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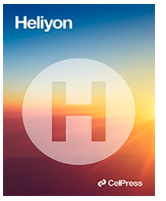

Research article

Evidence of microplastics accumulation in the gills and gastrointestinal tract of fishes from an estuarine system in Ghana

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ABSTRACT

The contamination of aquatic environments by microplastics (MPs) and their subsequent ingestion by fish continues to be a universal ecological challenge. Although numerous studies have been conducted on the accumulation of MPs by fishes globally, not much work has been done within the major estuaries along the Atlantic Coast. This study explored and characterized microplastics in the gills and gastrointestinal tract in 98 specimens of 10 fish taxa (Sarotherodon melanotheron, Pseudotolithus senegalensis, Gobionellus occidentalis, Ethmalosa fimbriata, Chrysichthys nigrodigitalus, Elops lacerta, Mugil bananesis, Cynoglossus senegalensis, Apsilus fuscus and Galeoides decadactylus) from the Pra Estuary, Ghana. The gastrointestinal contents of the fish were extracted, analysed and characterized using a stereomicroscope fitted with an Attenuated Total Reflectance Fourier Transform Infrared spectroscopy (ATR-FTIR). A total of 529 MP particles were found in the fishes. C. nigrodigitalus recorded the highest MP levels in the gills with an average of 4.83 ± 2.08 items/individual whiles S. melanotheron recorded the highest in the gastrointestinal tract at 9.83 ± 4.63 items/individual. Within the fish, transparent fibrous MPs of size <0.5 mm were the dominate types found. A vertical prevalence of MPs was observed across the feeding and habitat preference of the species suggesting a possible linkage with the ecological niche of fishes. Our findings further demonstrate the need for advance studies on the impacts and level of threat microplastic accumulation pose to the sampled fishes and potential consumers.

1. Introduction

Plastic production and usage continue to grow exponentially despite the overwhelming global concern about the detrimental effects plastic wastes pose to the environment, especially within the aquatic medium [1]. It is estimated that about 5–13 million tons of plastics enter the ocean annually with 80 % occurring through riverine discharge [2,3]. These plastics over time undergo wear and tear

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into smaller particles through intense exposure to ultraviolet (UV) light, microbial action, or mechanical abrasions [4–6]. Some of these smaller particles form relative size classes generally known as microplastics (MPs; size 1 μm - 5 mm) [7]. Microplastics are currently considered emerging contaminates within the aquatic environment with ubiquitous tendencies [8,9]. Several studies have reported on the proliferation within both the water and sediment column, attributing floatation to their buoyant nature and sinking caused by added weight from biofouling activities [10–12]. The substantial presence of MPs in the water makes them easily accessible to aquatic organisms especially when they conflict with dietary resemblance [13,14]. The ingestion of microplastics has been reported in several aquatic organisms such as fishes [15], turtles [16], amphibians [17], bivalves [18] and invertebrates [19].

Microplastics have been widely documented to impose severe physical (e.g., internal abrasions, gut blockage) and physiological damages (e.g., oxidative stress, inflammatory response, reproductive toxicity, gut microbiome disruptions) on aquatic organisms in some induced exposure studies [20–24]. Microplastics are also capable of absorbing harmful bio-accumulative toxins such as heavy metals (e.g., Cu, Hg, Pb) and persistent organic pollutants (e.g., Polycyclic Aromatic Hydrocarbons, bisphenol A, Dichlorodiphenyl-trichloroethane) from the environment. Currently, these toxicants are of global concern due to the advanced complications they impose on the exposed organisms namely; endocrine disruption, liver toxicity, mutation and mortality [25–29]. Aggravating the issue is the evidence of the trophic transfer of microplastics within the aquatic loop expanding species vulnerability to bioaccumulation of the contaminants which threatens food security [30,31]. Although there is no empirical data on the transitional complications MPs impose on humans, dietary exposure to the contaminant is well known [32,33]. The ease of plastics and microplastics transfer across food chains, along with their negative effects on ecosystems, drives scientific interest in understanding microplastics' dynamics and fate in fish habitats, forming the basis for policy action [13]. However, most of these studies are marine-biased, with limited traction for the estuarian environment [9,13,34–36].

In Ghana, microplastics have been reported in *Dentex angolensis* (32.0 ± 2.7 items/individual), *Sardinella maderensis* (26.0 ± 1.6) and *S. aurita* (40.0 ± 3.8) from the Eastern Central Atlantic Ocean [37]. In River Akora, MPs were found in *Oreochromis niloticus* (2.3 ± 1.0), *O. aureus* (2), *O. mossambicus* (2 ± 0.7), *S. melanotheron* (1.3 ± 0.5) and *Clarias anguillaris* (1) [38]. Also, within the Sakumo II Lagoon, MPs were recorded in *O. niloticus* (3 ± 2) and *Callinectes amnicola* (8 ± 1) indicating the prevalence of the contaminant within species of commercial importance in the region [39]. Here, we present the first evidence of microplastics in the fishes from the Pra

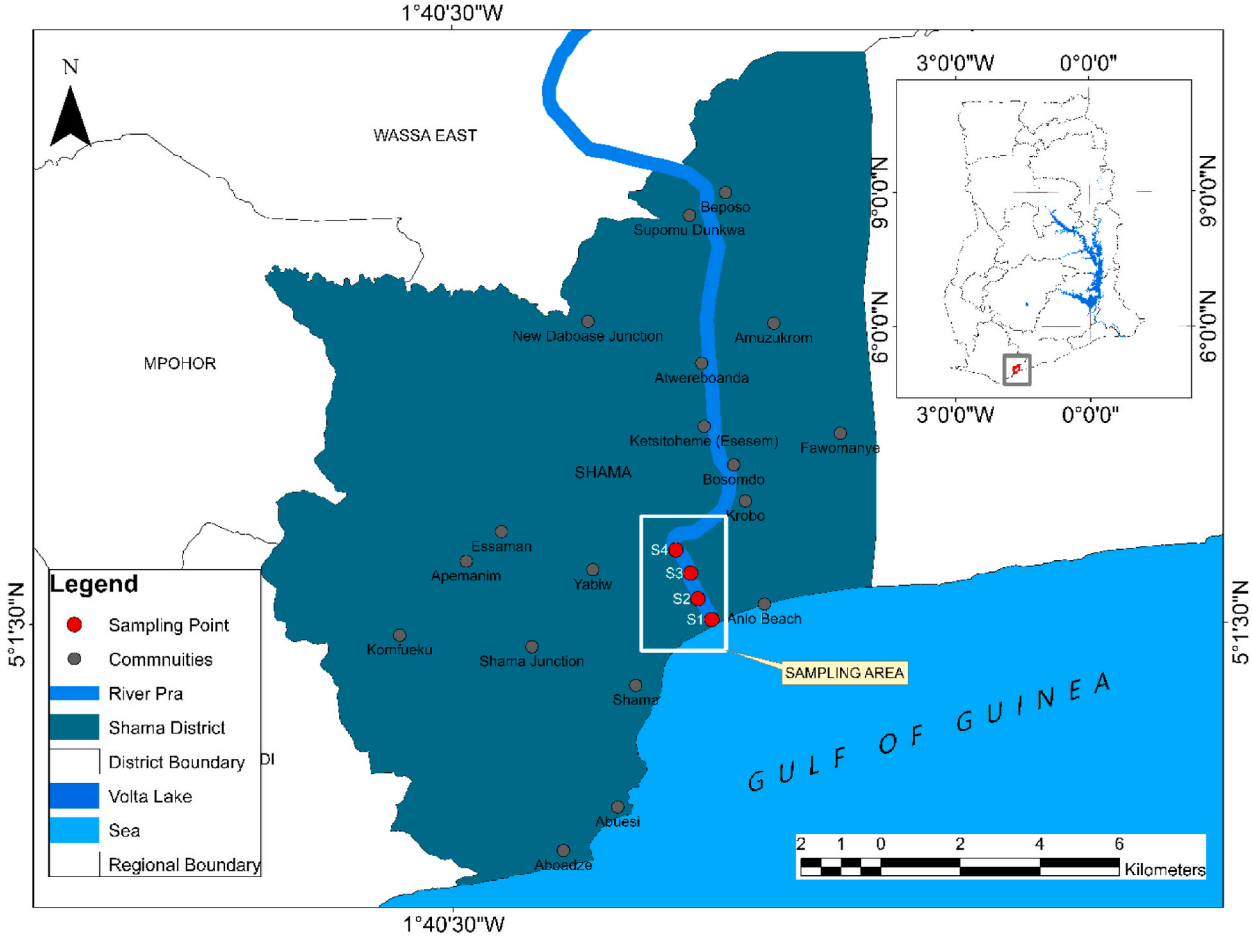

Fig. 1. Map of the Pra estuary catchment showing the sampling area.

estuary. The estuary is sourced from the main Pra River; the largest river that drains the southeastern section of Ghana. The Pra Estuary is ranked the second largest estuary in Ghana and joins the Gulf of Guinea at Shama. The vegetative landscape of the area is predominately thick mangrove ecosystems, swamps and salt marshes [40]. The rich fishery diversity of the estuary supports fishing activities for about 10 fringe communities [41]. This study aimed to identify fishes that are potential candidates for microplastic bioaccumulation, quantify and characterize the microplastics (shape, size, colour and polymer type) in the gastrointestinal tract and gills in the fish species from the Pra estuary.

2. Materials and methods

2.1. Study area

The study was conducted on the Pra estuary, with coordinates 5°01′00"N, 5°03′30"N and 1°36′30"W, 1°38′00"W. The Pra estuary is located within the Shama District in the Western Region of Ghana (Fig. 1). The sampling campaigns on the estuary were done monthly from December 2020 to April 2021.

2.2. Fish sampling

Fish were collected using set nets (mesh size 5 cm) deployed randomly within the study area. The nets were set in the morning (5:00 a.m.) for 12 h before removal. The catch was euthanized and rinsed with clean water to remove external debris and particles, placed in ice slurry for preservation and transported to the laboratory for further analysis. Specimens were grouped into various taxa and identified using identification manuals [42–46].

2.3. Fish gill and gut organ extraction

At the laboratory, the fish were defrosted and weighed using an electronic balance (RANGER 7000). Total Length (TL) of fishes were measured on a graduated measuring board. Width of fishes was recorded using a Vernier calliper. Condition factor (K) of fish was determined using the equation:

$$K = \frac{Standard\ weigh\ (W)}{Standard\ Lenght\ (L)^3} \quad (1)$$

Before dissecting the fish, specimens were placed on an aluminium foil and wiped with tissue paper to remove any external material attached to the samples. The whole visceral mass and gills were removed using surgical scissors. This was done by making straight incisions from the anal port through to the mouth region exposing visceral contents whiles cuts were made from the neck and on the operculum to access the gills. The gastrointestinal tract (GIT) of specimens was identified and cut from the visceral contents after weighing. The extraction of gastrointestinal tract was done following the techniques [25]. Before digestion of the GIT and gills, the gastrointestinal tract was analysed under a dissecting microscope (40x magnification) for plastic debris for effective assessment of microplastics in GIT in fish [9]. During the visual analysis of GIT, all non-natural prey entities were removed using forceps onto a filter paper and placed in a Petri dish to be categorized.

2.4. Microplastic extraction

After visual analysis of the GIT, the remaining gut contents and gills were transferred into a 250 ml glass beaker and flooded with 200 ml of 10 % (w/v) Potassium hydroxide (KOH) to digest the organic matter. The mixture was incubated at 40 °C for 72 h for the gills [47] and 60 °C for 24 h for the GIT [48] in an oven (GEOTECH EN 932-5). The digestion was followed by density separation. The mixture after incubation was soaked with 10–15 ml of 4.4 M sodium iodide (NaI) solution and stirred thoroughly with a glass rod for 1min before subjecting the supernatant to vacuum filtration for microplastics through a 1.2 μm, GF/D 47 mm chm fiberglass filter (Cat No. GF3-047).

2.5. Visual identification

Dry-labelled filters of the samples were placed on a Petri dish and analysed for micro plastics using a dissecting microscope (OPTIKA LAB-10, ITALY, magnification ×40). Under the microscope, microplastic particles were sorted out using distinct colour isolation (Blue, Black, Yellow, White, Red, Green, and Transparent). Sorted microplastic particles were categorized based on shapes (fragment, fibre, pellet, film, foam and sheet), and size [49]. The size of the microplastics was taken with the aid of an ocular rule calibrated into an image analysis software IMAGEJ (National Institutes of Health, USA) while visual images were taken with a camera (Sony Cyber-shot DSC-W350 4x).

2.6. Chemical identification

In determining the polymer type of the microplastics for this study, chemical identification was conducted spectroscopically using

an ATR-FTIR spectrometer (Bruker Alpha, Germany). Before the analysis, the device was sterilized with ethanol. Randomly selected subsamples of categorized microplastic particles were placed in a glass filter and placed under the device scanning table. The background spectrum was taken. The spectra signatures of samples were captured through 24 scans over a wavenumber range of 400–4500 cm^{-1} at resolution of 4 cm^{-1} and compared with the synthetic polymer spectra signature database (NICODOM IR Library) for validation with acceptance metrics >0.7.

2.7. Quality control and assurance

Before field sampling, the equipment was thoroughly cleaned. All unavoidable synthetic tools such as fish gear and clothing used during sampling were documented with respective colours outlined for any possible field contamination. At the laboratory, a cotton laboratory coat and nitrile gloves were always worn. The processing of the samples was carried out in a fume hood with limited access to the experimental environment. All the liquids used during the processing stage underwent filtration in a GF/D (2.7 μm) Whatman microfiber filter membrane. The instruments used during processing were washed once with detergent, rinsed with ultrapure deionized water, and finally with 70 % ethanol. Processing apparatus were covered with aluminium foil when not in use to limit external contamination. To track and correct possible contamination, triplicate blanks were conducted at every stage of the treatment and separation stage and tested for microplastic particles. The outlined contamination control protocol follows [47,50].

2.8. Statistical analysis

Microplastics in fish were presented as MP items per individual. All data were tested for normality using the Kolmogorov-Smimov test. Pearson correlation was used to analyse the relationship between microplastic occurrence in the fish organs and biological indices (Total length, body weight and condition factor). One-way analysis of variance (ANOVA) was used to determine the differences in the density of microplastics among mean microplastic accumulation based on habitat and feeding preferences. The differences were considered significant at $p < 0.05$ and differences in means were compared using the Tukey multiple comparison test. Principal component analysis (PCA) was used to evaluate association of fish species in accumulating MPs in gill and GIT as well as the type of MPs using OriginLab Pro 8. The results were presented in mean ± Standard deviation (SD) in tables and charts. Graphs and statistical analysis were executed using SigmaPlot (Version 12.0).

Table 1
The composition of fish species collected over the sampling period.

Family	Species	Common name	Habitat	Feeding Type	N	Mean weight (g)	TL Range (cm)	K	No. MP Gills (R)	No. MP GIT (R)
Gobiidae	*Gobionellus occidentalis* (Boulenger, 1909)[a]	Delta goby	Benthic	O	14	5.64 ± 0.46	9.6–13.0	0.38 ± 0.08	34 (1–5)	53 (4–10)
Elopidae	*Elops lacerta* (Valenciennes, 1846)[b]	West African ladyfish	Pelagic	C	5	33.51 ± 4.72	15.9–20.1	0.49 ± 0.05	23 (3–6)	36 (5–9)
Mugilidae	*Mugil bananesis* (Pellegrin, 1928)[b]	Banana mullet	Pelagic	O	2	8.70 ± 4.90	7.5–12.0	0.84 ± 0.08	3 (1–2)	5 (2–3)
Bagridae	*Chrysichthys nigrodigitalus* (Lacepède, 1803)[c]	African Forktail Catfish	Demersal	O	12	558.18 ± 147.9	20.8–53.4	0.76 ± 0.29	58 (2–9)	56 (3–9)
Cynoglossidae	*Cynoglossus senegalensis* (Kaup, 1858)[b]	Tongue soles	Demersal	C	2	264.36 ± 72.01	31.0–46.0	0.49 ± 0.21	5 (1–4)	2 (1)
Cichlidae	*Sarotherodon melanotheron* (Rüppel, 1852)[a]	Blackchin tilapia	Benthopelagic	P	25	14.28 ± 3.13	5.7–13.0	2.34 ± 0.25	32 (1–9)	66 (1–19)
Polynemidae	*Galeoides decadactylus* (Bloch, 1795)[b]	Lesser African threadfin	Demersal	C	1	713.4	45.0	0.78	3	6
Sciaenidae	*Pseudotolithus senegalensis* (Valenciennes, 1833)[d]	Cassava croaker	Demersal	C	21	114.57 ± 31.61	12.4–59.7	0.66 ± 0.21	82 (2–10)	17 (1–2)
Clupeidae	*Ethmalosa fimbriata* (Bowdich, 1825)[b]	Bonga shad	Pelagic	P	14	84.66 ± 7.47	17.6–26.3	0.91 ± 0.14	18 (1–3)	23 (1–3)
Lutjanidae	*Apsilus fuscus* (Valenciennes, 1830)[b]	African forktail snapper	Demersal	C	2	230.25 ± 8.96	40.0–42.0	0.34 ± 0.05	0	7 (1–6)

Where **N** = Number of specimens, P = Planktivorous, O = Omnivorous, C = Carnivorous, **TL** = Total Length, **K** = Condition factor, Mean ± Standard Error, **R** = Range. ID manual - a = [44], b = [46], c = [51] and d = [52].

3. Results

3.1. Occurrence and composition of fish sampled in the Pra Estuary

A total of 98 fish specimens were collected at the end of the study. Systematic identification of the specimens indicated 10 fish taxa. The mean weight and total length of the species are presented in Table 1. Among the fishes, *S. melanotheron* was the most abundant (25 specimens), followed by *P. senegalensis* (21 specimens). *G. occidentalis* and *E. fimbriata* had equal abundance (14 specimens), *C. nigrodigitalus* (12 specimens), *E. lacerta* (5 specimens), *M. bananesis*, *C. senegalensis,* and *A. fuscus* had abundance of 2 specimens each. The lowest abundance was *G. decadactylus* (1 specimen). The highest mean weight recorded was 558.18 ± 147.9g (*C. nigrodigitalus)* and the lowest was 5.64 ± 0.46g (*G. occidentalis)*. Specimen of *S. melanotheron* had the shortest total length at 5.7 cm and the longest total length of 59.7 cm was recorded for *P. senegalensis.* Four species habitats (benthopelagic, benthic, pelagic, and demersal) were identified to be occupied by the sampled specimen. The feeding types of the sampled species were planktivorous, omnivorous, and carnivorous.

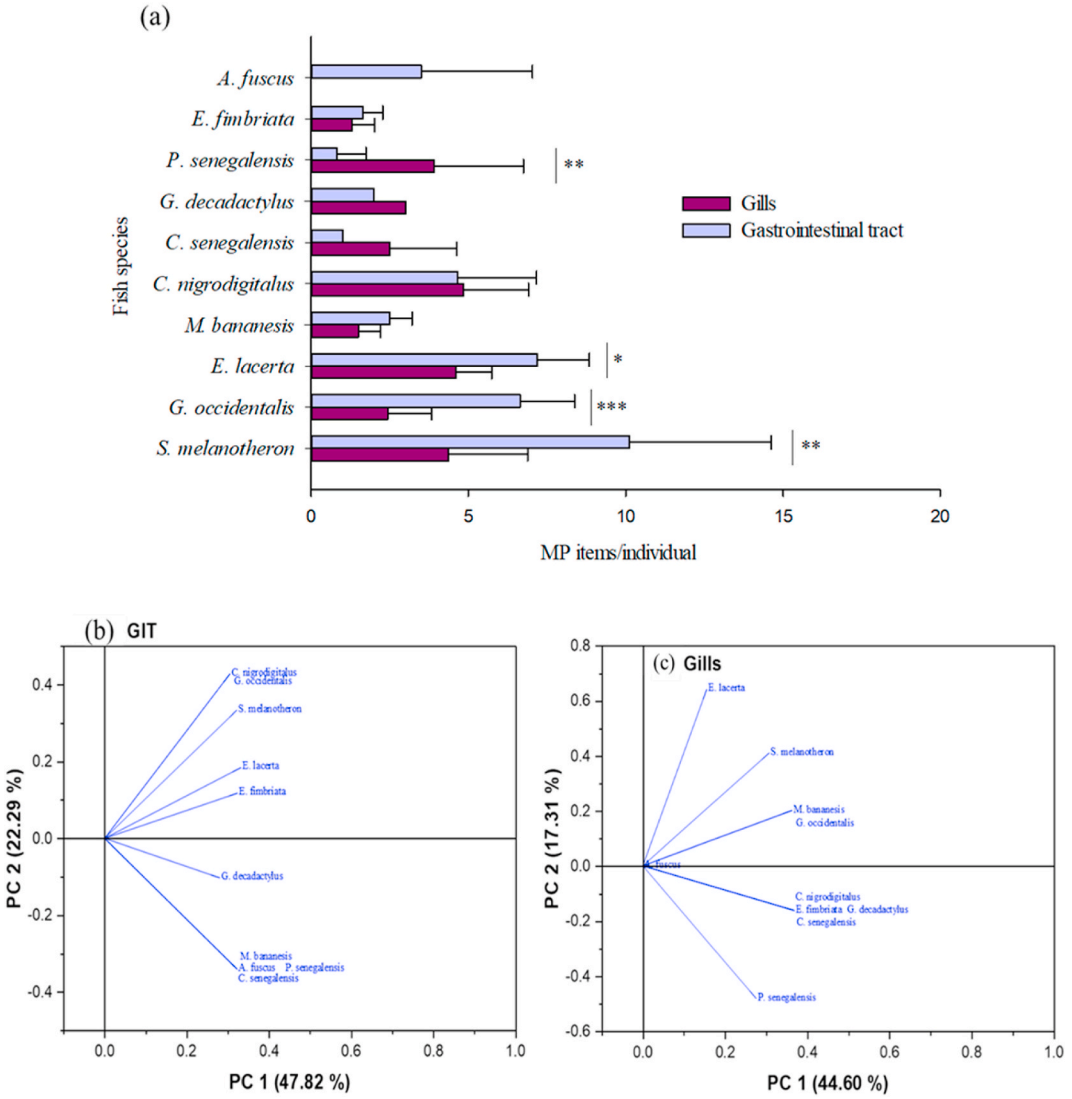

Fig. 2. Mean Microplastics load (abundance) in the sampled fishes within the Pra estuary. Asterix represent mean significant difference ($p < 0.05$). *P. senegalensis* (Mann-Whitney U, $p < 0.001$), *E. lacerta* (*t*-test $_{\text{One-tailed}}$, $p = 0.016$; *t*-test $_{\text{Two-tailed}}$, $p = 0.033$) and *S. melanotheron* (Mann-Whitney U, $p < 0.001$) (a); the principal component of fish species in terms of MPs quantities ingested in gills (b); and gastrointestinal tract (c).

3.2. Occurrence and abundance of microplastics in the fishes

Microplastics were detected in all the species (Table 1) sampled within the Pra estuary over the study period. The gills and gastrointestinal tract of individual fish specimen were investigated separately. Among the organs assessed, MP occurrence was 100 % in all species except *S. melanotheron* (92 % - gills and 100 % - GIT), and *P. senegalensis* (76 % - gills and 57 % - GIT). Microplastics were not detected in the gills of *A. fuscus*. Blanks showed zero MP presence throughout the extraction phase which could influence data corrections. A total of 529 microplastic particles were found in the fishes investigated. The average particle load (item/individual) in the species sampled is presented in Fig. 2a. The overall mean MPs in Gills and GIT of the fishes were 3.66 ± 2.31 and 5.42 ± 4.31 items/individual. We observed significantly higher MPs levels in the GIT than the gills at $p = 0.0002$. *E. fimbriata* recorded the lowest average microplastics of 1.29 ± 0.73 items/individual in the gills whiles *C. nigrodigitalus* recorded the highest microplastics of 4.83 ± 2.08 items/individual in the gills. The order of microplastic abundance in the gills was *C. nigrodigitalus* (4.83 ± 2.08) > *E. lacerta* (4.6 ± 1.14) > *S. melanotheron* (4.36 ± 2.52) > *P. senegalensis* (3.91 ± 2.84) > *G. decadactylus* (3) > *C.* senegalensis (2.5 ± 1.12), *G. occidentalis* (2.43 ± 1.40) > *M. bananesis* (1.5 ± 0.71) > *E. fimbriata* (1.29 ± 0.73 item/individual) as shown in Fig. 2. However, the order of microplastics abundance in the GIT recorded was *S. melanotheron* (9.83 ± 4.63) > *E. lacerta* (7.2 ± 1.64) > *G. occidentalis* (6.64 ± 1.74) > *G. decadactylus* (6) > *C. nigrodigitalus* (4.67 ± 2.50) > *A.s fuscus* (3.5 ± 3.54) > *M. bananesis* (2.5 ± 0.71) > *E. fimbriata* (1.64 ± 0.63) > *C. senegalensis* (1.0 ± 0.00) > *P. senegalensis* (0.81 ± 0.93). Apart from *P. senegalensis*, *E. lacerta*, *G. occidentalis* and *S. melanotheron*, no statistically significant differences existed in the microplastics levels recorded in the gills and gastrointestinal tracts. (Fig. 2).

The analysis showed a significant negative correlation between the total MP (item/individual) and the total length ($r = -0.286$, $p = 0.0045$). No significant correlation was observed between the total MP (item/individual) and the wet body weight of fish species ($r = -0.030$, $p = 0.769$). It was worth noting that a significant positive correlation was found between the total MPs per fish and the condition factor ($r = 0.514$, $p < 0.0001$). Planktivorous fish species recorded the highest microplastics levels of 3.845 ± 6.703 item/individual, followed by omnivores (2.567 ± 4.306 item/individual) and the carnivores (1.814 ± 3.459, item/individual). Statistically, there were no significant differences among the mean microplastic abundance in the sampled fishes per the feeding types recorded (One-way ANOVA, $H = 3.402$, $p = 0.182$). The highest amount of microplastics accumulated within the sampled fish species was observed in species inhabiting the benthopelagic region (2.459 ± 5.982, item/individual), followed by the Demersal species (1.711 ± 3.363, item/individual), benthic species (1.319 ± 2.926, item/individual), and the pelagic species (0.800 ± 2.446, item/individual). Statistically, no significant differences were observed among the mean microplastic abundance in the sampled fishes per the species habitat recorded (One-way ANOVA, $H = 6.066$, $p = 0.108$).

The PCA of fish species in terms of the MPs items quantified is presented in Fig. 2b and c. The PCA extracted two components based

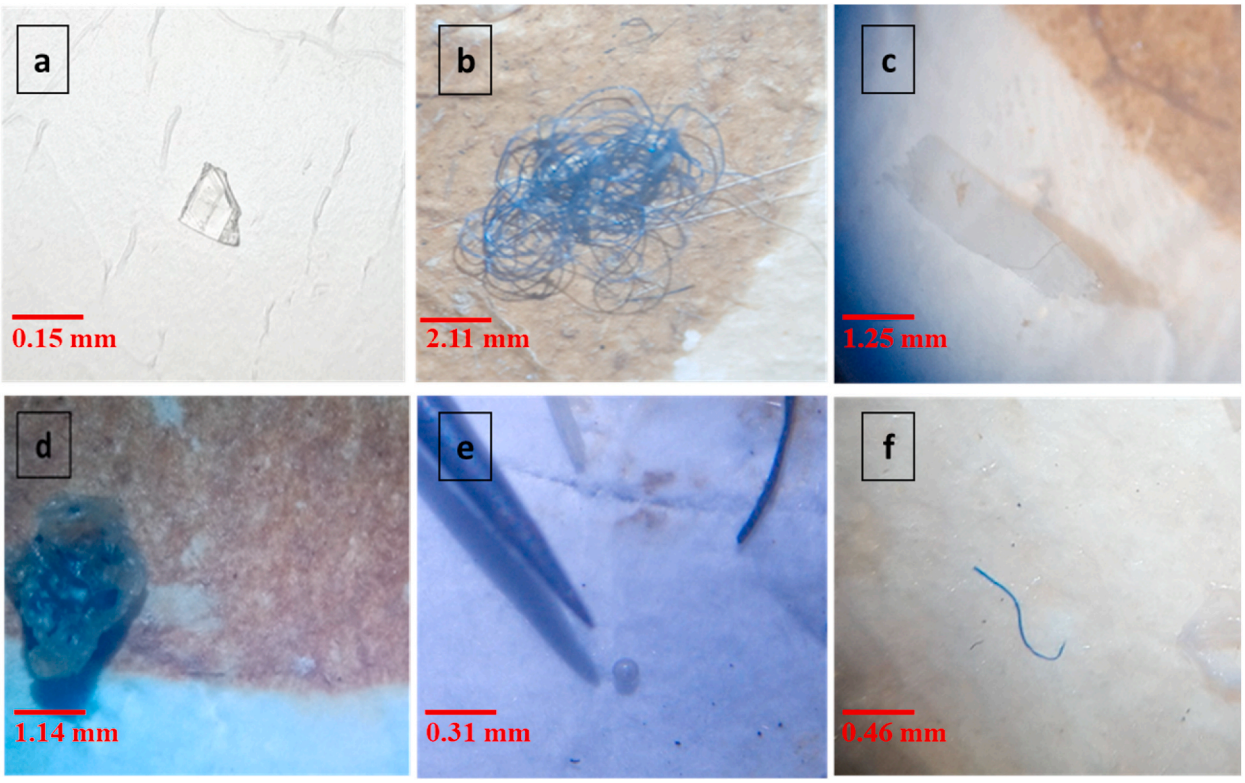

Fig. 3. Photographs of different microplastic shapes a. fragment, b. entangled fibre, c. fragment, d. fragment, e. pellet, f. fibre.

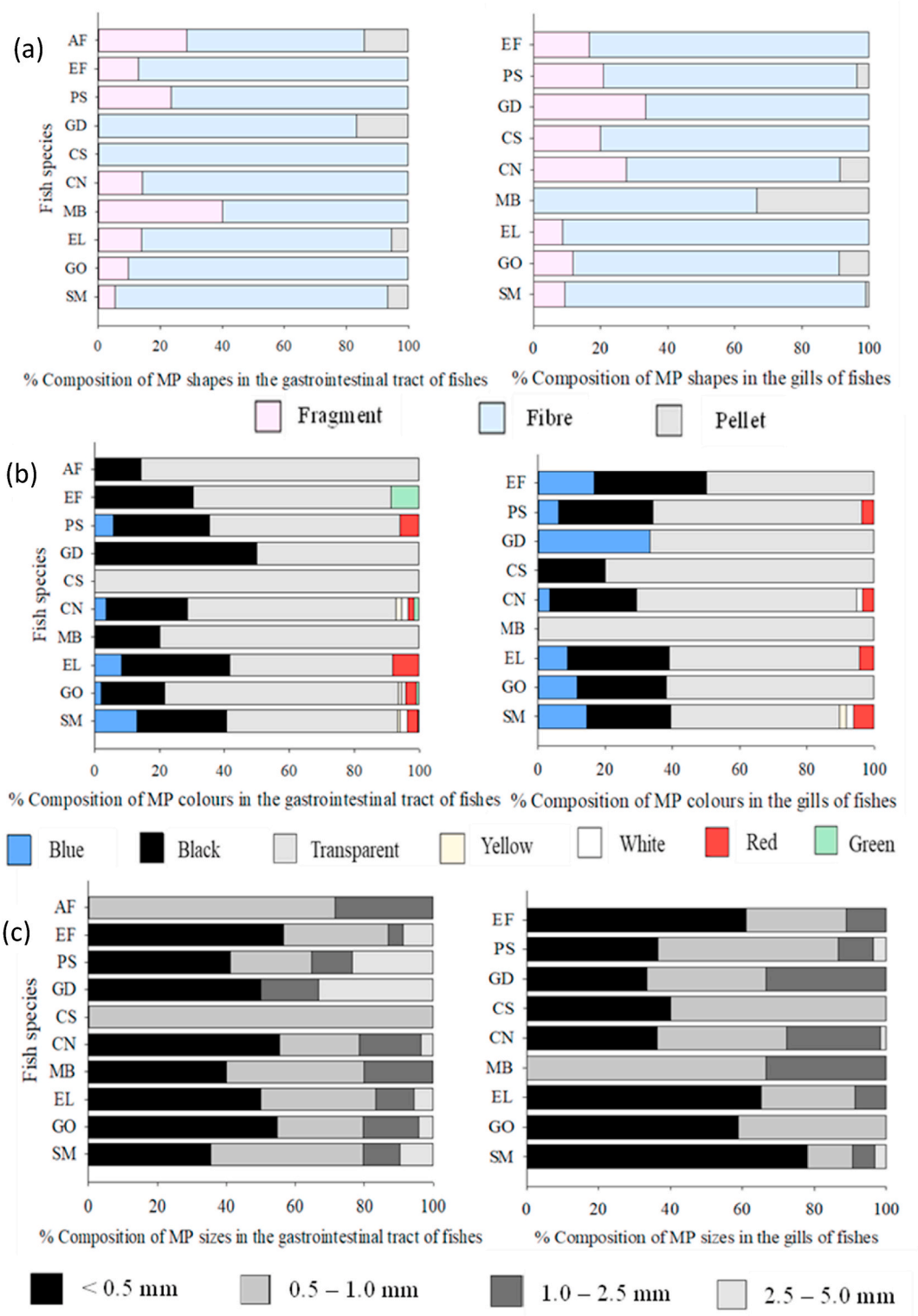

Fig. 4. Composition of microplastic (**a**) shapes, (**b**) colours and (**c**) sizes in the gastrointestinal tract and gills of fish samples. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

on eigen value > 1. However, there are groups or clusters within components. In the gills, *S. melanotheron* and *P. senegalensis*; *C. nigrodigitalus*, *E. lacerta, G. occidentalis* and *E. fimbriata; M. bananesis, G. decadactylus* and *C. senegalensis; and A. fungus* were the main groupings whilst *M. bananesis, A. fungus*, *G. decadactylus* and *C. senegalensis*; *S. melanotheron* and *P. senegalensis*; *C. nigrodigitalus*, *G. occidentalis* and *E. fimbriata;* and *E. lacerta* formed the groupings in the GIT.

3.3. Characteristics of microplastics (shape, colour, size and polymer) in fishes

Three differently shaped MPs: fibre (Fig. 3b and f), fragment (Fig. 3a, c, 3d) and pellets (Fig. 3e) were found in the gills and gastrointestinal tract of the fishes. Fibre was the dominant MP shape occurring within the gills and gastrointestinal tract of fishes at 79.5 % and 86.3 % respectively. Within the gastrointestinal tract, as shown in Fig. 4a, fragments occurred highest (40 %) in *M. bananesis*, fibre was recorded highest (100 %) in *C. senegalensis* whilst pellet occurred highest (6.7 %) in *G. decadactylus*. In the gills, fragment was recorded highest (33.3 %) in *G. decadactylus*, fibre was occurred highest (91.3 %) in *E. lacerta*, whiles pellet was highest (33.3 %) in *M. bananesis*.

As seen from Fig. 4b, transparent MPs dominated the samples with 58.7 %, and 59 % in the gills and GIT respectively. Within the gills, the blue coloured MP recorded the highest occurrence of 33.3 % in *G. decadactylus*, black was highest (33.3 %) in *E. fimbriata* with transparent dominating (100 %) in *M. bananesis*. Yellow was only present in *S. melanotheron* at 2.1 %, white was highest (2.1 %) in *S. melanotheron*, and red was also recorded highest (6.3 %) in *S. melanotheron* as shown in Fig. 4b. Within the GIT, blue-coloured MPs were highest (13.1 %) in *S. melanotheron*, black was highest (33.3 %) in *G. decadactylus*, transparent coloured MPs were 100 % in *C. senegalensis*, yellow was highest (1.8 %) in CN, red MPs were highest (8.3 %) in *E. lacerta* while green was found highest (8.7 %) in *E. fimbriata*.

The <0.5 mm classed MPs made up 54.3 %, and 43.5 % of total MPs in the gills, and GIT respectively. The size total composition ranges within the gills as illustrated in Fig. 4c was between 33.3 and 78.1 % for <0.5 mm, 0.5–1.0 mm (12.5–66.7 %), 1.0–2.5 mm (6.3–33.3 %), and 2.5–5.0 mm (1.7–3.7 %). Within the GIT inspected, the size ranges were between 35.6 and 78.9 % for <0.5 mm, 0.5–1.0 mm (15.8–71.4 %), 1.0–2.5 mm (4.3–28.6 %), and 2.5–5.0 mm (3.6 0–33.3 %) as shown Fig. 4c.

A total of 236 microplastic items isolated from the fishes were identified using an ATR-FTIR spectrometer. The gills accounted for 95 of the items while the GIT accounted for the remaining 141. The spectra of the different MPs identified is presented in Fig. 5 while the distribution and principal component analysis of the isolated MPs in the fish gills and GIT are presented in Fig. 6.

The distribution of the polymer types in the GIT and gills is as indicated in Fig. 6a and b respectively. Polyethylene was the most occurring polymer type within the organs, with 50.5 %, and 52.6 % occurrence in the gills, and GIT respectively. Within the gills, polyethylene occurred most (50.5 %) followed by polyethylene terephthalate (31.6 %), and polypropylene (17.9 %). In the GIT, the order of occurrence was polyethylene (50.5 %) > polyethylene terephthalate (25.2 %) > polypropylene (20.7 %) > polystyrene (3.6 %). The PCA of the different MP polymers showed two components: PE, PP and PET are in PC1 (47.82 %) and PS in PC2 (22.29 %) in the GIT (Fig. 6c) while PE and PET are in PC1 (44.62 %) and PP in PC2 (21.12 %) in the gill (Fig. 6d).

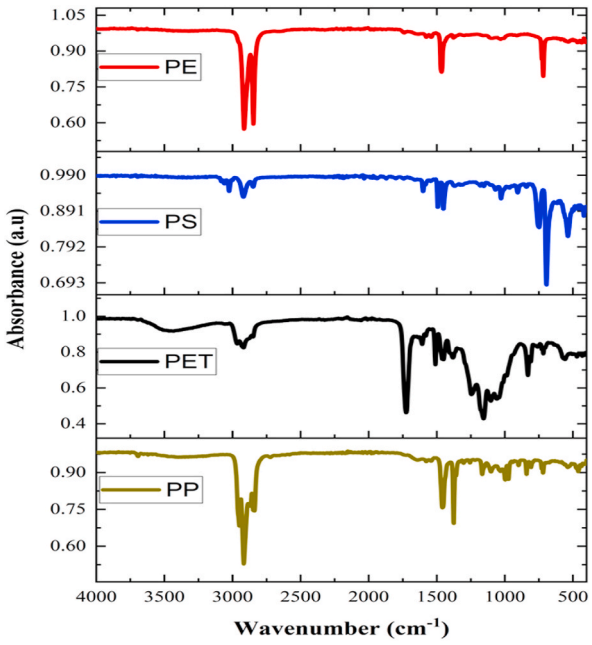

Fig. 5. ATR-FTIR spectra for the different MPs.

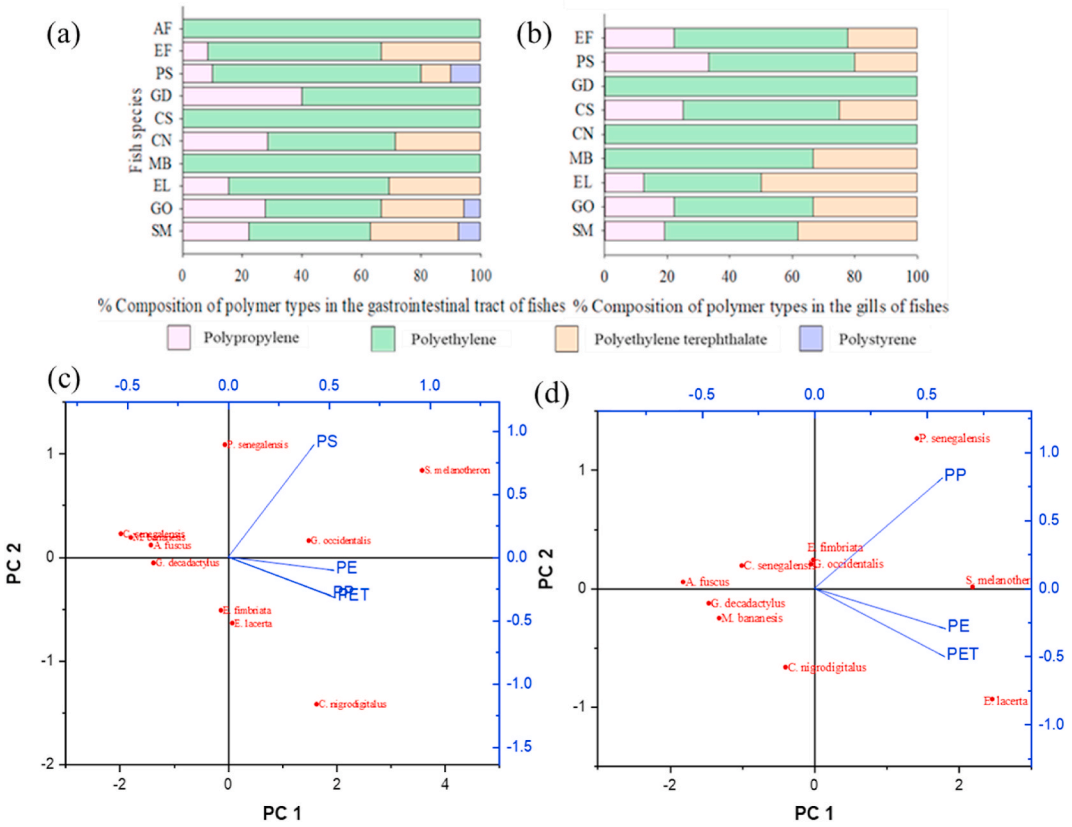

Fig. 6. Composition of microplastic polymer types in (**a**) – GIT, (**b**) – Gills of fish samples and principal component plot in GIT (**c**) and gills (**d**).

4. Discussion

4.1. Occurrence and abundance of microplastics in the fishes

Globally, microplastic ingestion by fishes are widely documented making them a perfect bioindicators for plastic pollution assessment. In this study, microplastics were found in all the sampled species indicating the severity of microplastics proliferation in the study area which merit serious attention for policy makers. Similar account of 100 % MPs prevalence in sampled fishes were reported by earlier works [37,53,54]. The gastrointestinal tract and gills of fishes are significant hotspots for microplastic accumulation compared to other organs such as the liver and muscles because of the readiness of materials to enter into the system with little restriction [13]. Here we observed that microplastics were prevalent in the GIT of all the sampled species. However, MP occurrence was lowest in *P. senegalensis* (57 %). This phenomenon could probably be highly dependent on the feeding strategy and habitat preference of the species [53,55–58]. Microplastics entry into the gastrointestinal tract could probably be through direct or indirect exposure to the material [12,59]. Herbivorous and planktivorous species (*S. melanotheron* and *E. fimbriata*) tend to mistakenly prey on small plankton-like materials that have visual resemblance to their diet, risking exposure to microplastics ingestion [13]. The high retention of microplastics in the gastrointestinal tract in herbivory or planktivory species could be attributed to the long digestive tract the species increasing the residence time for the digestion of complex fibrous plant matter [60]. Carnivorous species (*E. lacerta*, *C. senegalensis*, *G. decadactylus, P. senegalensis* and *A. fuscus*) are more prey selective, thus microplastics in GIT represent secondary exposure to the material, where prey items offload their MP burden upon being consumed by the predators [59]. The omnivorous species (*G. occidentalis, M. bananesis* and *C. nigrodigitalus*) have a wider feeding range alternating between diets due to availability or nutritive value imposing a high susceptibility to both direct and indirect MP exposure [16]. According to Pazos et al. (2017) biofouling of microplastic by microbial hitchhikers could present a favourable bait for fishes that consider them as more nutritious substances.

Microplastics were present in all the gills of the sampled species except for *A. fuscus* likely due to could constant flush out occurring. The accumulation of microplastics in the gills of fishes has well been described as accidental or non-selective in nature [61]. However, the variability in particle sizes in the gills in many studies indicates dependency on the efficiency of the filtration apparatus, especially the gap in-between gill rakers and filtration areas [15,36]. The presence of microplastics (MPs) in all the plankton-feeding and omnivorous species in this study is indicated by the combination of extensive filtering surfaces and closely spaced gaps in the gill rakers, which may enhance the entrapment of microplastics. However, the filtration area and gap size between gill rakers are mere complementary factors accounting for high MP accumulation in the gills of fish; suggesting habitat preference played an important.

This confirms the predominant occurrence of MPs in the gills of pelagic species compared to the occurrence in the gills of demersal species observed in this study. Considering the occurrence of MPs in fish species based on their habitat preference, the occurrence of microplastics in the sampled species occupying the benthic, demersal, benthopelagic and pelagic regions is an indication of the vertical prevalence of microplastics within the Pra estuary. Benthic species are well adapted to feeding within estuarine floors, preying on smaller invertebrates or detritus materials. Thus, exposure to microplastics by such species could be deliberate or accidental while foraging for food through contaminated sediments [13].

A significant negative correlation was observed between fish length and the total frequency of MPs in the fish indicating higher accumulation among smaller-sized fishes. The high consumption of MPs among smaller fishes is still unclear and could widely not be dependent on the size of the species. Our findings agree with a similar significant negative correlation found between MP in the GIT and total length of fishes in the Mondego estuary [9]. Here the positive relationship between the condition factor and the total frequency of MPs in the fish could indicate a higher feeding activity among healthier species within the estuary increasing microplastic accumulation in the area coincidental to the high productivity with the study location.

4.2. Characteristics (shape, colour, size and polymer) of microplastics in the fishes

Among the detected microplastics in the sampled fish, fibre dominated the shapes recovered in the gills and gastrointestinal tract of fish with 79.5 % and 86.3 % respectively. Fibrous MP dominance within gills and GIT have been found in several studies [9,13,34,36,61–63]. Presence of fibre could be linked to several potential sources such as fishing activities and shreds from textiles and old clothing introduced by laundry activities and sewage entering the estuary uncontrollably [12]. In Ghana, the direct entry of untreated greywater into waterways could be a major contributor to upstream microfibre in the estuary [38]. Fragments and pellets could be associated with weathering of macro-plastics entering the estuary. The sprouting of peri-urban communities upstream coupled with the wide use and poor waste management in the area are possible sources of the microplastic within the estuary. The colour of microplastics within the environment plays an important role in the dietary exposure of the materials to the inhabiting species [34,64]. Species such as fish are inconsiderate in the ingestion of particles mimicking the colour of prey items [9]. Here, transparent microplastics were the dominant colour found in all the organelles investigated from the sampled species. Transparent materials are optically colourless which presents an unseemly no resemblance to any distinctive dietary item suggesting that accumulation was accidental or secondary. However, the dominance of transparent MPs in the fishes could indicate their prevalence in the estuary. Our finding was consistent with [34] and contrasted with other studies with black MPs in the GIT and gills of fishes in the Pearl River Estuary and Musa Estuary [13,36] and blue MPs found most dominant in two seabreams [65]. For size, the ingestion of smaller sized particles in this study could be attributed to several factors such as mode of feeding, gill efficiency, gape size, biofouling of particles, easily digestible, energy conservation in feed ingestion [13,66–68]. Small microplastics present a large surface area to size ratio which supports biofouling by microbes that could attract ingestion [61].

Of the 236 microplastics that were analysed with ATR-FTIR, polyethylene was the most occurring MP item in the gills and GIT of fishes in the Pra estuary. Polyethylene materials are less dense (0.910–0.940 g/cm^3) compared to materials such as polyethylene terephthalate (**1.37 g/cm3**) which could cause PE to float in the water columns [69]. The presence of polyethylene within the benthic section of the estuary could be associated with sinks induced by biofouling [10,53]. The dominance of polyethylene MPs in the fishes most probably originated from fragments of fishing nets, ropes and plastic bags entering the estuary. According to Ref. [62], fishing nets and ropes are mainly composed of polyethylene (PE) or polypropylene (PP) which are easily damaged with minimal force making them readily available to be ingested by the onlooking fishes. The identification of polyethylene in the fish conformed with findings from several authors [13,65,70]. Our findings re-echo the ubiquitous prevalence of microplastics and the threat they impose on sensitive ecosystems that need attention.

5. Conclusion

In this study, we were able to systematically qualify and characterize the accumulation of microplastics in the 10 fish taxa the largest MPs biota study by far to our knowledge along the Atlantic Coast. Evidence on microplastic in these species adds them to the long list of vulnerable species susceptible to microplastic ingestion from the environment worldwide, several have already been used as bioindicators for other environment contamination assessments. Also, the fact of several dependencies on the fishery resources from this major estuary entreats the need for attention to combat plastic pollution in the estuary to limit exposure to people consuming the fish. Our findings further demonstrate the need for further studies on the impacts and level of threat microplastic accumulation pose to the sampled fishes and potential consumers.

Ethical approval

Ethical clearance for this study was approved by the University of Cape Coast Institutional Review Board (UCCIRB) with clearance ID (UCCIRB/CANS/2021/17)

Consent to participate

Consent to participate was not applicable in this research since no data on or from humans was needed.

Consent to publish

All the authors consented on the publication of any material or information used in this manuscript.

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Availability of the data and materials

Data will be made available on request from the corresponding author.

CRediT authorship contribution statement

Andoh Kwaku Amponsah: Writing – original draft, Visualization, Investigation, Funding acquisition, Data curation, Conceptualization. **Ernest Amankwa Afrifa:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Paul Kwame Essandoh:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Christian Ebere Enyoh:** Writing – review & editing, Visualization.

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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