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Characteristics of Microplastics in Water and Fish and Their Relationship with Migration from the East Coast of Surabaya, Indonesia

Aunurohim[1], Dian Saptarini[1], Abdus Junaedi[2], Shinta Dewi[1], Edo Danilyan[1], Hasan Adro'I[3], Prima Putra[3], Alfiah Hayati[3]*

[1]Department of Biology, Faculty of Science and Data Analytics, Institut Teknologi Sepuluh Nopember, East Java, Indonesia.
[2]Aquatic Resources Management, Department of Marine Affairs and Fisheries, Faculty of Agriculture, Trunojoyo University, Madura, East Java, Indonesia.
[3]Department of Biology, Faculty of Science and Technology, University of Airlangga, East Java, Indonesia.
***Corresponding Author:** alfiah-h@fst.unair.ac.id

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ABSTRACT

Microplastics (MP) contamination has become a crucial aspect of research concerning water environments including fish. The East Coast of Surabaya, Indonesia, is one of the fishery areas in the eastern part of Java Island, with MP in its waters having a negative impact on fish consumption. This study specifically focused on analyzing the characteristics of MP in both water and fish (gills and digestive tract). The results revealed approximately 0.46 particles/L of water, with fragments being the predominant form (79.9%), black color (54.9%), and a size range of 20-40µm. Eight species of fish showed the highest abundance of MP in the digestive tract (41.2 - 66.9%) and gills (33.1 - 58.8%). Overall, the physical characteristics of MP in fish are dominated by fragments (94.4%), black color (80.1%), and a size of 20-40µm (36.6%). Meanwhile, the polymer composition of MP in both water and fish is dominated by polypropylene (PP, 75%) and high-density polyethylene (HDPE, 25%). Based on the type of migration, *M. cephalus* as catadromous has the highest MP accumulation with a total of 1,194 and the lowest accumulation is *Rhynchobatus* sp. as oceanodromous with an accumulated total of 390. The fish organ that accumulated the most MPs is the digestive tract, showing a tight relationship with feeding behavior. Meanwhile, the relationship between migration type and microplastic accumulation still needs further study to provide accurate evidence.

INTRODUCTION

Plastic pollution is currently a global issue of concern to the public, researchers, and governments due to the risk of exposure through water, marine biota, and even air **(Guerrera *et al.* 2021; A`Yun *et al.* 2022; Brandts *et al.*, 2022)** It is estimated that 60-80% of all marine pollution is plastic based on IUCN data in 2021. This is because plastic is a material that has a low density, relatively high strength-to-weight ratio, relatively high resistance to chemical solvents, a simple design, an easy manufacturing process, and low production costs **(Seri *et al.*, 2023)**. The persistent nature of plastics in the environment causes plastics to last a long time and is difficult to degrade. Plastic fragmentation with a size of <5mm known as microplastics (MP) will still carry plastic properties and can pollute marine ecosystems in various ways, such as industrial and household wastewater disposal, littering, plastic use for marine activities, and human activities on the coast **(Ambarsari, 2022; Brandts *et al.*, 2022; Mitrano & Wohlleben, 2022; Nuamah *et al.*, 2023)**. The presence of MP in the aquatic environment can accumulate and persist in the water ecosystem for a long time affecting the health of aquatic biota in the future **(Hayati *et al.*, 2023a)**. If the marine ecosystem has been polluted with MP, it will witness an impact on low trophic level organisms followed by higher trophic levels. This will cause potential disturbances to marine biota at different trophic levels and will impact different physiological mechanisms in the body **(Guzzetti *et al.*, 2018; Zhou *et al.*, 2021)**.

MP accumulation in marine biota can occur through direct transfer (ingestion of MP while foraging) and indirect transfer (ingestion of organisms that already contain MP). Once accumulated in the body, potential negative impacts include internal physical damage (e.g. lesions or blockage of blood vessels), interference with digestive processes, and/or toxicological consequences **(Yang *et al.*, 2022; Fackelmann *et al.*, 2023; Selden *et al.*, 2023)**. Their toxic properties can be attributed to characteristics such as their small size, multiple color types, various polymer types, and additive composition **(Nuamah *et al.*, 2023)**. MP include chemicals from plastics, high- density polyethylene (HDPE), low-density polyethylene (LDPE), polyethylene terephthalate (PET, PETE), nylon/polyamide (PA), polypropylene (PP), polymethylmethacrylate (PMMA), polyurethane (PU, PUR), and polystyrene (PS). MP can absorb harmful chemicals, and ultimately, MP and associated additives and pollutants pose a significant risk to food webs in marine ecosystems and can threaten the source of seafood consumed by humans. The uncontrolled release of MP in aquatic habitats needs to be effectively managed due to the many problems associated with MP pollution. Therefore, MP are a threat to life and the environment **(Baechler *et al.*, 2020; Selden *et al.*, 2023; Thacharodi *et al.*, 2024)**. Sources of marine origin, such as fish, are a source of uptake and distribution of contaminants from plastic particles in humans. Several studies on potential health effects due to bioaccumulation and biomagnification of MP and chemical contaminants in the human body can lead to translocation from the gut to the spleen and the circulatory system. Other effects include oxidative stress, cellular damage, inflammation and disorders, reproductive effects, carcinogenicity, gastrointestinal problems and cardiovascular diseases **(Carbery *et al.*, 2018; Soliman *et al.*, 2023)**.

Gills and gastrointestinal (GI) are organs that are often associated with MP exposure through respiration and digestion. Gills as an organ of respiration and water filtration can accumulate MP, while the gastrointestinal through digestion has the potential for bioaccumulation and biomagnification **(Jaafar *et al.*, 2020; Hayati *et al.*,**

2023b; Nuamah *et al.*, 2023). However, the specific accumulation patterns in these organs are still not clearly understood and may vary according to the trophic level, environmental conditions, and life phase of the fish **(Yin *et al.*, 2022)**. The above problems occur almost all over the world including Indonesia and one of them is Surabaya, the second largest city in Indonesia. In 2019, the Surabaya government collected up to 23.5 tons of plastic waste **(Sunyowati *et al.*, 2020)**. Surabaya's East Coast is an important part of the eastern coastal side of the city of Surabaya and a fishery source area has been proven to experience MP contamination **(Ni'am *et al*., 2022; Raufanda *et al*., 2024)**. Many fish species are found on the coast, including fish that are commonly consumed by people around Surabaya. Based on feeding habits, fish can be classified into 3 types, namely herbivores, carnivores, and omnivores. Herbivorous are fish that consume plants, carnivorous are fish that eat small fish, crustaceans, and mollusks, meanwhile omnivorous are fish that eat all kinds of food **(Andrade *et al.*, 2019; Li *et al.* 2023)**. Fish with different feeding habits without exception can be transfer agents of MP accumulation to top predators, including humans **(Carbery *et al.*, 2018; Nelms *et al.* 2018)**. In addition, the ability of fish to travel can also provide the potential for higher or lower exposure to MP, as the movement of fish from one location to another is thought to increase the ability to bioaccumulate MP **(Neims *et al.*, 2018)**.

In this study, fish samples from 8 species were examined 37 (*Mugil cephalus*, *Hexanematichthys sagor*, *Johnius trachycephalus*, *Mystus tengara*, *Synanceia verrucosa*, *Rhynchobatus* sp., *Hypanus americanus*, *Plotosus canius*) that have different feeding habits and ranges. This study attempted to quantify the level of MP contamination and accumulation and relate it to feeding habits and ranges through physical characteristics, such as the abundance, shape, color, and size of MP in the gills and gastrointestinal tract. In addition, the presence of MP in the waters where the target fish live was also identified to determine the relationship between the accumulation of MP in the fish body and the habitat where it lives. In addition, the chemical polymer characteristics of the MP found were identified to determine the dominance of the MP chemical polymers obtained, both in the fish organs and in the waters as their habitat. This research has an important role in finding out how big the MPs contamination is on the east coast of Surabaya and its possibility of contaminating several fish species that are widely consumed by the local community. It is hoped that it will be used in the future as an approach to the possible impact of exposure to humans.

MATERIALS AND METHODS

1. Study area

The sampling location is the Surabaya East Coast, with sampling stations conducted 5-10km from the shoreline (Fig. 1). Water and fish samples were collected at the same time. Water samples were taken using a specific container and volume and filtered using a 80µm plankton net **(Dris *et al*., 2018)**. Fish sampling was carried out using nets and fishing rods. There were 8 species of fish with a total sample of 37 fish. Then, fish samples were measured for body length and weight and stored in a cool box. Body length measurements were taken from the snout to the tip of the tail, and weight was measured using Ohaus® digital scales. Wet biomass measurements were also made on fish organs to be observed, namely gastrointestinal and gills weight **(Pereira *et al*., 2023)**.

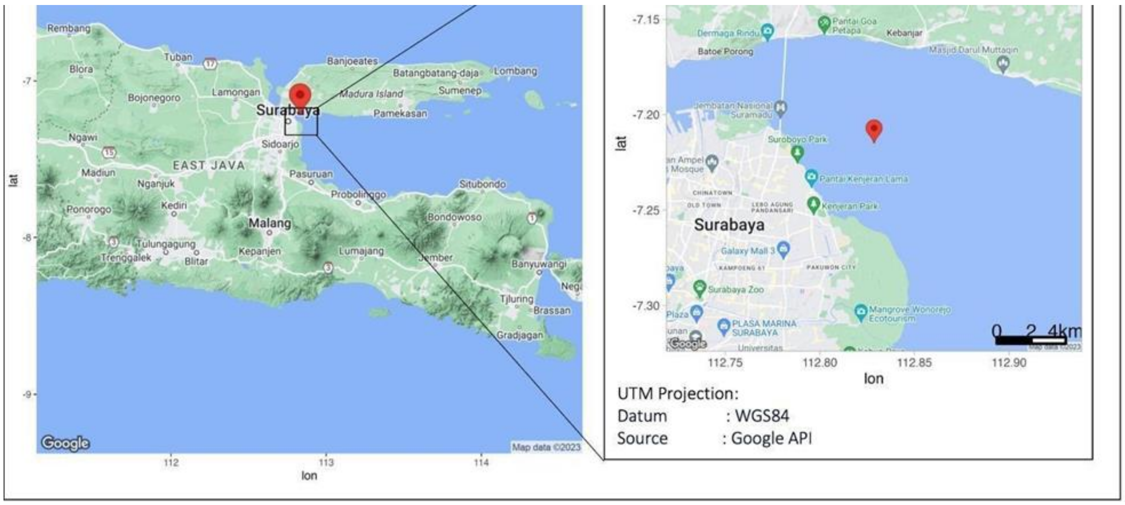

Fig. 1. Map of seawater sampling locations and fish caught by local fishermen on the East Coast of Surabaya with a radius of 5 - 10 kilometers

2. Procedures

Water samples

Water collection by modifying the method was carried out using an 80µm plankton net with the technique of pouring water into a 100ml bucket 10 times so that the total water sample was 100L **(Dris *et al*., 2018)**. Then, the water sample was put into a sample bottle and was stored in a cool box. The water sample ready for analysis was transferred to a glass beaker and 30% H_2O_2 was added in a 1:1 ratio, then heated at 80°C for 24 hours **(Ariyunita *et al*., 2021)**. Next, filtering was carried out using Whatman Grade 42 Cytiva® filter paper with 2.5µm pores with the help of a vacuum filtration Buchner funnel filtering kit. Afterward, the filter paper was transferred into a clean glass Petridish for drying using an oven at 50°C for 24 hours **(Jones *et al*., 2020; Maisto *et al*., 2022)**.

Fish samples

Fish sampling was carried out using nets and fishing rods. After that, the fish were left to die without anesthesia. There were 8 species of fish with a total sample of 37, fish length and weight varied for each fish (Table 1). Fish samples were dissected to obtain the gill and gastrointestinal tract. Next, 25ml of 30% H_2O_2 was added to a glass beaker. Subsequently, the glass beaker was sealed using aluminum foil and was then put in an oven at 50°C for 24 hours to dissolve the organic matter **(Maw *et al*., 2022)**. After the gills and gastrointestinal degradation, the MP filtration process was continued using vacuum filtration with a Buchner funnel filtering kit that was given Whatman Grade 42

Cytiva® filter paper with 2.5μm pores. Furthermore, the sample on Whatman paper was transferred into a glass petri dish container and was put in an oven at 40°C for 24 hours **(Barboza *et al.*, 2020; Maisto *et al.*, 2022)**. After potential MP particles were obtained, these particles were identified and characterized under a stereo microscope.

3. Visual characteristics of microplastics

All MP particles obtained were observed and visually identified using an Olympus® SZ61 stereo microscope based on shape, color, and size **(Free *et al.*, 2014; Sawalman *et al.*, 2021)**. Common shapes of MP observed include fragments and fibers **(Kooi & Koelmans, 2019)**. In addition, for color characters, the references of **dan Jian *et al.* (2022)**, **Abbasi *et al.* (2023)** and **Drabinski *et al.* (2023)** were used. The particle size of MP using grouping based on categories was identified according to **Nor and Obbard (2014)**, which are grouped into eight categories: 0 - 20, 20 - 40, 40 – 60, 60 - 80, 80 - 100, 100 - 500, 500 – 1000, and 1000 - 5000μm. Additionally, for the determination of MPs' size, Image Raster® software associated with Optilab® was used.

4. Chemical characteristics of microplastics

MP samples were obtained from the water, as well as the gills and gastrointestinal tract of organisms. After physical observation, polymer analysis was conducted using Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (ATR-FTIR). The resulting spectra and peak numbers, obtained in transmittance mode, were compared with literature references to identify the polymer composition of the MPs **(Dilshad *et al.*, 2022)**.

RESULTS

1. Microplastics abundance in water

MP were detected in all water samples indicating MP contamination in Surabaya's East Coast waters (Fig. 2).

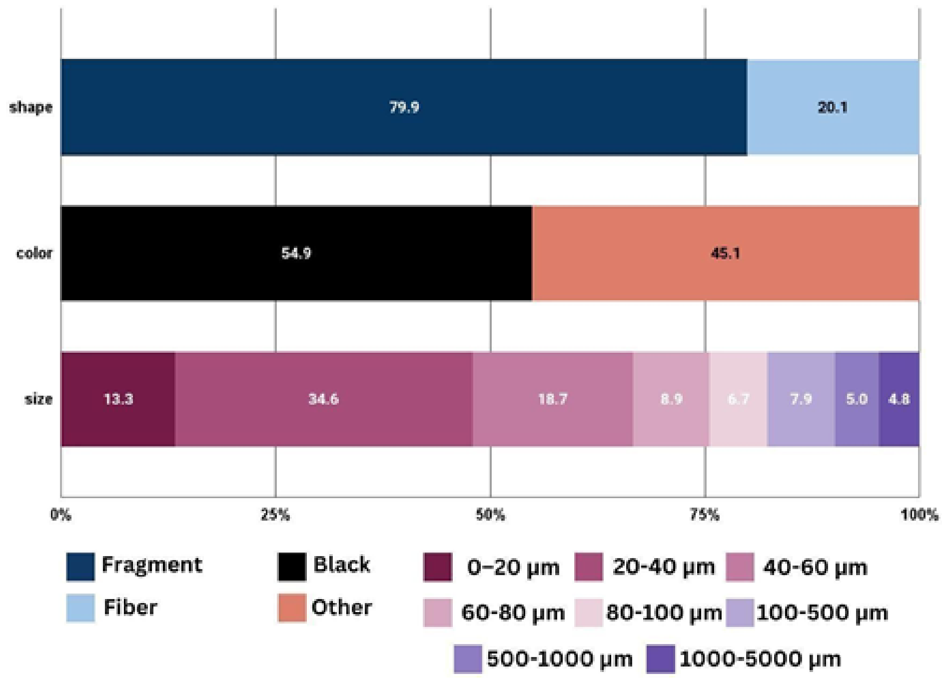

Fig. 2. Percentage proportion of microplastic abundance in the water column in Surabaya's East Coast area by shape, color, and size The abundance of MP in the East Coast waters of Surabaya ranged from 0.46 particles/L

Morphological analysis revealed that approximately 79.9% of the microplastics (MPs) were fragments, while the remaining 20.1% were fibers. The samples exhibited 12 distinct colors: black, blue, red, yellow, brown, orange, gray, purple, transparent, white, pink, and green. Among these, black was the most prevalent (54.9%), and the dominant particle size fell within the 20–40 µm range (34.6%). These findings are consistent with previous studies on MP contamination in aquatic environments **(Akdogan *et al.*, 2023; Ismanto *et al.*, 2023; Lu *et al.*, 2023; Napper *et al.*, 2023)**, which similarly report fragments as the predominant shape, followed by fibers.

The majority of MP found in the aquatic environment are caused by the fragmentation of macroplastics to produce plastics in relatively small sizes, including MP. Macroplastic fragmentation depends on temperature and high ultraviolet radiation, the higher the ultraviolet radiation will accelerate fragmentation. In addition to the natural fragmentation that occurs in the atmosphere, some plastic materials can fragment during use to form micro and even nanoplastics, such as fibers that are detached from fabrics during washing **(De Falco *et al.*, 2019)**, and MP formed through this mechanism are identified as secondary MP.

Secondary MP are formed due to damage or gradual disintegration due to ultraviolet light, wave abrasion, or microbial degradation of large plastics that accumulate in water. MP present in the environment can fragment and produce nanoplastics from 1nm to a size that is almost unknown in terms of adverse effects and toxic properties compared to larger sizes of plastic waste. Physical, chemical, and biological degradation processes that result in plastic fragmentation increase the number of MP, both primary and secondary, in aquatic systems, affecting the health of the aquatic environment including biota **(Issac & Kandasubramanian, 2021; Zhang *et al.*, 2021; Kye *et al.*, 2023)**.

2. Microplastics abundance in fish

A total of 37 fish samples from 8 fish species were examined and interestingly all fish species were found to be contaminated with MP. This finding confirms the assumption of MP contamination in many fish species and poses a potential threat to MP consumption in fish caught on the East coast of Surabaya.

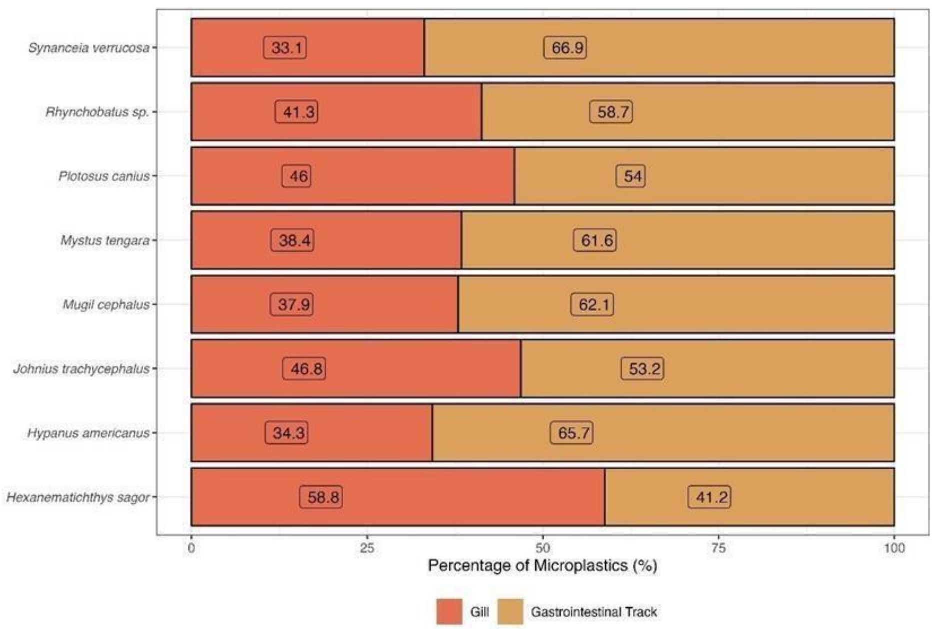

Fig. 3. Comparison diagram of the percentage of microplastic abundance in eight fish species obtained from the East coast of Surabaya in the gills and the gastrointestinal tract

Based on the observation and calculation of MP samples from eight fish species (Fig. 3), seven species showed that the amount of MP in the gastrointestinal tract was higher than in the gills. The percentage of MP in the gills ranged from 33.1 - 58.8% and in the gastrointestinal ranged from 41.2 - 66.9%. The only fish with a higher percentage abundance in the gills than in the gastrointestinal tract was *H. sagor* with 58.8 and 41.2%, respectively. The range of abundance with the highest disparity was found in *S. verrucosa* and *H. americanus*, which was close to double. Referring to Table (1), it can be seen that these two species are relatively smaller in body length than the other six fish species. The size of the body length provides life phase information which also states that the young adult phase is a relatively high food consumption phase **(Aunurohim *et al.*, 2023; Srisiri**

***et al.*, 2023)**, so it is suspected that the higher abundance of MP in the gastrointestinal tract is an implication of the high appetite and the impact on the accumulation of MP in these organs.

Table 1. Abundance of microplastics in 8 species of fish for each individual obtained from Surabaya East coast in the gills and gastrointestinal tract

Scientific name	Feeding habit	Migration	n	TL (cm)	TW (g)	Gill (g)	GI (g)	Total MPs	
								GI	Gill
Mugil cephalus	Omnivore	Catadromous	5	14-20	39-97	1	5-10	105-180	62-119
Hexanematichthys sagor	Carnivore	Amphidromous	5	28-32	190-321	18-22	23-27	30-89	58-81
Johnius trachycephalus	Carnivore	Diadromous	5	16-21	81-185	2-5	3-6	50-91	41-113
Rhynchobatus sp.	Carnivore	Oceanodromous	2	52-54	157-169	2	7-20	98-131	69-92
Synanceia verrucosa	Carnivore	Oceanodromous	5	13-21	20-145	1	1-5	38-94	28-36
Mystus tengara	Carnivore	Amphidromous	5	19-27	62-250	6-9	10-29	38-87	34-52
Hypanus americanus	Omnivore	Amphidromous	5	10-19	21-198	1-10	1-10	62-84	21-50
Plotosus canius	Carnivore	Amphidromous	5	30-35	190-211	8-18	11-18	60-132	56-103

In general, the dominance of MP abundance of the eight species of fish obtained from the East Coast of Surabaya was found in the gastrointestinal tract compared to the gills. The results of research by **Arossa *et al.* (2019)** and **Kim *et al.* (2023)** stated that the gastrointestinal tract of fish accumulates more MP than the gills. This reinforces that the main accumulation of MP in various organisms occurs through the food web. This can be caused by many factors such as gastrointestinal structure, feeding habits, and local plastic pollution levels. MP accumulation can be correlated with direct feeding when ingesting contaminated water and sediments without filtering, or indirectly through eating prey contaminated with MP **(Yona *et al.*, 2020; Debbarma *et al.*, 2022)**. MP also have a shape and color that resembles fish food so fish can consume the wrong food. The gastrointestinal tract is widely assumed to be the endpoint of MP accumulation because some large MP cannot be expelled through the anus **(Jabeen *et al.*, 2017)**. The large number of MP found in the gastrointestinal tract, especially the stomach, is thought to be due to the large surface area of the stomach so that MP accumulate on the stomach wall. In addition, the opening from the stomach to the large intestine is relatively narrow and can withstand more plastic accumulating in the stomach. MP with irregular shapes can stick to the stomach wall **(Jabeen *et al.*, 2017; Syafitri *et al.*, 2021)**. Retention of MP in the gastrointestinal tract can cause intestinal blockage, false satiety, and physical damage that can lead to fish death **(Guven *et al.*, 2017)**.

MP found in the gills are detected to come from direct exposure due to respiration pathways that can keep MP in the gills **(Wright & Kelly, 2017; Su *et al.*, 2019; Kwon *et al.*, 2020)**. The respiration process of fish will filter water in the aquatic ecosystem, and the relatively small size of MP will facilitate their movement to be eventually attached to the gills **(Yona *et al.*, 2020; Yona *et al.*, 2021)**. The accumulation of MP in the gills is often found to be less than that in the gastrointestinal tract, although some studies find it higher in the gills. This may be due to the flushing effect of water back into the gills so that it is not retained in the gills for a long time **(Zhang *et al.*, 2021)**. MP can cause physical injury to the gills such as filament rupture which facilitates the entry of other foreign bodies through the gills **(Jabeen *et al.*, 2017; Debbarma *et al.*, 2022)**. In gills, MP may also be rejected as pseudo-feces or directly assimilated by the gill epithelium or transported into the mouth and gastrointestinal tract **(Li *et al.*, 2021)**. The high accumulation of MP in the gastrointestinal tract and gills of fish is a serious threat to human health because they can migrate through various ways to the flesh of fish, which can increase the negative risk to top predators such as humans **(Debbarma *et al.*, 2022)**.

3. Potential exposure of microplastics via migratory fish

Based on Table (1), MP in *Mugil cephalus* have a high abundance of MP reaching a total of 1,194 particles, while *Synanceia verrucosa* is the lowest with a total of only 479 particles. *M. cephalus* is an omnivorous and catadromous fish. Based on previous studies, the same results were found that the abundance of MP in omnivorous fish is generally higher than in carnivorous fish **(Romeo *et al.*, 2015; Mizraji *et al.*, 2017)**. One of the main factors is the variety of food sources. This will cause omnivorous fish to be easily contaminated with MP from various types of food so that they accumulate in the body **(Al Mamun *et al.*, 2023; Aunurohim *et al.*, 2023; Siddique *et al.*, 2024)**. This suggests that feeding habits may lead to selective consumption of MP with different characteristics from the watersm and such eating habits may affect the uptake of MP in fish **(Tien *et al.*, 2020)**. Meanwhile, based on the type of migration, *Mugil cephalus* with catadromous migration has the highest MP accumulation. This can happen because of catadromous fish spend the majority of the time feeding and growing in freshwaters, and they migrate into the saline sea water as adults to reproduce. Therefore, they are vurnerable from pollution **(Tamario *et al.*, 2019)**. It is suspected that MP accumulation occurs throughout the migration journey, which means that MP encountered throughout the migration can be ingested along with the process of taking water or digestive mechanisms. The findings of this study, indicating higher microplastic (MP) accumulation in catadromous fish, align with the results of **Menendez *et al*. (2022)**, who observed similar MP accumulation patterns in juvenile *Anguilla anguilla* (a catadromous species).

Previous research explains that species that occupy both ocean and river (diadromous) are exposed to microplastics from both environments, especially when they are at the interface of ocean and continental waters. Diadromous fish undertake long migrations and undergo changes to adapt to different salinities, making them highly vulnerable to environmental disturbances due to their dual habitats **(Tamario *et al*., 2019)**. However, in this research, fish that were categorized as diadromous (*H. sagor*) did not get the highest amount of microplastics. However, research related to the relationship between MP and migration models still has a lot to be developed, considering that there are no differences in the physical and chemical characteristics of MP in eight fish species with the same or different migration models.

4. Shape, color, and size variations of microplastics in fish

4.1 Shape

From many shapes of MP, only two (fragment and fiber) shapes of MP were found in all fish species obtained (Fig. 4). The percentage of MP of various forms in eight fish species differentiated by the presence of their organs is presented in Fig. (5). Regardless of species, fragments dominated, accounting for 94.4% of the total MP, followed by fiber MP at 5.6%. All water and fish samples were detected to be contaminated with MP in the form of fragments and fibers. Fragment MP dominated both in the gill and in the gastrointestinal tract of the eight fish species obtained. In *Hexanematichthys sagor*, fragment-shaped MP were found in the range of 92.3% in the gills and 94.1% in the gastrointestinal tract, *Hypanusamericanus* 95.1% fragment particles in the gills and 98.6% in the gastrointestinal, *Johnius trachycephalus* 88.7% fragment particles in the gills and 96.8% in the gastrointestinal tract, *Mugil cephalus* 94.5% fragment particles in the gills and 96.5% in the gastrointestinal tract, *Mystus tengara* 90.3% fragment particles in the gills and 97.6% in the gastrointestinal tract, *Plotosus canius* 93% fragment particles in the gills and 99% in the gastrointestinal tract, *Rhynchobatus* sp. 93.8% fragment particles in the gills and 97.8% in the gastrointestinal tract, and *Synanceia verrucosa* 88.6% fragment particles in the gills and 98.1% in the gastrointestinal tract. Meanwhile, fiber forms were only found ranging from 1 to 11.4% of all fish samples.

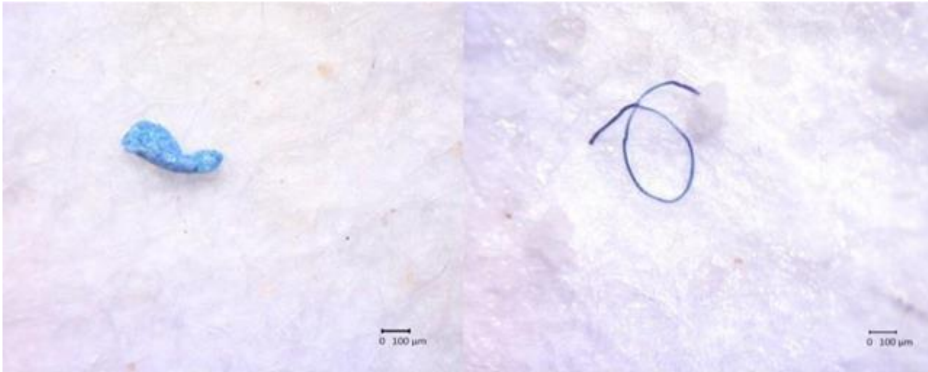

Fig. 4. Shape of microplastic fragments (left), and fibers (right) found in water samples and fish caught by local fishermen in the East Coast waters of Surabaya

Similar results were found in other studies conducted in the Baltic Sea, Mediterranean Sea, South Korea, and Singapore that detected fragmental MP as the dominant shape **(Curren & Leong, 2023)**. Fragmental MP in the marine environment are often mistaken by fish as food and ingested **(Nuamah *et al.*, 2023)**. Potential sources of fragmentary MP in seawater are thought to originate from the weathering of hulls and peeling of anti-fouling paint coatings, fishing gear, mining, agriculture, plantations, household activities, industrial activities, and the influx of plastic waste from urban areas into the ocean **(Dodson *et al.*, 2020; Curren & Leong, 2023)**. Abundant fragment plastics can undergo fragmentation into much smaller particles due to a combination of physical, chemical, and biological factors over time. Meanwhile, fiber-formed MP can originate from clothes washing, municipal waste, and wastewater discharge **(Kutralam *et al.*, 2023)**. Based on Fig. (5), fiber MP are found more in the gills than in the gastrointestinal tract. The high abundance of fiber MP in the gills compared to the gastrointestinal tract can be attributed to the anatomical structure of fish gills, which are shaped like combs so that they can capture and collect more particles than fragments **(Su *et al.*, 2019; Pan *et al.*, 2021)**.

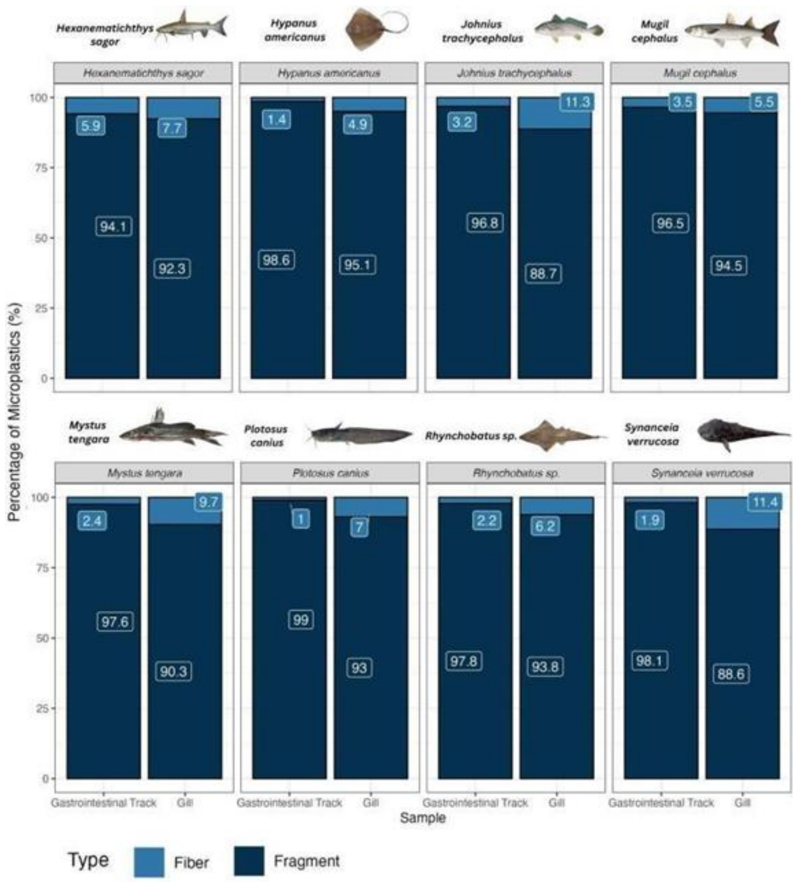

Fig. 5. Percentage proportion of microplastic shape in fish samples obtained from Surabaya East Coast in gill and gastrointestinal tract

4.2 Color

MP particles found in the gill and gastrointestinal tract of eight fish species ranged from 12 colors: black, blue, red, yellow, brown, orange, gray, purple, clear, white, pink, and green. Black color was detected to dominate overall in all fish samples, both in the gill and gastrointestinal tract (Fig. 6). The dominance of black MP in *Hexanematichthys sagor* was 65.5% in the gills and 61.3% in the gastrointestinal tract, *Hypanus americanus* 70.9% in the gills and 79.1% in the gastrointestinal tract, *Johnius trachycephalus* 64.5% in the gills and 81.7% in the gastrointestinal tract, *Mugil cephalus* 72.2% in the gills and 82.6% in the gastrointestinal tract, *Mystus tengara* 67.1% in the gills and 77.7% in the gastrointestinal tract, *Plotosus canius* 72.9% in the gills and 79.9% in the gastrointestinal tract, *Rhynchobatus sp*. 65.8% in the gills and 86.9% in the gastrointestinal tract, and *Synanceia verrucosa* 65.8% in the gills and 76.5% in thegastrointestinal tract.

Several other studies have also found black MP dominate in fish samples **(Akdogan *et al.*, 2023; Gedik *et al.*, 2023; Zhao *et al.*, 2023)**. The black color is the most commonly used plastic for household appliances, toys, electronic devices, and automotive equipment **(Turner, 2018; Huang & Xu, 2022)**, so it is suspected that the high level of black MP in this study was contributed by these materials. However, other researchers have also assumed that most of the black MP are paint particles from ships and boats **(Curren & Long, 2023)**. The color of MP can also fade due to environmental factors, resulting in the appearance of lighter-colored particles **(Akdogan *et al.*, 2023)**. Over time, exposure to high temperatures and light intensity can result in the fragmentation of large plastics into smaller ones that reach the marine environment **(Belioka & Achilias, 2023)**. Overall, black is the main color identified as affiliated with fragment shape and is dominant in this study.

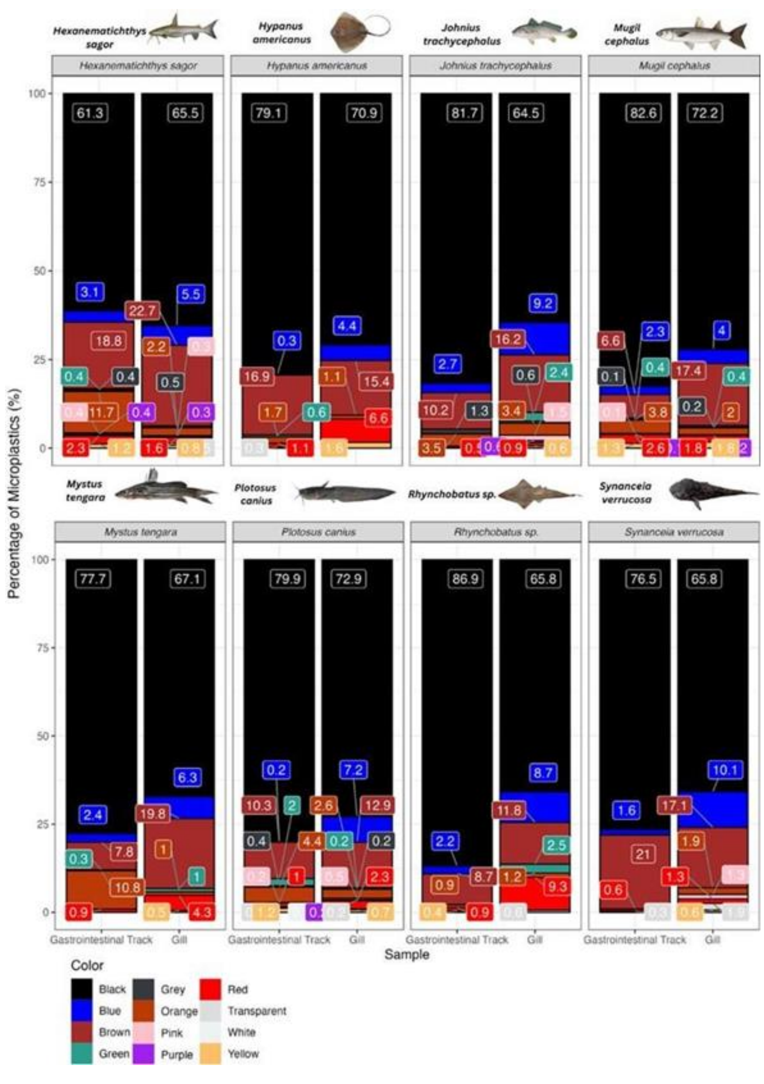

Fig. 6. Percentage proportion of microplastic color in fish samples obtained from the East Coast of Surabaya in the gill and the gastrointestinal tract

4.3 Size

Microplastic size categories can be grouped into 8 group, namely 0 – 20, 20 – 40, 40 – 60, 60 – 80, 80 – 100, 100 – 500, 500 – 1000, and 1000 – 5000µm **(Nor & Obbard, 2014)**. Size distribution of MP among the eight fish samples showed significant variation. In terms of particle size, the amount of MP in the eight fish samples decreased as the particle size increased. MP of 20-40µm dominated (36.12%), followed by 40-60µm (20.92%), 0-20µm (17.25%), 60-80µm (9.33%), 100-500µm (8.94%), 80-100µm (4.71%), 1000-5000µm (1.63%), and 500-1000µm (1.09%).

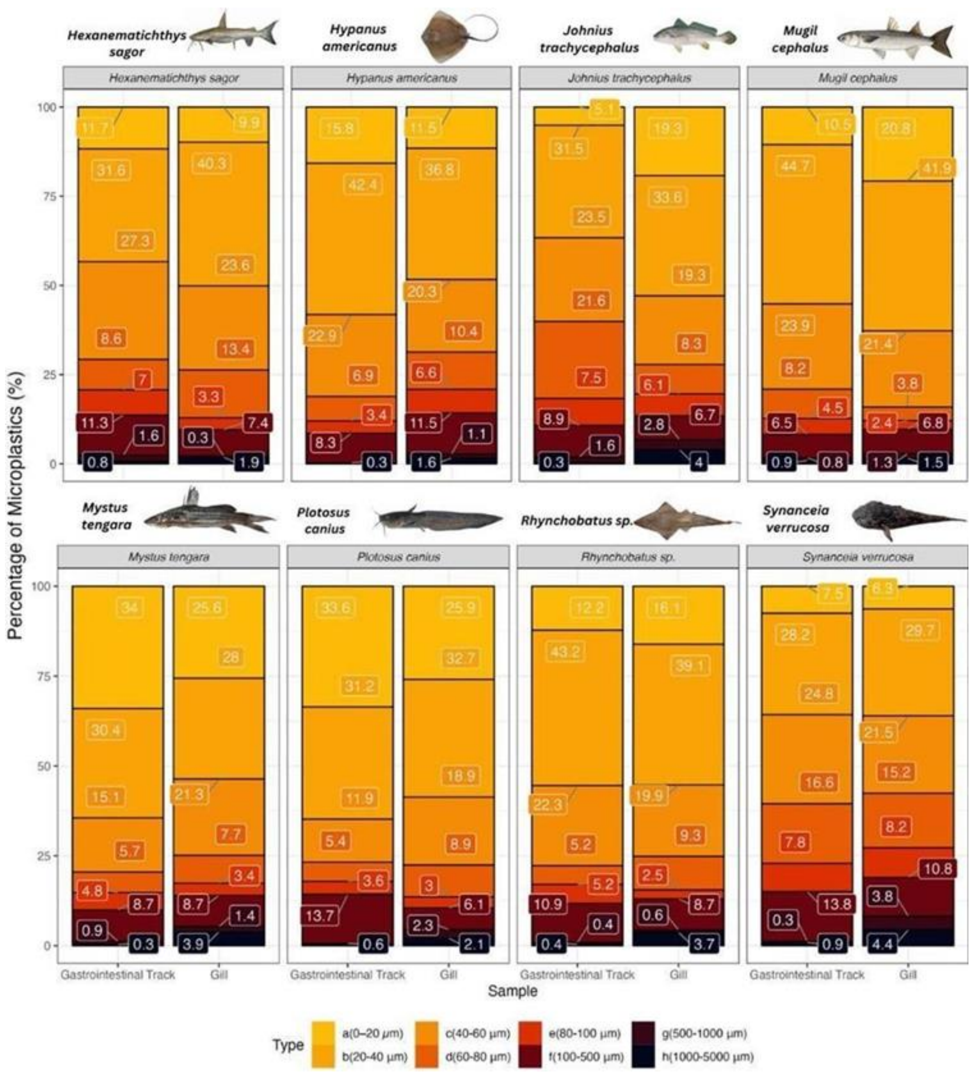

Fig. 7. Percentage proportion of microplastic size in fish samples obtained from Surabaya East Coast in gill and gastrointestinal tract

Fig. (7) indicates that all samples were dominated by small-sized MP of no more than 100µm. The prevalence of smaller size groups suggests that fish consume food items such as smaller fish either selectively or accidentally **(Kutralam *et al.*, 2023)**. MP ingested by fish and entering the gastrointestinal tract may be fragmented into smaller particles and remain in the gastrointestinal tract or be excreted through the excretion system with feces back into the water **(Barboza *et al.*, 2020)**. MP can be eliminated with feces due to peristalsis, which encourages digestion to move along the gastrointestinal tract at a speed suitable for digestion and absorption of food nutrients **(Pramono & Agustini, 2021)**. The size of MP comparable to food particles can also be ingested by fish accidentally, causing the accumulation of MP in the fish body **(Savoca *et al.*, 2021)**. MP that are small have a greater chance of being dispersed throughout the fish body and disrupting organ function **(Gall & Thompson, 2015)**. Therefore, our results on the prevalence of ingestion of smaller MP suggest the possibility of a significant risk that requires further toxicological research.

5. Polymeric composition of microplastics by FTIR ATR

The polymer types of selected samples from several combinations of MP shapes and colors were identified using FTIR-ATR. Of all the MP tested, 75% were PP (polypropylene) and the rest were HDPE (High Density Polyethylene). Generally, the dominant plastic polymers found in all ecosystems include PE (polyethylene), PP (polypropylene), PC (polycarbonate), PET (polyethylene terephthalate), PU (polyurethane), and PS (polystyrene) which make the largest contribution to MP contamination **(Geyer *et al.*, 2017; Lin *et al.*, 2023)**. PE, PP, and PS are widely used for fishing gear, food packaging materials, and manufactured products, such as plastic films, plastic bags, bottle containers, etc. **(Makhdoumi *et al.*, 2021; Kalaiselvan *et al.*, 2022; Lim *et al.*, 2022)**.

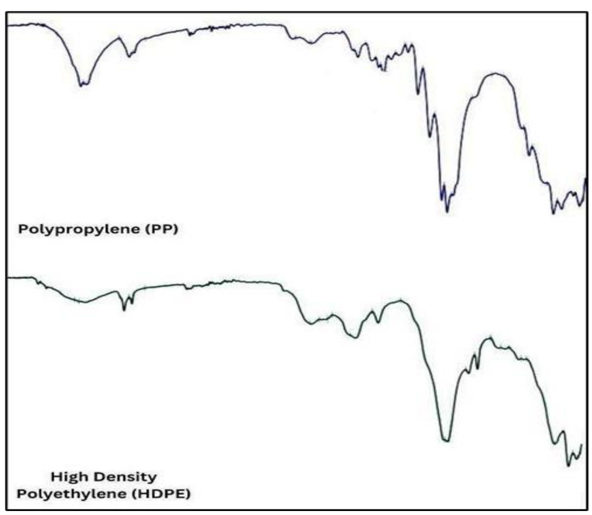

Fig. 8. The results of ATR-FTIR analysis of microplastic samples in the gill and gastrointestinal tract of eight species of fish caught by the local fishermen in the East Coast Surabaya are dominated by PP (polypropylene) which reaches 75% and the rest is HDPE (high-density polyethylene)

PE, PP, and PS can accumulate in the marine environment as primary and secondary plastics **(Kalaiselvan *et al*., 2022)**. Representative polymer spectra from ATR-FTIR are shown in Fig. (8). PP is one of the important polymers in packaging materials and disposable medical materials. The accumulation of this type is increasing due to the shift from recycling to single use. Examples of PP plastics from biomedical waste include surgical masks, syringes, and culture tubes generated from clinics, hospitals, and personal protection activities **(Li *et al*., 2024)**. HDPE has a high recycling rate as a single quality like PET **(Shanks, 2017)**. HDPE is a commonly used material in various industries, including packaging and automotive **(Zhou *et al*., 2022)**. In addition, HDPE is used in a wide variety of applications, including plastic bottles, milk containers, shampoo bottles, bleach bottles, cutting boards, and pipes.

CONCLUSION

This study documents microplastic (MP) contamination in both water samples and fish (gills and gastrointestinal tract) from the East Coast of Surabaya, Indonesia. The identified forms of MP include fragments (predominant) and fibbers, with the dominant color being black and a size range of 20-40µm. The identified polymer composition consists dominant of 75% PP and 25% HDPE. Based on the type of migration, *Mugil cephalus* as catadromous migration has the highest MP accumulation, but further research must be carried out to see the relationship.

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