Environmental Pollution 267 (2020) 115508

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Ingestion of plastic debris by commercially important marine fish in southeast-south Brazil[☆]

J. Gabriel B. Neto [a, b], Fábio L. Rodrigues [a, c], Ileana Ortega [a], Lucas dos S. Rodrigues [a], Ana L.d.F. Lacerda [a, b], Juliano L. Coletto [a, b], Felipe Kessler [d], Luis G. Cardoso [a, b], Lauro Madureira [a], Maíra C. Proietti [a, b, *]

[a] *Instituto de Oceanografia, Universidade Federal do Rio Grande – FURG, Avenida Itália Km 08, Rio Grande, RS, Brazil*
[b] *Pós-graduação em Oceanografia Biológica/Projeto Lixo Marinho, Instituto de Oceanografia, Universidade Federal do Rio Grande – FURG, Avenida Itália Km 08, Rio Grande, RS, Brazil*
[c] *Centro de Estudos Costeiros, Limnológicos e Marinhos (CECLIMAR), Universidade Federal do Rio Grande do Sul, Campus Litoral Norte, 95625-000, Imbé, RS, Brazil*
[d] *Escola de Química e Alimentos, Universidade Federal do Rio Grande – FURG, Avenida Itália Km 08, Rio Grande, RS, Brazil*

ARTICLE INFO

Article history:
Received 20 March 2020
Received in revised form
27 July 2020
Accepted 24 August 2020
Available online 27 August 2020

Keywords:
Plastic pollution
Microplastics
Fisheries
Polymer analysis
Habitats

ABSTRACT

Rising concentrations of plastics in the oceans are leading to increasing negative interactions with marine biota, including ingestion by endangered and/or economically important seafood species such as fish. In this paper, we visually evaluated plastic debris ingestion by 965 specimens of eight commercially exploited fish species from different marine habitats off the southeast-south coast of Brazil. All species ingested plastics, with pelagic animals having higher amounts, frequency of occurrence, diversity and sizes of ingested items than demersal-pelagic and demersal animals. Highest frequency of occurrence (FO%) of plastic ingestion (25.8%) was observed for the pelagic skipjack tuna *Katsuwonus pelamis* (Scombridae), and lowest (5%) for the demersal bluewing searobin *Prionotus punctatus* (Triglidae). Microplastics predominated in all species, and fibers/lines and fragments were the main items found, possibly derived from fishing materials. The most abundant plastic colors were transparent, black and blue, and the most common polymers were polyamide and polyurethane. With the available data, no relationship between the size of the individuals and amount of ingested plastics was observed. Considering the negative impacts of plastic ingestion on marine fish, and potentially on human health due to their consumption, understanding ingestion patterns is critical for better evaluating their origin and possible causes, and consequently for helping define prevention strategies for this problem.

1. Introduction

Plastics are highly versatile materials that have largely replaced other materials such as glass, paper and metal in the production of daily items (Andrady, 2011). The presence of plastics has been reported for several regions of the planet, including all ocean basins, numerous water bodies and remote areas such as Antarctica and the Everest (Cózar et al., 2014; Lacerda et al., 2019; Mazzolini, 2010). It is estimated that 5–10% of global annual plastic production (359 Mt in 2017; Plastic Europe, 2019) enters coastal and marine environments due to the improper disposal and inadequate management of produced waste (Jambeck et al., 2015). This is causing a serious, long-lasting and global environmental problem, with several impacts on ecosystems, economy and public health, and leading to large losses in ecosystem services (Beaumont et al., 2019).

Ingestion is one of the main impacts of plastics on marine biota, having already been reported for over 700 species from various groups, including invertebrates, birds, turtles, mammals and fish (Gall and Thompson, 2015; Kühn and van Franeker, 2020; Miranda and Carvalho-Souza, 2016). Ingestion of plastics can cause physical impacts, such as gastrointestinal tract perforation, false sense of satiety, malnutrition, physiological and behavioral changes (Gall and Thompson, 2015). Plastic is also a possible vector for

---

[☆] This paper has been recommended for acceptance by Baoshan Xing.

[*] Corresponding author. Instituto de Oceanografia, Universidade Federal do Rio Grande – FURG, Avenida Itália Km 08, Rio Grande, RS, CEP 96203-900, Brazil.
E-mail addresses: mairaproietti@gmail.com, mcproietti@furg.br (M.C. Proietti).

https://doi.org/10.1016/j.envpol.2020.115508

chemical pollutants, since several toxic compounds are used as additives in the manufacture or adsorbed to the surface of plastics from the environment (Rochman et al., 2013). In addition to ecological consequences, ingestion of plastics by seafood such as fish can potentially affect human health, considering that the compounds may bioaccumulate in the tissues of organisms and be transferred by biomagnification to higher trophic levels, including humans as top consumers (Setälä et al., 2014; Teuten et al., 2009). However, implications for humans are still debated, since the relation between consumption of plastic-ingesting seafood and human health has not yet been clearly demonstrated (Miranda and Carvalho-Souza, 2016).

Plastic ingestion by fish was first reported in 1972 (Carpenter et al., 1972) and has since been observed in at least 363 fish species in all oceans and several seas (Gall and Thompson, 2015; Markic et al., 2019; Kühn and van Franeker, 2020). This ingestion may take place when fish mistake plastic for food items, when it co-occurs with their food, or when prey that ingested plastic is consumed (Carson, 2013). Feeding strategy can influence this intake: for example, in the South Pacific it was observed that fish selected fragments in colors corresponding to their food items (Mizraji et al., 2017; Ory et al., 2017). It has also been suggested that fish with more selective diets tend to eat less plastics than those with more generalist feeding habits; however, smaller particles can be more easily ingested irrespective of feeding strategy (Mercogliano et al., 2020). In addition, the type of habitat could also influence ingestion, since it has been shown that some fish species that occur in coastal regions closer to urbanized areas had higher plastic intake than those in less urbanized areas (Peters and Bratton, 2016).

It is estimated that most plastic waste reaches the ocean via terrestrial sources, with between 1.15 and 2.41 million tonnes of this material entering the ocean from rivers every year (Lebreton et al., 2017); of these, ~20,000 tonnes flow from rivers to the ocean in Brazil's southeastern and southern regions (calculated based on Lebreton et al., 2017). Plastic ingestion by estuarine and marine fish has been reported in the northeast region of this country, and in these fish, nylon fragments from fishing activities were most frequently found (Possatto et al., 2011). Another study at the region found that three species of Gerreidae ingested blue nylon fishing lines (Ramos et al., 2012). When evaluating ingestion by 69 species of fish from two tropical estuaries in northeast Brazil, it was found that 9% had ingested microplastics, and this ingestion occurred irrespective of fish size and functional group (Vendel et al., 2017). In south Brazil, blue sharks have been reported to ingest items such as cardboard, nylon, plastic pieces and plastic bags (Hazin et al., 1994). Considering that humans consume these species, plastic ingestion could present a health issue for the Brazilian population and should be investigated at other regions of the country.

In southeastern Brazil, pelagic species with large economic importance include the bluefish *Pomatomus saltatrix* (Linnaeus, 1766; Pomatomidae) and skipjack tuna *Katsuwonus pelamis* (Linnaeus, 1758; Scombridae) (Madureira and Monteiro-Neto, 2020), which ingest pelagic, demersal and benthic prey such as fish, cephalopods and crustaceans (Castello and Habiaga, 1989; Haimovici and Miranda, 2005). Along the external shelf and upper slope, fisheries are focused mainly on demersal-pelagic fish such as the striped weakfish *Cynoscion guatucupa* (Cuvier, 1830; Sciaenidae), Jamaica weakfish *Cynoscion jamaicensis* (Vaillant and Bocourt, 1883; Scieanidae) and Southern king weakfish *Macrodon atricauda* (Günther, 1880; Sciaenidae), which feed on small fish and crustaceans (Cardoso and Haimovici, 2016). Demersal species, such as the Argentine croaker *Umbrina canosai* (Berg, 1895; Sciaenidae), whitemouth croaker *Micropogonias furnieri* (Desmarest, 1823; Sciaenidae) and bluewing searobin *Prionotus punctatus* (Bloch, 1793; Triglidae) are mostly fished along the continental shelf, and these species have diets composed of demersal and benthic prey such as fish, echinoderms, crustaceans, polychaetes and mollusks (Haimovici et al., 1989; Martins, 2000). Due to the different habitats occupied and the diversity of prey consumed, these fish may have distinct plastic ingestion patterns, which may lead to different impacts on these species and their consumers.

In this manner, this work aimed to evaluate the presence, quantities and characteristics of plastic debris ingested by fish species that occupy different marine habitats, caught in industrial fishing fleets in the southeastern and southern regions of Brazil. This is the first evaluation of this type for commercially exploited marine fish at these Brazilian regions, and is essential for understanding the ecological, economic and human health impacts of plastics, and for helping prevent this worldwide problem.

2. Materials and methods

2.1. Study area and sampling

In this study, we sampled 965 specimens of eight species from the southeast-south Brazilian coast, which occupy different habitats and present different feeding strategies. Pelagic *Katsuwonus pelamis* were captured in the southeast-south region from 2016 to 2018, using pole and line with live bait, and *P. saltatrix* were caught with surface gillnets from 2017 to 2018 (Fig. 1a). Demersal-pelagic specimens were captured between 2017 and 2018: *C. guatucupa* with pair trawls and surface gillnets, and *C. jamaicensis* and *M. atricauda* with pair trawls (Fig. 1b). Demersal fish *U. canosai*, *M. furnieri* and *P. punctatus* were captured between 2017 and 2018 with pair trawls (Fig. 1c). The pelagic and demersal-pelagic species occupy depths of up to 200 m, while demersal species inhabit preferably depths of up to 100 m. For each specimen of *K. pelamis*, the furcal length (FL – from the tip of the snout to the center of the fork of the caudal fin) was measured, and for the remaining seven species, total length (TL – from the tip of the snout to the tip of the longer lobe of the caudal fin) was recorded; all size measurements were done in centimeters, and mass was obtained in a precision scale (±0.0001 g).

2.2. Plastic identification and classification

Gastrointestinal tracts (GITs) were removed from fish via abdominal punctures made with surgical scissors. The extracted GITs were immediately placed in clean glass jars containing 5% formalin solution. The GITs were then placed on petri dishes with distilled water, cut open with a scalpel, and had their contents visually inspected with a binocular stereoscope microscope (LEICA CLS Cold-Light Source 150XD) to search for ingested plastics larger than 0.001 mm. When found, plastics were separated from the rest of the stomach contents and identified. In order to avoid external contamination, content analysis was performed in a low circulation environment on a surface cleaned with 70% alcohol, using vinyl gloves and a cotton lab coat. Additionally, two control petri dishes were used on both sides of the microscope during content evaluation, and checked after each GIT inspection. When items of the same shape present in the stomachs were also detected in the control plates, these false positives were excluded (methodology adopted according to Rummel et al., 2016). A total of 28 false positives, of type "fibers/lines", were detected and excluded from further analyses.

Plastic items ingested by fish were characterized in terms of type (fiber/line, rigid fragment, flexible fragment, pellet, and glitter), color and size classes (microplastic: from 0.001 to 5 mm;

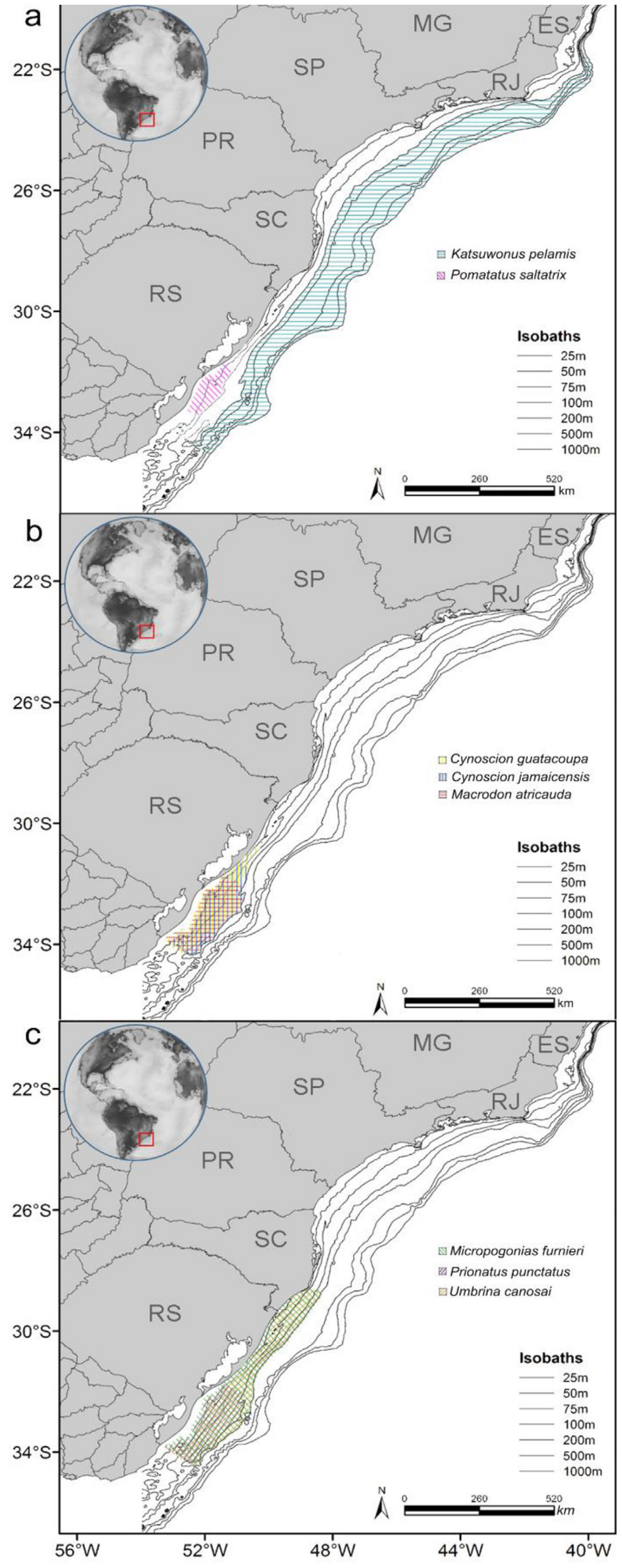

Fig. 1. Sampling regions of pelagic (a), demersal-pelagic (b) and demersal (c) fish captured along the southeast-south coast of Brazil.

mesoplastic: 5–25 mm; macroplastic: 25–1000 mm; GESAMP, 2015). Once separated, the main types of plastic items were photographed with the above-cited binocular stereoscope microscope. To identify the polymer constituent of plastics, 100 items were randomly selected; however, only 69 of these were large enough to produce reliable spectra and were included in the analyses. Items were dehydrated with a saline solution (75 mL ethanol + 75 mL methanol + 10.5 g sodium bromide), and then oven dried at 50 °C for 30 days (Pinho and Macedo, 2005). Polymers were identified by Fourier Transform Infrared Spectrophotometry (FTIR) with an IRPrestige-21 SHIMADZU mass spectrophotometer. The generated spectra (ranging from 800 to 4000 cm^{-1}, 24 scans) were compared with known spectra of plastic polymers for classification, with a 95% confidence interval (Barbosa, 2007). Additionally, natural diet items were classified into large taxonomic groups (see Fig. S1).

2.3. *Occurrence and abundance of plastic ingestion by marine fish*

The frequency of occurrence (FO%) of ingested plastics was calculated based on the total number of stomachs with plastic in relation to the total number of stomachs sampled from the eight fish species. Mean abundance was calculated as the mean number of plastic items per species, dividing the total number of plastic items found in a given species by the number of individuals analysed of the species. Total abundance was calculated as the total number of plastic items per species, and relative abundance as the total number of plastic items divided by all items (plastics + food) in the GITs of fish. Relative abundance of ingestion of different plastic categories (in terms of size, type, color and polymer) by species was also calculated by dividing the total number of plastic items of a given category by the total number of plastic items ingested by the species. The mean, total and relative abundances were also calculated for fish grouped into the three classes in terms of habitat.

The ecological indices diversity (H), richness (S) and evenness (J) for types and colors of plastics ingested by fish groups were estimated through DIVERSE analysis in PRIMER V6. Since plastic abundance presented high variability and a dominance of zeros, nonparametric approximations were used to evaluate possible differences in plastic ingestion according to the characteristics of the evaluated fish, as described in Anderson and Millar (2004).

2.4. *Characteristics of ingested plastics: size, type, color and polymer*

To evaluate potential selection of plastics by fish, univariate permutational variance analyses (Permanova) were used to compare the total abundances of ingested plastics of different sizes, types, colors and polymers and their ecological indices considering the following factors: species, as a random factor nested in habitat (eight levels: each fish species) and habitat, as a fixed factor (three levels: pelagic, demersal-pelagic, demersal). For each factor, data were permutated 4999 times to obtain significance (Anderson and Millar, 2004). The Permanova was done using a Euclidean distance matrix (Anderson and Millar, 2004) with 95% confidence interval and 5% significance. Significant results were evaluated through posterior comparisons, and 4999 random permutations were done to obtain p-values based on Monte Carlo corrections.

To analyse the abundance and diversity of plastic types in combination with colors, a multivariate Permanova was performed with the factor habitat, considering a Bray-Curtis distance matrix (Anderson and Millar, 2004). To reduce the effect caused by the absence of individuals in some samples, dummy values of one (+1) were added when calculating the distance matrix (Clarke et al., 2006). For each factor, 999 permutations were used in a reduced model (Anderson, 2005). Significant factors were analysed in clusters considering the group mean to estimate which levels presented the most similarity. All analyses of plastic characteristics were performed in PRIMER V6.

2.5. Plastic ingestion according to fish size

The relationship between the total abundance of ingested plastics and fish size was evaluated. Due to the limited range of sizes for most species, the analyses were performed only for those with FL or TL ranges of over 25 cm (*K. pelamis*, *P. saltatrix* and *C. guatucupa*). For these, a quantilic regression was performed, estimating for each species: i) the largest total abundance of plastic intake and ii) the FL/TL corresponding to the largest plastic intake. Quantilic regression trend lines (B-splines) (Koenker, 2005) were constructed for the 95th quantile (value at which 95% of the highest intake values are expected to appear), following Anderson (2008). The models were adjusted with the rq function using the quantreg package combined with the bs function of the splines package (Hastie and Tibshirani, 1993), in R. The bs function is adjustable for a given polynomial degree and the appropriate degree was determined using the small sample version of the Akaike Information Criteria (AICc), with the model with the lowest value of AICc being chosen from the set of models with polynomial degree = 1, 2, 3, 4 or 5. The highest intake rate for each species and their respective sizes was calculated considering the highest estimated value for the 95th quantile. Confidence intervals (95%) were constructed by applying 10,000 randomizations of the highest estimated intake (Miller et al., 2018).

3. Results

3.1. Occurrence and abundance of plastic ingestion by marine fish

Of the 965 analysed fish, 134 individuals had 210 visually identified plastic items in their GITs, of which 110 were found in pelagic (52.4%), 56 in demersal-pelagic (26.7%) and 44 in demersal fish (20.9%) (Table 1). The frequency of occurrence of plastic ingestion ranged from 5.0 to 25.8% in different species, with an overall mean of 13.9%. *Katsuwonus pelamis* showed highest FO% (25.8%), followed by *P. saltatrix* (19.7%), and lowest FO% was seen in *P. punctatus* (5.0%) (Table 1). The highest total and mean abundance of ingested plastics was also observed for *K. pelamis* (78 items, 1.65 ± 1.18 items/individual), followed by *P. saltatrix* (32 items, 1.18 ± 0.56 items/individual), and was lowest for *P. punctatus* (7 items, 0.06 ± 0.18 items/individual). When comparing the total abundance of plastics ingested by species within habitats, in pelagic fish it was observed that *K. pelamis* had significantly higher total abundance than *P. saltatrix* ($p = 0.004$), and in demersal fish *U. canosai* had significantly higher abundance than *P. punctatus* ($p = 0.02$); no difference was found for demersal-pelagic fish. The highest average abundance of plastics ingested per individual was observed in the pelagic habitat (pelagic: 0.45 ± 1.05, demersal-pelagic: 0.15 ± 0.49; demersal: 0.12 ± 0.40), with significant difference among habitats (Pseudo-F = 4.44, $p = 0.02$). Abundances of plastics relative to food items in the GITs were low, of 0.19% for *K. pelamis*, 3.50% for *P. saltatrix*, 1.20% for *C. guatucupa*, 2.09% for *C. jamaicensis*, 2.71% for *M. atricauda*, 0.36% for *U. canosai*, 1.55% for *M. furnieri* and 1.06% for *P. punctatus*.

3.2. Characteristics of ingested plastics: size, type, color and polymer

Fish ingested plastics with sizes ranging from 0.1 mm to 135 mm. In terms of size class, microplastics were more abundant (196 items; relative abundance: 93.3%). Four mesoplastics (1.9%) and 10 macroplastics (4.7%) were also found. Pelagic fish ingested microplastics (90%), mesoplastics (0.9%) and macroplastics (9.1%), including the largest macroplastic items (sizes from 63 to 135 mm). Demersal-pelagic fish ingested microplastics (94.6%) and mesoplastics (5.4%), while demersal fish ingested only microplastics (Fig. 2a). The same pattern was observed for the FO%, with pelagic fish presenting FO% = 89.1% micro, 1.4% meso and 9.5% macroplastics; demersal-pelagic fish FO% = 93.7% micro and 6.3% mesoplastics; and demersal fish FO% = 100% microplastics.

Of the ingested plastics, 124 were fibers/lines (59%), 69 rigid fragments (32.9%), eight pellets (3.8%), eight flexible fragments (3.8%) and one glitter (0.5%) (Fig. 3). Fibersre/lines were most abundant (over 40%) in all species, and there was variation in the abundance of plastic types ingested by different species (Fig. 2b), and significant differences among habitats (Pseudo-F = 4.327, $p = 0.023$). Cluster analysis showed largest difference between the pelagic habitat in relation to the other two (Fig. S2a). Apart from being the most abundant, fibers/lines were also the most frequent (FO% = 9.6%), along with varied rigid plastic fragments (FO % = 5.1%). Higher frequencies of these two types of plastics were observed in the pelagic habitat, with fiber/line FO% of 13.6% and rigid fragment FO% of 10.7%. In fish from the demersal-pelagic habitat, fiber/line FO% was 9.3% and rigid fragment FO% was 3.3%, and in the demersal habitat fiber/line FO% was 7.3% and rigid fragment FO% was 3.1%. The richness, diversity and evenness of plastic types were significantly different between habitats (Pseudo-F of 3.2, 7.3 and 3.1 respectively; $p < 0.05$), with higher indices in pelagic, followed by demersal-pelagic and demersal fish (Table 2).

In terms of color, 69 plastic items were transparent (relative abundance: 32.9%), 52 black (24.8%), 50 blue (23.8%), 19 white

Table 1

Marine fish species from southeast-south Brazil evaluated in this study, with size range (furcal length − FL and total length − TL, min-max in cm, mean ± SD), number of analysed fish (NF), number of fish with plastics (NFP), frequency of occurrence of plastics (FO%), total number of plastics found for each species (TP) and the mean number of plastics per individual (Mean NP ± SD).

Habitat	Species	FL*/TL (min-max)	NF	NFP	FO%	TP	Mean NP
Pelagic	*K. pelamis*	42.0−70.0 (50.4 ± 5.7)*	120	31	25.8	78	1.65 ± 1.2
	P. saltatrix	28.5−52.2 (39.6 ± 3.2)	122	24	19.7	32	1.18 ± 0.6
	Total	28.5−70.0 (45.1 ± 6.9)	242	55	22.7	110	0.45 ± 1.0
Demersal-pelagic	*C. guatucupa*	14.3−57.4 (30.7 ± 9.4)	124	13	10.5	14	0.23 ± 0.6
	C. jamaicensis	19.8−28.3 (24.2 ± 1.8)	120	13	10.8	22	0.18 ± 0.6
	M. atricauda	15.3−31.8 (23.8 ± 2.1)	121	16	13.3	20	1.17 ± 0.4
	Total	14.3−57.4 (26.3 ± 6.6)	365	42	11.5	56	0.15 ± 0.4
Demersal	*U. canosai*	19.1−28.2 (23.1 ± 1.7)	120	16	13.3	22	1.18 ± 0.5
	M. furnieri	19.7−37.1 (28.0 ± 3.3)	118	15	12.7	15	0.13 ± 0.3
	P. punctatus	17.5−31.4 (24.3 ± 2.5)	120	6	5	7	0.06 ± 0.2
	Total	17.5−37.1 (25.0 ± 3.1)	358	37	10.3	44	0.12 ± 0.4

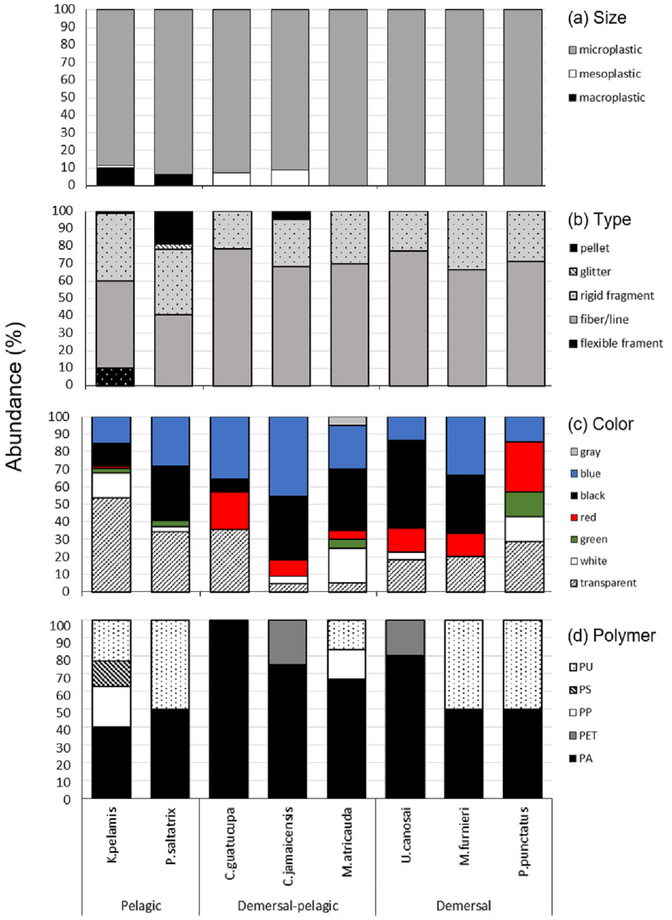

Fig. 2. Relative abundance (%) of the different sizes (a), types (b), colors (c) and polymer composition (d) of plastics ingested by each marine fish species from southeast-south Brazil, grouped by habitat. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

(9.0%), 14 red (6.7%), five green (2.4%) and 1 gray (0.5%) (Fig. 2c). In pelagic species the colors with highest frequencies of occurrence were transparent (FO% = 10.3%), blue (FO% = 7%), and black (FO% = 6.6%). In demersal-pelagic fish the highest frequencies of occurrence were blue (FO% = 4.4%), black (FO% = 2.5%) and transparent items (FO% = 2.5%), and in demersal fish, black (FO% = 3.6%), blue (FO% = 2.5%) and transparent plastics (FO% = 2.5%). Significant difference was found in the abundances colors of plastics ingested by fish among habitats (Pseudo-F = 4.0463, p = 0.024), and the cluster indicated largest difference between the pelagic habitat in relation to the other two habitats (Fig. S2b; Table S2). There was significant difference in richness of colors plastics ingested by fish among habitats (PseudoF = 6.8165, p = 0.02), but no difference was observed in diversity and evenness (Table 2).

Of the 69 plastic items evaluated in terms of polymer, 36 were polyamide (PA, relative abundance: 52.1%), 17 polyurethane (PU, 25%), nine polypropylene (PP, 13%), five polystyrene (PS, 7%) and two polyethylene terephthalate (PET, 2.9%). Pelagic fish presented relative abundances of polymers of 41% PA, 28% PU, 19% PP and 12% PS, demersal-pelagic fish had relative abundances of 77% PA, 8% PU and PP, and 7% PET, and demersal fish 61% PA, 31% PU and 8% PET items. Other plastics were found in smaller abundances (Fig. 2d). More detailed data on plastics ingested by the fish analysed this study are in Table S1.

3.3. *Plastic ingestion according to fish size*

Quantilic regressions showed the ingestion of plastic items over the entire size range of the three species evaluated (*K. pelamis*, *P. saltatrix* and *C. guatucupa*). In *K. pelamis* and *P. saltatrix*, intakes reached the maximum number of items of 5 and 2 in fish with sizes 53 and 41.7 cm, respectively. However, we did not observe ingestion of plastic items by specifically sized fish (see low curtosis of 'polynomial 3' models), and we were therefore unable to find a clear relationship between plastic intake and fish sizes. This pattern was similar for *C. guatucupa*, in which maximum ingestion was one item for all sizes (Fig. 4). Estimated sizes, polynomial degrees, AICc values for models, and confidence intervals for all species (including those with small size ranges) are available in Supplementary Table S3 and Supplementary Fig. S3.

4. Discussion

4.1. *Occurrence and abundance of plastic ingestion by marine fish*

The present study found plastics of various sizes, types, colors and polymers in the GITs of eight commercially exploited fish species sampled in the southwestern Atlantic, with ingestion frequencies from five to almost 26%. We found that pelagic and demersal-pelagic fish ingested plastics in higher frequencies and amounts when compared to demersal fish, although the relative abundance of plastics in relation to diet items was low for all species (less than 10%). The frequency of plastic ingestion in the fish analysed in our study (13.9%) was lower than the one previously observed in fish of the English Channel (36.5%) (Lusher et al., 2013) and the central North Pacific (19%) (Choy and Drazen, 2013). It was also lower than the frequency observed for marine fish in Northeast Brazil (55%; Dantas et al., 2020); differently, frequency was higher than the one described for two estuaries in Northeast Brazil (9%) (Vendel et al., 2017) and Scotland (6%) (Murphy et al., 2017). It has been hypothesized that marine fish may ingest more plastics due to a greater variety of plastic items present in the marine environment when compared with fresh/brackish water areas (Jabeen et al., 2017); however, this has yet to be confirmed by evaluating plastic contamination in the environment. In a general manner, plastic ingestion by fish is widespread, possibly due to high coastal urbanization and fishery activities worldwide. However, it must be stated that comparisons between regions are hindered by differences in sampling techniques, identification methods, and units of reported plastic concentration/abundance; there is also currently no consensus on how to define and categorize plastic debris (Hartmann et al., 2019; Al-Salem et al., 2020). To encourage comparisons, a recent study by Barletta et al. (2020) proposes standard protocols for sampling, extraction, enumeration and classification of microplastics and other pollutants ingested by fish.

The pelagic fish analysed in this study presented plastic ingestion FO% (22.7%) lower than that observed in pelagic species of the North Pacific (58% *Lampris megalopsis* and 43% in *Lampris incognitus*) (Choy and Drazen, 2013), Indian Ocean (37.5% in *Stolephorus commersonnii*) (Kripa et al., 2014) and the Mediterranean (58% in *Sciaena umbra*) (Güven et al., 2017). In Tokyo Bay, FO% of plastic ingestion was 77% in the pelagic *Engraulis japonicus* (Tanaka and Takada, 2016). The lower ingestion of plastic by fish off the Brazilian coast may also be due to a lower availability of plastic in pelagic waters of the South Atlantic when compared to the Pacific and Indian Oceans, which have been shown to present extremely high plastic concentrations (van Sebille et al., 2015). However, to confirm this it is necessary to better understand the concentration of plastics in waters of the South Atlantic, since few studies quantifying plastics have been conducted in this ocean basin.

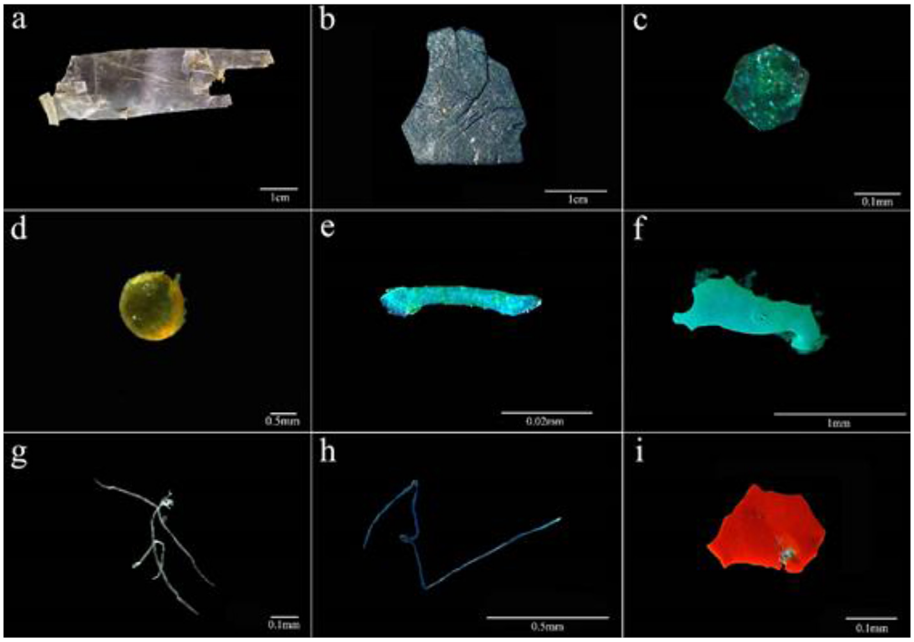

Fig. 3. Examples of types and colors of plastics found in marine fish from southeast-south Brazil: a) flexible fragment, (disposable cup piece, *K. pelamis*); b) blue rigid fragment (*K. pelamis*); c) green glitter (*P. saltatrix*); d) yellowed pellet with biofilm (*P. saltatrix*); e) blue line with biofilm (*C. guatucupa*); f) green rigid fragment with biofilm (*M. atricauda*); g) transparent fibers/lines (*U. canosai*); h) blue fiber/line (*U. canosai*); i) red rigid fragment (*M. furnieri*). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Diversity (H), richness (S) and evenness (J) of color and type of plastics ingested by fish from different habitats (pelagic, demersal-pelagic and demersal) in southeast-south Brazil (±SD).

Plastic Category	Habitat occupied (sample size)	Ecological indices		
		H	S	J
Type	Pelagic (242)	0.03 ± 0.14	0.28 ± 0.55	0.0002 ± 0.25
	Demersal-pelagic (364)	0.01 ± 0.07	0.13 ± 0.37	0.01 ± 0.11
	Demersal (358)	0	0.10 ± 0.30	0
Color	Pelagic (242)	0.03 ± 0.15	0.28 ± 0.56	0.05 ± 0.20
	Demersal-pelagic (364)	0.01 ± 0.09	0.11 ± 0.35	0.01 ± 0.11
	Demersal (358)	0.01 ± 0.07	0.11 ± 0.35	0.01 ± 0.10

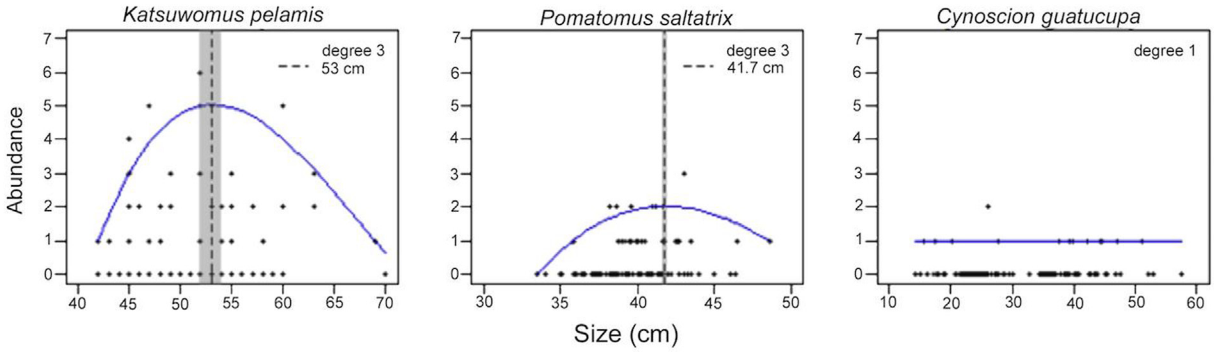

Fig. 4. Quantilic regression (blue lines) between abundance of ingested plastics and the furcal/total length of (a) *K. pelamis*, (b) *P. saltatrix* and (c) *C. guatucupa* from southeast-south Brazil. Dashed lines show the estimated sizes in which highest ingestion occurs; gray bars are the confidence intervals; best adjusted polynomial degree is given the upper right corner. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

We found relatively low plastic ingestion FO% (10.3%) in demersal fish, but this FO% was higher than found in demersal species from the Ionian Sea (1.1% in *Citharus linguatula*, *Mullus barbatus* and *Pagellus erithrinus*) (Anastasopoulou et al., 2013) and the North Sea (5.4% in *Limanda limanda*, Rummel et al., 2016; 6% in *Melanogrammus aeglefinus*, Foekema et al., 2013). Other studies in the southwest Atlantic have described microplastic ingestion by demersal fish, although FO is not reported: Arias et al. (2019) found 241 microplastic particles in twenty *Micropogonias furnieri* at an estuary in Argentina; in Uruguay, the presence of synthetic fibers was recently recorded for the first time in two coastal fish species (Limongi et al., 2019).

Differently from Lusher et al., 2013, in this study we observed significant difference in the abundance of plastics ingested by fish with different habitat uses, being greater in pelagic species. Pelagic fish can feed at different depth strata (Castello and Habiaga, 1989; Haimovici and Miranda, 2005), possibly finding and ingesting more plastics than species that are limited to certain depths. Higher prey consumption could also lead to increased passive intake of plastics, if ingested by prey; although we did not verify the GITs of food items, secondary plastic ingestion has been previously suggested for marine fish (Anastasopoulou et al., 2013; Possatto et al., 2011), especially those with larger body size that are higher up the food chain (Alomar et al., 2017). Nonetheless, it is important to note that ingestion in demersal fish could have been underestimated due to using a visual detection method, since these fish may be consuming smaller particles due to their small body/mouth size (Gerking, 1994) and the high concentration of micro and nanoplastics on the seafloor. Research using more efficient detection methods should be conducted to evaluate this.

4.2. *Characteristics of ingested plastics: size, type, color and polymer*

In terms of size, most ingested plastics were in the micro category (88.1%), followed by meso (7.2%) and macro (4.7%). Only pelagic fish ingested macroplastics and, along with demersal-pelagic, mesoplastics. Previous studies on plastic ingestion by fish also report a predominance of plastics in the “micro” size class, but with varied size ranges (from 0.09 to 16.2 mm) (Kripa et al., 2014; Lusher et al., 2013; Torre et al., 2016). The greater numerical abundance of microplastics in the marine environment (Cózar et al., 2014) could explain the high ingestion of this size class by fish. In addition, smaller particles can be more easily ingested by different species with different body and mouth sizes; indeed, morphometric studies of fish attribute prey size to mouth size. According to Deudero and Alomar (2014), fish from the pelagic environment may ingest meso and macro-sized plastics with more frequency due to their larger bodies and mouths, explaining the higher number of macroplastic and mesoplastic items observed for pelagic and demersal-pelagic fish.

The characterization of types of ingested plastics can help infer on their possible origins and uses. We found mainly plastic fibers/lines, rigid fragments and pellets in the analysed fish, and we believe that part of the fibers could be derived from clothing, as well as fishing materials such as nets and ropes. The dominance of fibers and lines among plastics ingested by fish has also been observed at other areas, such as the Mediterranean (71%) (Bellas et al., 2016), English Channel (83%) (Steer et al., 2017) and Gulf of Texas (86.4%) (Peters and Bratton, 2016), which the authors suggest could originate from fishing gear. These studies also report fragments as the second most frequent type of ingested plastics, but their origins are more difficult to infer. Pellets were the third most common type of ingested plastic in this study, being found in all species. These primary microplastic particles could be ingested since they resemble dietary items such as fish eggs and/or are commonly covered in biofilm (Amaral- Zettler et al., 2015) (see Fig. 3d), which can attract fish and possibly lead to intentional ingestion. Marine plastic biofilms can also host potentially pathogenic microorganisms, and concern has been raised on the possible impacts of such pathogens on plastic-ingesting fish (Oberbeckmann et al., 2016).

In terms of plastic colors found in the GITs of fish, transparent, black and blue were the most common; this could be due to their availability in the marine environment, since plastics of these colors are frequently used in single-use items as well as fishing gear (Ory et al., 2017). However, visual cues such as color can also contribute to the ingestion of plastics (Sacova et al., 2017). Pelagic fish feed mostly in waters with high transparency, and it is possible that these species easily detect and ingest plastics (McNicol and Noakes, 1984; Walls, 1943). In fact, *K. pelamis* and *P. saltatrix* predominantly ingested transparent items, which are highly reflectant and detectable, and it is possible that these species intentionally ingested such plastics. For demersal-pelagic and demersal fish that feed in deeper, turbid regions, ingestion could be more accidental since vision is secondary to other senses such as smell (Sacova et al., 2017). Coastal fish in eutrophic areas likely see wavelengths of 400–610 nm (Marshall et al., 2003; Perry et al., 2013), which could have favored the ingestion of blue and white items by *C. guatucupa*, *C. jamaicensis*, *M. atricauda*, *U. canosai* and *M. furnieri*. On the other hand, depth and turbidity could mask red and transparent plastics, and we suggest demersal-pelagic and demersal fish accidentally ingested these items. Other studies report a variety of plastic colors ingested by fish: in the English Channel, there was a predominance of black and blue items (Lusher et al., 2013); in the northAtlantic, white, blue and red (Choy and Drazen, 2013); in the China Sea, transparent, black and blue (Jabeen et al., 2017). Santos et al. (2016) speculate that marine animals that perceive floating plastic from below preferably ingest dark items, while animals that perceive floating plastic from above select fragments that reflect lighter colors or transparent plastics. Additional studies relating these factors to ingestion are needed to clarify this possible selection.

The most common polymers that composed ingested plastics were polyamide (PA) and polyurethane (PU), followed in lower amounts by polypropylene (PP), polystyrene (PS) and polyethylene tretaphtalate (PET). PA is a low-density polymer widely used in fishing gear and textile fibers (Challa, 1993; Mondal et al., 2019; Thomas and Lekshmi, 2017). Indeed, we found several fibers/lines that could be attributed to fishing gear and clothing. PU is also used to manufacture a wide range of plastic products, and composed various rigid fragments, pellets and the glitter observed in analysed fish. PP was observed in rigid and flexible fragments, including a disposable cup piece and a film. PS is mainly used for production of foam and expanded styrene (Paganucci, 2011), being observed in the expanded styrene pieces found in this work. PET can be used in the synthesis of fishery and textile fibers, films and packaging (MacDonald, 2002). In GITs of fish from the North and Baltic seas, PE was the most common polymer, followed by PA and PP (Collard et al., 2017; Rummel et al., 2016). In the northeast Atlantic, most plastics ingested by pelagic and demersal fish were composed of PA, PET and acrylic (Choy and Drazen, 2013). In fish in the Chinese Sea, cellophane, PET and PE polymers have been identified (Jabeen et al., 2017).

4.3. *Plastic ingestion according to fish size*

Fish size and abundance of ingested plastics did not follow a linear relationship. *K. pelamis* and *P. saltatrix* showed a parabolic relationship between these factors, while *C. guatucupa* presented the same intake regardless of size. This lack of a clear relation may be due to the fact that the studied specimens were collected though opportunistic sampling of industrial fishing vessels that target adult specimens, leading to a smaller size range of fish. However, in northeastern Brazil, plastic intake by three estuarine fish species was also unrelated to size (Possatto et al., 2011). The same was observed in the Mediterranean Sea, where there was no correlation between *Galeus melastomus* size and the amount of plastics ingested (Alomar and Deudero, 2017). On the other hand, a higher occurrence of plastics was found in adult Acoupa weakfish (FO% of 100%) when compared to the juvenile (64%) and sub-adult (50%)

stages in the Goiana estuary, also in the northeastern region of Brazil (Ferreira et al., 2016).

5. Conclusions

The increasing amounts of plastics in the oceans can lead to negative interactions between this type of debris and marine biota, including ingestion by exploited species. The eight commercially exploited and consumed fish evaluated in this study ingested plastics, with pelagic animals presenting higher amounts, frequency of occurrence, diversity and size of ingested items than demersal-pelagic and demersal fish. Microplastics predominated in all species, and fibers/lines and fragments were the most frequent types. Plastics were mainly transparent, black and blue, which may indicate greater availability in the environment or selection due to visual cues. The most abundant polymers were PA and PU, widely used in the manufacture of common products; these polymers, especially PU, can have toxic effects such as induction of oxidative stress, endocrine disruption and cytotoxicity (Zimmermann et al., 2019). With the available data we did not detect a relationship between individual size and plastic intake per species, which may suggest that plastics affect all species regardless of size, since most items were microplastics and could be ingested and impact fish of all size ranges.

Globally, overexploitation is still the biggest cause of mortality for many fishery resources (Worm et al., 2009), and intense fishing activities have reduced stocks of many species in the southwestern Atlantic, including *C. guatucupa*, *M. atricauda*, *U. canosai* and *M. furnieri* (Haimovici and Cardoso, 2016). In the current scenario of overfishing, climate change and habitat loss, plastic ingestion by fish could further impact resource maintenance and quality, since it is possible that such ingestion could reduce fish survival (Markic et al., 2019; Gove et al., 2019) and expose animal protein to chemical contaminants derived from plastics (Hahladakis et al., 2018). Considering the negative effects of plastic ingestion on marine fish, and potentially on human health due to their consumption, understanding plastic ingestion patterns is critical for identifying the causes and sources of ingested plastics and assisting in the definition of prevention strategies. The efficient implementation of the National Solid Waste Policy (PNRS, 2010), alongside the United Nations Sustainable Development Goals and a circular economy for plastics, is important to ensure this prevention. Finally, this understanding and management must address the dynamics of cross-border dispersion of marine plastics, as this type of pollutant surpasses geopolitical borders.

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.

Acknowledgements

This article was part of J.G.B's M.Sc. dissertation in the *Programa de Pós-graduação em Oceanografia Biológica* (IO/FURG), developed under the supervision of M.C.P and F.L.R. J.G.B. received a M.Sc. scholarship from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq); CNPq also provided a Research Fellowship to M.C.P. (PQ 312470/2018—5). Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) provided access to the *Portal de Periódicos* and financial support through *Programa de Excelência Acadêmica* — PROEX. Financial support for sample collection was provided by: *Projeto Tubarão Azul* (SEMA/RS) of the *Recursos Pesqueiros Demersais e Cefalópodes* lab (IO/FURG); *Projeto Bonito: ecologia e socioeconomia da pesca de Katsuwonus pelamis na costa do Rio de Janeiro visando a avaliação de estoque, o manejo sustentável e sua utilização na alimentação escolar* (financed by FUNBIO — *Edital February 2016 Apoio à Pesquisa Marinha*); and *Projeto Bonito Listrado (Katsuwonus pelamis), o ambiente oceanográfico e as alterações climáticas entre o Cabo de São Tomé-RJ e o Chuí-RS* (Leal Santos Ltda/FAURG/FURG). This work is part of the long-term ecological research program PELD — *Pesquisa Ecológica de Longa Duração no Estuário da Lagoa dos Patos e Costa Marinha Adjacente*, funded by CNPq/CAPES/FAPs/BC — Fundo Newton/PELD nº15/2016. We acknowledge M. Freire and F. Abbatepaulo for help in sample collection, S. Borges, L. Baldoni, C. Carvalho, A. Mesquita and D. Bueno for help in analyses, F. Rodrigues for creating graphical abstract and L. Moraes for revisions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2020.115508.

Author statement

José Gabriel B. Neto: Conceptualization, Formal analysis, Investigation, Writing - original draft and review, Visualization. Fábio L. Rodrigues: Conceptualization, Formal analysis, Investigation, Resources, Writing - original draft and review, Visualization, Supervision. Ileana Ortega: Formal analysis, Investigation, Writing - original draft and review, Visualization. Lucas dos S. Rodrigues: Formal analysis, Investigation, Writing - original draft and review, Visualization. Ana L. F. Lacerda: Investigation, Writing - original draft and review, Visualization. Juliano L. Coletto: Formal analysis, Writing - review & editing, Visualization. Felipe Kessler: Conceptualization, Formal analysis, Writing - review & editing, Resources, Supervision. Luis G. Cardoso: Conceptualization, Writing - review & editing, Resources, Funding acquisition. Lauro Madureira: Conceptualization, Writing - review & editing, Resources, Funding acquisition. Maíra C. Proietti: Conceptualization, Formal analysis, Investigation, Resources, Writing - original draft and review, Visualization, Supervision

References

Al-Salem, S., Uddin, S., Al-Yamani, F., 2020. An assessment of microplastics threat to the marine environment: a short review in context of the Arabian/Persian Gulf. Mar. Environ. Res. 159, 104961.

Alomar, C., Deudero, S., 2017. Evidence of microplastic ingestion in the shark Galeus melastomus Rafinesque, 1810 in the continental shelf off the western Mediterranean Sea. Environ. Pollut. 223, 223—229.

Alomar, C., Suredab, A., Capó, X., Guijarro, B., Tejada, S., Deudero, S., 2017. Microplastic ingestion by Mullus surmuletus Linnaeus, 1758 fish and its potential for causing oxidative stress. Environ. Res. 159, 135—142.

Amaral-Zettler, L.A., Zettler, E.R., Slikas, B., Boyd, G.D., Melvin, D.W., Proskurowski, G., Mincer, T.J., 2015. The biogeography of the Plastisphere: implications for policy. Front. Ecol. Environ. 13, 541—546.

Anastasopoulou, A., Mytilineou, M., Smith, C.J., Papadopoulou, K.N., 2013. Plastic debris ingested by deep-water fish of the Ionian Sea (eastern mediterranean). Deep Sea Res. Oceanogr. Res. Pap. 74, 11—13.

Anderson, M.J., 2005. PERMANOVA. Permutational Multivariate Analysis of Variance a Computer Program. Department of Statistics, University of Auckland. https://pdfs.semanticscholar.org/4d0c/430f6129b427e48fb407e59ac79ee29b4cae.pdf.

Anderson, M.J., 2008. Animal-sediment relationships re-visited: characterising species' distributions along an environmental gradient using canonical analysis and quantile regression splines. J. Exp. Mar. Biol. Ecol. 366, 16—27.

Anderson, M.J., Millar, R.B., 2004. Spatial variation and effects of habitat on temperate reef fish assemblages in northeastern New Zealand. J. Exp. Mar. Biol. Ecol. 305, 191—221.

Andrady, A.L., 2011. Microplastics in the marine environment. Mar. Poll. Bull. 62, 1596—1605.

Arias, A., Ronda, A., Oliva, A., Marcovecchio, J., 2019. Evidence of microplastic ingestion by fish from the Bahía Blanca estuary in Argentina, South America. Bull. Environ. Contam. Toxicol. 102, 750—756.

Barbosa, L.C., 2007. Espectroscopia no infravermelho na caracterização de compostos orgânicos. Editora UFV, Viçosa, p. 189.

Barletta, M., Costa, M., Dantas, D., 2020. Ecology of microplastics contamination within food webs of estuarine and coastal ecosystems. MethodsX 7, 100861.

Beaumont, N.J., Aanesen, M., Austen, M.C., Borger, T., Clark, J.R., Cole, M., Hooper, T., Lindeque, P.K., Pascoe, C., Wyles, K.J., 2019. Global ecological, social and economic impacts of marine plastic. Mar. Pollut. Bull. 142, 189—195.

Bellas, J., Martínez-Armental, J., Besada, V., Martínez-Cámara, A., 2016. Ingestion of microplastics by demersal fish from the Spanish Atlantic and Mediterranean coasts. Mar. Pollut. Bull. 109, 55—60.

Berg, C., 1895. Enumeración sistemática y sinonímica de los peces de las costas Argentina y Uruguaya. Anales del Museo Nacional de Historia Natural de Buenos Aires. 4 (1), 1—120.

Bloch, M.E., 1793. Naturgeschichte der ausländischen Fische. Pls. 7 (1—144), 325—360.

Cardoso, L.G., Haimovici, M., 2016. Density-dependent changes in the feeding behaviour of Macrodon atricauda of southern Brazil. J. Fish. Biol. 89 (1), 1002—1008.

Carpenter, E., Susan, J., Anderson, J., George, R., Harvey, H., Miklas, P., Bradford, B.P., 1972. Polystyrene spherules in coastal waters. Science 175, 1240.

Carson, H.S., 2013. The incidence of plastic ingestion by fishes: from the prey's perspective. Mar. Pollut. Bull. 74, 170—174.

Castello, J.P., Habiaga, R.P., 1989. The skipjack fishery in southern Brazil. ICCAT Collective Volume of Scientific Papers 30, 6—9.

Challa, G., 1993. Polymer Chemistry - an Introduction. Ellis Horwood, London, p. 192.

Choy, C.A.D., Drazen, J.C., 2013. Plastic for dinner? Observations of frequent debris ingestion by pelagic predatory fishes from the central North Pacific. Mar. Ecol. Prog. Ser. 485, 155—163.

Clarke, K.R., Somerfield, P.J., Airoldi, L., Warwick, R.M., 2006. Exploring interactions by second-stage community analyses. J. Exp. Mar. Biol. Ecol. 338 (2), 179—192.

Collard, F., Bernard, G., Gauthier, E., Laetitia, R., Compère, P., Krishna, D., Parmentier, E., 2017. Morphology of the filtration apparatus of three planktivorous fishes and relation with ingested anthropogenic particles. Mar. Pollut. Bull. 116, 182—191.

Cózar, A., Echevarria, F., González-Gordillo, I., Irigoien, X., Úbeda, B., Henández-León, S., Palma, A., Navarro, S., García-de-Lomas, J., Ruiz, A., Fernández-de-Puelles, M., Duarte, C., 2014. Plastic debris in the open ocean. Proc. Natl. Acad. Sci. U.S.A. 111 (28), 10239—10244.

Cuvier, G., 1830. Le règne animal distingué d'après son organisation, pour servir de base à l'histoire naturelle des animaux et d'introduction à l'anatomie comparée, , Nouvelle édition3. Deterville, Paris, pp. 1—20.

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

Desmarest, A.G., 1823. Première décade ichtyologique, ou description complète de dix espèces de poissons nouvelles ou imparfaitement connues, habitant la mer qui baigne les côtes de l'ile de Cuba. Mémoires de la Société linnéenne de Paris 2, 1—50.

Deudero, S., Alomar, C., 2014. Revising Interactions of Plastics with Marine Biota: Evidence from the Mediterranean. Marine Litter in the Mediterranean and Black Seas. CIESM, Tirana, Albania, p. 180.

Ferreira, G.V.B., Barletta, M., Lima, A.R.A., Dantas, D.V., Justino, A.K.S., Costa, M.F., 2016. Plastic debris contamination in the life cycle of Acoupa weakfish (*Cynoscion acoupa*) in a tropical estuary. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 73 (10), 2695—2707.

Foekema, E.M., Gruijter, C.d., Mergia, M.T., Franeker, J.A.V., Murk, A.T., Koelmans, A.A., 2013. Plastic in North Sea fish. Environ. Sci. Technol. 47 (15), 8818—8824.

Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. Mar. Pollut. Bull. 92, 170—179.

Gerking, S.D., 1994. Feeding Ecology of Fish. Academic Press, U.K, p. 416.

GESAMP, 2015. Sources, fate and effects of microplastics in the marine environment: a global assessment. In: Kershaw, P.J. (Ed.), IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), vol. 90. Reports and Studies GESAMP, p. 96.

Gove, J., Whitney, J., McManus, M., Lecky, J., Carvalho, F., Lynch, J., Li, J., Neubauer, P., Smith, K., Phipps, J., Kobayashi, D., Balagso, K., Contreras, E., Manuel, M., Merrifield, M., Polovina, J., Asner, G., Maynard, J., Williams, G., 2019. Prey-size plastics are invading larval fish nurseries. Proc. Natl. Acad. Sci. U.S.A. 116 (48), 24143—24149.

Günther, A., 1880. A contribution to the knowledge of the fish-fauna of the Rio de la Plata. Ann. Mag. Nat. History (Series 5) 6 (31), 7—13.

Güven, O., Kerem, G., Jovanović, B., Kıdeyş, A.E., 2017. Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. Environ. Pollut. 223, 286—294.

Hahladakis, J., Velis, C., Weber, R., Iacovidou, E., Purnell, P., 2018. An overview of chemical additives present in plastics: migration, release, fate and environmental impact during their use, disposal and recycling. J. Hazard Mater. 344, 179—199.

Haimovici, M., Cardoso, L., 2016. Long-term changes in the fisheries in the Patos Lagoon estuary and adjacent coastal waters in Southern Brazil. Mar. Biol. Res. 13, 135—150.

Haimovici, M., Miranda, L.V., 2005. Análise das Principais Pescarias Comerciais da Região Sudeste-Sul do Brasil: Dinâmica Populacional das Espécies em Exploração. Série Documentos Revizee-Score Sul, IOUSP, pp. 40—45.

Haimovici, M., Pereira, S., Vieira, P., 1989. La pesca demersal en el sur de Brasil en el period 1975-1985. Frente Marítimo 5, 151—163.

Hartmann, N., Hüffer, T., Thompson, R., Hasselöv, M., Verschoor, A., Daugaard, A., Rist, S., Karlsoon, T., Brennholt, N., Cole, M., Herrling, M., Hess, M., Ivleva, N., Lusher, A., Wagner, M., 2019. Are we speaking the same language? Recommendations for a definition and categorization framework for plastic debris. Environ. Sci. Technol. 53 (3), 1039—1047.

Hastie, T., Tibshirani, R.J., 1993. Varying-coefficient models. J. Roy. Stat. Soc. 55, 757—796.

Hazin, F.H.N., Lessa, R.P.T., Chammas, M., 1994. First observations on stomach contents of the blue shark, Prionace glauca, from southwestern equatorial Atlantic. Rev. Bras. Biol. 54 (2), 195—198.

Jabeen, K., Su, L., Li, J., Yang, D., Tong, C., Mu, J., Shi, H., 2017. Microplastics and mesoplastics in fish from coastal and fresh waters of China. Environ. Pollut. 221, 141—149.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. Science 347, 768—771.

Koenker, R., 2005. Quantile Regression. Cambridge University Press, Cambridge, U.K. http://assets.cambridge.org/97805218/45731/frontmatter/9780521845731_frontmatter.pdf.

Kripa, V., Preetha, G., Dhanya, A.M., Pravitha, V.P., Abhilash, K.S., Abbas, A., Mohammed, D., Vijayan, P.G., Gishnu, M.A., Kumar, P.S., Khambadker, L.R., Prema, D., 2014. Microplastics in the gut of anchovies caught from the mud bank area of Alappuzha, Kerala. Mar. Fish. Inf. Serv. Tech. Ext 219, 1—2.

Kühn, S., van Franeker, J., 2020. Quantitative overview of marine debris ingested by marine megafauna. Mar. Pollut. Bull. 151, 110858.

Lacerda, A.L., Rodrigues, L., van Sebille, E., Rodrigues, F.L., Ribeiro, L., Secchi, E.R., Kessler, F., Proietti, M.C., 2019. Plastics in sea surface waters around the Antarctic Peninsula. Sci. Rep. 9, 3977.

Lebreton, L.C.M., van der Zwet, J., Damsteeg, J.W., Slat, B., Andrady, A., Reissser, J., 2017. River plastic emissions to the world's oceans. Nat. Commun. 8, 15611.

Limongi, P., Lacerot, G., Segura, A., 2019. Plastic fibers in the gastrointestinal tract content of two South Atlantic coastal fish species with different trophic habitats (*Urophycis brasiliensis, Paralonchurus brasiliensis*) in Punta del Diablo-Uruguay. Pan Am. J. Aquat. Sci. 14 (1), 71—76.

Linnaeus, C., 1758. Systema naturae per regna tria naturae, secundum classes, ordinus, genera, species, cum characteribus, differentiis, synonymis, locis, , Editio decima,Tomus I. Impensis Direct. Laurentii Salvii, Holmiae, pp. 1—824.

Linnaeus, C., 1766. Systema naturae per regna tria naturae, secundum classes, ordinus, genera, species, cum characteribus, differentiis, synonymis, locis, , Editio duodecima,Tomus I. Impensis Direct. Laurentii Salvii, Holmiae, pp. 1—532.

Lusher, A.L., McHugh, M., Thompson, R.C., 2013. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. Mar. Pollut. Bull. 67, 94—99.

MacDonald, W.A., 2002. New advances in poly(ethylene terephthalate) polymerization and degradation. Polym. Int. 51 (10), 923—924.

Madureira, L.A., Monteiro-Neto, C., 2020. Sustainability of skipjack tuna fishing in Brazil. Walprint Gráfica e Editora, Rio de Janeiro, p. 256.

Markic, A., Gaertner, J.-C., Gaertner-Mazouni, N., Koelmans, A.A., 2019. Plastic ingestion by marine fish in the wild. Crit. Rev. Environ. Sci. Technol. 50, 657—697.

Marshall, N.J., Jennings, K., McFarland, W.N., Loew, E.R., Losey, G.S., 2003. Visual biology of Hawaiian coral reef fishes, Part III, Environmental light and an integrated approach to the ecology of reef fish vision. Copeia 3, 467—480.

Martins, A.S., 2000. Ph.D. Thesis. As assembléias e as guildas tróficas de peixes ósseos e cefalópodes demersais da plataforma continental e talude superior do extremo sul do Brasil, vol. 2000. FURG, Rio Grande, p. 169.

Mazzolini, E., 2010. Food, waste, and judgment on mount everest. Cult. Critiq. 76, 1—27.

McNicol, R.E., Noakes, D.L.G., 1984. Environmental influences of territoriality of juvenile brook charr, Salvelinus fontinalis, in a stream environment. Environ. Biol. Fish. 10, 29—42.

Mercogliano, R., Avio, C., Regoli, F., Anastasio, A., Colavita, G., Santonicola, S., 2020. Occurrence of microplastics in comercial seafood under the perspective of the human food chain. A review. J. Agric. Food Chem. 68 (19), 5296—5301.

Miller, J.C., Lang, J.C., Sterck, H.D., Kaiser, J.L., 2018. Analytic models for SIR disease spread on random spatial networks. J. Complex Netw. 6, 948—970.

Miranda, D.A., Carvalho-Souza, G.F., 2016. Are we eating plastic-ingesting fish? Mar. Pollut. Bull. 103, 109—114.

Mizraji, R.A.C., Perez-Venegas, D., Vargas, J., Pulgar, J., Aldana, M., Ojeda, F.P., Duarte, C., Galban-Malagon, C., 2017. Is the feeding type related with the content of microplastic in intertidal fish gut? Mar. Pollut. Bull. 116, 498—500.

Mondal, S., Thomas, S., Kumar, M., 2019. Changes in properties of polyamide netting materials exposed to different environments. Journal of Fisheries Research 3 (2), 1—3.

Murphy, F., Russell, M., Ewins, C., Quinn, B., 2017. The uptake of macroplastic and microplastic by demersal and pelagic fish in the Northeast Atlantic around Scotland. Mar. Pollut. Bull. 122, 353—359.

Oberbeckmann, S., Osborn, A., Duhaime, M., 2016. Microbes on a bottle: substrate, season and geography influence community composition of microbes colonizing marine plastic debris. PloS One 11 (8), e0159289.

Ory, N.C., Sobral, P., Ferreira, J.L., Thiel, M., 2017. Amberstripe scap Decapterus muroadsi (Carangidae) fish ingest blue microplastics resembling their copepod prey along the coast of Rapa Nui (Easter Island) in the South Pacific subtropical gyre. Sci. Total Environ. 586, 430–437.

Paganucci, C.R.M., 2011. Síntese e Caracterização de Padrão de Poliestireno para Cromatografia de Permeação em Gel através da Polimerização via Radical Livre Controlada mediada por Radicais Nitróxidos. M.Sc. Dissertation. UNICAMP, Campinas, São Paulo, p. 74.

Perry, M.C., Olsen, G.H., Richards, R.A., Osenton, P.C., 2013. Predation on dovekies by goosefish over deep water in the Northwest Atlantic Ocean. Northeast. Nat. 20, 148–154.

Peters, C.A., Bratton, S.P., 2016. Urbanization is a major influence on microplastic ingestion by sunfish in the Brazos River Basin, Central Texas, USA. Environ. Pollut. 210, 380–387.

Pinho, S.P., Macedo, E.A., 2005. Solubility of NaCl, NaBr, and KCl in water, methanol, ethanol, and their mixed solvents. J. Chem. Eng. Data 50 (1), 29–32.

Plastic Europe, 2019. Plastics – the Facts. 2019. An analysis of European plastics production, demand and waste data. https://www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf.

PNRS - Política Nacional de Resíduos Sólidos, 2010. Altera a Lei N. 9, p. 605. https://www2.camara.leg.br/legin/fed/lei/2010/lei-12305-2-agosto-2010-607598-publicacaooriginal-128609-pl.html.

Possatto, F.E., Barletta, M., Costa, F., Ivar do Sul, A.J., Dantas, D.V., 2011. Plastic debris ingestion by catfish: an unexpected fisheries impact. Mar. Pollut. Bull. 62, 1098–1102.

Ramos, J., Barletta, M.A.A., Costa, F.M., 2012. Ingestion of nylon threads by Gerreidae while using a tropical estuary as foraging grounds. Aquat. Biol. 17, 29–34.

Rochman, C.M., Hoh, E., Kurobe, T., Teh, S.J., 2013. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Sci. Rep. 3, 3263.

Rummel, C.D., Löder, M.G.J., Fricke, N.F., Lang, T., Griebeler, E.M., Janke, M., Gerdts, G., 2016. Plastic ingestion by pelagic and demersal fish from the north sea and Baltic sea. Mar. Pollut. Bull. 102, 134–141.

Sacova, M.S., Tyson, C.W., McGill, M., Slager, J., 2017. Odours from Marine Plastic Debris Induce Food Search Behaviours in a Forage Fish. Royal Society B Biological Sciences, p. 284.

Santos, R.G., Andrades, R., Fardim, L.M., Martins, A.S., 2016. Marine debris ingestion and Thayer's law: the importance of plastic color. Environ. Pollut. 214, 585–588.

Setälä, O., Fleming-Lehtinen, V., Lehtiniemi, M., 2014. Ingestion and transfer of microplastics in the planktonic food web. Environ. Pollut. 185, 77–83.

Steer, M., Cole, M., Thompson, R.C., Lindeque, P.K., 2017. Microplastic ingestion in fish larvae in the western English Channel. Environ. Pollut. 226, 250–259.

Tanaka, K., Takada, H., 2016. Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters. Sci. Rep. 6, 34–35.

Teuten, E.L., Saquing, J.M., Knappe, D.R.U., Barlaz, M.A., Jonsson, S., Bjorn, A., Rowland, S.T., Thompson, R.C., Galloway, T.S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P.H., Tana, T.S., Prudente, M., Boonyatumanond, R., Zkaria, M.P., Akkhavong, K., Ogata, Y., Hirai, H., Iwasa, S., Mizukawa, K., Hagino, Y., Imamura, A., Saha, M., Takada, H., 2009. Transport and release of chemicals from plastics to the environment and to wildlife. Phil. Trans. Biol. Sci. 364, 2027–2045.

Thomas, S., Lekshmi, M., 2017. Recent trends in fishing gear materials. In: Ravishankar, C.N., Prasad, M.M., Mohanty, A.K., Murugadas, V., ManjuLekshmi, N., Anandan, R., Sajeev, M.V., Mohan, C.O., Rejula, K., Aniesrani Delfiya, D.S. (Eds.), Recent Trends in Harvest and Post-harvest Technologies in Fisheries. Central Institute of Fisheries Technology, Kochi, India.

Torre, M., Nikoletta, D., Aikaterini, A., Tsangaris, C., Mytilineou, C., 2016. Anthropogenic microfibres pollution in marine biota: a new and simple methodology to minimize airborne contamination. Mar. Pollut. Bull. 113, 55–61.

Vaillant, L., Bocourt, F., 1883. Estudes sur les poissons. Misión Scientifique au Méxique et dans l'Amerique Centrale, 4. Imprimerie imperiale, Paris, pp. 121–200.

van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., van Franeker, J.A., Eriksen, M., Siegel, D., Galgani, F., Law, K.L., 2015. A global inventory of small floating plastic debris. Environ. Res. Lett. 10, 1–12.

Vendel, A.L., Bessa, F., Alves, V.E.N., Amorim, A.L.A., Patrício, J., Palma, A.R.T., 2017. Widespread microplastic ingestion by fish assemblages in tropical estuaries subjected to anthropogenic pressures. Mar. Pollut. Bull. 117, 448–455.

Walls, G.L., 1943. The Vertebrate Eye and its Adaptive Radiation. Cranbrook Inst. Hafner Publishing Company, NY, p. 785.

Worm, B., Hilborn, R., Baum, J., Branch, T., Collie, J., Costello, C., Michael, J., Fogarty, M.J., Fulton, E.A., Hutchings, J.A., Jennings, S., Jensen, O.P., Lotze, H.K., Mace, P.M., McClanahan, T.R., Minto, C., Palumbi, S.R., Parma, A.M., Ricard, D., Rosenberg, A.A., Watson, R., Zeller, D., 2009. Rebuilding global fisheries. Science 325 (5940), 578–585.

Zimmermann, L., Dierkes, G., Ternes, T., Völker, C., Wagner, M., 2019. Benchmarking the in vitro toxicity and chemical composition of plastic consumer products. Environ. Sci. Technol. 53 (19), 11467–11477.