

Seasonal impacts of microplastic contamination on benthic species using CMPI and PLI indices at Karangsong Estuary, West Java, Indonesia

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Abstract. Takarina ND, Azzahrah RM, Budianto LW, Soelias NJ, Anwar MZ, Samudra YR, Akhmad AAA. 2026. Seasonal impacts of microplastic contamination on benthic species using CMPI and PLI indices at Karangsong Estuary, West Java, Indonesia. *Biodiversitas* 27 (1): d270125. <https://doi.org/10.13057/biodiv/d270125>. Benthic species play a crucial role in estuarine environments. While there is ongoing research on microplastics, information regarding the seasonal variation of microplastics in benthic species remains limited. This study explores the impact of seasonal variation (wet and dry seasons) on microplastic contamination in two representative benthic species at the Karangsong Estuary in West Java, Indonesia. The samples were collected from nine sampling sites in the Karangsong Estuary, with a total of two benthic species and 27 individuals sampled. After a microplastic extraction procedure, Raman Spectroscopy was utilized to identify the microplastic polymers. During the wet season, the predominant types of microplastics found in both *Telescopium telescopium* and *Metaplex longipes* are fragments, pellets, and fibers, in that order. The results showed that total microplastic abundance was significantly higher during the wet season than the dry season ($\chi^2 = 9.108$, $p = 0.002$), with *M. longipes* consistently accumulating more microplastics than *T. telescopium*. During the wet season, microplastic fragments dominated in both species, reaching 0.37 particles g⁻¹ wet mass in *T. telescopium* (95% CI: 0.06-0.74) and 107.18 particles g⁻¹ wet mass in *M. longipes* (95% CI: 0-256.00). In contrast, fibers were more prevalent in the dry season, particularly in *M. longipes* (18.78 particles g⁻¹ wet mass; 95% CI: 6.60-32.80). According to the Comprehensive Microplastics Pollution Index (CMPI), fragments were extremely dominant in *M. longipes* during the wet season (CMPI = 0.984), while fibers were dominant in *T. telescopium* during the dry season (CMPI = 0.638). Pollution Load Index (PLI) values for all shapes remained within the low contamination category. Polymer analysis indicated that polyethylene terephthalate (PET) and polyethersulfone (PES) were the dominant polymers in *T. telescopium*, whereas polypropylene (PP) was most frequently associated with *M. longipes*. Differences likely influence seasonal variation in microplastic contamination in rainfall, tidal dynamics, surface runoff, and fishing activity between seasons. Although this study is limited by sample size, estuarine coverage, and the use of Raman spectroscopy for polymer identification, the findings highlight clear seasonal patterns in microplastic contamination. These results underscore the importance of season-specific management strategies and support the potential use of *M. longipes* as a sensitive bioindicator for microplastic pollution in tropical estuaries.

Keywords: Benthic fauna, estuary, fibers, fragments, polymer

INTRODUCTION

Microplastics have contaminated the marine ecosystem, and this is also occurring in Indonesia's marine environment (Wang et al. 2015; Avio et al. 2016; Auta et al. 2017). Microplastics are also identified in estuarine (Unice et al. 2018; Piperagkas et al. 2019) and freshwater ecosystems (Ding et al. 2018). Several marine ecosystems in Indonesia have reported the presence of microplastic pollution, including the coast of Jakarta (Manalu et al. 2017), Banten (Falahudin et al. 2019), Banyuurip in Gresik, and the Brantas River. Furthermore, there have been reports of microplastic contamination from the coast of Surabaya (Cordova et al. 2019; Radityaningrum et al. 2021), Gresik waters (Yona et al. 2019a), the Bali Strait (Yona et al. 2019b), and Pasuruan District (Yona et al. 2020, 2021). The presence of microplastics in the estuarine ecosystem has the potential to be ingested by marine

organisms, in particular benthic fauna that inhabit marine ecosystems.

The class of gastropods, along with crustaceans, constitutes the largest and most taxonomically varied group of benthic fauna thriving in marine, freshwater, and terrestrial habitats (Lobo-da-Cunha 2019) has been found to be contaminated with microplastics (Van Cauwenberghe et al. 2015; Green et al. 2018). Microplastic ingestions in gastropods have been observed in species like banded dye-murex (*Hexaplex trunculus*) and purple dye murex (*Bolinus brandaris*) in Bizerte lagoon, Northern Tunisia (Abidli et al. 2019), periwinkle snails *Littoraria scabra*, *Nerita articulata*, *Nerita polita*, and *Chicoreus capucinus* in Klang River estuary, Malaysia (Zaki et al. 2020), *Littoraria* sp. in the eastern coast of Thailand (Thushari et al. 2017), as well as snails *Lanistes varicus* and *Melanoides tuberculata* in West Africa (Akindele et al. 2019), *Helix* sp., *Nacella magellanica* in Beagle Channel, Argentina (Ojeda et al. 2021), *Eobania vermiculata* and *Rumina decollata* in the

Kingdom of Saudi Arabia (Al Malki et al. 2021), and *Strombus* sp. in Bintan Island, Indonesia (Idris et al. 2023). Furthermore, microplastic ingestion has also been noted in other benthic fauna such as the sea cucumber *Apostichopus japonicus* in China (Mohsen et al. 2019) and *Perna perna* (Birnstiel et al. 2019).

In Indonesia, a study conducted along the coastal region of Rambut Island in Jakarta observed average microplastic quantities in *Telescopium telescopium* of 764.81 particles/individual. *T. telescopium* typically resides in riverine areas close to fish and shrimp farming ponds, and its diet consists of mangrove detritus, leaves, and organic materials found in sediments (Adriman et al. 2020). Another key species of the Indonesian estuary represented by crustaceans, belonging to crab species, has been reported to be contaminated by microplastics. Rohmaniyah et al. (2024) reported the presence of *Portunus pelagicus* in the estuary of Gegunung Wetan, Rembang District, Central Java, which contained 68 particles/individual. In the estuary of Surabaya, located in the Gresik District of East Java, Kandita (2024) reported finding *Parathelphusa convexa* that contained microplastic particles ranging from 600 to 1,300 particles/g.

Karangsong Estuary in Indramayu District, West Java, is an area of intertwined ecological and economic value. Ecologically, it provides essential functions for aquatic organisms, including serving as a habitat for growth, foraging, and protection from predators. At the same time, the ecosystem supports local livelihoods through fisheries and tourism activities (Gunawan et al. 2017; Setyawati et al. 2023). According to Sihombing et al. (2017), the Karangsong Estuary harbors at least 18 species of freshwater biota and 9 species of coastal plants. However, the sustainability of this ecosystem is increasingly threatened by environmental degradation, including plastic pollution.

The coastal region of West Java is renowned for its abundant marine resources. Consequently, numerous ecotourism areas have been developed along the coast to enhance community livelihoods and increase regional revenue (Arwani 2021; Garsetiasih et al. 2021). Despite

current studies of microplastics on common benthic fauna organisms, in particular *T. telescopium* and *Metaplex longipes*, there is still a gap in how the seasons regulate and alter microplastic ingestion of benthic fauna. The objectives of this study were to (i) assess the levels of microplastic contamination in benthic organisms across seasons, (ii) identify the microplastic characteristics of the ingested particles (shape, color, and polymer), and examine seasonal variation impacts on microplastic contamination in benthic species. It is hypothesized that the microplastic content varies between seasons and between species, with higher microplastic abundance during the wet season due to increased rainfall, tidal exchange, and surface runoff, and greater accumulation in *M. longipes* than in *T. telescopium* as a consequence of differences in feeding behavior and sediment interaction. In this study, *T. telescopium* and *M. longipes* were chosen as focal species due to their abundance. The findings of this research can inform recommendations and provide data references regarding the seasonal variation impacts on the distribution of microplastics within the benthic fauna communities in the Karangsong estuary.

MATERIALS AND METHODS

Study area

This study was conducted within the Mangrove Conservation Area of Karangsong Estuary, Indramayu District, West Java, Indonesia. Sampling sites were selected using a purposive sampling approach considering the presence of sediment within the estuary that is suitable for benthic fauna, with coordinates recorded via Global Positioning System (GPS) Garmin Etrex (Table 1). A total of nine sampling sites were established (Figure 1) extending from 6.30160° S, 108.3680° E to 6.30880° S, 108.36910° E. Additionally, the sampling sites were selected based on their proximity to potential sources of microplastic pollution.

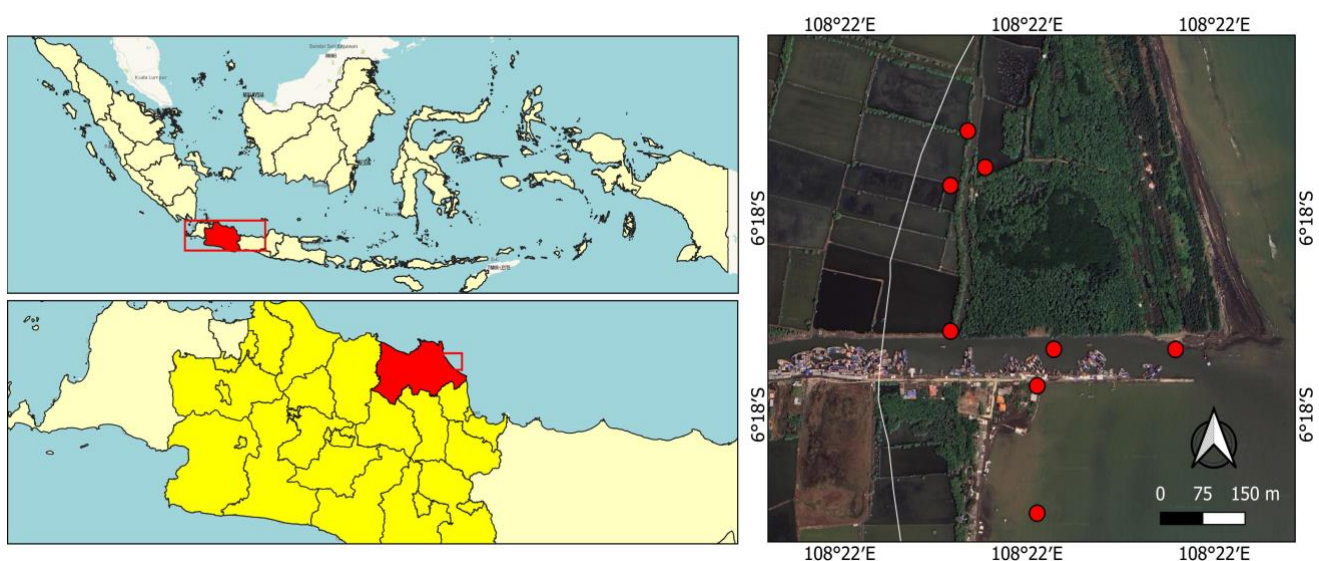


Figure 1. Locations of nine sampling sites (1-9) in Karangsong estuary, Indramayu District, West Java, Indonesia

Table 1. Coordinates of nine sampling sites in Karangsong estuary, Indramayu District, West Java, Indonesia

Sampling sites	Coordinates	
	South	East
1	6°18'06"	108°22'05"
2	6°18'08"	108°22'06"
3	6°18'09"	108°22'04"
4	6°18'17"	108°22'04"
5	6°18'18"	108°22'10"
6	6°18'18"	108°22'17"
7	6°18'20"	108°22'09"
8	6°18'27"	108°22'09"
9	6°18'32"	108°22'09"

Areas of mangrove forest characterize the estuary covers that provide habitat and food suitable for *T. telescopium* and *M. longipes*. Sampling activities were conducted during both the wet and dry seasons in November 2024 and June 2025. The estuaries are surrounded by fishing villages, fish ponds, and receive water from nearby rivers. During the wet season in November 2024, Indramayu District experienced 30 rainy days with an average annual precipitation of 334.40 mm, whereas in the dry season in June 2025, the region recorded only 3 rainy days with an annual average of 52.70 mm (BPS 2025). For the oceanography data, including rainfall and tidal information, the data was retrieved from <https://maritim.bmkg.go.id/cuaca/pasut>. The estuary receives water from the Cimanuk River and potential sources of microplastic pollution from fishing activities, ports, and nearby settlements.

Benthic fauna collection

Sediments containing benthic fauna, specifically *T. telescopium* and *M. longipes*, were sampled with three replications from each station following Zhang et al. (2024). Based on their method, all the benthic fauna were sieved from sediments collected with a Van Veen grab at 30 cm depth from a 10 × 10 m area at each sampling site. For further microplastic analyses and to avoid contamination, the benthic fauna samples were packed in aluminum foil, transported to the Marine Science Laboratory Facility located at the Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, under -4°C during transportation, and kept at -20°C in the laboratory freezer. Voucher specimens of the examined *T. telescopium* and *M. longipes* species are available from the zoological scientific collection of the Museum Zoologicum Bogoriense (MZB) in Bogor, West Java, and the zoological center of Indonesia's National Research and Innovation Agency (BRIN) in Cibinong, West Java.

Benthic fauna microplastic extraction

The soft tissues of the benthic samples were carefully dissected and extracted with a surgical blade and transferred into a glass beaker. Next, the tissues were immersed in 200 mL of HNO₃ (55%) solution for a duration of 24 hours to eliminate any organic matter and degrade the benthic tissues (Naidoo et al. 2017). The solution was subsequently saturated with a NaCl solution and diluted to one-tenth of

its original volume using H₂O₂. The supernatant solution was then subjected to vacuum filtration through Whatman filter paper that has a diameter of 90 mm and a pore size of 0.45 μm. Following this, the filters were positioned in clean petri dishes and allowed to dry at room temperature (25°C) until further analysis. The resulting filtrate was examined with a zoom stereo microscope, an Olympus CX22, with magnification settings of 10 × 4 or 10 × 10 to detect the presence of microplastics as recommended by a similar previous microplastic study on benthic fauna (Supriatna et al. 2023). The identified microplastics were then categorized based on their shape, which included fiber, fragment, pellet, and film. For color, the microplastics were categorized as black, red, and transparent.

Benthic fauna microplastic polymer type analysis

Polymer types of microplastic particles were analyzed using Raman Spectroscopy Horiba-LabRam HR Evolution with an excitation wavelength of 785 nm and a spectral range of 500–4,000 cm⁻¹. The analysis results were compared with the KnowItAll IR Spectral Library database reference with a minimum match level of 70%. The Raman scanning/mapping lateral resolution is less than 532 nm. The identified microplastics were then categorized based on their polymer type, which included polypropylene (PP), polyethylene terephthalate (PET), and polyethersulfone (PES). The number of particles required for microplastic polymer type analysis using Raman Spectroscopy ranges from one to five particles.

Microplastic quality control

Microplastic quality control was implemented to avoid external microplastic contamination. This procedure was implemented, starting from sample collection activities in the sampling sites to the laboratory. During benthic fauna sample collections in the sampling sites, plastic-made collection tools and materials were prohibited. As a substitute, collection tools were made of metal. All benthic fauna samples were immediately frozen at -20°C for further laboratory analyses and transferred to the Marine Science Laboratory Facility located at the Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia.

At the laboratory, the quality control measurement procedure followed Karami et al. (2017) and Barboza et al. (2020). To avoid microplastic contamination, benthic fauna samples were analyzed in a sterile facility with restricted access. Throughout the entire laboratory process, nitrile gloves and a clean, cotton laboratory coat were worn. To prevent cross-contamination, all work surfaces and dissection tools were cleaned with 70% ethanol both before and after each individual sample. To exclude any foreign objects from contaminating the samples, all work surfaces and dissection tools were cleaned twice—once with ethanol and once with ultrapure water. Controls were included in the experiment despite extreme caution to evaluate potential contamination from the laboratory atmosphere. These controls served as procedural blank controls for all procedures; they were positioned in three pristine petri dishes close to the work area. Additionally, during digestion procedures, petri

dishes containing ultrapure water were analyzed. No contamination was observed in the blank samples for microplastic quality control.

Data analysis

Pollution Load Index (PLI)

Pollution load index was employed to assess the degree of microplastic pollution in the benthic fauna, and in this context is a relative index rather than an absolute risk indicator. Pollution load index has been used to assess levels of microplastic pollution (Li et al. 2020; Ranjani et al. 2021; Soursoy et al. 2024; Faisal et al. 2025), and is calculated thus following Qiu et al. (2023) and Haque et al. (2024):

$$C_f = C_i / C_o$$

$$PLI = \sqrt{C_f}$$

$$PLI_n = \sqrt{PLI_1 \times PLI_2 \times \dots \times PLI_n}$$

Where: C_f is the microplastic contamination factor, C_i is the concentration of microplastics in an individual organism (i), denoted as particles/g wet mass, and C_o is the background value. Due to a lack of background value for microplastics, the lowest microplastic concentration in benthic fauna in this study was used as the background value (Li et al. 2020; Ranjani et al. 2021; Faisal et al. 2025). The use of minimum observed concentration as C_o allows relative comparison within the dataset but may underestimate absolute pollution levels. PLI is classified as <10: low, 10-20: high, 20-30: dangerous, and >30: extremely dangerous (Ilechukwu et al. 2025). Using the minimum observed value as C_o may underestimate absolute pollution, but allows relative comparison within the dataset.

Coefficient of Microplastic Impact (CMPI)

The Coefficient of Microplastic Impact (CMPI) was calculated following Pervez et al. (2023) and Rojas-Luna et al. (2023). CMPI represents a portion of microplastics with particular shapes, with the total microplastics with all shapes. The CMPI is calculated by dividing the microplastic contents for particular shapes in organisms by the total microplastic content. The values of CMPI were as follows: 0.0001 to 0.100: minimum, 0.110 to 0.500: average, 0.510 to 0.800: maximum, 0.810 to 1.000: extreme.

The CMPI is expressed as: $CMPI = C_{shp} / C_{tot}$, with C_{shp} is a portion of microplastic with particular shapes and C_{tot} is the total microplastic with all shapes.

Statistical analysis

Chi-square and Mann-Whitney U statistical tests were used to compare the weight and length of *T. telescopium* and *M. longipes*, and microplastic contents in particles/g wet mass between dry and wet seasons. The comparative variables included weight and length of benthic species, microplastic shapes, and colors. The significance level was

set at $p < 0.05$. Chi-square and Mann-Whitney U statistical tests were done using R version 3.6.3 software. The Mann-Whitney U statistical test was used because of the small sample size. Numbers of microplastic contents were pooled per species and across sampling sites.

RESULTS AND DISCUSSION

Benthic fauna species

The collected benthic fauna consisted of two species (Figure 2): *T. telescopium*, representing mollusks, and *M. longipes*, representing crustaceans. Seasonally, *Telescopium* was more abundant in the dry season (8 individuals) than in the wet season (6 individuals). A similar finding was found with *M. longipes*, which was more abundant in the dry season (9 individuals) than in the wet season (4 individuals). In the wet season, *Telescopium* was more abundant than *M. longipes*. Meanwhile, in the dry season, *M. longipes* was more abundant than *Telescopium*. The chi-square analysis indicates that the numbers of individuals do not differ for both species and seasons ($\chi^2 = 0.422$, $p = 0.515$).

As seen in Table 2, the length and wet mass of *Telescopium* obtained in the wet season were higher than the length ($p = 0.022$) and mass of *Telescopium* obtained in the dry season. The average mass of *Telescopium* obtained in the wet season was 49.57 ± 13.16 g, which was higher than the average weight of *Telescopium* obtained in the dry season, which was 43.85 ± 18.02 g. The maximum mass of *Telescopium* reached 67.40 g in the wet season, while in the dry season it decreased to 55.00 g (Table 3). A similar thing was also found in *M. longipes*, namely, the average mass of *M. longipes* obtained in the wet season was 1.42 ± 0.12 g, while in the dry season, the mass of *M. longipes* decreased by almost half to 0.53 ± 0.34 g ($p = 0.006$). The maximum mass of *M. longipes* reached 5.20 g in the wet season, while in the dry season it decreased to 1.20 g.



Figure 2. Benthic fauna: A. *Telescopium telescopium*, B. *Metaplex longipes* in Karangsang estuary, Indramayu District, West Java

Microplastics in benthic fauna species

Table 4 reports the total microplastic contents in benthic fauna species by season. The wet season always has higher total microplastic contents than the dry season ($\chi^2 = 9.108$, $p = 0.002$). For benthic fauna species, *M. longipes* always has higher total microplastic contents than *Telescopium*. Table 5 reports the compositions (Figure 3) and average abundance of microplastics by shape (Figure 5) and season. Wide confidence intervals reflect a small sample size and high individual variability. Regarding the compositions, fragments dominated the wet season, and fibers dominated the dry season. For *Telescopium*, fiber abundance was higher in the dry season (0.20 particles/g wet mass, 95% CI: 0.09-0.33) compared to the wet season (0.15 particles/g wet mass, 95% CI: 0.01- 0.35). Conversely, fragment abundance was higher ($p=0.002$, Table 7) in the wet season (0.37 particles/g wet mass, 95% CI: 0.06-0.74) compared to the dry season (0.08 particles/g wet mass, 95% CI: 0.03-0.14). A similar pattern was found for microplastic pellet abundance, with microplastic abundance higher ($p=0.006$, Table 7) in the wet season (0.24 particles/g wet mass, 95% CI: 0.01-0.66) than in the dry season (0.03 particles/g wet mass, 95% CI: 0.01-0.05).

For *M. longipes*, fiber abundance was higher in the dry season (18.78 particles/g wet mass, 95% CI: 6.60-32.80, $p=0.000$, Table 5) than in the wet season (0.52 particles/g wet mass, 95% CI: 0-0.77). A similar pattern was also found for pellet abundance, with higher abundance in the dry season (5.57 particles/g wet mass, 95% CI: 0.30-12.20) ($p=0.001$, Table 7) than in the wet season. Conversely,

fragment abundance was higher in the wet season (107.18 particles/g wet mass, 95% CI: 0-256.00, $p=0.020$, Table 7) than in the dry season (18.03 particles/g wet mass, 95% CI: 8.60-30.60). Regarding the compositions (Figure 3), fragments dominated the wet season, and fibers dominated the dry season.

Table 6 reports the compositions (Figure 4) and average abundance of microplastics by color (Figure 5) and season. Regarding the compositions, transparent colors dominated the wet season, and black colors dominated the dry season. For *Telescopium*, the abundance of black microplastics was higher (0.34 particles/g wet mass, 95% CI: 0.07-0.55, $p=0.018$, Table 7) in the wet season compared to the dry season (0.20 particles/g wet mass, 95% CI: 0.13, 0.28). A similar pattern was found for the abundance of transparent microplastics ($p=0.006$, Table 7), with transparent microplastics being higher in the wet season (0.53 particles/g wet weight, 95% CI: 0.01-1.15) than in the dry season (0.06 particles/g wet mass, 95% CI: 0-0.15).

In *M. longipes*, the average abundance of black microplastics was higher in the wet season (102.50 particles/g wet weight, 95% CI: 0.60-146.00) than in the dry season (23.83 particles/g wet mass, 95% CI: 3.50-48.30). A similar pattern was also found for the abundance of transparent microplastics, with transparent microplastics being higher in the wet season (17.70 particles/g wet mass, 95% CI: 1.90-55.50) than in the dry season (2.93 particles/g wet mass, 95% CI: 0.10-6.62). Regarding the compositions, black colors dominated both the wet season and the dry season.

Table 2. The mean (\pm SD) wet mass (g) and length (cm) of benthic fauna species in Karangsang estuary, Indramayu District, West Java

Species	Wet mass (g)		Length (cm)	
	Wet season	Dry season	Wet season	Dry season
<i>Telescopium telescopium</i>	49.57 \pm 13.16	43.85 \pm 18.02	7.51 \pm 0.43	7.47 \pm 3.05
<i>Metaplax longipes</i>	1.42 \pm 0.12	0.53 \pm 0.34	4.07 \pm 0.89	3.30 \pm 0.91

Table 3. The minimum and maximum ranges of wet mass (g) and length (cm) for benthic fauna species in Karangsang estuary, Indramayu District, West Java

Species	Wet mass range (g)		Length range (cm)	
	Wet season	Dry season	Wet season	Dry season
<i>Telescopium telescopium</i>	35.80-67.40	45.40-55.00	6.80-8.10	8.00-9.00
<i>Metaplax longipes</i>	3.30-5.20	0.20-1.20	3.30-5.20	1.80-4.50

Table 4. Total microplastic contents in benthic fauna species in Karangsang estuary, Indramayu District, West Java

Species	Total microplastic contents		Average microplastic contents (particles/g wet mass for each individual)**	
	Wet Season	Dry Season	Wet Season	Dry Season
<i>Telescopium telescopium</i>	231 (6)*	115 (8)*	0.77	0.32
<i>Metaplax longipes</i>	621 (4)*	203 (9)*	108.95	42.39

Note: * Numbers in brackets indicate the quantity of benthic fauna individuals collected, ** The total microplastic content divided by the number of benthic fauna individuals collected, along with their wet mass

Table 5. Microplastic contents (particles/g wet mass) according to shapes and seasons of benthic fauna species in Karangsong estuary, Indramayu District, West Java (confidence intervals/CI for some estimates are wide and include zero, reflecting small sample size and high variability)

Species	Metrics	Fiber		Fragment		Pellet	
		Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
<i>Telescopium telescopium</i>	Average	0.15	0.20	0.37	0.08	0.24	0.03
	95% CI	0.01-0.35	0.09-0.33	0.06-0.74	0.03-0.14	0.01-0.66	0.01-0.05
	Range	0.04-0.34	0.11-0.31	0.11-0.71	0.03-0.13	0.01-0.64	0.01-0.05
<i>Metaplax longipes</i>	Average	0.52	18.78	107.18	18.03	1.25	5.57
	95% CI	0-0.77	6.60-32.80	0-256.00	8.60-30.60	0-5.02	0.30-12.20
	Range	0-1.25	8.57-31.66	27.5-250.00	10.71-30.00	0-5.00	0.62-11.66

Table 6. Microplastic contents (particles/g wet mass) according to colors of benthic fauna species in Karangsong estuary, Indramayu District, West Java (confidence intervals/CI for some estimates are wide and include zero, reflecting small sample size and high variability)

Species	Metrics	Black		Red		Transparent	
		Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
<i>Telescopium telescopium</i>	Average	0.34	0.20	0	0.05	0.53	0.06
	95% CI	0.07-0.55	0.13-0.28	0	0.01-0.10	0.01-1.15	0-0.15
	Range	0.14-0.66	0.14-0.27	0	0.02-0.09	0.02-1.08	0-0.14
<i>Metaplax longipes</i>	Average	102.50	23.83	0	3.24	17.70	2.93
	95% CI	0.60-146.00	3.50-48.30	0	1.99-4.09	1.90-55.50	0.10-6.62
	Range	12.50-255.00	7.14-46.66	0	2.50-3.57	3.33-55.00	0.71-6.42

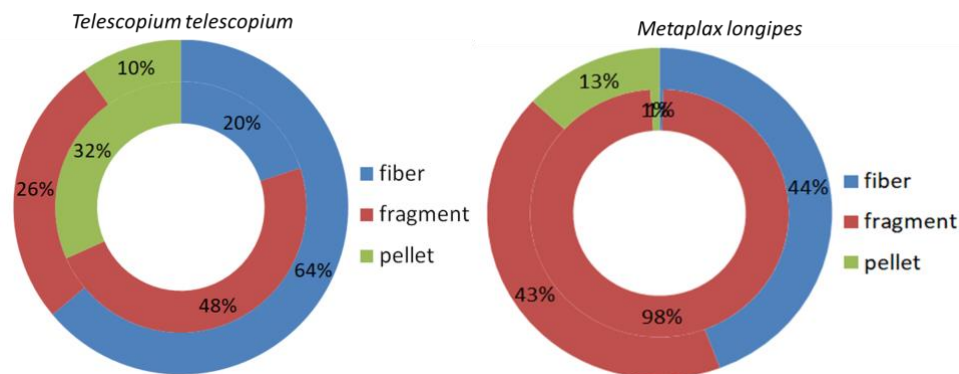


Figure 3. The compositions of microplastic shapes in benthic fauna species according to seasons from innermost to outermost circles: wet season (inner circle), dry season (outer circle)

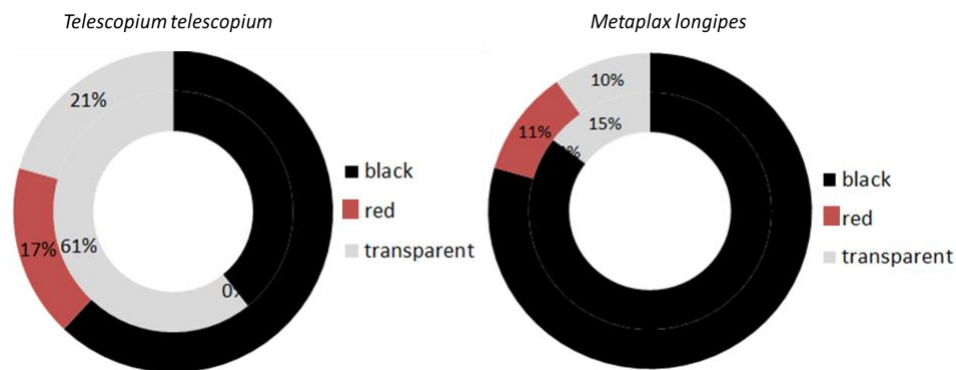


Figure 4. The compositions of microplastic colors in benthic fauna species according to seasons, from innermost to outermost circles: wet season (inner circle), dry season (outer circle)

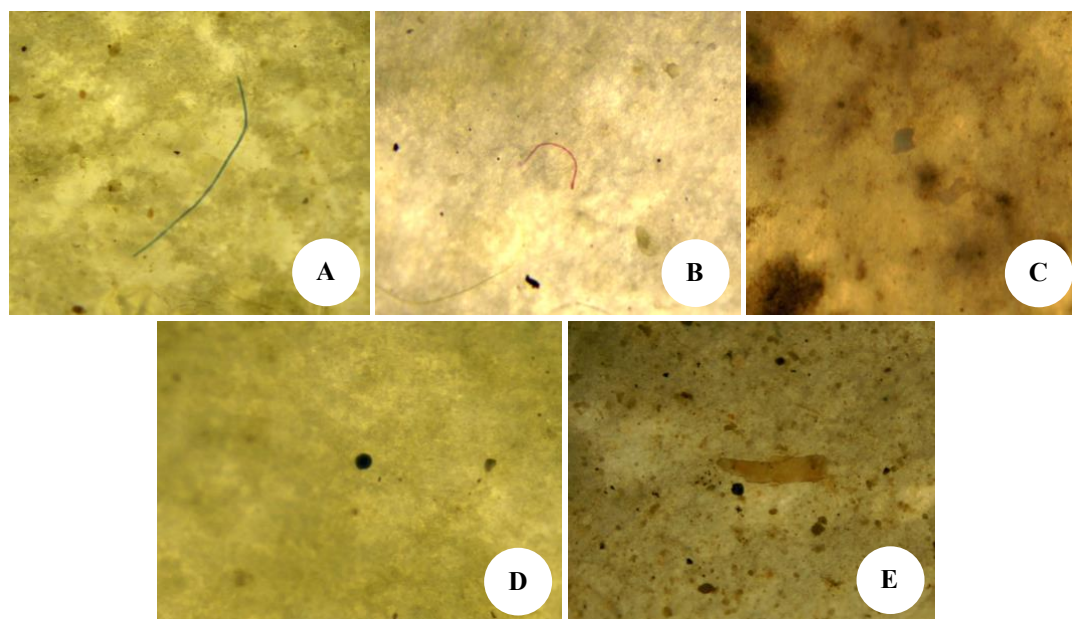


Figure 5. Microplastic contents according to shapes and color: A. blue fiber, B. red fiber, C. blue fragment, D. black pellet, E. brown film in Karangsong estuary, Indramayu District, West Java

Table 7. Mann-Whitney U statistical analyses for weight and length of *Telescopium telescopium* and *Metaplax longipes* and microplastic contents based on color and shapes (significant at $p < 0.05$)

Species	Variable (Dry season vs Wet season)	P value	U value
<i>Telescopium telescopium</i>	Weight	0.448	22.50
	Length	0.022*	8.00
	Fiber	0.235	13.00
	Fragment	0.002*	0.00
	Pellet	0.006*	2.00
	Black	0.018*	4.50
	Red	0.086	9.00
	Transparent	0.006*	2.00
<i>Metaplax longipes</i>	Weight	0.006*	3.50
	Length	0.115	13.00
	Fiber	0.000*	0.00
	Fragment	0.020*	12.00
	Pellet	0.001*	4.00
	Black	0.480	32.00
	Red	0.000*	0.00
	Transparent	0.158	22.00

Note: *significant at $p < 0.05$

Polymer of microplastics in benthic fauna species

The graph (Figure 6) shows a strong peak in the spectrum number $1,612.93 \text{ cm}^{-1}$, which indicates the presence of an aromatic ring (C=C), combined with the spectrum number $1,724.59 \text{ cm}^{-1}$, which is a typical carbonyl group (C=O) in polyester. The combination of the two peaks is also supported by the presence of C-O stretching in the spectrum numbers

996.69 cm^{-1} and $1,094.11 \text{ cm}^{-1}$, which are also characteristic of groups in polyester. Thus, the results of the analysis of the graph shown in the *Telescopium* sample are the type of polyester (polyethersulfone/PES or polyethylene terephthalate/PET).

A similar type of polymer was also found in the *M. longipes* sample (Figure 7). Strong peaks were detected through the spectrum with a similar range, where C=C was at $1,614.78 \text{ cm}^{-1}$ and C=O at $1,727.00 \text{ cm}^{-1}$. The combination of the two peaks was supported by C-O stretching at 988.60 cm^{-1} and $1,092.74 \text{ cm}^{-1}$. C=O at $1,727.00 \text{ cm}^{-1}$ is characteristic of polyethylene terephthalate/PET or polyethersulfone/PES.

The Raman spectra of *M. longipes* show two types of spectra (Figure 8). In addition to PES, the graph also indicates the presence of Polypropylene, or PP, detected. This can be seen through the characteristic combination of spectral numbers at 841.76 cm^{-1} and 973.49 cm^{-1} , which represent CH_3 rocking, a typical marker of PP, and $1,152.40$ and $1,460.16$, which represent bending or stretching common to PP.

Microplastic CMPI and PLI in benthic fauna species

CMPI indicates a prevalence of specific microplastic shapes and colors based on the data presented in Tables 5 and 6. Based on the CMPI in Table 8, *Telescopium* was contaminated at the minimum level by any form of microplastic in the wet season. Meanwhile, in the dry season, *Telescopium* was contaminated by fibers, with a CMPI of 0.638. *M. longipes* in the wet season was contaminated by microplastic fragments, with a CMPI of 0.984. However, in the dry season, *M. longipes* was not contaminated at all.

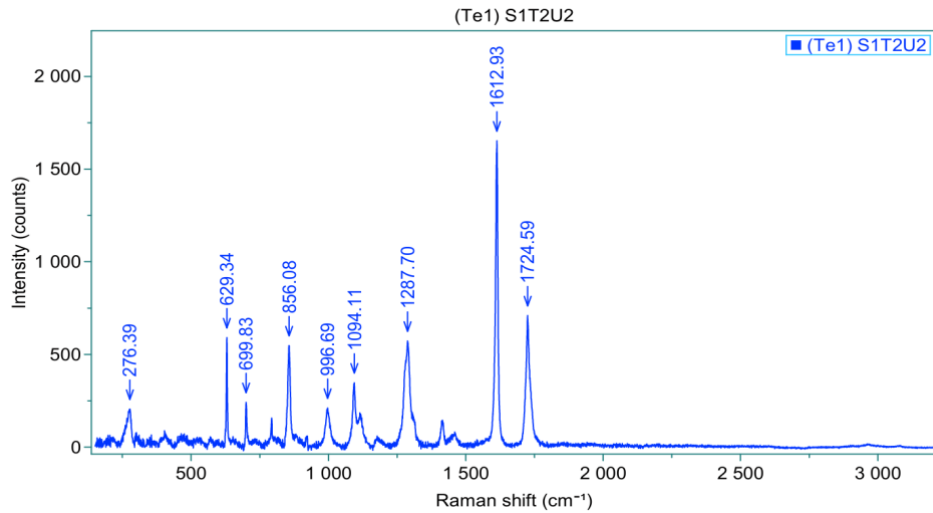


Figure 6. Raman spectrum of a microplastic particle extracted from *Telescopium telescopium*, identified as polyethersulfone (PES). Characteristic peaks are labelled

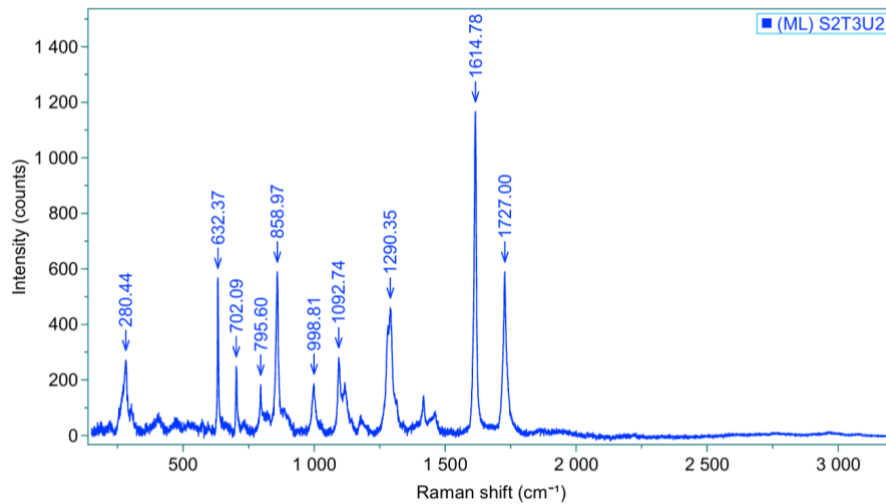


Figure 7. Raman spectrum of a microplastic particle extracted from *Metaplax longipes*, identified as polyethersulfone (PES). Characteristic peaks are labelled

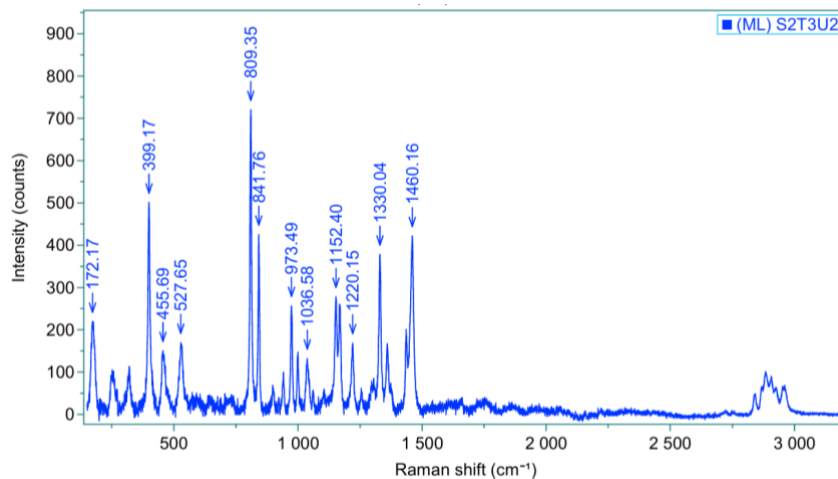


Figure 8. Raman spectrum of a microplastic particle extracted from *Metaplax longipes*, identified as polypropylene (PP). Characteristic peaks are labelled

Table 8. Microplastic CMPI of benthic fauna species according to shapes and seasons in Karangsong estuary, Indramayu District, West Java

Species	Metrics	Fiber		Fragment		Pellet	
		Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
<i>Telescopium telescopium</i>	Average	0.200	0.638	0.483	0.264	0.317	0.099
<i>Metaplex longipes</i>	Average	0.005	0.443	0.984	0.425	0.011	0.131

Note: *CMPI classification: 0.0001-0.100 (minimum), 0.110-0.500 (average), 0.510-0.800 (maximum), and 0.810-1.000 (extreme)

Table 9. Microplastic CMPI of benthic fauna species according to colors in Karangsong estuary, Indramayu District, West Java

Species	Metrics	Black		Red		Transparent	
		Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
<i>Telescopium telescopium</i>	Average	0.409	0.620	0.000	0.180	0.591	0.200
<i>Metaplex longipes</i>	Average	0.972	0.532	0.000	0.072	0.028	0.395

Note: *CMPI classification: 0.0001-0.100 (minimum), 0.110-0.500 (average), 0.510-0.800 (maximum), and 0.810-1.000 (extreme)

Table 10. Microplastic PLI of benthic fauna species according to shapes and seasons in Karangsong estuary, Indramayu District, West Java

Shape	Season	Species	
		<i>Telescopium telescopium</i>	<i>Metaplex longipes</i>
Fiber	Wet	1.922	1.414
	Dry	0.732	1.480
Fragment	Wet	0.563	1.974
	Dry	0.657	1.297
Pellet	Wet	0.246	1.118
	Dry	0.605	2.986

Note: *PLI is classified as <10: low, 10-20: high, 20-30: dangerous, and >30: extremely dangerous

Based on the color CMPI in Table 9, *Telescopium* was contaminated by transparent microplastic in the wet season, with a CMPI of 0.591, while in the dry season, *Telescopium* was contaminated by black microplastic with a CMPI of 0.62. *M. longipes* in the wet season was contaminated by black microplastic with a CMPI of 0.972. In the dry season, *M. longipes* was also contaminated by black microplastic with a CMPI of 0.532.

The calculation of PLI is based on the microplastic data presented in Table 6. The fiber PLI value for *Telescopium*, as shown in Table 10, decreased from the wet season to the dry season, with a minimal decrease of nearly half. In contrast, the fragment PLI value increased from wet to dry conditions. Similarly, the pellet PLI value also rose by almost half in the dry season compared to the wet season.

The fiber PLI value (Table 10) for *M. longipes* was relatively stable between wet and dry seasons, with a minimal increase of 4.7% from 1.414 to 1.480. The fragment PLI value decreased significantly by 34.3% from wet (1.974) to dry (1.297) seasons. The pellet PLI value showed a noticeable increase of 167% in dry season conditions compared to wet season from 1.118 to 2.986.

Discussion

The microplastic content in *T. telescopium* and *M. longipes* in this study is comparable to that found in benthic fauna in other locations (Table 11). Microplastic content in Karangsong, in general, is higher than that in those locations. Based on the microplastic abundances reported in overseas (Leslie et al. 2017; Digka et al. 2018), Makassar (Sari 2018), Gresik (Yona et al. 2021), and Subang, the magnitude of contamination is indicated. In comparison, microplastics in Karangsong are comparable to the microplastic content in the nearby Blanakan estuary, Subang (Takarina et al. 2023), which is also located within the West Java region. This similarity then indicates that microplastics have contaminated the estuaries in West Java.

Microplastic content varies by season. During the wet season, fragments of microplastics were found to be dominant in both *T. telescopium* and *M. longipes*. The seasonal variation in microplastic content, as observed in this study, is closely related to environmental conditions that influence the transport of microplastics. Estuaries, situated near rivers, serve as areas where rivers carry various materials, including microplastics, from upstream areas to the downstream estuary. In the wet season, as water flow increases, so does the transport of materials from inland regions. In Karangsong, the microplastic content, particularly in fragments, is notably higher in the wet season compared to the dry season. For *T. telescopium*, the concentration of fragments reaches 0.37 particles/g wet mass during the wet season, compared to only 0.08 particles/g wet mass in the dry season. Similarly, for *M. longipes*, the concentration of fragments increases to 107.18 particles/g wet mass in the wet season, up from 18.03 particles/g wet mass in the dry season. This pattern is in agreement with the findings of Moses et al. (2023), which indicate that a rise in microplastic content often accompanies increased water flow during the wet season.

Table 11. Comparisons of microplastic abundance (particles/g wet mass) in benthic fauna species from other marine ecosystems

Location	Benthic fauna	Microplastic abundance	References
Jiaozhou Bay, China	Bivalves and gastropods Crustaceans (shrimp, crabs, and isopods)	18.3 particles/g 35.0 particles/g	Zhang et al. (2023)
Yangtze Estuary, Chongmin Island, China	<i>Chiromantes dehaani</i> (H.Milne Edwards, 1853)	1.90 particles/g	Wu et al. (2023)
Vembanad Lake Mangrove Wetlands, South-West Coast of India	<i>Neripteron violaceum</i> (Gmelin, 1791) <i>Meretrix casta</i> (Gmelin, 1791) <i>Villorita cyprinoides</i> (Gray, 1825) <i>Telescopium telescopium</i> (Linnaeus, 1758)	59.51 particles/g 23.37 particles/g 21.65 particles/g 6.88 particles/g	Roshni et al. (2025)
Negombo Lagoon, Sri Lanka	<i>Scylla serrata</i> (Forskål, 1775)	0.09 particles/g	Dias et al. (2024)
Dubibir mangrove forest, Madura Strait water, Indonesia	<i>Geloina expansa</i> (Mousson, 1849) <i>Telescopium telescopium</i> (Linnaeus, 1758)	1.72 particles/g 1.06 particles/g	Yona et al. (2023)
Karangsong estuary, Indramayu District, West Java	<i>Telescopium telescopium</i> (Linnaeus, 1758) <i>Metaplex longipes</i> Stimpson, 1858	0.32-0.77 particles/g 42.39-108.95 particles/g	This study*

Note: *Refer to the values presented in Table 4

Table 12. Seasonal tides (m) of sampling sites in Karangsong estuary, Indramayu District, West Java, Indonesia (<https://maritim.bmkg.go.id/cuaca/pasut>)

Seasons	Tides (m)		Rainfall (mm)
	High	Low	
Dry	0.24-0.37	-0.20-0.04	50-100
Wet	0.21-0.61	-0.43-0.30	100-150

Water flow, especially surface runoff from rainfall, significantly contributes to the movement of microplastics from urban areas into rivers, lakes, and oceans, transporting particles from tire degradation, road paint, and various debris. This runoff facilitates the mobilization of microplastics, resulting in higher concentration levels. During the rainy season, the overall abundance and foraging activity of benthos often increase due to the food resources and nutrients transported by water flow. This situation increases the exposure of sediments containing microplastics to benthic species. During the dry season, the fiber content is higher compared to other microplastic shapes. This increase is associated with fishing activities, which tend to be more prevalent during the dry season due to the calm weather and safe ocean conditions for fishing. As a result, the fibers primarily come from fishing nets. The abundance of PET polymer is linked to fiber production. PET pollution primarily originates from synthetic textiles, particularly polyester fibers that are released during clothing washes. PP polymer pollution primarily comes from single-use plastic (SUP) products, especially packaging and other consumer goods used by fishermen to store fish, as well as those from nearby settlements.

During the wet season, a high accumulation of microplastics is presumably linked to tides and rainfall, which are different and higher compared to the dry season (Table 12). Microplastics accumulate in the sediments at the bottom of the sea, as the tides play a role (Embulaba et al. 2022) in their movement by shifting and redepositing

sediments across various coastal regions. The cycles of the tides affect the quantity of microplastics present, with research on microplastic accumulation influenced by tides indicating elevated concentrations during certain phases. The movement of tides results in the displacement of particles, which in turn resuspends microplastics from the ocean floor and carries them throughout the water column. Additionally, tides and currents play a role in the settling and subsequent accumulation of microplastics in the sediment, which serves as the habitat for benthic organisms.

Higher microplastics in the wet season than in the dry season can also be explained by comparing the body size. During the wet season, the weights of both *T. telescopium* and *M. longipes* are higher than the weights measured in the dry season. In agreement with Gad and Midway (2022), microplastic concentrations in marine organisms positively correlated with marine organism body size. *M. longipes* are known to have a higher microplastic content compared to *T. telescopium*, which can be attributed to the feeding behavior of *M. longipes* (Vidayanti and Retnaningdyah 2024). As a decapod, *M. longipes* is capable of foraging over a greater distance than *T. telescopium*, resulting in increased exposure to environmental contaminants, including microplastics. Additionally, *M. longipes* is both a predator and a saprophagous organism. This feeding behavior contributes to the contamination and accumulation of microplastics from its prey. Saprophages that feed on detritus can easily ingest microplastics, which accumulate in sediment. These saprophage benthic organisms (Zhang et al. 2020), living on the sediment—a major sink for microplastics—are directly exposed to high concentrations of these pollutants. In *M. longipes*, a decrease in weight was associated with an increase in microplastic abundance, particularly in fibers and pellets. This suggests that sediment exposure affects juvenile individuals, who have lower body mass compared to adults.

According to CMPI, the benthic community has been contaminated from maximum to extreme degrees. During the wet season, fragments were very common and were

ingested more by *M. longipes* than by *T. telescopium*. During the dry season, fiber was very common and was also ingested more by *M. longipes* than by *T. telescopium*. According to PLI, microplastic contamination is still considered low. Despite this fact, the prevalence and contribution of fibers during the dry season and fragments during the wet season are particularly noteworthy as calculated by CMPI. This index-based calculation guide provides a practical approach to regulating particular activities that may contribute to the fibers and fragment contamination following the season. Approaching the wet season, the use of plastic that can contribute to the fragment inputs should be minimized. Similar to this, fishing activities approaching the dry season should also be minimized.

Several factors limit this study. First, the sample size is small, particularly for *M. longipes* during wet seasons. This can be due to the limited population of samples and sample areas. Small sample sizes make accurately quantifying this risk and understanding the true extent of microplastic contamination much harder and less representative. Larger sample sizes and sampling areas are consistently recommended for more reliable and robust conclusions in microplastic research. To address this issue, it is recommended to expand the sampling areas to collect more individuals of *M. longipes*. Moreover, this study is limited to the *T. telescopium* and *M. longipes* in the estuary and should be expanded to include the benthic species in the transition zones between the estuary and the ocean. This expansion can also help in gathering more samples. Another notable limitation is the lack of universal microplastic background values for specific benthic fauna, and it requires alternative background values in the future. In addition, a lack of long-term monitoring includes an inability to detect long-term trends over a multi-year sampling period, which may limit the ability to understand the microplastic content variability and establish reliable baseline data for microplastic management and reporting. Regarding the method used, this study uses HNO₃ digestion. Despite the effectiveness of HNO₃ digestion in removing organic matter during microplastic analysis, a significant limitation is its potential to degrade certain polymers, especially polyamide (nylon) and polyurethane. The analysis of polymers in this research employs Raman Spectroscopy. Although Raman can identify particles as small as 1 μm, there are significant limitations, such as low signal sensitivity, prolonged mapping times, the risk of sample damage, and interference from fluorescence or background substances (Huang et al. 2022).

Microplastic content in the environment, including in organisms, is very dynamic and different depending on the season. In this regard, current research about microplastics on benthic fauna is limited to only one season instead of comparing seasons, as can be seen in Table 11. Here, this study has attempted to compare microplastics in benthic fauna across seasons. In this study, we conclude that the wet season is characterized by abundances of fragments with the order of fragments > pellets > fibers. At the same time, the dry season is characterized by an abundance of fibers with the order of fibers > fragments > pellets. According to the Comprehensive Microplastics Pollution

Index (CMPI), fragments were more common in *M. longipes* during the wet season, while fibers were more common in *T. telescopium* in the dry season. In the wet season, *M. longipes* accumulates more microplastics than *T. telescopium*. This pattern was also observed in the dry season. This confirms that *M. longipes*, inhabiting the Karangsong Estuary particularly, are ingesting more microplastics than *T. telescopium*. The consistently higher accumulation in *M. longipes* supports its potential use as a sentinel species for estuarine microplastic monitoring. In terms of polymer types, polyethylene terephthalate (PET) and polyethersulfone (PES) are the dominant polymers found in *T. telescopium*, while polypropylene is the most common polymer associated with *M. longipes*. This study benefits estuary conservation and management by identifying critical seasons for targeted clean-up and highlighting the potential of *M. longipes* as a highly sensitive indicator.

This study reveals pronounced seasonal variation in microplastic contamination of benthic fauna in the Karangsong Estuary, West Java. Overall microplastic abundance was significantly higher in the wet season than in the dry season ($\chi^2 = 9.108$, $p = 0.002$), with *M. longipes* consistently accumulating higher microplastic loads than *T. telescopium*. Fragments dominated during the wet season, reaching 0.37 particles g⁻¹ wet mass in *T. telescopium* and 107.18 particles g⁻¹ wet mass in *M. longipes*, whereas fibers predominated in the dry season, particularly in *M. longipes* (18.78 particles g⁻¹ wet mass).

Index-based analyses supported these patterns, with the Comprehensive Microplastics Pollution Index (CMPI) indicating extreme dominance of fragments in *M. longipes* during the wet season (CMPI = 0.984) and maximum dominance of fibers in *T. telescopium* during the dry season (CMPI = 0.638). Although Pollution Load Index (PLI) values remained within the low contamination category, the seasonal dominance of specific microplastic types highlights localized ecological concerns.

In conclusion, polymer identification showed that polyethylene terephthalate (PET) and polyethersulfone (PES) were dominant in *T. telescopium*, while polypropylene (PP) was most prevalent in *M. longipes*, reflecting differences in exposure pathways and feeding behavior. Overall, the results demonstrate that seasonal dynamics and species traits strongly regulate microplastic accumulation in estuarine benthic communities and support the use of *M. longipes* as a sensitive bioindicator. Future studies should expand spatial and temporal coverage on multi-year scales and apply complementary analytical techniques (e.g., GC-MS or FTIR imaging) to improve polymer resolution and ecological risk assessment.

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