Microplastic ingestion by Atlantic chub mackerel (*Scomber colias*) in the Canary Islands coast

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Abstract

In recent years, microplastics have become a subject of intense investigation due to the increasing concerns about their negative impact on wildlife and possible toxicity to living organisms (including humans). In the ocean microplastics can be easily ingested by numerous marine organisms because of their small size (<5 mm). The Northwest African upwelling system is an important fishery area, the present study is the first one in the region to reveal the presence of microplastic particles in the digestive tract of Atlantic chub mackerel (*Scomber colias*). From 120 fish gastrointestinal tracts examined, 78.3% contained some type of microplastics, 74.2% contained fibres, 17.5% plastic fragments and 16.7% paint. More studies are needed on fish, but *S.*

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colias is a candidate for being a good indicator of microplastic contamination in the region.
Keywords: fish, marine litter, Canary Current, wastewater, plastic pollution

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1. Introduction

Microplastics (MPs) were described more than 40 years ago (Carpenter et al., 1972; Shiber, 1982, 1987), but since the beginning of the new millennium they have become an object of intense study (Thompson et al., 2004; Andrady, 2011; Ivar Do Sul and Costa, 2014; Lusher, 2015; Barboza and Garcia Gimenez, 2015; Avio et al., 2016; Shim and Thomposon, 2015) due to the increasing concerns about their negative impact on wildlife and their toxicity on living organism including humans (Wright et al., 2013). Here, we consider microplastics any plastic particles smaller than 5 mm (secondary or primary-sourced) which is the agreed definition of the National Oceanic and Atmospheric Administration (NOAA) workshop (Arthur et al., 2009). lndustrial and fishing activities, and indiscriminate disposal of waste material leads to direct or indirect transfer of plastic litter to the marine environment. Most common types of microplastics, found in the oceans, are fragments of larger plastics, microparticles from cosmetic products, synthetics fibres from washing laundry, and resin pellets from the plastic industry that were lost during the production process (Veiga et al., 2016). Although wastewater treatment plants are able to filter most of the microplastics and plastic debris (Talvitie et al., 2017; Mason et al., 2016), there is still a considerable amount of microplastics that enters into aquatic ecosystems (Browne et al., 2007, 2011; Fendall and Sewell, 2009; Mason et al., 2016; Correia Prata, 2018). In addition, plastics that enter river systems - directly or indirectly - will eventually end up in the sea (Lebreton et al., 2017).

Due to their small size and abundance, microplastics are potentially consumed by a wide range of organisms. Ingestion has been observed in several invertebrate and vertebrate species, including fishes (reviewed in Ivar Do Sul and Costa (2014), Lusher (2015) and Rezania et al. (2018)). However, most of the research on invertebrates is restricted to controlled laboratory experiments (Phuong et al., 2016). Microplastics can be ingested directly or indirectly as a result of eating lower trophic-level organisms that have consumed microplastics themselves (Browne et al., 2008; Cole et al., 2011; Nelms et al., 2018).

Once ingested, microplastics may be egested, retained or block the digestive tract, cause pseudo-satiation leading to decreased food consumption, get absorbed by the gut or be translocated into other tissues (Derraik, 2002; Wang et al., 2016; Jovanović, 2017). Browne et al. (2008) observed that microplastics ingested by *Mytilus edulis* were translocated from the gut to the circulatory system and persisted there for several weeks. Microplastic ingestion in *Mytilus edulis* is commonly studied and transference of microplastics from *M. edulis* to higher trophic levels has been observed (Farrell and Nelson, 2013). The implication for the rest of the food web, including humans is concerning (Farrell and Nelson, 2013; Setälä et al., 2014). There are several studies that reveal microplastic ingestion in various fish species in different parts of the world (Carson, 2013; Lusher, 2015), including planktivorous fish in the North Pacific Central Gyre (Boerger et al., 2010a); various small pelagic fish in North Pacific (Davison and Asch, 2011); pelagic and demersal species from the English Channel (Lusher et al., 2013), marine catfish on the Brazilian coast (Possatto et al., 2011); fish from markets in Indonesia and California (Rochman et al., 2015); fish species from the Mediterranean Sea (Nadal et al., 2016; Romeo et al., 2015; Compa et al., 2018; Anastasopoulou et al., 2018) and also fish from fresh water and estuaries (Pinheiro et al., 2017; Silva-Cavalcanti et al., 2017; McGoran et al., 2017; Pazos et al., 2017). Davison and Asch (2011) estimate the ingestion rate of plastic debris by mesopelagic fish in the North Pacific to be from 12,000 to 24,000 tons per year.

In addition, persistent organic pollutants (POPs) such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDTs) can be adsorbed onto plastics, mainly due to a greater affinity of these pollutants for the hydrophobic surface of plastics compared to seawater (Wang et al., 2016). Rochman et al. (2013) found greater concentrations of PCBs and polybrominated diphenyl ethers (PBDEs) in fish fed with marine plastic than those fed with virgin plastic particles, which indicates that plastic litter serve as an accumulation point and a pathway for the adsorbed POPs into the food web. PCBs can lead to reproductive disorders and alteration of hormone levels and have a harmful effect on marine organism even at low levels (Derraik, 2002).

Atlantic chub mackerel *Scomber colias* (Gmelin, 1789) is a coastal pelagic species present in Atlantic Ocean and Mediterranean and Black Sea. Previously cited as *Scomber japonicus*, it has been demonstrated that there are morphological and genetic differences between species, now being accepted the classification of *S. colias* in the Atlantic and *S. japonicus* in the Indo-Pacific. *S. colias* reach the first sexual maturity (50% of individuals) at 20 cm of total length (TL) at the first year of life (Lorenzo Nespereira and González Pajuelo, 1993). It is an important fishery resource in the Canary Islands, with an estimated biomass in the Canary archipelago of 38,000 tones (Lorenzo Nespereira and González Pajuelo, 1993). It is the most important resource of the traditional purse seine fleet, accounting for about 60% of the total coastal pelagic catch (Lorenzo and Pajuelo, 1996). Studies carried out on Gran Canaria (Canary Islands) showed that *S. colias* is mainly planktivorous, with mysids being an important component in their diet.

In the present work we aim to: (1) asses, for the first time, the ingestion of microplastics in a coastal pelagic fish (*Scomber colias*) in the Canary archipelago; (2) determine if there are differences in the number of microplastics in the digestive tract of fish from two different fishing areas: Lanzarote and Gran Canaria; and (3) analyze the types of plastic particles found and their possible sources.

2. Materials and Methods

2.1. Fish sampling and laboratory analysis

The fish were bought from artisanal fishing fleets in Gran Canaria and Lanzarote (Fig. 1). In the Canary Islands Atlantic chub mackerel are fished with purse-seine nets at a depth of 40-50 m, and fish are lured with light (Castro, 1995). To determine microplastic ingestion we applied a slighty modified methodology recommended by MSFD GES Technical Subgroup on Marine Litter and MSDF Technical Subgroup on Marine Litter (2013). Each specimen was weighted and total length (TL) was measured prior dissection. Gastrointestinal tracts were removed, rinsed and stored in ethanol 70%. The digestive tract content was removed and treated with 10% KOH during 24 h at 60℃, in order to degrade as much organic matter as possible (Dehaut et al., 2016).

After digestion, the remaining material was filtered using a 50 μm zooplankton mesh and visually examined under the stereomicroscope for at least 10 minutes. All potential microplastic particles were photographed and measured. Items were classified according to size, texture and shape into fragments, fibres, lines, paint and films. The fibres were distinguished from lines by being smaller and more flexible than the lines derived from fishing nets. Microplastic particles were determined by visual inspection, in the case of doubt, FTIR (Perkin Elmer spectrometer, model FTIR Spectrum BX) was used to confirm the material composition (Supplementary Material Figs. 1-7). In the case of the fibres, no micro-FTIR inspection was performed, they were visually determined according to the homogeneous color, brightness and absence of cellular structures. However, in particles smaller than 500 microns, and particularly in fibres, the visual determination error can reach 70% (Lusher et al., 2017), therefore, in the case of fibres it is not possible to determine with certainty whether they are synthetic or natural (e.g. cotton, linen, manila, kenaf, sisal rope, silk, wool, cellulose) (Halstead et al., 2018).

The stomach content filtration and final sample observation was performed under a laboratory fume hood, and all material and working places were cleaned with alcohol in order to reduce any air-born fibre contamination. During the entire process (extraction, digestion, filtration and visual examination), cotton lab coats were worn to prevent contamination of the samples. A petri dish with clean 50 μm mesh was placed near the stereomicroscope during the visual inspection as contamination control. If any fibres were found in the control, the sample was discarded. During the analysis only one control was contaminated with fibres and that sample was discarded because we could not determine if the fibres present were due to air borne contamination.

2.2. Statistical analysis

Data normality were analyzed by the Shapiro-Wilk test and data homoscedasticity was assessed graphically. Since the distribution of data was not normal, Wilcoxon Mann Whitney test was applied to determine significant differences in microplastic ingestion (items/fish) among fishing areas. The results were represented in box plots. Statistical analysis and graphics were performed with R statistical software (R Core Team, 2017) and its extension, RStudio.

3. Results

Overall, 120 specimens of *Scomber colias* were studied, 60 from fish markets of Gran Canaria and 60 from Lanzarote. Total length of fish ranged from 15 to 44 cm, and wet weight ranged from 30 to 830 g. A total of 94 individuals (78.3%) had microplastics in the digestive tract (Fig. 2). A percentage of 74.2% of the sampled fish (89 individuals) had ingested fibres, 17.5% (21 individuals) fragments, 16.7% (20 individuals) paint, 3.3% (4 individuals) lines and 1.7% (2 individuals) films (Figs. 2 and 3).

The average number of microplastics ingested by all fish sampled was 2.17±2.04 items per fish, (mean±SD). Of the 96 fish that ingested microplastics, an average of 2.77±1.91 items per individual (mean±SD) was found, ranging from 1 to 9 items. Significant differences were found in the number of items per individuals (total sampled) among fishing zones ($p<0.01$). The average number of microplastics per fish in Lanzarote was 2.55 and in Gran Canaria, it was 1.78. The median values were 2 and 1 for Lanzarote and Gran Canaria, respectively (Fig. 4).

From the 260 microplastics found, 193 were fibres (74.23%), 31 fragments (11.93%), 30 paint chips (11.54%), 4 lines (1.54%) and 2 films (0.77%) (Fig. 5). The size range (maximum length) of the microplastics found was between 0.035 and 29.5 mm, with a median of 0.9 mm. Only 7 items (4 fibres and 3 lines) had a maximum length higher than 5 mm (Fig. 3).

In the plastic debris ingested, the most frequent colors were blue (55%) and black or dark (23.5%). If we analyze the fibres only, the most frequent colors were blue (51.8%) and black or dark (30.8%). In the other types of plastic debris (fragments, paint, lines and films) blue was also the most frequent (64.2%), followed by white or light (13.4%) (Figs. 6 and 7).

4. Discussion

The percentage of fish that ingested microplastics was higher than the percentages reported in most other studies of demersal and pelagic fish (Table 1). However, recent studies in estuaries, bays and enclosed seas show percentages of microplastic intake similar to those found in the present work (Table 1). Jabeen et al. (2017) found microplastics in almost 100% of the fish studied from the Shangai market; Nadal et al. (2016) found microplastics in 57% of bogue from the Mediterranean Sea; Pellini et al. (2018), in 95% of flatfish from the Adriatic Sea and Tanaka and Takada (2016), in 77% of the Japanese anochovy from Tokyo Bay. In addition, microplastic ingestion was reported in 73% of two banded seabream in the Mondego estuary in Portugal (Bessa et al., 2018) and in 100% of the fishes from the Río de la Plata estuary (Pazos et al., 2017). High incidence was also found in *Mugil cephalus* with MPs present in 60% of mullets from fishery markets of Hong Kong (Cheung et al., 2018), 73% from an urban harbour in South Africa (Naidoo et al., 2016) and 64% from Sydney Bay (Halstead et al., 2018).

Here, most of the microplastics found were fibres, consistent with the majority of the published studies (Table 1). According to the types of plastic particles found, we have deduced the possible sources. Most of the fibers are washed out from sewage (74.2%). Washing clothes has been shown to release thousands of synthetic fibres into the sea through wastewater discharges (Browne et al., 2011; Napper and Thompson, 2016). Paint and lines could come from the fishing activity (13.1%). However, the fragments and films are from undetermined sources, from land and sea (12.7%).

While the present study was carried out in the coastal waters of the Canary Islands, located in the North Atlantic Ocean, the fishing areas were close to urban areas. This could determine the high incidence of microplastics in the gastrointestinal content of Atlantic chub mackerel. In the Canary Islands, sewage, after treatment in wastewater treatment plants (WTPs), discharges directly to sea. According to official data of the Canary Islands Government (http://visor.grafcan.es/visorweb/)(GRAFCAN Cartográfica de Canarias), there are 20 wastewater effluents in Gran Canaria and 31 in Lanzarote, located less than 10 Km from fishing areas. Of these discharges, 6 in Gran Canaria and 22 in Lanzarote do not have treatment or data are not known because they do not have valid legal authorization (Fig. 1b). In addition, untreated wastewater is occasionally discharged to the sea during heavy rain.

These submarine discharges could be a source of pollution, especially of synthetic fibres, and this could be the reason for the difference in the amount of fibres found in the fish from Lanzarote, compared to Gran Canaria. Talvitie et al. (2017) determined that about 98% of the plastics debris are removed in pre-treatment phase, however, other authors argue that wastewater discharges represent a source of microplastics in aquatic ecosystems (Browne et al., 2011; Estahbanati and Fahrenfeld, 2016; Murphy et al., 2016; Mason et al., 2016; Correia Prata, 2018). Though a major part of microplastics are removed in WTPs, due to the large volume that is processed every day, sewages effluents discharge from aprox. 50,000 up to nearly 15 million particles to the environment (Mason et al., 2016).

Although the high incidence of fibres, similar to that found in estuaries or areas with high anthropogenic pressure (Pazos et al., 2017), points to a local source of pollution, we cannot ensure its origin without an ad hoc experimental design assessing the nature and quantity of microplastics released by each of the WTPs discharges along the eastern coasts of Lanzarote and Gran Canaria. In addition to the hypothesis of local sources of fibres as a product of WTPs discharges, we have also inspected the mean ocean circulation in the region of study based on modeling data. This suggests that a relatively strong current (see black arrow in Figure 1) connecting the east coasts of Lanzarote, Fuerteventura and Gran Canaria might be causing a downstream cumulative effect between the islands. In this case, due to the cumulative effect, fish from Gran Canaria would be contaminated with more fibres than fish from Lanzarote; however our results indicate, counterintuitively, the opposite. Findings in this work highlight the complexity of this polluted system, stressing the need of further ad hoc studies to determine the origin of microplastics that enter the ocean from the islands, primarily due to the release of untreated wastewater discharges.

In microplastics found in the present work, the predominant colour was blue, both in the fibres and in the other plastic particles. Other authors reported similar results (Boerger et al., 2010b; Davison and Asch, 2011; Güven et al., 2017; Pazos et al., 2017; Peters et al., 2017; Ferreira et al., 2018; Bessa et al., 2018). Ory et al. (2017) argue that high incidence of blue color could be due to mistakenly ingested microplastics similar to their natural prey, for instance, some species of blue copepods. In samples collected with a manta net in surface waters off the Canary Islands, a high percentage of blue copepods (*Labidocera* sp.) were found (unpublished data) (Fig. 8), which could support this hypothesis.

Blue paint chips found here are likely to be fragments of fishing vessel coating, and ingestion could occur during capture (net feeding). Rummel et al. (2016) also found red and green fragments that were identified as chips from the research vessel coating. The study excluded these results because they were attributed to post-capture feeding. In the present study, we have not excluded these data from the results, due to the importance they may have in future studies, even if they are due to post-capture feeding. It is necessary to investigate whether this is the case, or if there is contamination by ship painting in coastal areas.

5. Conclusions

1- The present study shows that Atlantic chub mackerel caught in coastal waters of the Canary Islands have a high incidence of microplastics in the gastrointestinal content (78%).

2- Future studies are needed to determine: which fish species are affected by microplastics, which fish could serve as indicator species, and what effects the microplastics have on fish physiology and health.

3- It is necessary to carry out studies to investigate different stages of wastewater processing, as well as submarine effluents, to determine the impact of WTPs as sources of microplastics, mainly synthetic fibres.

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7. Figures

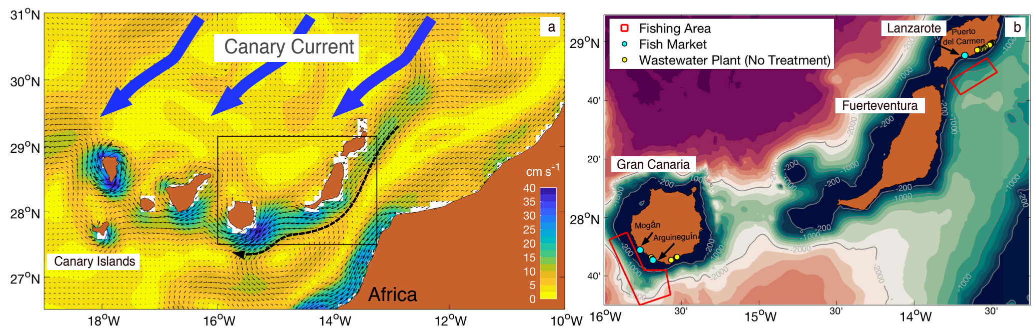


Figure 1: a) Canary basin circulation (depth-averaged annual mean of 2016 for the upper 40 m) based on model data from the high resolution (1/12∘) global analysis and forecasting system PSY4V3R1 version 3.1 of NEMO ocean model (Madec and NEMO-Team, 2008) provided by the Copernicus Marine Environment Monitoring Service (CMEMS). Currents are shown as a vector velocity field (shades of colors are cm^{-1}). A zoom in panel (b) is indicated with a black rectangle. b) Bathymetric map with indication to he fishing areas south of Gran Canaria and Lanzarote (red rectangles), wastewater discharges without treatment prior to water disposal (yellow circles) (GRAFCAN Cartográfica de Canarias) and fish markets (cyan circles).

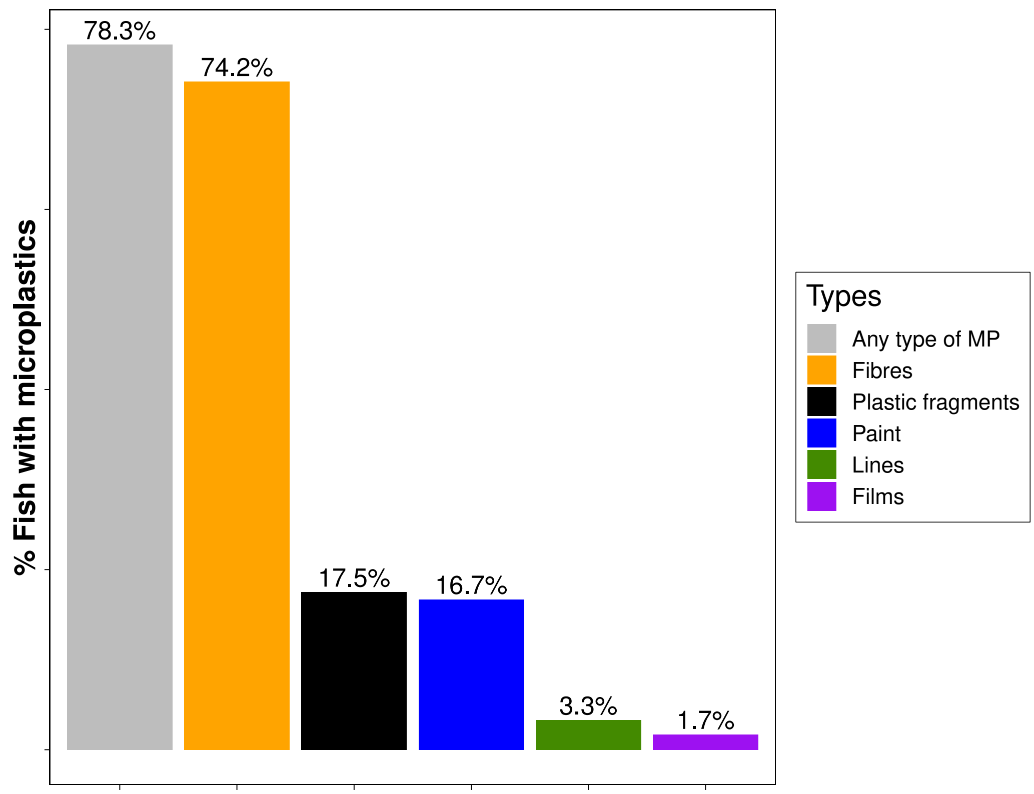


Figure 2: Percentage of fish with microplastics in the gastrointestinal content.

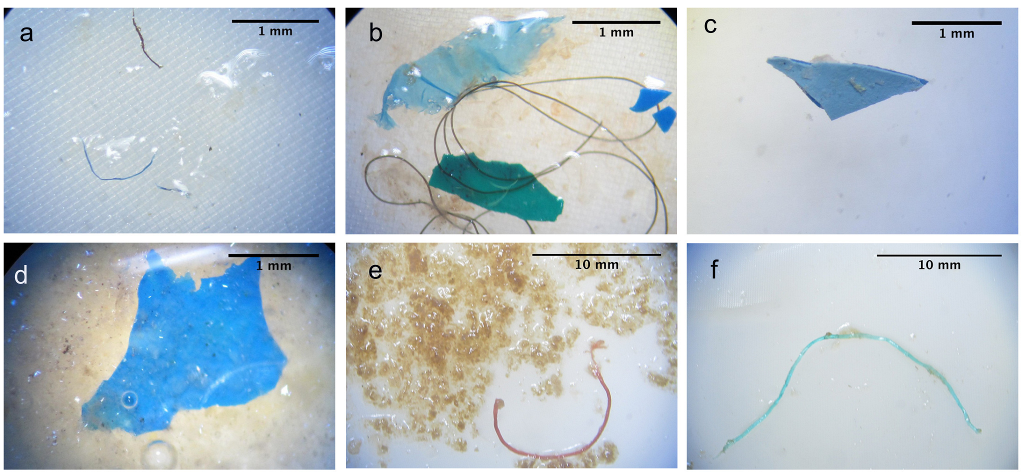


Figure 3: Microplastics found in the gastrointestinal contents of fish purchased from fish markets in Gran Canaria and Lanzarote. a) Fibres. b) Film, fragments and line found in one fish. c) Plastic fragment. d) Chip paint. e) Red line from fishing gear. f) Green line from fishing gear.

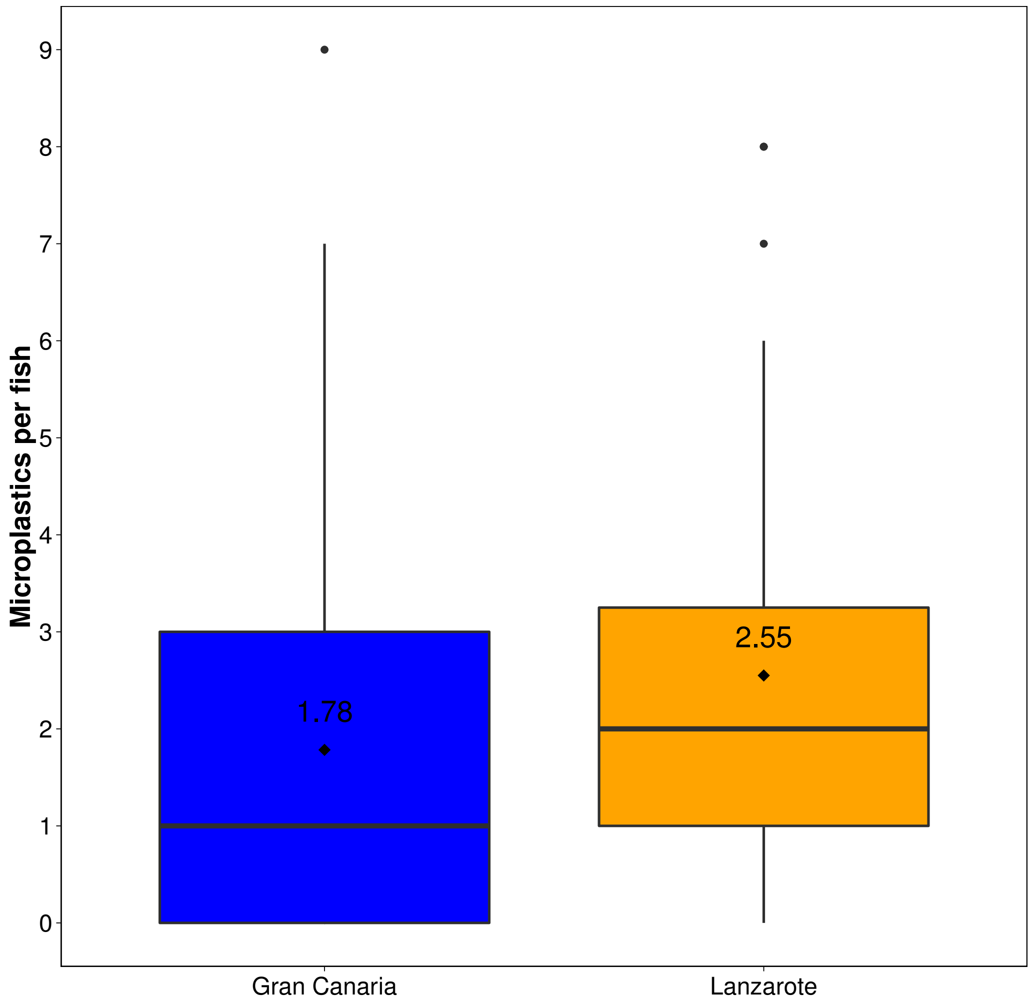


Figure 4: Microplastics per fish collected from Lanzarote and Gran Canaria. The point and the number in the box represent the mean microplastics per fish. The thick central line of each box designates the median, the box height shows the interquartile range, and the whiskers indicate the lowest and the highest values.

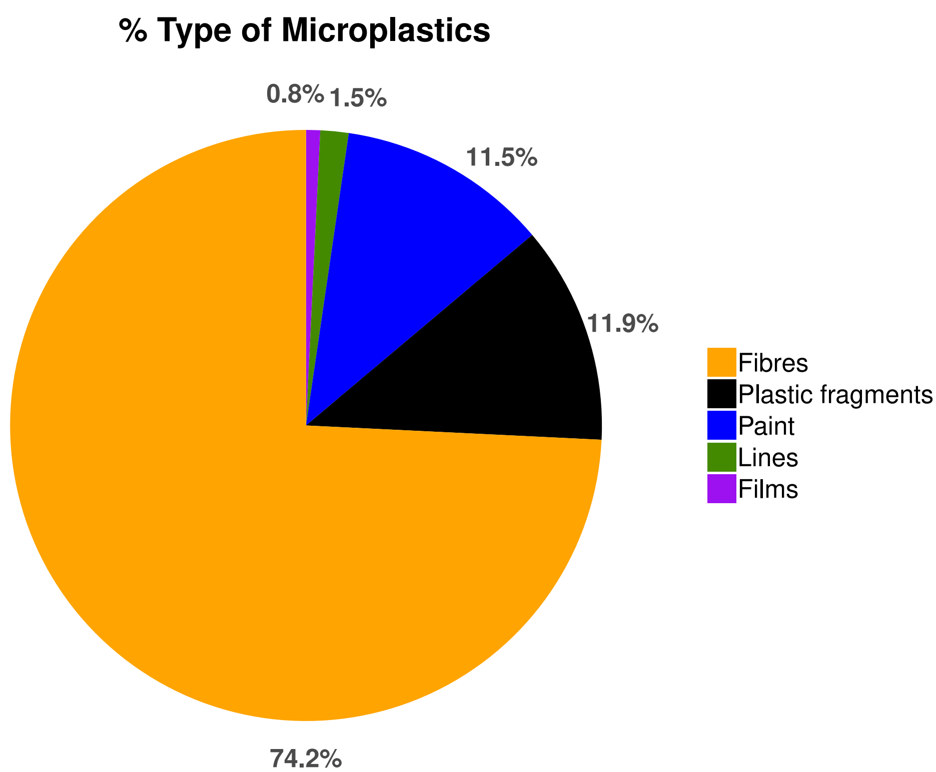


Figure 5: Percentage of each type of microplastics found.

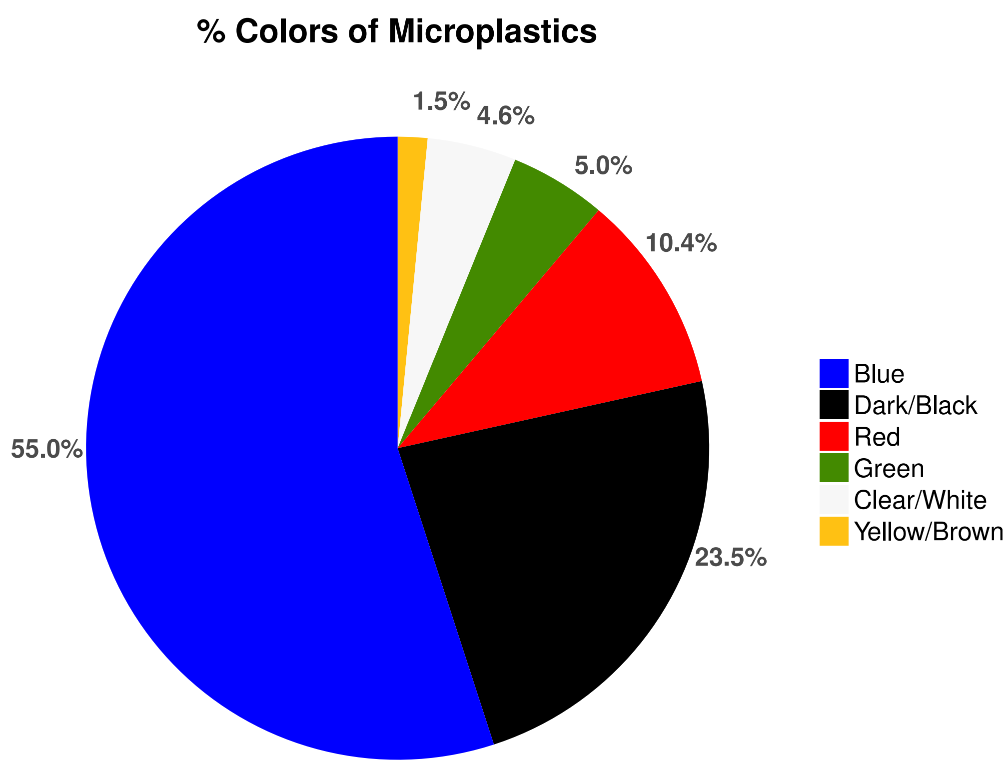
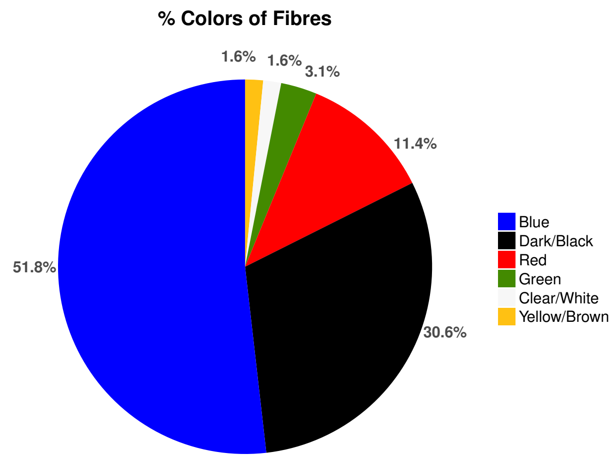
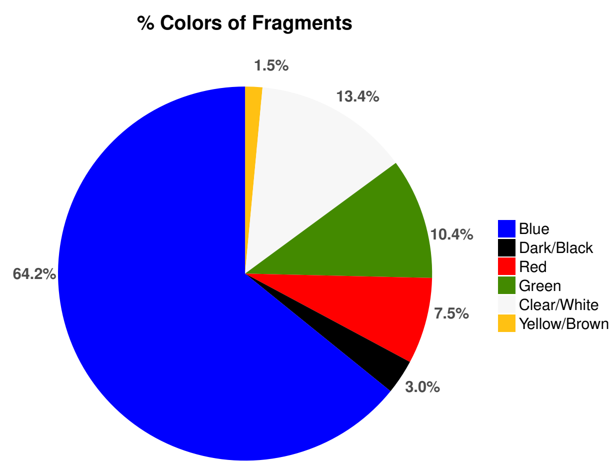


Figure 6: Percentage of colors of total microplastics found in the stomach content.



(a) Color of Fibres



(b) Color of Fragments, Lines, Films and Paint

Figure 7: Percentage of colors of (a) Fibres and (b) Fragments, lines, films and paint.

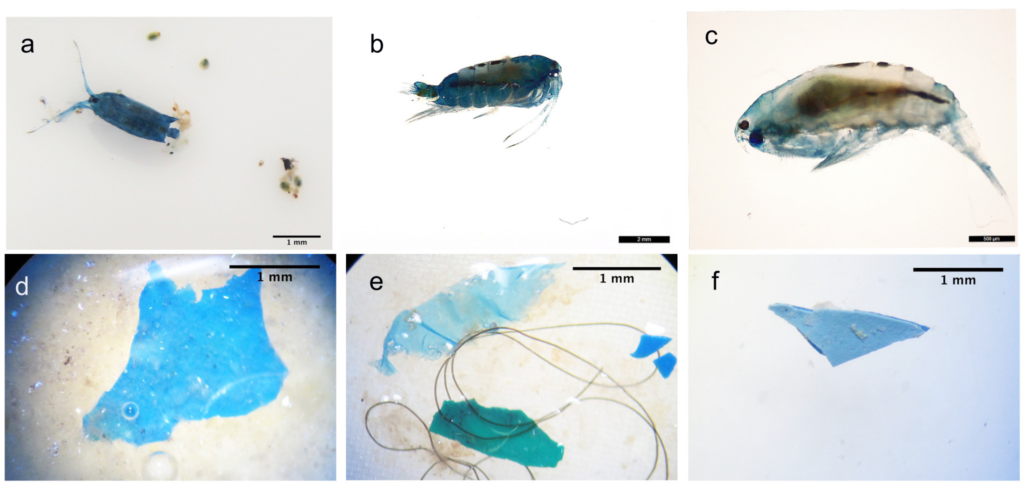


Figure 8: Copepods of the genus *Labidocera* (a-c) compared with blue microplastics found in fish (d-f).

Table 1: Literature review

Location	Digestion	Sample size (n)	Specie	Fish with MPs (%)	Average MPs/fish	predominant color (%)	predominant type (%)	Reference
North Pacific Gyre	no	670	6 species	35%	5.9	58% white	94% fragments	Boerger et al. (2010b)
North Pacific Gyre	no	141	27 species	9.2%	1.2	N/A	56% fragments	Davison and Asch (2011)
North Sea, Atlantic**	10% KOH	1203	7 species	2.6%	N/A	N/A	Fibres N/A	Foekema et al. (2013)
English Channel	no	504	10 species	36.5%	1.9	45% black	68% fibres	Lusher et al. (2013)
Portuguese coast, Atlantic	no	263	26 species	19.8%	1.40	N/A	66% fibres	Neves et al. (2015)
Gulf of Mexico	no	419	44 freshwater species	8.2%	N/A	N/A	fragments	Phillips and Bonner (2015)
Gulf of Mexico	no	116	8 marine species	10.4%	N/A	N/A	filaments	Phillips and Bonner (2015)
Eolian Islands, Mediterranean Sea***	no	123	*3 species*	18.2%	N/A	N/A	N/A	Romeo et al. (2015)
Spain, Atlantic and Mediterranean	1M NaOH	212	3 species	17.5%	1.56	51% black	71% fibres	Bellas et al. (2016)
Norwegian coast	no	302	*Gadus morhua*	3%	1.77	N/A	N/A	Bråte et al. (2016)
Balearic Islands, Mediterranean Sea	no	337	*Boops boops*	57.8%	3.75	N/A	100% fibres	Nadal et al. (2016)
South Africa urban harbour	no	70	*Mugil cephalus*	73%	5.1	White and clear	51% fibres	Naidoo et al. (2016)
Tokio Bay	10% KOH	64	*Engraulis japonicus*	77%	2.3	N/A	86% fragments	Tanaka and Takada (2016)
North and Baltic Sea***	no	290	5 species	5.5%	1.44	N/A	N/A	Rummel et al. (2016)
Balearic Islands, Mediterranean Sea	no	125	*Galeus melastomus*	16.8%	N/A	42% transparent	86% filaments	Alomar and Deudero (2017)
Turkish waters, Mediterranean Sea	35% H_2O_2	1337	28 species	58%	2.36	blue	70% fibres	Güven et al. (2017)
North Sea, Atlantic	10% KOH	400	4 species	0.25%	N/A	transparent	spherical particles	Hermsen et al. (2017)
China	30% H_2O_2	378	21 species	100%	N/A	transparent	Fibres	Jabeen et al. (2017)
		108	6 species	95.7%				
Northeast Atlantic, Scotland	no	128	3 species	47.7%	1.8	43% black	82% fibres	Murphy et al. (2017)
	no	84	9 species	2.4%				
Texas Gulf coast	no	1381	6 species	42.4%	1.93	purple/blue	86.4% fibres	Peters et al. (2017)
Argentina, Ro de la Plata estuary	30% H_2O_2	87	11 species	100%	19	blue	96% fibres	Pazos et al. (2017)
Paje river, Brazil***	no	48	*Hoplosternum littorale*	83%	4.4	N/A	47% fibres	Silva-Cavalcanti et al. (2017)
Western English Channel	no	347	23 species	2.9%	1.2	83% blue	83% fibres	Steer et al. (2017)
Estuaries, Brazil	no	2233	69 species	9%	1.05	N/A	90% fibres	Vendel et al. (2017)
	no	84	9 species	2.4%				
Goiana Estuary, Brazil	no	552	*Cynoscion acoupa*	51%	3.03	44% blue	99.9% fibres	Ferreira et al. (2018)
Adriatic Sea	10% KOH	533	*Solea solea*	95%	1.6	N/A	72% fragments	Pellini et al. (2018)
Southest Pacific Ocean**	no	292	7 species	2.1%	N/A	N/A	Fibres N/A	Ory et al. (2018)
Hong Kong east coast	30% H_2O_2	30	*Mugil cephalus* culture	16.7%	0.2	33% blue	100% fibres	Cheung et al. (2018)

Continued on next page

Location	Digestion	Sample size (n)	Specie	Fish with MPs (%)	Average MPs/fish	predominant color (%)	predominant type (%)	Reference
	30% H_2O_2	30	*Mugil cephalus* wild	60%	4.3	44% green	60% fibres	
		24	*Acanthopagrus australis*	25%	1.6			
Sydney Harbour, Australia*	no	45	*Mugil cephalus*	64%	4.6	N/A	83% fibres	Halstead et al. (2018)
		24	*Gerres subfasciatus*	21%	0.2			
Spanish coast, Mediterranean Sea		105	*Sardina pilchardus*	15.2%	0.21			
	no	105	*Engraulis encrasicolus.*	14.3%	0.18	N/A	83% fibres	Compa et al. (2018)
		40	*Dicentrarchus labrax*	23%	0.30			
Mondego estuary, Portugal	10% KOH	40	*Diplodus vulgaris*	73%	3.14	47% blue	96% fibres	Bessa et al. (2018)
		40	*Platichthys flesus*	13%	0.18			
		20	*Chelon auratus*	95%	9.5			
Adriatic Sea, Mediterranean Sea	30% H_2O_2	20	*Chelon auratus*	95%	9.5	N/A	75.6% filaments	Anastasopoulou et al. (2018)
		20	*Solea solea*	100%	7.3			
		30	*Mullus surmuletus*	70%	1.8			
Adriatic Sea, Mediterranean Sea	30% H_2O_2	30	*Pagellus erythrinus*	50%	1	N/A	97.7% filaments	Anastasopoulou et al. (2018)
		30	*Sardina pilchardus*	37%	0.9			
		25	*Mullus barbatus*	32%	0.5			
Ionian Sea, Mediterranean Sea	30% H_2O_2	19	*Pagellus erythrinus*	42%	0.8	N/A	79% filaments	Anastasopoulou et al. (2018)
		36	*Sardina pilchardus*	47%	0.8			
*Canary Island, North Atlantic	10% KOH	120	*Scomber colias*	78%	2.77	55% blue	74% fibres	Present work

* includes natural fibres

** fibres not account

*** includes micro and macroplastics