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Baseline

Evidence of microplastic ingestion by cultured European sea bass (*Dicentrarchus labrax*)

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ABSTRACT

The presence of microplastics (MPs) in the marine environment is a concerning topic due to the ecotoxicological effects and possible seafood contamination. Data is needed to evaluate human exposure and assess risks, in the context of a healthy and beneficial seafood consumption. While microplastic ingestion by wild fish has been reported since the early 70's, farmed fish are rarely investigated. Here, for the first time the presence of microplastics in fish cultivated in the coastal water of Tenerife (Canary Island, Spain) was evaluated. From 83 examined individuals, 65% displayed microplastics in their gastrointestinal tracts, with averages between 0.6 ± 0.8 (SD) and 2.7 ± 1.85 (SD) particles per fish. The total number of microplastics detected was 119. Fibres (81%) and fragments (12%) were the predominant shapes. FTIR analysis showed that fibres were mostly composed by Cellulose (55%) and Nylon (27%), whereas fragments by PE (25%) and PP (25%).

Since the beginning of the century, plastic pollution in the marine environment has continuously gained attention and has become a major problem worldwide (GESAMP, 2019; UNEP, 2016). Yearly increasing numbers of production (PlasticsEurope, 2016, 2018a, 2018b, 2019) and effects on marine wildlife due to entanglement, ingestion and even hitch-hiking of invasive species are of global concern (Gregory, 2009).

Ingestion of plastic by fish was first reported in the 1970's (Carpenter et al., 1972; Kartar et al., 1973). Carpenter et al. (1972) already suspected that the ingestion of plastic could cause intestinal blockage and therefore lead to major health problems and eventually death, but further investigations were sparse until 2010. Since then, the occurrence of plastic in fish and the resulting health threats have been well documented. Not only can ingestion of plastic lead to intestinal blockage, but it has also been directly linked to inflammatory responses of cells, alteration of gut microbiota, ulcerations, internal injuries and an increasing effect on mortality (Carpenter et al., 1972; Gall and Thompson, 2015; Hoss and Settle, 1990; Jabeen et al., 2018; Jin et al., 2018; Lu et al., 2016; Mazurais et al., 2015; Pedà et al., 2016; Wright et al., 2013). Studies have also shown that the ingested particles can travel within fish, as plastic was found in the liver, brain and even in the eggs (Avio et al., 2015; Chae et al., 2018; Collard et al., 2017; Ding et al., 2018; Pitt et al., 2018). Since plastic particles may also contain harmful chemicals, used as additives during plastic production or absorbed by the plastics in the water (Bakir et al., 2014; Camacho et al., 2019; Lee et al., 2014; Moore et al., 2005; Ogata et al., 2009; Rios et al., 2007; (Rochman et al., 2013a)), the combination of these chemicals and the plastic can cause a wide range of health problems such as liver toxicity, alteration of the endocrine system, neurotoxic effects, oxidative stress and even change of behaviour in fish (e.g. swimming behaviour, lethargy, predatory performance) (Barboza et al., 2018b(Barboza et al., 2018c); Chen et al., 2017; Luís et al., 2015; Oliveira et al., 2013; Rainieri et al., 2018; Rochman et al., 2013b; Rochman et al., 2014; Zhang et al., 2019).

The exposure of fish to microplastic is a matter of concern not only for fish health, but also for human health. Seafood is an important protein and polyunsaturated fatty acid source in human consumption and ingested microplastics were not only found in the gut, but also in muscle tissue (Abbasi et al., 2018; Garcia et al., 2020). Additionally, humans may be exposed to the harmful chemicals carried by microplastic that leached into animal guts (Bakir et al., 2014; Camacho et al.,

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2019; Engler, 2012; Lee et al., 2014; Moore et al., 2005; Ogata et al., 2009; Panio et al., 2020; Rios et al., 2007; (Rochman et al., 2013a); Saliu et al., 2020; Teuten et al., 2007). Currently, the magnitude of humans' exposure to plastic debris and attached chemicals through seafood is unclear, but concerns for human health rose (Lusher et al., 2017; Rochman, 2016; Seltenrich, 2015; Smith et al., 2018).

While the presence of microplastic in wild fish is well documented, studies on microplastic ingestion in captive fish are scarce (Cheung et al., 2018; Feng et al., 2019; Garcia et al., 2020; Wu et al., 2020). So far, there are only four studies available reporting the presence of plastic particles in the guts of farmed fish. Specifically, two of these studies investigated plastic ingestion by fish raised in cages in coastal waters (Feng et al., 2019; Wu et al., 2020). One study considered fish farms located in rivers (Garcia et al., 2020) and another study observed fish from fish ponds (Cheung et al., 2018). Moreover, only one study until now – focused on flathead grey mullets (*Mugil cephalus*) – has examined differences in the presence of microplastics between farmed and wild specimens, highlighting in this case lower contamination in the farmed specimens, which were raised in fish ponds.

Starting from this basis, in this work for the first time, the presence of microplastic in the European sea bass (*Dicentrarchus labrax*) cultivated in aquaculture facilities located in the coastal waters of Tenerife (Canary Islands, Spain) was investigated. This study has a value as baseline assessment not only for farmed fish, but also for the Canary Islands, since until now only one previous study has investigated the microplastic ingestion by fish from the archipelago (Herrera et al., 2019).

Fish samples were obtained between July 2016 and June 2017 from two different aquaculture companies: Punta Rasca Cultivos Marinos de Canarias, S.L. and Socat Canarias, S.L. Both companies were based in Tenerife, Canary Island (Spain) and cultivated – amongst other fish – European sea bass. Farming cages for growing purposes were made out of blue and black polyethylene (Punta Rasca Cultivos Marinos de Canarias, S.L.) or polyvinylchloride (Socat Canarias, S.L.). However, both companies used harvesting fishing nets made out of black and/or red nylon. Punta Rasca Cultivos Marinos de Canarias, S.L. used farming cages with a mesh size of 15 mm for adult animals, whereas Socat Canarias, S.L. used a mesh size of 24 mm. Both aquaculture facilities were located in the southern part of the West Coast of Tenerife close to the shoreline (Fig. 1). Adult fish were fed once a day with dry pellet food. Two sampling batches of 10 and 13 fish respectively were collected from a catch from Punta Rasca Cultivos Marinos de Canarias, S.L. The rest of the samples - batches of 10 individuals - were obtained from Socat Canarias, S.L.

Fish were obtained directly from the aquaculture companies after fish farm harvesting. Hence, fish did not pass any packaging process and therefore did not undergo any further contamination after being captured. Immediately after receiving the samples from the aquaculture companies, fish were stored in a clean new plastic bag to prevent airborn contamination. Subsequently, they were transported to the laboratory, where they were stored at −20° until further processing. For microplastic detection, fish were processed based on the method of Foekema et al. (2013) with minor adjustments. Length and weight of each individual fish was recorded before dissection. All viscera were removed and the digestion tracts from the oesophagus to the anus were carefully separated from the rest of the organs. Each tract was weighed and stored in clean glass jars. A 10% KOH solution was added, three

Fig. 1. Google Earth satellite images: a) Position of the Canary Island in the Atlantic Ocean; b) Location of the aquaculture sites in Tenerife; c) Location of the aquaculture sites according to the official data of the Canary Islands Government (Source: Google Earth Pro, ©2021 / Maxar Technologies, GRAFCAN, TerraMetrics, Landsat/Copernicus; Data SIO, NOAA, U.S. Navy, NGA, GEBCO).

times the amount of the organic material. Subsequently, the guts and their contents were left to digest at room temperature for at least 2 weeks before further processing. Once all of the biological material was dissolved, the supernatants were vacuum filtered over stainless steel filters with a mesh size of 25 μm. Hereafter, the filters were rinsed several times with pure water before being placed into a 10% EDTA solution for another day. EDTA was used to prevent possible salt formations on the steel gauze since it can sequester metal ions. After 24 h, filters were rinsed again with pure water, stored in petri dish bottoms, and left to dry in a desiccator. Finally, filters were covered and petri dishes were sealed with parafilm. All filtration processes were performed under a clean bench with filters covered at all times to avoid air born contamination. A Leica Microscope was used to visually analyse the stainless steel filter with the fish intestine contents. Particles on the gauze were counted and their colours and shapes were recorded. Due to the large amount of particles, only the content of 10% of all filters were further analysed via FTIR.

Larger particles (>200 μm) were analysed by using a Perkin Elmer Spectrum Two FTIR instrument, equipped with a deuterated triglycine sulfate (DTGS) detector and a diamond crystal ATR unit. Smaller particles (<200 μm) were analysed with a Spotlight 200i FTIR Microscopy System, equipped with a diamond coated μATR unit and a liquid nitrogen cooled mercury cadmium telluride (MCT) 100 * 100 μ single detector, displaying a 0.5 cm^{-1} spectral resolution and 40,000/1 RMS sensitivity for 2 min acquisition at 4 cm^{-1}. Spectra were recorded with a resolution of 4 cm^{-1} and 32 co-added scans in the wave-number range 400–4000 cm^{-1}. A point mode approach was applied to identify the particles and to collect the related spectra. A background spectrum was collected after every ten measurements. In the case of suspected cross contamination, analysis were repeated. Finally, patented COMPARE™ spectral comparison algorithm was used for spectral searching in commercially available library. A positive identification with the reference library was assigned for matches ≥75%.

Strict QA/QC procedures and measures to prevent contamination were followed throughout the entire sample manipulation. Specifically, a maximum of two persons were present in the laboratory during the dissection. Air circulation such as air conditioning, open window, etc. was minimized. White cotton lab coats and disposable latex gloves were used while manipulating the samples. All instruments, as well as the glass jars, were cleaned with alcohol and rinsed three times with pure water. KOH-Solution was filtered through a stainless steel filter (mesh size: 25 μm) prior to its use. Seven procedural blanks were run to determine background contamination and limit of quantitation (based the average of the blanks plus six times their standard deviation). An artificially contaminated sample with PE microparticles was used to determine the recoveries and validate the microplastics extraction and analysis procedure.

Finally, statistical analysis were performed with R statistical software (R Core Team, 2017) and its extension, Rstudio. Graphics were generated with Microsoft Excel (2013). Data normality of plastic concentration was analysed by the Shapiro Wilk test and the homoscedasticity was assessed graphically. Statistical differences between batches were tested using Kruskal-Wallis test.

The total accumulation of plastic particles in fish didn't show significant differences between batches (Kruskal-Wallis-Test, p-value = 0.1646) despite the higher abundance of plastic in fish from the first batch (Table 1).

Results showed, that 80 individuals (96%) within the 83 analysed fish had ingested material in their digestion tracts: 53 (65%) of all sampled fish displayed ingested anthropogenic debris (Table 1). 24 had ingested fine transparent fibres, detection of which was not feasible via FTIR due to their small diameter (less than 10 μm). They were not taken in further account for this study. The total number of items found in the digestive tracts equalled 119, where 97.5% of items were considered as microplastics (<5 mm). However, one individual had ingested three lines longer than 5 mm (Fig. 2), which should be accounted as mesoplastics. Fish from the first batch (Origin: Punta Rasca Cultivos Marinos de Canarias, S.L.) ingested the most amount of particles with an average of 2.7 ± 1.85 (SD) particles per fish. The lowest number of ingested items was presented in the fish from the third batch (origin: Socat Canarias, S.L.), with an average of only 0.6 ± 0.8 (SD) particles per fish. The highest amount of particles (n = 9) were found in an individual in the second batch. Overall, the portion of European sea bass that displayed the presence of microplastics in this study (65%) was considered very high compared to the contamination of fish species reported in other investigations (Barboza et al., 2018a; Herrera et al., 2019). Barboza et al. (2018a) reviewed 30 studies, which reported microplastic ingestion in fish. Investigations examined sample sizes from 1 to 566 individuals from a total of 70 different fish species. Only 23% of the sampled batches registered higher amounts of fish with ingested microplastic (66–100%). However, most of these batches (89%) consisted in a lower sample size (1–64) than the one of the present study (83). Recently, Herrera et al. (2019) conducted a literature review, complementing sources from Barboza et al. (2018a) with another additional 16 studies. In 6 of these studies a higher percentage of fish with ingested microplastic was reported, including the findings of Herrera et al. (2019), in which 78.3% of Atlantic chub mackerels (*Scomber colias*) caught around Gran Canaria and Lanzarote were detected with ingested microplastic. This study, together with our findings suggests that fish captured in the coastal waters of the Canary Islands may have a higher risk of contamination. This may be caused by a very high plastic contamination recently found washed ashore on the coastlines, as well as floating in the coastal waters of the Canary Islands (Herrera et al., 2020; Rapp et al., 2020; Reinold et al., 2020), reaching maximum amounts of 28,218.75 items/m^2 on the coastline of Poris (Tenerife) and 1,007,872 items/km^2 in the water near Las Canteras (Gran Canaria) (Herrera et al., 2020; Reinold et al., 2020). As farming cages in this study were situated close to urban cores with high touristic pressure, it needs to be considered, that the fish not only receive microplastic from the Canary current, but also from wind-blown litter nearby.

Compared to the only previous study regarding microplastic ingestion by European sea bass (Bessa et al., 2018) from the Mondego estuary

Table 1
General data of analysed fish organized by collecting date.

Date	Number of fish	Mean of length [cm]	SD of length	Mean of weight [g]	SD of weight	Mean of organ weight [g]	SD of organ weight	Percent of fish with ingested particles	Mean particles per fish	SD of particles per fish
05.07.2016	10	29.98	1.73	321.89	57.66	42.09	9.15	90	2.7	1.85
21.07.2016	13	33.03	2.29	424.77	92.26	55.93	16.7	62	1.5	2.29
10.08.2016	10	35	1.35	518.85	59.14	66.02	8.07	40	0.6	0.8
29.09.2016	10	37.06	2.75	607.18	141.74	64.76	20.1	40	0.9	1.22
19.01.2017	10	31.26	1.13	316.54	28.61	27.88	5.52	60	1.3	1.49
02.03.2017	10	27.78	2.12	221.87	56.86	17.66	7.61	70	1	0.77
25.04.2017	10	26.2	0.85	202.14	19.81	15.65	2.5	90	1.8	2.14
01.06.2017	10	29.75	0.9	282.84	28.58	26.29	4.72	70	1.5	1.5
Total	83	31.32	3.82	364.28	151.48	39.81	22.25	65	1.43	1.75

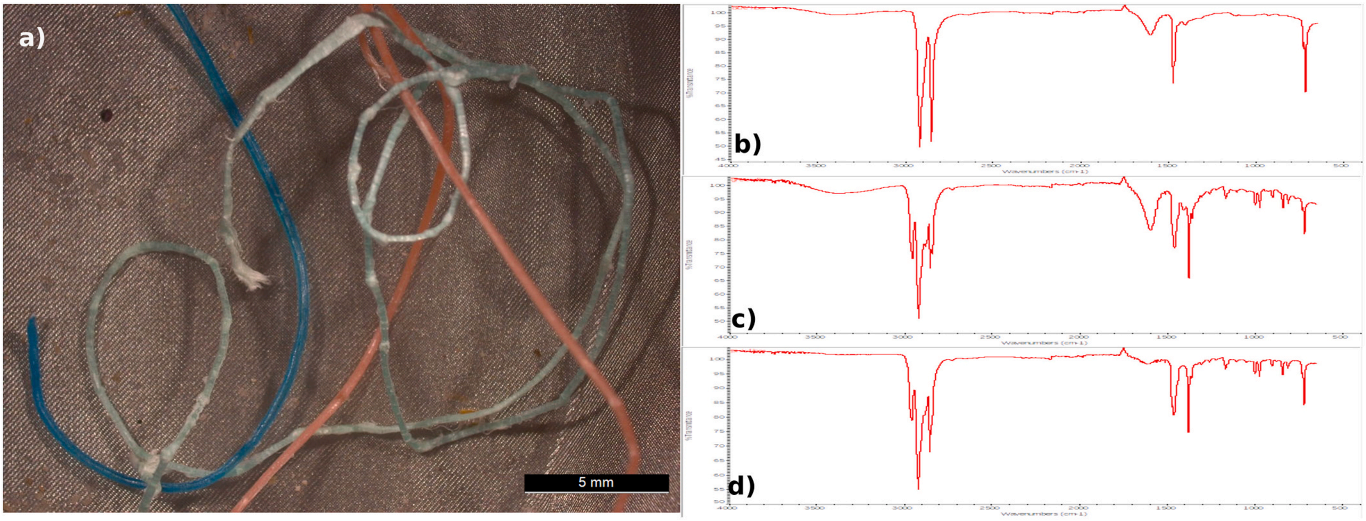

Fig. 2. a) Stomach content of a European sea bass from the 01.06.2017 b) FTIR spectra of the blue fibre – Polyethylene (PE) c) FTIR spectra of the green fibre – Polypropylene (PP) d) FTIR spectra of the red fibre – Polypropylene (PP). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

in Portugal, which considered both wild specimens, the fish in the present study displayed higher rates of ingested microplastic (65% vs 23%). Furthermore, higher averages of ingested particles (from a minimum of 0.6 particles to a maximum of 2.7 items/fish) were found compared to the wild sea bass (0.3 items/fish) This may lead to the suspicion that fish raised in aquaculture facilities may ingest more microplastic than wild fish, even if two different environment are considered.

Analysis of the items colours showed that 81% of all found microplastic were within the colour ranges of blue, yellow, black and transparent (Fig. 3). Blue (26%) and yellow (24%) particles alone made up half of all coloured material, but black (17%) and transparent (14%) particles were still present in considerable amounts. While blue, black and transparent have been reported dominating colours in other investigations, yellow items are normally found in lower rates (Abbasi et al., 2018; Azad et al., 2018; Bessa et al., 2018; Boerger et al., 2010; Herrera et al., 2019; Hipfner et al., 2018; Markic et al., 2018; McGoran et al., 2018; Pazos et al., 2017; Peters et al., 2017; Romeo et al., 2015; Rummel et al., 2016; Tanaka and Takada, 2016). However, yellow or orange plastic particles were found in fish of all feeding types (grazer, omnivore, planktivore, benthic predator, and pelagic predator), although predators seem to ingest a minor range of colours (Markic et al., 2018). Adult European sea bass are predators, which usually feed on invertebrates and other fish. Animals of the present study might have presented a wide range of coloured items, because they captured smaller fish of other feeding types (grazer, omnivores planktivores), which have been shown to be less selective regarding the colour of ingested particles (Markic et al., 2018). These fish could have passed through the cage mesh already containing coloured items in their guts. Differently, the higher amount of black and blue particles can be interpreted as fish nibbling on the cages or attacking fishing gear at the time of harvesting, as these were the predominant colours of the fishing equipment used by both companies. In addition, Carson (2013) claimed, that yellow and blue plastic particles presented significantly more bite marks than other colours. This justifies the vast amount of blue particles and also explains

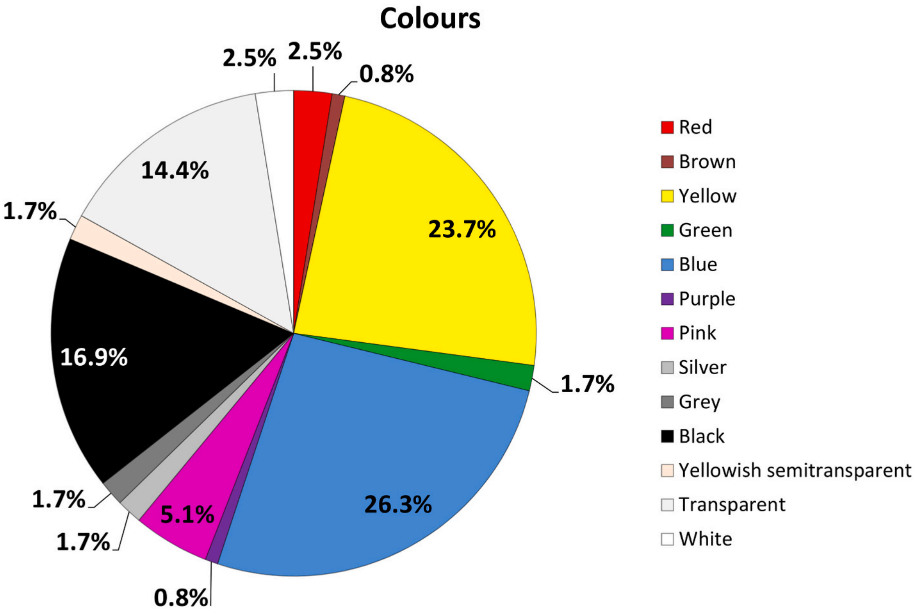

Fig. 3. Colours of particles ingested by fish.

the high percentage of yellow particles found in the fish guts. Animals might attack yellow objects in nature and even though they might not always swallow them, tiny pieces can end up in the digestion tracts of the fish. Furthermore, Wu et al. (2020) detected similar profiles of microplastic type between sediment and fish from fish farms. The wide range of colours as well as the excess of yellow particles could originate from the nearby urban areas. Although wind-blown litter, which enters the body of water, can reach farming cages by being dragged by the current, nearby sewage outflows can be a major source of microplastic in the coastal sediment. In the Canary Islands, wastewater is discharged directly into the sea after passing the wastewater treatment plants. 24 sewage outflows existed within a radius of 5 km around the aquaculture facilities, 10 of which were not authorized according to the official data of the Canary Islands Government (http://visor.grafcan.es/visorweb/) (GRAFCAN Cartográfica de Canarias IDE Canarias, 2018). Although it has been shown that wastewater treatment plants are very efficient and retain up to 99.9% of microplastics (Correia Prata, 2018), water from outflows is still found to discharge an average of 4.9 fibres/L, respectively 8.6 particles/L into the ocean (Talvitie et al., 2015). In urban areas, this amount can even reach 14–50 particles/L (Dris et al., 2015).

Microplastics were found in form of fibres, fragments, lines and films (Fig. 4). Fibres were the most common shape (81%), followed by fragments (12%). Films and lines accounted for less than 10%.

This result is consistent with the microplastic types reported in the majority of studies (Barboza et al., 2018a; Herrera et al., 2019). A recent study even determined, that smaller microplastics (0.01–1 mm) found on the shorelines of one of the Canary Islands only consisted of fibres (Rapp et al., 2020). It supports the suggestion that sewage outflows can act as a major source of fibre pollution in the marine environment. Browne et al. (2011) evaluated the amount of fibres being expulsed by washing machines and found that one single garment can shed more than 1900 fibres per wash. Accounting the number of washing runs and the amount of washed clothes in a densely populated area with additional touristic use, wastewater treatment plants can receive millions of litres every day. Hence, even miner wastewater treatment plants can discharge more than 52,000 particles (corresponding 0.004 particles/L) daily (Mason et al., 2016). Another important source of fibres, as well as lines in the ocean, comes from the fishing industry, as modern fishing gear is primarily made out of polyolefins and nylon (Andrady, 2011). Plastics from fishing nets and ropes used by the aquaculture companies can become brittle over time due to degradation processes and eventually break down into smaller pieces (Andrady, 2011; Barnes et al., 2009; Cole et al., 2011). As it has been proven that marine organisms attack plastic objects (Carson, 2013), captive *D. labrax* might have swallowed these microparticles accidentally by nibbling on the fishing gear. Furthermore, fish might have attacked fishing nets at the time of harvesting and therefore ingested small net pieces. Both sources, sewage outflows and plastic-based fishing gear, could explain the high amount of ingested fibres.

Finally, detection of plastic polymeric material was obtained by μFTIR. 8 analysed filters displayed 12 types of polymers and 2 types of resins (Fig. 5). Fibres (11) were identified either as cellulose/cellophane (55%), nylon (27%), rayon (9%) or as acrylic (9%). Particles (20) were mostly represented by PE (25%) and PP (25%). Other polymers were: PS (5%), SAN (5%), PA (5%), EPDM (5%), E/P (5%), EVA (5%), polynorbornene (5%), nitrocellulose (5%) as well as epoxy resin (5%) and phenolic resin (5%). Fig. 6 shows examples of the most popular polymer types found in this study.

Additionally, the three biggest particles found in a fish from the last batch, were identified as PP (67%) and PE (33%) (Fig. 2). Based on their shape they seemed to originate from fishing nets or ropes.

As recovered fibres consisted either of cellulose/cellophane, nylon, rayon or acrylic, results indicate that the presence of fibres may be related to local sewage outflows, since all of these polymers are commonly used in the textile industry and therefore are a fallout from washing clothes. The fact that cellulose and its derivates are the most represented polymers in this study is also in line with previous findings on cultured fish (Feng et al., 2019; Garcia et al., 2020; Wu et al., 2020). Differently, the detected nylon fibres could originate from textile as well as from fishing gear used in the local aquaculture facilities. Identified material of the fragment partition were rather diverse, but contained mostly polymers, which have been already reported to be ingested by fish in former studies (Table 2) such as PP and PE, which are commonly used in the fishing industry (Andrady, 2011). Finally two particles were assigned to pretty unusual polymers, which have not been reported so far in digestive tracts of fish: Polynorbornene and phenolic resin. Polynorbornenes are polymers that are characterized by high glass transition temperatures and high optical clarity. They are used in elastomers.

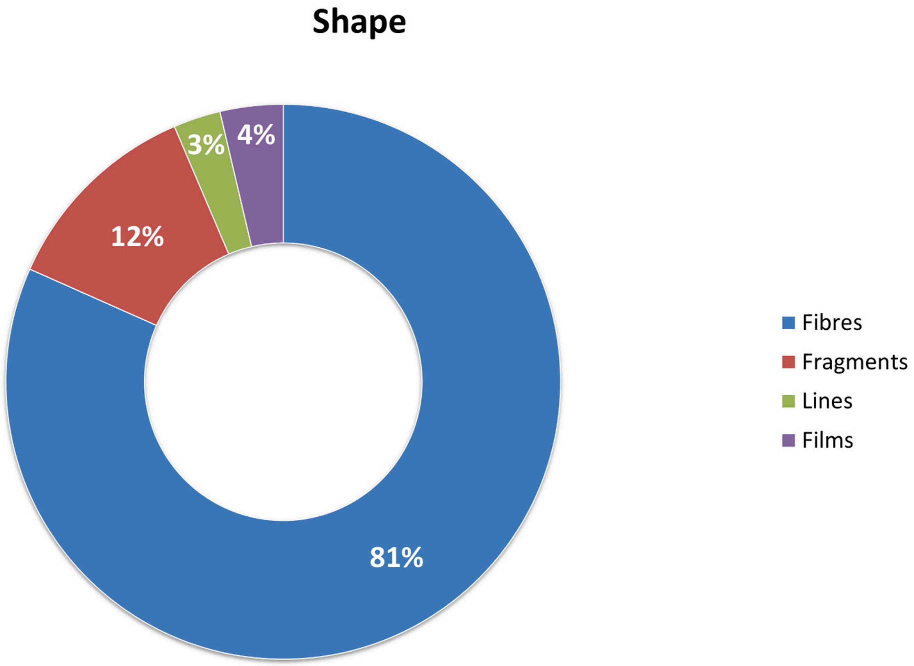

Fig. 4. Shapes of particles ingested by fish.

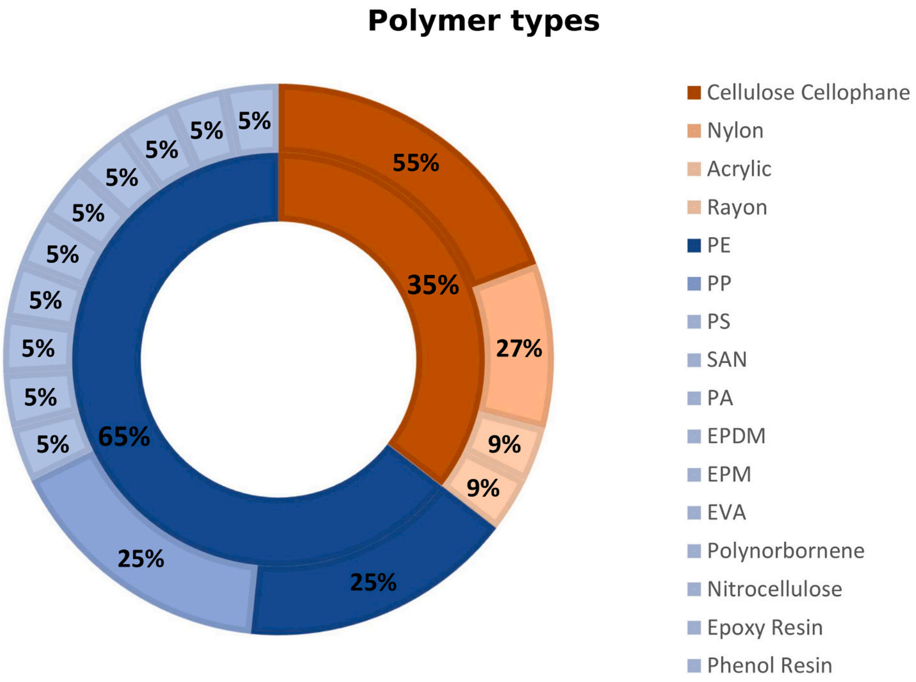

Fig. 5. Percentage of polymer types of ingested particles: Fibres are represented by the red compartment; Particles are represented by the blue compartment, Inner donut: Percentage of particle shape; Outer donut: Percentage of polymer types. Abbreviations: PE: Polyethylene, PP: Polypropylene, PS: Polystyrene, SAN: Styrene-Acrylonitrile-Copolymer, PA: Polyamide, EPDM: Ethylene-Propylene-Dien-Monomer, E/P: Ethylene-Propylene-Copolymer, EVA: Ethylene-Vinyl Acetate. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

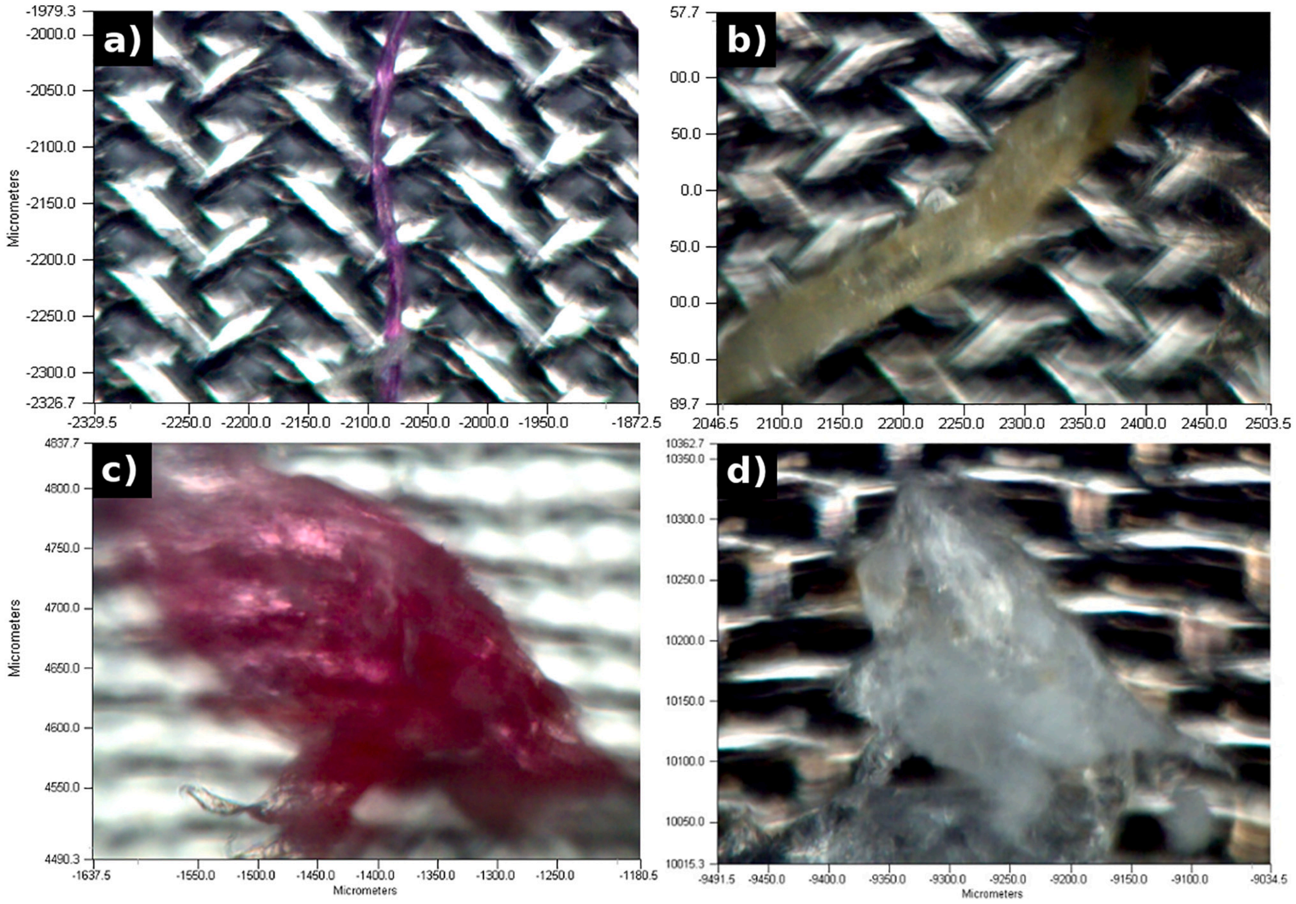

Fig. 6. µ-FTIR images of the 4 most common found polymer types: a) Cellulose/Cellophane b) Nylon c) Polyethylene (PE) d) Polypropylene (PP).

Phenolic resins have been widely used for moulded products, as well as in coatings and adhesives in the past, but today, epoxy resins have largely replaced them. This indicates, that plastics have the ability to travel in the ocean for a long time.

In summary, this study showed for the first time the presence of microplastic in the digestive tract of *D. labrax* from aquaculture facilities

Table 2
Polymer types ingested by fish; *including nylon and aramide.

Author	Ding et al., 2019	Nelms et al., 2018	Halstead et al., 2018		Rummel et al., 2016	Digka et al., 2018	Foekema et al., 2013	Cheung et al., 2018	Markic et al., 2018	Tanaka and Takada, 2016	(Jabeen, 2017)	Bråte et al., 2016	Morgana et al., 2018	Compa et al., 2018	Alomar et al., 2017	McGoran et al., 2018	Renzi et al., 2019		Murphy et al., 2017	Chagnon et al., 2018	Hipfner et al., 2018	Bessa et al., 2018	Baalkhuyur et al., 2018	Lusher et al., 2013	Peters et al., 2018
PP (Polypropylene)	0.54%	5.55%		10.42%	13%	27.7%	33.33%	42%	9%	43.3%		12.50%				15.00%	50.00%		5.00%		8.33%	14.00%	42.00%		
PE (Polyethylene)		22.22%			40%	55.5%	33.33%	25%	26%	52.0%		6.25%	17%	20.00%						27.27%		6.00%	42.00%	0.30%	
Polyester			17.50%	18.75%	4%			16%	28%		7.9%	37.50%	34%			33.00%				18.18%	41.67%	31.00%		5.10%	
PA (Polyamide)*		5.55%			22%			4%	4%			6.25%	21%	10.00%		20.00%	10.00%		77.00%			5.00%		35.60%	9.30%
PET (Polyethylene terephthalate)	33.87%	5.55%			4%	5.5%	16.67%	6%			10.6%			30.00%	36.36%			7.00%	17.00%						9.30%
PS (Polystyrene)	2.15%				9%	5.5%				2.0%		6.25%							1.00%				4.00%	0.90%	
Acrylic			0.00%	4.17%					3%				24%		15.15%				17.00%		25.00%			0.30%	
Rayon	48.92%		17.50%	14.58%					17%													30.00%		57.83%	
PTFE (Polytetrafluoroethylene)	4.84%					5.5%		3%				6.25%					10.00%								
PVC (Polyvinyl chloride)									7%			12.50%					30.00%	93.00%					8.00%		34.80%
PAN (Polyacrylonitrile)															12.12%							14.00%	4.00%		
Cellulose/Cellophane			15.00%	6.25%							49.1%			20.00%	30.30%										
EPDM (ethylene propylene diene monomer)		5.55%								0.7%															
E/P (Ethylene propylene)		27.78%								2.0%															
PAM (Polyacrylamid)		5.55%												20.00%											
PU (Polyurethane)					4%				3%																
Acrylic Polyester Blend			42.50%	37.50%																					
NBR (Nitrile rubber)		5.55%																							
rubber									2%																
Neoprene		11.11%																							
Alkyd															3.03%										
PBT (Polybutylene terephthalate)		5.55%																							
SAN (Styrene acrylonitrile resin)												6.25%													
Polystyrene acrilonitrile methyl methacrylate															3.03%										
SA (Styrene acrylate)							16.67%																		
PBMA (Poly(n-butyl methacrylate))												6.25%													
EVA (ethylene-vinyl acetate)													7%												
CPE (Chlorinated polyethylene)	9.68%																								
PVA (Poly(vinyl alcohol))																				54.55%					
Epoxy resin																									2.30%
Silicone																									2.30%
Amount of particles	186	18	66		23	N/A	6	79	128	150	227	16	30	10	N/A	1128	N/A		118	11	12	32	26	351	43

located in coastal waters. The number of fish, which had ingested plastic (85%), were found to be high and in line with previous findings regarding fish farmed in coastal waters (Wu et al. 2020; Feng et al. 2019. Although the precise origin of ingested microplastic could not be determined, the high amount of fibres and their composition indicate that local contamination plays an important role. Therefore, the regulations and management of the sewage outflows into the open sea needs to improve. Furthermore, it is recommended for aquaculture companies to choose facility locations away from urban and touristic nucleus to distance from sewage outflows. It is also proposed to limit the use of plastic materials in fishing gear used by aquaculture companies.

CRediT authorship contribution statement

S.R. designed the experimental work, conducted the sampling, processed the samples in the laboratory, analysed the data and wrote the manuscript. F.S. performed spectroscopical analyses via FTIR. C.H. contributed to design the experimental work. All authors contributed to the acquisition of the data and edited the article.

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.

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References

Abbasi, S., Soltani, N., Keshavarzi, B., Moore, F., Turner, A., Hassanaghaei, M., 2018. Microplastics in different tissues of fish and prawn from the Musa Estuary, Persian Gulf. Chemosphere 205, 80–87. https://doi.org/10.1016/j.chemosphere.2018.04.076.

Alomar, C., Sureda, 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. https://doi.org/10.1016/j.envres.2017.07.043.

Andrady, A.L., 2011. Microplastics in the marine environment. Mar. Pollut. Bull. 62, 1596–1605. https://doi.org/10.1016/j.marpolbul.2011.05.030.

Avio, C.G., Gorbi, S., Regoli, F., 2015. Experimental development of a new protocol for extraction and characterization of microplastics in fish tissues: first observations in commercial species from Adriatic Sea. Mar. Environ. Res. 111, 18–26. https://doi.org/10.1016/j.marenvres.2015.06.014.

Azad, S.M.O., Towatana, P., Pradit, S., Patricia, B.G., Hue, H.T.T., Jualaong, S., 2018. First evidence of existence of microplastics in stomach of some commercial fishes in the lower Gulf of Thailand. Appl. Ecol. Environ. Res. 16, 7345–7360. https://doi.org/10.15666/aeer/1606_73457360.

Baalkhuyur, F.M., Bin Dohaish, E.-J.A., Elhalwagy, M.E.A., Alikunhi, N.M., AlSuwailem, A.M., Røstad, A., Coker, D.J., Berumen, M.L., Duarte, C.M., 2018. Microplastic in the gastrointestinal tract of fishes along the Saudi Arabian Red Sea coast. Mar. Pollut. Bull. 131, 407–415. https://doi.org/10.1016/j.marpolbul.2018.04.040.

Bakir, A., Rowland, S.J., Thompson, R.C., 2014. Enhanced desorption of persistent organic pollutants from microplastics under simulated physiological conditions. Environ. Pollut. 185, 16–23. https://doi.org/10.1016/j.envpol.2013.10.007.

Barboza, L.G.A., Dick Vethaak, A., Lavorante, B.R.B.O., Lundebye, A.-K.K., Guilhermino, L., Barboza, L.G.A., Guilhermino, L., Dick Vethaak, A., Lundebye, A.-K.K., 2018a. Marine microplastic debris: An emerging issue for food security, food safety and human health. Mar. Pollut. Bull. 133, 336–348. https://doi.org/10.1016/j.marpolbul.2018.05.047.

Barboza, L.G.A., Vieira, L.R., Branco, V., Figueiredo, N., Carvalho, F., Carvalho, C., Guilhermino, L., 2018b. Microplastics cause neurotoxicity, oxidative damage and energy-related changes and interact with the bioaccumulation of mercury in the European seabass, *Dicentrarchus labrax* (Linnaeus, 1758). Aquat. Toxicol. 195, 49–57. https://doi.org/10.1016/j.aquatox.2017.12.008.

Barboza, L.G.A., Vieira, L.R., Guilhermino, L., 2018c. Single and combined effects of microplastics and mercury on juveniles of the European seabass (*Dicentrarchus labrax*): changes in behavioural responses and reduction of swimming velocity and resistance time. Environ. Pollut. 236, 1014–1019. https://doi.org/10.1016/j.envpol.2017.12.082.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. Lond. B Biol. Sci. 364, 1985–1998. https://doi.org/10.1098/rstb.2008.0205.

Bessa, F., Barría, P., Neto, J.M., Frias, J.P.G.L., Otero, V., Sobral, P., Marques, J.C., 2018. Occurrence of microplastics in commercial fish from a natural estuarine environment. Mar. Pollut. Bull. 128, 575–584. https://doi.org/10.1016/j.marpolbul.2018.01.044.

Boerger, C.M., Lattin, G.L., Moore, S.L., Moore, C.J., 2010. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Mar. Pollut. Bull. 60, 2275–2278. https://doi.org/10.1016/j.marpolbul.2010.08.007.

Bråte, I.L.N., Eidsvoll, D.P., Steindal, C.C., Thomas, K.V., 2016. Plastic ingestion by Atlantic cod (*Gadus morhua*) from the Norwegian coast. Mar. Pollut. Bull. 112, 105–110. https://doi.org/10.1016/j.marpolbul.2016.08.034.

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R., 2011. Accumulation of microplastic on shorelines woldwide: sources and sinks. Environ. Sci. Technol. 45, 9175–9179. https://doi.org/10.1021/es201811s.

Camacho, M., Herrera, A., Gómez, M., Acosta-Dacal, A., Martínez, I., Henríquez-Hernández, L.A., Luzardo, O.P., 2019. Organic pollutants in marine plastic debris from Canary Islands beaches. Sci. Total Environ. 662, 22–31. https://doi.org/10.1016/j.scitotenv.2018.12.422.

Carpenter, E.J., Anderson, S.J., Harvey, G.R., Miklas, H.P., Peck, B.B., 1972. Polystyrene spherules in coastal waters. Science 178, 749–750. https://doi.org/10.1126/science.178.4062.749.

Carson, H.S., 2013. The incidence of plastic ingestion by fishes: from the prey's perspective. Mar. Pollut. Bull. 74, 170–174. https://doi.org/10.1016/j.marpolbul.2013.07.008.

Chae, Y., Kim, D., Kim, S.W., An, Y.-J., 2018. Trophic transfer and individual impact of nano-sized polystyrene in a four-species freshwater food chain. Sci. Rep. 8, 284. https://doi.org/10.1038/s41598-017-18849-y.

Chagnon, C., Thiel, M., Antunes, J., Ferreira, J.L., Sobral, P., Ory, N.C., 2018. Plastic ingestion and trophic transfer between Easter Island flying fish (*Cheilopogon rapanouiensis*) and yellowfin tuna (*Thunnus albacares*) from Rapa Nui (Easter Island). Environ. Pollut. 243, 127–133. https://doi.org/10.1016/j.envpol.2018.08.042.

Chen, Q., Yin, D., Jia, Y., Schiwy, S., Legradi, J., Yang, S., Hollert, H., 2017. Enhanced uptake of BPA in the presence of nanoplastics can lead to neurotoxic effects in adult zebrafish. Sci. Total Environ. 609, 1312–1321. https://doi.org/10.1016/j.scitotenv.2017.07.144.

Cheung, L.T.O., Lui, C.Y., Fok, L., 2018. Microplastic contamination ofwild and captive flathead grey mullet (*Mugil cephalus*). Int. J. Environ. Res. Public Health 15, 597. https://doi.org/10.3390/ijerph15040597.

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: a review. Mar. Pollut. Bull. 62, 2588–2597. https://doi.org/10.1016/j.marpolbul.2011.09.025.

Collard, F., Gilbert, B., Compère, P., Eppe, G., Das, K., Jauniaux, T., Parmentier, E., 2017. Microplastics in livers of European anchovies (*Engraulis encrasicolus* , L.). Environ. Pollut. 229, 1000–1005. https://doi.org/10.1016/j.envpol.2017.07.089.

Compa, M., Ventero, A., Iglesias, M., Deudero, S., 2018. Ingestion of microplastics and natural fibres in *Sardina pilchardus* (Walbaum, 1792) and Engraulis encrasicolus (Linnaeus, 1758) along the Spanish Mediterranean coast. Mar. Pollut. Bull. 128, 89–96. https://doi.org/10.1016/j.marpolbul.2018.01.009.

Correia Prata, J., 2018. Microplastics in wastewater: state of the knowledge on sources, fate and solutions. Mar. Pollut. Bull. 129, 262–265. https://doi.org/10.1016/j.marpolbul.2018.02.046.

Digka, N., Tsangaris, C., Torre, M., Anastasopoulou, A., Zeri, C., 2018. Microplastics in mussels and fish from the northern Ionian Sea. Mar. Pollut. Bull. 135, 30–40. https://doi.org/10.1016/j.marpolbul.2018.06.063.

Ding, J., Zhang, S., Razanajatovo, R.M., Zou, H., Zhu, W., 2018. Accumulation, tissue distribution, and biochemical effects of polystyrene microplastics in the freshwater fish red tilapia (*Oreochromis niloticus*). Environ. Pollut. 238, 1–9. https://doi.org/10.1016/j.envpol.2018.03.001.

Ding, J., Li, J., Sun, C., Jiang, F., Ju, P., Qu, L., Zheng, Y., He, C., 2019. Detection of microplastics in local marine organisms using a multi-technology system. Anal. Methods 11, 78–87. https://doi.org/10.1039/C8AY01974F.

Dris, R., Gasperi, J., Rocher, V., Saad, M., Renault, N., Tassin, B., 2015. Microplastic contamination in an urban area: a case study in greater Paris. Environ. Chem. 12, 592. https://doi.org/10.1071/EN14167.

Engler, R.E., 2012. The complex interaction between marine debris and toxic chemicals in the ocean. Environ. Sci. Technol. 46, 12302–12315. https://doi.org/10.1021/es3027105.

Feng, Z., Zhang, T., Li, Y., He, X., Wang, R., Xu, J., Gao, G., 2019. The accumulation of microplastics in fish from an important fish farm and mariculture area, Haizhou Bay, China. Sci. Total Environ. 696, 133948. https://doi.org/10.1016/j.scitotenv.2019.133948.

Foekema, E.M., De Gruijter, C., Mergia, M.T., van Franeker, J.A., Murk, A.J., Koelmans, A.A., 2013. Plastic in north sea fish. Environ. Sci. Technol. 47, 8818–8824. https://doi.org/10.1021/es400931b.

Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. Mar. Pollut. Bull. 92, 170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041.

Garcia, A.G., Suárez, D.C., Li, J., Rotchell, J.M., 2020. A comparison of microplastic contamination in freshwater fish from natural and farmed sources. Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-020-11605-2.

GESAMP, 2019. Guidelines or the monitoring and assessment of plastic litter and microplastics in the ocean. In: Kershaw, P.J., Turra, A., Galgani, F. (Eds.), (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 99, p. 130.

Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos. Trans. R. Soc. Lond. B Biol. Sci. 364, 2013–2025. https://doi.org/10.1098/rstb.2008.0265.

Halstead, J.E., Smith, J.A., Carter, E.A., Lay, P.A., Johnston, E.L., 2018. Assessment tools for microplastics and natural fibres ingested by fish in an urbanised estuary. Environ. Pollut. 234, 552–561. https://doi.org/10.1016/j.envpol.2017.11.085.

Herrera, A., Ŝtindlová, A., Martínez, I., Rapp, J., Romero-Kutzner, V., Samper, M.D., Montoto, T., Aguiar-González, B., Packard, T., Gómez, M., 2019. Microplastic ingestion by Atlantic chub mackerel (*Scomber colias*) in the Canary Islands coast. Mar. Pollut. Bull. 139, 127–135. https://doi.org/10.1016/j.marpolbul.2018.12.022.

Herrera, A., Raymond, E., Martínez, I., Álvarez, S., Canning-Clode, J., Gestoso, I., Pham, C.K., Ríos, N., Rodríguez, Y., Gómez, M., 2020. First evaluation of neustonic microplastics in the Macaronesian region, NE Atlantic. Mar. Pollut. Bull. 153, 110999. https://doi.org/10.1016/j.marpolbul.2020.110999.

Hipfner, J.M., Galbraith, M., Tucker, S., Studholme, K.R., Domalik, A.D., Pearson, S.F., Good, T.P., Ross, P.S., Hodum, P., 2018. Two forage fishes as potential conduits for the vertical transfer of microfibres in northeastern Pacific Ocean food webs. Environ. Pollut. 239, 215–222. https://doi.org/10.1016/j.envpol.2018.04.009.

Hoss, D.E., Settle, L.R., 1990. Ingestion of plastics by teleost fishes. NOAA Tech. Memo. 693–709.

Jabeen, et al., 2017. Microplastics and mesoplastics in fish from coastal and fresh waters of China. Environmental Pollution 221. https://doi.org/10.1016/j.envpol.2016.11.055.

Jabeen, K., Li, B., Chen, Q., Su, L., Wu, C., Hollert, H., Shi, H., 2018. Effects of virgin microplastics on goldfish (*Carassius auratus*). Chemosphere 213, 323–332. https://doi.org/10.1016/j.chemosphere.2018.09.031.

Jin, Y., Xia, J., Pan, Z., Yang, J., Wang, W., Fu, Z., 2018. Polystyrene microplastics induce microbiota dysbiosis and inflammation in the gut of adult zebrafish. Environ. Pollut. 235, 322–329. https://doi.org/10.1016/j.envpol.2017.12.088.

Kartar, S., Sainsbury, M., Milne, R.A., 1973. Polystyrene waste in the severn estuary. Mar. Pollut. Bull. 4, 144.

Lee, H., Shim, W.J., Kwon, J.-H., 2014. Sorption capacity of plastic debris for hydrophobic organic chemicals. Sci. Total Environ. 470–471, 1545–1552. https://doi.org/10.1016/j.scitotenv.2013.08.023.

Lu, Y., Zhang, Y., Deng, Y., Jiang, W., Zhao, Y., Geng, J., Ding, L., Ren, H., 2016. Uptake and accumulation of polystyrene microplastics in Zebrafish (*Danio rerio*) and toxic effects in liver. Environ. Sci. Technol. 50, 4054–4060. https://doi.org/10.1021/acs.est.6b00183.

Luís, L.G., Ferreira, P., Fonte, E., Oliveira, M., Guilhermino, L., 2015. Does the presence of microplastics influence the acute toxicity of chromium(VI) to early juveniles of the common goby (*Pomatoschistus microps*)? A study with juveniles from two wild estuarine populations. Aquat. Toxicol. 164, 163–174. https://doi.org/10.1016/j.aquatox.2015.04.018.

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. https://doi.org/10.1016/j.marpolbul.2012.11.028.

Lusher, A., Hollman, P., Mandoza-Hill, J., 2017. Microplastics in Fisheries and Aquaculture (FAO Fisheries and Aquaculture Technical Paper).

Markic, A., Niemand, C., Bridson, J.H., Mazouni-Gaertner, N., Gaertner, J.-C., Eriksen, M., Bowen, M., 2018. Double trouble in the South Pacific subtropical gyre: increased plastic ingestion by fish in the oceanic accumulation zone. Mar. Pollut. Bull. 136, 547–564. https://doi.org/10.1016/j.marpolbul.2018.09.031.

Mason, S.A., Garneau, D., Sutton, R., Chu, Y., Ehmann, K., Barnes, J., Fink, P., Papazissimos, D., Rogers, D.L., 2016. Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent. Environ. Pollut. 218, 1045–1054. https://doi.org/10.1016/j.envpol.2016.08.056.

Mazurais, D., Ernande, B., Quazuguel, P., Severe, A., Huelvan, C., Madec, L., Mouchel, O., Soudant, P., Robbens, J., Huvet, A., Zambonino-Infante, J., 2015. Evaluation of the impact of polyethylene microbeads ingestion in European sea bass (*Dicentrarchus labrax*) larvae. Mar. Environ. Res. 112, 78–85. https://doi.org/10.1016/j.marenvres.2015.09.009.

McGoran, A.R., Cowie, P.R., Clark, P.F., McEvoy, J.P., Morritt, D., 2018. Ingestion of plastic by fish: a comparison of Thames estuary and firth of clyde populations. Mar. Pollut. Bull. 137, 12–23. https://doi.org/10.1016/j.marpolbul.2018.09.054.

Moore, C.J., Lattin, G.L., Zellers, A.F., 2005. A Brief Analysis of Organic Pollutants Sorbed to Pre and Post- Production Plastic Particles From the Los Angeles and San Gabriel River Watersheds, p. 9.

Morgana, S., Ghigliotti, L., Estévez-Calvar, N., Stifanese, R., Wieckzorek, A., Doyle, T., Christiansen, J.S., Faimali, M., Garaventa, F., 2018. Microplastics in the Arctic: a case study with sub-surface water and fish samples off Northeast Greenland. Environ. Pollut. 242, 1078–1086. https://doi.org/10.1016/j.envpol.2018.08.001.

Murphy, F., Russell, M., Ewins, C., Quinn, B., 2017. The uptake of macroplastic & microplastic by demersal & pelagic fish in the Northeast Atlantic around Scotland. Mar. Pollut. Bull. 122, 353–359. https://doi.org/10.1016/j.marpolbul.2017.06.073.

Nelms, S.E., Galloway, T.S., Godley, B.J., Jarvis, D.S., Lindeque, P.K., 2018. Investigating microplastic trophic transfer in marine top predators. Environ. Pollut. 238, 999–1007. https://doi.org/10.1016/j.envpol.2018.02.016.

Ogata, Y., Takada, H., Mizukawa, K., Hirai, H., Iwasa, S., Endo, S., Mato, Y., Saha, M., Okuda, K., Nakashima, A., Murakami, M., Zurcher, N., Booyatumanondo, R., Zakaria, M.P., Dung, L.Q., Gordon, M., Miguez, C., Suzuki, S., Moore, C., Karapanagioti, H.K., Weerts, S., McClurg, T., Burres, E., Smith, W., Van Velkenburg, M., Lang, J.S., Lang, R.C., Laursen, D., Danner, B., Stewardson, N., Thompson, R.C., 2009. International pellet watch: global monitoring of persistent organic pollutants (POPs) in coastal waters. 1. Initial phase data on PCBs, DDTs, and HCHs. Mar. Pollut. Bull. 58, 1437–1446. https://doi.org/10.1016/j.marpolbul.2009.06.014.

Oliveira, M., Ribeiro, A., Hylland, K., Guilhermino, L., 2013. Single and combined effects of microplastics and pyrene on juveniles (0+ group) of the common goby *Pomatoschistus microps* (Teleostei, Gobiidae). Ecol. Indic. 34, 641–647. https://doi.org/10.1016/j.ecolind.2013.06.019.

Panio, A., Fabbri Corsarini, S., Bruno, A., Lasagni, M., Labra, M., Saliu, F., 2020. Determination of phthalates in fish fillets by liquid chromatography tandem mass spectrometry (LC-MS/MS): a comparison of direct immersion solid phase microextraction (SPME) versus ultrasonic assisted solvent extraction (UASE). Chemosphere 255, 127034. https://doi.org/10.1016/j.chemosphere.2020.127034.

Pazos, R.S., Maiztegui, T., Colautti, D.C., Paracampo, A.H., Gómez, N., 2017. Microplastics in gut contents of coastal freshwater fish from Río de la Plata estuary. Mar. Pollut. Bull. 122, 85–90. https://doi.org/10.1016/j.marpolbul.2017.06.007.

Pedà, C., Caccamo, L., Fossi, M.C., Gai, F., Andaloro, F., Genovese, L., Perdichizzi, A., Romeo, T., Maricchiolo, G., Andaloro, F., Pedà, C., Caccamo, L., Maricchiolo, G., Fossi, M.C., Gai, F., Romeo, T., Genovese, L., 2016. Intestinal alterations in European sea bass *Dicentrarchus labrax* (Linnaeus, 1758) exposed to microplastics: preliminary results. Environ. Pollut. 212, 251–256. https://doi.org/10.1016/j.envpol.2016.01.083.

Peters, C.A., Thomas, P.A., Rieper, K.B., Bratton, S.P., 2017. Foraging preferences influence microplastic ingestion by six marine fish species from the Texas Gulf Coast. Mar. Pollut. Bull. 124, 82–88. https://doi.org/10.1016/j.marpolbul.2017.06.080.

Peters, C.A., Hendrickson, E., Minor, E.C., Schreiner, K., Halbur, J., Bratton, S.P., 2018. Pyr-GC/MS analysis of microplastics extracted from the stomach content of benthivore fish from the Texas Gulf Coast. Mar. Pollut. Bull. 137, 91–95. https://doi.org/10.1016/j.marpolbul.2018.09.049.

Pitt, J.A., Trevisan, R., Massarsky, A., Kozal, J.S., Levin, E.D., Di Giulio, R.T., 2018. Maternal transfer of nanoplastics to offspring in zebrafish (*Danio rerio*): a case study with nanopolystyrene. Sci. Total Environ. 643, 324–334. https://doi.org/10.1016/j.scitotenv.2018.06.186.

PlasticsEurope, 2016. Plastics – the facts 2016. PlasticsEurope. https://www.plasticseurope.org/en.

PlasticsEurope, 2018a. Plastics – the facts 2018. PlasticsEurope. https://www.plasticseurope.org/en/resources/publications/619-plastics-facts-2018.

PlasticsEurope, 2018b. Plastics - the facts 2017. PlasticsEurope. https://www.plasticseurope.org/en/resources/publications/274-plastics-facts-2017.

PlasticsEurope, 2019. Plastics - the facts 2019. PlasticsEurope. https://www.plasticseurope.org/en/resources/publications/1804-plastics-facts-2019.

R Core Team, 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rainieri, S., Conlledo, N., Larsen, B.K., Granby, K., Barranco, A., 2018. Combined effects of microplastics and chemical contaminants on the organ toxicity of zebrafish (*Danio rerio*). Environ. Res. 162, 135–143. https://doi.org/10.1016/j.envres.2017.12.019.

Rapp, J., Herrera, A., Martinez, I., Raymond, E., Santana, Á., Gómez, M., 2020. Study of plastic pollution and its potential sources on gran Canaria Island beaches (Canary Islands, Spain). Mar. Pollut. Bull. 153, 110967. https://doi.org/10.1016/j.marpolbul.2020.110967.

Reinold, S., Herrera, A., Hernández-González, C., Gómez, M., 2020. Plastic pollution on eight beaches of Tenerife (Canary Islands, Spain): An annual study. Mar. Pollut. Bull. 151, 110847. https://doi.org/10.1016/j.marpolbul.2019.110847.

Renzi, M., Specchiulli, A., Blašković, A., Manzo, C., Mancinelli, G., Cilenti, L., 2019. Marine litter in stomach content of small pelagic fishes from the Adriatic Sea: sardines (Sardina pilchardus) and anchovies (*Engraulis encrasicolus*). Environ. Sci. Pollut. Res. 26, 2771–2781. https://doi.org/10.1007/s11356-018-3762-8.

Rios, L.M., Moore, C., Jones, P.R., 2007. Persistent organic pollutants carried by synthetic polymers in the ocean environment. Mar. Pollut. Bull. 54, 1230–1237. https://doi.org/10.1016/j.marpolbul.2007.03.022.

Rochman, C.M., 2016. The role of plastic debris as another source of hazardous chemicals in lower-trophic level organisms. In: Hazardous Chemicals Associated With Plastics in the Marine Environment, pp. 281–295. https://doi.org/10.1007/698_2016_17.

Rochman, C.M., Hoh, E., Hentschel, B.T., Kaye, S., 2013a. Long-term field measurement of sorption of organic contaminants to five types of plastic pellets: implications for plastic marine debris. Environ. Sci. Technol. 47 https://doi.org/10.1021/es303700s, 130109073312009.

Rochman, C.M., Hoh, E., Kurobe, T., Teh, S.J., 2013b. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Sci. Rep. 3, 3263. https://doi.org/10.1038/srep03263.

Rochman, C.M., Kurobe, T., Flores, I., Teh, S.J., 2014. Early warning signs of endocrine disruption in adult fish from the ingestion of polyethylene with and without sorbed chemical pollutants from the marine environment. Sci. Total Environ. 493, 656–661. https://doi.org/10.1016/j.scitotenv.2014.06.051.

Romeo, T., Pietro, B., Pedà, C., Consoli, P., Andaloro, F., Fossi, M.C., 2015. First evidence of presence of plastic debris in stomach of large pelagic fish in the Mediterranean Sea. Mar. Pollut. Bull. 95, 358–361. https://doi.org/10.1016/j.marpolbul.2015.04.048.

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. https://doi.org/10.1016/j.marpolbul.2015.11.043.

Saliu, F., Montano, S., Hoeksema, B.W., Lasagni, M., Galli, P., 2020. A non-lethal SPME-LC/MS method for the analysis of plastic-associated contaminants in coral reef invertebrates. Anal. Methods 12, 1935–1942. https://doi.org/10.1039/C9AY02621E.

Seltenrich, N., 2015. New link in the food chain? Marine plastic pollution and seafood safety. Environ. Health Perspect. 123, A34–A41. https://doi.org/10.1289/ehp.123-A34.

Smith, M., Love, D.C., Rochman, C.M., Neff, R.A., 2018. Microplastics in seafood and the implications for human health. Curr. Environ. Health Rep. 5, 375–386. https://doi.org/10.1007/s40572-018-0206-z.

Talvitie, J., Heinonen, M., Pääkkönen, J.-P., Vahtera, E., Mikola, A., Setälä, O., Vahala, R., 2015. Do wastewater treatment plants act as a potential point source of microplastics? Preliminary study in the coastal Gulf of Finland, Baltic Sea. Water Sci. Technol. 72, 1495–1504. https://doi.org/10.2166/wst.2015.360.

Tanaka, K., Takada, H., 2016. Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters. Sci. Rep. 6, 34351. https://doi.org/10.1038/srep34351.

Teuten, E.L., Rowland, S.J., Galloway, T.S., Thompson, R.C., 2007. Potential for plastics to transport hydrophobic contaminants. Environ. Sci. Technol. 41, 7759–7764. https://doi.org/10.1021/es071737s.

UNEP, 2016. Marine plastic debris and microplastics - global lessons and research to inspire action and guide policy change. In: United Nations Environment Programme, Marine Plastic Debris and Microplastics – Global Lessons and Research to Inspire Action and Guide Policy Change. United Nations Environment Programme, Nairobi.

Wright, S.L., Thompson, R.C., Galloway, T.S., 2013. The physical impacts of microplastics on marine organisms: a review. Environ. Pollut. 178, 483–492. https://doi.org/10.1016/j.envpol.2013.02.031.

Wu, F., Wang, Y., Leung, J.Y.S., Huang, W., Zeng, J., Tang, Y., Chen, J., Shi, A., Yu, X., Xu, X., Zhang, H., Cao, L., 2020. Accumulation of microplastics in typical commercial aquatic species: a case study at a productive aquaculture site in China. Sci. Total Environ. 708, 135432. https://doi.org/10.1016/j.scitotenv.2019.135432.

Zhang, S., Ding, J., Razanajatovo, R.M., Jiang, H., Zou, H., Zhu, W., 2019. Interactive effects of polystyrene microplastics and roxithromycin on bioaccumulation and biochemical status in the freshwater fish red tilapia (*Oreochromis niloticus*). Sci. Total Environ. 648, 1431–1439. https://doi.org/10.1016/j.scitotenv.2018.08.266.