related to the use of the region as a feeding/resting area or for migration, as observed by Reis et al. (2019) in the SE/AL basin, between 2010 and

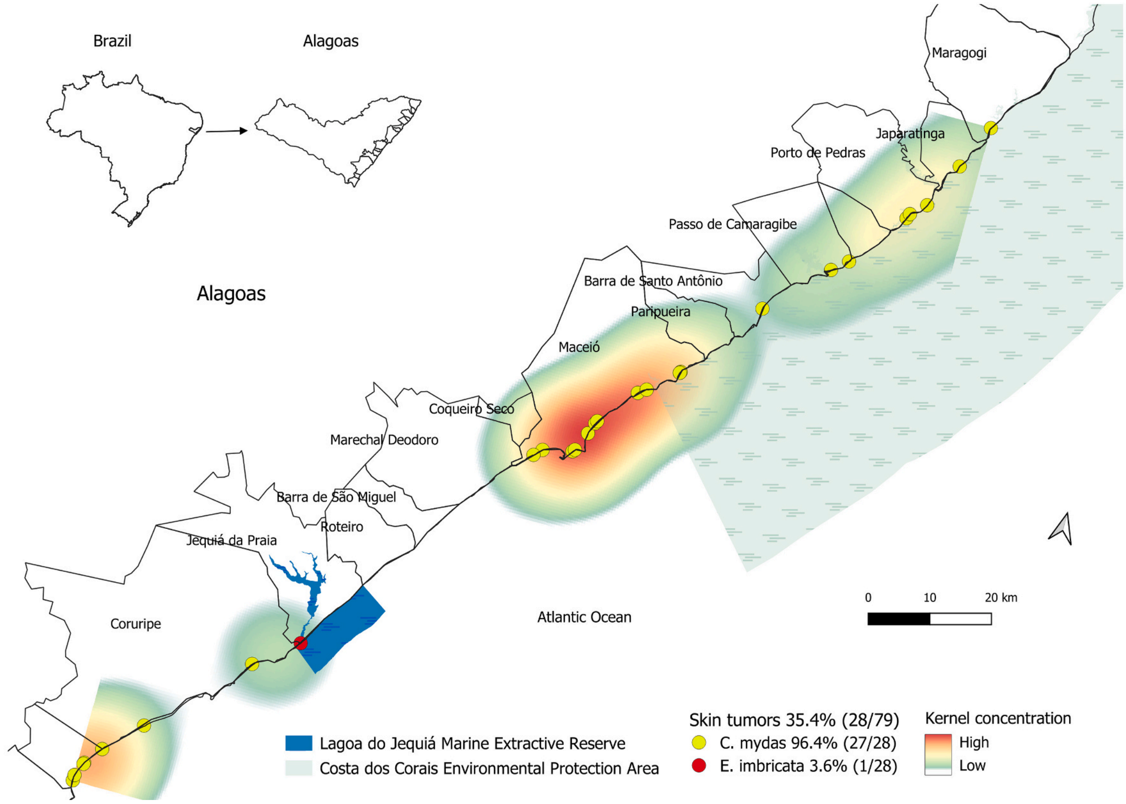

Fig. 4. Spatial distribution and Kernel density analysis of sea turtles with skin tumors necropsied between May 2018 and May 2022 on the coast of Alagoas.

2015, in which they recorded 53.40 % (2456/4582) of *C. mydas* specimens. This information corroborates the stranding data found by Silva et al. (2019), on the south coast of Pernambuco, between 2008 and 2016, with 52.4 % (219/418) of individuals of this species. The same pattern of occurrence, with a higher frequency of *C. mydas*, is also repeated on most of the Brazilian coast, as reported by Reis et al. (2010) in north-central Rio de Janeiro, Oliveira and Schmiegelow (2015) on the south coast of São Paulo and by Cantor et al. (2020) in the South and Southeast regions. The only exception, however, is the state of Rio Grande do Sul, where Monteiro et al. (2016) described a higher number of strandings of *C. caretta* followed by *C. mydas*, with 50.8 % (3192/6285) and 40.9 % (2572/6285), respectively. According to the authors, the region is an important feeding area for the species, which ends up interacting with different fisheries.

The coastal foraging habits of *C. mydas*, from the neritic stage onwards, make it more subject to human interference by exposure (Márquez, 1990; Santos et al., 2015a; Cantor et al., 2020). Santos et al. (2015a) comments that feeding strategies in the water column or in estuarine areas can increase the ingestion of plastic waste by these animals, since most of these materials are positively buoyant. These animals are vulnerable to interactions with coastal fisheries, greater contact with plastic waste, chemical substances, and untreated urban and industrial effluents (Aguilar-González et al., 2014; Vasconcelos et al., 2019). In addition, urban sprawl and unsustainable tourism on the coast can lead to the degradation of important habitats for turtle conservation (Dias et al., 2014; Lopez et al., 2015).

The animals with evidence of interactions with fishing were concentrated mainly in the central region of Alagoas, despite the fact that there is a large shrimp fishery fleet in the far south of the state (IBAMA, 2008), and the rest of the state is dominated by artisanal fishing (Santos and Marinho, 2019). Even so, Santos (2021) warns of the impact of shrimp trawling due to the low selectivity of the nets. According to the author, who monitored shrimp trawling in the extreme south of Alagoas, for every kilo of shrimp caught, an average of 2.17 k of accompanying or non-target fauna (i.e., bycatch) is captured. Animals caught in fishing nets and released immediately after the net is removed can develop debilitating clinical conditions as a result of the interaction. Weakness leads to prostration, where the animal limits its movement and is therefore at the mercy of currents and winds (Guimarães et al., 2021; Escobedo-Bonilla et al., 2022). The location of a stranding depends on a series of intrinsic and extrinsic factors. The influence of winds, currents and extreme weather events, and the existence of coral barriers, parallel to the central-north coast of the state, can determine the number of strandings and the distribution over a given area (Flint et al., 2017; Alagoas, n.d.). All of these influences can interfere with the dispersal pattern of carcasses further north and high water temperatures can accelerate the degree of decomposition of carcasses, limiting necroscopic assessment.

In addition to environmental factors, the seasonality of fishing and the distance of the gear from the coast can also influence the distribution of strandings and the number of individuals that reach the beaches (Monteiro et al., 2016). Claro et al. (2019) warned of the difficulty of distinguishing between abandoned, lost or discarded fishing gear and materials used for active fishing, since the injuries caused are similar. Da Silva et al. (2010) report in their study that increased marine monitoring efforts associated with awareness-raising among fishermen and enforcement by the competent environmental agencies can contribute to a decrease in sea turtle mortality in fisheries. The author highlights the importance of data collection in mediating stakeholders, through a cooperative process, in decision-making on resource management and environmental protection.

Bonfim et al. (2019) reported the presence of plastic fragments in the digestive tract of 34.4 % (79/229) *C. mydas* stranded on the coast of Alagoas. Rodamilans et al. (2009) also found plastic debris in 60 % (27) of the 45 animals analyzed on the northern coast of the state of Bahia. Kühn and van Franeker (2020), in a retrospective analysis of 42 studies published up to 2019 on the contents of the entire digestive tract of 3421 sea turtles, found a 51.45 % (1760) rate of occurrence of plastic waste.

Although the numbers found in Alagoas are not in line with the average of other studies, the fact that plastic waste was not seen in some of the individuals studied does not rule out the presence of nano and micro particles of plastic, which may not have been detected with the naked eye. In some turtles with plastic debris in the digestive tract, partial or total obstruction with the formation of fecalomas and gastroenteritis associated with inflammation of the enteric mucosa were observed. Santos et al. (2015b) and Rodríguez et al. (2022), in their surveys with juvenile *C. mydas* along the Brazilian coast and in the Azores archipelago, respectively, showed that small amounts of anthropogenic debris can be enough to block the digestive tract, causing the death of juvenile *C. mydas*. Santos et al. (2015b) further hypothesized that fishing activities may mask the impacts of plastic waste ingestion by sea turtles, due to the acute lethality potential of fishing compared to the chronic damage of ingested debris. The authors believe that it is possible that deaths from ingesting solid waste are underestimated, thus hindering conservation and management actions.

In this study, about a third of the juveniles (35.4 %) exhibited skin tumors with characteristics suggestive of FP, all of which were *C. mydas*. As reported by Koproski et al. (2017) in their survey between 2010 and 2014 in the Sergipe/Alagoas basin, a rate of 16 % (315/1957) of juvenile *C. mydas* was affected by FP. In principle, animals can live with these tumors normally, as long as they do not hinder locomotion, vision or feeding, as pointed out by Baptistotte (2007). However, possible comorbidities and other stressors can contribute to immunosuppression and the exacerbated development of these neoformations, making them a limiting factor (Herbst and Klein, 1995; Van Houtan et al., 2014; Sánchez-Sarmiento et al., 2017; Vilca et al., 2018). In the global meta-analysis study carried out by Dujon et al. (2021), the authors note that this is a multifactorial disease and that areas with high eutrophication favor the development of the pathology. This study corroborates the findings documented here, where half of the animals with FP were in the vicinity of the capital Maceió, which has 1,031,597 inhabitants in the metropolitan region (IBGE, 2021) and a low sanitation rate (23.73 %), proportional to the population (SNIS, n.d.). In the study, more than half of these *C. mydas* with skin tumors had bad body condition. Rossi et al. (2019) found no relationship between *C. mydas* with FP and their body condition. According to the authors, individuals with FP from intentional capture were in a similar condition to animals without the disease. However, the same authors consider an opposite situation when the animals are found stranded or floating on the surface, suggesting weakness.

Endoparasites were found in the four species of sea turtles evaluated, a finding that is in line with the reports of Silva (2020), in his survey of parasitic fauna in marine chelonians in northeastern Brazil. Endoparasites were also found in various organs of these animals, as reported by Binoti et al. (2016). Free-living animals commonly live with parasites, however, in the presence of an organic imbalance, these parasites can contribute to worsening the animal's clinical condition (Granroth-Wilding et al., 2014). Almost half of the parasitized animals had bad body condition, unlike the findings of Binoti et al. (2016) who, in a study of 50 turtles from strandings, found no significant association between parasitism and cachexia. Pereira et al. (2023), in a study of 99 *C. mydas* parasitized by blood vessel trematodes, reported that macroscopic pathological changes ranged from none, in lightly parasitized animals, to severe cachexia. Werneck (2011) suggests that the herbivorous habit of *C. mydas* contributes to the high variability of endoparasite specimens that they host, and that drastic changes in food and habitat components during the transition between life stages, in addition to being stressful factors, expose the animal to new infective forms. The identification of the endoparasites found in turtles that use the coast of Alagoas, at the lowest possible taxonomic level, could expand knowledge about the parasite-host relationship and understand the influence of this relationship on the animals' state of health. Each species of parasite recorded is important for future studies on population stocks, migratory routes and the diet of turtle species that occur along the Brazilian coast, as proposed by Meira Filho et al. (2017).

5. Final considerations and implications

Strandings were more frequent in the central northern region of the Alagoas coast and the species of sea turtles identified are the same as those that also occur in neighboring states. The higher frequency of strandings of juvenile individuals of the *C. mydas* species in the study area, as well as on the rest of the Brazilian coast, implies a possible future reduction in the number of adult individuals in the reproductive phase, which would guarantee the continuity of the species. The global population of *C. mydas* is in decline and is considered an "Endangered" species by the IUCN (2023). Studies should be conducted in order to generate knowledge to support more effective public policies for environmental conservation.

Sea turtle strandings in the Costa dos Corais Environmental Protection Area were similar to strandings in non-protected areas along the coast. This fact reinforces the need to improve this management model for protected areas, so that they can truly become a refuge for marine species.

The most common anthropogenic impacts observed in this study were interaction with fishing gear and/or plastic waste, either alone or in combination. Bearing in mind that most of the state's fisheries are artisanal, it is necessary to raise awareness among fishing villages about using techniques and equipment that have less impact on the accompanying fauna, as well as emphasizing the viability and sustainability of resources for future generations.

The ubiquity of plastic and its resistance in the environment raises concerns, since its biodegradation occurs through biological and non-biological factors, resulting in fragmentation into small particles that remain in the environment and end up being easily absorbed by organisms at the base of the food chain.

The observed frequency of animals with FP and endoparasitosis is probably associated with the loss of quality of the coastal environment and contributes to the progressive impairment of the turtles' immunity and body condition, making them less resilient to other risk factors, usually anthropogenic.

CRediT authorship contribution statement

Eliane Macedo Bernieri: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Luciana Santos Medeiros:** Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Data curation. **Uylla Hipper Lopes:** Validation, Supervision, Methodology, Investigation, Data curation. **Francielly Gomes Vilas Boas:** Investigation, Methodology, Validation. **Silvanise Marques dos Santos:** Data curation, Investigation, Methodology, Validation. **Oscar Kadique de Lima Marques:** Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation. **Gustavo Rodamilans de Macêdo:** Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Ricardo Lustosa:** Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **Carlos Roberto Franke:** Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

Aguilar-González, M.E., et al., 2014. Perceptions of fishers to sea turtle bycatch, illegal capture and consumption in the San Ignacio-Navachiste-Macapule lagoon complex, Gulf of California, Mexico. Integrative Zoology 9 (1), 70–84.
Alagoas. Recifes de Corais. Secretaria de Estado do Planejamento, Gestão e Patrimônio - Seplag/AL. Disponível em: https://dados.al.gov.br/catalogo/dataset/recifes-de-corais. (Accessed 7 May 2023).
Almeida, A.P., et al., 2011. Green turtle nesting on Trindade Island, Brazil: abundance, trends, and biometrics. Endanger. Species Res. 14, 193–201.
Andrade dos Santos, J., et al., 2022. Identificação de áreas críticas para tartarugas marinhas e sua relação com unidades de conservação no Brasil. Biodiversidade Brasileira 12 (4), 1–24.
Asif, Z., et al., 2022. Environmental impacts and challenges associated with oil spills on shorelines. Journal of Marine Science and Engineering 10 (6), 762.
Baptistotte, C., 2007. Caracterização espacial e temporal da fibropapilomatose em tartarugas marinhas da costa brasileira. Universidade de São Paulo – Escola Superior de Agricultura 'Luiz de Queiroz', Piracicaba (66f. Tese de Doutorado, 2007).
Baptistotte, C., Thomé, J.C.A., Bjorndal, K., 2003. Reproductive biology and conservation status of the loggerhead sea turtle (*Caretta caretta*) in Espírito Santo State, Brazil. Chelonian Conservation and Biology 4 (3), 523–529.
Binoti, E., et al., 2016. Helminth fauna of *Chelonia mydas* (Linnaeus, 1758) in the south of Espírito Santo State in Brasil. Helminthologia 53 (2), 195–199.
Bonfim, W.A.G., et al., 2019. Avaliação da ingestão de resíduos plásticos por tartarugas marinhas: efetividade dos métodos utilizados. In: XX Encontro de Zoologia do Nordeste. Maceió.
Botterell, Z.L.R., et al., 2020. Long-term insights into marine turtle sightings, strandings and captures around the UK and Ireland (1910–2018). J. Mar. Biol. Assoc. U. K. 100 (6), 869–877.
Canabarro, et al., 2018. Tartarugas marinhas recebidas no CRAM-FURG oriundas da interação com atividade pesqueira. In: Anais do 4° Congresso Latino-Americano de Reabilitação de Fauna Marinha. Florianópolis.
Cantor, M., et al., 2020. High incidence of sea turtle stranding in the southwestern Atlantic Ocean. ICES J. Mar. Sci. 1–15.
Claro, F., et al., 2019. Tools and constraints in monitoring interactions between marine litter and megafauna: insights from case studies around the world. Mar. Pollut. Bull. 141, 147–160.
Da Silva, A.C.C., et al., 2007. Nesting biology and conservation of the olive ridley sea turtle (Lepidochelys olivacea) in Brazil, 1991/1992 to 2002/2003. J. Mar. Biol. Assoc. U. K. 87 (4), 1047–1056.
Da Silva, A.C.C.D., et al., 2010. Efforts to reduce sea turtle bycatch in the shrimp fishery in Northeastern Brazil through a co-management process. Ocean Coast. Manag. 53 (9), 570–576.
Dias, R.B., et al., 2014. Tourists and sea turtles: a first evaluation of tourism potential and risks in Cananéia, Brazil. Mar. Turt. Newsl. 142, 14–17.
Dujon, A.M., et al., 2021. Sea turtles in the cancer risk landscape: a global meta-analysis of fibropapillomatosis prevalence and associated risk factors. Pathogens 10 (1295).
Escobedo-Bonilla, C.M., Quiros-Rojas, N.M., Rudín-Salazar, E., 2022. Rehabilitation of marine turtles and welfare improvement by application of environmental enrichment strategies. Animals 12 (282).
Flint, J., et al., 2017. The impact of environmental factors on marine turtle stranding rates. PLoS One 12 (8), e0182548.
Fuentes, M.M.P.B., et al., 2021. Conservation interventions to reduce vessel strikes on sea turtles: a case study in Florida. Mar. Policy 128 (104471).
García-Párraga, D., et al., 2014. Decompression sickness ('the bends') in sea turtles. Dis. Aquat. Org. 111, 191–205.
Geraci, J.R., Lounsburry, V., 1993. Marine Mammals Ashore: A Field Guide for Strandings. A&M Sea Grant Publication, Texas, pp. 43–78.
Granroth-Wilding, H.M.V., et al., 2014. Parasitism in early life: environmental conditions shape within-brood variation in responses to infection. Ecol. Evol. 4 (17), 3408–3419.
Guimarães, S.M., et al., 2021. Distribution and potential causes of sea turtle strandings in the state of Rio de Janeiro, southern Brazil. Herpetol. Conserv. Biol. 16 (2), 225–237.
Herbst, L.H., Klein, P.A., 1995. Green turtle fibropapillomatosis: challenges to assessing the role of environmental cofactors. Environ. Health Perspect. 103 (Suppl. 4), 27–30.
IBAMA, 2008. Instituto Brasileiro de Meio Ambiente e dos Recursos Naturais Renováveis. In: Boletim Estatístico da Pesca Marítima e Estuarina do Nordeste do Brasil - 2007. Ibama, Tamandaré.
IBGE, Instituto Brasileiro de Geografia e Estatística, 2021. Cidades e Estados. Maceió. Disponível em: https://www.ibge.gov.br/cidades-e-estados/al/maceio.html. (Accessed 13 June 2023).
ICMBio, Instituto Chico Mendes de Conservação da Biodiversidade, 2021. Plano de Manejo da Área de Proteção Ambiental Costa dos Corais. Tamandaré, Pernambuco. Disponível em: https://www.icmbio.gov.br/apacostadoscorais/plano-de-manejo. (Accessed 18 April 2023) (Abr.).
ICMBio, Instituto Chico Mendes de Conservação da Biodiversidade, 2023. Plano de Manejo da Reserva Extrativista Marinha da Lagoa do Jequiá. Maceió, Alagoas. Disponível em: https://www.gov.br/icmbio/pt-br/assuntos/biodiversidade/unidade-de-conservacao/unidades-de-biomas/marinho/lista-de-ucs/resex-marinha-da-lagoa-do-jequia. (Accessed 23 May 2023) (Mar.).
IUCN, 2023. International Union for Conservation of Nature. The IUCN Red List of Threatened Species. Version 2022.2. Disponível em: http://www.iucnredlist.org. (Accessed 8 April 2023).
Koproski, L., et al., 2017. Perfil epidemiológico da fibropapilomatose em tartarugas-marinhas encalhadas entre o litoral sul de Alagoas e norte da Bahia, Nordeste do Brasil. Arq. Ciênc. Vet. Zool. UNIPAR, Umuarama 20 (2), 49–56.
Kühn, S., van Franeker, J.A., 2020. Quantitative overview of marine debris ingested by marine megafauna. Mar. Pollut. Bull. 151.
Lopes-Souza, A., Schiavetti, A., Álvarez, M., 2015. Analysis of marine turtle strandings (Reptilia: Testudine) occurring on coast of Bahia State, Brazil. Lat. Am. J. Aquat. Res. 43 (4), 675–683.
Lopez, G.G., et al., 2015. Coastal development at sea turtles nesting ground: efforts to establish a tool for supporting conservation and coastal management in northeastern Brazil. Ocean Coast. Manag. 116, 270–276.
Marcovaldi, M.A., Filippini, A., 1991. Trans-Atlantic movement by a juvenile hawksbill turtle. Mar. Turt. Newsl. 52 (3).
Marcovaldi, M.A., Marcovaldi, G.G., 1999. Marine turtles of Brazil: the history and structure of Projeto TAMAR-IBAMA. Biol. Conserv. 93, 35–41.
Márquez, M.R., 1990. Sea turtles of the world. An annotated and illustrated catalogue of sea turtle species known to date. In: FAO Fisheries Synopsis, vol. 11(125). FAO, Rome.
Matushima, E.R., 2007. Técnicas necroscópicas. In: Cubas, Z.S., Silva, J.C.R., Catão-Dias, J.L. (Eds.), Tratado de animais selvagens: medicina veterinária, 1a ed. Roca, São Paulo, pp. 983–990 (cap. 61).
Meira Filho, M.R.C., et al., 2017. A review of helminths of the green turtle (*Chelonia mydas*) in Brazil. Oecologia Australis 21 (1).
Meylan, A.B., Meylan, P.A., 1999. An introduction to the evolution, life history, and biology of sea turtles. In: Eckert, K.L., Bjorndal, K.A., Abreu-Grobois, F.A., Donnelly, M. (Eds.), Research and Management Techniques for the Conservation of Sea Turtles, vol. 4. Consolidated Graphic Communications. IUCN/SSC Publication, Pennsylvania, pp. 3–5.
Miguel, C., et al., 2020. Physiological effects of incidental capture and seasonality on juvenile green sea turtles (*Chelonia mydas*). J. Exp. Mar. Biol. Ecol. 533, 151460.
MMA (Ministério do Meio Ambiente). Lista Nacional de Espécies Ameaçadas de Extinção. PORTARIA N° 148, DE 7 DE JUNHO DE 2022. Diário Oficial da União de 8 de junho de 2022.
Monteiro, D.S., et al., 2016. Long-term spatial and temporal patterns of sea turtle strandings in southern Brazil. Mar. Biol. 163, 247.
Oliveira, A.D., Schmiegelow, J.M.M., 2015. Monitoramento de encalhes de tartarugas marinhas em áreas costeiras do mosaico de Unidades de Conservação Juréia-Itatins, Perúibe/Iguape – SP. Revista Ceciliana 7 (2), 16–18.
Origlia, J.A., et al., 2023. Fibropapillomatosis associated with *Chelonid alphaherpesvirus 5* (ChHV5) in a green turtle *Chelonia mydas* in Argentine waters. J. Wildl. Dis. 59 (2).
Parga, M.L., et al., 2020. On-board study of gas embolism in marine turtles caught in bottom trawl fisheries in the Atlantic Ocean. Sci. Rep. 10 (1), 5561.
Pereira, G.O., et al., 2023. Pathology of Spirorchiidae (Digenea: Schistosomatoidea) infection in green turtles. Pesqui. Vet. Bras. 43, e07235.
Phillips, B.E., et al., 2015. Exertional myopathy in a juvenile green sea turtle (*Chelonia mydas*) entangled in a large mesh gillnet. Case Reports in Vet. Med. 2015.
Poli, C., et al., 2014. Patterns and inferred processes associated with sea turtle strandings in Paraíba State, Northeast Brazil. Brazilian Journal of Biology, João Pessoa 74 (2), 283–289.
Reis, E.C., et al., 2010. Condição de saúde das tartarugas marinhas do litoral centronorte do estado do Rio de Janeiro, Brasil: avaliação sobre a presença de agentes bacterianos, fibropapilomatose e interação com resíduos antropogênicos. Oecol. Aust. 14 (3), 756–765.
Reis, E.C., et al., 2019. Quelônios Marinhos da Bacia de Sergipe-Alagoas Mamíferos marinhos da Bacia Sergipe-Alagoas. In: Borges, J.C.G., et al. (Eds.), Quelônios, aves e mamíferos marinhos da Bacia de Sergipe-Alagoas. Editora UFS, São Cristóvão, pp. 39–68 (cap. 2).
Rodamilans, G., et al., 2009. Ocorrência de resíduos antropogênicos no trato digestório de tartarugas marinhas encalhadas no litoral norte da Bahia. In: Encontro da Associação Brasileira de Veterinários de Animais Selvagens, 12., 2009. Águas de Lindoia, Soa Paulo. Livro de Resumos… Águas de Lindóia, São Paulo [s.n.].
Rodríguez, Y., et al., 2022. Litter ingestion and entanglement in green turtles: an analysis of two decades of stranding events in the NE Atlantic. Environ. Pollut. 298.
Rossi, S., et al., 2015. Fibropapillomas in a loggerhead sea turtle (*Caretta caretta*) caught in Almofala, Ceará, Brazil: histopathological and molecular characterizations. Mar. Turt. Newsl. 147 (1), 12–16.

Rossi, S., et al., 2019. Monitoring green sea turtles in Brazilian feeding areas: relating body condition index to fibropapillomatosis prevalence. J. Mar. Biol. Assoc. U. K. 1–9.

Sánchez-Sarmiento, A.M., et al., 2017. Organochlorine pesticides in green sea turtles (*Chelonia mydas*) with and without fibropapillomatosis caught at three feeding areas off Brazil. J. Mar. Biol. Assoc. U. K. 97 (1), 215–223.

Santos, D.F., 2021. A pesca artesanal do camarão e sua fauna acompanhante no Estado de Alagoas, Nordeste do Brasil. 2021. 26f. Trabalho de Conclusão de Curso (Especialização Lato Sensu em Gestão em Meio Ambiente). Universidade Federal de Alagoas. Campus Arapiraca. Unidade Educacional de Penedo.

Santos, M.C.F., Marinho, F.R.C., 2019. A pesca de arrastão-de-praia em Coruripe (Alagoas, Brasil). Agroforestalis News 4 (1), 22–36.

Santos, R.G., et al., 2015a. Regional and local factors determining green turtle Chelonia mydas foraging relationships with the environment. Mar. Ecol. Prog. Ser. 529, 265–277.

Santos, R.G., et al., 2015b. Debris ingestion by juvenile marine turtles: an underestimated problem. Mar. Pollut. Bull. 93, 37–43.

Silva, C.G., 2020. Identificação da Fauna Parasitária de Tartarugas-Marinhas Encalhadas ao Norte do Sudoeste Atlântico, Brasil. Universidade Federal Rural do Semi-árido, Programa de Pós-graduação em Produção Animal (Dissertação (Mestrado), 2020).

Silva, I., 2023. O uso de drones na quantificação de tartarugas marinhas na APA Costa dos Corais - AL. 2023. 42 f. Monografia (Trabalho de Conclusão de Curso em Ciências Biológicas: bacharelado). Universidade Federal de Alagoas. Instituto de Ciências Biológicas e da Saúde, Maceió.

Silva, K.O., et al., 2019. Encalhes de tartarugas marinhas no litoral sul de Pernambuco, Brasil. Revista Ibero Americana de Ciências Ambientais 10 (2), 53–64.

SNIS, Sistema Nacional de Informações sobre Saneamento. Ministério da Integração e do Desenvolvimento Regional, Painel de Saneamento. Mapa de Indicadores de Esgoto – Maceió/AL 2021. Disponível em: http://appsnis.mdr.gov.br/indicadores/web/agua_esgoto/mapa-esgoto/?cod=2704302. (Accessed 24 May 2023).

Sperling, V.B., 2012. Mapeamento da superfície do mar no litoral de Alagoas utilizando imagens MODIS. 2012. 109 f. Universidade Federal de Alagoas. Instituto de Ciência Atmosférica, Maceió (Dissertação (Mestrado em Meteorologia)).

Stefanis, B.S.P.O., et al., 2016. Registros de encalhes de tartarugas marinhas no extremo sul da APA Costa dos Corais: a importância do monitoramento comunitário. In: Livro de Resumos I Seminário de Pesquisa APA Costa dos Corais: Prioridades para a conservação da biodiversidade. Tamandaré.

Tagliolatto, A.B., et al., 2019. Spatio-temporal distribution of sea turtle strandings and factors contributing to their mortality in south-eastern Brazil. Aquat. Conserv. Mar. Freshwat. Ecosyst. 30 (2), 331–350.

Thomson, J.A., et al., 2009. Validation of a rapid visual-assessment technique for categorizing the body condition of green turtles (*Chelonia mydas*) in the field. Copeia 2009 (2), 251–255.

Van Houtan, K.S., et al., 2014. Eutrophication and the dietary promotion of sea turtle tumors. PeerJ 2, e602.

Vasconcelos, A.C., et al., 2019. Análise da ingestão de plástico por tartarugas verdes (*Chelonia mydas*) na área de proteção ambiental Costa dos Corais. In: Anais I Simpósio de Biologia e Conservação Marinha. Rio de Janeiro.

Vilca, F.Z., et al., 2018. Concentrations of polycyclic aromatic hydrocarbons in liver samples of juvenile green sea turtles from Brazil: can these compounds play a role in the development of fibropapillomatosis? Mar. Pollut. Bull. 130, 215–222.

Wallace, B.P., et al., 2020. Oil spills and sea turtles: documented effects and considerations for response and assessment efforts. Endanger. Species Res. 41, 17–37.

Werneck, M.R., 2011. Estudo da helmintofauna de tartarugas-marinhas procedentes da costa brasileira. Instituto de Biociências, Universidade Estadual Paulista (Tese (doutorado), 2011).

Work, T.M., Balazs, G.H., 2010. Pathology and distribution of sea turtles landed as bycatch in the Hawaii-based North Pacific pelagic longline fishery. J. Wildl. Dis. 46 (2), 422–432.

Wyneken, J., 2001. The Anatomy of Sea Turtles. U.S. Department of Commerce NOAA Technical Memorandum NMFS-SEFSC-470, pp. 1–172.

Zwarg, T., et al., 2014. Hematological and histopathological evaluation of wildlife green turtles (*Chelonia mydas*) with and without fibropapilloma from the north coast of São Paulo State, Brazil. Pesquisa Veterinária Brasileira. Rio de Janeiro 34 (97), 682–688.