Human Health Risk and Food Safety Implications of Microplastic Consumption by Fish from Coastal Waters of the Eastern Equatorial Atlantic Ocean.

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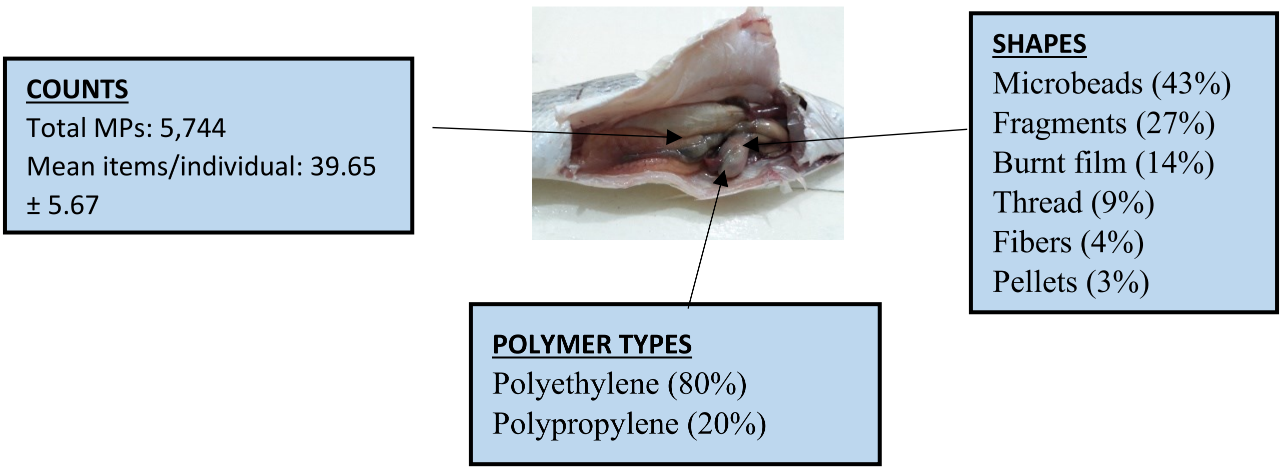
GRAPHICAL ABSTRACT



Abstract

We examined the gastro-intestinal tracts (guts) of 160 fish species obtained from Nigerian coastal waters for microplastics and estimated annual microplastic intake by adult human population in the region from the fish species. A total of 5,744 microplastics were recovered from the fish species analyzed with an average of 39.65 ± 5.67 items/individual. Microbeads (43%) occurred in all guts assessed, followed by fragments (27%), burnt film (14%), thread (9%), fibers (4%), and pellets (3%). Most microplastics recovered were below 1000 µm with the least size being 85 µm. Based on the size classes estimated for this study, we argue based on literature that close to 15% (i.e., >100 µm) of the microplastics in the guts studied have the potential to translocate gut barriers of the fish species into muscles, where they get ingested by humans, and thereon get translocated to other human organ tissues. The estimated annual intake of microplastics from the consumption of whole fish by the adult population followed the trend; *M. cephalus* (178,220) > *I. Africana* (131,670) > *P. senegalensis* (115,710) > *P. jubelini (*109,060) > *S. maderensis* (101,080) > *G. decadactylus* (101,346) > S. *melanotheron* (65,170). Estimated annual intakes were generally higher for fish species with broad habitat and feeding preferences.

Keywords: Microplastic, fish, gut, annual intake, habitats.

1.0 Introduction

Plastic pollution is considered a global issue whose effect in magnitude has been compared to climate change (Giacovelli, 2018). This is due to its widespread nature in the ocean (i.e. water column, seafloor, and biota) and adjoining ecosystems such as lagoons, estuaries, and rivers, coupled with its deleterious impacts on the environment and man (Auta et al., 2017). For example, it is estimated that 4.8–12.7 million tons of plastic enter the marine environment annually(Jambeck et al., 2015). The majority of these plastics originate from land-based sources such as landfills and the remainder from other human activities such as fishing (Munari et al., 2016).

When present in the marine environment, the larger pieces of plastic get fragmented under the actions of waves, U.V radiation, and physical abrasion, eventually becoming microplastics ranging in length from 1 µm to 5 mm (Barnes et al., 2009; Hidalgo-Ruz et al., 2012). Microplastics have been described as a complex cocktail of polymers, also containing additive chemicals, absorbed organic/inorganic materials and living substances that can interact with biotic and abiotic components of all marine environments (Guzzetti et al., 2018). They are recalcitrant materials under marine exposure conditions and can be considered emerging xenobiotics for marine ecosystems. Ingestion of microplastic is the most likely interaction that occurs among a wide range of species from low trophic level organisms to higher predators, including invertebrates, fishes, mammals, turtles, seabirds and humans among others due to its tiny size (Cole et al., 2013; Desforges et al., 2015; Lusher et al., 2015; Nadal et al., 2016). Of great concern is the potential for marine organisms to mistake these microplastics for food and indiscriminately feed on them (Besseling et al., 2015; Hall et al., 2015), thereby, becoming exposed to a suit of hazardous contaminants including persistent organic pollutants (POPs) such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and dichloro-diphenyl-trichloroethane (DDTs), and heavy metals that are absorbed onto their surfaces from the surrounding (Bowmer & Kershaw, 2010; Rochman et al., 2014). In addition to these absorbed contaminants are chemicals additives [e.g. emollients, flame-retardants, anti-microbials and titanium-dioxide nanoparticles (TiO_2-NPs)] added to plastic products during manufacturing processes to improve their final property (Guzzetti et al., 2018). These additives also become bioavailable to marine biota upon ingestion and can have a variety of harmful effects on marine biota, such as alteration of metabolic and reproductive activity, decreased immune response, oxidative stress, cellular or sub-cellular toxicity, inflammation and cancer (Barboza et al., 2020; Bellas & Gil, 2020; Cole et al., 2015; Huang et al., 2021; Kim et al., 2021; Ogonowski et al., 2016; Peda et al., 2016; Sun et al., 2018; Watts et al., 2016; Wright et al., 2013; Yu et al., 2022; Zhang et al., 2019).

Humans are not exempted from the impact of microplastic pollution as they depend on fish from the ocean and its adjoining ecosystems as a significant source of protein and vitamins (Sana et al., 2020; Sun et al., 2021; Yang et al., 2022). The consumption of seafood by man is among the most important routes through which plastics get introduced into the human body (Cox et al., 2019). Microplastics have been detected in human placenta (Ragusa et al., 2021), lungs (Amato-Lourenço et al., 2021), stool (Schwabl et al., 2019) and colon (Ibrahim et al., 2021). While research on the internal exposure measurements of plastic particles in human body fluids and tissues and their impacts are still in their infancy, it is important that potential exposure routes are investigated to inform their management and minimize exposures in humans. In Africa, fish constitute more than 60% of the total protein consumed in the sub-region, hence may serve as an important exposure pathway of microplastics and associated contaminants to several people (Béné & Heck, 2005; Chan et al., 2019; Desiere et al., 2018). In most parts of Africa, including Ghana and Nigeria, smoked, fried, cured and powdered fish sold in markets and streets are prepared together with the guts, thereby making the gut of fish an important direct exposure route of microplastics and their concomitant pollutants such as heavy metals, PCBs and PAHs to humans in the Region. Fish meals used by the global aquaculture industry are prepared from a cocktail mixture of various fish species either in whole, or parts such as guts and head (Miles & Chapman, 2006), and fed to cultured fish which are then consumed by humans. The use of fish meal by the aquaculture industry can therefore be considered another important route of microplastic additives and associated contaminants to humans as the processes involved in the preparation of the feed can further breakdown the microplastics into further smaller sizes. Ingestion of microplastics could expose humans to harmful additives and absorbed chemicals on plastics which have been linked to various health problems, including reproductive harm, developmental delays in children and cancers (Liu et al., 2021; Smith et al., 2018). In addition to additive chemicals, microplastics when in the ocean accumulate persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and organochlorine pesticides like dichlorodiphynyltrichloroethane (DDT) or hexachlorobenzene (HCB) from the water (Smith et al., 2018).

Ranking as the 9th producer of plastic globally, Nigeria is undoubtedly a significant contributor to the estimated 4.8–12.7 million tons of plastic that enters the ocean annually (Dumbili & Henderson, 2020; Ebere et al., 2019; Jambeck et al.). Nigeria's plastic production and packaging industry has grown from 50 companies in the early 1960s to over 3,000 companies in 2013 (Hanafi, 2018; Kehinde et al., 2020). In 2015, Nigeria's plastic consumption peaked at approximately 1,000,000 tons and was projected to increase to 1,500,000 tons by 2020. Unfortunately, this fast-growing plastic industry has not been in equilibrium with managing the waste generated from plastic use. The result of this has led to indiscriminate disposal and release of plastic debris into the environment (Dumbili & Henderson, 2020). Associated with the increasing trend in single-use plastic in Nigeria and West Africa are impacts to the marine ecosystem, the seafood industry and consequently human health yet to be unravelled.

In Africa, the only coastal region with significant information on the presence and distribution of microplastics in the marine environment is South Africa (Collins & Hermes, 2019; Naidoo et al., 2020; Nel & Froneman, 2015; Preston-Whyte et al., 2021; Sparks, 2020; Sparks et al., 2021). Within the West African sub-region, knowledge and data on the presence and distribution of microplastic are sparse, with only a few documented marine studies (Adika et al., 2020; Chico-Ortiz et al., 2020; Ilechukwu et al., 2019; Mayoma et al., 2020; Tata et al., 2020). Most of these studies are focused on the occurrence and distribution in river and wastewater channels (Adu-Boahen et al., 2020; Akindele et al., 2019, 2020; Blankson et al., 2022; Wirnkor et al., 2019). These few studies highlight the need to scale up research on microplastics in the region to increase our understanding of the extent of the problem and its possible impacts to food security, safety, and human health. Also, of essence is our understanding of how the consumption of fish with broad habitats and feeding preference in the marine environment impact the numbers of microplastics humans are ingesting on a daily to annual basis. The present study seeks to expand on the existing knowledge, by assessing the microplastic composition (shapes, size and polymer) of frequently consumed coastal fish species landed in Lagos, Nigeria. Data collected on microplastic numbers per fish was used to assess human exposure to these microplastics.

2. 0 Methodology

2.1 Study Area

The fish samples were obtained from Nigerian Coastal waters immediately after landing at the Makoko community seafood market (6°29'22.1"N; 3°24'00.6"E) in Nigeria. Nigeria is a large, densely populated West African country in the Gulf of Guinea with a coastal zone of approximately 853 Km and an Exclusive Economic Zone of 210,900 km^2. Threats to the coastal zone emanate from the discharge of solid waste and untreated industrial effluent into the marine environment, land reclamation, deforestation, and unsustainable fishing among others. Waste management continues to be one of the major challenges confronting Nigeria (Kehinde et al., 2020). Nigeria generates over 42 million tonnes of waste per annum, exceeding half of the 62 million tons that the whole of sub-Saharan Africa generates each year (Ike et al., 2018). About 20% of the total waste generated is made up of plastics, most of which end up in landfills, sewers, beaches, and water bodies.

2.2 Sample Preparation

A total of 160 fish comprising; *Pseudotolithus senegalensis* (n=30), *Pomodasys jubelini* (n=10), *Galeoides decadactylus* (n=15), *Sardinella maderensis* (n=50), *Mugil cephalus* (n=20), *llisha africana* (n=15) and *Sarotherodon melanotheron* (n=20) were analyzed for microplastics. Length-weight measurements and degutting of the fish were carried out in a plastic-free hood at the Nigerian Institute for Oceanography and Marine Research. Isolated guts were wrapped individually in aluminum foil, kept frozen and transported to the

Department of Marine and Fisheries Sciences of the University of Ghana for microplastic identification, enumeration, and polymer analysis. Preparation of the fish guts for microplastics followed the procedure outlined in Lusher et al. (2015) for isolating microplastics in fish gut. Thawed samples were rinsed thoroughly with triple-distilled water before sample preparation. Guts were isolated and wholly digested in pre-cleaned test tubes by adding 1M KOH to each content and incubating at 60°C for 24 hours. Each digestate was filtered through a moistened 1.2μm Whatman GF/C microfiber filter paper. Filtrates were oven-dried overnight at 40°C.

2.3 Observation, Identification and Enumeration of Microplastics

Microplastic observation, identification, and enumeration were carried out under a Leica EZ4 HD stereo microscope with an image analysis system IC80 HD camera. Microplastic particles were counted, classified, and sorted into types according to their shapes (i.e. fibers/threads-elongated, fragments-angular and irregular pieces, burnt film, microbeads and pellets-rounded) and sizes using identification guides (Liboiron, 2019) and Lusher et al. (2015). For this study, we considered fibers to be thinner in terms of thickness whereas threads mostly from relicts of fishing gear were relatively thicker and, in some cases, could be seen with the naked eye. Microbeads are relatively smaller in diameter compared to industrial pellets which were larger, tougher when hit with tweezers and could be seen in some cases with the naked eye. Fourier-transform infrared spectroscopy analysis was carried out on 280 microplastic samples selected randomly to determine the polymer types present in the fish samples using a Spectrum Two PerkinElmer FTIR Spectrometer with $LiTaO_3$ (Lithium Tantalate) detector type and a UATR accessory. Spectra obtained were analyzed in the Open Specy software (Cowger et al., 2020) compared with a database of references and accepted with at least a 60% match. The 280 constitute 5% of the total microplastic counted. Microplastics obtained in the gut of each fish species were reported as items/individual.

2.4 Quality control

Throughout the study, measures were put in place to reduce/avoid microplastic contamination from the working environment. Maintenance of a plastic-free working environment was adhered to which included working under fume hoods in both laboratories, use of glass filter papers to avoid contamination from cellulose fibers, wearing of white cotton less shredding laboratory coats. We set up three (3) Petri dishes containing dampened 1.2 µm Whatman GF/C glass filter papers during sample dissection and digestion to account for airborne contamination. Three procedure blanks consisting of the extraction solution (10% KOH) without samples were analyzed in parallel with the digested fish samples. No microplastics were detected in each of these blanks. Only glass digestion vials and Petri dishes with glass covers were used in the sample preparation.

2.5 Statistical Analysis and Data Visualization

Results obtained are presented as mean ± standard error of the mean (SE) in PAST 4.03 (Hammer et al., 2001). A one-way analysis of variance (ANOVA) test was used to establish any significant differences in microplastic numbers across fish species. The data was subjected to a normality test to ensure that data was normally distributed before the ANOVA test was run. Stacked bars and box whiskers were used to graphically present the data. The condition factor of a fish reflects physical and biological circumstances and fluctuations by interaction among feeding conditions, parasitic infections and physiological factors (Ighwela et al., 2011). To compute the condition factor (k) of the fish species, measurements of fish length and weight were taken prior to dissection and the condition factor was computed using the relationship below:

$K = W/L^3 \times 100$ (Ighwela et al., 2011) 1

where W = weight of the fish in grams and L = total length of the fish in centimetres. The Condition Factor (K) allows quantitative assessment of the growth condition of individual fish within a population.

3.0 Results and Discussion

Microplastics were detected in all 160 fish specimens analyzed in this study. A total of 5,744 microplastics were counted with a mean of 39.65 ± 5.67 items per fish. Six types of microplastics were identified based on shapes. These were microbeads, fragments, burnt film, fibers, pellets and thread, with microbeads constituting the most abundant microplastic and fibers constituting the least in the fish guts (Fig. 1). See photographs of microplastic types in figure 3. Microbeads constituted the most abundant plastic shape and were frequently reported in demersal fish than pelagic fishes. This was followed by fragments and burnt films. Microbeads are polysynthetic resins found in beauty products, generally serving as abrasives or bulking agents in cleaning products and exfoliants in numerous beauty products (Napper et al., 2015). Due to their microscopic nature, most sewage treatment plants are unable to effectively filter these microbeads (Leslie, 2014). These microbeads, thus infiltrate the aquatic ecosystem posing adverse effects to its constituents. Once adsorbed to substances and contaminants in the environment, they may become relatively denser than other microplastic types and thus, likely to sink to the bottom where they become available to bottom-dwelling fishes (Browne et al., 2011).

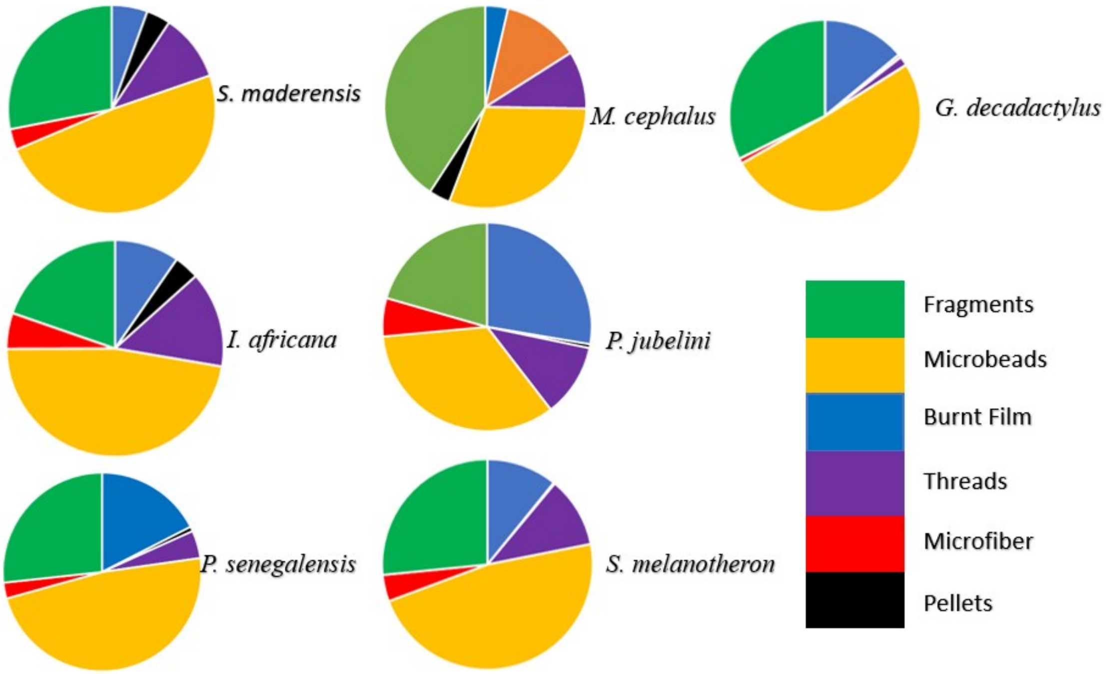


Figure 1: Percent composition of microplastic type (shape) in the gut of the fish species.

Polystyrene microbeads have been found to inhibit the proliferation of Caco-2 cells in vitro in a time- and concentration-dependent pattern and chronic exposure to low doses induced cytotoxicity, characterized by epithelial cells injury and alterations to intestinal barrier function, oxidative stress, and deintoxication and transcriptional level in human-derived cells (Wu et al., 2020). Fragmented plastics are formed from the breakdown of larger plastics at sea through photodegradation, physical impacts and other processes, resulting in the generation of a larger number of plastic fragments (Andrady, 2011). Considerable numbers of fragmented plastics have been reported in the digestive tract of fish from other oceanic regions (Adika et al., 2020; Baalkhuyur et al., 2018; Ferreira et al., 2018; Jabeen et al., 2017; Pozo et al., 2019; Rochman et al., 2015; Savoca et al., 2019). Na et al. (2021) reported that the acute toxicity (48-hour) of fragmented polyethylene microplastics (37.24 ± 11.76) was 80 times higher than that of polyethylene microbeads (37.05 ± 3.96 mm), possibly due to the irregular shape and high specific surface area of the former. Distinct from other microplastics, fragmented microplastics can cause damage and morphological changes in the digestive tract of aquatic organisms (Qiao et al., 2019). While human toxicity studies on microplastics are very limited, one study confirmed that on exposure to human-derived cells polystyrene micro fragments increased; the acute inflammation of immune cells 20 times than in control, the production of reactive oxygen species, cell death of fibroblasts and cancer cells Choi et al. (2020). Additionally, when in direct contact with fibroblasts and red blood cells, the physical stress caused by PS micro fragments resulted in lactose dehydrogenase and haemoglobin release, respectively, due to cell membrane damage and hemolysis (Choi et al., 2020). This phenomenon was amplified when the concentration and roughness of the micro fragments increased. Although fibers least dominated the fish guts, their presence in the fish and potential impacts to fish and human health must not be downplayed. Microfibers are produced from the breakdown of synthetic fabrics in washing machines and to a lesser extent worn-out fishing nets. Coupled with the rapid rise in worldwide production of synthetic polyester clothes from 5 Mts in 1980 to 50 Mts in 2017 (Kataoka et al., 2019; Lamichhane, 2018), the gradual increase in washing machine use and the increase in the exportation of worn-out second-hand clothings into the West African sub-region should be a cause for global concern. The latter is particularly worrying as huge piles of such worn-out unwearable clothing's with very high shredding potential are being discharged into the coastal environment on daily basis. Just as other microplastic types, microfibers, when consumed may transfer a suite of toxic chemicals such as methylmercury, arsenic, polychlorinated biphenyls into the human body, where they can accumulate over time. It has been hypothesized that such long-term exposures can lead to various health effects including reproductive problems, cancer, and DNA damage.

Size is another significant parameter that influences the ingestion and accumulation of microplastics by aquatic organisms as well as its toxicity potential to humans. Public health concerns are focused on smaller size fractions that have the propensity to absorb environmental pollutants, which may increase human susceptibility to contaminants through seafood consumption. Size fractions below 1000 μm were the most prevalent size recorded in all our fish species, accounting for 84% in *S. maderensis*, 81% in *I. africana*, 71% in *P. senegalensis*, 75% in *M. cephalus*, 83% in *P. jubelini*, 82% in *S. melanotheron* and 71% in *G. decadactylus* (Fig. 2). Size fractions below 100 μm constituted close to 10-15% in most of the fish guts examined with the least size being 85 μm. There is scientific evidence, beyond human studies, that MPs < 20 μm could enter and translocate in the tissue of a wide range of biota (Hale et al., 2020), while others argue that particles of sizes < 150 μm are expected to be able to pass the human gut barrier and cause systemic exposure with limited absorption (≤ 0.3%) and only even smaller particles < 1.5 μm to have the ability to translocate to other organs (Chain, 2016). Yet, recent studies analyzing various human sample tissue reported the discovery of MPs in diverse size ranges.

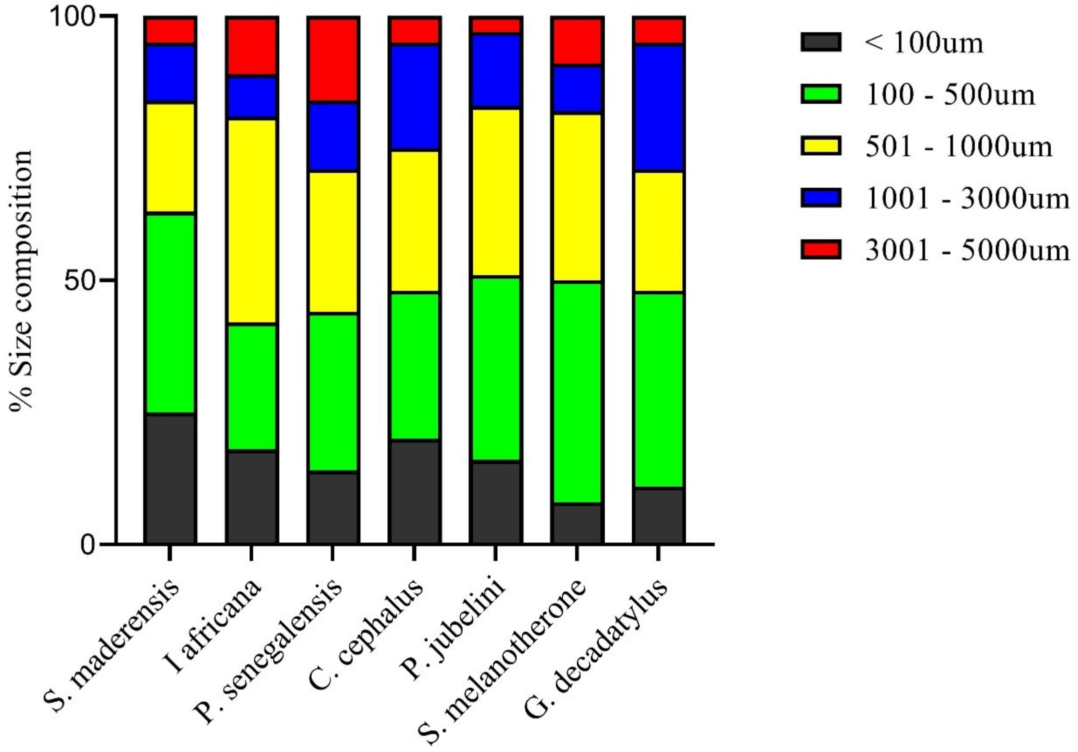


Figure 2: Variabilities in microplastic size fractions in the various fish species.

In human colectomy samples for example, the size of identified MPs ranged from 800 to 1600 µm (Daud et al., 2021; Ibrahim et al., 2021), whereas microplastics ranging between 5 to 10 µm have been found in human placenta (Ragusa et al., 2021). Microplastics in the size range of the range size range of 4 to 30 µm in human cirrhotic liver tissues (Horvatits et al., 2022). Bringing these reported sizes into line with our study, we argue that close to 20% of the microplastics in the guts studied have the potential to pass through gut barriers of the fish species into muscles where they get ingested by humans, and thereon get translocated to other human organ tissues. While bigger size-fractioned may never get translocated across gut tissues into muscles and remain in the gut of fish, it is important to note that microplastics in the guts of the fish could also become biologically available to human directly through consumption of whole fish. For instance, in Africa, most smoked, fried, dried, cured and powdered fish sold on markets are prepared using whole fish without degutting. The cooking process could further transfer toxic chemicals adsorb onto microplastics into muscles. Another angle from which the presence of microplastics in fish guts may be relevant to human health globally is the use of whole fish in the preparation of fishmeal used in the global aquaculture industry (Thiele, 2021). The processes used in the preparation of fishmeal could further breakdown microplastics into smaller fragments which may become biologically available to cultured fish and subsequently humans.

Mean numbers of microplastics varied significantly (ANOVA: n=160, F= 6.68, P=3.2E-06) among the 7 fish species and followed the order M. cephalus> I. Africana> P. senegalensis> P. jubelini> G. decadactylus> S. maderensis> S. melanotheron (Table 1; Fig. 3).

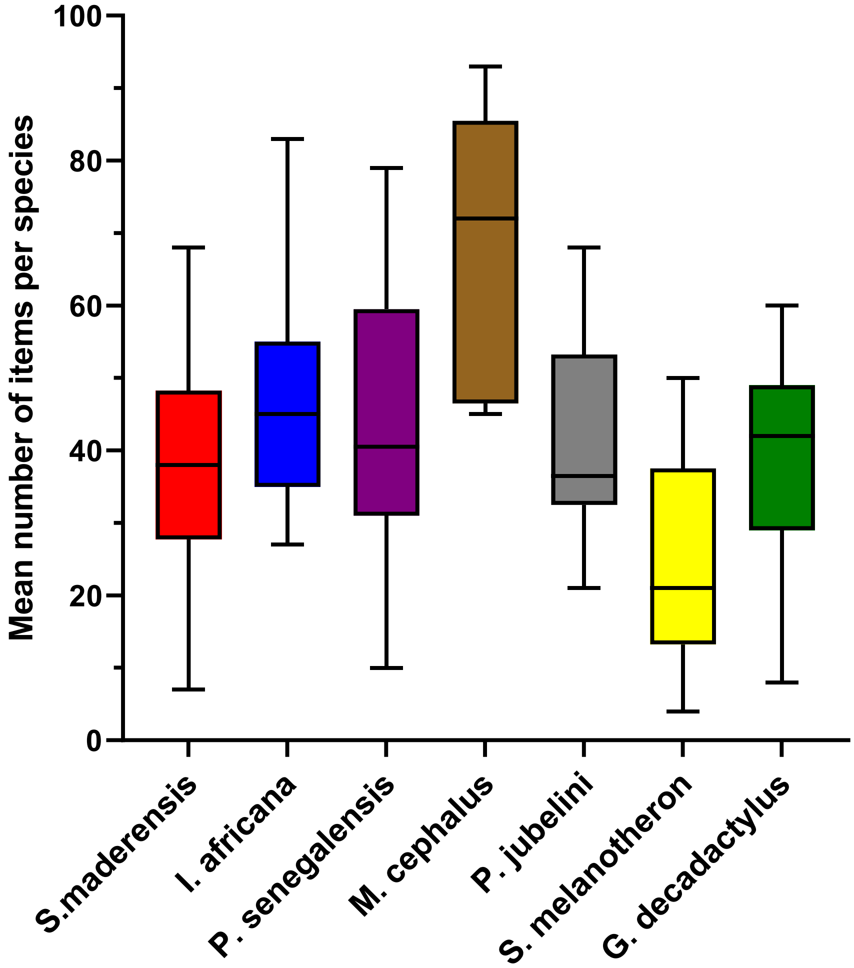


Figure 3: Variations in mean microplastic numbers across fish species.

By comparing the measured length of fish species to the expected length at maturity (Froese & Pauly, 2010), we established that *S. maderensis*, *P. jubelini*, *S. melanotheron* and *G. decadactylus* had all reached maturity prior to harvesting while *M. cephalus*, *I. africana* and *P. senegalensis* were considered juvenile fishes because their standard length was less than the expected length at maturity (Table 1). Whereas it is expected that fish that has reached maturity would have prolonged exposure to any contaminant (assuming they all come from the same environment), thereby having a high concentration of the contaminant, our study reported higher numbers of microplastics in the relatively younger fishes. Aside age, other factors such as size, dietary preference and habitat could be influencing the accumulation of microplastics in the guts of the relatively younger fish. By reviewing literature on the dietary and habitat preference of each species (Table 1), we established that the relatively high loads of microplastics in the gut of *M. cephalus* for instance could be linked to its broader diet and habitat preference. *M. cephalus* is omnivorous, feeding on a wide variety of food items from detritus, microalgae, zooplankton, crustaceans, bivalves to smaller fishes (Froese & Pauly, 2010). This broad dietary preference increases its potential to bioaccumulate microplastics. In addition, *M. cephalus* is euryhaline (it can be found in marine, brackish and freshwater environments) and benthopelagic. This broad feeding and habitat preference are unique to only *M. cephalus* in this study, as all the other fish species studied are either carnivorous/marine, omnivorous/marine, or carnivorous/brackish/marine (Table 1). High numbers of microplastics have been detected in crustaceans (Devriese et al., 2015) and zooplankton (Cole et al., 2013; Desforges et al., 2015), which are major food items of most of the fish species studied. Whereas fish feeding in the pelagic zone are likely to ingest more microplastics than demersal feeders, likely due to the low density of highly prevalent plastic polymers in the environment (e.g., polyethylene and polypropylene) (Hidalgo-Ruz et al., 2012), chemofouling or biofouling may increase the density of these polymers (Karami et al., 2017; Morét-Ferguson et al., 2010), causing them to sink to the bottom and become readily available to demersal feeders. This may have accounted for the high numbers of microplastics found in the fish species studied most of which are demersal.

Table 1: Mean Length, weight and condition factors of the fish species studied. Data on Length at maturity (Lm), diet and habitats were obtained from (Froese & Pauly, 2010).

	Item/Ind.	Length (cm)	Lm (cm)	Weight (cm)	Condition Factor	Diet	Habitat
M. cephalus	67.2±9.1	16.9±2.1	35.4	37.9±7.1	0.8±0.3	Omnivore	Euryhaline Benthopelagic
I. africana	48.4±4.0	16.9±1.6	13-18	34.4±12.5	0.7±0.1	Carnivore	Marine/Brackish, Pelagic
P. senegalensis	43.7±3.5	24.9±4.0	35	125.3±59.1	0.8±0.3	Carnivore	Marine, Demersal
P. jubelini	41.2±4.4	21.8±3.6	13.1	127.4±54.6	1.2±0.3	Carnivore	Marine/Brackish Demersal
G. decadactylus	38.1±3.6	23.39±4.37	11.6	123.3±82.8	0.8±0.3	Carnivore	Marine/Brackish Demersal
S. maderensis	37.98±2.2	11.5±1.8	11-19.5	12.4±4.9	0.95±0.3	Omnivore	Marine, Pelagic
S. melanotheron	24.5±3.1	15.0±0.9	13.2	62.9±15.9	1.8±0.4	Omnivore	Brackish, Demersal

Using the data on microplastic numbers per fish species, we estimated the annual intake (AI) of microplastics (Table 2) based on the assumption of eating whole fish using the equation below (Piyawardhana, 2022)

AI = C x AIR …………………………………………………………………………..(1)

Where C is the mean microplastic concentration based on fish gut weight (ww). AIR is the annual fish consumption rate for Nigeria (13.3 kg per capita) according to FAO (2022). The mean microplastic concentration was 7.60 ± 3.04 items per gram^{-1} for *S. maderensis*, 9.86 ± 3.12 items per gram^{-1} for *I. Africana*, 8.73. ± 3.86 items per gram^{-1} for *P. senegalensis*, 13.44 ± 4.08 items per gram^{-1} for *M. Cephalus*, 8.24 ± 2.80 items per gram^{-1} for *P. jubelini*, 4.89 ± 2.08 items per gram^{-1} for *S. melanotheron* and 7.62 ± 2.67 items per gram $^{-1}$ for *G decadactylus*.

Table 2: Estimated weekly and annual intake of microplastic for adult populations

Exposure	**Mean Weekly Intake (MPs particles per week)**	**Mean Annual Intake (MPs particles per year)**
M. cephalus	3,430	178,220
I. africana	2,534	131,670
P. senegalensis	2,227	115,710
P. jubelini	2,099	109,060
G. decadactylus	1,951	101,346
S. maderensis	1,946	101,080
S. melanotheron	2,577	65,170

The estimated annual intake of microplastics from the consumption of the fish species studied ranged between 178,220 and 65,170 particles per year for adults on the assumption that fish is consumed together with the gut with a mean of 114,608 ± 34575. These values far exceed the annual intake values of 51814 ± 8172 and 46013 ± 7755 for adult male and female in North America from all sources except for air (Cox et al., 2019). It is important to also note that in our study we have used the gut and not the muscle.

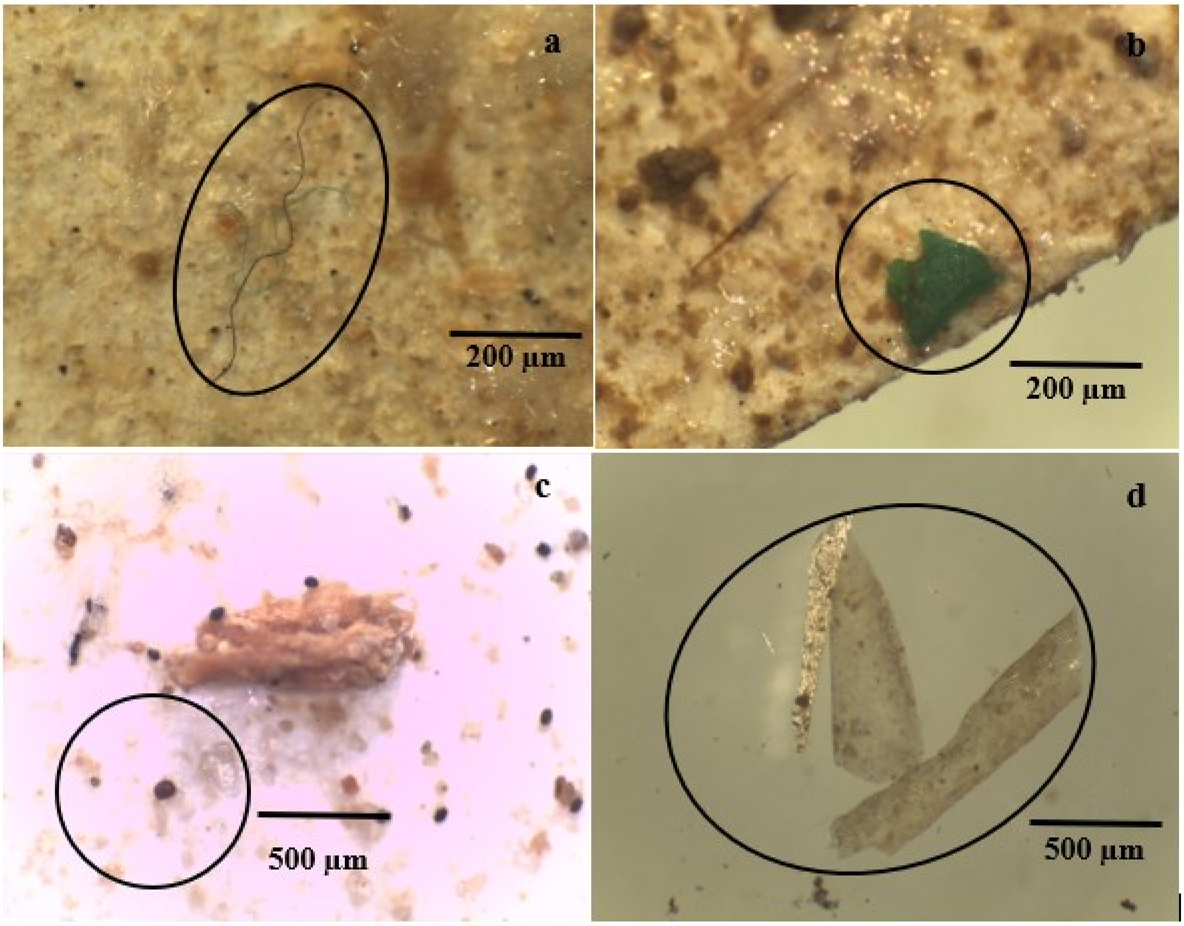


Figure. 4: Images of some microplastic types; a) fiber b) film, c) microbeads and d) fragment found in the fish species.

Euryhaline fish may be ingesting microplastics from the marine, freshwater, and estuarine zones, thereby portraying both marine and continental sources of the microplastic ingested. Although the ingestion can be selective (i.e., intentional feeding on plastic fragments that resemble natural food in size and appearance), they may also be non-selective (i.e., particles randomly ingested as a result of suspension, deposit or filter-feeding behaviour) (Bellas et al., 2016; Santillo et al., 2017; Wesch et al., 2016). The latter may be the case of the microplastics ingested by *I. africana, P. jubelini, P. senegalensis* and *G. decadactylus,* which are carnivorous in nature.

The polymer analysis from the FTIR study (Fig. 5), revealed two major groups of microplastic polymers; high-density polyethylene (HDPE) comprising eighty percent (80%) polyethylene and polypropylene (PP) comprising twenty percent (20%) of microplastics analyzed for polymers. The dominance of HDPE and PP in the sub-sample analyzed for FTIR analysis supports the submission in earlier paragraphs that the microplastics studied in this work may be primarily sourced from industries that use this material in the production of plastic bottles, cups, shampoo bottles, cutting boards, and piping.

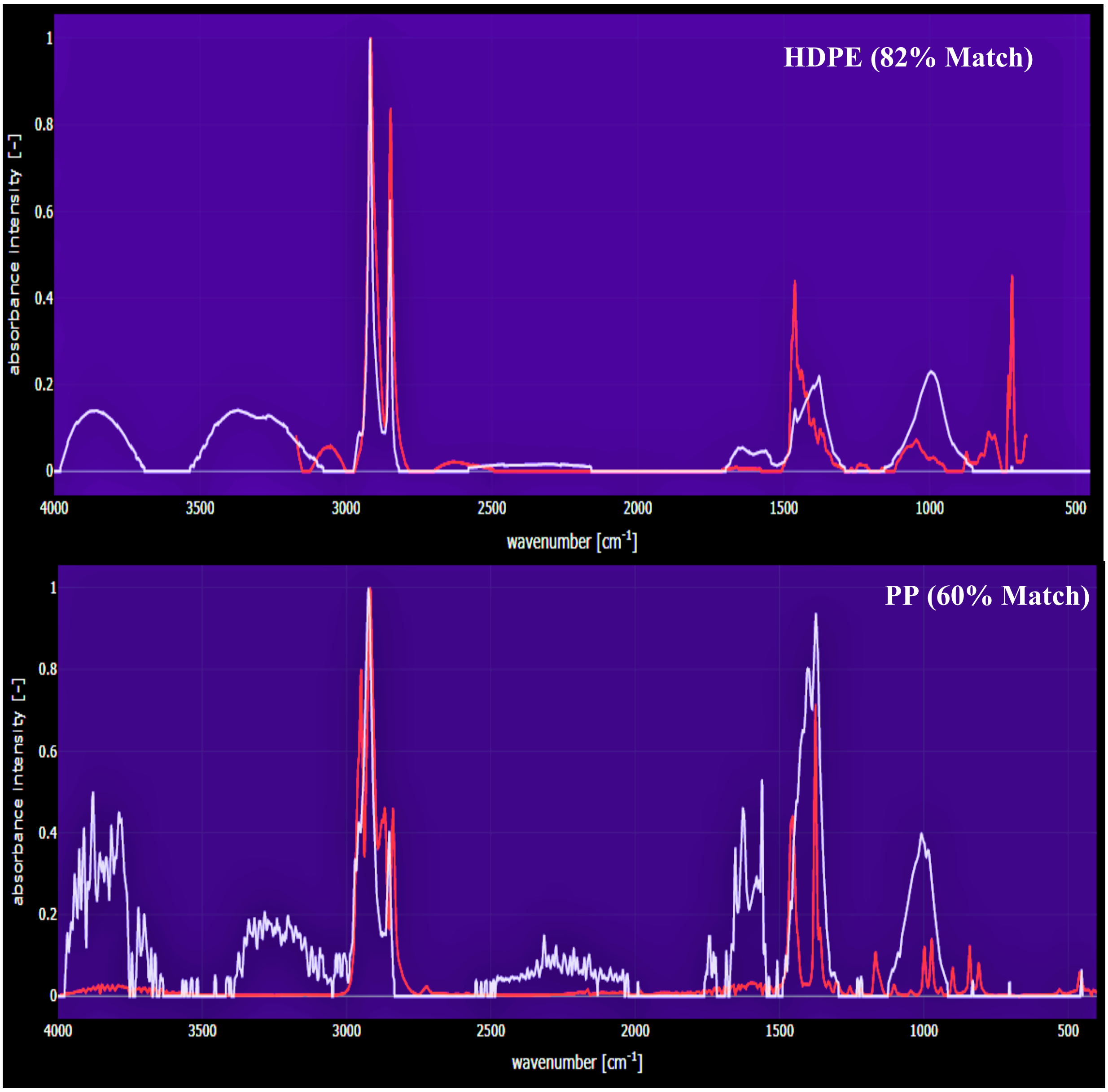


Figure 5: Representative FTIR spectra of the microplastic polymers analyzed (white) and their reference spectra on top (red).

On the other hand, commonly used polypropylene products such as plastic containers, water bottles, medical components, dustbins, outdoor furniture, toys, luggage, and car parts are comparatively less flexible, hence may require more effort and time to fragment in the marine environment.

4.0 Conclusion

The study looked at the occurrence of microplastics and their composition in the guts of *P. senegalensis, P. jubelini, G. decadactylus, S. maderensis, M. cephalus, l. africana* and *S. melanotheron*. A mean of 39.65 ± 5.67 microplastics was found per gut of the 160 fish species analyzed, with microbeads constituted the dominant group followed by fragments while fibers constituted the least group. Most microplastics recovered were below 1000 µm with close to 20% falling within a size range of 85 to 100 µm. Based on the size classes estimated for this study, we argue that close to 20% could be translocated from gut barriers into fish muscle. The estimated annual intake of microplastics from the consumption of the fish species studied ranged between 178,220 and 65,170 particles per year for adults. Feeding habits and habitats played a role in the microplastic distribution across the different fish species analyzed. Mugil cephalus, an omnivorous, euryhaline benthopelagic fish had the highest number of microplastics. Consumption of fish with broad feeding habits and habitat range must be done with caution as this has the potential to increase microplastic intake by humans.

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