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Gastrointestinal microplastic abundance in relation to fish feeding guilds in Balikpapan Bay, East Kalimantan, Indonesia

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Abstract. *Sjamsir BFH, Pribadi TDK, Ghitarina. 2026. Gastrointestinal microplastic abundance in relation to fish feeding guilds in Balikpapan Bay, East Kalimantan, Indonesia. Biodiversitas 27 (4): d270420. https://doi.org/10.13057/biodiv/d270420.* Microplastic pollution in marine ecosystems has emerged as a major environmental concern, particularly in regions with intense human activity. This study examined the relationship between feeding guild and gastrointestinal microplastic abundance in fish from Balikpapan Bay, Indonesia. A total of 162 fish representing 25 species, 21 families, and 11 orders were collected, of which 133 individuals from all 25 species were analyzed for gastrointestinal microplastic contamination. Microplastics were extracted using chemical digestion, identified under a stereomicroscope, and polymer composition was confirmed using pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS). In total, 1,378 microplastic particles were detected, with an average abundance of 10.35±3.80 particles per fish. Fibers dominated the particles (57.4%), followed by fragments (35.0%), films (4.5%), beads (2.2%), and foam (0.9%). Polymer analysis identified nylon as the dominant polymer type, suggesting fishing gear as a probable source. Microplastic abundance differed significantly among feeding guilds (Kruskal-Wallis test, $p<0.05$), with herbivorous species exhibiting the highest abundances, while no significant difference was observed between demersal and pelagic fish. These findings provide baseline data on microplastic contamination in fish from an intensively used tropical coastal system and suggest exposure may vary with feeding guild, with herbivorous species potentially more vulnerable to contamination associated with high-volume grazing on benthic substrates, where microplastics accumulate and adhere to biofilms.

Keywords: Coastal ecosystem, East Kalimantan, feeding guilds, microplastic ingestion, marine fish

INTRODUCTION

Plastic particles smaller than 5 mm are classified as microplastics. They may originate either from plastic materials manufactured at small sizes (primary microplastics) or from the degradation of larger plastic waste (secondary microplastics) (Balasaraswathi and Rathinamoorthy 2021; Ghosh et al. 2023). Microplastic particles can be broadly categorized into five shapes: fibers, fragments, films, beads/pellets, and foams, which originate from different plastic products and materials (Singh et al. 2022).

Marine microplastic pollution primarily originates from land-based sources, including industrial and shipping activities, coastal landfills, and discarded fishing gear (Bank and Hansson 2021). The degradation of plastic waste into microplastics is influenced by mechanical, biological, and photolytic factors (Hill 2020). The physical durability and slow rate of degradation of microplastics contribute to their widespread distribution within the environment, including marine ecosystems. Biofouling, the process by which biological matter accumulates on surfaces, is also thought to further impact the distribution of microplastics in the marine ecosystem by increasing their density and causing them to sink to the seafloor (Amaral-Zettler et al. 2021).

Microplastics have been detected in a wide range of marine organisms, including plankton and fish, indicating that these particles can enter marine food webs through multiple pathways (Wang et al. 2020). Alfaro-Núñez et al. (2021) reported microplastic contamination in all examined specimens from multiple marine taxa collected in the tropical East Pacific, while Aunurohim et al. (2023) reported microplastics in 99% of sampled marine fish from Bitung, North Sulawesi. The presence of microplastics in fish gastrointestinal tracts suggests that feeding ecology may influence microplastic abundance. For example, benthic feeders may ingest microplastics that accumulate in sediments, while filter-feeding species may consume particles suspended in the water column (D'Avignon et al. 2023). In carnivorous fish, the small size of microplastic particles and their resemblance to natural food items may increase the risk of ingestion through accidental consumption or mistaken identification as prey (A'yun et al. 2022). These differences may result in measurable variation in microplastic exposure between feeding guilds.

Microplastic contamination is associated with negative health effects in fish, such as oxidative stress and disruptions in growth and metabolism (Bhuyan 2022). In addition, the consumption of contaminated fish could be a pathway for microplastic exposure in humans. The extent of human health impacts remains uncertain (Kannan and Vimalkumar 2021;

Alberghini et al. 2022), particularly as the gastrointestinal tracts of most fish are removed prior to consumption, although microplastic translocation within fish is known to occur. Microplastics may also act as vectors for other contaminants, such as heavy metals and persistent organic pollutants (POPs) (Tumwesigye et al. 2023), which may be transferred to edible tissues through the digestive tract (Ma et al. 2021; Hampuwo et al. 2026).

Bays act as transitional ecosystems between rivers and the ocean and are particularly vulnerable to anthropogenic pollution due to dense human activity (Mendes et al. 2024). Balikpapan Bay in East Kalimantan serves as a transportation route, fishing area, and center for mining and industrial activities, creating multiple potential sources of microplastic pollution. A study by Priscilla et al. (2019) found a high abundance of fiber-type microplastics in the waters of Pramuka Island, suspected to result from fishing activities and industrial textile waste. In addition, Napper et al. (2022) and Kim et al. (2024) demonstrated the potential for microplastic release from ship ropes and antifouling paint.

Fish consumption per capita in Penajam Paser Utara reached 54.79 kg in 2024 (Satu Data Kalimantan Timur, 2025), indicating that fish are a substantial component of the local diet. Considering the high levels of human activity in the area, microplastics may accumulate in fish species commonly consumed locally. Due to limited research on microplastics in Balikpapan Bay and their association with fish feeding guilds, this study seeks to examine the relationship between feeding guilds and gastrointestinal microplastic abundance. The results are expected to provide baseline data on microplastic pollution in fish in Balikpapan Bay and improve understanding of microplastics in marine food webs.

MATERIALS AND METHODS

Study area

Fish samples were collected in Jenebora Village, Balikpapan Bay, East Kalimantan, Indonesia (-1.211548, 116.726368) (Figure 1) in September 2023. This location was chosen due to the high levels of fishing activities within the area, potentially releasing microplastic waste into the habitats of commercially important fish species.

The fish samples in this study were collected using a *belat*, a type of traditional passive fishing gear (Figure 2). As Balikpapan Bay experiences a semidiurnal tide cycle, with two high and two low tides in a single day, fish swimming toward the shore during high tide are trapped within the *belat* and are subsequently collected during low tide. A *belat* typically consists of fences made of wooden poles connected by fishing nets, which function to funnel and trap fish. It is divided into four compartments: a main fence, wing, body, and crib (Taufik et al. 2023). The non-selective nature of the *belat* allows for a more diverse catch (Ardiansyah 2022). However, smaller fish species and juveniles of larger species may be able to slip through the *belat* chambers.

Although *belat* fishers typically collect their catch daily, the *belat* used in this study was set for three days to acquire a larger catch. Fish samples were collected from the *belat* in the daytime during low tide. The samples were stored in an icebox and transported to the Laboratory of Water Quality, Faculty of Fisheries and Marine Sciences, Universitas Mulawarman. Fish samples were then stored in a freezer prior to analysis.

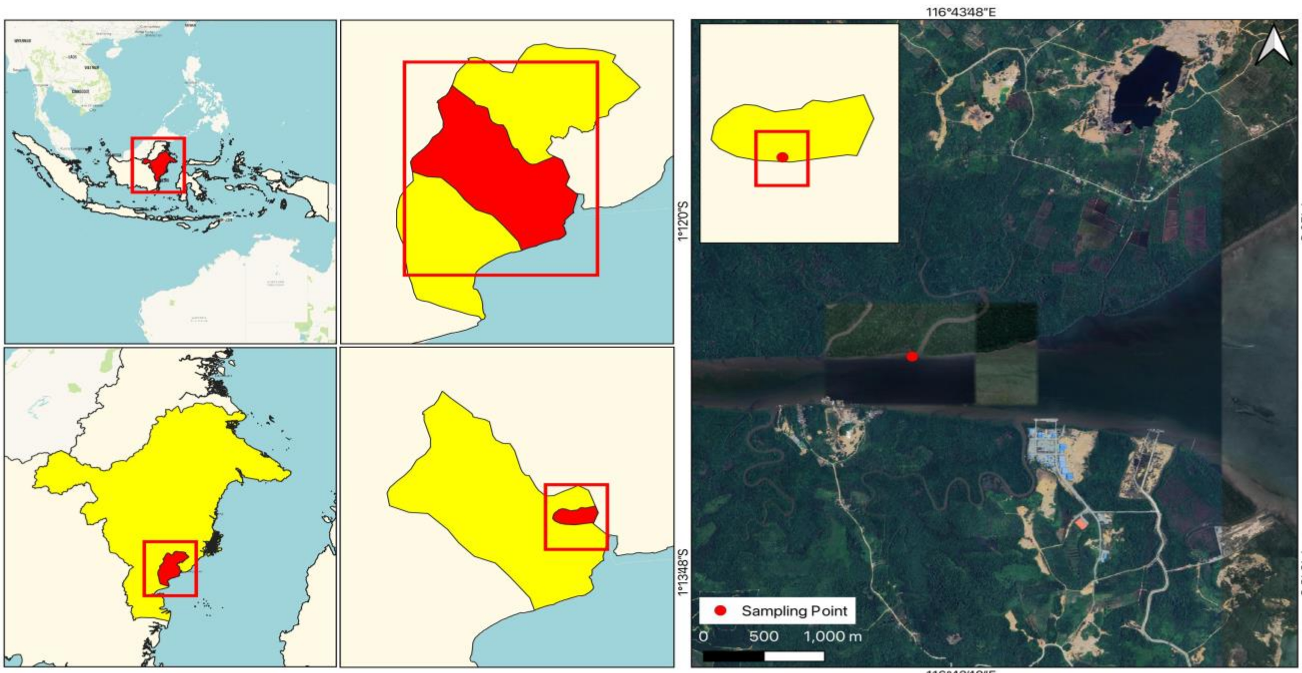

Figure 1. Map of sampling location in Jenebora Village, Balikpapan Bay, East Kalimantan, Indonesia

Figure 2. Belat in Jenebora Village, Balikpapan Bay, documented during low tide

Procedures

Fish species identification

Fish samples were identified to a species level based on the book "Market Fishes of Indonesia" by White et al. (2013), as well as the website "FishBase" (Fishbase 2024), which was also used to acquire supporting data regarding fish trophic level and depth.

Gut content analysis

Gut content analysis was performed on a subset of individuals from each species, after which all individuals were assigned to guilds based on species-level dietary composition. In total, 41 fish representing the sampled species were used for gut content analysis, and 133 fish were used for gastrointestinal microplastic analysis. Samples for gut content and microplastic analyses were separated to ensure basic representation, as the number of fish samples varied between species. This was also done because the two sample types required different storage methods. Gut content analysis requires immediate processing to preserve identifiable food matter, whereas microplastic analysis permits frozen storage. A minimum of three individuals per species were used for gut content analysis whenever available to ensure basic representation. If only one individual of a species was available, gut content and microplastic analyses were performed on the same gastrointestinal tract within a short timeframe. Due to the non-specific nature of the *belat* fishing gear, sample sizes differed among species. As a result, analysis was not performed at a species level.

Gut content analysis consisted of dissecting the gastrointestinal tract to observe its contents under an RL-M3T stereo microscope. Distinguishable food fragments were identified based on their classification (fish, algae, zooplankton, and crustaceans) and counted. Species were assigned to feeding guilds based on the dominant food category observed in gut contents (>60% of all identified food items) (Garcia et al. 2020; Palacios-Narváez et al. 2024). Species exhibiting mixed diets were assigned to feeding guilds based on the dominant food item by relative abundance rather than the presence of incidental or trace food material. Due to a limited number of samples, the results of the gut content analysis were supplemented with and compared to previous species-level literature.

Gastrointestinal microplastic analysis

The method used for gastrointestinal microplastic analysis in this study was a modification of the procedures used by Garcia et al. (2020), Kama et al. (2021), and Edwin et al. (2023) in accordance with the materials and tools available in the laboratory. The procedure involved the chemical digestion of fish gastrointestinal tracts using 20% KOH and 30% H_2O_2, dissolving most organic matter and yielding microplastic particles, which were then filtered with Whatman No. 41 filter paper (20 µm pore size) utilizing a vacuum pump. The filtered samples were then oven-dried and observed under a microscope at 10x magnification. Only particles visually identifiable as plastic based on shape, color uniformity, and structural integrity were counted.

In addition, pyrolysis-gas chromatography-mass spectrometry (Py-GC/MS) analysis was performed to identify plastic polymer types within the samples. The method used in this study was adapted from Garcia et al. (2024). Within the pyrolyzer, the samples were heated to 600°C. The total runtime for each analysis was set to 45 minutes. Plastic polymers were then identified in reference to the interface's internal library. Polymers identified with a ≥80% match with the library were reported (Santos et al. 2023). For this study, four samples representing one species from each feeding guild were selected for analysis with one replication per sample. This was done to ensure basic representation with the limited samples available. Samples for polymer analysis were selected from species with relatively higher average microplastic abundance to increase detection likelihood. The results, therefore, reflect the types of polymers present rather than their overall abundance.

Gastrointestinal microplastic abundance of each species was calculated based on the formula used by Kasamesiri and Thaimuangphol (2020). In addition, a Kruskal-Wallis test was performed to understand the relationship between feeding guild and gastrointestinal abundance of microplastics. As a non-parametric test, the Kruskal-Wallis test does not assume normal distribution or equal variance, and so it is suitable for datasets with unequal sample sizes among groups, such as fish samples acquired using a *belat*.

Quality assurance

Quality assurance and contamination prevention were done in accordance with Cordova et al. (2019) and Yona et al. (2021). All equipment used in this study was rinsed using distilled water before use. Masks and gloves were used at all times during laboratory analysis. Airborne microplastic contamination was minimized by covering samples with aluminum foil, which is then stored away from any potential sources of plastic contamination after each use. In addition, a reagent blank consisting solely of 20% KOH was processed using the same digestion and filtration procedures to assess potential laboratory or reagent-derived plastic contamination. If the blanks were found to be contaminated with microplastics, correction procedures included re-cleaning equipment, such as flasks using distilled water stored in glass bottles.

RESULTS AND DISCUSSION

Fish species identification

A total of 162 individual fish samples from 25 species, 21 families, and 11 orders were collected from a *belat* in Jenebora Village, Balikpapan Bay. The list of fish species obtained in this study is presented in Table 1.

Order Perciformes consisted of nine families and nine species, the most represented in this study, comprising *Leiognathus equula*, *Gerres erythrourus*, *Upeneus vittatus*, *Lutjanus russellii*, *Scatophagus argus*, *Siganus guttatus*, *Toxotes jaculatrix*, *Epinephelus coioides*, and *Eleutheronema tetradactylum*. The order Carangiformes consisted of only one family, Carangidae, the least of all the orders. However, Carangidae also contained the most species, comprising *Caranx sexfasciatus*, *Alepes kleinii*, and *Scomberoides tala*. Most of the fish species found within this study were demersal (Figure 3).

In addition, 18 demersal and 7 pelagic fish species were found, respectively accounting for 72% and 28% of the species observed. In addition, while most demersal fish in this study were fish feeders, the majority of pelagic fish in this study were crustacean feeders. Neither zooplankton-feeding demersal fish nor algae-feeding pelagic species were found in this study.

Gut content analysis

Gut content analysis to classify the feeding guilds of fish was performed on 41 individuals. The results of the gut content analysis are presented in Table 2.

In order of frequency, the most common feeding guilds found in this study were fish feeders and crustacean feeders (10 species each), zooplankton feeders (3 species), and herbivorous fish (2 species). *S. argus* and *S. guttatus* were the only herbivorous fish species found in this study based on gut content analysis (although low amounts of animal matter were found in some samples of *S. guttatus* and *S. argus*). In addition, *Anodontostoma chacunda* is typically an algae/phytoplankton-feeder. However, the samples in this study did not contain such food matter.

Microplastic analysis

In this study, a total of 1,378 microplastic particles (10.35±3.80 per fish) were found within the 133 gastrointestinal tracts that were analyzed. Mean microplastic abundance values are reported per species and represent the average number of particles per individual fish. The most common microplastic shape found was fibers, consisting of 791 particles, followed by 483 fragments, 62 films, 30 beads, and 12 foam particles (Table 3). Black was the most common color for microplastic particles, comprising 41% of all particles identified. Blue and clear were the second most common colors, each comprising 12% of identified particles. Film microplastics, in particular, were predominantly clear. Meanwhile, foam microplastics were only found in white or light gray. Microplastic shapes observed in this study are presented in Figure 4.

Table 1. List of fish samples collected from Balikpapan Bay

Order	Family	Species	Local name	Individual
Acanthuriformes	Sciaenidae	*Pennahia argentata*	*Gulama*	2
Aulopiformes	Synodontidae	*Saurida tumbil*	*Beloso*	1
Carangiformes	Carangidae	*Alepes kleinii*	*Selar*	2
		Caranx sexfasciatus	*Trakulu*	13
		Scomberoides tala	*Talang-talang*	2
Clupeiformes	Dorosomatidae	*Anodontostoma chacunda*	*Selangat*	6
		Sardinella fimbriata	*Tembang*	13
	Pristigasteridae	*Ilisha elongata*	*Puput*	13
Gobiiformes	Butidae	*Butis butis*	*Butuh/Butis*	6
	Gobiidae	*Acentrogobius caninus*	*Belodok*	3
Istiophoriformes	Sphyraenidae	*Sphyraena jello*	*Alu-alu*	6
Perciformes	Gerreidae	*Gerres erythrourus*	*Kapas-kapas*	13
	Leiognathidae	*Leiognathus equula*	*Pepetek*	13
	Lutjanidae	*Lutjanus russellii*	*Kakap Bintik*	7
	Mullidae	*Upeneus vittatus*	*Kuniran*	13
	Polynemidae	*Eleutheronema tetradactylum*	*Senangin*	1
	Scatophagidae	*Scatophagus argus*	*Ikan Kiper*	13
	Serranidae	*Epinephelus coioides*	*Kerapu*	2
	Siganidae	*Siganus guttatus*	*Baronang*	2
	Toxotidae	*Toxotes jaculatrix*	*Ikan Sumpit*	3
Scombriformes	Scombridae	*Rastrelliger kanagurta*	*Kembung*	13
Spariformes	Sillaginidae	*Sillago sihama*	*Rejung*	2
Siluriformes	Plotosidae	*Plotosus canius*	*Sembilang*	1
Tetraodontiformes	Tetraodontidae	*Lagocephalus inermis*	*Buntal*	9
		Sphoeroides pachygaster	*Buntal bintik*	3
Total	21	25		162

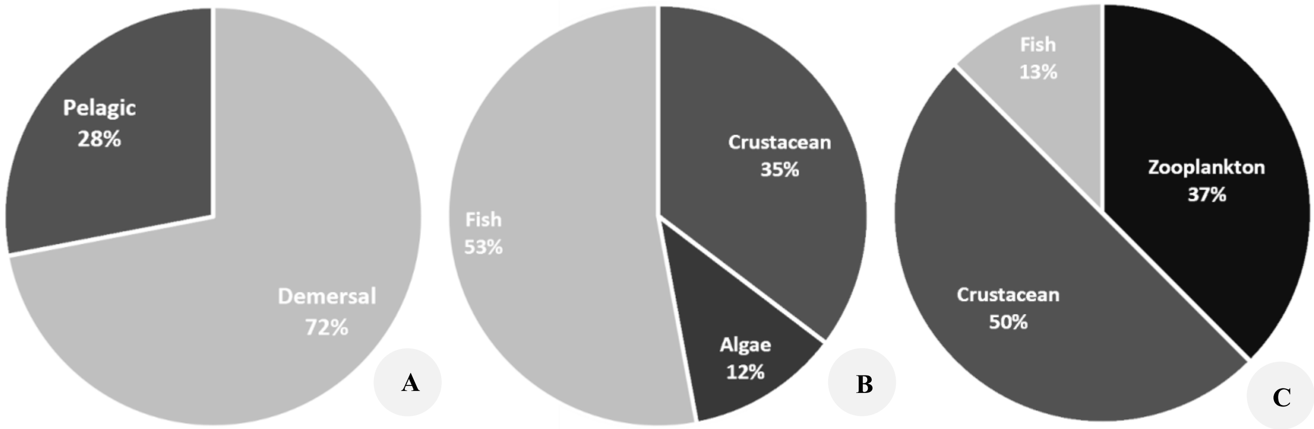

Figure 3. Distribution of sampled fish by habitat and feeding guild. A. Proportion of demersal and pelagic species, B. Feeding guild composition of demersal species, C. Feeding guild composition of pelagic species

Table 2. Gut content analysis results

Species	Feeding guild
Acentrogobius caninus	Crustaceans
Alepes kleinii	Zooplankton
Anodontostoma chacunda	Crustaceans
Butis butis	Fish
Caranx sexfasciatus	Fish
Eleutheronema tetradactylum	Fish, crustaceans
Epinephelus coioides	Fish
Gerres erythrourus	Crustaceans
Ilisha elongata	Crustaceans
Lagocephalus inermis	Fish, crustaceans
Leiognathus equula	Crustaceans
Lutjanus russellii	Fish
Pennahia argentata	Fish
Plotosus canius	Crustaceans
Rastrelliger kanagurta	Zooplankton
Sardinella fimbriata	Zooplankton
Saurida tumbil	Fish
Scatophagus argus	Algae, fish
Scomberoides tala	Crustaceans
Siganus guttatus	Algae, fish
Sillago sihama	Crustaceans
Sphoeroides pachygaster	Crustaceans, algae
Sphyraena jello	Fish
Toxotes jaculatrix	Crustaceans
Upeneus vittatus	Fish

Herbivorous fish were found to have the highest gastrointestinal microplastic abundance (18.8±8.06 particles per fish), followed by fish feeders (10.3±2.65), crustacean feeders (9.1±2.30), and zooplankton feeders (8.9±1.90), suggesting that differences in feeding guilds, defined by diet and feeding mode, may be associated with different levels of microplastic ingestion. The microplastic shape composition for each feeding guild is shown in Figure 5.

Py-GC/MS analysis identified three polymer types within the samples. Nylon (N6, N66) was the most common polymer type and represented 62.5% of the total identified polymers, a pattern commonly associated with sources such as fishing gear, including nets and lines, as well as synthetic textile fibers. This was followed by acrylonitrile butadiene styrene (ABS) (25%) and polystyrene (PS) (12.5%). In addition, polyvinyl chloride (PVC) and polymethyl methacrylate (PMMA) were possibly identified within the samples (70-79% library match). When taking into account the polymer types identified with a 70-79% library match, nylon was still the most common polymer type (53.8%), followed by ABS (23%). PS, PMMA, and PVC together comprised 23% of all polymers identified. No polymers were identified within the control sample. Due to the limited number of fish samples analyzed, these results may not fully represent the overall polymer distribution within the digestive tracts of fish in Balikpapan Bay. A representative spectral match for nylon-6,6 (N66), the most commonly identified polymer type, is shown in Figure 6.

The Kruskal-Wallis test performed showed a significant difference in the microplastic abundance of each feeding guild ($p = 0.047$). Thus, a Dunn post hoc test was subsequently performed. A significant difference was found in the gastrointestinal microplastic abundance of herbivorous fish compared to zooplankton feeders ($p = 0.01$), crustacean feeders ($p = 0.013$), and fish feeders ($p = 0.008$). Furthermore, no significant difference was found in gastrointestinal microplastic abundance between the other feeding guilds. These non-parametric tests were selected due to the non-normal distribution of microplastic abundance within this study. On average, herbivorous fish contained significantly higher microplastic abundances compared with the other guilds, indicating a markedly greater exposure.

Demersal fish were found to have a higher gastrointestinal microplastic abundance than pelagic fish. Demersal fish had an average gastrointestinal microplastic abundance of 10.73±5.63 particles per fish, compared to 9.06±3.93 particles per fish for pelagic fish. However, there was no significant difference between the gastrointestinal microplastic abundance of demersal and pelagic fish.

Discussion

Environmental conditions strongly shape fish feeding habits and food preferences. Numerous studies have shown that disturbances in aquatic environments can lead to changes in feeding behavior (Jacquin et al. 2020; Prado et al. 2020; Turner et al. 2023), consistent with Park et al. (2020), who suggested that abnormal water quality can alter feeding patterns in fish. In the present study, phytoplankton was not observed in the gastrointestinal contents of *A. chacunda*, a species typically associated with phytoplankton feeding. This may reflect changes in food availability and feeding behavior. However, phytoplankton abundance was not measured directly or observed outside of gut content analysis, and therefore ecological disturbance cannot be confirmed through this observation alone.

The condition of Balikpapan Bay's watershed provides relevant environmental context for this observation. Wulandari et al. (2020) found light to moderate pollution levels in the Somber River, a watershed of Balikpapan Bay. Combined with the relatively high turbidity observed in the region (Anwar et al. 2024), these conditions may influence phytoplankton productivity in the bay. Oil and coal spills may also be contributors to this stress, as Balikpapan Bay is home to high levels of mineral and energy extraction as well as transportation activities. Coal dust is known to absorb sunlight and disrupt the photosynthesis of aquatic plants and algae (Tretyakova et al. 2021).

Table 3. Microplastic analysis results

Species	Mean microplastic abundance (Particles/Fish)					
	Fiber	Fragment	Film	Bead	Foam	Total
Acentrogobius caninus	3.7	3.7	0.3	0.3	-	8.0±1.0
Alepes kleinii	3.5	3.0	1.5	-	-	8.0±4.0
Anodontostoma chacunda	5.8	2.6	0.8	-	0.2	9.4±4.5
Butis butis	5.8	2.2	0.2	-	-	8.2±2.9
Caranx sexfasciatus	8.8	5.3	0.4	0.1	0.4	15.0±9.0
Eleutheronema tetradactylum	4.0	3.0	-	1.0	-	8.0±0
Epinephelus coioides	5.0	4.5	-	0.5	-	10.0±3.0
Gerres erythrourus	5.2	2.6	0.3	-	-	8.1±3.3
Ilisha elongata	4.8	4.0	0.7	0.2	0.3	11.2±3.6
Lagocephalus inermis	3.4	4.4	0.6	0.5	-	8.9±3.6
Leiognathus equula	10.6	2.2	0.3	0.3	-	13.4±5.4
Lutjanus russellii	5.7	4.3	0.3	0.7	-	11.0±4.1
Pennahia argentata	3.0	9.0	-	-	-	12.0±0
Plotosus canius	7.0	2.0	-	-	-	9.0±0
Rastrelliger kanagurta	5.1	1.3	0.6	0.5	0.2	7.7±3.3
Sardinella fimbriata	4.6	5.7	0.7	0.1	-	11.1±3.8
Saurida tumbil	11.0	3.0	-	-	-	14.0±0
Scatophagus argus	6.8	5.8	0.3	0.1	0.1	13.1±5.3
Scomberoides tala	7.0	2.0	0.5	-	-	9.5±2.5
Siganus guttatus	16.5	7.0	0.5	0.5	-	24.5±5.5
Sillago sihama	4.0	1.5	-	-	-	5.5±0.5
Sphoeroides pachygaster	4.7	4.3	1.3	0.3	-	10.7±1.2
Sphyraena jello	4.8	3.4	-	0.4	0.2	8.8±2.3
Toxotes jaculatrix	4.0	2.3	0.3	-	-	6.7±1.7
Upeneus vittatus	4.5	2.4	0.1	0.1	-	7.1±3.6
20% KOH control	-	-	-	-	-	0

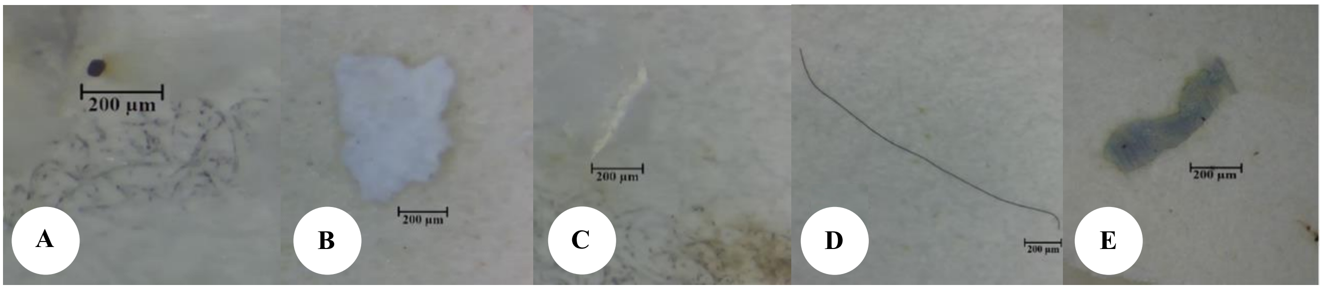

Figure 4. Microplastic shapes found in the gastrointestinal tracts of fish (10x magnification). A. Bead, B. Foam, C. Film, D. Fiber, E. Fragment

Plastic pollution may also contribute to phytoplankton decline. Certain plastic types (e.g., PS) can inhibit algal photosynthesis (Wu et al. 2019; Wu et al. 2021; Wang et al. 2023), and chemical additives such as flame retardants and plasticizers can further impair algal growth. For example, TCPP inhibits microalgal growth (Antonopoulou et al. 2022), while TDCPP disrupts photosynthesis and induces oxidative stress (Tang et al. 2020). These environmental pressures highlight potential pathways through which human activities could affect aquatic ecosystems in Balikpapan Bay and may influence the availability of phytoplankton as a food source, potentially contributing to the limited representation of herbivorous fish and the absence of phytoplankton in *A. chacunda* gut contents observed in this study. However, evaluating such relationships would require direct measurements of local phytoplankton abundance and environmental parameters.

Among the microplastic particles identified in the present study, fibers dominated across all feeding guilds. This pattern is consistent with the study by Hidayati et al. (2023), who reported that 62% of microplastics in fish from Tuban, East Java, were fibers, as well as findings by Maulana et al. (2023) in Banda Aceh, Ghosh et al. (2021) in the Bay of Bengal, and Clere et al. (2022) in southern New Zealand. In Balikpapan Bay, the high prevalence of fibers may be influenced by fishing activities. This aligns with the most common polymer type identified in this study, nylon, which is widely used in fishing gear known to produce microplastic fibers, such as lines, ropes, and nets (Nelms et al. 2021). These materials undergo degradation through mechanical abrasion, biological degradation, or UV exposure, producing fibers that enter marine food webs. Additional sources, such as wastewater discharge and laundering of synthetic textiles, may further contribute to fiber abundance in the region (Firdaus et al. 2020; Silva and Nanny 2020).

Fragments were also present in notable quantities and may originate from the degradation of larger plastic debris through physical and photochemical processes (Song et al. 2022). Many such fragments originate from land sources, including materials such as ABS (Buhhalko et al. 2025). In addition, ship paint, particularly antifouling paint, may contribute additional microplastic inputs while also releasing heavy metals and biocidal substances (Gaylarde et al. 2021).

A significant difference in gastrointestinal microplastic abundance between herbivorous fish and other feeding guilds was found in this study. These results are consistent with Keerthika et al. (2023), who found that herbivorous fish displayed a significantly higher microplastic abundance compared to other feeding guilds. In addition, the presence of microplastics within primary producers was found in a study conducted on periphyton in several rivers in Sumedang, West Java (Pribadi et al. 2023). Herbivorous fish often consume larger volumes of plant material to meet their nutritional requirements, which may increase the likelihood of ingesting microplastics associated with their food sources (Pan et al. 2021).

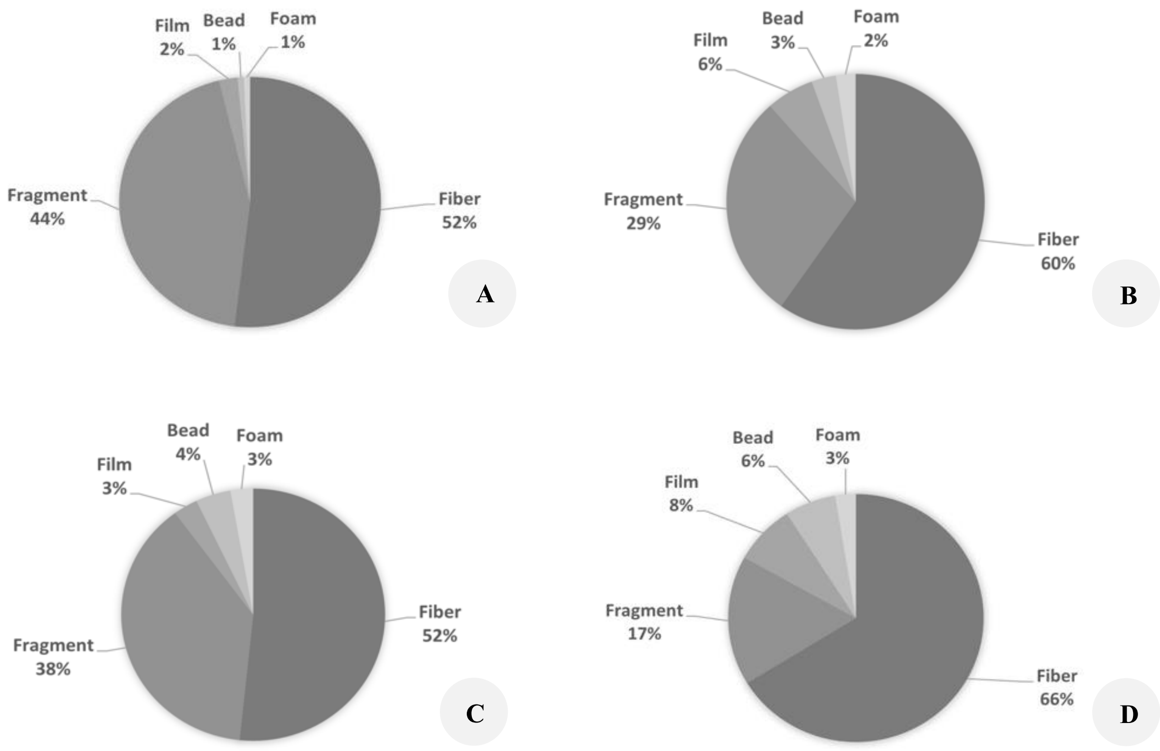

Figure 5. Composition of microplastic shapes across feeding guilds in fish from Balikpapan Bay. Fibers dominated across all feeding guilds, followed by fragments, while films, beads, and foam were present in lower proportions. A. Alga feeder, B. Crustacea feeder, C. Fish feeder, D. Zooplankton feeder

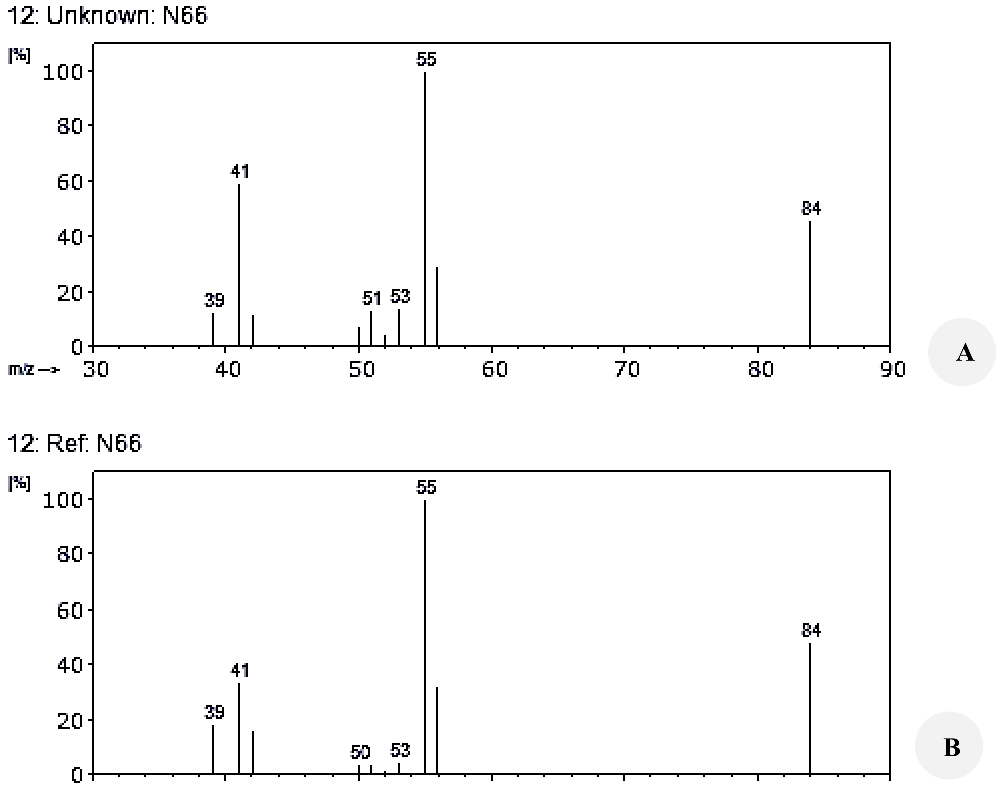

Figure 6. Mass spectral comparison of an unknown microplastic particle isolated from a *Sardinella fimbriata* sample, matched to nylon-6,6 (N66). A. The mass spectrum of the unknown sample, B. The reference spectrum for N66 from the Py-GC/MS library. The diagnostic ions present with relatively similar intensities support the identification of the particle as N66

In addition, the herbivorous fish species found in this study, *S. guttatus* and *S. argus*, were both demersal species that graze on benthic substrate. Studies have shown that benthic algal biofilms accumulate and retain microplastics (Berg et al. 2025). A study by Kostelnik et al. (2025) also highlighted the ability of benthic algae to accumulate microfibers, the most prominent type of microplastic found in this study. High-density microplastics tend to settle into sediments as well (Erni-Cassola et al. 2019), while even low-density particles may sink after biofouling (Amaral-Zettler et al. 2021; Parvin et al. 2021; Sfriso et al. 2024). These processes may increase the likelihood of microplastic adherence to benthic algae and substrates, thereby increasing ingestion by demersal herbivores.

The results of this study suggest higher microplastic abundance in primary consumers, though microplastic trophic transfer itself cannot be assessed based on diet alone. Similar results were found in a review by Walkinshaw et al. (2020). The lower microplastic abundance within predatory species observed in this study may be a result of egestion, whereby undigested microplastic particles are excreted within the span of hours to days (Xiong et al. 2019; Hou et al. 2022). This process could also explain the high variability of microplastic abundance within species, potentially reflecting different stages of microplastic excretion. Regardless, studies such as by Justino et al. (2021), have identified higher microplastic contamination in predatory fish, suggesting that multiple variables, including habitat, feeding strategy, particle types, and environmental conditions, may influence microplastic abundance.

Demersal fish were found to have a higher average gastrointestinal microplastic abundance compared to pelagic fish in this study. However, statistical analysis showed no significant difference between the two. Similar results were found in a previous study conducted on the western coast of Bangladesh (Matluba et al. 2023). This pattern is consistent with studies reporting the accumulation of both high- and low-density microplastics near the seabed. Several other studies also did not find a significant difference between the gastrointestinal microplastic abundance of pelagic and demersal fish (Filgueiras et al. 2020; Klangnurak and Chunniyom 2020). These results suggest that variation in gastrointestinal microplastic abundance among species may be more strongly associated with feeding guild than with habitat.

In terms of overall abundance, Aunurohim et al. (2023) found similar microplastic abundance levels to this study, ranging from 7 to 12 microplastic particles per fish. However, much lower abundances, under 3 particles per fish, were found by Wu et al. (2020), Piskula and Astel (2023), and Rasta et al. (2023). In a similar ecosystem to this study, Siregar et al. (2025) found an average of fewer than 2 particles per fish in the estuarine mangrove forest of Banda Aceh City. Meanwhile, Hastuti et al. (2019) found similarly high microplastic abundance dominated by fibers in the gastrointestinal tracts of fish off the coast of Pantai

Indah Kapuk, Jakarta, a major urban center. Such differences further emphasize the possible influence of local environmental factors, such as human activity levels.

In conclusion, microplastics were detected in all examined fish species from Balikpapan Bay, with fibers as the most abundant particle type, along with nylon as the most commonly identified polymer. Significant differences in gastrointestinal microplastic abundance were observed among feeding guilds, with herbivorous fish species, which in this study were demersal, exhibiting the highest abundance, potentially associated with high-volume feeding on benthic substrates where microplastics are thought to accumulate. Differences in gastrointestinal abundance appeared to be more closely linked to fish feeding guild rather than habitat alone, suggesting that microplastic exposure in fish may be influenced by multiple interacting factors, including feeding strategy, habitat use, environmental conditions, and particle characteristics. Despite limitations such as a single sampling period and the limited scope of polymer identification, this study provides baseline data for microplastic contamination in fish from Balikpapan Bay and contributes to understanding microplastic distribution within marine food webs. Future studies could incorporate multi-seasonal sampling, expand polymer identification across all particles, and evaluate biological impacts, such as tissue translocation and sublethal effects. In addition, incorporating stable isotope analysis could help evaluate microplastic abundance among feeding guilds and assess potential trophic transfer.

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