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SHORT RESEARCH AND DISCUSSION ARTICLE

Ingestion of plastic fragments by the Guri sea catfish *Genidens genidens* (Cuvier, 1829) in a subtropical coastal estuarine system

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Abstract

One of the most recognized anthropogenic impacts in marine environments is solid waste pollution, especially plastic, which can be ingested by fish, thus interfering with their health. In this context, the aim of this study is to describe the ingestion of plastic fragments and to identify the possible effect of this contamination in the condition factor of *Genidens genidens* in the Laguna Estuarine System. The stomach contents of 92 *G. genidens* (26 juveniles and 66 adults) were analyzed. The Index of Relative Importance was performed to identify the contribution of each prey item. Condition factor (CF) was used to analyze the effect of plastic ingestion on the fish's body condition (by comparing individuals in the same ontogenetic phase). For the juveniles, eight items were observed, the most important of which were Penaeidae, followed by Portunidae and plastic. For the adults, 12 items were observed, the most important of which were Penaeidae, Portunidae, Polychaeta, and plastic. The analysis of CF demonstrated higher values for individuals without plastic in the stomach, which indicated a better health condition. The CF of a fish may be affected by variations in the physiological condition, environmental stresses, and nutritional and biological variations, and could be used to compare the body condition or health of a fish species. The ingestion of plastic could significantly influence the worst body condition of the individuals that were analyzed in the present study. The plastic pollution in marine coastal waters is associated with the appropriate waste management levels.

Keywords Marine pollution · Fishery impacts · Feeding ecology · Condition factor

Introduction

Ocean ecosystems, especially transitional coastal environments, such as beaches, estuaries, and coastal lagoons, are the direct connection between the continents and the oceans (Thurman and Trujillo 2004), and thus provide nutrient and sediment flux changes, as well as support a high diversity of ecological services for biodiversity (Barletta and Dantas 2016; McLusky and Elliott 2004). However, worldwide ocean and coastal pollution are recognized as two of the main factors that affect environmental quality and threaten biodiversity (Jambeck et al. 2015; Lusher et al. 2017a). For coastal ecosystems, such as estuaries, the impact of the intense rise in urbanization, agriculture, industries, and fisheries in the last decades, and the multiple uses that occur in these transitional ecosystems, brings a series of impacts that can irreversibly degrade these environments (Barletta et al. 2017).

One of the most relevant anthropogenic impacts in marine environments in the last decade is the solid waste pollution, especially plastic, which can cause irreversible damage to all trophic levels of aquatic fauna (Cardozo et al. 2018; Denuncio et al. 2017; Ivar do Sul et al. 2011; Lusher et al. 2017a; Tourinho et al. 2010). Estuaries and coastal transitional ecosystems are recognized for providing shelter and nursery habitats for fish and juvenile invertebrates (Beck et al. 2001; Dantas et al. 2012), and food for fishes, invertebrates, marine turtles, mammals, and birds of all life cycles (McLusky and Elliott 2004). Pollution by plastic waste, either microplastic (< 5 mm) or macroplastic (> 5 mm), in marine environments

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significantly affects the biotic component, thus causing damage that can lead to the death of organisms of different trophic levels (Costa and Barletta 2015). Two main types of biological interactions with plastic wastes are entanglement, when the loops and/or opening of various types of debris involve the appendages or imprison the animals, and ingestion, when the debris is ingested accidentally or intentionally and enters the treatment digestive system of organisms (Laist 1997).

The ingestion of plastic fragments by fish in marine environments, for example, occurs accidentally when it is together with the prey, or intentionally when confusing the detritus with a potential prey (Cardozo et al. 2018; Dantas et al. 2012; Ferreira et al. 2016). The ingestion of plastic by fish species has been scientifically documented in the last decade, especially to quantify and qualify its occurrence (Dantas et al. 2012; Ferreira et al. 2016; Possatto et al. 2011), and few studies have evaluated its effect on the health or condition of the species (Cardozo et al. 2018; Rochman et al. 2013). The condition of a fish may be affected by the variations in physiological condition, environmental or anthropogenic stresses, or nutritional and biological variations, which could be used to compare the body condition or health of a fish species (Cardozo et al. 2018; Froese 2006; Richardson et al. 2011), based on the assumption that, under a condition of scarce food resources, fish weight will tend to decrease relative to fish length (Richardson et al. 2011). In addition, no information exists about the contamination that is caused by the ingestion of plastic fragments in fish species in the coastal lagoons of southern Brazil; nor is there much information about the effects of this contamination on fish health. In estuarine and coastal lagoons, in the tropical and subtropical regions, the catfishes species from the family Ariidae, which are considered to be the most abundant in density and biomass (Barletta et al. 2008; Dantas et al. 2010), are of great ecological importance as a link in the food chain and represent an important food resource for seabirds and top fish predators (Bittar and Di Beneditto 2009; Oliveira et al. 2018), while still representing an important resource in small-scale fisheries (Barletta et al. 2017; Dantas et al. 2010). In this context, the aim of this study is to describe the ingestion of plastic fragments and to identify the possible effect of this contamination on the condition factor of the Guri sea catfish, *Genidens genidens* (Cuvier, 1829), in the Laguna Estuarine System.

Material and methods

Study area

The study area comprises the Santo Antônio dos Anjos and Imaruí Lagoons, which are located in the Laguna Estuarine System (LES) in southern Brazil (48° 45′ 14″ W and 28° 29′ 40″ S) (Fig. 1). Each lagoon is connected to the other by a small channel, and all of the estuaries have significant anthropogenic stress associated with small-scale fishery and navigation (Barletta et al. 2017). The Santo Antônio dos Anjos

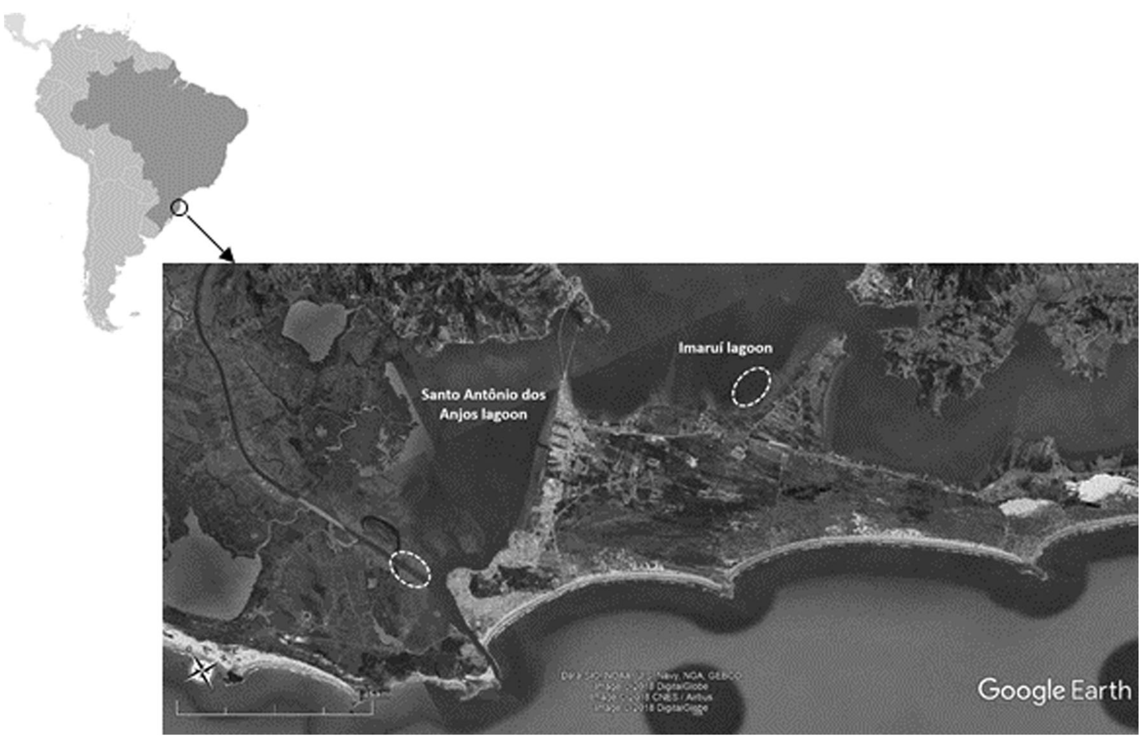

Fig. 1 Laguna Estuarine System. The white dotted lines represent the sampling sites in the Santo Antônio dos Anjos and Imaruí lagoons. Modified from Google Earth

Lagoon sample location is characterized by a high hydrodynamic that is influenced by the fluvial discharge, tides, and proximity of the channel access with the sea. The Imaruí Lagoon sample location is a shallow area with low water circulation, where artisanal fishermen act intensely using fyke nets (Barletta et al. 2017). The system supports an intense artisanal and subsistence fishing activity, with approximately 7000 fishermen acting without adequate management (Dantas 2018). Studies have already shown intense pollution from fishery sources in habitats that are located at the mouth of the lagoon system (Farias et al. 2018). The LES presents multiple uses, with many ecological and socio-economic services, such as nursery and feeding grounds for fishes and invertebrates and support for artisanal and recreational fisheries (Barletta et al. 2017). The system exports nutrients, sediments, and organic matter to adjacent coastal waters, which increases the biological productivity (Farias et al. 2018), but significant anthropogenic impacts due to urban and agricultural expansions could be observed in all estuaries (Barletta et al. 2017). Other possible sources of contamination by plastic fragments may be correlated with urban sprawl, small fishing ports, the continental drainage basin and the Tubarão River, which drains approximately 20 municipalities, and poor solid waste management (Barletta et al. 2017).

Sample design

Individuals of the Guri sea catfish *Genidens genidens* were sampled between August and December 2017 in shallow waters of the Santo Antônio dos Anjos and Imaruí lagoons (Fig. 1). A total of 92 individuals were measured (total length and weight) and dissected for stomach content analysis. The individuals were distributed according to ontogenetic phases, juveniles ($N = 26$) and adults ($N = 66$), based on the mean length of first maturity (L_{50}) (Hostim-Silva 2001), with a length range between 9.2 and 31.0 cm of the total length (juvenile 9.2 to 16.0 cm and adults 16.1 and 31.0 cm). The juveniles were sampled in shallow waters in the Imaruí Lagoon using a fyke net, while adults were sampled in the main channel of the Santo Antônio dos Anjos Lagoon using gill nets. The stomach contents were analyzed following the methodology proposed by Cardozo et al. (2018) and Ferreira et al. (2019), and the food items were identified according to Ruppert et al. (2005) and Stachowitsch (1992). The gut contents of each individual were analyzed to identify contamination by microplastic (< 5 mm) and/or plastic (> 5 mm). The methodology applied for the screening of the stomach for microplastic and plastic followed that of Ferreira et al. (2019) and Lima et al. (2014), where precautionary measures were taken to avoid airborne and inter-sampling contamination. Before each analysis, the work station was wiped with absolute ethanol, and all of the equipment used was double washed with distilled water, oven dried, and checked for previous contamination under a stereomicroscope (Ferreira et al. 2019). The identification of the microplastic items was made by visual inspection, physical consistency, shape, and brightness. After identification, samples were separated into individual petri dishes, covered by a watch glass to avoid airborne contamination, and oven dried at 70 °C for 48 h (Lima et al. 2014; Ferreira et al. 2019). Resected and wilted particles that had lost their characteristics, were considered to be nonsynthetic materials and were discarded from analysis, and those particles that maintained their characteristics, were considered to be plastics (Lusher et al. 2017b; Ferreira et al. 2019). The plastic fragments were grouped in a single category, "plastic," due to the low variety found. All plastic particles were measured with photograph images (stereomicroscope-mounted camera: Tucsen Digital) and Software (ISC Tucsen). The quantification of the dietary items that were ingested by *G. genidens* followed the method described in Cardozo et al. (2018). The indices proposed by Hynes (1950) and Hyslop (1980) were used to identify the importance of each prey, including plastic. The indices that were used in the present study were the percent frequency of occurrence (%*F*) of each prey, the percent of prey abundance in number (%*N*), the percent of prey abundance in weight (%*W*), and the percentage of the Index of Relative Importance (%*IRI*) (Pinkas et al. 1971; Prince 1975) (for more details, see Cardozo et al. (2018)).

With the aim to find the possible effects of plastic ingestion on the fish's body condition, the condition factor (CF) was applied, following Froese (2006) and Richardson et al. (2011). Based on the method proposed by Cardozo et al. (2018), the condition factor (CF) was calculated for individuals that had ingested plastic fragments (7 individuals for juveniles and 6 for adults), and for individuals that had not ingested plastic fragments (19 individuals for juveniles and 60 for adults). The condition factor was calculated according to the equation that was proposed by Richardson et al. (2011):

$$\mathrm{CF} = 100^{*}\left(W/(L)^{b}\right)$$

where W is the weight in grams, L is the length in centimeters, and b has been calculated to be 2.9338 for the weight-length relationships of the type $W = a\mathrm{L}^{b}$ of the *Genidens genidens*.

Statistical analysis

A Mann-Whitney U test (STATISTICA 10) was applied to compare two independent samples (groups) for differences in the number and weight of the main ingested prey items within the ontogenetic phases (juveniles and adults) (Zar 2010). These analyses were performed only for items that presented values higher than 10% in the Index of Relative Importance (%*IRI*) (Table 1). The Mann-Whitney U test was also realized to identify possible differences in the condition factor (k) between individuals that had ingested plastic

Table 1 Items ingested by *Genidens genidens* for each ontogenetic phase (juveniles and adults)

	Juvenile				Adults			
Items	*%F*	*%N*	*%W*	*%IRI*	*%F*	*%N*	*%W*	*%IRI*
Penaeidae	26.9	11.7	76.0	52.5	54.5	25.2	91.8	91.4
Portunidae	26.9	16.1	22.1	22.9	18.1	7.3	3.6	2.8
Gastropoda	11.5	10.2	0.1	2.6	9.0	5.0	0.09	0.6
Brachiura	0.0	0.0	0.0	0.0	1.5	0.5	0.01	0.01
Actinopterygii	11.5	4.4	0.2	1.2	9.0	3.3	0.2	0.4
Insecta	0.0	0.0	0.0	0.0	3.0	1.1	0.02	0.04
Polychaeta	15.3	8.8	0.3	3.1	9.0	19.6	0.07	2.5
Amphipoda	11.5	14.7	0.2	3.8	1.5	25.2	0.4	0.5
Corophiidae	0.0	0.0	0.0	0.0	1.5	0.5	0.01	0.01
Cumacea	7.6	16.1	0.1	2.7	0.0	0.0	0.0	0.0
Bivalvia	0.0	0.0	0.0	0.0	4.5	1.6	0.09	0.1
Crustacea not identify	0.0	0.0	0.0	0.0	3.0	1.6	0.6	0.1
Plastic fragments	26.9	17.6	0.5	10.8	9.0	7.8	0.06	1.03

%F, percentage frequency of occurrence; *%N*, percentage of prey abundance in number; *%W*, percentage of prey abundance in weight; *%IRI*, percentage of Index of Relative Importance

fragments and the individuals that had not ingested plastic by each ontogenetic phase (Cardozo et al. 2018). The mean size of the plastic fragments of each gut content was measured and tested statistically (Mann-Whitney *U* test) to identify the possible relation with the contamination and the size of the fish. In relation to the mean size of the plastic that had been ingested, no significant differences ($P > 0.05$) were found in relation to the size classes of the fishes.

Results

In the stomach contents of the catfishes analyzed, 13 items were observed, including Penaeidae shrimps, Portunidae blue crabs, Gastropoda, Actinopterygii, Polychaeta, Amphipoda, and plastic as the most frequent items (Table 1).

For the juveniles, eight items were observed, with Penaeidae shrimps, Portunidae blue crabs, and plastic occurring most frequently at 26.9% of the contents of analyzed stomachs. These items also present the highest values for the Index of Relative Importance (*%IRI*), with 52.5% for Penaeidae, 22.9% for Portunidae, and 10.8% for plastic (Table 1). For the adults, 12 items were observed in the stomach contents, with Penaeidae shrimps occurring in 54.5% of the stomachs analyzed, Portunidae blue crabs in 18.1% of the stomachs, and Gastropoda, Actinopterygii, Polychaeta, and plastic occurring in 9% of the stomachs. In relation to the *%IRI*, Penaeidae shrimps was the most important item, at 91.4% of the *%IRI*, while plastic showed 1.03% of *%IRI* (Table 1).

Moreover, in relation to the number and weight of the main items that were ingested by *Genidens genidens*, significant differences were observed ($P < 0.05$) between juveniles and adults, only for the ingestion of Penaeidae shrimps (Fig. 2). For plastic ingestion, the highest mean values in number (0.46 individuals) and weight (0.002 g) were observed in juveniles (Fig. 2a, b). For Penaeidae shrimps, the highest mean values in number (0.68 individuals) and weight (1.04 g) were observed in adults (Fig. 2c, d). Portunidae blue crabs did not present significant differences; however, the highest values were observed in number (0.43 individuals) and weight (0.09 g) in the juveniles (Fig. 2e, f).

A significant difference ($P < 0.05$) for the Mann-Whitney test was observed between individuals that ingested plastic and those that had not ingested plastic by each ontogenetic phase (juveniles and adults) (Fig. 3). The highest mean values of the CF were observed for juveniles that had not ingested plastic, followed by adults that had also not ingested plastic and demonstrated a better body condition (Fig. 3). The plastic fragments (< 5 mm) were not separated in categories for analyses due to the high dominance of one kind of material, nylon polyamide fragment. Only one fragment of boat paint was found, but it was also pooled for analysis (Fig. 4). The mean size of microplastic ingested by juveniles (2.16 mm ± 1.95 standard deviation) and adults (2.07 mm ± 3.02 standard deviation) did not show significant differences ($P > 0.05$). However, the largest fragment found (14,671 mm) was observed in an adult stomach content.

Discussions

Plastic waste in marine ecosystems is already considered to be one of the greatest current global impacts, because it pollutes all types of habitats and contaminates different trophic levels of

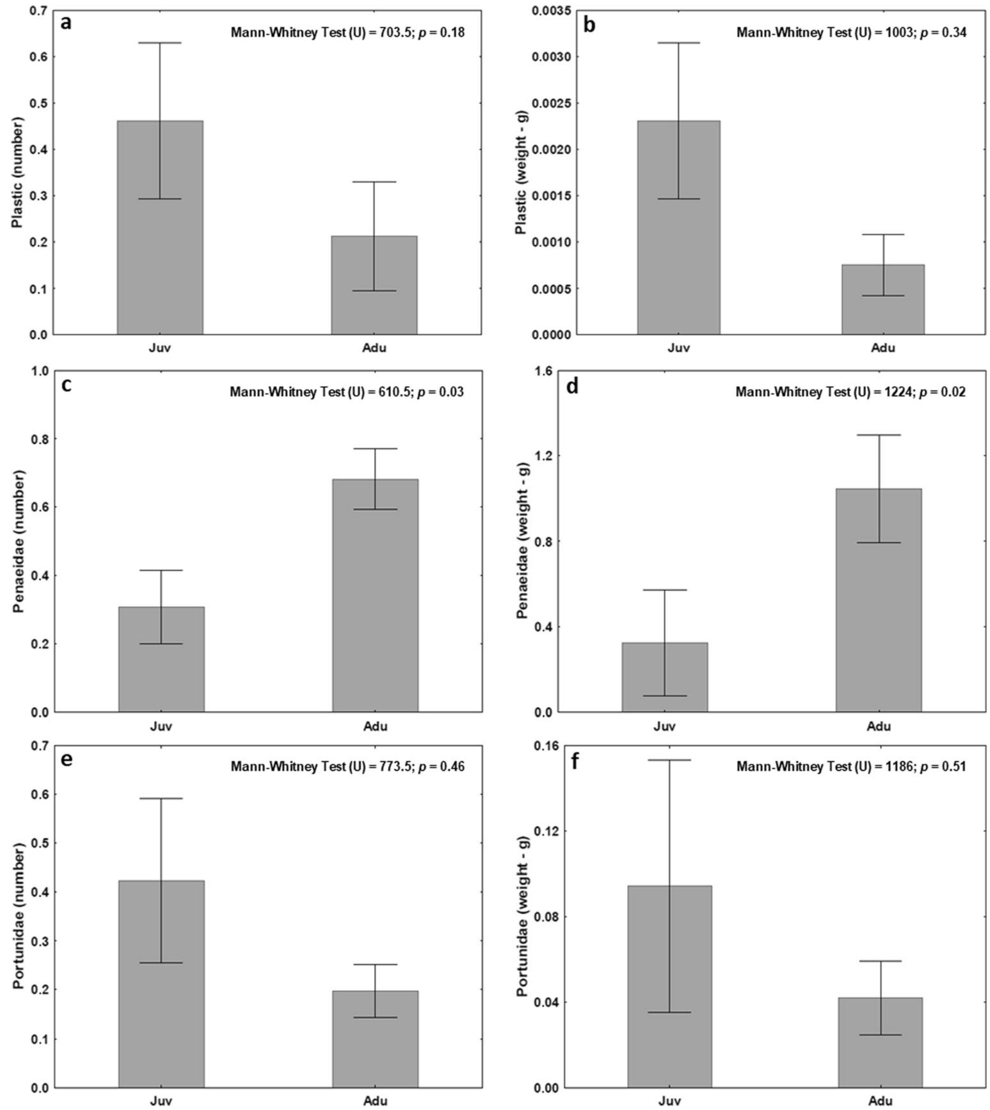

Fig. 2 Mean (± standard error) and Mann-Whitney *U* test results of the number and weight (grams) of the main items ingested by juveniles (Juv) and adults (Adu) of *Genidens genidens*. **a**, **b** Plastic fragments. **c**, **d** Penaeidae shrimps. **e**, **f** Portunidae blue crabs

aquatic biota (Denuncio et al. 2017; Eriksen et al. 2014; Lusher et al. 2017a; Tourinho et al. 2010). In coastal transitional ecosystems, such as estuaries and coastal lagoons, or in oceanic environments, the impact of plastic ingestion by fish species has been documented for different trophic levels, such as the piscivore acoupa weakfish *Cynoscion acoupa* (Ferreira et al. 2016) and for the zoobenthivores *Cathorops spixii*, *C. agassizii*, and *Sciades herzbergii* (Possatto et al. 2011). In the present study, the *G. genidens* species showed a zoobenthivore habit, feeding on preys associated with the substrate. Catfishes from the family Ariidae that inhabit estuarine environments are known to be associated with the substrate (Burgess 1989). In relation to the ingestion of plastic by fish, the knowledge of the feeding habitat is essential to better understanding possible

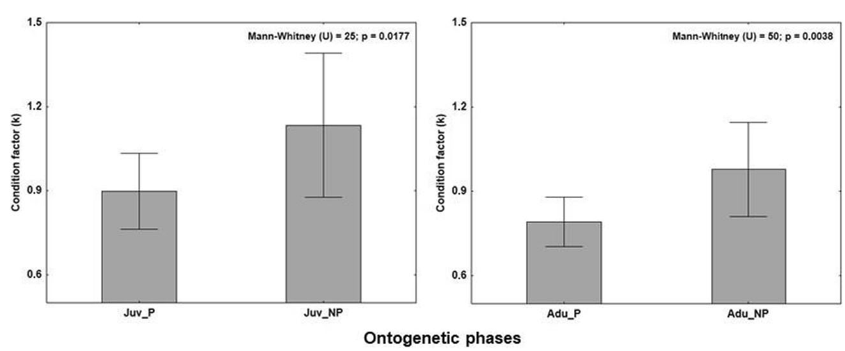

Fig. 3 Mean (± standard deviation) of condition factor and Mann-Whitney *U* test results for *Genidens genidens* by each ontogenetic phase. Juv_P, juveniles that ingested plastic; Juv_NP, juveniles that not ingested plastic; Adu_P, adults that ingested plastic; Adu_NP, adults that not ingested plastic

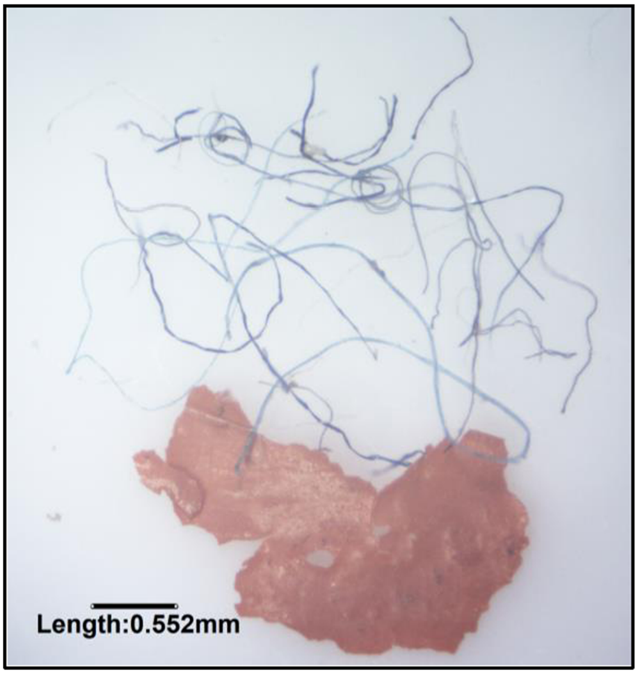

Fig. 4 Examples of plastic fragments found in the stomach contents of *Genidens genidens* in the Laguna Estuarine System

sources of contamination, or with which habitat the contaminants are associated (Cardozo et al. 2018). The feeding habit of fishes can be an important indicator of the contamination level of the individual foraging location. In this sense, understanding the trophic niche of the species and relating its food to the degree of contamination can bring a better understanding of the dynamics of this process (Dantas et al. 2012; Ramos et al. 2014; Ferreira et al. 2016, 2019).

The main prey items that were observed for the *G. genidens* in the Laguna Estuarine System (LES) were the Penaeidae shrimps, Portunidae blue crabs, and plastics, with other benthonic preys also demonstrating importance in the frequency of occurrence, such as Gastropoda, Polychaeta, and Amphipoda. The preference of the *G. genidens* by benthic preys could indicate that the microplastic fragments found in the stomach content analyses were associated with the substrate. For the estuarine catfishes *C. spixii*, *C. agassizii*, and *Sciades herzbergii*, which were all zoobenthivores, plastic fragments were also found to be associated with the substrate, in the Goiana estuary (Possatto et al. 2011). Moreover, the types of plastic ingested by fishes can indicate the main sources of pollution. Studies conducted in estuarine and coastal waters with a high intensity of fisheries activity have demonstrated that these activities are responsible for a great contribution to the amount of plastic that is ingested by fishes (Possatto et al. 2011; Dantas et al. 2012; Cardozo et al. 2018). The LES presents a high fishing activity (artisanal, recreational, and industrial), and the types of plastic found in the *G. genidens* stomachs indicated that this activity is the main source of contamination. The main types of plastic that were found were fragments of nylon polyamide and boat paint, which corroborated the contribution of the fisheries to the problem.

The feeding habitat of fish species can change during the lifespan, thus demonstrating an ontogenetic influence on prey preference, including changes in the niche habitat, and an ontogenetic change in feeding habit could also affect the ingestion of plastic fragments (Possatto et al. 2011; Dantas et al. 2012; Ferreira et al. 2016). Although the *G. genidens* present a zoobenthivorous habit, juveniles and adults showed differences in the feeding amplitude. The adults presented a greater amplitude, ingesting 11 prey, excluding microplastic, while the juveniles ingested seven prey. The greater amplitude may increase the chance of individuals ingesting plastic fragments (Dantas et al. 2015), which was not observed in the present study, where the juveniles that presented a lower feeding amplitude presented a greater frequency of contamination. The contamination may be related to a higher correlation of the prey types and the occurrence of plastic fragments (Possatto et al. 2011; Ramos et al. 2014); however, this high ingestion of microplastic by juveniles could be influenced by the sampling location in the present study. In the LES, juveniles use shallow areas as the nursery and are generally caught as bycatch in fyke net fishing gear in locations with low hydrodynamics. Adults use the deeper water that is located in the main channels and are captured by gill nets in regions with higher hydrodynamics, which are markedly influenced by tidal currents and river runoff. The low density of the nylon polyamide fragments that was found in the present study may influence the high transport capacity of these residues by surface currents, especially the tidal currents, thus delaying their sinking towards the substrate (Costa et al. 2011). Although the juveniles present a higher frequency of microplastic ingestion, in addition to a large number and average weight of ingested microplastic, significant differences were not observed in the present study for the ingestion of microplastic between juveniles and adults.

Several studies have evaluated the ingestion of plastic by fish in coastal ecosystems, but most of these studies describe qualitatively and quantitatively the occurrence of plastic fragments that are ingested by fish (Possatto et al. 2011; Dantas et al. 2012; Ferreira et al. 2016; Ramos et al. 2014). However, few studies describe the possible influence of these contaminants on the body condition of the fish (Cardozo et al. 2018; Critchell and Hoogenboom 2018), or their toxicological effect (Barboza et al. 2018). The condition factor (CF) of a fish may be affected by the variations in physiological condition, environmental stresses, and nutritional and biological variations (Jin et al. 2015; Nash et al. 2006). The CF could be used to compare the body condition, fatness, or well-being of a fish species (Tesch 1968), and this is based on the assumption that heavier fish of a given length are of better health (Froese 2006). In the present study, a higher CF was observed for juveniles and adults without plastic fragments in the stomach, which indicated that the ingestion of plastic can cause a worse body condition. Cardozo et al. (2018) observed that the ingestion of plastic fragments affected the CF of the Atlantic bigeye, *Priacanthus arenatus* and that the presence of plastic fragments may cause the fish to feel satiated, which causes the fish to stop feeding, thus decreasing the body weight and reducing the CF. In this sense, the CF can be used as an indicator of the health status of the individual, and this state of health can be related to several factors, including the ingestion of plastic fragments (Cardozo et al. 2018). Exploring the fish CF may indicate a health problem, thus emphasizing the importance of more detailed analyses of the impact of plastic contamination on individuals.

These results demonstrated the problem of pollution in marine ecosystems, which, due to lack of proper management, dumps tons of solid waste into the environment. It is estimated that approximately 2% to 5% of all plastic waste from coastal areas (4.8 to 12.7 million tons) enters the marine environments every year (Jambeck et al. 2015). Plastic waste directly affects aquatic fauna, thus endangering all biodiversity. The high dominance of nylon polyamide fragments, commonly used for manufacture of fishing gears, demonstrates the relevant contribution of the fishing activity to the problem. Appropriate environmental education and waste management strategies are urgently needed to minimize this negative impact on marine ecosystems.

Conclusions

Fishing activity, especially artisanal and industrial, contributes largely to the amount of plastic ingested by *Genidens genidens* in the Laguna Estuarine System (LES). The main source of plastic ingested can be related to the substrate, which is reflected in the zoobenthivore habitat of the catfishes. Moreover, due to the importance of this group of fish for the trophic chain in this environment, a transference of the contaminant through the food chain needs to be verified. The worse condition factor observed for individuals that had ingested plastic fragments in the present study could indicate that individuals were affected by this contamination and that it can cause harm to their health. A total of 26.9% of juveniles and 9% of adults had plastic in their stomachs, which showed high pollution by plastic residue in the LES, which was associated with fishing activity. More studies involved different trophic guilds and ecological groups, and a better quali-quantification of the spatial and temporal influence of this contaminant are needed. The plastic pollution in marine coastal waters is associated with the appropriate waste management levels. More studies could help to enhance environmental plans for aquatic ecosystems and help in the development of better strategies to mitigate pollution and conserve the marine environments for the benefit of biodiversity and for the human population that uses the ecosystem for tourism and other activities.

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