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Exploring microplastic contamination in Guiana dolphins (*Sotalia guianensis*): Insights into plastic pollution in the southwestern tropical Atlantic

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A R T I C L E I N F O

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A B S T R A C T

Marine mammals are considered sentinel species and may act as indicators of ocean health. Plastic residues are widely distributed in the oceans and are recognised as hazardous contaminants, and once ingested can cause several adverse effects on wildlife. This study aimed to identify and characterise plastic ingestion in the Guiana dolphins (*Sotalia guianensis*) from the Southwestern Tropical Atlantic by evaluating the stomach contents of stranded individuals through KOH digestion and identification of subsample of particles by LDIR Chemical Imaging System. Most of the individuals were contaminated, and the most common polymers identified were PU, PET and EVA. Microplastics were more prevalent than larger plastic particles (meso- and macroplastics). Smaller particles were detected during the rainy seasons. Moreover, there was a positive correlation between the stomach content mass and the number of microplastics, suggesting contamination through trophic transfer.

1. Introduction

Highlighted by their charismatic appearance and cosmopolitan distribution, marine mammals compose a diverse and heavily impacted by anthropogenic activities group (Avila et al., 2018). In addition, they play an important role in ecosystem structures and functionality due to their high trophic status and metabolic rates (Roman and McCarthy, 2010). Marine mammals are also considered sentinels species since they can act as bioindicators providing early warnings about anthropogenic impacts (Tabor and Aguirre, 2004; Bossart, 2011; Hazen et al., 2019; Fossi et al., 2020). Hunting (Hovelsrud et al., 2008), bycatch (Hamilton and Baker, 2019), hydrocarbon exploration (Gales et al., 2003; Helm et al., 2014; Bröker, 2019;), persistent organic pollutants (Hall et al., 2017), habitat degradation (Brakes and Dall, 2016), and marine litter (Panti et al., 2019) are some of the significant threats for this group. Plastic residues became a major environmental issue because of their widespread use associated with poor waste management (Worm et al., 2017; Sharma and Chatterjee, 2017), making them ubiquitous in rivers, coastal areas, and ocean basins (Borrelle et al., 2017; Morales-Caselles et al., 2021).

Once in the environment, plastic particles are classified based on their size as macroplastics (20–100 mm), mesoplastics (5–20 mm), and microplastics (1–5000 μm) (Barnes et al., 2009). Considering their abundance, small size (Betts, 2008; Ferreira et al., 2019a), and the colonisation of the particles by microorganisms (Galloway et al., 2017), microplastics (MPs) can be easily ingested by marine biota. Among cetaceans, ingestion of marine litter has been documented in at least 50

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species, representing 56 % of the diversity of this infraorder (Baulch and Perry, 2014; Kühn et al., 2015; Fossi et al., 2018; Padula et al., 2023). From the ingested material, 46 % of the composition was plastic items (Baulch and Perry, 2014). Regarding microplastic ingestion, studies are still scarce (Lusher et al., 2018; Fossi et al., 2020), which reinforces the relevance of investigating what these sentinel species can tell us about plastic pollution and its effects.

Brazil is the world's fourth largest producer of plastic waste (de Aguiar and Manning, 2020); associated with inadequate solid waste management, it may be a powerful threat to marine biota. In the Southwestern Tropical Atlantic, the Brazilian coast is home to 43 cetacean species (Instituto Chico Mendes de Conservação da Biodiversidade, 2018). Among this list, the Guiana dolphin (*Sotalia guianensis*) is a near-threatened cetacean (Secchi et al., 2018) that stands out due to its common presence on most of the Brazilian coast (Carvalho and Meirelles, 2020). This species is susceptible to several anthropogenic impacts, with a high rate of strandings (Domit et al., 2021).

The Guiana dolphin is a small cetacean that preferentially inhabits sheltered coastal and estuarine waters and port areas (Cunha et al., 2020). It has an estimated life expectancy of 30 years (Rosas and Monteiro-Filho, 2002). The basis of its diet is composed of coastal demersal fishes, cephalopods and crustaceans (Santos et al., 2002; Gurjão et al., 2003; Pansard et al., 2011). The Guiana dolphin is exposed to several anthropogenic impacts as a coastal species, especially in highly urbanised regions. Latent threats to the species are i) accidental capture in fishing nets, ii) exposure to contaminants and vessel traffic, iii) noise pollution and iv) habitat loss (Di Beneditto and Ramos, 2014; Salgado et al., 2018; Schiavetti et al., 2020). Within Brazilian waters, they are considered vulnerable to extinction (Instituto Chico Mendes de Conservação da Biodiversidade, 2018), which emphasises the need for immediate implementation of conservation actions.

Although most scientific investigations on plastic contamination in the Brazilian ecosystem (46 %) between 2009 and 2017 have focused on analyses of microplastics associated with biota (Castro et al., 2018), to our best knowledge, this species has only been investigated for larger anthropogenic debris through naked-eye inspection (Di Beneditto and Ramos, 2014; Salgado et al., 2018). Moreover, *S. guianensis* has not yet been investigated for plastic contamination by applying chemical digestion, quality assurance and quality control protocols aligned with a size detection down to the millimeter particles.

Therefore, this study aims to (i) quantify and characterise (size, shape and colour) plastic debris (from macro to microplastic) contamination in the stomachs of stranded *S. guianensis* on the Northeastern Brazilian coast (Southwestern Tropical Atlantic), (ii) evaluate whether individual's characteristics are linked to contamination and (iii) investigate seasonal variability.

2. Methods

2.1. Study area

The samples (stranded individuals) were collected along the 573 km of the Ceará state (Northeastern Brazil), which is located on the Southwestern Tropical Atlantic (Fig. 1). The Ceará state has an estimated population size of 9,240,580, with a greater concentration in its capital (Fortaleza) located on the coastal line (population size:

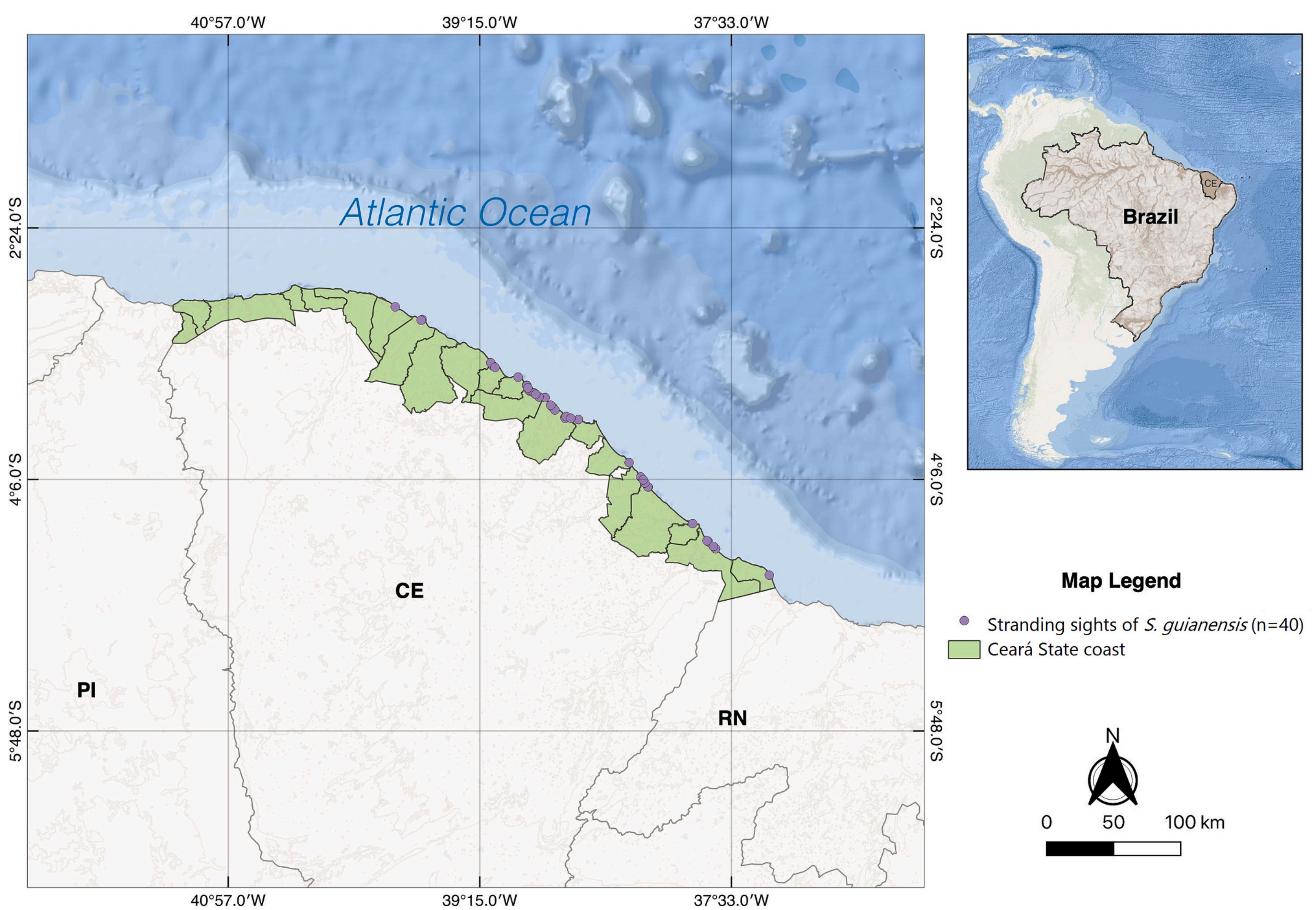

Fig. 1. Distribution of stranding sights of *S. guianensis* along the study area on the Northeastern Brazilian coast in the Tropical Southwestern Atlantic. PI (Piauí state); CE (Ceará state); RN (Rio Grande do Norte state).

2,447,409 in 2010 and 2,703,391 in 2020) and its metropolitan region (IBGE, 2021).

The study area is tropical (26 to 32 °C) and characterised by an irregular rainy season ruled by the Intertropical Convergence Zone migration, with the highest volume (90 %) of annual precipitation occurring in the first semester (January to June), whereas the second semester (July to December) is marked by the dry season combined with the presence of strong trade winds (up to 4 m/s) (Campos et al., 2003).

2.2. Sampling

During a decade, from 2011 to 2021, carcasses of *S. guianensis* were recovered (Fig. S1) during rescuing activities and beach monitoring on the coastline of Ceará state by Aquasis, a non-governmental organisation (NGO) with efforts to promote research and actions focusing on the conservation of endangered species in Ceará state (S1). Rescues were opportunistic since they depended on calls from the local community. For this study, a total of 40 individuals were used; among them, 23 were full stomachs, and 17 were stomach contents only (Table S1).

Whenever a dead individual of *S. guianensis* was found, basic information was collected for registering the stranding: geographic coordinates, date, season, total length, and stranding code according to Geraci and Lounsbury (2005) (1- alive, 2 - freshly dead, 3 – decomposed, 4 - advanced decomposition, 5 – mummified). The entire stomach or stomach contents were removed from the body cavity at the laboratory or in the field. To avoid stomach contents leaking, the oesophagus' terminal portion and the initial portion of the duodenum were tied using a cotton rope, and then the stomach was cut away using a scalpel (Pugliares et al., 2007).

Once collected, samples were stored in plastic bags and frozen (−20 °C) until further analysis. The stomach contents were stored without the stomach chambers for specimens that went through necropsy. For individuals inappropriate to undergo necropsy (Code 4), stomach or stomach contents were removed in the field using a scalpel. When the specimen was in an advanced stage of decomposition (Code 4), at least the total length was measured or estimated to access the age class of the specimen, following Rosas and Monteiro-Filho (2002), which state that individual males reach sexual maturity at 170 cm and females at 165 cm of total length.

2.3. Laboratory procedures for microplastic extraction

The protocol applied for microplastic extraction in the *S. guianensis* samples was adapted from Lusher and Hernandez-Milian (2018) and Justino et al. (2021). Firstly, samples were removed from the freezer, kept inside the bags on covered metal trays, and maintained at room temperature (30 °C) for approximately 14 h for thawing. Once thawed, the external stomach surface was rinsed with filtered (cellulose fibre filter, 8 μm pore size, Whatman GR 40) distilled water to remove any particles attached and weighed (10^{-1} g). Stomach chambers were cut off using a scalpel and were then inverted directly on the beaker. The excess attached to the mucosa was rinsed out into the beaker using filtered distilled water. When the sample had no stomach chambers and represented the stomach contents solely, they were transferred to the beaker and then weighed.

Chemical digestion was used to extract microplastic particles from the samples. Stomach contents were digested in a filtered (cellulose fibre filter, 8 μm pore size, Whatman GR 40) 10 % KOH solution (Lusher and Hernandez-Milian, 2018; Zhu et al., 2018; Moore et al., 2022) in a volume three times greater than the sample and kept in an oven (60 °C) for 24 h (Justino et al., 2021). Beakers were covered with glass lids, and the solution was mixed two times during the process, using a glass stick, to homogenise the solution. If the sample had large bone parts, such as the skull and vertebral column, they were removed from the sample after the digestion step using steel forceps.

After digestion, samples were filtrated onto a cellulose fibre filter (8 μm pore size) using a vacuum pump system. Filters were transferred to covered Petri dishes and oven-dried at 60 °C. After 24 h, the samples were observed under a stereomicroscope (Zeiss Stemi 508, using 40-50× magnification) coupled with a device camera (Axiocam 105 Colour), with a detection limit of 20 μm. Potential microplastic particles were photographed, measured (longest particle axis; Zeiss ZEN 3.2), counted, and characterised according to shape [fibres (filamentous particles), fragments (thick particles with an irregular shape), film (flat particles with an irregular shape), foam (soft particles with an irregular shape) and beads (spherical particles)] and colours in black, blue, green, red, and white (Lusher et al., 2017). Two observers conducted the inspection separately to avoid under or overestimating particles; whenever the plastic count diverged, the sample inspection was repeated.

A sub-sample of 7 % (22 particles) of the detected particles was randomly selected and had the polymer composition investigated through Laser Direct Infrared analysis (LDIR). The absorbance of the suspected microplastics was obtained using the Agilent 8700 LDIR Chemical Imaging System and compared with the reference spectra of polymers from the Microplastics Starter 1.0 library. Each spectral curve resulted from at least ten scans performed in the wavelength ranging from 1800 to 975 cm^{-1} (Ourgaud et al., 2022). Then, the specific polymer was asserted when the analysed particle registered above 60 % of similarity with the reference spectrum.

2.4. Quality assurance and quality control

During the field samplings, precautionary measurements were not implemented to avoid airborne MP contamination. However, workstations and equipment at the laboratory were cleaned with filtered 70 % ethanol to prevent contamination and rinsed out with filtered distilled water before the analysis. Additionally, the KOH solution was prepared using filtered distilled water, and the solution was also filtered before the digestion (8 μm pore size: Whatman GR 40). During laboratory procedures, 100 % cotton lab coats, facemasks, and latex gloves were worn. The use of the room where the analysis took place was restricted to two or three people involved in the procedures. In addition, a procedural blank (beaker filled with 50 ml of 10 % KOH solution) was implemented for each sample, and blanks were submitted to the same methodological steps as samples. The use of the room where the analysis took place was restricted to two or three people involved in the procedures. Contamination on blank procedures was observed on 26 out 40 filters, totalling 49 particles. Thereby, any particles matching characteristics from particles recorded on blank filters were subtracted from the correspondent sample.

2.5. Data analysis

Since the data did not meet parametric assumptions, Wilcoxon tests were applied to determine whether there were any differences in the number and size of microplastic particles detected according to the season. In addition, we tested whether the number and size of detected particles were correlated with stomach content mass (g) and total length of specimens using the Spearman correlation test. All analyses were carried out using R 3.6 (R Core Team, 2020) with a 5 % significance level.

3. Results

In total, 317 suspected plastic particles were detected in the 40 Guiana dolphins analysed (Fig. 2), with a frequency of occurrence of 95 % (38 out of 40 samples). Most of the suspected plastic particles detected were microplastics (311 particles <5 mm), while three were mesoplastics (5–20 mm), and three were macroplastics (20–100 mm). Considering the number of suspected MP particles solely, the general mean was 7.77 ± 1.25 particle individuals^{-1} (± standard error) (Fig. 3). Our results revealed that the size of detected MPs ranged from 0.018 to

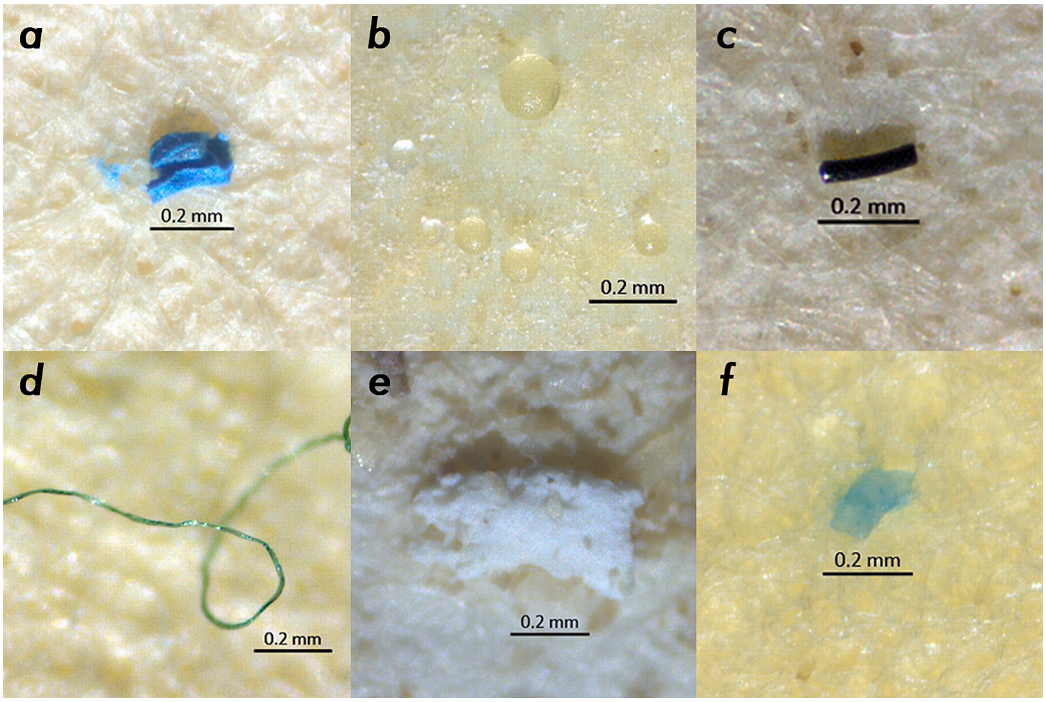

Fig. 2. Microplastic particles extracted from *S. guianensis* in the Southwestern Atlantic (a) fragment, (b) beads, (c) fragment, (d) filament, (e) foam, and (f) film.

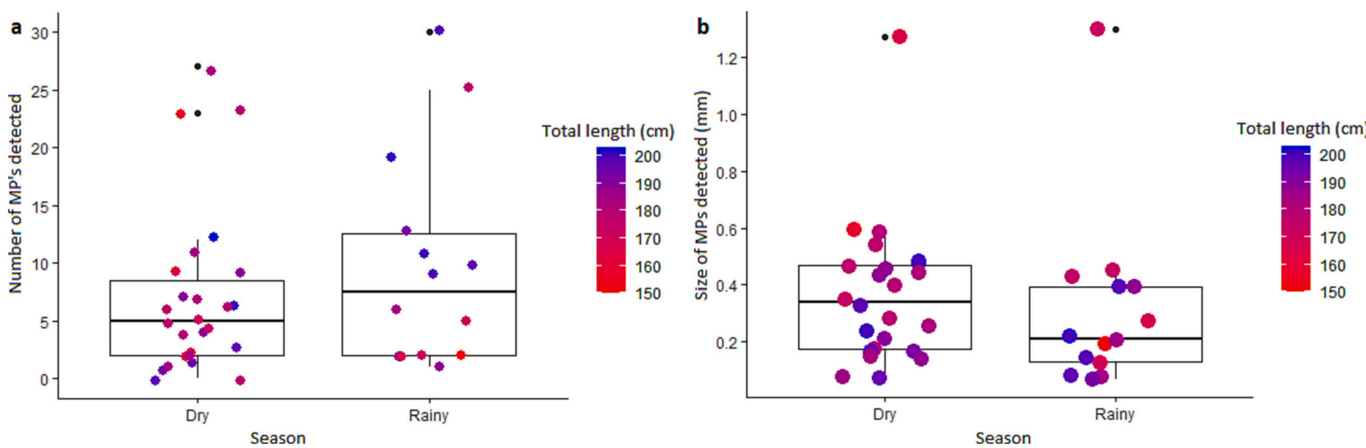

Fig. 3. (a) Number and (b) size of detected microplastics (individual^{-1}) in *S. guianensis* from the Northeastern Brazilian coast (Ceará state) in the Tropical Southwestern Atlantic, according to the seasons and individual total length.

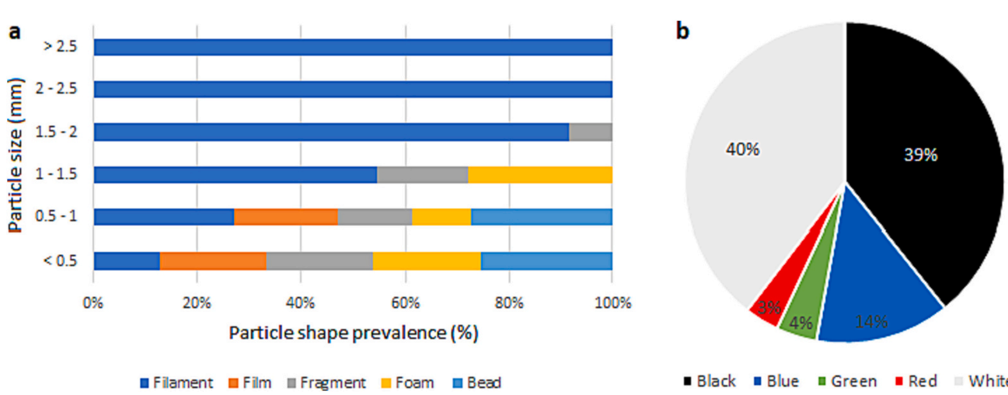

Fig. 4. (a) Size distribution of the detected microplastic shapes and (b) proportion of different colours of microplastics ingested by *S. guianensis* from the Northeastern Brazilian coast (Ceará state) in the Tropical Southwestern Atlantic.

4.24 mm, averaging 0.36 ± 0.03 mm per individual.

Regarding the number of detected particles, ingestion was not significantly different between seasons (W = 144; $p = 0.292$). Furthermore, there was no correlation between the number of suspected MPs with the dolphin's total length (Table S2). On the other hand, the particles were smaller during the rainy season (0.30 ± 0.04 mm) than in the dry season (0.40 ± 0.04 mm) (W = 13,712; $p = 0.021$) (Table S2 and Fig. 3).

The Spearman correlation analysis showed a positive moderate relationship ($\rho = 0.42$; $p = 0.006$) between the number of MPs detected and the stomach content weight (Table S3). On the other hand, there was no correlation between the number of particles detected regarding the total length of specimens ($\rho = 0.17$; $p \geq 0.05$).

Among the different suspected microplastic shapes detected in the dolphins, fragments (57.2 %) were predominant, followed by filaments (15.8 %), foam (10.3 %), films (9.6 %), and beads (7.1 %) (Fig. 4). White and black were the most abundant colour (39.5 %), followed by blue (13.2 %), green (4.2 %), and red (3.5 %) (Fig. 4).

From the analysed subsample (7 %; 22 of the 317 detected particles), 55 % (i.e. 12 particles) were successfully identified as plastic polymers, 10 % (i.e. 2 particles) were biopolymers, and 35 % (i.e. 8 particles) did not match the cutoff point (below 60 % of similarity with the reference spectra) (Fig. 5). Regarding the identified plastic polymers, polyurethane (PU), polyethylene terephthalate (PET), and ethylene-vinyl acetate (EVA) were the most prevalent (18 % each), followed by styrene-butadiene rubber (SBR), polypropylene (PP), polyamide (PA), acrylonitrile butadiene styrene (ABS) and high-density polyethylene (HDPE) (9 % each) (Fig. 5).

4. Discussion

MPs are widely distributed in different aquatic ecosystems and raise concerns about their potential as pollutants (Battaglia et al., 2020). Larger plastics might represent a greater concern when ingested by marine biota due to the cause of potential injuries and blocking of the digestive tract (Derraik, 2002). However, the smaller size fractions (MPs) represent the majority of plastic particles detected in our samples, likewise as observed by Lusher et al., 2018.

Comparison between our results for MPs with other populations of *S. guianensis* was not possible because, to our knowledge, this is the first study to document exposure to MPs in this species following up-to-date recommendations (Lusher et al., 2017; Provencher et al., 2017; Woodall et al., 2015). Two previous studies have investigated mesoplastic ingestion in this species (Di Beneditto and Ramos, 2014; Padula et al., 2023), and the frequency of occurrence of mesoplastics was comparable to our data (FO% = 5 %). In addition, Padula et al. (2023) also reported marine debris down to 1 mm through sieving but did not measure the MP particles. Moreover, to our best knowledge, there is no data available on MP contamination in small cetaceans from coastal waters of South America that would allow extrapolations for comparisons and correlations in the region. Worldwide, most studies on microplastic contamination in marine mammals were conducted on carcases stranded on European coastlines (Zantis et al., 2021). Furthermore, the sample size for each species is usually small, which can hinder comparisons and induce type II errors (Underwood et al., 2017).

Some studies have reported MP contamination in cetaceans from Europe, China, and North American coastal waters, where the number of detected particles varied greatly. While we detected 1 to 30 MPs per sample (sample size = 40; 8 μm pore size), Zhu et al. (2018) detected 2 to

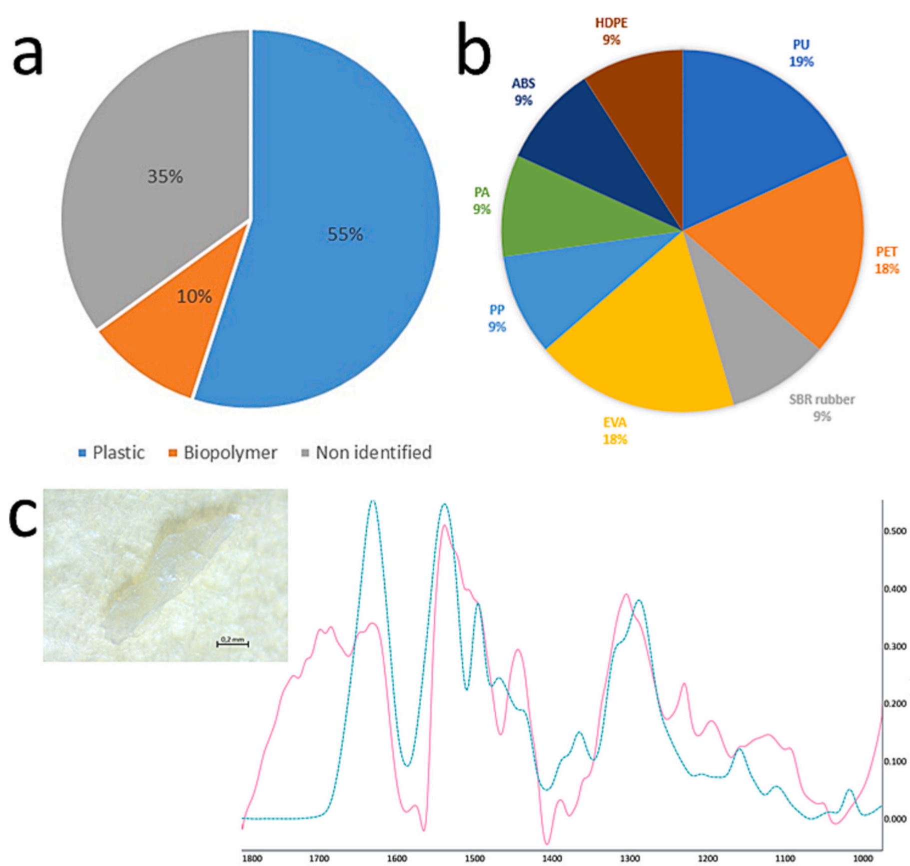

Fig. 5. Microplastic polymers extracted from *S. guianensis* identified by the LDIR analysis: (a) particle composition, (b) plastic polymers composition, (c) PA (polyamide) white fragment (pink line: particle spectrum; blue line: reference spectrum). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

45 MPs per individual of *Sousa chinensis* (3; 5 μm, respectively), Battaglia et al. (2020) extracted 67 to 304 MPs from *Tursiops truncatus* (7; 0.45 μm, respectively) and Hernandez-Gonzalez et al. (2018) detected 3 to 41 MPs in *Delphinus delphis* (sample size = 35; sieving down to 355 μm). These expressive differences in the number of detected particles are probably related to the different methods of MP extraction used associated with the sample type (stomach/intestine) or both (Hart et al., 2022). Furthermore, the different feeding strategies of the target species as well as the abundance of MPs in the environment of the study area, may influence the differences observed (Di Beneditto and Ramos, 2014; Ferreira et al., 2019b; Justino et al., 2021).

However, the mean number of MPs per individual (7.77 ± 1.25 particles) was quite similar to those observed in several marine mammal species (mean = 5.5 ± 2.7 particles), including the *L. acutus*, *T. truncatus*, *P.phocoena*, *G. griseus*, *S. coeruleoalba*, and *L. albirostris* (Nelms et al., 2019). Similar findings may be related as the species share some characteristics: they are all small odontocetes, inhabit coastal and shallow waters, have a similar pattern of a diverse diet composed of fish and cephalopods, and are raptorial feeders (Hocking et al., 2017).

In agreement with Hernandez-Gonzalez et al. (2018) and Battaglia et al. (2020), the individual's total length did not correlate with the number of MPs detected in the stomach content, suggesting that there is no difference in the foraging process between juveniles and adults (Rodrigues et al., 2020). However, we identified a positive correlation between the number of particles and the stomach contents mass (g). This finding, associated with the sparse ingestion of macro and mesoplastics by *S. guianensis,* supports the hypothesis that individuals are less susceptible to intentionally/actively ingesting plastic particles, which suggests that plastic contamination is more prone to occur through trophic transfer (Farrell and Nelson, 2013) or by accidental ingestion of the contaminant during the foraging process (Takada and Karapanagioti, 2019; Roch et al., 2020).

Moreover, the small size of detected MPs indicates that the major source of contamination might be the trophic transfer from the prey (Moore et al., 2020) since odontocetes do not feed using a filtering method contrarily to the baleen whales. This hypothesis is strengthened by data from Dantas et al. (2020), who documented MP contamination (average of 1 particle individual^{-1}; size not reported) in four coastal fishes (*Opisthonema oglinum*, *Conodon nobilis*, *Chloroscombrus chrysurus*, *Pomadasys corvinaeformis*), which compose the diet of *S.guianensis* (Pansard et al., 2011; Campos, 2012; Rodrigues et al., 2020), in the same study areas as ours.

MPs from the continent are usually retained along riverbanks and therefore exposed to weathering (mainly photooxidation), resulting in the potential breakdown into smaller pieces (Gewert et al., 2015; Enfrin et al., 2020.). During the rainy season, when runoff increases, there is a higher MP input to the sea, specifically among smaller fractions (Lima et al., 2014; Lebreton et al., 2017). The transboundary nature of plastic pollution and the fragmentation of these particles could explain the association we found between the smaller particles being detected in the dolphins' stomachs during the rainy season. In addition, during this seasonal period (April and May), the Brazilian current flows to the adjacent surface coastal waters, mainly influencing the study area's western portion (Dossa et al., 2020) and may transport MPs from allochthonous sources.

Different MP shapes are found in the environment of our study area, and the most abundant shapes are fibres and fragments (Garcia et al., 2020; Nolasco et al., 2022). Most studies on Cetacea also found fibres to be the most abundant shape (Zantis et al., 2021; Lusher et al., 2017). In our case, most detected MPs were fragments (57.2 %), agreeing with Moore et al. (2020), who identified half of the MPs in Beluga whales as fragments. The same was observed in pinniped samples (Zantis et al., 2021).

Though the adverse effects of MP ingestion by marine mammals are not well described per se, it is known that these animals are exposed to the toxicological effects of endocrine disruptor chemicals (Fossi and Marsili, 2003), which are found in plastic particles as chemical additives (Rani et al., 2015). The variety of polymers identified in this study raises concerns, as each polymer may be associated with different chemical pollutants (Nabi et al., 2022) and consequently with different toxic effects.

We want to point out that our results need to be considered carefully since our study has certain limitations. The subsample used for MP identification was relatively low due to time limitations and logistical issues. It is, therefore, not recommended to generalise the results from the subsample to the total samples but rather to consider them as an exploratory snapshot. We consider this acceptable since our study aimed not to investigate in detail the polymer composition and the sources of the MP contamination but to give a first description of the presence of MP particles in *S. guianensis* and insights into temporal variability and size distribution. Furthermore, while we cannot confirm that the 35 % of unidentified particles in the subsample were plastics, it should be considered that the particles were strongly weathered, hampering identification and that the LDIR is a relatively new technique with a still limited number of reference spectra, which will increase in the future.

Finally, we address that *S. guianensis* is suitable as indicator species for microplastic contamination in the tropical Atlantic because they are long-term coastal residents that can provide valuable information on the highest trophic levels from the coastal zone food web (Cremer et al., 2011; Cunha et al., 2020; Rosas and Monteiro-Filho, 2002). Different from the other coastal apex predators from the SWTA, such as bull sharks that have a wide migratory range along the coastline, swimming up to dozens of kilometres a day (Daly et al., 2014; Niella et al., 2017), or the snooks that migrate upwards into the river seasonally (Ferreira et al., 2019a, 2019b), the *S. guianensis* forms pods with strong resident patterns (Cremer et al., 2011), that can be systematically monitored along the years. Moreover, *S. guianensis* have long life spans and relevant fat stores that can be used to investigate contaminants used as plastic tracers, such as phthalate esters (Baini et al., 2017); this information could be coupled with the plastic debris data retrieved from the stranded individuals' stomachs.

5. Conclusion

Our study promoted unprecedented findings of contamination by MPs for cetaceans, with emphasis on the Guiana dolphin, in South America and opened an important space for undefined questions about the origin of the contamination of these animals. In addition, it reinforces the title and use of the species as a sentinel of the seas, since through the investigation of stomach contents of dead individuals, it was possible to verify the contamination along the entire Ceará state coast, which can be further expanded to the Tropical Western Atlantic, due to the species distribution range.

Although the findings of this study have not been related to the cause of death of individuals, it is strongly recommended to investigate the effect of microplastics as chemical pollutants since MPs have a high adsorptive potential for persistent organic pollutants (POPs) and heavy metals and pathogens available in the environment (Liu et al., 2022; Pedrotti et al., 2022). Our study found that the presence of MP in this species is disturbing; however, we expect no major health effects at this concentration. The low frequency of occurrence of macro to mesoplastics and the fact that the contamination seems to come from the trophic transfer (and not from trophic transfer associated with active ingestion, which would lead to higher concentrations) further indicates that the impact from POPs associated with MPs on this species is rather low.

Furthermore, we recommend continuous assessment and monitoring of plastic pollution and its impacts on this threatened marine mammal species since its findings may provide important subsidies for designing mitigation action plans for species conservation. We also encourage expanding the study area for future research to compare the degree of contamination along different coastal ecosystems and habitats.

CRediT authorship contribution statement

Letícia Gonçalves Pereira: Conceptualization, Investigation, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Guilherme V.B. Ferreira:** Conceptualization, Investigation, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Anne K.S. Justino:** Investigation, Methodology, Writing – review & editing. **Kelen Melo Tavares de Oliveira:** Investigation, Methodology, Writing – review & editing. **Monique Torres de Queiroz:** Investigation, Methodology, Writing – review & editing. **Natascha Schmidt:** Methodology, Writing – review & editing. **Vincent Fauvelle:** Methodology, Funding acquisition, Writing – review & editing. **Vitor Luz Carvalho:** Conceptualization, Funding acquisition, Writing – review & editing. **Flávia Lucena-Frédou:** Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2023.115407.

References

Avila, I.C., Kaschner, K., Dormann, C.F., 2018. Current global risks to marine mammals: taking stock of the threats. Biol. Conserv. 221, 44–58.

Baini, M., Martellini, T., Cincinelli, A., Campani, T., Minutoli, R., Panti, C., Fossi, M.C., 2017. First detection of seven phthalate esters (PAEs) as plastic tracers in superficial neustonic/planktonic samples and cetacean blubber. Anal. Methods 9 (9), 1512–1520.

Barnes, D.K., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 364 (1526), 1985–1998. https://doi.org/10.1098/rstb.2008.0205.

Battaglia, F.M., Beckingham, B.A., McFee, W.E., 2020. First report from North America of microplastics in the gastrointestinal tract of stranded bottlenose dolphins (*Tursiops truncatus*). Mar. Pollut. Bull. 160, 111677.

Baulch, S., Perry, C., 2014. Evaluating the impacts of marine debris on cetaceans. Mar. Pollut. Bull. 80 (1–2), 210–221. https://doi.org/10.1016/j.marpolbul.2013.12.050.

Betts, K., 2008. Why small plastic particles may pose a big problem in the oceans. Environ. Sci. Technol. 42 (24), 8995. https://doi.org/10.1021/es802970v.

Borrelle, S.B., Rochman, C.M., Liboiron, M., Bond, A.L., Lusher, A., Bradshaw, H., Provencher, J.F., 2017. Opinion: why we need an international agreement on marine plastic pollution. Proc. Natl. Acad. Sci. U. S. A. 114 (38), 9994–9997. https://doi.org/10.1073/pnas.1714450114.

Bossart, G.D., 2011. Marine mammals as sentinel species for oceans and human health. Vet. Pathol. 48 (3), 676–690. https://doi.org/10.1177/0300985810388525.

Brakes, P., Dall, S.R.X., 2016. Marine mammal behavior: a review of conservation implications. Front. Mar. Sci. 3 https://doi.org/10.3389/fmars.2016.00087.

Bröker, K.C., 2019. An overview of potential impacts of hydrocarbon exploration and production on marine mammals and associated monitoring and mitigation measures. Aquat. Mamm. 45, 576–611. https://doi.org/10.1578/AM.45.6.2019.576.

Campos, A.A., Monteiro, A.Q., Monteiro-Neto, C.A., 2003. Zona Costeira do Ceará: Diagnóstico para a Gestão Integrada. AQUASIS, Fortaleza, 248p.

Campos, T.M., 2012. Ecologia alimentar do boto-cinza, *Sotalia guianensis* (CETACEA, DELPHINIDAE), no estado do Ceará, Brasil. Dissertação. (Mestrado em Ecologia e Conservação) - Universidade Federal do Paraná.

Carvalho, V.L., Meirelles, A.C.O., 2020. Boto-cinza: Biologia e conservação no Brasil. In: Guiana Dolphin: Biology and Conservation in Brazil.

Castro, R.O., Silva, M.L., Araújo, F.V., de., 2018. Review on microplastic studies in Brazilian aquatic ecosystems. Ocean Coast. Manag. 165, 385–400. https://doi.org/10.1016/j.ocecoaman.2018.09.013.

Cremer, M.J., Hardt, F.A., Tonello-Júnior, A.J., Simões-Lopes, P.C., 2011. Distribution and status of the Guiana dolphin Sotalia guianensis (Cetacea, Delphinidae) population in Babitonga bay, Southern Brazil. Zool. Stud. 50 (3), 327–337.

Cunha, H.A., Fettucia, D., Santos-Neto, E.B., Bisi, T.L., 2020. Biology. In: Meirelles, A.C.O., Carvalho, V.L. (Eds.), Guiana Dolphin: Biology and Conservation in Brazil. Bambu Editora e Artes Gráficas, São Paulo.

Daly, R., Smale, M.J., Cowley, P.D., Froneman, P.W., 2014. Residency patterns and migration dynamics of adult bull sharks (Carcharhinus leucas) on the east coast of southern Africa. PLoS One 9 (10), e109357. https://doi.org/10.1371/journal.pone.0109357.

Dantas, N.C., Duarte, O., Ferreira, W.C., Ayala, A.P., Rezende, C.F., Feitosa, C.V., 2020. Plastic intake does not depend on fish eating habits: identification of microplastics in the stomach contents of fish on an urban beach in Brazil. Mar. Pollut. Bull. 153, 110959.

de Aguiar, L.K., Manning, L., 2020. In: Aktas, E., Bourlakis, M. (Eds.), The Role of Informal and Semi-formal Waste Recycling Activities in a Reverse Logistics Model of Alternative Food Networks BT - Food Supply Chains in Cities: Modern Tools for Circularity and Sustainability. Springer International Publishing, Cham, pp. 145–169.

Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. Mar. Pollut. Bull. 44, 842–852. https://doi.org/10.1016/S0025-326X(02)00220-5.

Di Beneditto, A.P., Ramos, R.M., 2014. Marine debris ingestion by coastal dolphins: what drives differences between sympatric species? Mar. Pollut. Bull. 83 (1), 298–301. https://doi.org/10.1016/j.marpolbul.2014.03.057.

Domit, C., Caballero, S., Miranda, A., Fruet, P., Torres-Florez, J.P., Cunha, H., Farro, A.P., Azevedo, A., Bisi, T., Briceño, Y., Cremer, M.J., Tardin, R., Barreto, A.S., Bertozzi, C.P., Lailson-Brito Jr., J., Barrios-Garrido, H., Van Belleghem, T., May-Collado, L., Di Tullio, J., Bracarense, A.P.L., Cantor, M., Andriolo, A., 2021. Report of the *Sotalia guianensis* pre-assessment workshop: main results and status of the current knowledge. J. Cetacean Res. Manag. (suppl.) 22, 333–378.

Dossa, A.N., Costa da Silva, A., Chaigneau, A., Eldin, G., Araujo, M., Bertrand, A., 2020. Near-surface western boundary circulation off Northeast Brazil. Prog. Oceanogr. 102475 https://doi.org/10.1016/j.pocean.2020.102475.

Enfrin, M., Lee, J., Gibert, Y., Basheer, F., Kong, L., Dumée, L.F., 2020. Release of hazardousnanoplastic contaminants due to microplastics fragmentation under shear stress forces. J. Hazard. Mater. 384 https://doi.org/10.1016/j.jhazmat.2019.121393.

Farrell, P., Nelson, K., 2013. Trophic level transfer of microplastic: *Mytilus edulis* (L.) to *Carcinus maenas* (L.). Environ. Pollut. (Barking, Essex: 1987) 177, 1–3. https://doi.org/10.1016/j.envpol.2013.01.046.

Ferreira, G.V.B., Barletta, M., Lima, A.R.A., Morley, S.A., Costa, M.F., 2019a. Dynamics of marine debris ingestion by profitable fishes along the estuarine ecocline. Sci. Rep. 9 (1), 13514. https://doi.org/10.1038/s41598-019-49992-3.

Ferreira, G.V.B., Barletta, M., Lima, A.R.A., 2019b. Use of estuarine resources by top predator fishes. How do ecological patterns affect rates of contamination by microplastics? Sci. Total Environ. 655, 292–304. https://doi.org/10.1016/j.scitotenv.2018.11.229.

Fossi, M., Marsili, L., 2003. Effects of endocrine disruptors in aquatic mammals. Pure Appl. Chem. 75 (11–12), 2235–2247. https://doi.org/10.1351/pac200375112235.

Fossi, M.C., Panti, C., Baini, M., Lavers, J.L., 2018. A review of plastic-associated pressures: cetaceans of the Mediterranean sea and eastern Australian shearwaters as case studies. Front. Mar. Sci. 5 https://doi.org/10.3389/fmars.2018.00173.

Fossi, M.C., Baini, M., Simmonds, M.P., 2020. Cetaceans as ocean health indicators of marine litter impact at global scale. Front. Environ. Sci. 8 https://doi.org/10.3389/fenvs.2020.586627.

Gales, N.J., Hindell, M.A., Kirkwood, R., 2003. Marine Mammals: Fisheries, Tourism and Managementissues. CSIRO Publishing, Collingwood, Victoria, Australia.

Galloway, T.S., Cole, M., Lewis, C., 2017. Interactions of microplastic debris throughout the marine ecosystem. Nat. Ecol. Evol. 1 (5), 116. https://doi.org/10.1038/s41559-017-0116.

Garcia, T.M., Campos, C.C., Mota, E.M.T., Santos, N.M.O., Campelo, R.P.S., Prado, L.C.G., Melo Junior, M., Soares, M.O., 2020. Microplastics in subsurface waters of the western equatorial Atlantic (Brazil). Mar. Pollut. Bull. 150, 110705 https://doi.org/10.1016/j.marpolbul.2019.110705.

Geraci, J.R., Lounsbury, V.J., 2005. Marine Mammals Ashore: A Field Guide for Strandings. National Aquarium in Baltimore.

Gewert, B., Plassmann, M.M., MacLeod, M., 2015. Pathways for degradation of plastic polymers floating in the marine environment. Environ Sci Process Impacts 17 (9), 1513–1521. https://doi.org/10.1039/c5em00207a.

Gurjão, L.M., Furtado Neto, M.A., Dos Santos, R.A., Cascon, P., 2003. Feeding habits of marine tucuxi, *Sotalia fluviatilis*, at Ceará state, northeastern Brazil. Lat. Am. J. Aquat. Mamm. 2 (2), 117–122.

Hall, A.J., McConnell, B.J., Schwacke, L.H., Ylitalo, G.M., Williams, R., Rowles, T.K., 2017. Predicting the effects of polychlorinated biphenyls on cetacean populations through impacts on immunity and calf survival. Environ. Pollut. 233, 407–418.

Hamilton, S., Baker, G.B., 2019. Technical mitigation to reduce marine mammal bycatch and entanglement in commercial fishing gear: lessons learnt and future directions. Rev. Fish Biol. Fish. 29, 223–247. https://doi.org/10.1007/s11160-019-09550-6.

Hart, L.B., Dziobak, M., Wells, R.S., Ertel, B., Weinstein, J., 2022. Microplastics in gastric samples from common bottlenose dolphins (*Tursiops truncatus*) residing in Sarasota Bay FL (USA). Front. Mar. Sci. 9, 947124 https://doi.org/10.3389/fmars.2022.947124.

Hazen, E.L., Abrahms, B., Brodie, S., Carroll, G., Jacox, M.G., Savoca, M.S., Scales, K.L., Sydeman, W.J., Bograd, S.J., 2019. Marine top predators as climate and ecosystem sentinels. Front. Ecol. Environ. 17 (10), 565–574.

Helm, R.C., Costa, D.P., DeBruyn, T.D., O'Shea, T.J., Wells, R.S., Williams, T.M., 2014. Overview of effects of oil spills on marine mammals. In: Fingas, M. (Ed.), Handbook of Oil Spill Science and Technology. https://doi.org/10.1002/9781118989982.ch18.

Hernandez-Gonzalez, A., Saavedra, C., Gago, J., Covelo, P., Santos, M.B., Pierce, G.J., 2018. Microplastics in the stomach contents of common dolphin (*Delphinus delphis*) stranded on the Galician coasts (NW Spain, 2005-2010). Mar. Pollut. Bull. 137, 526–532. https://doi.org/10.1016/j.marpolbul.2018.10.026.

Hocking, D.P., Marx, F.G., Park, T., Fitzgerald, E.M., Evans, A.R., 2017. A behavioural framework for the evolution of feeding in predatory aquatic mammals. Proc. Biol. Sci. 284 (1850), 20162750 https://doi.org/10.1098/rspb.2016.2750.

Hovelsrud, G.K., McKenna, M., Huntington, H.P., 2008. Marine mammal harvests and other interactions with humans. Ecol. Appl. 18 (2), S135–S147. http://www.jstor.org/stable/40062161.

IBGE, 2021. População estimada. In: Inst. Bras. Geogr. e Estatística. https://cidades.ibge.gov.br/brasil/ce/panorama. (Accessed 17 March 2022).

Instituto Chico Mendes de Conservação da Biodiversidade. 2018. Livro Vermelho da Fauna Brasileira Ameaçada de Extinção: Volume II - Mamíferos. In: Instituto Chico Mendes de Conservação da Biodiversidade. (Org.). Livro Vermelho da Fauna Brasileira Ameaçada de Extinção. Brasília: ICMBio. 622p.

Justino, A.K.S., Lenoble, V., Pelage, L., Ferreira, G.V.B., Passarone, R., Frédou, T., Lucena Frédou, F., 2021. Microplastic contamination in tropical fishes: an assessment of different feeding habits. Reg. Stud. Mar. Sci. 45, 101857 https://doi.org/10.1016/j.rsma.2021.101857.

Kühn, S., Bravo Rebolledo, E.L., van Franeker, J.A., 2015. Deleterious effects of litter on marine life. Mar. Anthrop. Litt. 75–116 https://doi.org/10.1007/978-3-319-16510-3_4.

Lebreton, L.C.M., van der Zwet, J., Damsteeg, J.W., Slat, B., Andrady, A., Reisser, J., 2017. River plastic emissions to the world's oceans. Nat. Commun. 8, 15611. https://doi.org/10.1038/ncomms15611.

Lima, A.R., Costa, M.F., Barletta, M., 2014. Distribution patterns of microplastics within the plankton of a tropical estuary. Environ. Res. 132, 146–155. https://doi.org/10.1016/j.envres.2014.03.031.

Liu, Y., Zhang, K., Xu, S., Yan, M., Tao, D., Chen, L., Wei, Y., Wu, C., Liu, G., Lam, P.K.S., 2022. Heavy metals in the "plastisphere" of marine microplastics: adsorption mechanisms and composite risk. Gondwana Res. 108, 171–180. https://doi.org/10.1016/j.gr.2021.06.017.

Lusher, A.L., Hernandez-Milian, G., 2018. Microplastic extraction from marine vertebrate digestive tracts, regurgitates and scats: a protocol for researchers from all experience levels. Bio-protocol 8 (22), e3087. https://doi.org/10.21769/BioProtoc.3087.

Lusher, A.L., Welden, N.A., Sobral, P., Cole, M., 2017. Sampling, isolating and identifying microplastics ingested by fish and invertebrates. Anal. Methods 9, 1346–1360. https://doi.org/10.1039/C6AY02415G.

Lusher, A.L., Hernandez-Milian, G., Berrow, S., Rogan, E., O'Connor, I., 2018. Incidence of marine debris in cetaceans stranded and bycaught in Ireland: recent findings and a review of historical knowledge. Environ. Pollut. (Barking, Essex : 1987) 232, 467–476. https://doi.org/10.1016/j.envpol.2017.09.070.

Moore, R.C., Loseto, L., Noel, M., Etemadifar, A., Brewster, J.D., MacPhee, S., Bendell, L., Ross, P.S., 2020. Microplastics in beluga whales (*Delphinapterus leucas*) from the eastern Beaufort Sea. Mar. Pollut. Bull. 150, 110723 https://doi.org/10.1016/j.marpolbul.2019.110723.

Moore, R.C., Noel, M., Etemadifar, A., Loseto, L., Posacka, A.M., Bendell, L., Ross, P.S., 2022. Microplastics in beluga whale (Delphinapterus leucas) prey: an exploratory assessment of trophic transfer in the Beaufort Sea. Sci. Total Environ. 806, 150201 https://doi.org/10.1016/j.scitotenv.2021.150201.

Morales-Caselles, C., Viejo, J., Martí, E., González-Fernández, D., Pragnell-Raasch, H., González-Gordillo, J.I., Montero, E., Arroyo, G.M., Hanke, G., Salvo, V.S., Basurko, O.C., Mallos, N., Lebreton, L., Echevarría, F., van Emmerik, T., Duarte, C. M., Gálvez, J.A., van Sebille, E., Galgani, F., García, C.M., Ross, P.S., Bartual, A., Ioakeimidis, C., Markalain, G., Isobe, A., Cózar, A., 2021. An inshore–offshore sorting system revealed from global classification of ocean litter. Nat. Sustain. 4, 484–493. https://doi.org/10.1038/s41893-021-00720-8.

Nabi, Ghulam, Ahmad, Shahid, Ullah, Sana, Zada, Sahib, Sarfraz, Maliha, Guo, Xinle, Ismail, Muhammad, Wanghe, Kunyuan, 2022. The adverse health effects of increasing microplastic pollution on aquatic mammals. J. King Saud Univ. - Sci. 34, 102006 https://doi.org/10.1016/j.jksus.2022.102006.

Nelms, S.E., Barnett, J., Brownlow, A., Davison, N.J., Deaville, R., Galloway, T.S., Lindeque, P.K., Santillo, D., Godley, B.J., 2019. Microplastics in marine mammals stranded around the British coast: ubiquitous but transitory? Sci. Rep. 9 (1), 1075. https://doi.org/10.1038/s41598-018-37428-3.

Niella, Y.V., Afonso, A.S., Hazin, F.H., 2017. Bioecology and movements of bull sharks, Carcharhinus leucas, caught in a long-term longline survey off northeastern Brazil. Neotrop. Ichthyol. 15 https://doi.org/10.1590/1982-0224-20170106.

Nolasco, M.E., Lemos, V.A.S., López, G., Soares, S.A., Feltosa, J.P.M., Araújo, B.S., Ayala, A.P., de Azevedo, M.M.F., Santos, F.E.P., Cavalcante, R.M., 2022. Morphology, chemical characterisation and sources of microplastics in a coastal city in the equatorial zone with diverse anthropogenic activities (Fortaleza city, Brazil). J. Polym. Environ. https://doi.org/10.1007/s10924-022-02405-5.

Ourgaud, M., Phuong, N.N., Papillon, L., Panagiotopoulos, C., Galgani, F., Schmidt, N., Fauvelle, V., Brach-Papa, C., Sempere, R., 2022. Identification and quantification of microplastics in the marine environment using the laser direct infrared (LDIR) technique. Environ. Sci. Technol. https://doi.org/10.1021/acs.est.1c08870.

Padula, A.D., Machado, R., Milmann, L., De León, M.C., Gana, J.C.M., Wickert, J.C., Argañaraz, M.E., Bastida, R.O., Rodríguez, D.H., Denuncio, P.E., 2023. Marine debris ingestion by odontocete species from the Southwest Atlantic Ocean: absence also matter. Mar. Pollut. Bull. 186, 114486.

Pansard, K.C.A., Gurgel, H.D.C.B., Andrade, L.C.D.A., Yamamoto, M.E., 2011. Feeding ecology of the estuarine dolphin (*Sotalia guianensis*) on the coast of Rio Grande do Norte, Brazil. Mar. Mammal Sci. 27, 673–687. https://doi.org/10.1111/j.1748-7692.2010.00436.x.

Panti, C., Baini, M., Lusher, A., Hernandez-Milan, G., Bravo Rebolledo, E.L., Unger, B., Syberg, K., Simmonds, M.P., Fossi, M.C., 2019. Marine litter: One of the major threats for marine mammals. Outcomes from the European Cetacean Society workshop. Environ. Pollut. (Barking, Essex : 1987) 247, 72–79. https://doi.org/10.1016/j.envpol.2019.01.029.

Pedrotti, M.L., de Figueiredo Lacerda, A.L., Petit, S., Ghiglione, J.F., Gorsky, G., 2022. Vibrio spp and other potential pathogenic bacteria associated to microfibers in the North-Western Mediterranean Sea. PLoS One 17 (11), e0275284. https://doi.org/10.1371/journal.pone.0275284.

Provencher, J.F., Bond, A.L., Avery-Gomm, S., Borrelle, S.B., Bravo Rebolledo, E.L., Hammer, S., Kühn, S., Lavers, J.L., Mallory, M.L., Trevail, A., van Franeker, J.A., 2017. Quantifying ingested debris in marine megafauna: a review and recommendations for standardization. Anal. Methods. https://doi.org/10.1039/c6ay02419j.

Pugliares, K.R., Bogomolni, A., Touhey, K.M., Herzig, S.M., Harry, C.T., Moore, M.J., 2007. Marine mammal necropsy: an introductory guide for stranding responders and field biologists. In: WHOI Technical Report 2007-06. Woods Hole Oceanographic Institution, Woods Hole, MA. https://doi.org/10.1575/1912/1823, 133pp.

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing.

Rani, M., Shim, W.J., Han, G.M., Jang, M., Al-Odaini, N.A., Song, Y.K., et al., 2015. Qualitative analysis of additives in plastic marine debris and its new products. Arch. Environ. Contam. Toxicol. 69, 352–366. https://doi.org/10.1007/s00244-015-0224-x.

Roch, S., Friedrich, C., Brinker, A., 2020. Uptake routes of microplastics in fishes: practical and theoretical approaches to test existing theories. Sci. Rep. 10 https://doi.org/10.1038/s41598-020-60630-1.

Rodrigues, V.L.A., Wedekin, L.L., Marcondes, M.C.C., Barbosa, L., Farro, A.P.C., 2020. Diet and foraging opportunism of the Guiana dolphin (*Sotalia guianensis*) in the Abrolhos Bank, Brazil. Mar. Mam. Sci. 36, 436–450. https://doi.org/10.1111/mms.12656.

Roman, J., McCarthy, J.J., 2010. The whale pump: marine mammals enhance primary productivity in a coastal basin. PLoS One 5 (10), e13255. https://doi.org/10.1371/journal.pone.0013255.

Rosas, F.C., Monteiro-Filho, E., 2002. Reproduction of the Estuarine Dolphin (*Sotalia guianensis*) on the Coast of Paraná, Southern Brazil.

Salgado, L.S., Rosa, S.M., Azevedo, J.C.R., 2018. Concentrations of metals in liver of Guiana dolphins (*Sotalia guianensis*) from an estuary in southeast of Brazil. Ecotoxicol. Environ. Contam. 13, 51–61. https://doi.org/10.5132/eec.2018.01.06.

Santos, M.C.O., Rosso, S., Aguiar, S.R., Bassoi, M., 2002. Insights on small cetacean feeding habits in southeastern Brazil. Aquat. Mamm. 28, 38–45.

Schiavetti, A., Meirelles, A.C.O., Tischer, M.C., Schiavetti, M.B.M.P., Marega-Imamura, M., 2020. Conservation. In: Meirelles, A.C.O., Carvalho, V.L. (Eds.), Guiana Dolphin: Biology and Conservation in Brazil. Bambu Editora e Artes Gráficas, São Paulo.

Secchi, E., Santos, M.C. de O. & Reeves, R. 2018. *Sotalia guianensis* (errata version published in 2019). The IUCN Red List of Threatened Species 2018: e. T181359A144232542.https://doi.org/10.2305/IUCN.UK.2018-2.RLTS.T181359A144232542.en. Accessed 04 February 2023.

Sharma, S., Chatterjee, S., 2017. Microplastic pollution, a threat to marine ecosystem and human health: a short review. Environ. Sci. Pollut. Res. Int. 24 (27), 21530–21547. https://doi.org/10.1007/s11356-017-9910-8.

Tabor, G., Aguirre, A.A., 2004. Ecosystem health and sentinel species: adding an ecological element to the proverbial "canary in the mineshaft". EcoHealth 1, 226–228.

Hazardous chemicals associated with plastics in the marine environment. In: Takada, H., Karapanagioti, H.K. (Eds.), 2019. The Handbook of Environmental Chemistry. https://doi.org/10.1007/978-3-319-95568-1.

Underwood, A.J., Chapman, M.G., Browne, M.A., 2017. Some problems and practicalities in design and interpretation of samples of microplastic waste. Anal. Methods 9 (9), 1332–1345. https://doi.org/10.1039/C6AY02641A.

Woodall, L.C., Gwinnett, C., Packer, M., Thompson, R.C., Robinson, L.F., Paterson, G.L.J., 2015. Using a forensic science approach to minimize environmental contamination and to identify microfibres in marine sediments. Mar. Pollut. Bull. 95, 40–46. https://doi.org/10.1016/j.marpolbul.2015.04.044.

Worm, B., Lotze, H.K., Jubinville, I., Wilcox, C., Jambeck, J., 2017. Plastic as a persistent marine pollutant. Annu. Rev. Environ. Resour. 42 (1), 1–26. https://doi.org/10.1146/annurev-environ-102016-060700.

Zantis, L.J., Carroll, E.L., Nelms, S.E., Bosker, T., 2021. Marine mammals and microplastics: a systematic review and call for standardisation. Environ. Pollut. (Barking, Essex : 1987) 269, 116142. https://doi.org/10.1016/j.envpol.2020.116142.

Zhu, J., Yu, X., Zhang, Q., Li, Y., Tan, S., Li, D., Wang, J., 2018. Cetaceans and Microplastics: First Report of Microplastic Ingestion by a Coastal Delphinid. Science of The Total Environment, Sousa chinensis. https://doi.org/10.1016/j.scitotenv.2018.12.389.