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## Human health and ecological risks associated with microplastic contamination in widely consumed catfish from a large-scale estuary

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### ABSTRACT

Microplastic (MP) pollution threatens aquatic ecosystems and food safety, yet organ-specific contamination in tropical estuarine fish remains largely unexplored. In Bangladesh, where fish is a vital protein source, such assessments are critically lacking. This study quantified MPs in two commercially important catfishes, *Pangasius pangasius* and *Mystus gulio* (n = 60), from the Meghna Estuary, and assessed ecological and human health risks. MPs were extracted from gills, digestive tracts, and muscles and characterized by microscopy and FTIR. Results showed tissue-specific patterns, with higher loads in gills and digestive tracts than in muscles. Mean abundance was significantly greater in *P. pangasius* (38.7 ± 10.1 items) than in *M. gulio* (23.9 ± 7.3 items). Fibers < 0.5 mm, mostly violet, were dominant. Ecological risk indices revealed higher values for *P. pangasius* across all metrics: Polymeric Hazard Index (2006 vs. 1340), Risk Index (160 vs. 101.5), and Pollution Load Index (1.71 vs. 1.34), indicating substantial polymer-related risks and contamination level. Nylon posed the greatest hazard in *P. pangasius* (risk level, E<sub>i</sub> = 127.3), reflecting its persistence and adsorptive potential. Human exposure was higher from *P. pangasius* (2.44 particles/day for adults; 2.35 for children) than from *M. gulio*, confirming tissue- and species-specific risks.

### 1. Introduction

Globally, microplastics (MPs), plastic particles smaller than 5 mm, have emerged as persistent and pervasive pollutants in aquatic ecosystems (Pingki et al., 2025). These particles originate either as primary MPs (e.g., microbeads, industrial pellets, synthetic fibers) or as secondary MPs resulting from the degradation of larger plastic debris (Cole et al., 2011; Boucher and Friot, 2017). Due to their small size, buoyancy, and resistance to degradation, MPs are easily dispersed in aquatic environments and are readily ingested by a wide range of organisms, including fish, crustaceans, and mollusks (Wang et al., 2021; D'Costa et al., 2022; Pingki et al., 2025).

MP ingestion by fish has been shown to induce a number of negative biological effects that include gastrointestinal damage, oxidative stress, immune suppression, and feeding behavior and energy homeostasis alterations (Wright et al., 2013; Ding et al., 2018; Barboza et al., 2020).

Moreover, MPs are able to absorb and transfer toxic substances, including heavy metals and persistent organic pollutants, as indicated by Sheng et al. (2021) and Xia et al. (2023). This property facilitates the potential for bioaccumulation and biomagnification in aquatic food webs. There is a growing body of evidence showing that MPs and heavy metals can migrate to edible tissues, with important seafood consumption-related food safety and public health implications (Akhbarizadeh et al., 2019; Miller et al., 2020).

Bangladesh, one of the top contributors to mismanaged plastic waste, has its rivers and estuarine systems burdened with widespread plastic pollution (Banik et al., 2024). Such ecosystems are also reservoirs of MP which are inadvertently consumed by fish as unintentional food sources. Since fish are a staple component of the Bangladeshi diet—making up the cultural identity of "machhe bhate Bangali" (fish and rice makes a Bengali)—the people are highly exposed to the health hazards of MP-contaminated seafood. This underlines the need for careful

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monitoring of MP loads in all commercially important fish species to assess ecological risks and safeguard public health.

The Meghna Estuary is classified as a *large-scale estuary* owing to its remarkable hydrological and geomorphological attributes. It ranks as the fourth-largest river system globally in terms of water discharge and exhibits the world's highest sediment discharge rate ( $\sim 1 \times 10^9$  t yr<sup>-1</sup>) (Mukherjee et al., 2009; Hossain et al., 2023). The estuary drains a vast catchment area of 1612,000 km<sup>2</sup>—nearly four times larger than that of the Pearl River basin (453,700 km<sup>2</sup>)—before debouching into the Bay of Bengal and ultimately the Indian Ocean. Ecologically, it represents the largest and most productive estuarine ecosystem in the Bay of Bengal region, providing essential breeding and nursery grounds for numerous ecologically and commercially valuable species, including the nationally important hilsa (*Tenualosa ilisha*) (Pramanik et al., 2017; Islam et al., 2024). As the primary outflow of the Ganges–Brahmaputra–Meghna river system, the estuary delivers critical ecosystem services such as shoreline stabilization, nutrient cycling, and pollution buffering, which support hundreds of thousands of artisanal fishers and underpin national food security and rural livelihoods (Booi et al., 2022; DoF, 2020). But growing human pressures, especially the buildup of plastic waste and microplastic pollution, are increasingly compromising the estuary's natural balance and endangering the long-term viability of its fisheries.

Among the estuarine fish species, *Pangasius pangasius* (yellowtail catfish) and *Mystus gulio* (long-whiskered catfish) are of significant socio-economic and ecological importance. *P. pangasius* is a large, demersal, migratory species commonly found in estuarine and freshwater habitats, valued for its commercial significance and protein-rich flesh (Chakma et al., 2022). *M. gulio*, a small indigenous catfish thriving in brackish and tidal freshwater zones, serves as a key micro-nutrient source and is widely consumed in rural communities of Bangladesh and Asian region (Sarker et al., 2022; Chakraborty et al., 2024). Both species are frequently marketed and form an essential part of the Bangladeshi diet.

Despite the growing worldwide concern about MP pollution, research on MP contamination of commercially valuable estuarine fish species in Bangladesh is comparatively scarce. Although MPs have already been reported in marine and freshwater fish (Parvin et al., 2021; Hossain et al., 2023a; Sultana et al., 2024; Das et al., 2025), interestingly, information on widely consumed catfish species like *M. gulio* and *P. pangasius* is limited, despite their key ecological roles and significance to human diets. While many earlier studies have looked into MP accumulation, they often missed focusing on specific organs, especially in edible tissues like muscle. This is crucial for truly understanding the health risks that seafood consumption poses to humans. Many of these studies focus primarily on MP present in the gastrointestinal tract—parts typically discarded rather than consumed—so their findings are not especially relevant when it comes to actual dietary exposure. Additionally, several of these studies (Parvin et al., 2021) did not thoroughly characterize the MPs, including their polymer makeup, which is vital for assessing their potential toxicity. Some reports were just preliminary, observing the presence of MPs without using established human health risk assessment tools like the Polymer Hazard Index (PHI) or Estimated Daily Intake (EDI) values. This omission limits their usefulness in shaping public health policies and food safety guidelines. This study addresses these knowledge gaps by presenting the first organ-specific assessment of MP pollution in these estuarine cat fishes, integrating tissue-level analysis to ascertain species-specific accumulation profiles. Based on these data, the study aims to inform ecological risk assessment and guide public health policy in nations dependent on estuarine fisheries. We hypothesized that MP bioaccumulation is tissue- and species-specific, resounding environmental exposure differences and concomitant human health risks. The specific objectives of this study are:

- i. Quantify tissue- and species-specific abundance, morphology, and polymer composition of MPs in catfishes, *P. pangasius* and *M. gulio* from the Meghna Estuary.
- ii. Evaluate the ecological hazard and human-health exposure risks posed by MP contamination in these catfish.

Given the significant accumulation of plastic pollutants in Bangladeshi estuarine environments—combined with the country's strong reliance on fish as a major protein source—these findings provide crucial data on species-specific plastic ingestion pathways. This evidence highlights potential risks for both ecosystem stability and human health through seafood consumption, underlining the need for targeted intervention and ongoing monitoring.

## 2. Materials and methods

### 2.1. Study area and sampling

This study was conducted in the lower Meghna River Estuary, located in the Noakhali district along the northern Bay of Bengal coast, Bangladesh. The Meghna Estuary is classified as a *large-scale estuary* based on its hydrological and geomorphological characteristics. It ranks 4th among the largest river systems in the world in terms of water and sediment discharge and drains the most extensive catchment area in South Asia, ultimately falling into the Bay of Bengal. Ecologically, it is the most productive estuarine ecosystem in the Bay of Bengal region, supporting critical breeding and nursery grounds for numerous ecologically and commercially important fish species. It also provides essential ecosystem services, including shoreline stabilization, nutrient cycling, and pollution buffering, sustaining the livelihoods of hundreds of thousands of artisanal fishers. The Meghna Estuary is strongly influenced by seasonal river discharge and tidal action, and is characterized by high sediment load, organic enrichment, and increasing anthropogenic pressures such as urban effluents, industrial discharges, and aquaculture runoff (Datta and Subramanian, 1998; Rahman et al., 2019; Napper et al., 2021). These features make it a critical hotspot for evaluating MP pollution in aquatic organisms

(Datta and Subramanian, 1998; Rahman et al., 2019; Napper et al., 2021). These conditions make the Meghna estuary a critical hotspot for MP pollution and an ideal site for evaluating contamination in aquatic biota.

A total of 60 samples (digestive tract = 20; gills = 20; muscle = 20) from 20 individuals were collected—10 each of *P. pangasius* (benthopelagic, carnivorous) and *M. gulio* (demersal, omnivorous) during February to June 2023 from Chairmanghat Fish Landing Center, Noakhali, a key distribution marketplace for estuarine and coastal fish in southeastern Bangladesh. This location was chosen because it receives landings from professional fishers who operate across different fishing grounds within the Meghna Estuary. Thus, the specimens obtained from this landing center are representative of fish harvested throughout the estuary, rather than from a single localized site. Fish were immediately transferred to the laboratory using sterile zip-lock bags in iceboxes and stored at  $-20$  °C prior to analysis to prevent biological degradation and MP contamination, as recommended by Hossain et al. (2022) and Pingki et al. (2025). This design yielded 10 tissue-specific replicates per species, consistent with sample sizes used in earlier estuarine MP studies (Bessa et al., 2018; Sultana et al., 2024; Hossain et al., 2024), and allowed reliable intra- and inter-species comparisons. Chairmanghat Fish Landing Center was chosen because it receives fish from multiple fishing grounds across the Meghna estuary, increasing spatial representativeness within the pre-monsoon period while balancing statistical robustness with the analytical demands of polymer-level characterization.

### 2.2. Sample processing and tissue dissection

Each fish specimen was thawed in the laboratory and carefully rinsed

with distilled, deionized, and filtered water to eliminate any surface contaminants. Biometric measurements including total length (to nearest 0.1 cm) and wet body weight (to nearest 0.01 g) were recorded. Using pre-cleaned stainless-steel tools, three tissue types were carefully dissected: muscle, gill, and gastrointestinal tract (GIT). Dissected tissues were weighed individually and transferred into separate, pre-labeled 500 mL borosilicate glass beakers wrapped in aluminum foil to minimize airborne contamination (Li et al., 2015; Pingki et al., 2025). All dissections and sample handling were carried out under a laminar flow hood (BIOBASE Laminar Air Flow Clean Bench Vertical, Model BBS-V900, China) to minimize external contamination. Details of quality control procedures are provided in Section 2.5.

### 2.3. Microplastic extraction procedure

MPs were extracted using a modified wet peroxide oxidation (WPO) protocol adapted from Li et al. (2015), with optimization for estuarine fish tissues (Sultana et al., 2024; Pingki et al., 2025) described in Fig. S1. Approximately 5 g of each tissue (muscle, gill, or GIT) was digested in 100 mL of 30 % hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>; Smart Lab, India) at a sample-to-reagent ratio of 1:20 (w/v). The digestion process was carried out on a hot plate at a constant temperature of 60–65 °C for 48–72 h, with periodic addition of H<sub>2</sub>O<sub>2</sub> to maintain the reaction volume. This method efficiently degrades organic matter without compromising MP integrity compared to acid or alkaline digestion (Cole et al., 2013).

Once digestion was complete, the mixture was allowed to cool and then subjected to density separation by adding 300 mL of a saturated NaCl solution (density = 1.2 g/cm<sup>3</sup>). The mixture was stirred and left undisturbed overnight to allow less-dense plastic particles to float. The supernatant was carefully decanted and vacuum-filtered through a 47 mm diameter cellulose nitrate membrane filter (pore size 5.0 µm, Millipore, NY2004700) using a glass filtration unit. Filters were preserved in clean Petri dishes for microscopic analysis (Hidalgo-Ruz et al., 2012; Pingki et al., 2025).

### 2.4. Observation, morphological classification, and FTIR analysis

All filters were examined under a Leica EZ4E stereomicroscope (8x–35x magnification) to quantify and categorize potential MP particles. Suspected particles were characterized based on their morphological traits—shape (fiber, fragment, film), color (e.g., red, blue, transparent), and size (<2 mm: small MPs; 2–5 mm: large MPs; >5 mm: mesoplastics)—as defined by Hidalgo-Ruz et al. (2012) and Phillips & Bonner (2015). Particles with irregular, non-organic appearance and uniform coloration were selected for polymer validation.

Representative particles were analyzed for polymer composition using Fourier-transform infrared spectroscopy (FTIR) equipped with an attenuated total reflectance (ATR) module (Nicolet iS50, Thermo Scientific, USA). Spectra were collected in the 4000–650 cm<sup>-1</sup> range at a resolution of 4 cm<sup>-1</sup> with 16 scans per sample. Polymer types were identified by comparing spectra to known standards in the OMNIC polymer library. Particles with ≥ 70 % spectral match were confirmed as MPs; those between 60–70 % were visually cross-validated (Frias et al., 2014; Sultana et al., 2024).

### 2.5. Contamination control measures

To minimize the risk of laboratory contamination, all glassware and dissection instruments were rinsed three times with filtered distilled water before use and dried in a dust-free environment. Plastic tools were avoided throughout the experiment. All solutions (H<sub>2</sub>O<sub>2</sub>, NaCl, deionized water) were pre-filtered through 5.0 µm filters. Sample processing was performed under a laminar airflow cabinet using cotton lab coats and nitrile gloves.

Procedural blanks (one per five samples) were processed simultaneously without tissue to monitor contamination; for muscle tissue,

dedicated procedural blanks were included, and no MPs were detected in any blank, confirming procedural reliability. To prevent airborne and tool-based contamination, only stainless-steel scalpels and forceps were used, pre-cleaned by triple rinsing with pre-filtered distilled water and wrapped in aluminum foil between uses. To avoid cross-contamination between organs, dissections were performed in the order of gills → muscle → gastrointestinal tract (GIT), using separate pre-cleaned tools for each tissue type, with work surfaces cleaned using 70 % ethanol and filtered distilled water between dissections.

### 2.6. Data processing and statistical analysis

MP abundance was calculated and expressed in three formats: (i) particles per gram of wet tissue (muscle, gill, GIT), (ii) particles per tissue type per individual, and (iii) total particles per individual. Descriptive statistics were computed for all variables. Data were tested for normality and homogeneity of variance prior to parametric tests. One-way analysis of variance (ANOVA) was used to determine significant differences in MP abundance among tissue types and between species. Pearson correlation was used to explore relationships between MP load and biometric parameters (body weight, organ weight).

All statistical analyses were performed using SPSS (Version 25), PAST (Version 4.03), and GraphPad Prism (Version 9.4). Differences were considered statistically significant at  $p < 0.05$ .

### 2.7. Potential risk assessment of MPs in fish

To evaluate the potential health risks of plastic polymers, the Polymer Hazard Index (PHI) was calculated following the methods of Lithner et al. (2011) and Ranjani et al. (2021). This index considers the percentage of each polymer type identified and its associated hazard score. Detailed formula and parameter definitions used for PHI computation are provided in Supplementary Table S1.

The index of polymer risk (PHI) resulting from tiny plastic particles can be computed by applying the following formula:

$$PHI = \sum P_n \times S_n \quad (1)$$

Additionally, the Estimated Daily Intake (EDI) of MPs was calculated to estimate human exposure through fish consumption, following EFSA (2014) and Trabelsi et al. (2008). Parameters such as MP concentration, ingestion rate, and body weight were used to derive EDI values for both adults and children. The complete formula and assumptions for this assessment are included in Supplementary Table S1.

$$EDI = \frac{C \times IR}{BW} \quad (4)$$

Here, "C" represents the median concentration of MPs measured in items per gram (items/g). The ingestion rate (IR) is based on fish consumption recommendations provided by the European Food Safety Authority (EFSA), set at 300 g per week for adults and 50 g per week for children aged 2–6 years (EFSA, 2014). Here, EFSA IR values were used since these recommendations offer standardized and well recognized reference values that are commonly used in risk evaluations for human health. Adopting a country-specific IR is difficult since there are inconsistent trustworthy, nationally recognized dietary intake statistics for fish consumption in Bangladesh. In order to establish a cautious and solid foundation for risk assessment and to guarantee comparability with studies conducted elsewhere, EFSA principles were applied. The average body weight (BW) considered for adults is 66.0 kg while for children aged 7–14 years, it is 35.0 kg (Trabelsi et al., 2008; Ferrante et al., 2022).

### 3. Results and discussion

#### 3.1. Contamination status of MPs in fish samples

MPs were identified in all the samples of examined estuarine catfish samples (*P. pangasius* and *M. gulio*). The abundance of MPs in *P. pangasius* ranged from 1.00 to 4.20 items/g in the digestive tract ( $2.26 \pm 1.04$ ), 0.88–3.63 items/g in the gills ( $2.25 \pm 0.87$ ), and 0.21–2.65 items/g in muscles ( $0.79 \pm 0.62$ ). In *M. gulio*, MPs ranged from 0.56 to 4.98 items/g in the digestive tract ( $2.85 \pm 1.33$ ), 1.25–5.67 items/g in the gills ( $2.99 \pm 1.24$ ), and 0.20–2.20 items/g in muscles ( $1.24 \pm 0.71$ ) (Fig. 1). In The organ-wise trend of MPs in *P. pangasius* was digestive tract  $\approx$  gills > muscle and gills > digestive tract > muscle in *M. gulio*. However, two-way ANOVA revealed a significant interaction between species and tissue type on MPs abundance. Post-hoc Tukey's test showed that MPs abundance in the digestive tract of *M. gulio* was significantly higher than in its muscle ( $p < 0.01$ ) and *P. pangasius* muscle ( $p < 0.01$ ). Similarly, MPs in *M. gulio* gills were significantly higher than the muscle of both species ( $p < 0.01$ ). MPs in *P. pangasius* digestive tract and gills were also significantly higher than in its muscles ( $p < 0.05$ ).

The findings of this study were supported by previous studies conducted worldwide, which also found MPs in marine and estuarine fish (Barboza et al., 2020; Bessa et al., 2018; Cannon et al., 2016; Rummel et al., 2016; Tanaka and Takada, 2016). Recent investigations led by Hossain et al. (2019), Hossain et al. (2023a), Hossain et al. (2024), and Pingki et al. (2025) also confirmed the presence of MPs in fish from Bangladesh, which aligns with the present study. Furthermore, the outcomes of Hossain et al. (2023b) and Hossain et al. (2023c) ensured the MP contamination in the Meghna river estuary. These findings were further emphasized by the findings of Nur et al. (2022), who confirmed the presence of MPs in sea salt, indicating wide spread distribution of MPs in the Bay of Bengal and its adjacent estuaries. However, in this study, MPs were found to be higher in the fish gill and digestive tract than fish muscle. As fish gills are the primary points of environmental exposure, these trap MPs during respiration process. Besides, digestive tract receives MPs directly through ingestion, whereas the muscle is relatively isolated (Ghosh, 2025). A recent study on Atlantic killifish (*Fundulus heteroclitus*) found  $85.5 \pm 70.2$  items/g digestive tract, while muscle contained  $11 \pm 12.5$  items/g (Pitt et al., 2024), which were much higher than the present findings. This difference can be attributed to particle size as smaller MPs (particularly  $< 50 \mu\text{m}$ ) can cross epithelial barriers and eventually deposit in muscle (Pitt et al., 2024).

Despite being less common than in the gills or gastrointestinal tracts, the finding of MPs in muscle tissue is in line with new research and has significant ramifications for food safety. For instance, Di Giacinto et al. (2023) found 0.14–0.27 MPs/g ww in swordfish (*Xiphias gladius*) and

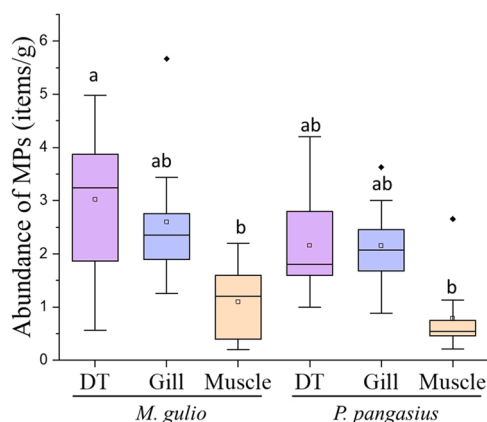


Fig. 1. Abundance of MPs in *P. pangasius* and *M. gulio* collected from the Meghna estuary. Groups sharing different letter (a, ab, b) are significantly different ( $p < 0.05$ ).

bluefin tuna (*Thunnus thynnus*) from the Mediterranean Sea, while Wu et al. (2023) observed 0.01 MPs/g ww in the muscle of Pacific tuna (*Katsuwonus pelamis*). Higher values of  $6 \pm 10$  MPs/g were found in the muscle of Atlantic killifish (*Fundulus heteroclitus*) by Pitt et al. (2024), demonstrating that MPs can accumulate in edible tissues across a variety of species. Pitt et al. (2024) added that although MP concentrations are often higher in gastrointestinal contents than in epithelial tissues, uptake is somewhat size-dependent, with smaller particles having a higher chance of passing through epithelial barriers, entering the systemic circulation, and eventually depositing in muscle. This translocation mechanism is supported by the predominance of fibres  $< 0.5 \text{ mm}$  in our investigation. Crucially, strict contamination control measures were followed, and no MPs were found in procedural blanks, confirming that the presence of MPs in muscle is indicative of actual tissue contamination rather than distortions from the lab. Bioaccumulation studies further confirmed that MPs initially concentrate in gills and gut, and then disseminate via the circulatory system into other tissues (Ghosh, 2025).

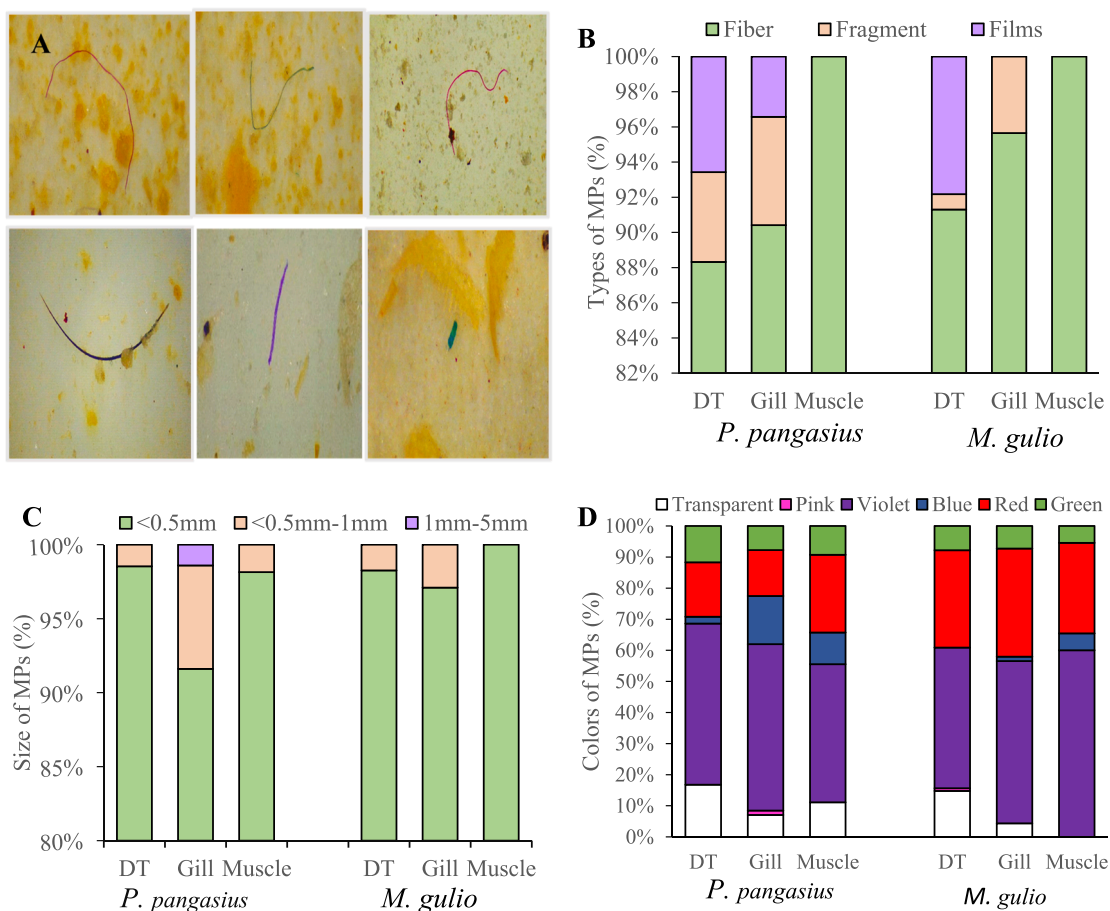
#### 3.2. Morphological characteristics of MPs

MPs in *P. pangasius* and *M. gulio* were categorized as fibers, fragments, and films, with fibers being the most frequent. In *P. pangasius*, fibers constituted 33–37 % across various organs (12.1–13.2 items/individual), whereas in *M. gulio*, they represented 24–47 % (5.5–10.5 items /individual) (Fig. 2B), consistent with previous research on estuarine fish (Mizraji et al., 2017; Bessa et al., 2018; Campanale et al., 2019; Simon-Sánchez et al., 2019; Zhao et al., 2019). Fragments and films associated with secondary degradation were also identified, corroborating degradation mechanisms through UV exposure, thermal influence, and mechanical stress (Cooper and Corcoran, 2010; Andrady, 2011; Ng and Obbard, 2006).

MPs measuring  $< 0.5 \text{ mm}$  were predominant in both species (digestive tract: 13.5 in *P. pangasius*, 11.3 in *M. gulio*) (Fig. 2C), corroborating other findings about the predominance of small-sized MPs (Hossain et al., 2022; Liu et al., 2022; Haddout et al., 2022; Banik et al., 2022). Six colors of MPs were found (Fig. 2D), with violet being the most prevalent, indicating contributions from synthetic textiles, packaging, and fishing gear (Di & Wang, 2018). The color distribution patterns were similar to previous findings from the Bay of Bengal fish (Hossain et al., 2019).

#### 3.3. Polymer identification and species-specific pathways

The polymer composition of MPs isolated from *P. pangasius* and *M. gulio* revealed similarities as well as differences, which explained the sources of contamination in both cases and the difference in the origin of the exposure. In *P. pangasius*, identified polymers were polyethylene (PE) (24.55 %), polypropylene (PP) (22.34 %), polyethylene terephthalate (PET) (25.67 %), and nylon (27.44 %) (Fig. 3). The excessive presence of nylon usually associated with the activity of fishing gear, synthetic textiles, and industrial discharge, indicates that *P. pangasius*, a benthic and detritivorous feeder, could be fed more often with fiber-based MPs coming from decomposed fishing nets, ropes, or textile effluents especially in estuarine regions affected by artisanal fishing activities and land-based pollution sources. Conversely, *M. gulio* displays a distinct polymer composition compared to *P. pangasius*: EVA accounts for 26.58 %, followed by PET (26.12 %), PE (25.43 %), and PP (21.87 %) (Fig. 3). The presence of EVA—a polymer common in packaging, footwear, and foam products—points to alternative anthropogenic sources, likely stemming from industrial or urban runoff. Interestingly, nylon is entirely absent in *M. gulio*, while EVA is missing from *P. pangasius*, suggesting that each species experiences exposure to MPs through different pathways. Factors such as habitat selection, feeding habits, and proximity to pollution sources likely contribute to these contrasting profiles (Mizraji et al., 2017; Rahman et al., 2019).



**Fig. 2.** Morphological characteristics of MPs identified in fish samples: (A) Representative microscopic image, (B) Distribution by shape, (C) Size classification, and (D) Color composition.

Despite these specific differences, both species show a relatively even distribution of PE, PP, and PET. These polymers are globally ubiquitous, typically originating from plastic packaging and general household waste, and are consistently reported in aquatic systems worldwide. This overlap highlights the widespread presence of mainstream plastic pollution in the Meghna Estuary, indicating shared contamination sources affecting both species. These results are consistent with prior studies (Park et al., 2022; Hossain et al., 2024), which reported similar MP polymer profiles in other estuarine and freshwater fish. In contrast to earlier work, the current analysis offers a comparative, species-level perspective, emphasizing the influence of both environmental exposure and species-specific traits (like feeding behavior or habitat use) on the types and retention of MPs. Critically, polymers such as PET and EVA are known to release hazardous chemicals (e.g., antimony, phthalates), while nylon may carry toxic dyes and residues. Their detection raises concerns about potential toxicological effects following accumulation in edible tissues. These polymers have been associated with oxidative stress, endocrine disruption, and immunotoxicity in aquatic life (Barboza et al., 2020; Xia et al., 2023). They also present potential risks to human health via trophic transfer. Consequently, identifying polymer types is essential not only for tracing pollution sources but also for evaluating human health risks—emphasizing the need for comprehensive monitoring using indices like the Polymer Hazard Index (PHI) at the tissue level.

### 3.4. Ecological risk assessment

The ecological risk assessment of MP polymers associated with *P. Pangasius* and *M. gulio* was evaluated based on individual risk levels

(Ei), risk index (RI), polymer hazard index (PHI), and average polymer load index (PLI). Among the detected polymers, nylon exhibited the highest risk levels in both species, with Ei values of 127.27 for *P. pangasius* and 63.64 for *M. gulio*, indicating a significant contribution of nylon to the overall risk. The total risk index (RI) was also higher in *P. pangasius* (160.10) compared to *M. gulio* (101.52), suggesting that *P. pangasius* poses a greater ecological risk due to its higher MP contamination. Similarly, the PHI was substantially higher in *P. pangasius* (2113.30) than in *M. gulio* (1340.00), reinforcing the higher risk potential of MPs in *P. pangasius*. The average PLI values further support this observation, with *P. pangasius* showing a higher PLI (1.71) compared to *M. gulio* (1.34) (Table 1).

*P. pangasius* exhibited remarkably higher ecological risk scores specifically in Ei, RI, PHI, and PLI metrics—compared to *M. gulio*, emphasizing a high MP load in this species. This trend likely stems from its benthic feeding habits and close association with sediment-bound contaminants. Nylon is widespread throughout the Meghna Estuary, largely due to discarded fishing nets and textile waste (Banik et al., 2024). This clearly indicates ongoing human activity and continuous waste input in the region. As such, *P. pangasius* may serve as an effective sentinel species for monitoring MP contamination in estuarine environments. These observed, species-specific patterns in polymer accumulation raise concerns about broader ecological impacts, particularly regarding trophic transfer and potential disruption of food webs issues especially pressing in biologically rich and sensitive habitats such as estuaries (Barboza et al., 2020; Park et al., 2022).

At present, there are no internationally established safety thresholds for MP ingestion through seafood, as highlighted in recent EFSA (2021) and WHO (2022) assessments. These bodies conclude that, due to data

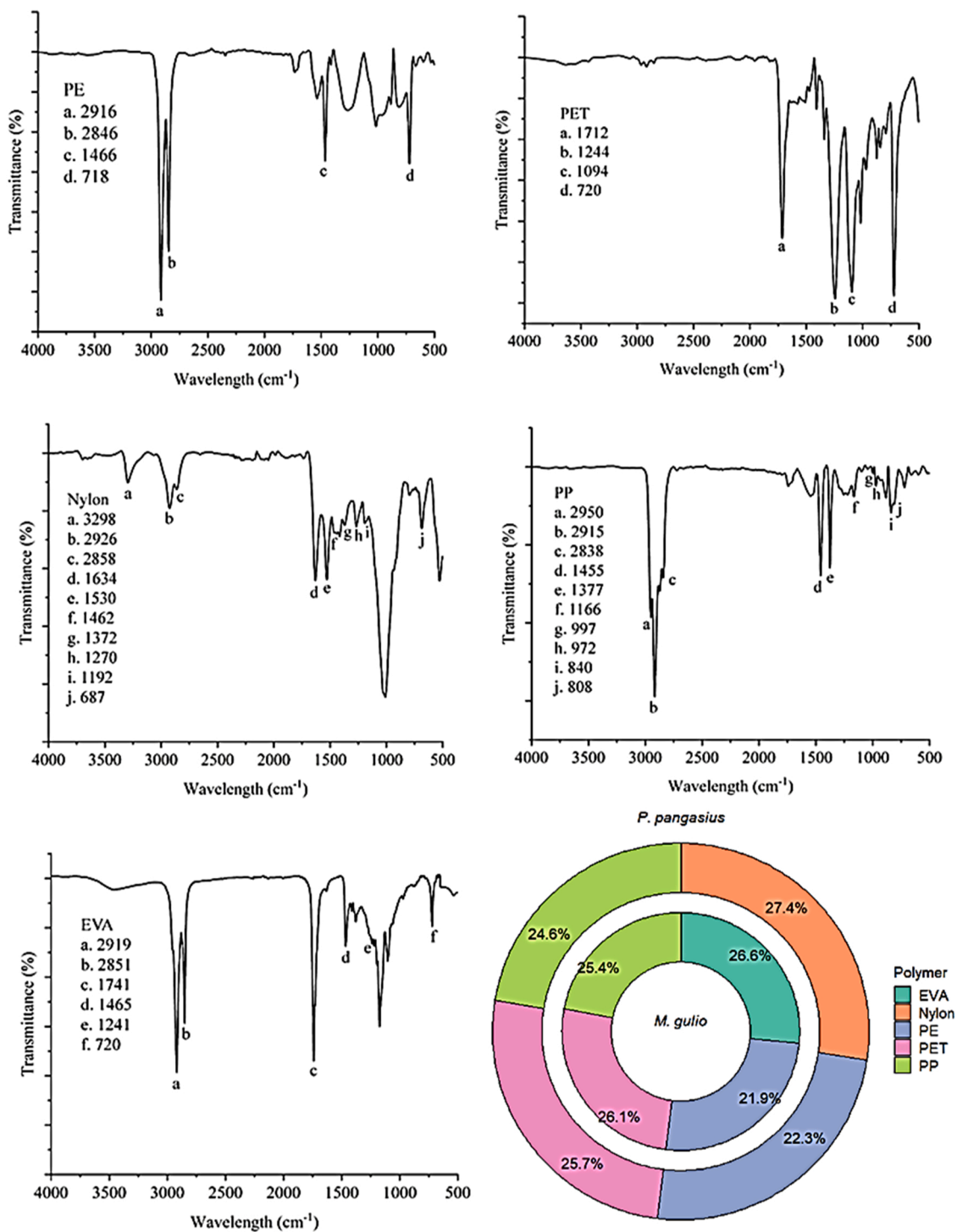


Fig. 3. Polymer identification of MPs in *P. pangasius* and *M. gulio* collected from Meghna estuary.

Table 1

Potential ecological risk evaluation for MPs in fish samples from Meghna estuary (Av. indicates average).

Species	$E_i$ (Risk level)					$RI = \sum E_i$	PHI	Av. PLI
	PE	PP	PET	EVA	Nylon			
<i>P. pangasius</i>	11.11	0.51	12.12	9.09	127.27	160.10	2113.30	1.71
<i>M. gulio</i>	16.67	0.51	16.16	4.55	63.64	101.52	1340.00	1.34

gaps in toxicokinetics, particle translocation, and long-term health effects, it is not yet possible to set a tolerable daily or weekly intake for MPs. Therefore, while the EDI values reported here cannot be compared directly with a regulatory limit, they should be interpreted as indicative of potential exposure levels that warrant precautionary monitoring and further risk assessment in line with emerging global recommendations.

### 3.5. Human health risk assessment

The Estimated Daily Intake (EDI) of MPs through the consumption of *P. pangasius* and *M. gulio* reflects potential human exposure risks (Fig. 4). Higher EDI values were recorded for *P. pangasius*, with adults and children exposed to 2.44 and 2.35 particles/day, respectively, while *M. gulio* contributed lower values of 1.24 particles/day for adults and 1.19 particles/day for children. This indicates that *P. pangasius* consumption may pose a comparatively higher risk of MPs intake.

Continuous consumption of MPs-contaminated fish may lead to the accumulation of MPs in the human body, raising several health concerns. MPs primarily enter the human system through persorption and endocytosis (Bhuyan, 2022). Once inside, they can accumulate in the gastrointestinal tract, potentially leading to gut barrier dysfunction and inflammatory bowel diseases (Liebezeit and Liebezeit, 2013; Schwabl et al., 2019). Additionally, inhalation of airborne MPs has been associated with respiratory complications, including lung inflammation and obstructive bronchiolitis (Amato-Lourenço et al., 2021; Persoons et al., 2018).

At the cellular level, MPs may induce oxidative stress and cytotoxic effects, as evidenced in human cell line studies. Furthermore, reproductive and developmental impacts have been reported in animal models, including reduced fertility and gonadal damage (Sarasamma et al., 2020; Sun et al., 2021). Additional adverse effects may include endocrine disruption, mitochondrial dysfunction, metabolic alterations, bone loss, neurotoxicity, and immune system impairment (Bhuyan, 2022; Sana et al., 2020). Although potential links between MPs exposure and malignancies have been suggested, conclusive evidence remains limited (Bhuyan, 2022).

## 4. Conclusion

This investigation delivered a novel, organ-specific, polymer-based hazard assessment of MP contamination in two cat fishes, *P. pangasius* and *M. gulio*, from the Meghna River Estuary, addressing key gaps in edible tissue exposure to MPs. Results confirmed the widespread occurrence of MPs in gills, digestive tracts, and muscle tissues, with a dominance of fiber-shaped, small-sized (<0.5 mm), and colored MPs suggesting contamination from synthetic textiles, fishing gear, and

urban runoff. FTIR analysis indicated varied polymeric composition, with nylon being predominant in *P. pangasius* and EVA detected in *M. gulio*. The calculated ecological risk indices (PHI, RI, and PLI) and human exposure assessments (EDI) demonstrated that *P. pangasius* poses a higher ecological and potential health risk. Within the scope of this two-species comparison, *P. pangasius* exhibited consistently higher MP loads and ecological risk indices, suggesting potential suitability as a candidate bio-indicator species for estuarine MP contamination. This preliminary observation is based on traits such as benthic feeding habits, association with sediment-bound pollutants, and year-round occurrence in the Meghna estuary. However, confirmation will require comparative assessments across a broader range of species with differing ecological niches, applying established bio-indicator selection criteria including habitat fidelity, pollutant accumulation consistency, and ecological representativeness. These findings provide critical baseline data for understanding MP pollution in tropical estuaries and call for targeted policies to reduce plastic input into coastal systems. Future studies should explore trophic transfer, biomagnification, and long-term health implications of MP exposure in aquatic and human systems.

### Author statement

All authors made significant contributions to the conception, design, data collection, analysis, and interpretation of the study, as well as to drafting and revising the manuscript. All authors have approved the final version for submission. The authors declare that there are no conflicts of interest regarding this work.

### Author contributions

Conceptualization and supervision: Hossain and Lipi; Methodology, Sample analysis, and draft writing: Riya, Nur and Banik; FTIR analysis: Y.N. Jolly; Literature survey, reviewing and editing- Hossain, Yu, Arai, and Norhayati; Visualization and funding- Arai.

### CRediT authorship contribution statement

**Takaomi Arai:** Writing – review & editing, Resources. **Jimmy Yu:** Writing – review & editing, Resources. **Norhayati Ngah:** Writing – review & editing, Software. **M. Belal Hossain:** Writing – review & editing, Writing – original draft. **Yeasmin N. Jolly:** Investigation, Formal analysis, Data curation. **As-Ad Ujjaman Nur:** Investigation, Formal analysis, Data curation. **Partho Banik:** Investigation, Formal analysis, Data curation. **Jahanara Akhter Lipi:** Writing – original draft, Conceptualization. **Khadijatul Kubra Riya:** Writing – original draft, Formal analysis, Data curation.

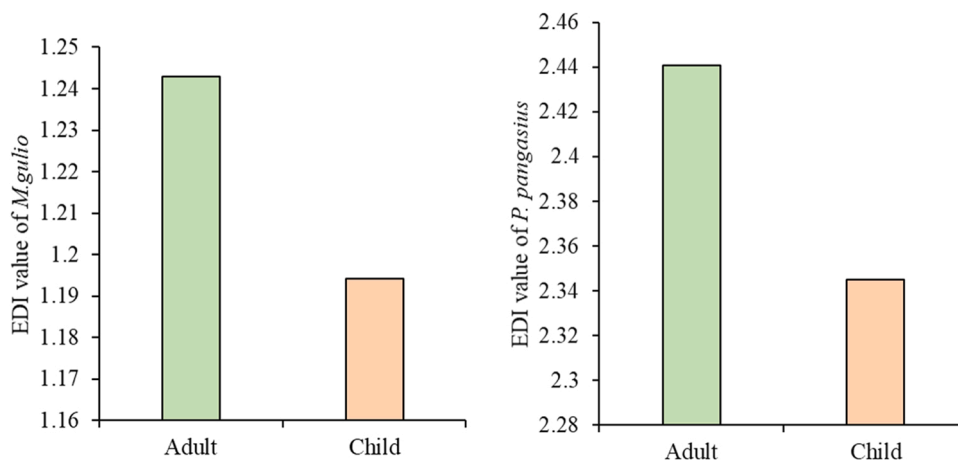


Fig. 4. Estimated daily intake for *M.gulio* and *P. pangasius*.

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## 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.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.jfca.2025.108487](https://doi.org/10.1016/j.jfca.2025.108487).

## Data availability

Data will be made available on request.

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