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Are we eating plastic-ingesting fish?

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ABSTRACT

Yes, we are eating plastic-ingesting fish. A baseline assessment of plastic pellet ingestion by two species of important edible fish caught along the eastern coast of Brazil is described. The rate of plastic ingestion by king mackerel (*Scomberomorus cavalla*) was quite high (62.5%), followed by the Brazilian sharpnose shark (*Rhizoprionodon lalandii*, 33%). From 2 to 6 plastic resin pellets were encountered in the stomachs of each fish, with sizes of from 1 to 5 mm, and with colors ranging from clear to white and yellowish. Ecological and health-related implications are discussed and the potential for transferring these materials through the food-chain are addressed. Further research will be needed of other species harvested for human consumption.

Marine debris is a growing threat to marine wildlife (Moore et al., 2001). Plastic pollution is found in all coastal and marine environments, from beaches, reefs, mangroves and estuaries, to the open ocean, and takes on many different shapes and forms (pellets, debris, and objects) (Ivar do Sul et al., 2009; Carvalho-Souza and Tinôco, 2011; Costa et al., 2009; Mordecai et al., 2011; Vieira et al., 2011).

Several papers have explored issues related to the accumulation and distribution of plastics in marine habitats and the resulting impacts on aquatic species and various ecological processes (e.g., behavior, bioinvasion, food resources, chemical pollutants) (Laist, 1997; Barnes et al., 2009; Gregory, 2009; Browne et al., 2011; Rochman et al., 2014; Carvalho-Souza, 2015). The ingestion of marine debris by marine wildlife, ranging from zooplankton to marine megafauna (fish, seabirds, sea turtles, and marine mammals) has been widely documented (Laist, 1997; Tourinho et al., 2010; Schuyler et al., 2013; Di Beneditto and Awabdi, 2014).

The first reports of marine debris ingestion by fish was published by Carpenter et al. (1972) and described the presence of plastic particles in larvae and adult fish. Many other species of fish, rays, and sharks have been documented ingesting plastic debris in recent decades, with the number of records still growing steadily (Hoss and Settle, 1990; Laist, 1997; Jackson et al., 2000; Cliff et al., 2002; Boerger et al., 2010; Possatto et al., 2011; Dantas et al., 2012; Choy and Drazen, 2013; Jantz et al., 2013; Foekema et al., 2013; Lusher et al., 2013; Di Beneditto and Awabdi, 2014; Ramos et al., 2012; Romeo et al., 2015).

Plastic can cause direct damage to marine wildlife through entanglement, malnutrition (gut blockage and pseudo-satiation), suffocation and decreased mobility – often resulting in their death (Laist, 1997). Indirect effects have also been documented relating to the accumulation of heavy metals and chemical pollutants such as polychlorinated biphenyls (PCBs), polybrominated diphenyls (PBDEs), and polycyclic aromatic hydrocarbons (PAHs) (Teuten et al., 2009; Frias et al., 2010).

Other harmful effects of discarded plastics include the transport of alien/invasive species (so-called 'hitch-hiking') and the inhibition of gas-exchange and the resulting smothering of seabeds (Gregory, 2009).

Rochman and Browne (2013) proposed classifying plastics (synthetic polymers) as hazardous wastes, and the risks of plastic ingestion are now focusing on its transfer between trophic levels, health impacts across food-chains, and possible effects on humans. New research is needed in this key area.

Laboratory studies have confirmed plastic transfer between mussels and crabs (Farrel and Nelson, 2013); a more recent investigation reported the ingestion of plastic microspheres by several zooplankton groups and plastic micro-particle transfer (via planktonic organisms) between trophic levels (mesozooplankton-macrozooplankton) (Setälä et al., 2014). Likewise, medaka fish exposed to a complex mixture of plastic (and their associated chemical pollutants) via ingestion showed disturbances of endocrine system functioning (Rochman et al., 2013, 2014). Matsson et al. (2015) – demonstrating that nanoparticle uptake occurs throughout the algae-zooplankton-fish food chain with resulting genetic, morphological, and behavioral alterations.

In light of these disturbing impacts, it will be important to identify fish species showing plastic residues in their stomachs. We report here a baseline assessment of the ingestion of plastic pellets by two

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commercially valuable fish species caught by artisanal fishermen on the eastern coast of Brazil.

The study area was located along the coast of the city of Salvador, Bahia State, in northeastern Brazil (Fig. 1).

Salvador is the capital of Bahia State and the third largest city in Brazil, with an estimated population of nearly 3 million (IBGE, 2014). The city has two public ports, seven private marine terminals, one oil refinery, and the largest integrated industrial-petrochemical complex in Latin America (since the late 1970s).

The plastic production chains in these industries are composed of three basic steps: 1) monomer generation (cracking, e.g., ethene, propene, butene, benzene); 2) polymerization (e.g., the formation of polyethylene, polypropylene, polystyrene, PVC, EVA, and others); and 3) transformation (manufacturing finished products for consumer markets) (ABIPLAST, 2013).

Occasional unintentionally resin pellet losses into rivers and other watercourses can occur during these steps or during logistic stages (e.g., terrestrial/aquatic transport), and these plastics will eventually migrate to coastal and marine environments (Ogata et al., 2009).

Metal and solid waste contamination has been documented in the Todos os Santos Bay in the metropolitan region of Salvador, impacting beaches, rocky shores, estuaries, and mangrove swamps (Hatje et al., 2010; Carvalho-Souza and Tinoco, 2011; Eça et al., 2013). These sites are known to be nurseries for many aquatic species and are used by artisanal fishermen. Coastal fisheries are an important economic activity in many areas in northeastern Brazil (Diegues, 2008).

Sampling was undertaken from April to May/2011 at two fishing ports in the city of Salvador: Pituba (Z1-APEPI) and Itapuã (Z6-COOPI) (Fig. 1). These are traditional fishing communities (e.g., COOPI was established more than two centuries ago) with artisanal fleets of small wooden boats. The fishermen generally use hook and line fishing techniques to capture high-value specimens (Dominguez et al., 2013).

Fish were collected randomly at the landing points from among recently captured specimens. Biometric measurements (furcal length – cm, weight – g) and taxonomic identifications (based on the scientific literature – Carvalho-Filho, 1999; Froese and Pauly, 2014) were performed at the landing points. The stomachs were removed from the fish and subsequently examined in the laboratory using a binocular dissecting microscope (40×).

The stomach contents were analyzed and separated into natural foods (prey and organic material) and plastic items. The plastic debris was further separated, quantified, and then classified according to its shapes and colors. The fish species were sorted according their habitats (pelagic or demersal) and trophic categories (Carvalho-Filho, 1999; Ferreira et al., 2004; Bornatowski et al., 2012; Froese and Pauly, 2014), noting, for each individual, where it was captured, the presence of plastics debris, and the numbers of plastic items and their frequencies.

The stomach contents of 32 fish specimens belonging 11 species and 9 families (2 elasmobranches and 9 teleosts) were examined (Table 1). Resin pellets were the only type of plastic observed in their stomachs. Plastic pellets were found in the stomachs of 7 individuals (22%) of two species: the king mackerel, *Scomberomorus cavalla* (Cuvier, 1829) (Scombridae) and the Brazilian sharpnose shark, *Rhizoprionodon lalandii* (Müller & Henle, 1839) (Carcharhinidae) (Fig. 2a-b). The highest frequency of plastic occurrence was recorded for *S. cavalla*, with 5 specimens containing pellets (62.5% of the individuals of the species), followed by 2 individuals of *R. lalandii* (33%). From 2 to 6 plastic pellets were encountered in *S. cavalla*, with sizes ranging from 2 to 5 mm in their longest dimension. From 1 to 3 small pellets were encountered in individuals of *R. lalandii* with sizes varying from 1 to 3

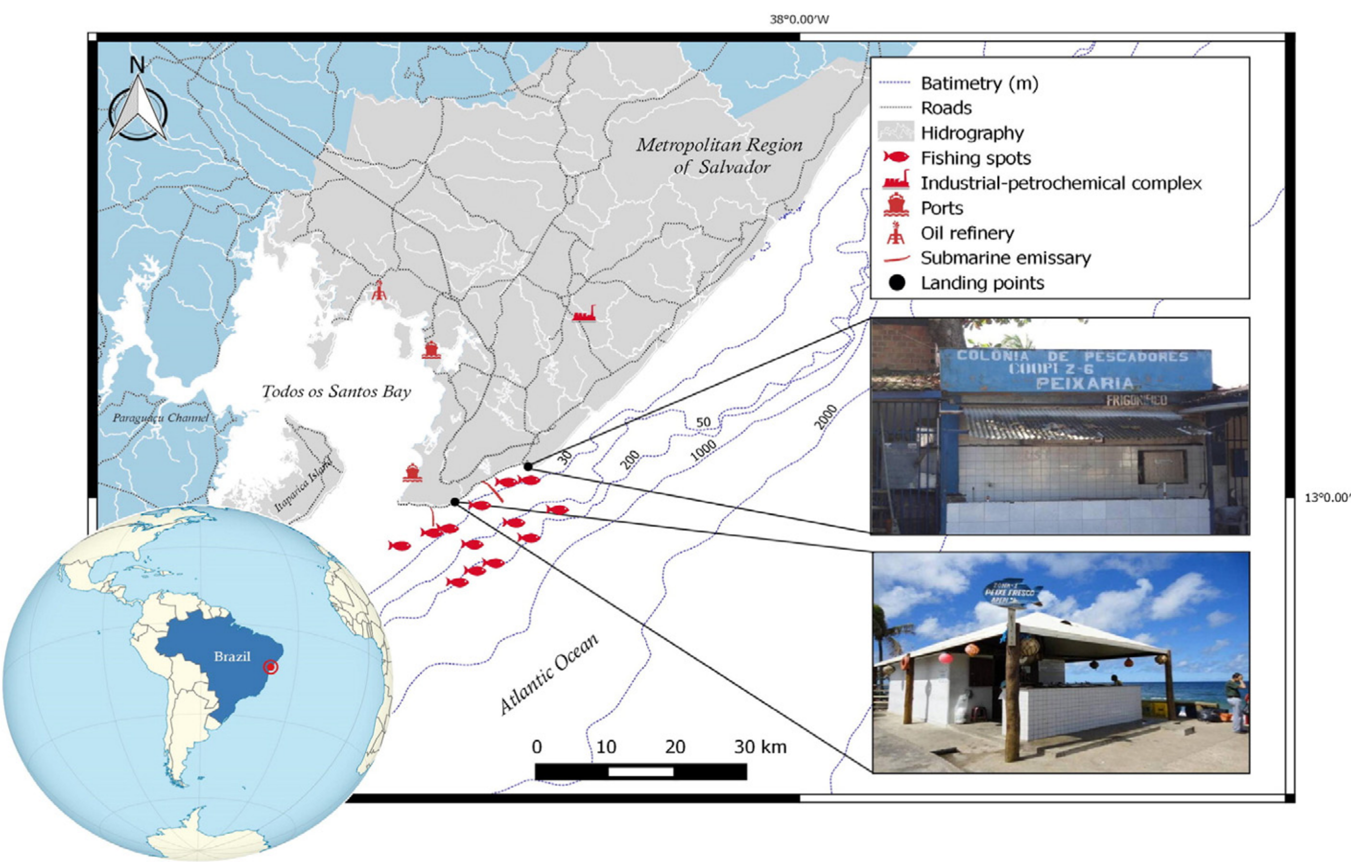

Fig. 1. Map of the metropolitan region of Salvador indicating two fishing ports, Bahia State, Brazil.

Table 1
The fish species analyzed with quantitative data concerning the micro-plastic pellets ingested.

Taxa	N Fish	N Fish Plastic	FOP (%)	N Plastic	Size Pellet (mm)	Habitat and Trophic Categories
Acanthurus coeruleus (*Bloch & Schneider, 1801*)	1	-	-	-	-	Reef/Roving Herbivore
Caranx crysos (*Mitchill, 1815*)	3	-	-	-	-	Pelagic-Coastal/Carnivore
Dasyatis americana (*Hildebrand & Schroeder, 1928*)	3	-	-	-	-	Sandy and Muddy Bottoms/Carnivore
Lagocephalus laevigatus (*Linnaeus, 1766*)	1	-	-	-	-	Pelagic-Coastal, Sandy and Muddy Bottoms/Omnivore
Lutjanus analis (*Cuvier, 1828*)	2	-	-	-	-	Reef/Carnivore
Lutjanus jocu (*Cuvier, 1828*)	5	-	-	-	-	Reef/Carnivore
Mycteroperca sp.	1	-	-	-	-	Reef/Carnivore
Paralichthys brasiliensis (*Agassiz, 1831*)	1	-	-	-	-	Sandy and Muddy Bottoms/Omnivore
Rhizoprionodon lalandii (*Müller & Henle, 1839*)	6	2	62.5	2-Jun	1-Mar	Pelagic-demersal/Carnivore
Scomberomorus cavalla (*Cuvier, 1829*)	8	5	33	1-Mar	2-May	Bentho-pelagic/Carnivore
Sphyraena guachancho (*Cuvier, 1829*)	1	-	-	-	-	Pelagic-Coastal/Carnivore

mm. The plastic resin pellets encountered had cylindrical shapes, and colors ranging from clear to white, and yellowish.

This study quantified the incidence of plastic pellets in the stomachs of carnivorous fish considered "generalist-predators" species that occupy high trophic levels. These predator species play a key role in environmental dynamics and contribute to maintaining the overall balance of marine ecosystems (Heithaus et al., 2008). Intensive fishing, habitat losses, and pollution have caused serious declines in the populations of large marine fish, and the present records are apparently the first to describe plastic pellet ingestion in two commercially important fish species (*S. cavalla* and *R. lalandii*) along the Brazilian coast.

The king mackerel is one of the most important fishery resources caught by artisanal fishermen in northeastern Brazil (Lessa et al., 2004). *S. cavalla* occurs in the Western Atlantic from Massachusetts (USA) south to Sao Paulo State (Brazil) (ICCAT, 2014). This species is considered over-exploited in the Gulf of Mexico, and protective actions are recommended for northeastern Brazil to avoid over-fishing (Lessa et al., 2004).

R. lalandii is an abundant, small, coastal elasmobranch distributed from the southwestern to western-central Atlantic Ocean (Rosa et al., 2004). The Brazilian sharpnose shark is important commercial resource commonly caught by artisanal fishermen; it has been reported to be impacted by marine pollution in the form of entanglement in plastic collars (Sazima et al., 2002; Rosa et al., 2004).

Fish have been consumed since time immemorial by human societies, and are known for their many health benefits (McManus and Newton, 2011). Organic compounds (e.g., PAHs) and heavy metals are known to impact fish behavior and health (Atchison et al., 1987; Ajiboye et al., 2011; Sevcikova et al., 2011; Weis and Candelmo, 2012), and maximum contamination levels have been established by government health agencies worldwide (Commission Regulation, 2006; Buchman, 2008; Brasil, 2013).

Many concerns regarding toxic compound transfers between trophic levels have resulted in laboratory experiments showing severe impacts of plastics on marine wildlife – including endocrine disruption and behavioral, physiological, and metabolic alterations (Rochman et al., 2013, 2014; Matsson et al., 2015).

Plastic pellets are a clear threat in aquatic environments due to their potential for accumulating and transporting contaminants adsorbed from the surrounding water (Teuten et al., 2009; Ogata et al., 2009). Carpenter et al. (1972) found white polyethylene spherules in the guts of several fish species caught along the New England coast (USA), indicating probable consumption selectivity. The three pellet colors (clear, white, and yellowish) encountered in the present work suggest that these plastics had been adrift in the sea for long periods of time and had undergone oxidation (Ogata et al., 2009) – although we cannot discount the possibility that digestive enzymes in the fishes' stomachs provoked color alterations. According to Endo et al. (2005), yellowing pellets may contain high concentrations of persistent organic pollutants (POPs).

Aquatic contamination by plastic pellets has been well documented globally (Ogata et al., 2009) and Brazil is not exempt (Costa et al., 2009; Ivar do Sul et al., 2009; Fisner et al., 2013; Turra et al., 2014). According to the International Pellet Watch (IPW), high concentrations of DDT have been identified in pellet samples collected in the waters off southern Bahia State (IPW, 2014).

The percentage of predator fish with ingested plastic pellets (50 %) was similar to, or greater than, reports of other studies of pelagic and demersal species. Lusher et al. (2013), studying pelagic and demersal fish in the English Channel, found plastic residues in 36.5% of the gastrointestinal tracts examined. The stomach contents of the sharpnose lancetfish, *Alepisaurus ferox*, were examined in the northern Pacific, and 24.5% of all individuals were found to contain plastic marine debris (Jantz et al., 2013). Pelagic predatory fish were reported to have frequencies of plastic ingestion ranging from <1% to 58% in the central-northern Pacific. Plastic ingestion has been documented in estuarine fishes such as catfish (23%), drums (7.9%), and gerreids (13.4%) (Possatto et al., 2011; Dantas et al., 2012; Ramos et al., 2012) as well as in pelagic coastal fish (0.7%) in Brazil (Di Beneditto and Awabdi, 2014). Even more recently, Romeo et al. (2015) encountered macro-, meso-, and micro-plastic debris in 12.5% to 32.4% of the stomachs of three large pelagic fish (*Xiphias gladius*, *Thunnus thynnus*, and *Thunnus alalunga*) in the Mediterranean Sea.

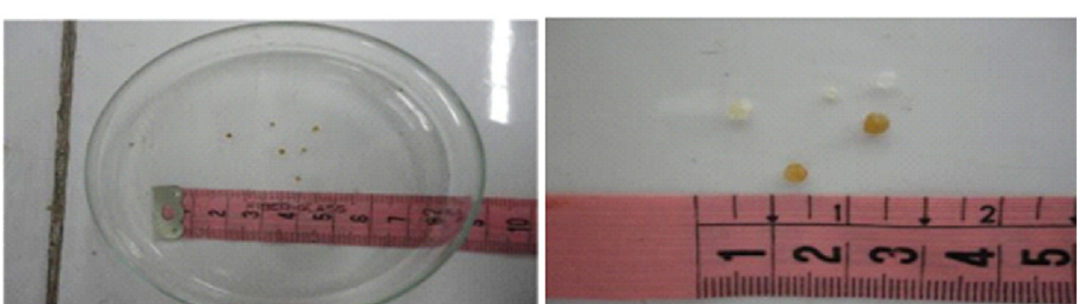

Fig. 2. Samples of the plastic pellets encountered in the stomach contents of fish. Scale (cm).

Plastic ingestion by marine organisms is commonly reported as "mistaken identity" consumption because of its similarity to natural prey. This hypothesis is well supported in the case of sea turtles ingesting clear plastic items (e.g., plastic bags floating in the water) due to their 3D shapes and movements that are similar to jellyfish (Schuyler et al., 2013). Many species of seabirds have also been found with high concentrations of micro-plastic (transparent or colored) debris in their digestive tracts, which were apparently mistaken for potential prey (e.g., fish eggs, plankton) (Azzarello and Van-Vleet, 1987; Laist, 1997). Nylon ingestion by estuarine fish during suction feeding in sediments could reflect their resemblance to polychaetes (Possatto et al., 2011) or to the consumption of organisms aggregated to plastic debris (mixed with natural prey items) (Ramos et al., 2012). These hypotheses do not appear appropriate for explaining the ingestion of micro-plastic debris by top fish predators.

Recent hypotheses concerning the consumption of plastic debris by large fish have considered different aspects of their predatory feeding behaviors, including opportunist strategies, accidental ingestion during feeding strikes, or the ingestion of aggregated prey items (Battaglia et al., 2013; Romeo et al., 2015).

Previous studies of plastic ingestion, and available information on the dietary and feeding ecology of *S. cavalla* and *R. lalandii*, provide clues and suggest two hypotheses concerning why these "generalist-predator" species also ingest micro-plastic debris (Fig. 3).

(i) The voracious feeding habits of generalist predatory fish result in the non-intentional ingestion of plastic debris.
Mackerel fish (genus *Scomberomorus*) are known to perform rapid feeding attacks in pelagic environments, during vertical migrations, and on the seabed (Godcharles and Murphy, 1986; ICCAT, 2014). Similarly, sharpnose sharks (genus *Rhizoprionodon*) are opportunistic coastal predators dwelling and foraging along sandy and muddy inshore bottoms (Silva and Almeida, 2001; Rosa et al., 2004; Bornatowski et al., 2012). Some predator fishes (e.g., sharks) are also known to tentatively bite objects to examine them, and have been observed attacking drifting plastic (see Carson, 2013). As plastic micro-pellets are commonly encountered floating in aquatic environments or mixed with surface sediments (Ivar do Sul and Costa, 2013), there ingestion can occur non-intentionally during foraging and attack behavior.

(ii) Ingestion can occur through the food chain if micro-plastics were ingested by smaller prey items.
Fish such as clupeids and scianids (both reported ingesting plastic, see Carpenter et al., 1972; Dantas et al., 2012), together with crustaceans and squids, are the main food items of larger generalist-predators, (Bornatowski et al., 2012; ICCAT, 2014). Cephalopods and crustaceans are known to ingest plastic debris (Murray and Cowie, 2011; Braid et al., 2012), and the food-chain hypothesis has been described for marine mammals (Eriksson and Burton, 2003).

The ingestion of plastic pellets by predatory fish therefore comes as no surprise, but indicates that this type of contamination in tropical coastal areas will certainly increase and will require more attention in the near future – especially in terms of human health – as resin pellets in the guts of fish prized for human consumption are a potential public health hazard.

Environmental pollution by plastics is a growing challenge for health and governmental agencies, society as a whole, and the scientific community. Further studies will be needed of commercially valuable species destined for human consumption, to verify their health statuses, maximum contamination tolerance levels, and the potential transfer of contaminants to upper trophic levels in the environment – including humans.

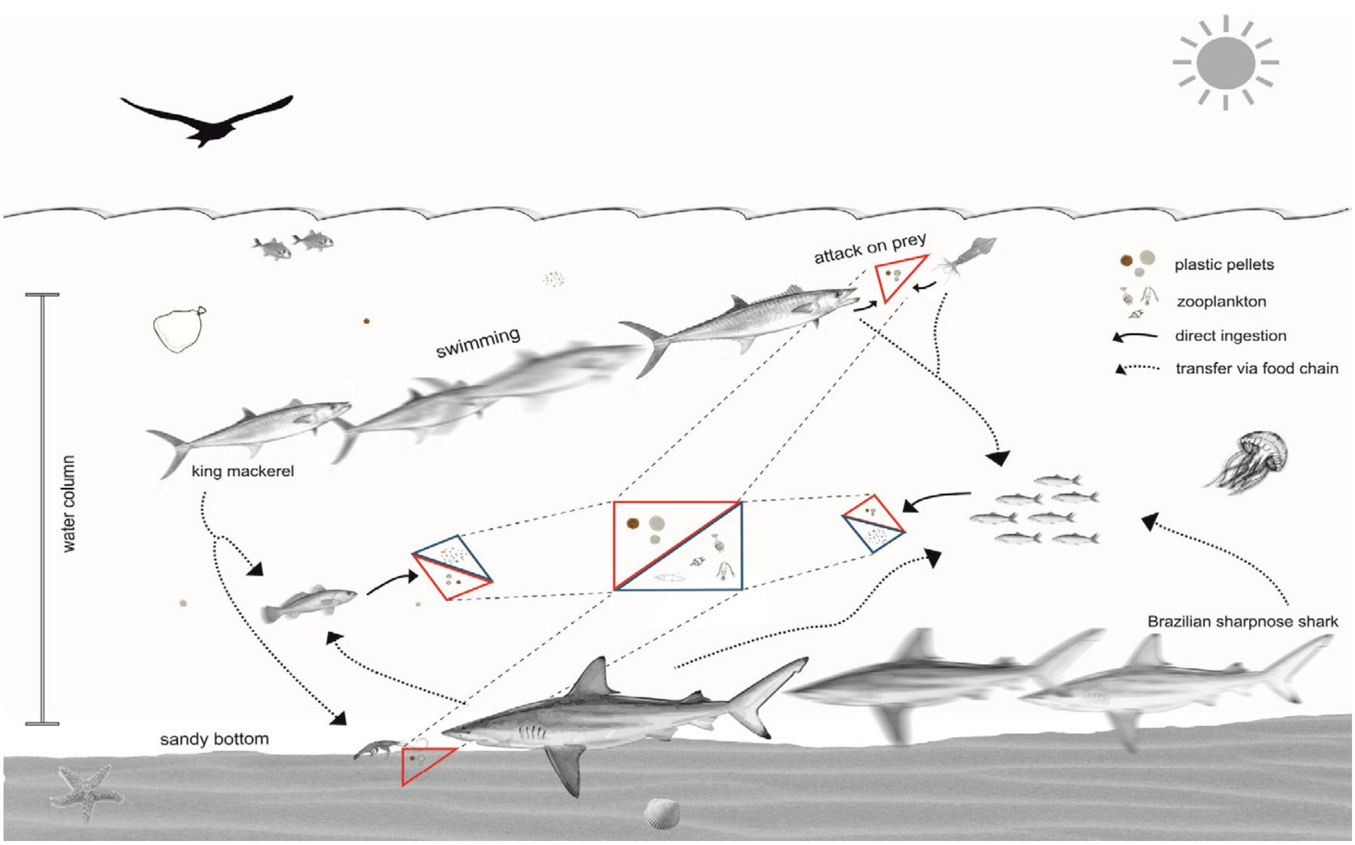

Fig. 3. Conceptual model of plastic pellet ingestion by generalist-predators.

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