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High intake rates of microplastics in a Western Atlantic predatory fish, and insights of a direct fishery effect☆

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Microplastic contamination was investigated in the gut contents of an economically important estuarine top predator, *Cynoscion acoupa*, according to spatiotemporal and ontogenetic use of a tropical estuary. Microplastic contamination was found in more than half of the analysed fish. Ingested microplastics were classified by type, colour and length with most of the particles consisting of filaments (<5 mm). Longer filaments were more frequently ingested in the upper estuary and smaller filaments in the lower estuary, as a result of differences in hydrodynamic forces and proximity to the probable input sources. The river is likely an important source of filaments to the estuary and filaments ingested in the upper estuary showed little sign of weathering, when compared with those from the lower estuary, which are subject to intense weathering and consequent break-up of particles to smaller sizes. Most filaments, of all colours, accumulated in adults of *C. acoupa*, which are more susceptible to contamination through both direct ingestion and trophic transference as they shift their feeding mode to piscivory. Moreover, the highest ingestion of filaments in adults occurred in the lower estuary, during the late rainy season, likely associated with the intense fishing activities in this habitat, which results in a greater input of filaments from fishing gear, which are mainly blue in colour. Overall, 44% of the ingested filaments were blue, 20% purple, 13% black, 10% red and 12% white. The next most common colour, the purple filaments, are most likely blue filaments whose colour has weathered to purple. Red filaments were proportionally more ingested in the lower estuary, indicating a coastal/oceanic source. White and black filaments were more commonly ingested in the inner estuary, suggesting that they have a riverine origin and/or were actively ingested by juveniles and sub-adults, which inhabit the inner estuary and have zooplankton as an important food resource.

1. Introduction

The intensification of anthropogenic activities, especially in the mid-20th century, has resulted in many threats to marine wildlife. Impacts caused by dredging, overfishing, introduction of alien species, coastal habitat losses and illegal dumping of solid wastes in the marine environment are widely recorded (Barletta et al., 2016; Barnes, 2002; Barnes and Milner, 2005; Blaber et al., 2000; Costa and Barletta, 2015; Jackson et al., 2001; Lima et al., 2016b; Myers and Worm, 2003).

Plastic materials are one of the most frequent among the great variety of solid wastes illegally dumped in the marine environment (Barnes et al., 2009; Gregory, 2009). The high and increasing loads of environmental pollutants recorded in the sedimentary cycle of terrestrial and marine environments suggest that plastics are a geological indicator of the Anthropocene (Williams et al., 2016). This results from the widespread use of plastic products since the 19th century; their flexibility and competitive prices making them suitable for a wide range of uses (Thompson et al., 2009; Zalasiewicz et al., 2016). Once in the aquatic environment, plastics undergo weathering processes, caused by waves, wind, tidal action and ultraviolet radiation, resulting in their mechanical breakdown into smaller particles (Browne et al., 2007; Wang et al.,

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Microplastics are those particles smaller than 5 mm (Arthur et al., 2009; Lusher et al., 2017a,b), which are ubiquitous in the marine environment (Collignon et al., 2012; Lima et al., 2014). The widespread occurrence of microplastic in the aquatic ecosystems results in an inevitable interaction with organisms (Gregory, 2009), occurring mostly by ingestion (Wright et al., 2013). Indeed, many studies have reported microplastic ingestion by shellfish (Davidson and Dudas, 2016), marine mammals (Fossi et al., 2012) and fishes in a variety of marine environments (Boerger et al., 2010; Bråte et al., 2016; Dantas et al., 2012; Ferreira et al., 2016; Possatto et al., 2011; Ramos et al., 2012).

Although widely spread in the marine environment, including in remote oceanic islands (Ivar do Sul et al., 2013; Lima et al., 2016a), microplastics are somewhat diluted in the open ocean but have recently been reported in higher concentration within semi-enclosed environments, such as estuaries (Lima et al., 2014; Zhao et al., 2014). Concentration of microplastics can be so high that their densities are comparable with those of eggs and larval fishes (Lima et al., 2015). Microplastics are found in every habitat within the estuarine system, including intertidal mudflats (Costa et al., 2011), mangrove forests (Ivar do Sul et al., 2014), mangrove creeks (Lima et al., 2016b) and the main estuary channel (Lima et al., 2014). Microplastic pollution in estuaries has multiple and complex sources from urban settlements along their margins, nearby cities and fishing activities. However, the river basin has been identified as one of the main contributors of continental microplastics into estuaries (Fok and Cheung, 2015; Lebreton et al., 2017; Silva-Cavalcanti et al., 2017). Since estuaries are pathways connecting rivers to the oceans, they function as a retainer of microplastics during drier months, as well as the main exporters of microplastics to coastal and high seas when runoff increases seaward (Lebreton et al., 2017; Lima et al., 2014).

This means that fishes and other organisms inhabiting any estuarine habitat and adjacent coastal environments are susceptible to ingest microplastics (Dantas et al., 2012; Ferreira et al., 2016; Ramos et al., 2012). Once ingested, microplastics can be hazardous to the contaminated organisms, resulting in digestive injuries or a decrease in predatory efficiency that can induce starvation (de Sá et al., 2015; Moore, 2008; Teuten et al., 2007). In addition, they can be toxic through persistent organic pollutants that absorb onto microplastics and are bioaccumulated and biomagnified (Oehlmann et al., 2009; Rochman et al., 2013).

The contamination of important food species, is a pressing issue because of the potential implications for human health (Santillo et al., 2017; Talsness et al., 2009). Thus, commercial target species should be a focus for studies on microplastic ingestion. Usually, fishes from higher trophic levels are primary targets of fishing activities because of the protein quality and higher sales prices (Pinnegar et al., 2002). Unfortunately, top predators are also more vulnerable to plastic debris contamination (Au et al., 2017; Cole et al., 2011). The build-up of plastic particles along the trophic chain through biotransference of microplastic from the contaminated prey may result in higher levels of contamination in top predator fishes (Ferreira et al., 2016).

The 45 species of fish from the Sciaenidae family (Cervigón et al., 1993), represent the most important taxonomic group for the South American coastal fisheries (Cervigón et al., 1993), with landings of ~42,000 tons in Brazil (MPA, 2011). One of the most important commercial fish inhabiting Western Atlantic estuaries is the acoupa weakfish *Cynoscion acoupa* (Barletta et al., 1998; Ferreira et al., 2016), which represents the most economically important species of the Sciaenidae family.

In the Goiana estuary (northeast Brazil), juveniles of *C. acoupa* occur mainly, in the upper estuary, which is an extremely important habitat for the species since it is a nursery ground during the early rainy season (March to May). Sub-adults also inhabit the upper estuary, as it is an excellent feeding ground, with an absence of marine predators and reduced competition (Ferreira et al., 2016). Adults of *C. acoupa*, are one of the main predators inhabiting the coastline. They gather for foraging and reproduction in the estuary mouth where they are captured by the artisanal fishery (Ferreira et al., 2016). Therefore, studying the effects of non-natural food items on *C. acoupa* is fundamental to understanding how microplastics might alter the ecology of the estuary.

Studies on microplastic distribution and interactions with marine biota are increasing in quantity and quality. Such studies must quantify the spatial and temporal variation in microplastics and the many factors that influence this (Costa and Barletta, 2015; Lusher et al., 2017a; Underwood et al., 2017). Standard protocols for sampling, extraction and enumeration of microplastics ingested by fishes have also been developed to enable worldwide comparisons (Lusher et al., 2017b). Although several studies have focused on the contamination of fishes by plastic debris, few attempts have been made to understand spatiotemporal patterns of availability and ingestion of microplastics (Boerger et al., 2010; Bråte et al., 2016; Dantas et al., 2012; Jovanović, 2017; Lima et al., 2015; Lusher et al., 2013; Possatto et al., 2011; Silva-Cavalcanti et al., 2017).

Both the distribution patterns of fishes and microplastic availability vary with the spatial and seasonal variability in environmental factors within tropical estuaries (Barletta et al., 2008; Lima et al., 2015, 2014). Any investigation must include the role of the estuarine ecocline on fish ecological behaviour and on their encounter rate with microplastics (Ferreira et al., 2016). This approach is important to detect which environmental variables are associated with patterns of microplastic ingestion through the life cycle of fish species, in addition to changes in their patterns of use within the estuary (Ferreira et al., 2016).

A recent survey reported no relationship between ingested microplastic quantity and trophic level (Güven et al., 2017). Although the evidence for trophic transfer was equivocal, there was no assessment of microplastics previously ingested by prey items, especially prey of piscivorous fishes by Güven et al. (2017). Therefore, the present study assesses possible preferences for different types, colour and sizes of plastics ingested in relation to the main feeding mode and shows evidences of microplastic transference in the food web. The aim of this study is to investigate whether the ecological patterns of this species (including categories of prey) are related with ingestion rates of the different categories of microplastic (colour and length) with respect to the seasonal and spatial shifts in the diet of different ontogenetic phases (juvenile, subadults and adults) in a tropical estuarine ecosystem.

2. Material and methods

2.1. Study area

The Goiana Estuary (~4700 ha) is a tropical ecosystem, located in the easternmost portion of South America, which separates the humid coast from a semi-arid continent (Fig. 1). This ecosystem encompasses many habitats, such as the main channel (average depth of 6 m ±4 m), tidal creeks surrounded by a dense mangrove forest and dissipative sandy beaches in the mouth of the estuary (Barletta and Costa, 2009). The estuary is under influence of a semi-diurnal meso-tidal regime, with a tidal range of up to 2.5 m. The ecosystem is spatially divided into upper, middle and lower estuary, based on salinity gradient and geomorphology (Barletta and Costa, 2009) (Fig. 1).

The climate is tropical with an average annual air temperature of 27 °C. Although temperature varies little around the year, well-