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Assessment of the ingestion of anthropogenic debris by green turtles along the south-central coast of Rio de Janeiro, Brazil

Beatriz Guimarães Gomes[1,2*], Suzana Machado Guimarães[2], Alícia Bertoloto Tagliolatto[2], Estéfane Cardinot Reis[2], Bruno Pereira Masi[3], Fábio Vieira de Araújo[1,4]

[1] Programa de Pós-graduação em Biologia Marinha e Ambientes Costeiros – Universidade Federal Fluminense (Niterói – RJ – Brazil).
[2] Projeto Aruanã – Tartarugas Marinhas da Guanabara – Instituto de Pesquisas Ambientais Littoralis (Niterói – RJ – Brazil).
[3] Instituto Socioambiental e dos Recursos Hídricos – Universidade Federal Rural da Amazônia (Belém – PA – Brazil).
[4] Universidade do Estado do Rio de Janeiro – Faculdade de Formação de Professores (São Gonçalo – RJ – Brazil).

* Corresponding author: beatrizggomes20@gmail.com

ABSTRACT

Among the various forms of pollution, anthropogenic debris has been widely documented to cause entanglement and premature death of sea turtles, in addition to being ingested by these animals. One of the most affected species is the green turtle, which is commonly found along the south-central coast of Rio de Janeiro (RJ), an area characterized by high human population density. This study aimed to assess the impact of anthropogenic debris on green turtles by analyzing the gastrointestinal tracts of 66 individuals stranded along the south-central coast of RJ, as documented by the Santos Basin Beach Monitoring Project. Pieces of debris (1,683 in total) were found in 69.7% of the individuals analyzed, with the highest concentration observed in the large intestine. The most common types of debris were flexible plastic waste (50.5%; 850 items) and amber/brown debris (36.5%; 614 items) within the size range of 0.5 mm to 2.5 cm (41.2%; 693 items). No significant differences in debris composition were observed between turtles encountered inside and outside the bays. The substantial number of individuals with debris in their gastrointestinal tract underscores the severity of the impact of these debris on sea turtles in this region.

Keywords: Bays, *Chelonia mydas*, Marine debris, Plastic, Pollution

INTRODUCTION

In recent decades, there has been an increase in the number of studies investigating the ingestion of anthropogenic debris by marine fauna. Many of these studies have concluded that litter, particularly plastics, poses a significant threat to ecosystem sustainability (Laist, 1997; Derraik, 2002; Barnes et al., 2009; Browne et al., 2011; Cole et al., 2011; Moura and Vianna, 2020; Nunes et al., 2021; Santos et al., 2021). The impacts resulting from the accumulation of anthropogenic debris, including the ingestion of unnatural materials by marine fauna, are widely recognized, yet the production of such debris and their release into the environment continue to increase (Thompson et al., 2009; Rochman et al., 2013; Plastics Europe, 2019).

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In addition to ingestion, entanglement of marine species in debris such as ghost nets and plastic ropes can lead to mortality (Laist, 1997; Gall and Thompson, 2015). Among affected marine organisms, sea turtles are particularly vulnerable to these pollutants in the marine environment (Gall and Thompson, 2015; Nelms et al., 2016; Santos et al., 2020).

Five of the seven species of sea turtles are found in Brazil, including *Chelonia mydas* (green turtle), *Eretmochelys imbricata* (hawksbill turtle), *Caretta caretta* (loggerhead turtle), *Lepidochelys olivacea* (olive turtle), and *Dermochelys coriacea* (leatherback turtle) (Marcovaldi and Marcovaldi, 1999). These species use the Brazilian coast as a feeding and reproduction habitat, with the northernmost state of Rio de Janeiro representing the southern limit of nesting areas in Brazil (Marcovaldi and Marcovaldi, 1999).

Researchers have consistently reported debris ingestion across all life stages of sea turtle species (Mrosovsky et al., 2009; Schuyler et al., 2012; Kühn et al., 2015). One possible reason for ingestion is the visual similarity between debris and these turtles' natural food sources, such as macroalgae (Schuyler et al., 2014). Green turtles are susceptible to accidental ingestion because anthropogenic debris can become entangled with macroalgae, a food source for these animals (Di Beneditto et al., 2014). *Chelonia mydas* is the species with the most coastal habits (Bugoni et al. 2001; Schuyler et al., 2014; Santos et al. 2015a). As a result, they are more exposed to the impacts of human activities and are at increased risk of boat collisions, exposure to chemical and waste pollution, and accidental entanglement in fishing gear (Tagliolatto et al., 2019; Gomes et al., 2021). While green turtles primarily feed on algae and seagrass, they can exhibit opportunistic feeding behavior, adapting their diet based on food availability in their foraging areas (Mortimer, 1982; Bjorndal, 1997; Hirth, 1997; Gama et al., 2016; Esteban et al., 2020).

The south-central coast of Rio de Janeiro is characterized by the presence of large industrial enterprises, ports, urban centers, significant tourist activity, heavy boat traffic, and intense artisanal and industrial fishing activities. In addition, it is home to three different bays: Guanabara Bay; Sepetiba Bay; and Ilha Grande Bay. This region is an important feeding ground for sea turtles, which means that a significant number of individuals inhabit it (Tagliolatto et al., 2019; Gomes et al., 2021). According to Katsanevakis et al. (2007), bays generally have a higher abundance of marine litter compared with open coastal areas. In addition, larger debris are more common in bays than in open areas (Rakib et al., 2022), which tend to have a higher prevalence of fragmented debris (Povoa et al., 2022).

This study aimed to evaluate the presence of anthropogenic debris in the gastrointestinal contents of green turtles found dead on the south-central coast of the state of Rio de Janeiro. The types, colors and sizes of debris most commonly found in the digestive tracts of the dead stranded animals in the region were assessed, comparing more polluted (inside bays) and less polluted (outside bays) stranding sites. The hypothesis tested was that turtles found dead inside the bays would have ingested greater quantities and larger pieces of anthropogenic debris than those found outside the bays. Therefore, evaluating the ingestion of anthropogenic debris by sea turtles in feeding areas, such as the coast of Rio de Janeiro, is crucial for obtaining information on the impact of debris on sea turtle populations. Furthermore, this information can contribute to population management and conservation efforts for these species (Bjorndal, 2000).

METHODS

Study area

The municipalities that make up the south-central region of the state of Rio de Janeiro and that were specifically considered in this study are: Paraty; Angra dos Reis; Mangaratiba; Itaguaí (southern region); Rio de Janeiro; Duque de Caxias; Magé; Guapimirim; Itaboraí; São Gonçalo; Niterói; Maricá; and Saquarema (central region). The Guanabara, Sepetiba, and Ilha Grande Bays are located within this area (Figure 1). These municipalities are part of the Santos Basin Beach Monitoring Project (BMP-SB) activity area in the state of Rio de Janeiro (up to Praia da Vila, in Saquarema). This project is an environmental requirement for Petrobras, the main Brazilian oil and gas company operating along the coast of Brazil. The main objective of the BMP-SB is to record stranded marine animals, especially turtles, mammals, and seabirds, and to investigate a possible correlation between their stranding and the activities carried out in the region (Werneck et al., 2018).

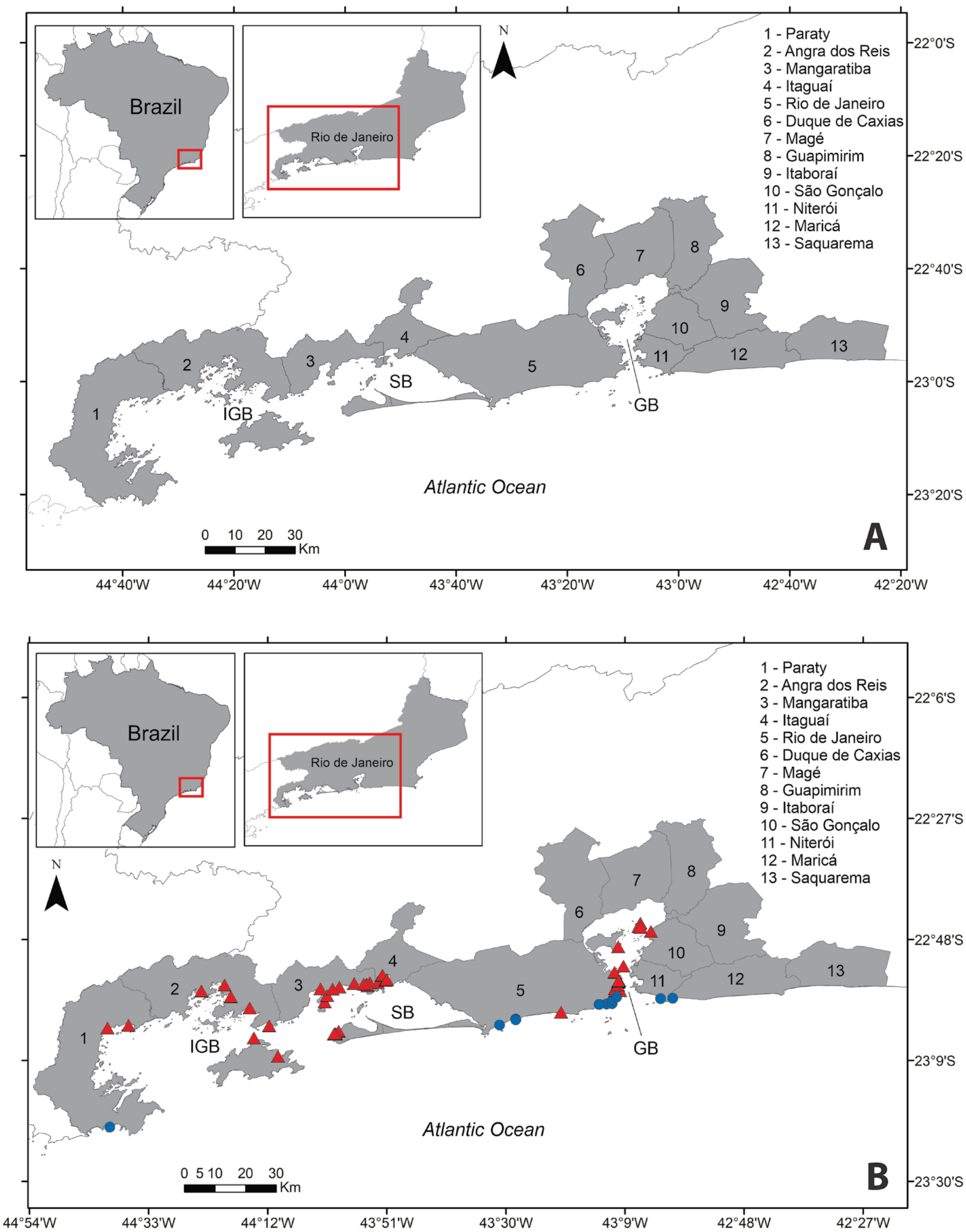

Figure 1. (A) Municipalities in the state of Rio de Janeiro that are covered by the Santos Basin Beach Monitoring Project (BMP-SB). IGB: Ilha Grande Bay; SB: Sepetiba Bay; GB: Guanabara Bay. (B) Locations of green turtle strandings analyzed for gastrointestinal contents inside the bays (red) (n = 53) and outside the bays (blue) (n = 13) on the south-central coast of the state of Rio de Janeiro.

Data and sample collection

Data and samples for this study were collected from the companies involved in the Santos Basin Beach Monitoring Project (BMP-SB), specifically CTA – Serviços em Meio Ambiente and Econservation – Estudos e Projetos Ambientais, from May 2019 to March 2021 in the state of Rio de Janeiro. However, due to the COVID-19 pandemic, no animals were recorded from April to June 2020.

The gastrointestinal tract (GIT) contents of *Chelonia mydas* were collected either directly by the Projeto Aruanã team at the headquarters in the city of Rio de Janeiro or by the veterinary team and later sent to the project headquarters in Rio de Janeiro and Angra dos Reis. Only individuals in a stage of decomposition up to code 3, moderately decomposed but with an intact carcass (Werneck et al., 2018), were selected for content analysis, as most of the GIT organs were still intact. Data collected included stranding location (latitude, longitude, city name, and beach name), carcass decomposition stage, and curvilinear carapace length and width (in cm) (CCL and CCW). All data on individuals collected by the BMP-SB are publicly available in the Aquatic Biota Information System (SIMBA).

Processing, storage, and screening of GIT contents

The GIT was completely removed and sealed using bindings at both ends. Each organ (esophagus, stomach, small intestine, and large intestine) was then weighed separately (in grams) while still wet. The contents of each organ were then extracted and stored in glass jars filled with 92.8° alcohol, with proper identification. The organs were subsequently weighed individually without their gastrointestinal contents. To determine the weight of the contents, present in each organ, the weight of the empty organ was subtracted from the weight of the organ with the contents.

A 1 mm (millimeter) mesh sieve was used to examine the GIT contents. All contents were washed under running water to separate food contents from anthropogenic debris. The debris were then weighed using a digital scale (accurate to 1 g), quantified, and categorized based on material type (e.g., soft plastic, rigid plastic, line/rope, Styrofoam, rubber, foam, and pellets), color (e.g., amber/brown, white, blue, translucent, black, green, yellow, red, gray, orange, pink, and purple)—based on visual observation—, and size (micro $<$ 0.5 mm, meso from 0.5 mm to 2.5 cm, and macro $>$ 2.5 cm) according to the classification by Kershaw et al. (2019).

Data analyses

The frequency of occurrence (%) of each of the categories examined was calculated using the equation $FO = (N \times 100) / NT$, in which N represents the number of times an item of a specific category was present in the contents of an organ, and NT represents the total number of debris found in all individuals that ingested debris.

First, differences in the total number of debris ingested inside and outside the bays were tested using Welch's two-sample t-test. Differences between types, sizes, and colors of debris found in dead turtles were tested separately for each category using Analysis of Variance (ANOVA), followed by Tukey's multiple comparisons of means at a 95% family-wise confidence level. The data were used to generate a resemblance matrix using the Bray-Curtis coefficient, and multivariate analysis was conducted according to Clarke et al. (2014). Multi-Dimensional Scaling (MDS) was used to represent the turtles, with data subjected to square root transformation and Wisconsin double standardization. Permutational Multivariate Analysis of Variance (adonis) under a reduced model was used to verify significant differences between groups using 999 permutations. The Similarity Percentages (SIMPER) routine tabulated factors' contributions to the average similarity of samples within each group and the average dissimilarity between all pairs of groups, with a cut-off of 70% cumulative contribution. Statistical analyses were performed using the R statistical program (version 3.1.1, R Core Team, 2021) with the vegan package (Oksanen et al., 2014) for multivariate techniques.

RESULTS

From May 2019 to March 2021, a total of 1,616 sea turtles were collected between Paraty and Praia da Vila (Saquarema), of which 1,376 individuals belonged to the species *Chelonia mydas*. Among these, 66 individuals, collected in the Angra and Rio de Janeiro headquarters, were subjected to analysis of composition of gastrointestinal contents. Regarding the decomposition stage of the analyzed turtles, 19 (28.78%) were classified as code 2, 46 (69.69%) as code 3, and one (1.51%) as code 4. Although the analyses were performed on individuals up to code 3, one code 4 individual was included in the study because its entire GIT contents were preserved. The analyzed individuals had curvilinear carapace lengths ranging from 30 cm to 76.3 cm (mean ± SD: 76.8 cm ± 8.5 cm). Upon examining the GIT contents of each turtle, a total of 1,683 anthropogenic debris items were counted. In total, 46 turtles (69.7%) had at least one item of anthropogenic debris, while 20 individuals (30.3%) had no pieces of anthropogenic debris. Of the 20 individuals that did not ingest debris, 18 were found inside bays and two were found outside bays.

The organ in which the majority of anthropogenic debris items were found was the large intestine, accounting for 83% (n = 1,390 items) of the total items found, followed by the stomach (8%; n = 139 items), small intestine (6%; n = 108 items), and esophagus (3%; n = 46 items). Of the 46 sea turtles with waste in their GIT contents, debris was found in the large intestine of 37 individuals (80.4%), in the esophagus of 16 individuals (34.8%), and in the stomach and small intestine of 15 individuals each (32.6% each).

Number of ingested debris items

The results showed that there was no significant difference in the number of debris items between turtles found inside and outside bays ($t = 0.34949$, $df = 60.529$, $p > 0.05$). Although there was no significant difference, a higher number of items was observed in the GIT contents of turtles found inside bays (n = 1,388 items) than in the GIT contents of turtles found outside bays (n = 295 items).

Type of ingested debris

There was a significant difference between the types of debris found in the dead turtles ($F = 7.027$, $p < 0.05$; ANOVA). Tukey's multiple comparisons of means showed that soft plastic differed significantly from the other types of debris ($p < 0.05$), except for line/rope ($p > 0.05$).

Soft plastic was the most commonly ingested item by the animals analyzed in this study (Figures 2 and 3), accounting for 50.5% of the total items (n = 850), followed by line/rope (28.5%, n = 479 items), hard plastic (12.7%; n = 214 items), Styrofoam (5.8%; n = 97 items), rubber (1.7%; n = 28 items), foam (0.8%; n = 13 items), and pellets (0.1%; n = 2 items). The most common types of debris found in the 46 turtles that ingested debris were: soft plastic and line/rope (found in 38 individuals, 82.6%); hard plastic (26 individuals, 56.5%); Styrofoam (11 individuals, 23.9%); rubber (10 individuals, 21.7%); pellets (2 individuals, 4.3%); and foam (2 individuals, 4.3%).

There was no significant difference in terms of debris types between the regions inside and outside the bays ($R2 = 0.02428$, $F = 1.0947$, $p > 0.05$). Soft plastic accounted for 41.23% of the difference between regions, while line/rope accounted for 37.95% of this difference (79.18% cumulative contribution). Inside the bays, soft plastic was the most common debris type, accounting for 52% of items (722 of 1,388 items), while outside the bays, line/rope accounted for 48.8% of items (144 of 295 items) (Table 1).

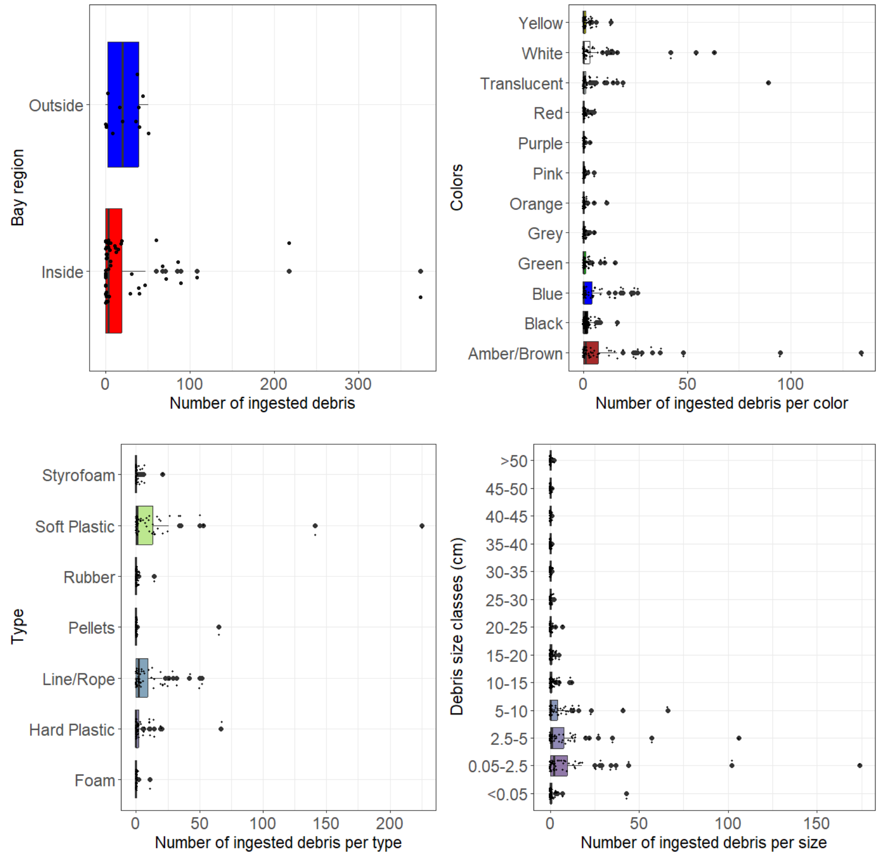

Figure 2. Number of ingested debris inside and outside bays on the south-central coast of the state of Rio de Janeiro (A); number of ingested debris per color (B), type (C), and size (D). The plots show the median, interquartile range, minimum, maximum, and outliers. Individual observations are represented by small dots over the boxes.

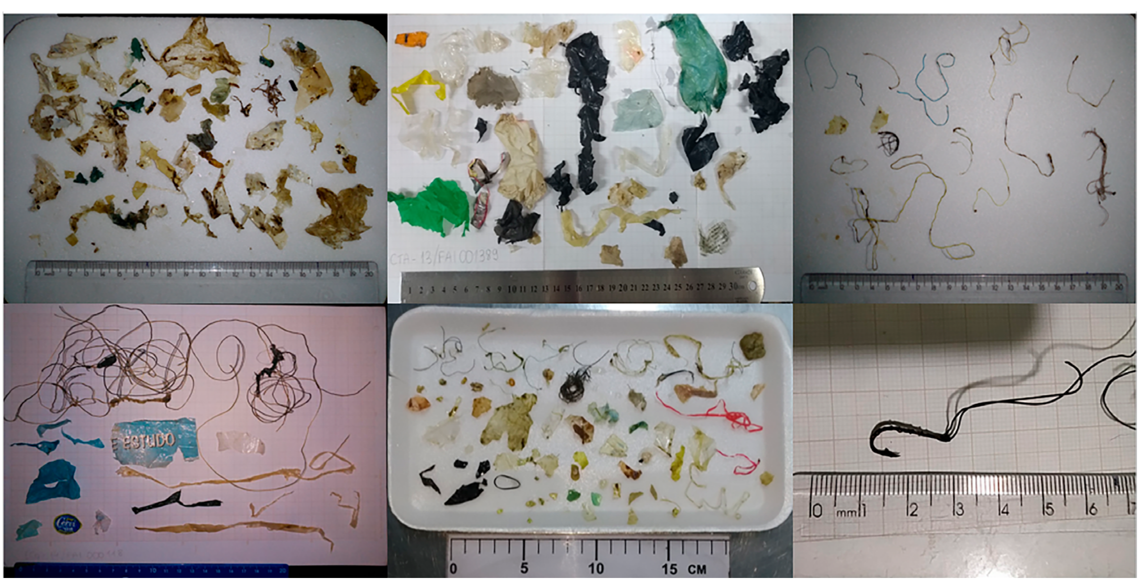

Figure 3. Different types, colors and sizes of anthropogenic debris found in the gastrointestinal contents of green turtles stranded on the south-central coast of the state of Rio de Janeiro.

Table 1. Percentage of anthropogenic debris (by organ, type, color, and size [n = 1,683 items]) ingested by turtles found inside and outside bays on the south-central coast of the state of Rio de Janeiro.

			Stranding location	
			Inside bays (n = 53) (%)	**Outside bays (n = 13) (%)**
No. of debris found in each organ		Esophagus	1.5	8.8
		Stomach	7.6	11.2
		Small Intestine	3.0	22.0
		Large Intestine	87.8	58.0
No. of items ingested by debris type		Hard Plastic	13.2	10.5
		Soft Plastic	52.0	36.3
		Line/Rope	24.1	48.8
		Styrofoam	3.3	2.4
		Pellets	4.8	0.0
		Foam	0.9	0.0
		Rubber	1.6	2.0
No. of items ingested by debris color		Blue	12.2	21.0
		Green	4.4	5.8
		Red	1.7	1.4
		Yellow	4.0	6.4
		Orange	1.5	0.3
		Purple	0.3	0.0
		Pink	0.6	0.3
		Grey	1.6	1.4
		Black	5.0	8.1
		White	18.8	14.6
		Translucent	13.8	3.1
		Amber/Brown	36.2	37.6
No. of items ingested by debris size	MICRO	< 0.05 cm	5.3	1.7
	MESO	0.05-2.5 cm	41.2	41.0
	MACRO	2.5-5 cm	26.2	30.2
		5-10 cm	18.0	15.9
		10-15 cm	4.5	7.1
		15-20 cm	2.1	3.4
		20-25 cm	1.1	0.3
		25-30 cm	0.4	0.3
		30-35 cm	0.2	0.0
		35-40 cm	0.2	0.0
		40-45 cm	0.1	0.0
		45-50 cm	0.2	0.0
		>50 cm	0.3	0.0

Colors of ingested debris

Significant differences (F-value = 7.226, $p < 0.05$; ANOVA) were observed in the colors of debris items found in the dead turtles. Tukey's multiple comparisons of means revealed that amber/brown was significantly different from other colors. Among the anthropogenic debris items found in the turtles' GIT, amber/brown was the predominant color, accounting for 36.2% of items (Table 1).

No significant differences were found when analyzing the debris colors in the GIT contents of the dead turtles between the regions inside and outside the bays (R2 = 0.02367, F = 1.0669, $p > 0.05$). The debris colors with the most contributions to the difference between the groups were: amber/brown, with 30.83%; blue, with 18.45%; white, with 16.01%; and black, with 8.02%. There were more color restrictions outside the bays. The debris items found in turtles outside the bays represented a subset of the debris items found in turtles inside the bays (Figure 4).

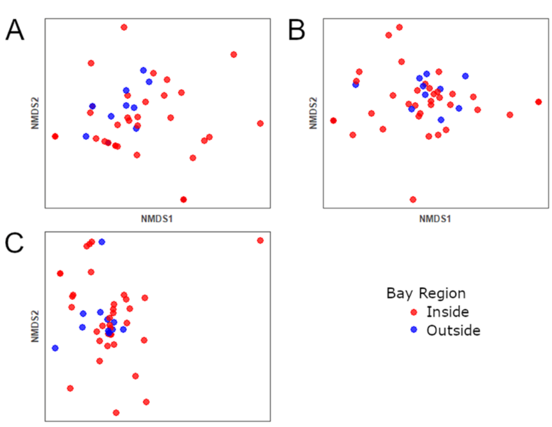

Figure 4. Non-metric multidimensional scaling (NMDS) computed for the samples from inside and outside bays of the south-central coast of the state of Rio de Janeiro, using the Bray-Curtis similarity matrix of the number of ingested debris per type (A; stress = 0.13), color (B; stress = 0.15), and size (C; stress = 0.13).

Size of ingested debris items

There was a significant difference between the size classes of the debris items found in the dead turtles (F = 8.939, $p < 0.05$; ANOVA). Tukey's multiple comparisons of means revealed that the < 0.05 cm size class was significantly different from both the 0.05 - 2.5 cm class ($p < 0.05$) and the 2.5 – 5 cm class ($p < 0.05$). The 0.05 - 2.5 cm class was significantly different from most other classes, except for the 2.5 – 5 cm class ($p > 0.05$). The 2.5 – 5 cm class was not significantly different from the 0.05 - 2.5 class ($p > 0.05$) and the 5 – 10 cm class ($p > 0.05$). The 0.05 - 2.5 cm and 2.5 - 5 cm classes had the highest percentages of debris found (Figure 2).

The hypothesis that dead turtles found inside the bays would have ingested larger anthropogenic debris items than those found outside the bays was not supported (R2 = 0.04351, F = 2.0013, $p > 0.05$). Despite the lack of a significant difference between the groups, the 0.5 mm - 2.5 cm class contributed 37.32% to the difference between items found in turtles inside and outside the bays, and the 2.5 - 5 cm and 5 - 10 cm classes contributed 27.33% and 16.95% to this difference (79% cumulative contribution), respectively.

DISCUSSION

The results of this study showed that 69.7% of the green turtles analyzed had ingested at least one solid debris item. Similar findings have been reported in other recent studies, including those by Guebert-Bartholo et al. (2011), who found solid debris items in 69.7% of dead turtles analyzed in the Paranaguá Estuary; Santos et al. (2015b) who found solid debris items in 70.6% of dead turtles collected along the Brazilian coast; and Velez-Rubio et al. (2018), who found solid debris items in 70% of dead turtles in Uruguayan waters. This high frequency of anthropogenic debris ingestion (> 50%) by green turtles has also been observed in several other regions worldwide, such as the United States, Australia, and Uruguay (Bjorndal et al., 1994; Bugoni et al., 2001; Boyle and Limpus, 2008; Tourinho et al., 2010; Guebert-Bartholo et al., 2011; Macedo et al., 2011; Vélez-Rubio et al., 2018).

The individuals analyzed had a curvilinear carapace length (CCL) ranging from 30 cm to 76.3 cm (mean ± SD: 76.8 ± 8.5 cm), which indicates that they were juvenile turtles (Bjorndal, 1997; Santos et al., 2011; Colman et al., 2014). As juvenile green turtles begin to use coastal regions, their dietary habits change from omnivory to herbivory. However, depending on the availability of food sources in the environment, they may also opportunistically feed on other available resources (Mortimer, 1982; Bjorndal, 1997; Hirth, 1997). This opportunistic foraging behavior may influence the ingestion of anthropogenic debris (Santos et al., 2015b; Andrades et al., 2019; Santos et al., 2020).

Bjorndal et al. (1994) showed that 56% of sea turtles examined had ingested debris when their entire digestive tract was analyzed, compared to only 14% when the analysis was limited to the esophagus and stomach. In this study, we examined all organs of the GIT and found that the large intestine had the highest number of debris, containing 83% of the total items found. These findings highlight the importance of analyzing all organs of the GIT to avoid underestimating the number of debris items ingested. Studies that focused only on the stomach showed lower percentages of debris ingestion, such as 25% and 45% (Mendes et al., 2015; Ng et al., 2016). On the other hand, studies that analyzed all organs of the digestive tract registered higher percentages of ingestion, such as 85.7% and 70% (Vélez-Rubio et al., 2018; Yaghmour et al., 2018), with the large intestine being the organ with the highest concentration of debris. One possible explanation for the high occurrence of debris in the large intestine is its curvature, which causes debris to remain longer in the animal's digestive tract (Schulman and Lutz, 1992).

There was no significant difference between the total number of items ingested by turtles found inside and outside the bays. However, a higher number of items was observed in the GIT contents of turtles from inside the bays. Furthermore, among all the variables analyzed, it was observed that the type, color, and size of the debris items found outside the bays were a subset of the debris items found in turtles collected inside the bays. This observation can be explained by the fact that areas within bays tend to have a higher accumulation of waste compared with open sea areas, likely due to improper disposal by the local population, hydrodynamics, and, consequently, the residence time and availability of debris in the environment (Neto and Fonseca, 2011; Macedo et al., 2019; Silva et al., 2020). In addition, in areas with less debris in the water, turtles are less likely to encounter and ingest such debris (Santos et al., 2021). Moreover, this study identified a greater number of stranded and dead turtles inside bays. The stranding location does not always reflect the animal's foraging site, as a turtle may have fed outside the bay and entered it already dead or dying. Therefore, further investigation is needed to verify residence patterns for better inference (Tagliolatto et al., 2019).

The south-central coast of the state of Rio de Janeiro is a foraging ground for green turtles, supporting their development, growth, and feeding activities (Guimarães et al., 2009; Nunes, 2016; Guimarães et al., 2017; Reis et al., 2017; Gomes et al., 2021). The presence of debris in foraging areas increases the likelihood of accidental ingestion of anthropogenic waste (Sigler, 2014). Gonzalez-Carman et al. (2014) documented a high frequency of anthropogenic debris ingestion by turtles in feeding areas characterized by a high abundance of juvenile green turtles overlapped with elevated concentrations of marine plastic debris. The accumulation of debris in the marine environment promotes the distribution of these waste materials to the foraging grounds of marine organisms. The increase in ingestion records follows an increase in the concentration of debris in the ocean, which is a trend observed over the years (Williams et al., 2011). These residues are found both suspended in the water column and on the seafloor, and both habitats are used by green turtles (Schuyler et al., 2014).

Given that sea turtles forage by sight and smell, the high frequency of ingestion of anthropogenic debris such as soft plastics has been linked to its similarity to the natural food of these animals, such as algae, seagrass, and gelatinous organisms (jellyfish, salps, and ctenophores) (Schuyler et al., 2014; Pfaller et al., 2020). Another explanation could be that these residues become attached to their food, leading to accidental ingestion (Tourinho et al., 2010; Schuyler et al., 2012; Camedda et al., 2014; Di Beneditto and Awabdi, 2014; Hoarau et al., 2014; Rizzi et al., 2019). Santos et al. (2021) addressed debris ingestion as an example of an evolutionary trap, defined as a sub-optimal choice made by organisms following a decision rule shaped by natural selection. Another factor that may contribute to the ingestion of these materials is the presence of microbial biofilm on plastic debris, which may attract sea turtles (Reisser et al., 2014; Pfaller et al., 2020). The long-term persistence of debris in the marine environment, which prevents it from decomposing and allows it to remain intact while floating in water bodies, promotes the formation of these biofilms (De-la-Torre et al., 2021).

The types of debris found in the GIT of the turtles analyzed in this study support the findings of previous studies on residues along the Brazilian coast (Bernardino and Franz, 2016; Ferreira et al., 2011; Macedo et al., 2017; Macedo et al., 2019), with plastics (soft and hard) being the most commonly found debris type, followed by Styrofoam, nylon, and rope. A study carried out in southern Brazil showed that 23 of 38 sea turtles examined (60.5%) had anthropogenic debris in their stomachs, likely from fishing and tourist activities on the beaches of the region (Bugoni et al., 2001). The higher prevalence of soft plastics in areas within the bays may explain the higher proportion (50.5% of the total) of debris items of this type, such as plastic bags, found in the analyzed individuals. Among the types of anthropogenic debris affecting marine animals, plastic is the most frequently reported in sea turtles (Balazs, 1985; Plotkin and Amos, 1990; Sadove and Morreale, 1990; Shaver, 1991; Bjorndal et al., 1994; Bugoni et al., 2001; Mascarenhas et al., 2004; Campani et al., 2013; Camedda et al., 2014; Poli et al., 2015; Santos et al., 2015b; Abreo et al., 2016), as observed in this study.

Amber/brown debris was found to be the most ingested (36.2%). The high frequency of amber debris in the GIT of the sampled organisms can be explained by the fact that this color closely resembles that of natural food sources. In addition, the amber color is a result of the aging of plastics in the marine environment, which indicates that the ingested waste may have been available in this environment for a long time, making it more likely to be ingested by marine organisms. Swimmer et al. (2005) conducted an experiment with dyed squid and demonstrated that sea turtles are capable of distinguishing colors, which influences their food selection behavior. Santos et al. (2016) found that the color of plastic debris affects its detection by animals, with white or transparent items being the most commonly consumed (Tourinho et al., 2010; Schuyler et al., 2012; Camedda et al., 2014; Hoarau et al., 2014; Rizzi et al., 2019). In the case of debris with less influential colors, such as gray, orange, pink, purple, and red, it is possible that ingestion occurred accidentally, as these items may have been consumed along with the turtle's natural food sources (Tomas et al., 2002; Mendes et al., 2015). Furthermore, red and orange colored items fall within the longer visible light spectrum (560-700 nm) for turtles, which ranges from 450 nm to 620 nm (Bartol and Musick, 2003).

The debris size class with the highest frequency was in the range of 0.05 cm to 2.5 cm (41.2%). Similar results were observed by Gonzalez-Carman et al. (2014), who found debris ranging in size from 0.5 to 3.0 cm, and by Mendes et al. (2015), who showed that 76% of the residues found were in the range of 0 to 5 cm. The high consumption of these residues can be attributed to the prevalence of fragmented items in the marine environment, which result from mechanical abrasion by waves and photochemical breakage due to prolonged residence time in the ocean (Corcoran et al., 2009; Wabnitz and Nichols, 2010; Possatto et al., 2011; Andrady, 2015). Micro debris items were the least common in the GIT of the turtles studied. Due to their relatively small size, these items may have been passively ingested rather than resulted from active selection, as they are associated with natural food sources (Tomas et al., 2002; Di Beneditto and Awabdi, 2014; Mendes et al., 2015). This also explains why the hypothesis that turtles found dead inside bays would have ingested larger anthropogenic debris than those found outside was not supported.

The ingestion of debris poses several risks to sea turtles, including intoxication and death due to GIT obstruction (Lutz, 1990; Bjorndal et al., 1994; Bjorndal, 1997; Derraik, 2002; Koch and Calafat, 2009; Oehlmann et al., 2009; Teuten et al., 2009; Santos et al., 2015b). The consequences depend on the type, size, and number of debris ingested. Plastic debris ingested in large quantities can cause constipation. Even a small hook ingested, despite its size and weight, can cause perforation and subsequent death. Nylon threads can interfere with the functioning of the digestive tract and cause intussusception, an obstruction caused by a linear foreign body (Bjorndal et al., 1994; Orós et al., 2004). The ingestion of debris can have several negative consequences for animals. It can induce the formation of fecalomas, which are masses of hardened fecal material that obstruct the intestines of these animals. It can also create a false sense of satiety, reducing the frequency of food consumption and leading to malnutrition and cachexia (Lutz, 1990; Bjorndal et al., 1994; Bjorndal, 1997; Santos et al., 2015b). In addition, the buoyancy of turtles can be affected by the formation of gases due to the ingestion of debris and accumulation in the GIT. Ingested plastic fragments can also transfer chemicals with possible carcinogenic effects and cause endocrine disruption (Laist, 1987; Koch and Calafat, 2009; Oehlmann et al., 2009; Teuten et al., 2009).

Several studies have been carried out in southeastern Brazil to investigate the contents consumed by sea turtles. Most of these studies focused on green turtles, and all of them reported the ingestion of anthropogenic debris, including flexible and rigid plastics, rubber, foam, Styrofoam, and hooks. The debris varied in color, ranging from transparent to colorful, and in size, ranging from micro to macro classifications (Reis et al., 2010; Awabdi et al., 2013; Bezerra, 2014; Di Beneditto and Awabdi, 2014; Ferreira, 2015; Mendes et al., 2015; Santos et al., 2015b; Nunes, 2016).

CONCLUSION

The results of our study support previously published studies on green turtles in Brazil. As a novelty, we carried out a comparative analysis between more polluted areas (inside the bays) and less polluted areas (outside the bays), assessing the type, color, and size of the residues found in the GIT of the animals. This comparison aimed to understand how different classifications of debris affect animals in each region. Furthermore, this study is the first to analyze the contents in the GIT of stranded turtles collected by the BMP-SB, providing the initial data for the activities of this project on the central-south coast of the state of Rio de Janeiro.

Our results highlight the need for more quantitative studies on the ingestion of anthropogenic debris by sea turtles to assess its impact on these animals and, consequently, on the marine environment. In addition, the substantial number of debris found in the GIT of the turtles studied suggests that debris plays an important role in the mortality of sea turtles in the study area, regardless of the concentration of waste. We recommend that future research in this area use standardized methodologies for each category to facilitate comparative analysis over time. In this study, we encountered challenges in standardizing collections due to the methodology used by the BMP-SB. Furthermore, future investigations should strive to collect information at smaller geographic scales, focusing on areas where pollution from anthropogenic debris, particularly plastic, has affected sea turtles in their feeding grounds. Likewise, it is crucial to identify the primary sources of marine debris at the regional level in order to develop effective solutions for proper disposal of such debris in specific geographic areas. In addition, social media and environmental education can help local communities make more informed decisions about plastic waste disposal.

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AUTHOR CONTRIBUTIONS

B.G.G.: Conceptualization; Investigation; Writing – original draft; Writing – review & editing.

S.M.G.: Supervision; Methodology; Writing – review & editing.

A.B.T.; E.C.R.; B.P.M.: Methodology; Formal Analysis; Writing – review & editing.

F.V.A.: Supervision; Resources; Project Administration; Funding Acquisition; Writing – review & editing.

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