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RESEARCH ARTICLE

Spatio-temporal distribution of sea turtle strandings and factors contributing to their mortality in south-eastern Brazil

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Abstract

1. Data on stranded sea turtles were examined between 2010 and 2016 along the northern region of Rio de Janeiro state and between 2016 and 2017 in the southern region, looking for spatio-temporal patterns and determining which factors contributed to their mortality.
2. A total of 12,162 strandings of all five species that occur in Brazil were recorded, with *Chelonia mydas* being the most common (89.9%). Sea turtles use the Rio de Janeiro coast as a feeding and/or migration area. The intense upwelling (October to April) may be an important factor for the sea turtles feeding in this region, mainly for *Eretmochelys imbricata* and *Dermochelys coriacea*, which had a higher number of strandings during this period.
3. Areas further north of the study area include an important nesting site for *Caretta caretta* in Brazil, which explains the higher concentration of strandings of subadults/adults of this species in this region and during its nesting season.
4. Many anthropogenic threats to sea turtles were documented, mainly incidental capture in fisheries and marine debris, indicating possible hotspots for these threats in the regions of Sepetiba and Guanabara Bays, Cabo Frio, and São Francisco de Itabapoana.
5. Among the natural causes of strandings, the primary factors were chronic illness, endoparasites, and fibropapillomatosis. However, pollution may also be an indirect threat, which negatively affects these animals through reduced health and immunosuppression, leaving them more susceptible to opportunistic diseases.
6. These data are valuable for directing and implementing specific and local mitigation measures along the Rio de Janeiro state coast, such as avoiding bycatch hotspots through fleet communication programmes and/or area and seasonal closures, enforceable legislation, effective penalties and proper waste management.

KEYWORDS

beach, coastal, diseases, endangered species, fishing, pollution, reptiles, urban development

1 | INTRODUCTION

Continental and island coastal waters in Brazil constitute an important migratory, foraging, or reproductive habitat for five species of sea turtles: the green turtle (*Chelonia mydas*, Linnaeus 1758); the loggerhead turtle (*Caretta caretta*, Linnaeus 1758); the hawksbill turtle (*Eretmochelys imbricata*, Linnaeus 1766); the olive ridley turtle (*Lepidochelys olivacea*, Eschscholtz 1829); and the leatherback turtle (*Dermochelys coriacea*, Vandelli 1761) (Marcovaldi & Marcovaldi, 1999).

Sea turtles in Brazil have been protected since the 1980s (Marcovaldi & Marcovaldi, 1999), and all five species are included in the Brazilian Red Book of Threatened Species of Fauna (Chico Mendes Institute for Biodiversity Conservation/Ministry of Environment—ICMBio/MMA, 2018). Information on threats faced by sea turtles in coastal waters comes from strandings. Dead, sick, or injured turtles found washed up on the coast can provide valuable information on their health status, and point to the primary causes of morbidity and mortality in a zone or region. Threats identified in stranded sea turtles include interactions with fishing gear (Monteiro et al., 2016; Tomás, Gozalbes, Raga, & Godley, 2008; Vélez-Rubio, Estrades, Fallabrino, & Tomás, 2013), marine debris (Bugoni, Krause, & Petry, 2001; Santos, Andrades, Boldrini, & Martins, 2015; Tourinho, Sul, & Fillmann, 2009), boats and others watercrafts (Hazel & Gyuris, 2006; Work, Balazs, Summers, Hapdei, & Tagarino, 2015), hopper dredges (Goldberg et al., 2015), and oil and natural gas exploration/production activities (Stacy et al., 2017; Ylitalo et al., 2017). Natural factors, including diseases such as fibropapillomatosis (FP) (Chaloupka, Work, Balazs, Murakawa, & Morris, 2008; Reis, Pereira, et al., 2010), other neoplasms (Orós, Torrent, Calabuig, & Déniz, 2005), endoparasitosis (Flint et al., 2014), septicaemic processes (Goldberg et al., 2016), and hypothermia (Shaver et al., 2017; Vélez-Rubio, Trinchin, Estrades, Ferrando, & Tomás, 2017), are also reported as causes of stranding.

Stranding records can also provide insights into other aspects of sea turtle populations, including spatio-temporal distribution, life stages, sex ratio, migratory patterns, diet, and habitat use (Guebert-Bartholo, Barletta, Costal, & Monteiro-Filho, 2011; Reis, Moura, Lima, Rennó, & Siciliano, 2010; Vélez-Rubio et al., 2013). In addition, data on stranded turtles can serve as a baseline for assessing impacts from management and conservation measures (Crowder, Hopkins-Murphy, & Royle, 1994; Epperly & Teas, 2002; Shaver & Teas, 1999). However, it is important to consider that the distribution of stranded turtles is often influenced by marine currents and other oceanographic events and these data represent a minimum measure of at-sea mortality (Hart, Mooreside, & Crowder, 2006; Koch, Peckham, Mancini, & Eguchi, 2013).

The occurrence of stranded sea turtles along the coast of Rio de Janeiro state, south-eastern Brazil, was summarized with a focus on four objectives: (i) to identify the species and life stages of stranded sea turtles; (ii) to quantify the sites of occurrence and the concentration of stranded turtles; (iii) to analyse the temporal patterns of stranded turtles; and (iv) to identify the contributing factors of sea turtle mortality.

2 | METHODS

2.1 | Study site

The study area spanned approximately 1251 km (95%) of beaches of the Rio de Janeiro state in Brazil, where two regular beach monitoring programmes (BMPs) are required through federal environmental licensing of the Brazilian oil company PETROBRAS, because of its activities for the production and disposal of oil and natural gas in the Santos and Campos Basins, under the supervision of the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA/MMA) (PETROBRAS, 2017; PETROBRAS, 2018; Werneck et al., 2018). The other 66 km, running between Barra do Furado (22°05'34.8"S 41°08'03.8"W) and the Paraíba do Sul River mouth (21°37'09.1"S 41°00'53.3"W), was monitored by a separate programme licensed by the private mixed-use port complex Açu Superport (21°48'56.5"S 41°00'21.6"W; Figure 1). For this study, the coast of Rio de Janeiro was divided into south and north regions, to differentiate the monitoring efforts. The southern study region extended from the municipality of Paraty (23°22'02.6"S 44°43'26.8"W) to the Vila beach (22°56'10.7"S 42°29'36.2"W), in the municipality of Saquarema (Figure 1). This coastline runs east–west along Santos Basin (Muehe, Lima, & Lins-de-Barros, 2006), including the Guanabara Bay and, to the west, the Sepetiba Bay, protected by the Marambaia Island and the Ilha Grande Bay. The northern study region extended from Itaúna beach (22°56'07.1"S 42°29'26.2"W), in the municipality of Saquarema, to the municipality of São Francisco de Itabapoana (21°18'28.3"S 40°57'29.3"W), excluding Campos dos Goytacazes and São João da Barra (Figure 1). This region's coastline borders the Campos Basin and runs north-north-east and south-south-west, interrupted by the broad delta-shaped plain of the Paraíba do Sul River (Muehe et al., 2006).

The coast of the state of Rio de Janeiro is quite diverse and rugged, with many rivers, lakes, ponds, bays, and islands of different sizes (Muehe et al., 2006; Rossi-Wongtschowski et al., 2006). The most striking oceanographic feature in the region is a coastal upwelling (Valentin, 2001), in which the South Atlantic Central Water, a deep, cold, low salinity and nutrient-rich water mass, moves beyond the continental shelf towards the coast, especially between October and April (Rossi-Wongtschowski et al., 2006; Valentin, 2001). The South Atlantic Central Water penetration into the coastal region increases primary production and, consequently, facilitates the development of all trophic levels (Guimaraens, Paiva, & Coutinho, 2005; Rossi-Wongtschowski et al., 2006; Valentin, 2001). This upwelling occurs between 22° and 23°S, moving in a south-west direction, even reaching the southern coast of Rio de Janeiro and the island of São Sebastião, São Paulo (24°S) (Lorenzzetti & Gaeta, 1996).

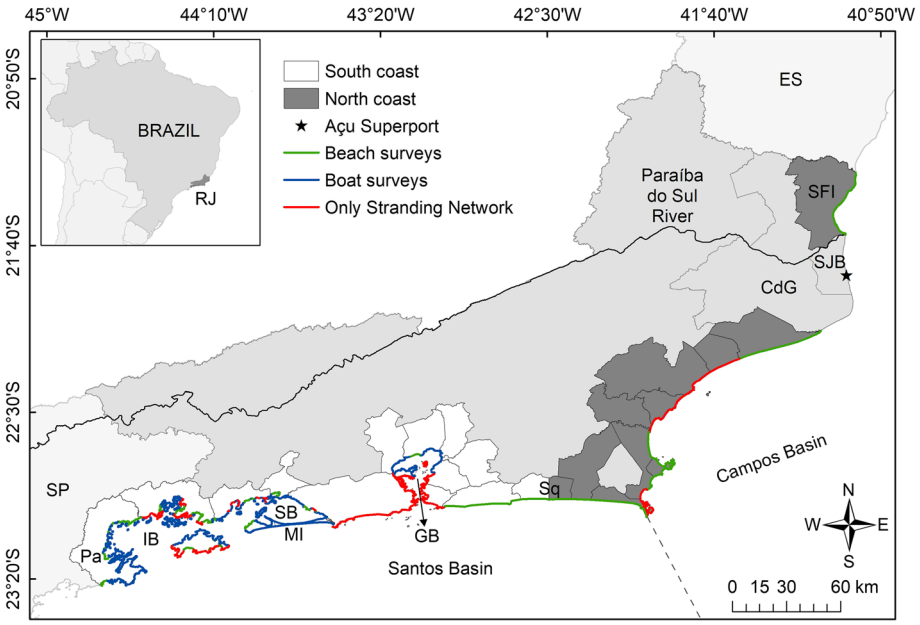

FIGURE 1 Location of the study area along the southern region (white) and northern region (dark grey) of the Rio de Janeiro coast, south-eastern Brazil, where three monitoring strategies (beach surveys, boat surveys, and stranding network) were adopted for data collection of stranded sea turtles. The black line represents the Paraíba do Sul River and the dashed line delimits the Santos and the Campos Basins. SP = São Paulo; Pa = Paraty; IB = Ilha Grande Bay; SB = Sepetiba Bay; MI = Marambaia Island; GB = Guanabara Bay; Sq = Saquarema; CdG = Campos dos Goytacazes; SJB = São João da Barra; SFI = São Francisco de Itabapoana; ES = Espírito Santo

2.2 | Data collection

In this study, any sea turtle found alive or dead on the beaches or floating in coastal waters was considered a stranding, except for nesting females. Data on stranded sea turtles were collected by the BMPs from September 2016 to September 2017 in the southern region and from October 2010 to September 2016 in the northern region.

Three different monitoring strategies were used depending on the particularities of each area: beach (total extension = 276 km) or boat surveys (742 km) complemented by a collaborative stranding network, or a beach-based stranding network only (233 km; Figure 1). The beach surveys were carried out daily, either using motorized quadricycles (particularly on long stretches of beach and/or with difficult access), bike or on foot. The boat surveys were carried out weekly in front of beaches with no access by land, on rocky shore areas and on islands off the south region of Rio de Janeiro. Except for the coastal region of Marambaia Island, the boat surveys were carried out bi-weekly. Areas monitored only by the collaborative stranding network were sections of the coast in urban areas or in front of private condominiums that have daily urban cleaning services and/or locations with lifeguards, who reported observed stranded animals. Ad hoc reports of stranded turtles were also submitted by local people, tourists, fishermen, commercial establishments, and coastal enterprises, either directly or through telephone hotlines.

For each stranded turtle encountered, the following information was collected: species; date; location (latitude and longitude); decomposition state (Table 1); curved carapace length (CCL; according to Bolten, 1999); life stage (Table 2); presence or absence of tumours suggestive of FP; any abnormal condition (i.e. clinical signs, ectoparasites, emaciation, tumours, and others) as well as possible interactions with anthropogenic activities, such as entanglement in fishing gear, injuries, mutilation, fractures, and/or knife cuts.

Live-stranded animals were transferred to the nearest sea turtle rehabilitation centre established by local BMPs. Whenever possible, carcasses in fresh, moderate, and advanced stages of decomposition were necropsied following a detailed protocol. Turtles were classified using a body condition scoring based on an evaluation of fat deposits and muscle development, because weight alone is an unreliable

TABLE 1 Characteristics of decomposition state for sea turtle carcasses, adapted from Reis et al. (2017)

Decomposition state	Characteristics
Alive	Animal found alive, with reflexes to external stimuli.
Freshly dead	Recent death; normal appearance with little scavenger damage; fresh smell; absence of swelling; intact viscera; firm dark-red muscles; and fair eyes.
Moderate	Carcass intact; evident swelling; mild odour; viscera soft but still intact; intestine dilated by the presence of gas; there may be necrophagy of soft tissue.
Advanced	Epidermis may be completely lost; significant swelling; strong odour; bones may be detached and viscera identifiable but possibly friable or with liquefied texture; keratin may be peeling off the carapace; externalized internal organs and parts of the body predated.
Mummified/only bone remains	Exposed skeleton, without internal organs; mummified skin; only part of the skeleton, such as carapace, plastron, or skull.

TABLE 2 Sea turtle life stages, based on the curved carapace length (cm) of oceanic juveniles, and minimum curved carapace length of nesting females (adults) on Brazilian beaches by species and according to the literature

Species	Hatchlings and oceanic juveniles	Juveniles	Subadults and adults
Caretta caretta	≤46 (Bjorndal, Bolten, & Martins, 2000)	>46 and <83	≥83 (Baptistotte, Thomé, & Bjorndal, 2003)
Chelonia mydas	≤30 (Bjorndal, 1996)	>30 and <90	≥90 (Almeida et al., 2011)
Dermochelys coriacea	—	<139	≥139 (Thomé et al., 2007)
Eretmochelys imbricata	≤30 (Bjorndal, 1996)	>30 and <83	≥83 (Santos, Freire, Bellini, & Corso, 2010)
Lepidochelys olivacea	—	<62	≥62 (Silva, Castilhos, Lopez, & Barata, 2007)

indicator of body condition (Thomson, Burkholder, Heithaus, & Dill, 2009). Body condition scoring was classified as emaciated (concave plastron with extensive loss of muscle mass and fat reserves), poor (flat to slightly concave plastron and some reduction in muscle mass), fair (less rounded plastron, slightly reduced muscle mass), or good (robust turtles; rounded plastron and good muscle mass). During necropsy, any observed gross alterations of tissues or organs were recorded, as well as any sign of anthropogenic interaction, including marine debris ingestion, entanglement in fishing gear, propeller injuries, and dredging related lesions.

Recognizing the exact cause of death of a stranded sea turtle is often challenging due to the possible simultaneous action of two or more factors contributing to the stranding and/or because of advanced decomposition of the carcass (Goldberg et al., 2013). Therefore, for this study the factors contributing to mortality were reported, rather than definitively deriving the precise cause of death. The descriptions of these factors are in Appendix 1. These factors were determined only for the individuals submitted for necropsy. Considering that multiple factors may contribute to a turtle's death, individuals were sometimes grouped into more than one category.

2.3 | Data analysis

A year of monitoring was defined as the interval between October of one year and September of the subsequent year. For each species, significant differences between the mean/median numbers of sea turtle strandings per month in the northern region, between 2010-2016, were verified by the one-way ANOVA test plus Tukey tests post hoc, or the Kruskal–Wallis test, followed by Dunn tests post hoc. In the southern region, the differences between the relative frequencies of sea turtle strandings per month during 2016–2017 were verified by the Pearson's chi-square test (χ^2).

To analyse the spatial distribution pattern of the stranding records and to identify where greater or lesser concentrations of strandings occur along the coastline of Rio de Janeiro, density maps from the absolute number of strandings in the southern and northern regions were generated, per species, for areas monitored by beach or boat surveys and complemented by stranding network and areas monitored only by stranding network. The maps were generated in the software *ArcMap* 10.5, using the point density tool with no population field.

All statistical analyses were computed in the program *R 3.1.1* (R Core Team, 2017). The normality of the data was tested by the Shapiro–Wilk test and the homoscedasticity of the variances was tested by the F-test. The data that were not normally distributed were transformed logarithmically before using parametric tests. However, if the logarithmic data were also non-normal, non-parametric statistics were used on the original data.

3 | RESULTS

A total of 12,162 stranded sea turtles were recorded in the study area between 2010 and 2017. Although five species were observed, 89.9% of the records were *Chelonia mydas*, and 1.3% could not be reliably identified, mostly because of advanced decomposition (Table 3). One turtle found in the southern region presented morphological characteristics suggestive of hybridization between *Caretta caretta* and *Lepidochelys olivacea*, but there was no genetic confirmation.

In the north region, all life stages were recorded for *C. caretta*, and 72.7% were subadults/adults. In the southern region, there were no hatchlings/oceanic juveniles of this species and 59.1% were juveniles. For *C. mydas*, all life stages were recorded, both in the northern and southern regions, with 95% and 95.9% being juveniles, respectively. Strandings of juveniles and subadults/adults of *D. coriacea* were recorded in the northern (20% and 80%, respectively) and southern regions (50% each). All life stages of *E. imbricata* were recorded in the northern region, with 91.6% being juveniles. In the southern region, three juveniles were recorded. Juveniles and subadults/adults of *L. olivacea* were recorded in the northern (30.7% and 69.3%, respectively) and southern regions (40% and 60%, respectively; Table 4). The only possible hybrid individual had CCL of 60.3 cm.

Along the southern region, during 2016–2017, *C. caretta* strandings were more frequent in September (n = 7; 20%; χ^2 = 36.17, df = 11, P < 0.05). Along the northern region, during the years 2010 to 2016, the mean numbers of *C. caretta* strandings per month were not significantly different (F = 1.91, df = 11, P > 0.05; Figure 2a). For *C. mydas*, the relative frequencies of strandings per month in the southern region were not significantly different (χ^2 = 10.49, df = 11, P > 0.05). For the northern region, July (mean ± standard deviation [SD] = 186.0 ± 35.8; range = 143–245; n = 1116) was the month with the highest mean number of strandings and April was the lowest (mean ± SD = 102.0 ± 42.2; range = 64–177; n = 612; F = 2.56, df = 11, P < 0.05; Tukey: P < 0.05; Figure 2b). The strandings

TABLE 3 Number and percentage values (%) of stranded sea turtles on the northern and southern regions of Rio de Janeiro state per area monitoring strategy and species. *Including an individual with morphological characteristics suggestive of hybridization between *Caretta caretta* and *Lepidochelys olivacea*

			Number of strandings						
Region	**Year**	**Area monitoring strategy**	***C. caretta***	***Chelonia mydas***	***Dermochelys coriacea***	***Eretmochelys imbricata***	***L. olivacea***	**Undetermined species**	**Total**
North	2010–2016	Beach surveys + stranding network	568	9,515	34	95	215	124	10,551
		Only stranding network	57	411	6	13	15	12	514
		Undetermined	2	18	0	0	1	1	22
		Total	627	9,944	40	108	231	137	11,087
South	2016–2017	Beach surveys + stranding network	27	657	7	3	11	15	720
		Boat surveys + stranding network	2	70	0	0	0	1	73
		Only stranding network	6	261	1	1	5	1*	275
		Undetermined	0	6	0	0	1	0	7
		Total	35	994	8	4	17	17	1,075
Total	2010–2017	Total	662	10,938	48	112	248	154	12,162
%		Total	5.4	89.9	0.4	0.9	2.0	1.3	100

TABLE 4 Sample size (*n*), mean ± standard deviation (SD) and range of curved carapace length (CCL, cm); number and percentage values (%) of hatchlings/oceanic juveniles (H/OJ), juveniles (J) and subadults/adults (S/A) of stranded sea turtles on the northern (2010–2016) and southern regions (2016–2017) of Rio de Janeiro state

Coast	**CCL (cm) /Life stages**		***Caretta caretta***	***Chelonia mydas***	***Dermochelys coriacea***	***Eretmochelys imbricata***	***Lepidochelys olivacea***
North	CCL	*n*	579	9635	30	107	218
		Mean	87.9	38.5	143.4	46.2	64.0
		SD	18.7	9.0	11.3	14.4	6.7
		Range	4.5–130.0	16.4–131.0	115.0–171.0	27.5–90.6	32.7–87.5
	Life stages	H/OJ (%)	22 (3.8)	440 (4.6)	0 (0)	8 (7.5)	0 (0)
		J (%)	136 (23.5)	9153 (95.0)	6 (20)	98 (91.6)	67 (30.7)
		S/A (%)	421 (72.7)	42 (0.4)	24 (80)	1 (0.9)	151 (69.3)
South	CCL	*n*	22	830	8	3	10
		Mean	82.0	40.7	131.1	59.5	63.0
		SD	12.7	8.9	20.8	4.9	4.8
		Range	61.3–116.0	24.4–96.5	100.5–155.5	55.5–64.9	57.5–72.8
	Life stages	H/OJ (%)	0 (0)	32 (3.9)	0 (0)	0 (0)	0 (0)
		J (%)	13 (59.1)	796 (95.9)	4 (50)	3 (100)	4 (40)
		S/A (%)	9 (40.9)	2 (0.2)	4 (50)	0 (0)	6 (60)

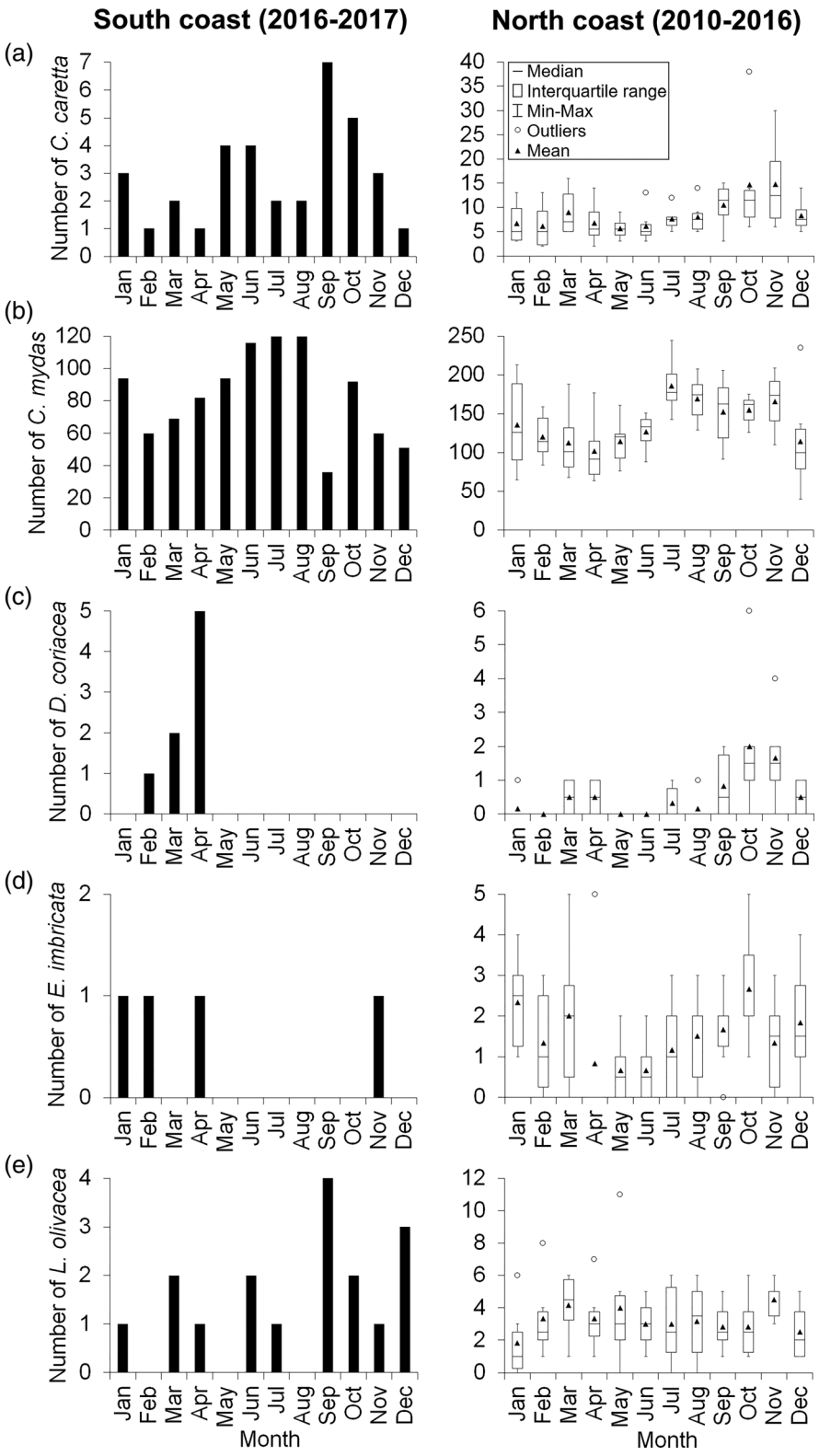

FIGURE 2 Number of stranded sea turtles by species per month along the southern region, during 2016–2017, and the northern region of the state of Rio de Janeiro, between 2010 and 2016. (a) *Caretta caretta*; (b) *Chelonia mydas*; (c) *Dermochelys coriacea*; (d) *Eretmochelys imbricata*; (e) *Lepidochelys olivacea*

of *D. coriacea* along the southern region were more frequent in April (n = 5; 62.5%; χ^2 = 462.50, df = 11, P < 0.05). In the northern region, October (mean ± SD = 2.0 ± 2.1; range = 0–6; n = 12) and November (mean ± SD = 1.7 ± 1.4; range = 0–4; n = 10) were the months with the highest number of strandings (Kruskal–Wallis χ^2 = 29.04, df = 11, P < 0.05; Dunn: P < 0.05; Figure 2c). Only four stranded *E. imbricata* were recorded along the southern region, each occurring in a different month. In the northern region, stranding numbers per month were not significantly different (Kruskal–Wallis χ^2 = 14.86, df = 11, P > 0.05; Figure 2d). The strandings of *L. olivacea* were more frequent in September (n = 4; 23.53%; χ^2 = 70.26, df = 11, P < 0.05) along the southern region. In the northern region, stranding numbers

per month were not significantly different (Kruskal–Wallis χ^2 = 8.65, df = 11, P > 0.05; Figure 2e).

Of all the strandings, 1,065 (8.8%) individuals were found alive and underwent veterinary evaluation: 73.9% (n = 787) died and were necropsied; 22.9% (n = 244) were treated and rehabilitated; 3.2% (n = 34) remain in treatment. Of all individuals found dead (n = 11,097; 91.2%), 3.9% (n = 429) were fresh dead, 33.2% (n = 3,690) in a moderate state of decomposition, 58.2% (n = 6,458) were in an advanced decomposition state, 3.5% (n = 388) were mummified or contained only bones, and the remaining 1.2% (n = 132) lacked information about decomposition state. During the study, 2,538 individuals were necropsied, but only 67.7% (n = 1,719) of these reported information about factors contributing to mortality. The remaining 32.3% (n = 819) were in an advanced stage of decomposition and/or were predated prior to observation, making it difficult to assign mortality factors; these were discarded from further analysis.

It was possible to determine the contributing factors to mortality in 147 *C. caretta*. Of these, 126 were categorized as interactions with fishing gear (Appendix 2), identifying specific gear types affecting 28 *C. caretta*, as follows: n = 15 (53.6%) longline gear (all along the northern region, nine in São Francisco de Itabapoana); n = 10 (35.7%) trawl gear (one in Guanabara Bay region and nine in São Francisco de Itabapoana); n = 2 (7.1%) gillnets (northern region); and n = 1 (3.6%) in Sepetiba Bay had in its gastrointestinal tract a hook used by recreational hook-and-line fishery (Figure 3a). Of the individuals who ingested marine debris (n = 24), the main lesions caused in the gastrointestinal tract were hard faecal matter within the intestines (faecaloma; 12.5%), perforated ulcers (8.3%), total obstruction (4.2%), and haemorrhagic lesions (4.2%). Among the turtles with endoparasites (n = 48), 14.6% had high endoparasitic loads (Appendix 2).

The strandings of *C. caretta* analysed in the southern region (n = 34) were concentrated in the municipalities of Niterói, Maricá and the western Saquarema, where interaction with fishing gear, endoparasites, and diseases occurred. However, strandings of this species were recorded throughout the north region (n = 597), with a higher concentration in the north end of the state, specifically in São Francisco de Itabapoana, where the interaction with fishing gear was predominant (n = 97), as in the Cabo Frio region (n = 12) and Quissamã (n = 4; Figure 3a).

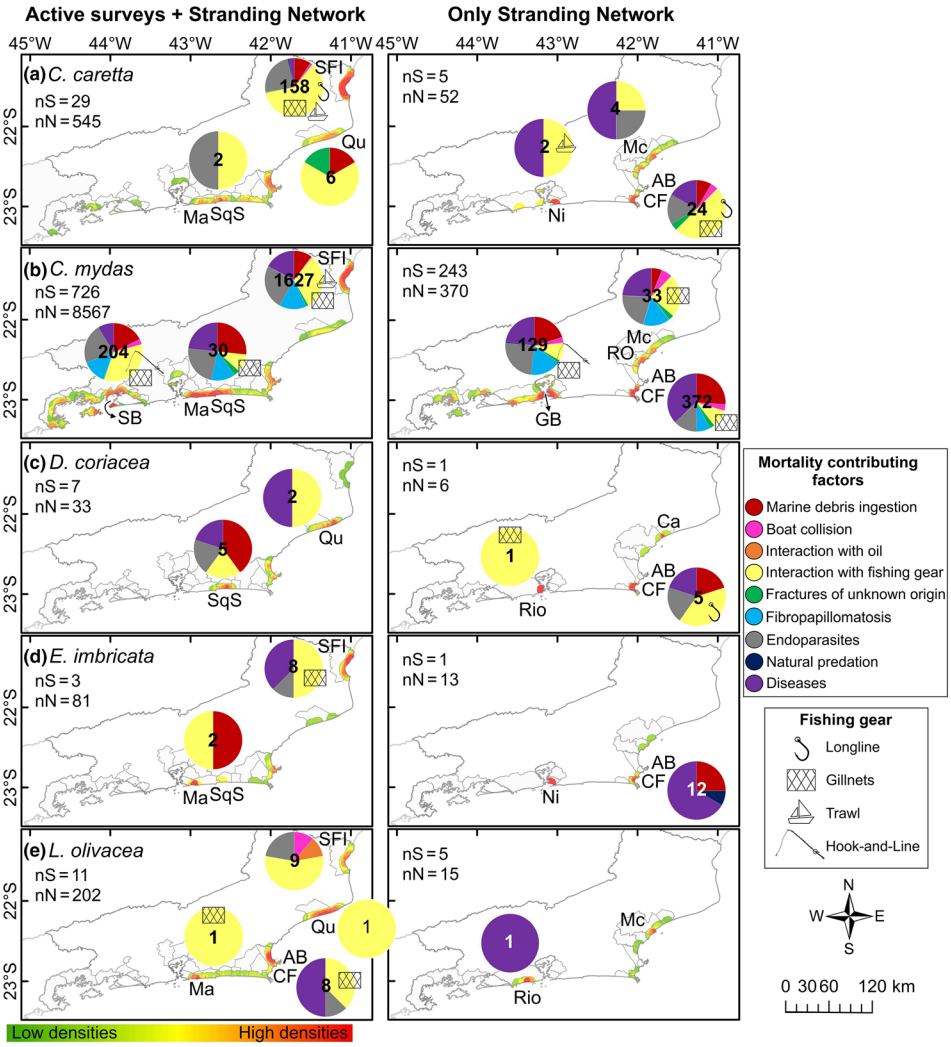

FIGURE 3 Density maps from the absolute number of (a) *Caretta caretta*; (b) *Chelonia mydas*; (c) *Dermochelys coriacea*; (d) *Eretmochelys imbricata*; (e) *Lepidochelys olivacea* strandings (with latitude/longitude information) on the southern (nS) and northern (nN) regions of Rio de Janeiro state for areas monitored by beach or boat surveys and complemented by stranding network and areas monitored only by stranding network. Reddish areas of the coastline indicate higher density of stranded turtles and green areas indicate lower density. Pie charts indicate mortality contributing factors, with the fishing gear responsible for the interactions in the areas of higher stranding concentrations. The numbers within the pie charts represent the total number of occurrences of the mortality contributing factors for that region. For regions with both types of monitoring effort (Sepetiba and Guanabara Bays, Cabo Frio), mortality factors were analysed together. SB = Sepetiba Bay; Rio = Rio de Janeiro municipality; GB = Guanabara Bay; Ni = Niterói; Ma = Maricá; SqS = Saquarema (southern region); CF = Cabo Frio; AB = Armação dos Búzios; RO = Rio das Ostras; Mc = Macaé; Ca = Carapebus; Qu = Quissamã; SFI = São Francisco de Itabapoana

For *C. mydas*, 1525 had their mortality contributing factors determined, with interactions with fishing gear (*n* = 692), endoparasites (*n* = 587), and diseases (*n* = 540) being the most common (Appendix 2). It was possible to identify the fishing gear in 83 specimens: 72 (86.8%) by gillnets in the southern and northern regions, mainly in Sepetiba Bay (*n* = 32) and in São Francisco de Itabapoana (*n* = 24); seven (8.4%) had hooks used by recreational fishers in their gastrointestinal tract and/or trapped in their body (including the eyelids) in the Guanabara Bay and along the northern region; two (2.4%) were caught in trawl gear in São Francisco de Itabapoana; and two (2.4%) were caught by gillnets and had hooks used by recreational fishers in their gastrointestinal tract in Sepetiba Bay and north region (Figure 3b). A total of 442 individuals had marine debris in their tracts and the main lesions found were faecaloma formation (34.2%), non-perforated ulcers (9.3%), total obstruction (8.8%), and haemorrhagic lesions (5.0%). Tumour masses suggestive of FP were found in 372 turtles. Of those with endoparasites, 17.2% had high endoparasitic loads (Appendix 2).

Stranded *C. mydas* were recorded along the entire coast of the state of Rio de Janeiro. In the southern region (*n* = 969), there were higher concentrations in Sepetiba Bay, where interaction with fishing gear was predominant (*n* = 71); in Maricá/Saquarema, where marine debris ingestion (*n* = 8), endoparasites (*n* = 7), and diseases (*n* = 7) had the highest occurrences, and at the entrance of Guanabara Bay, where endoparasites (*n* = 32), diseases (*n* = 29), marine debris ingestion (*n* = 26), and FP (*n* = 22) predominated. In the northern region (*n* = 8937), São Francisco de Itabapoana also presented the highest concentration for *C. mydas*, with predominance of the category interaction with fishing gear (*n* = 500), followed by the Cabo Frio region, where diseases were predominant (*n* = 137), and Rio das Ostras/Macaé, where interaction with fishing gear (*n* = 8), diseases (*n* = 8), and endoparasites (*n* = 7) occurred (Figure 3b).

The main contributing factors found in the nine individuals of *D. coriacea* were interactions with fishing gear (*n* = 5) and marine debris ingestion (*n* = 4; Appendix 2). It was possible to identify the fishing gear in only two specimens: one was caught on a longline in Cabo Frio and one in a gillnet in Rio de Janeiro municipality (Figure 3c). Of the four individuals with marine debris in their gastrointestinal tracts, one presented faecaloma formation and one a non-perforated ulcer. Of the two individuals with endoparasites, one presented a moderate load (Appendix 2).

The occurrence of stranded *D. coriacea* in the southern region (*n* = 8) was concentrated in Saquarema, where marine debris ingestion (*n* = 2) predominated. In the northern region (*n* = 39), there were higher concentrations in the Cabo Frio region, where interaction with fishing gear (*n* = 2) predominated; and in Quissamã, where interaction with fishing gear and diseases occurred (Figure 3c).

For the 20 individuals of *E. imbricata* analysed, the main contributing factor found was disease (*n* = 11). Of the five individuals with marine debris in their digestive tract, the main lesions found were faecaloma formation (40%), partial obstruction (20%), perforated ulcer (20%), and haemorrhagic lesions (20%; Appendix 2). Six individuals interacted with fishing gear and one was caught in a gillnet in São Francisco de Itabapoana (Figure 3d). Only one individual presented endoparasites, with a low load (Appendix 2).

Only four stranded *E. imbricata* were recorded along the southern region and these were in the Niterói and Maricá region, where marine debris ingestion and interaction with fishing gear occurred. In the north region (*n* = 94), this species concentrated in the municipality of São Francisco de Itabapoana, with a majority of known mortality factors being interaction with fishing gear (*n* = 4); and in the region of Cabo Frio, where diseases (*n* = 8) predominated (Figure 3d).

The main contributing factor found in the 18 individuals of *L. olivacea* was also interactions with fishing gear (*n* = 12; Appendix 2). It was possible to identify the fishing gear in only two specimens and both were caught by gillnets in Maricá and Cabo Frio (Figure 3e). None had marine debris in their digestive tract. The three individuals with endoparasites did not have endoparasitic load determined (Appendix 2).

Stranded *L. olivacea* analysed in the southern region (*n* = 16) were mainly concentrated in Maricá and Rio de Janeiro, where only one individual was analysed for mortality factors at each site and was grouped in the categories interaction with fishing gear and diseases, respectively. In the northern region (*n* = 217), this species was recorded along the entire coast, with four major concentrations: in the Cabo Frio region, where the diseases (*n* = 4) and interaction with fishing gear (*n* = 3) predominated; in Quissamã, where only one individual was analysed for mortality factors and was grouped in the interaction with fishing gear; in São Francisco de Itabapoana, where interaction with fishing gear (*n* = 5) was also predominant; and in Macaé, without mortality factors analysed (Figure 3e).

The other categories (boat collision, interaction with oil, fractures of unknown origin, and natural predation) had low frequencies of occurrence for all species (Appendix 2). No individual analysed in this study presented evidence of interaction with hopper dredges.

4 | DISCUSSION

This is the first study to analyse regular beach monitoring effort from BMPs throughout most of the coast of Rio de Janeiro state, focusing on factors of sea turtle mortality. Strandings of the five species of sea turtles that occur in Brazil have already been recorded on the north (Reis et al., 2010; Reis, Goldberg, & Lopez, 2017; Reis, Silveira, & Siciliano, 2009) and south coast of the state (Werneck et al., 2018). The highest occurrence of stranded juveniles *C. mydas* may be related to its abundance in Brazilian waters and coastal habits, being more exposed to anthropogenic threats (Almeida et al., 2011; Sforza, Marcondes, & Pizetta, 2017). This predominance corroborates the previous studies conducted in Rio de Janeiro (Reis et al., 2017; Reis, Pereira, Rodriguez, et al., 2010; Reis, Silveira, & Siciliano, 2009; Werneck et al., 2018) and along much of the Brazilian coast, from Maranhão to the north of Rio Grande do Sul (Berrêdo et al., 2013; Bugoni et al., 2001; Farias, 2014; Lima, Melo, Spiandorin, & Santana, 2007; Lopes-Souza, Schiavetti, & Álvarez, 2015; Mascarenhas, Santos, & Zeppelini, 2005; Poli, Lopez,

Mesquita, Saska, & Mascarenhas, 2014; Ribeiro, Barreto, Ribeiro, & Azevedo, 2014; Silva, Vaz-dos-Santos, & Maracini, 2012), except in the state of Sergipe, where the strandings of adult *L. olivacea* predominate, especially during its reproductive period (Castilhos et al., 2011; Silva et al., 2011), and in the south–central coast of Rio Grande do Sul, where the strandings of *Caretta caretta* predominate (Monteiro et al., 2016; Soto, Serafini, & Celini, 2003a).

The prevalence of juvenile *C. mydas* in this study illustrates the importance of the coastal waters of Rio de Janeiro as a migratory corridor, juvenile development habitat, and feeding ground. After an initial developmental period in oceanic waters, *C. mydas* with 30–40 cm CCL shift to more coastal environments (Balazs, 1995), with a marked change in diet (Vélez-Rubio et al., 2016). As they develop and reach sexual maturity, green turtles migrate to their breeding grounds (Plotkin, 2003). Genetic analysis revealed that the feeding areas of *C. mydas* in Brazil are composed of mixed stock individuals, mainly from Ascension Island and Aves Island, Suriname, Guinea Bissau, and Trindade Island (Bondioli, 2009; Jordão, Bondioli, Guebert, Thoisy, & Toledo, 2015; Naro-Maciel et al., 2012; Proietti et al., 2012). The main nesting areas of this species in Brazil are located on isolated oceanic islands (Almeida, Santos, et al., 2011), and thus there are few recorded occurrences of adults along the continental Brazilian coast.

Caretta caretta was the second most frequent species observed in this study. It was also the second most recorded between 2008 and 2010 between the municipalities of Saquarema and São Francisco de Itabapoana (Reis et al., 2017) but was third after *C. mydas* and *Lepidochelys olivacea* in studies that monitored stranded turtles along the northern coast of Rio de Janeiro, from Saquarema to Quissamã, between 1994 and 2009 (Reis, Pereira, Rodriguez, et al., 2010; Reis, Silveira, & Siciliano, 2009). The highest concentration of *C. caretta* strandings in the extreme north of the state suggest a greater abundance of this species in this region, which is one of its priority nesting sites in Brazil (Lima, Wanderlinde, Almeida, Lopez, & Goldberg, 2012; Marcovaldi & Chaloupka, 2007; Marcovaldi & Marcovaldi, 1999). The prevalence of strandings of subadult/adult individuals of this species, as well as the records of hatchlings in the north region, reflect the use of the area for reproduction. The nesting season of *C. caretta* in northern Rio de Janeiro state occurs from September to May (Lima et al., 2012; Reis et al., 2017), which may also be related to the greater number of strandings of this species during this period. Therefore, considering the biological value of animals in reproductive activity, nest protection is not sufficient to ensure their survival, considering the overall mortality of adult turtles in waters near nesting grounds.

Studies in the south–central coast of Rio Grande do Sul suggest that waters off southern Brazil are an important feeding area for *C. caretta*, as stranded juveniles are the most common sea turtle species found at nearly all times of year (Monteiro, 2017; Monteiro et al., 2016). Females of this species tagged in northern Espírito Santo have been found stranded in Rio de Janeiro (Marcovaldi et al., 1999) and Uruguay (Almeida, Baptistotte, & Schineider, 2000); and a female tagged in northern of Bahia was captured incidentally in a common fishing area between Argentina and Uruguay (Laporta & Lopez, 2003). Genetic studies have also demonstrated that *C. caretta* found in Uruguay and Argentina are from nesting sites in Brazil (Caraccio et al., 2008; Prosdocimi, Bugoni, Albareda, & Remis, 2015). Therefore, the southern study region is also used as a migratory route between nesting and feeding sites of *C. caretta*.

Relatively high numbers of strandings of *L. olivacea* were recorded, mainly subadults/adults, corroborating other studies on the north coast of Rio de Janeiro (Reis, Silveira, et al., 2009; Reis et al., 2017; Reis, Moura, Lima, et al., 2010). The main feeding and nesting sites of *L. olivacea* in the south-west Atlantic are concentrated in the north and north-east regions of Brazil (Castilhos et al., 2011; Marcovaldi, 2001; Silva et al., 2011). However, there are also bycatch records of this species in the south-south-east regions (Guimarães, Tavares, & Monteiro-Neto, 2018; Pinedo & Polacheck, 2004; Sales, Giffoni, & Barata, 2008), as well as stranding records along much of the Brazilian coast, from Ceará (Lima et al., 2007) to the southernmost part of the country, where they are less frequent (Monteiro et al., 2016). Reis, Moura, Lima, et al. (2010) also reported a female *L. olivacea* in the region of Quissamã that had been tagged during nesting in Sergipe. Thus, based on the evidence, some adult *L. olivacea* migrate from the north-north-east of Brazil to the coast of Rio de Janeiro, using the region as a feeding area, as suggested previously by Reis, Moura, Lima, et al. (2010).

In addition, as documented previously by Reis, Silveira, and Siciliano (2009); Reis, Moura, Lima, et al. (2010); Reis, Pereira, Rodriguez, et al. (2010); Reis et al. (2017); and Guimarães et al. (2018), the coast of Rio de Janeiro is also an important feeding area for all species of sea turtles, due to the occurrence of the coastal upwelling, which increases primary productivity and, consequently, the availability of food (Guimaraens et al., 2005; Rossi-Wongtschowski et al., 2006; Valentin, 2001). The Paraíba do Sul River and other smaller rivers, lakes, lagoons, and bays of the region also contribute to a large amount of organic matter entering the coastal zone (Souza & Knoppers, 2003). The upwelling system and the high primary productivity have been reported as important factors for the sea turtles feeding elsewhere in the world (Amorocho & Reina, 2007; Domiciano, Domit, & Bracarense, 2017; James, Myers, & Ottensmeyer, 2005; Polovina et al., 2004).

The reduced relative rate of occurrences of *E. imbricata* and *D. coriacea* may reflect the lower abundance of these species in the region, mainly due to *E. imbricata* preferences for reef (Marcolvaldi et al., 2007; Marcovaldi et al., 2011) and *D. coriacea* preferences for oceanic habitats (Almeida et al., 2011; Thomé et al., 2007). This also corroborates previous studies in Rio de Janeiro (Reis et al., 2017; Reis, Pereira, Rodriguez, et al., 2010; Reis, Silveira, & Siciliano, 2009; Werneck et al., 2018).

The primary nesting sites of *E. imbricata* are located in north-eastern Brazil, as well as their foraging areas, which are around the main reef areas of Brazil (Fernando de Noronha—PE, Atol das Rocas—RN, Abrolhos Archipelago—BA) (Marcovaldi et al., 2011). However, some areas in the south-south-east region are also considered important for the feeding of the juveniles of this species, such as Trindade Island—ES and Arvoredo Island—SC (Marcovaldi et al., 2011). Consequently, *E. imbricata* strandings are most common in north-eastern

Brazil (Farias, 2014; Lima et al., 2007; Poli et al., 2014) and in Espírito Santo (Berrêdo et al., 2013). Although the southernmost true reefs in the South Atlantic are in the Abrolhos Archipelago—BA, large coral communities are also found from the state of Maranhão to the region of Cabo Frio—RJ. The latter is described as a 'coralline oasis' because it has a great wealth of species of the coralline fauna compared to neighbouring localities (Castro & Pires, 2001). Therefore, the relatively higher concentration of juvenile *E. imbricata* strandings in the Cabo Frio region suggests they use this area for feeding, especially during intense upwelling (October to April: Rossi-Wongtschowski et al., 2006; Valentin, 2001), period in which a higher number of strandings occurred.

Although *D. coriacea* is considered an oceanic species, satellite telemetry data have revealed that individuals of this species also forage in coastal waters of the south-western Atlantic (Almeida, Eckert, et al., 2011; López-Mendilaharsu, Rocha, Miller, Domingo, & Prosdocimi, 2009). The main nesting site for *D. coriacea* in the south-west Atlantic is located on northern coast of the Espírito Santo (Thomé et al., 2007). Nevertheless, relative to the rest of Brazil, Uruguay, and Argentina, the southern coastline of Brazil has the highest occurrence of this species in the whole region (Barata et al., 2004; Carman et al., 2011; Monteiro et al., 2016; Vélez-Rubio et al., 2013). It is reported that *D. coriacea* migratory movements are mainly related to the seasonal concentrations of their preferred prey of gelatinous zooplankton (James et al., 2005; López-Mendilaharsu et al., 2009). Considering that upwelling events increase the productivity of phytoplankton and zooplankton communities (Valentin, 2001) and that the highest number of strandings occurred during the months when this is intense, these data suggest that the coast of Rio de Janeiro is an important feeding site for leatherback turtles. In addition, the highest number of *D. coriacea* strandings in October and November along the northern study region, where subadult/adult individuals are also predominant, may be related to the reproductive period (September to March, Thomé et al., 2007) of the species in the north of Espírito Santo, which is about 200 km from the study area.

Finally, the observation of a possible hybrid between *C. caretta* and *L. olivacea* is not unprecedented for the region. Genetic studies previously have reported high levels of hybridization between sea turtle species off the Brazilian coast, especially between these reported species (Reis et al., 2010; Reis, Soares, & Lôbo-Hajdu, 2009; Reis, Soares, & Lôbo-Hajdu, 2010), *E. imbricata*/*C. caretta* and *E. imbricata*/*L. olivacea* (Lara-Ruiz, Lopez, Santos, & Soares, 2006).

This study suggests that bycatch is one of the main threats to sea turtles along the coast of Rio de Janeiro. Of these animals categorized as experiencing fisheries interaction, about 73% were found entangled, had marks of nets and/or presence of fishing gear or were found with intentionally inflicted lesions. The other 26% were in good body condition and with no other apparent cause of death, and 1% were reproductively active females with eggs in their oviducts. For these non-reproductive animals, the fact that the stranded animals were in good body condition (with no other apparent cause of death) is indicative that they had been feeding recently and suffered a sudden death, which we assumed was the result of bycatch in fishing gear. Reproductively active turtles are generally in good health because they are capable of reproducing. Thus, we also assume that the death or injury occurred suddenly as a result of interactions with fishing gear because chronic afflictions would probably have rendered adult individuals incapable of reproduction (Castilhos, Silva, Marcovaldi, Lopez, & Goldberg, 2014; Goldberg et al., 2013).

Although Brazilian environmental laws prohibit the capture, consumption, and trade of sea turtle products and by-products, evidence of sea turtle consumption was observed in several instances, mostly of green turtles. In these cases, meat appeared to have been removed by means of clean rectilinear cuts, bordering the plastron. Therefore, the consumption of meat and shells continues to threaten their survival. Sometimes, the whole carcass is harvested, making documentation difficult. Human consumption of sea turtles is not restricted to the coast of Rio de Janeiro. It has also been reported in some Brazilian cities (Damasio & Carvalho, 2010; Marcovaldi & Marcovaldi, 1999; Pupo, Soto, & Hanazaki, 2006), as well as in several Mediterranean countries (Casale, 2008; Kopsida, Margaritoulis, & Dimopoulos, 2000), and elsewhere (Humber, Godley, & Broderick, 2014).

Bycatch hotspots in the south region were in the Sepetiba Bay and its surrounding municipalities for *C. mydas*, and along the northern region in São Francisco de Itabapoana for all species (except *D. coriacea*). Sepetiba Bay has a rich mangrove environment, constituting a natural breeding ground for molluscs, fish, and crustaceans, and attracts a large number of fishing activities (Tolentino & Soares, 2004). Similarly, the northern coastal region regularly receives deposits of organic matter and therefore hosts a large number of fishery resources (Gomes, Cunha, & Zalmon, 2003). As a result, fishing effort is also intense, particularly around the municipality of São Francisco de Itabapoana, located between the Paraíba do Sul River to the south and the Itabapoana River to the north (already on the border with Espírito Santo).

In this study, gillnet gear had the highest interaction rates with *C. mydas*. Gillnets are also considered the main threat to this species in the municipality of São João da Barra—RJ (Masi, Esteves, Lima, & Wanderlinde, 2005), along the northern coast of Rio de Janeiro (Nogueira, 2011; Reis et al., 2017), as well as in other Brazilian states (São Paulo: Gallo, Macedo, Giffoni, Becker, & Barata, 2006; Paraná: López-Barrera, Longo, & Monteiro-Filho, 2012; Santa Catarina: Pupo et al., 2006; Rio Grande do Sul: Soto et al., 2003a; Brazilian coast: Marcovaldi et al., 2006) and elsewhere in the world (Uruguay: Lezama, Miller, & Fallabrino, 2004; Mexico: Mancini, Koch, Seminoff, & Madon, 2011; USA: Byrd, Hohn, & Godfrey, 2011; several countries: Gilman, 2009). *Caretta caretta*, *E. imbricate*, and *L. olivacea* interactions with gillnets were also documented along the northern region of Rio de Janeiro. Other studies along the Brazilian coast have also reported the interaction of *C. caretta* with this fishing gear (Marcovaldi et al., 2006; Masi et al., 2005; Ramos & Vasconcellos, 2013). For *E. imbricata* in Brazil, gillnets are reported as the principal gear type that results in bycatch (Gallo et al., 2006; Marcovaldi et al., 2006).

Longline gear was identified as the most frequent gear interacting with *C. caretta* in this study. Interactions between longline gear and *D. coriacea* were also documented, which indicates that this fishery

also poses as a threat to species in Rio de Janeiro. Studies focused on the pelagic longline fleet in the south-south-east region of Brazil also report that these two species are the most affected by this fishing gear (Kotas, Santos, Azevedo, Gallo, & Barata, 2004; Marcon, 2013). The same is reported for other regions in Brazil and in the south-western Atlantic (Domingo et al., 2006; Giffoni, Domingo, Sales, Fiedler, & Miller, 2008; Sales et al., 2008). In the Pacific, the longline has been identified as a major cause of regional declines in *D. coriacea* populations (Spotila, Reina, Steyermark, Plotkin, & Paladino, 2000).

The records of interactions of trawl gear with two *C. mydas* may be related with artisanal or industrial trawling activities, which are also quite intense along the coast of Rio de Janeiro (Guimarães et al., 2018; Martins-Ingletto, 2013). Industrial fishing mainly operates with medium to large sized vessels and occurs further away from the coastline, both in the coastal and oceanic zones. Guimarães et al. (2018) identified a high bycatch rate of sea turtles, mainly *C. caretta* and *L. olivacea*, in this fishery. The authors highlighted that operators of the industrial trawl gear often neglect to properly install and use turtle excluder devices, as required on trawlers >11 m in length by national law (IBAMA Order No. 5 of 02/19/1997). Records of trawling interaction with *C. caretta* individuals in the study area highlight this threat. However, the rate of bycatch in trawlers may be higher than observed, considering that it is difficult to clearly recognize sea turtle–trawl interactions because the gear rarely leaves visible marks on the turtles, and captured turtles are generally easily manipulated and released into the sea without a rope (Monteiro et al., 2016).

Small-scale trawling is one of the main fishing activities on the coast of São Francisco de Itabapoana and is mainly focused on Atlantic seabob (*Xiphopenaeus kroyeri*) (PETROBRAS, 2017). This fishery uses vessels <11 m, and therefore are exempt from turtle excluder device requirements. This is thought to result in regular occurrence of bycatch of the most coastal species, such as *C. mydas* and *E. imbricata* (Gallo et al., 2006; Marcovaldi et al., 2006; Soto, Serafini, & Celini, 2003b). Interestingly, a decrease in the number of stranded green turtles along the northern region from March to April was found, with a progressive increase from May and a peak in July, which may be related to the closure of the shrimp fishing season in the region from March 1 to May 31 (IBAMA Normative Instruction No. 189 of 09/23/2008). More direct research is needed on bycatch in this fishery.

Interactions of *C. mydas* and *C. caretta* with recreational hook-and-line gear were also documented. This fishing gear is widespread in coastal regions around the world and interaction with sea turtles can occur either from discarded or lost hooks and fishing lines (Oravetz, 1999), or when the gear is being actively used (Coleman et al., 2016). Depending on the location where the turtle is hooked and the intensity and location of the entanglement of the lines, interactions with this gear can cause serious health problems. The risk increases with ingestion: the hooks can pierce the gastrointestinal tract (two cases reported in this study) and the lines can cause plication and intussusception of the intestinal tract, with consequent blood interruption (one case reported in this study). In the region of Guanabara Bay and surrounding municipalities, there are frequent cases of interaction and ingestion of recreation hook and line by green turtles (Projeto Aruanã, personal communication).

In addition to bycatch, there was a prevalence of diseases as a contributing factor for mortality in the study area. Although they are classified as natural causes, they may be indirectly associated with anthropogenic impacts, such as pollution (Domiciano et al., 2017; Ward & Lafferty, 2004) and climate change (Harvell et al., 1999). Sea turtles may serve as sentinels for the health of coastal marine ecosystems (Aguirre & Lutz, 2004; Domiciano et al., 2017), thus sick animals in the study area may indicate environmental degradation of the coastal zones of the state of Rio de Janeiro.

Fibropapillomatosis can be an indicator of ecosystem health, as it is often associated with highly polluted coastal areas, high human density, and high contaminant supply (Aguirre & Lutz, 2004; Foley, Schroeder, Redlow, Fick-Child, & Teas, 2005; Santos et al., 2010). In Brazil, FP is mainly found in *C. mydas* along the entire coast (Baptistotte, 2007), and the highest prevalence is reported in Espírito Santo (Santos, Martins, et al., 2010) and in Rio de Janeiro (Tagliolatto, Guimarães, Lobo-Hadju, & Monteiro-Neto, 2016). The coastal waters of Rio de Janeiro are impacted by the release of domestic, industrial, and agricultural effluents (Fiori et al., 2013; Lema, 2012), which may explain the concentrated occurrence of FP in green turtles in this study.

Presence of endoparasites was frequently recorded in stranded sea turtles in the study area. In general, endoparasites can affect reptiles through infection, tissue destruction, competition for host nutrients, obstruction of the alimentary canal, production of toxins, induction of allergic reactions and, indirectly, can decrease fitness, affect behaviour and reproductive success (Klingenberg, 1993). According to Werneck (2011), animals with clinical signs of weakness had the highest parasitic loads, although it is challenging to determine if the animals acquired more parasites because they were weak or if the parasitism was the primary cause of the weakness. Endoparasites, even if they are not the cause of death of these animals, can generate and/or contribute conditions that lead to mortality (Werneck, 2011). Given the high rate of endoparasites reported in this study, future research on sea turtle helminth fauna and the pathogenesis of these endoparasites would help improve the understanding of this factor.

Marine debris was also an important threat factor for sea turtles in this study, especially for *D. coriacea*, *C. mydas*, *E. imbricate*, and *C. caretta*. The ingestion of marine debris is considered a principal threat to sea turtles in several regions of the Brazilian coast (Rio Grande do Norte: Farias, 2014; Paraíba: Poli et al., 2014; Bahia: Macedo et al., 2011; São Paulo: Bezerra, 2014; Paraná: Guebert-Bartholo, Barletta, Costa, & Monteiro-Filho, 2011; Rio Grande do Sul: Bugoni et al., 2001, Tourinho et al., 2009; Brazilian coast: Santos et al., 2015) and elsewhere (Uruguay: Vélez-Rubio et al., 2013; Florida, USA: Bjorndal, Bolten, & Lagueux, 1994; western Mediterranean: Tomás, Guitart, Mateo, & Raga, 2002; several countries: Nelms et al., 2015). Some coastal areas along Rio de Janeiro have been characterized by large amounts of marine debris introduced mainly by river systems and by inhabitants/tourists with inadequate disposal practices (e.g. Guanabara Bay and nearby region: Neto & Fonseca, 2011; Silva,

Araújo, Castro, & Sales, 2015; Arraial do Cabo/Cabo Frio region: Oigman-Pszczol & Creed, 2007; Silva, Castro, Sales, & Araújo, 2018). In this study, these regions had the highest occurrences of marine debris ingestion among the analysed turtles, which reinforces the urgent need for management actions on this issue.

Most cases of marine debris ingestion in this study were not linked to damage in the gastrointestinal tract of the turtles. However, there are the sub-lethal impacts from ingestion, such as positive buoyancy and reduced eating, generating chronic conditions of malnutrition (Bjorndal et al., 1994). In addition, the presence of marine debris can affect intestinal motility and induce the formation of faecalomas, which were the most frequent gastrointestinal damage recorded in this study. This condition is often irreversible and lethal as it can compromise or even obstruct the flow of digest in the intestinal tract (Awabdi, Siciliano, & Di Beneditto, 2013; Bjorndal et al., 1994). Ingested plastic fragments may also transfer harmful chemicals (Koch & Calafat, 2009; Oehlmann et al., 2009), and possible associated carcinogenic effects and endocrine disruption (Teuten et al., 2009).

Less frequent mortality factors affecting sea turtles in the study area included boat collision, particularly in areas with heavy traffic of vessels, such as in ports, anchorages, and pier (e.g. Sepetiba Bay, Guanabara Bay, region of Arraial do Cabo and Cabo Frio). Exposure to oil was recorded only along the north region, where oil exploration is concentrated in the Campos Basin (Winter, Jahnert, & França, 2007). The threats to sea turtles posed by oil exploration and production activities extend beyond contact and contamination with petroleum-derived toxic substances. Seismic prospecting emits high-intensity and low-frequency sounds in the marine environment (Samuel, Morreale, Greene, & Richmond, 2005) and may cause disorientation and physiological alterations in turtles (O'Hara & Wilcox, 1990), as well as a temporary reduction in hearing of these animals (McCauley et al., 2000). Increased vessel traffic associated with oil extraction may also lead to more boat collisions.

A few cases of natural predation on sea turtles in Rio de Janeiro were recorded, mainly for smaller turtles (5–40 cm CCL). Larger turtles generally have fewer predators, with adults in the water being susceptible only to the occasional attack by sharks, killer whales, and crocodiles (Heithaus, 2013).

No interaction of sea turtles with dredging operations was observed in this study. However, high rates of sea turtle mortality by dredging activities have been reported in the northern coast of Rio de Janeiro, specifically in the municipalities of Campos dos Goytacazes and São João da Barra (not analysed in this study), where a port complex was established in 2008 and hopper dredges are used extensively for maintenance of its channels (Goldberg et al., 2015; Reis et al., 2017).

Local physical and oceanographic conditions also play a large role in whether and where floating turtles end up washing up on land (Epperly et al., 1996; Hart et al., 2006; Koch et al., 2013; Tomás et al., 2008). In this study, high concentrations of strandings for all species of sea turtles in the region between Maricá and Saquarema in the southern region, and in the region of Cabo Frio/Armação dos Búzios in the north, may have been more influenced by local winds, the orientation of the coastline, and the upwelling event in Cabo Frio, as previously proposed by Reis et al. (2017). Sea turtle carcasses drifting along the southern region of the state may have been pushed into the region of Maricá and Saquarema, which acts as a bulkhead to the north, as well as the region of Cabo Frio/Armação dos Búzios, which acts as a bulkhead to the south (Reis et al., 2017). In addition, not all sick, injured or dead sea turtles will end up becoming stranded on land. Other studies estimate that only 7–20% of all floating turtles end up stranding on land (Epperly et al., 1996; Hart et al., 2006). Therefore, total mortality estimates provided in this study should be considered as minimum estimates affecting sea turtles in this region.

Considering the importance of the Rio de Janeiro coast as a feeding and/or migration area for all five sea turtle species and reproduction/nesting site for *C. caretta*, and the potential impact of anthropogenic threats on their populations, these data suggest that there is an urgent need to implement conservation actions. Many anthropogenic threats to sea turtles were documented, mainly incidental capture in fisheries and marine debris, identifying the possible hotspots for these threats in the regions of Sepetiba and Guanabara Bays, Cabo Frio, and São Francisco de Itabapoana. Pollution may also be an indirect threat, negatively affecting these animals through reduced health and immune suppression, which leaves them more susceptible to opportunistic diseases, such as FP.

Many strategies can be adopted to reduce bycatch and mortality of sea turtles in different fishing gear: formal constraints through laws, regulations, and policies with effective enforcement; multilateral accords; avoiding bycatch hotspots through fleet communication programmes and/or area and seasonal closures; best practices for handling and releasing bycatch animals; changes in gear designs, materials, and fishing methods; eco-labelling; industry self-policing; and raising awareness and capacity-building (Eayrs, 2007; Gilman, 2009; Gilman et al., 2010; Gilman, Dalzell, & Martin, 2006). Successful management of marine debris requires collaboration of public and industrial sectors, with emphasis on education and behavioural changes based on environmental responsibility, enforceable legislation and effective penalties, innovative technologies, and proper waste management (Sheavly & Register, 2007).

Longer-term monitoring of stranded sea turtles, particularly in the southern region, is needed to better contextualize these data that are based on a single year. Long-term regular monitoring also provides a mechanism for assessing changes in threats and mortality factors, and would provide insight into population trends and possible population responses to conservation actions. We strongly recommend that monitoring continue for stranded sea turtles in Rio de Janeiro, and that data collected from all regions of the state be integrated into comprehensive analyses.

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APPENDIX 1

Categories of contributing factors of sea turtle mortality.

Mortality contributing factor	Description
Marine debris ingestion	Presence of marine debris in the gastrointestinal tract, causing partial or total obstruction and/or perforations or non-perforated ulcers, consequently compromising the health of the animals.
Boat collision	Presence of multiple linear and parallel lacerations and/or fractures that penetrate the skin, coelomic cavity, or skull.
Interaction with oil	Presence of oil adhered to the skin or in the gastrointestinal tract.
Interaction with fishing gear (Castilhos et al., 2014; Goldberg et al., 2013)	A) Total evidence: entangled animals, marks of nets around flippers or neck; and/or presence of fishing gear, such as net pieces, ropes, leads, fishing lines, or hooks. The fishing activities responsible for the incidental capture were identified according to Monteiro et al. (2016), assuming: (i) turtles found with large hooks in the beak, oral cavity, internally or elsewhere on the body and/or with pieces of the main or branch lines around their flippers were classified as longline interactions; (ii) turtles found entangled in gillnets, or found with pieces of monofilament net around the head, flippers, or carapace were classified as gillnet interactions; (iii) turtles with pieces of ropes around their flippers, head, or carapace were classified as trawl fisheries interactions, because trawl fisherman use ropes to move heavy turtles from deck back to the sea; (iv) turtles found with smaller hooks and/or pieces of lines used by hook-and-line fishery trapped in any part of the body and/or gastrointestinal tract were classified as recreational fishery interactions. B) Very strong evidence: animals that were found with intentional lesions, such as amputations and/or decapitation by knives or other sharp objects, as well as turtles with the carapace separated from the plastron, used for meat consumption and/or forced submersion of the carcass. C) Strong evidence: Animals found with good body condition, based upon the subcutaneous and visceral adipose tissue and musculature, or reproductively active female, based on the presence of eggs in their oviducts, with no other apparent cause of stranding/death.
Interaction with dredging operations (Goldberg et al., 2015)	Animals with blunt traumas, usually with extensive fractures, crushed tissues, lacerations, and amputations, found in areas with active or recent dredge projects.
Fractures of unknown origin	Animals with fractures, traumas, and/or injuries without evidence of interaction with boats, dredgers, or natural predation, and the origin of such traumas are not recognized. Healed fractures or injuries are also included here.

(Continues)

Mortality contributing factor	Description
Fibropapillomatosis (Foley et al., 2005)	Contagious infectious disease with a multifactorial aetiology caused by a herpes virus and associated with factors such as environmental variations. It is characterized by the presence of multiple cutaneous tumours and occasional internal tumours ones, which may interfere with the animal's behaviour and its immune system.
Endoparasites	Animals with parasites in the viscera, which were counted in classes of infestation (low, moderate, or high endoparasitic loads), compromising their health. Parasite taxonomic analysis was not performed.
Natural predation (Chaloupka et al., 2008)	Animals that have had recent evidence of traumatic amputation of body parts with irregular abrasions or tooth marks (i.e. semicircular ablation) in the carapace and/or flippers.
Diseases and health complications due to natural causes (except fibropapillomatosis and endoparasites)	Sick animals, in an emaciated state, with clear signs of sickness and weakness linked to chronic illnesses, with no discernible relation to human activities.

APPENDIX 2

Mortality contributing factors rates, detailed in: apparent gastrointestinal damage associated to marine debris ingestion; evidence of interaction with fishing gear; fibropapillomatosis tumour location; and endoparasitic load for stranded sea turtles, per species and total, along the coast of Rio de Janeiro state, between 2010 and 2017.

Mortality contributing factor		Number of specimens					
		Caretta caretta	*Chelonia mydas*	*Dermochelys coriacea*	*Eretmochelys imbricata*	*Lepidochelys olivacea*	Total
Marine debris ingestion	No apparent injury	19	252	2	2	0	275
	Faecaloma	1	82	1	1	0	85
	Partial obstruction	0	4	0	0	0	4
	Total obstruction	1	7	0	0	0	8
	Haemorrhagic lesions	0	3	0	0	0	3
	Perforated ulcers	1	8	0	0	0	9
	Non-perforated ulcers	0	9	1	0	0	10
	Faecaloma + partial obstruction	0	3	0	0	0	3
	Faecaloma + total obstruction	0	22	0	0	0	22
	Faecaloma + haemorrhagic lesions	1	14	0	0	0	15
	Faecaloma + perforated ulcers	1	1	0	1	0	3
	Faecaloma + non-perforated ulcers	0	18	0	0	0	18
	Faecaloma + total obstruction + perforated ulcers	0	2	0	0	0	2
	Faecaloma + total obstruction + non-perforated ulcers	0	6	0	0	0	6
	Faecaloma + haemorrhagic lesions + non-perforated ulcers	0	3	0	0	0	3
	Partial obstruction + haemorrhagic lesions	0	0	0	1	0	1
	Partial obstruction + non-perforated ulcers	0	1	0	0	0	1
	Total obstruction + perforated ulcers	0	0	0	0	0	0
	Total obstruction + non-perforated ulcers	0	2	0	0	0	2

(Continues)

Mortality contributing factor		Number of specimens					
		Caretta caretta	*Chelonia mydas*	*Dermochelys coriacea*	*Eretmochelys imbricata*	*Lepidochelys olivacea*	Total
	Haemorrhagic lesions + non-perforated ulcers	0	2	0	0	0	2
	Not determined	0	3	0	0	0	3
	TOTAL	24	442	4	5	0	475
Boat collision		3	46	0	0	1	50
Interaction with oil		0	4	0	0	1	5
Interaction with fishing gear	Total evidence	89	500	5	3	7	604
	Very strong evidence	2	11	0	0	0	13
	Strong evidence	35	181	0	3	5	224
	TOTAL	126	692	5	6	12	841
Fractures of unknown origin		2	54	0	0	0	56
Natural predation		2	5	0	1	0	8
Fibropapillomatosis tumour location	Eyes	0	68	0	0	0	68
	Viscera	0	3	0	0	0	3
	Eyes + viscera	0	1	0	0	0	1
	Other parts of the body	0	244	0	0	0	244
	Not determined	0	56	0	0	0	56
	TOTAL	0	372	0	0	0	372
Diseases		14	540	3	11	7	575
Endoparasitic load	Low	3	87	0	1	0	91
	Moderate	6	68	1	0	0	75
	High	7	101	0	0	0	108
	Not determined	32	331	1	0	3	367
	TOTAL	48	587	2	1	3	641