Linking microplastic pollution to coastal ecosystem connectivity and blue economy sustainability: evidence from green mussels (*Perna viridis*) in Tambak Lorok, Semarang, Indonesia

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Abstract. Microplastic pollution has become a major environmental concern in coastal ecosystems, particularly in areas with high anthropogenic pressure, such as Tambak Lorok, Semarang, Indonesia. This study aimed to investigate temporal variation in microplastic abundance in coastal waters and green mussels (*Perna viridis*) and to identify their morphological and polymer characteristics. Sampling was conducted at three stations over a five-month period (May–September 2025). Microplastics were identified and classified into fibers, fragments, films, and pellets, while polymer types were analyzed using ATR-FTIR spectroscopy. The results showed that microplastics were consistently detected throughout the study period, with the highest abundance in water recorded in July (97 particles/L), indicating temporal variability influenced by environmental conditions and human activities. Fibers were the dominant microplastic type, followed by fragments, films, and pellets. ATR-FTIR analysis identified polypropylene (PP), polyethylene terephthalate (PET), polymethyl methacrylate (PMMA), and poly(diallyl phthalate), suggesting inputs from domestic, fisheries, port, and industrial activities. The occurrence of microplastics in green mussels and their temporal variation demonstrate connectivity between environmental and biological compartments. These findings highlight potential risks to seafood safety and emphasize the need for effective coastal management to support ecosystem resilience and a sustainable blue economy.

Keywords: microplastics, *Perna viridis*, temporal variation, connectivity, blue economy, pollution.

1. Introduction

Plastic waste has become a major challenge for the environment and human health worldwide [1]. In 2022, it is estimated that around 398,000 tons of plastic waste entered the ocean, consisting of 309,625 tons from land and 88,374 tons from marine activities [2]. Plastics are persistent and degrade very slowly, with degradation times ranging from 20 to 100 years through photo-oxidative, chemical, and biological processes, until they are finally fragmented <5 mm microplastics [5]. These small particles are then widely dispersed in the aquatic environment through various human activities, such as fishing, shipping, tourism, industry, and river flows.

Microplastics are a major concern due to their slow decomposition, widespread dispersal, and potential to enter the seafood chain [5]. In addition, microplastics are able to absorb toxic pollutants on their surfaces and become vectors for these contaminants into the organism's body through the ingestion process. When ingested, additives and chemicals attached to microplastics can be released, causing toxic effects on marine organisms. Coastal areas are ecosystems highly susceptible to microplastic pollution, especially under high anthropogenic pressure.

Tambak Lorok, Semarang, is one of the coastal areas characterized by population density, fishery activities, and intensive domestic waste disposal. As the largest fishing village in Semarang City, which serves as a center of settlement and fisheries activities, this area is a potential source of microplastics entering the aquatic environment, both through river flows and direct activities in coastal areas. This condition makes Tambak Lorok a representative site for examining the relationship between human activities, microplastic pollution, and their accumulation in marine organisms. The distribution of microplastics in the aquatic environment is dynamic, influenced by environmental factors and human activities. Temporal variations, such as monthly changes, can reflect fluctuations in pollutant sources and hydrodynamic conditions of the waters [6]. Therefore, studying temporal variations in microplastics

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is important for understanding the distribution patterns and dynamics of pollution in coastal ecosystems.

Green mussels (*Perna viridis*) are among the organisms widely used as bioindicators of microplastic pollution. As filter-feeding organisms, green mussels have the ability to filter suspended particles in the water column, including microplastics, so that they can represent the conditions of the surrounding environment. In addition, the presence of microplastics in mussels' bodies reflects the transfer of particles from the environment into biological systems, indicating the interconnectedness between ecosystem components. On the other hand, green mussels are an important fishery commodity with high economic value to coastal communities. Microplastic contamination in these organisms has the potential to pose a risk to food security and the sustainability of aquatic resource use. This is relevant in the context of the blue economy, which emphasizes the sustainable use of marine resources without compromising ecosystem health.

Based on this background, this study aims to analyze temporal variation in microplastic abundance in water and green mussels (*Perna viridis*) in the Tambak Lorok area, and to identify the characteristics of microplastics based on their shape. In addition, this study also aims to examine the relationship between microplastic pollution, coastal ecosystem dynamics, and its implications for the sustainability of the blue economy.

2. Materials and Methods

This research was conducted from May–September 2025 in the waters of Tambak Lorok (Figure 1), Semarang, Central Java. The sampling location was determined using the purposive sampling method, a technique based on specific considerations related to the research purpose. Three observation stations were selected based on the level of anthropogenic activity, namely: Station I (near settlements and coastal activities), Station II (relatively far from the source of anthropogenic pressure), and Station III (near the mouth of the East Canal Flood River).

Green mussels (*Perna viridis*) samples were taken every month, as many as 50 individuals per station by random sampling using the handpicking method [7], bringing the total sample for 5 months to 750 individuals. All samples were measured morphometrically (length and shell height) using calipers (0.01 mm accuracy) and weighed to obtain total weight. Microplastic samples in the waters were collected using plankton nets (mouth diameter 50 cm; pore size 110 μm) using the horizontal tow method for 10 seconds at a speed of ±4 knots. The withdrawal distance was approximately ±20.5 m, and the filtered water volume was estimated based on the net opening area and the withdrawal distance. The filtered samples were collected, homogenized, and then taken as much as 1 L as a sub-sample for microplastic analysis with three repetitions (250 mL each).

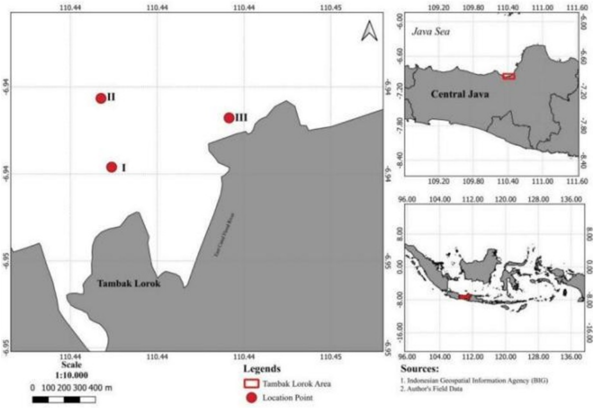

Fig. 1. Sampling Location of Green Mussels (*P. viridis*) in the Waters of Tambak Lorok, Semarang, Central Java

Green mussels are dissected into three parts of tissue, namely the coat and gills, the digestive tract, and the muscles and legs. The microplastic extraction process is carried out using a chemical destruction method with a 30% H_2SO_4 and H_2O_2 solution (1:3 ratio) to remove organic matter without damaging the microplastic particles, as described by Wijayanti [8]. The sample was incubated at room temperature for 24 hours, then heated in a steam bath for 2 hours. Next, the sample was filtered using a 15–20 μm porous filter paper with the help of a vacuum pump. Microplastic identification was carried out visually using a binocular microscope (magnification 48×) based on shape and color.

3. Result and Discussion

3.1 Temporal Variation of Microplastics in the Waters of Tambak Lorok

The abundance of microplastics in the waters of Tambak Lorok during the May–September period showed temporal variation across observation stations (Fig. 2). In May, the abundance of microplastics was relatively low, at 12-13 particles/L. This value increased in June and peaked in July with the highest abundance of 97 particles/L at station I. Subsequently, the abundance of microplastics declined in August before increasing again in September to reach 57 and 56 particles/L at stations II and III.

The observed variations in microplastic exposure are thought to be related to rainfall conditions in coastal areas of Central Java. Based on data from the Meteorology, Climatology and Geophysics Agency (BMKG)[9], the highest rainfall occurs in May (365.0 mm) and August (200.1 mm), while the lowest rainfall occurs in July (9.8 mm), reflecting the dry season.

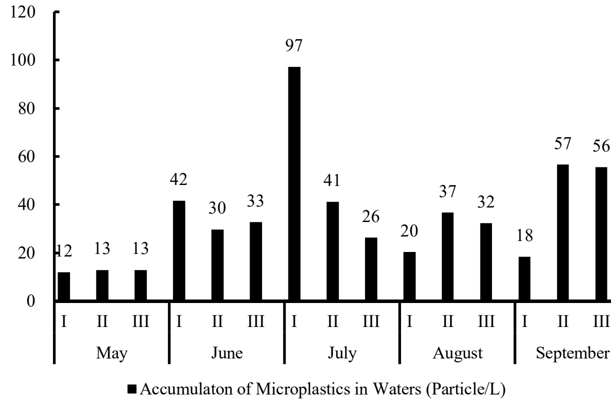

Fig. 2. Average microplastics (particles/L) in the waters of Tambak Lorok from three observation stations during the May–September period.

The decrease in rainfall in June, July, and September is thought to have contributed to the detection of microplastics by reducing dilution, so that particles from various sources become more visible in the water column. In addition, more stable water conditions allow microplastics to persist longer, increasing the likelihood of accumulation.

On the other hand, high rainfall in May and August increases particle dilution and transport, thereby decreasing the concentration of microplastics in water.

3.2 Morphological Characteristics of Microplastics (Shape)

The identification results showed that the microplastics found in the waters of Tambak Lorok consisted of four main types, namely fragments, fibers, pellets, and films (Fig. 3). Microplastics in the waters of Tambak Lorok were found in various forms, such as fragments, fibers, films, and pellets, which are generally derived from polymers such as polypropylene, polyethylene, and polyethylene terephthalate (PET) that are widely used in domestic and industrial activities [10]. Among these forms, fiber is often the dominant type (Fig. 4), thought to come from household waste, specifically textile fibers such as rayon, cotton, PET, and azlon, released during the washing process[10].

Microplastics not only pollute waters, but also accumulate in marine organisms such as shellfish and fish, potentially entering the food chain. The particles found are generally fragments, fibers, films, and pellets of varying sizes, where fiber is often reported as the most dominant form in various studies. As in previous studies, the dominance of fiber-shaped microplastics in this study indicates the significant contribution of domestic activities to microplastic pollution in coastal waters [11].

The presence of these microplastics is closely linked to anthropogenic activities, such as unmanaged disposal of plastic waste, fishing and shipping, and runoff from land that carries plastic waste into the marine environment. These findings are in line with previous studies showing that the main sources of microplastics in coastal areas are driven by land-based human, and urban areas [11].

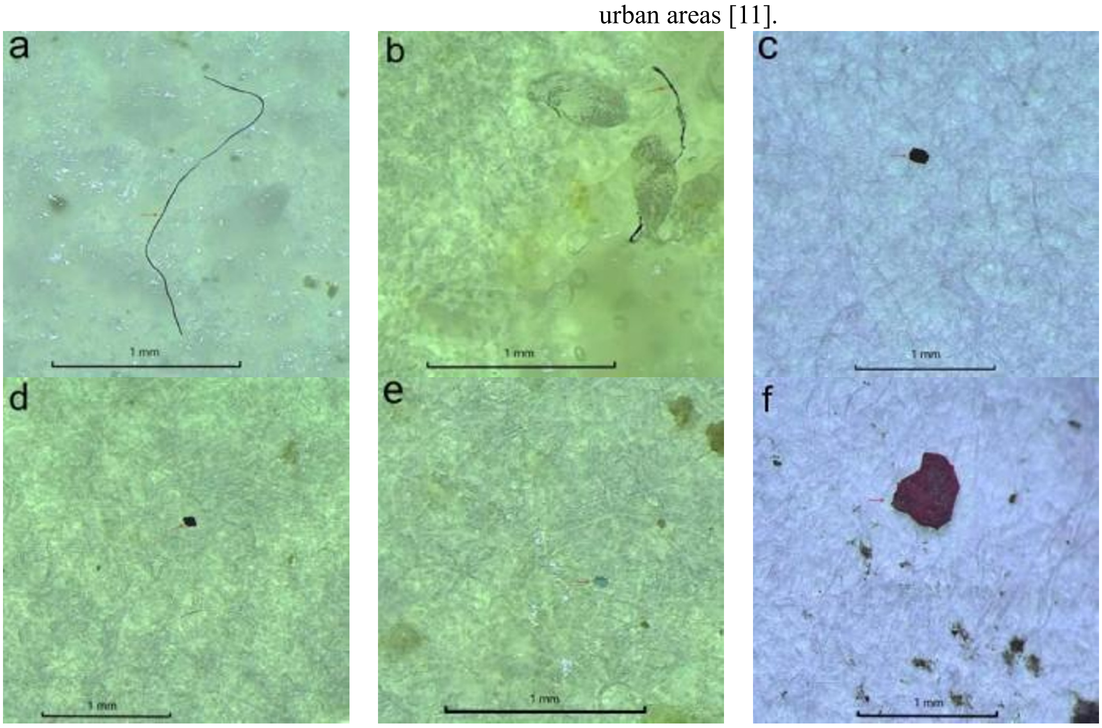

Fig. 3. Shapes of microplastics observed in Tambak Lorok Waters: (a-b) Fibers, (c-d) Pellets, (e) film, (f) fragment

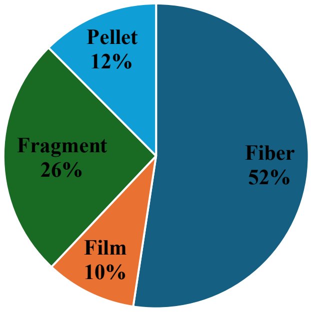

Fig. 4. Composition of microplastic shapes in coastal waters of Tambak Lorok.

3.3 Identification of Polymer Types Using ATR-FTIR Analysis

ATR-FTIR analysis revealed that the microplastics identified in this study consisted of polypropylene (PP), polyethylene terephthalate (PET), polymethyl methacrylate (PMMA), and poly(diallyl phthalate). PP was characterized by the presence of aliphatic C–H stretching bands at 2950–2837 cm⁻¹, whereas PET and PMMA were identified by the characteristic ester carbonyl (C=O) absorption bands at 1713 cm⁻¹ and 1711 cm⁻¹, respectively. Meanwhile, poly(diallyl phthalate) was identified based on the combination of ester carbonyl bands at 1716 cm⁻¹ and aromatic ring vibrations at 1634–1581 cm⁻¹ (Fig. 5).
The occurrence of PP and PET suggests contributions from plastic packaging waste and single-use plastic products commonly utilized in coastal areas. This finding is consistent with previous studies reporting PP and PET as dominant polymers in aquatic environments due to their widespread use and persistence. Furthermore, the presence of PMMA and poly(diallyl phthalate) indicates inputs from acrylic-based materials, resins, and degraded industrial products in the aquatic environment [12]. This interpretation is consistent with the characteristics of Tambak Lorok, which experiences high anthropogenic pressure due to dense settlements, fishery processing activities, and the presence of industrial and port facilities that potentially contribute to microplastic pollution.

3.4 Temporal Variation of Microplastics in Green Mussels

The results showed that the average accumulation of microplastics in green mussels (*Perna viridis*) varied between stations during the observation period (Fig. 6). In May, the highest values were found at station II (104 particles/individual), followed by station I (103 particles/individual) and station III (93 particles/individual). In the following months, the accumulation of microplastics tended to decrease, but differences between stations remained evident, with a tendency toward higher values at station II. These findings suggest that the distribution of microplastics is not always directly proportional to proximity to polluting sources. Theoretically, stations I, adjacent to settlements and fishing activities, and III, near river mouths, are expected to have higher pollution levels. However, the results show a dominance of accumulation at station II, suggesting the influence of other factors, especially hydrodynamic dynamics.

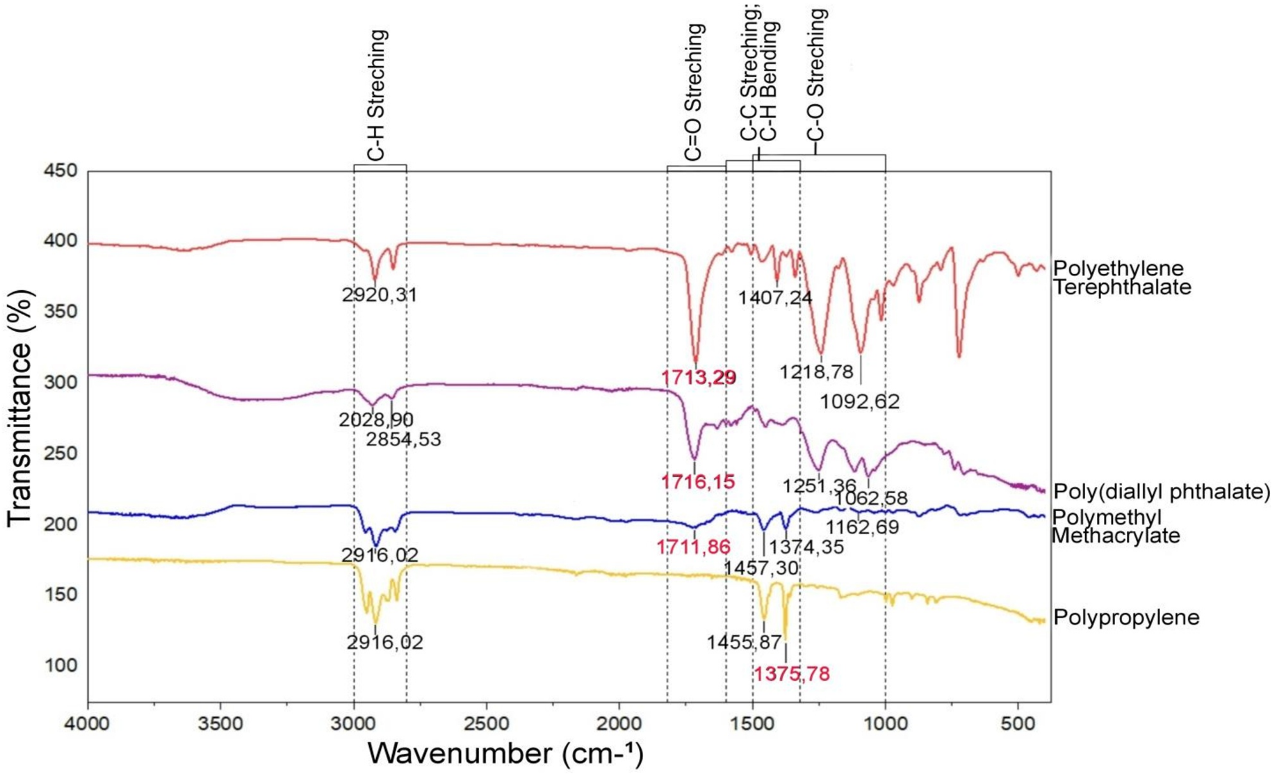

Fig. 1. Peak graph of FTIR results of Microplastics.

Microplastics, which are lightweight and easily carried by currents facilitate the transport and redistribution of particles, allowing them to accumulate at certain locations. Station II is suspected to act as an accumulation area due to currents carrying microplastics from the surrounding area, including river mouths and coastal activities in Tambak Lorok. This is in line with research by Tielman [11], which shows that there are stations that function as microplastic accumulation zones due to the contribution of currents from various sources. In addition, microplastics originating from river flows do not always accumulate directly in the estuary area, but can be carried further along current and wave patterns before finally settling in a specific location [11]. This phenomenon explains why station III does not always show the highest accumulation value, even though it is close to the river input source.

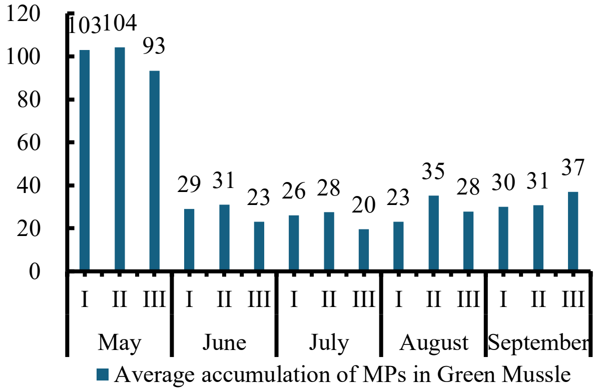

Fig. 5. Average accumulation of microplastics in Green Mussels (particles/Individual) from three stations during the period May–September.

Globally, the distribution of microplastics in estuarine and coastal regions is influenced by complex interactions among land-based inputs, tidal dynamics, currents, and waves. Interactions between currents and waves can also form accumulation zones in areas with low hydrodynamic energy or specific morphologies, such as shallow waters that allow for particle retention.

A biological perspective, the accumulation of microplastics in green mussels is not only determined by the availability of particles in the environment, but also by the physiological processes of the organism. As a filter feeder, green mussels filter particles from the water column, but the selection, retention, and excretion processes do not cause all particles to accumulate permanently. This results in variations in accumulation between individuals and between locations. These findings are supported by research by Tielman [11] in Tambak Lorok, which shows the presence of microplastics in the bodies of organisms, but without a significant correlation with concentrations in the waters.

The high accumulation of microplastics at station II can be explained by interactions between hydrodynamic factors that facilitate particle the accumulation and biological factors that affect retention processes in organisms. This condition confirm that the distribution of microplastics in coastal ecosystem is complex and does not always follow a linear pattern of pollutan sources; instead, it is instead influences by interactions among sources, aquatic dynamics, and biological responses of organisms[13].

3.5 Microplastic Accumulation in Green Mussel Tissues

The accumulation of microplastics in green mussels (*P. viridis*) varied by length size class and tissue type (Fig. 7). Microplastics were found in all tissues, namely the coat and gills (M+I), the gastrointestinal tract (P), and the muscles and legs (O+K). The highest accumulated values were recorded in July in the 38–44 mm size class in coat and gills tissue, with values of up to 57 particles/individual, indicating that small to medium-sized individuals tend to have higher microplastic accumulation than large individuals. The high accumulation of small microplastics is thought to be related to the organism's filtration activity. Green mussels are filter-feeding organisms that filter suspended particles in water, so that microplastics can enter with food particles.

Green mussels are filter-feeding organisms that filter suspended particles in water, so that microplastics can enter along with food particles. This result is in accordance with the research of Rahim and Yaqin [14], who stated that the high filtration process makes mussels filter more small particles in the environment, including microplastics, which can then accumulate, especially in organs such as gills, hepatopancreas, and gonads.

The distribution of microplastics in tissues also suggests that the gastrointestinal tract is the main site of for microplastic accumulation, as it directly ingests particles from the environment. In addition, the presence of microplastics in mantle and gill tissues suggests that microplastic particles can be trapped during the water filtration process before entering the digestive system [14]. The month-to-month variation in microplastic accumulation is also thought to be related to aquatic environmental conditions. The increase in accumulation in July is in line with the high abundance of microplastics in the waters in the same period, indicating a relationship between the concentration of microplastics in the environment and the rate of accumulation in filter-feeding organisms [5].

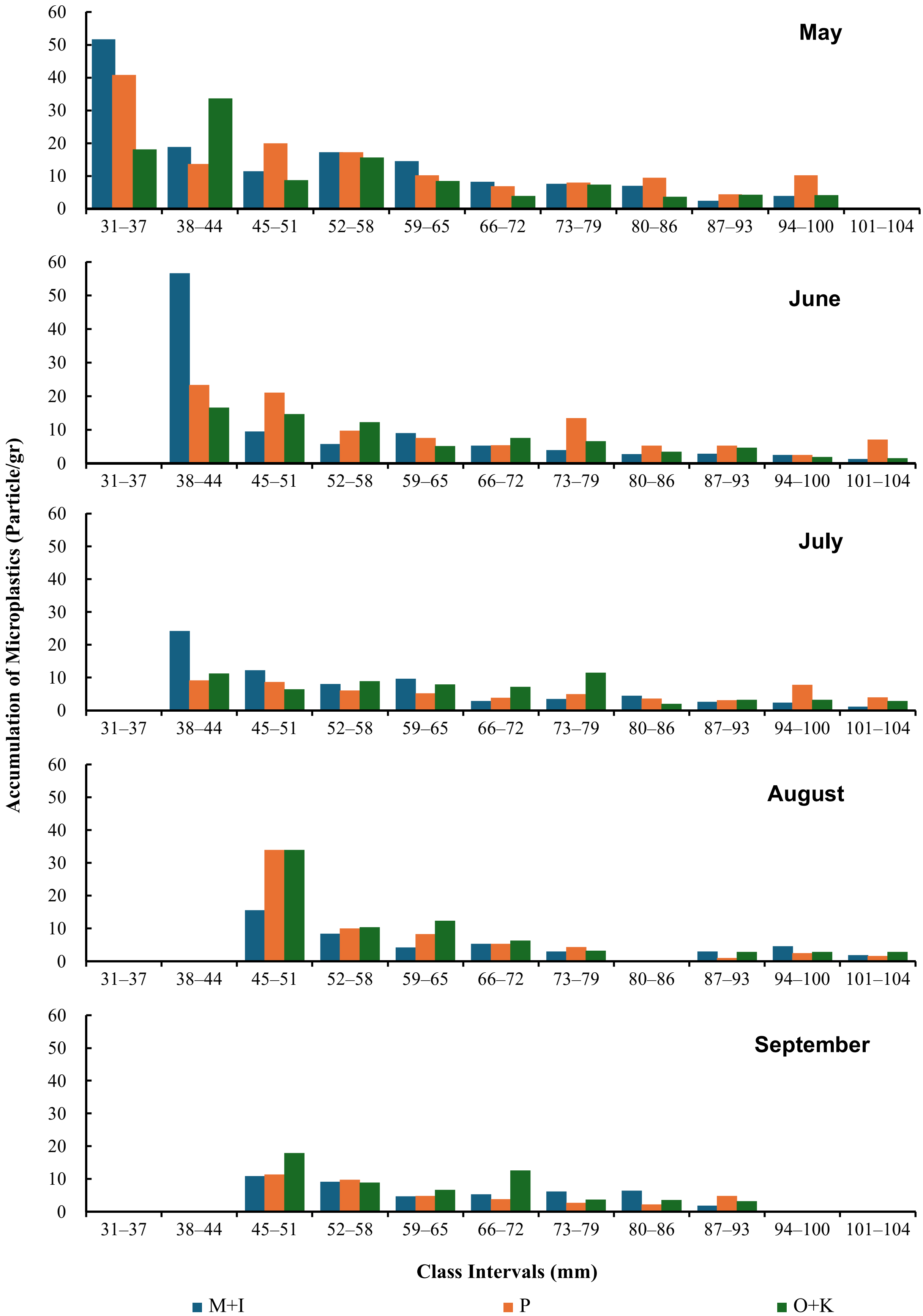

Fig. 6. Microplastic Accumulation in Mantles and Gills (M+I), Digestion (P), Muscles and Leg (O+K) by Length Size Class.

4. Linking Environmental and Biological Compartments (Connectivity)

The results of the correlation analysis showed a relationship between microplastic the abundance in the water and accumulation in green mussels at all observation stations (Table 1). The Pearson correlation coefficient showed a moderate negative association (r = -0.489), indicating that an increase in the microplastic abundance in the water was not always accompanied by an increase in accumulation in organisms. However, the significance test showed that the association was not statistically significant (p = 0.064; p > 0.05).

Table 1. Correlation across Average microplastics (particles/L) in the waters vs Average microplastics (particles/Individual) in Green Mussels

Variabel	r	p-value	n
Average microplastics (particles/L) in the waters vs Average microplastics (particles/Individual) in Green Mussels	-0.489	0.064	15

These findings suggest that the relationship between environmental and biological compartments in coastal ecosystems is complex and non-linear. In general, the presence of microplastics in waters remain the main source of exposure for filter-feeding organisms such as green mussels [15]. However, the rate of accumulation in the organism's body is not only influenced by the concentration of microplastics in the environment, but also by various biological and ecological factors. As a filter-feeding organism, *Perna viridis* actively filters suspended particles from the water column, including microplastics. However, not all filtered particles will accumulate permanently in the body. The processes of particle selection, retention, and excretion can cause variations in the amount of microplastics retained in the organism's tissues. In addition, environmental dynamics such as currents, waves, and hydrodynamic processes also affect the distribution of microplastics in waters, causing a mismatch between concentrations in the environment and the rate of accumulation in organisms.

Thus, although there is no statistically significant relationship, this study still indicates a connection between microplastics in water and their accumulation in green mussels. This linkage reflects the process of transferring microplastics from the environmental compartment to the biological compartment via the organism's biological mechanisms. In a broader context, these findings are relevant to the concepts of connectivity and resilience in aquatic ecosystems, where the interactions between physical and biological compartments determine the ecosystem's response to pollution stress. The accumulation of microplastics in consuming organisms such as green mussels indicates the entry pathway of pollutants into the food chain, which has the potential to affect ecosystem health and the quality of fishery resources.

Therefore, the results of this study have important implications for the sustainability of the blue economy, especially for maintaining food security and sustainable coastal resource utilization. Efforts to manage microplastic pollution need to focus not only on reducing pollutant sources but also on understanding the dynamics of distribution and their relationship with organisms, in order to support more adaptive and sustainable ecosystem management.

5. Conclusion

This study showed that microplastic abundance in the water and green mussels (*Perna viridis*) accumulation in the Tambak Lorok area varied over time during the observation period. In general, the distribution of microplastics in the water was not always directly proportional to accumulation in the organism, suggests a potential relationship, although not statistically significant. This indicates that the accumulation of microplastics in the shellfish is not only influenced by the availability of particles in the environment, but also by hydrodynamic factors of the waters, as well as the biological processes of the organism. Further studies with larger datasets are required.

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