



DOI: <https://doi.org/10.38035/rrj.v8i3>
<https://creativecommons.org/licenses/by/4.0/>

Identification of Microplastics in the Hepatopancreas of Green Mussels (*Perna viridis*) in Gunung Jati Waters, Cirebon, West Java

Nelly Oktaviani Masode¹, M. Rudyansyah Ismail², M. Wahyudin Lewaru³, M. Untung Kurnia Agung⁴

¹ Padjadjaran University, Jatinangor, Indonesia, nelly22001@mail.unpad.ac.id

² Padjadjaran University, Jatinangor, Indonesia, m.rudyansyah@unpad.ac.id

³ Padjadjaran University, Jatinangor, Indonesia, m.w.lewaru@unpad.ac.id

⁴ Padjadjaran University, Jatinangor, Indonesia, mochamad.untung@unpad.ac.id

Corresponding Author: nelly22001@mail.unpad.ac.id¹

Abstract: Microplastics are pollutants commonly found in aquatic environments and have the potential to accumulate in marine organisms, particularly filter-feeding organisms such as the green mussel (*Perna viridis*). This study aims to analyze the abundance, characteristics, and types of microplastic polymers using a microscope and FTIR (Fourier transform infrared) spectroscopy at two stations in the waters of Gunung Jati, Cirebon, and their accumulation in the hepatopancreas of green mussels. The results showed that the abundance of microplastics in the waters of Station 1 was 0.425 particles/L, higher than that of Station 2 at 0.325 particles/L. In the hepatopancreas of green mussels, the abundance of microplastics was higher in small mussels compared to large ones. At Station 1, the microplastic abundance in small mussels reached 5.80 ± 0.72 particles/g, while in large mussels it was 1.22 ± 0.88 particles/g. A similar pattern was also found at Station 2 with values of 4.78 ± 2.15 and 0.58 ± 0.41 particles/g, respectively. Microplastics in the water and the hepatopancreas of green mussels were dominated by fiber types with a percentage of 95–100%, and the color variation was dominated by black. The identified microplastic polymers include polyester, polyvinyl acetate, nylon, spandex, and polyethylene, as well as natural polymers such as cellulose. This research demonstrates that green mussels have the potential to serve as bioindicators of pollution in aquatic environments and provides a foundation for further research on ecological impacts and marine environmental health. Therefore, there is a need to improve plastic waste management in the Gunung Jati coastal area, as well as to educate the public on how to reduce the use of plastic waste and improve its management.

Keyword: Microplastics, *Perna viridis*, Hepatopancreas, FTIR

INTRODUCTION

Currently, marine pollution caused by plastic waste is a major challenge faced by many countries, including Indonesia. Plastic is highly stable and difficult to degrade, so it can persist for a long time in aquatic environments (Ningrum et al., 2022). In the ocean, plastic

undergoes physical and chemical degradation due to exposure to sunlight, abrasion, and oxidation, resulting in microplastic particles measuring <5 mm (Thompson et al., 2009; Mutlu et al., 2025). Microplastics originate from the fragmentation of large plastic items, synthetic fibers from textile activities, and microbeads from personal care products (Ogunola & Palanisami, 2016; Mutlu et al., 2025). Microplastics commonly found in aquatic environments are categorized into fragments, pellets, films, foams, and fibers. The primary materials used in plastic production include polyethylene (PE), polyvinyl chloride (PVC), polystyrene (PS), polyethylene terephthalate (PET), and polypropylene (PP) (Ragu Prasath et al., 2025). Their extremely small size makes microplastics difficult to identify and remove from aquatic environments.

Marine dynamics such as currents, waves, and wind can cause microplastics to spread widely and be ingested by various aquatic organisms, ranging from zooplankton to commercial fish (Botterell et al., 2019; Tian et al., 2024). The accumulation of microplastics in marine biota has the potential to disrupt the food chain and can enter the human body through the consumption of seafood (Rahman et al., 2021; Li et al., 2023). The green mussel (*Perna viridis*) is a filter-feeding organism that is prone to accumulating microplastics from the aquatic environment (Rahim & Yaqin, 2022). Microplastics filtered through the gills can enter the digestive system and accumulate in the hepatopancreas, an organ involved in digestion, nutrient absorption, and detoxification (Kolandhasamy et al., 2018; Rahim & Yaqin, 2022). Previous research has shown that the hepatopancreas experiences the highest level of damage due to microplastic exposure compared to other organs (Rahim & Yaqin, 2022).

The waters of Gunung Jati, Cirebon Regency, West Java, is a major site for green mussel aquaculture, and the harvest is widely consumed by the local community. However, domestic and fishing activities in the surrounding waters have the potential to increase plastic waste pollution. Research on microplastic contamination in green mussels in the waters of Gunung Jati remains limited. Therefore, this research was conducted to analyze the potential for microplastic contamination in the hepatopancreas of green mussels.

METHOD

Date and Location



Figure 1. Sampling site location in Gunung Jati Water, Cirebon

The research was conducted from November 2025 to January 2026. Samples were collected from the waters off Gunung Jati, Cirebon, West Java (Figure 1). Microplastic identification was performed at the Biogeochemistry Laboratory of the Faculty of Fisheries and Marine Sciences, the Finder Laboratory, and the Central Laboratory of Padjadjaran University.

Tools and Materials

The equipment used for sampling included a GPSmap 60CSx to determine sampling coordinates, a cool box for sample storage and temperature maintenance, a plankton net for seawater filtration, glass bottles for sample collection, and water quality measurement instruments including a pH meter, dissolved oxygen (DO) meter, thermometer, and refractometer. A camera was also used to document field activities.

For laboratory analysis, samples were stored in a freezer to prevent degradation. An analytical balance was used for weighing samples, while a ruler was used for measuring shell length of green mussels. A magnetic hot plate stirrer and incubator were used for digestion processes, and an alcohol thermometer was used to monitor solution temperature. A spatula and tweezers were used for handling samples and microplastic particles, and surgical scissors were used to open mussel shells. Filtration was carried out using a Buchner funnel and Whatman No. 42 filter paper. Petri dishes and glass beakers were used for sample storage and solution preparation, while measuring cylinders were used for volume measurement. Microplastics were identified using a stereo microscope (ZEISS Stemi 508), and polymer types were analyzed using a Fourier Transform Infrared (FTIR) spectrometer.

The materials used in this research included green mussel and seawater samples, 10% KOH for digesting organic matter, saturated NaCl for separating microplastics based on density, distilled water for solution preparation and rinsing equipment, 70% alcohol for sterilizing work surfaces and equipment, labels for sample identification, aluminum foil for preventing contamination, and zip-lock bags for storing green mussel samples.

Methods

1. Sea Water

Seawater sampling was conducted following a modified protocol from Phaksopa et al. (2023), seawater was collected using glass containers from green mussel aquaculture sites, water quality was measured, and the seawater was then filtered using a plankton net and transferred into glass bottles. The seawater samples were treated with 10% KOH, then stirred on a hot plate stirrer and incubated at 40°C for 24 hours. For density separation, saturated NaCl was added, and the mixture was allowed to stand for 24 hours. The supernatant was filtered using Whatman No. 42 filter paper, and microplastic characteristics and polymers were identified.

2. Green Mussels

Sampling of green mussels was based on a modified protocol from the studies by Ramli et al. (2021) and Tantanarrit et al. (2013). Green mussels were collected from two different stations at a green mussel aquaculture site in the waters of Gunung Jati, Cirebon, with 90 individuals collected per station. The green mussel samples were grouped into two shell length categories: small (2.5–4.3 cm) and large (6.0–8.0 cm). Mussels were grouped to represent differences in life stages and physiological capacity. Shell length was used as a common indicator, where larger individuals assumed to have been exposed to contaminants for a longer period of time. All green mussel samples were placed in ziplock bags and stored in a coolbox for transport to the laboratory. Microplastic analysis followed a modified protocol of Phaksopa et al. (2023). Green mussel samples were first cleaned to remove contaminants adhering to the shells. Shell length measurements were taken, and samples were

grouped into two shell size categories (small and large). Within each category, the samples were pooled into three subgroups, with each composite sample consisting of 10 hepatopancreas organs.

The hepatopancreas organs were extracted using forceps and surgical scissors, weighed using an analytical balance and placed into glass bottles, after which a 10% KOH solution was added in a 1:5 (w/v) ratio. The mixture was stirred and heated on a hot plate for 15 minutes, followed by incubation at 40°C for 24 hours. A saturated NaCl solution was added to the sample and stirred for 5 minutes, then allowed to stand for 24 hours. The supernatant was then filtered using Whatman No. 42 filter paper. The characteristics of the microplastics were then analyzed using a stereo microscope, and the microplastic polymers were analyzed using FTIR.

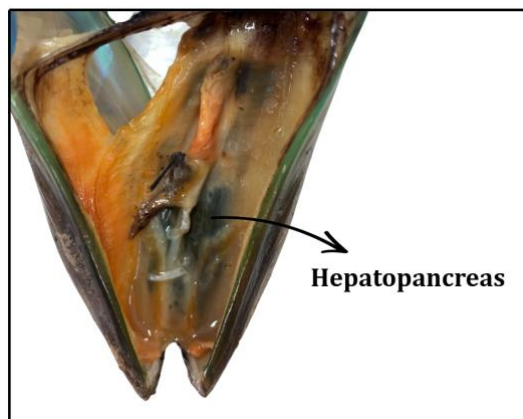


Figure 2. Hepatopancreas of the Green Mussel (*Perna viridis*)

3. Contamination Control

Lab coats and gloves must always be worn during microplastic analysis to prevent contamination. Before beginning the procedure, the workbench is cleaned with 70% alcohol; all glassware is rinsed with distilled water and covered with aluminum foil before use. Distilled water and saturated NaCl solution are filtered using filter paper with a pore size of 15 µm. Blank tests are performed by following the extraction and separation procedures described earlier, without adding a sample. Afterward, the filter is examined under a stereo microscope. If microplastic contamination is found in the blank test, the blank value is used as a correction factor by subtracting the number of those particles from the sample analysis results.

Data Analysis

1. Abundance of Microplastics

The abundance of microplastics in the hepatopancreas of green mussels (Phaksopa et al., 2023) and in seawater (Nugroho et al., 2018) was calculated using the following equation:

$$A_{\text{hepatopancreas}} = \frac{N_{\text{total (particles)}}}{W_{\text{organ (g)}}}$$
$$A_{\text{seawater}} = \frac{\text{amount of microplastics (particles)}}{\text{Volume of filtered water (L)}}$$

A represents the abundance of microplastics in the hepatopancreas of green mussels and in seawater; total N represents the number of microplastic particles in the sample; and organ weight represents the weight of the composite organ. Microplastic abundance in the hepatopancreas is expressed in particles/g, and in seawater it is expressed in particles/L.

2. Statistical Analysis

Microplastic abundance in the hepatopancreas of green mussels is presented as the mean ± standard deviation (SD). Meanwhile, microplastic abundance in seawater is presented descriptively. Polymer characteristics and types are presented as percentages. Statistical analysis was performed using the Shapiro-Wilk normality test and Levene’s homogeneity test, followed by a one-way ANOVA or a nonparametric Mann-Whitney test to analyze the relationship between size categories and microplastic abundance.

RESULTS AND DISCUSSION

Environmental Conditions and Seawater Quality Parameters

The Gunung Jati waters are located in Mertasangi Village, Gunungjati Subdistrict, Cirebon Regency, and are extensively utilized by local communities for activities such as aquaculture, fishing, boat mooring, and agriculture. The results of seawater quality parameter measurements are presented in Table 1. The water conditions are still considered suitable for supporting the growth of green mussels (*Perna viridis*). Water temperature falls within the optimal range for green mussel growth, namely 26–32°C (Soon & Ransangan, 2014). Green mussels can also adapt well to salinities of 20–30 ppt (Patty, 2013). Additionally, the water pH remains within the standard range for marine water quality for aquatic life, namely 7–8.5. However, the dissolved oxygen (DO) level measured at 4 mg/L is below the standard threshold of >5 mg/L.

Table 1. Seawater Quality Parameters in Gunung Jati Waters

Parameters	Unit	ST 1	ST 2
Temperature	°C	27.4	31.1
Salinity	ppt	24	26
pH	-	7.33	7.24
DO	mg/L	4.0	4.0

Microplastics in Seawater

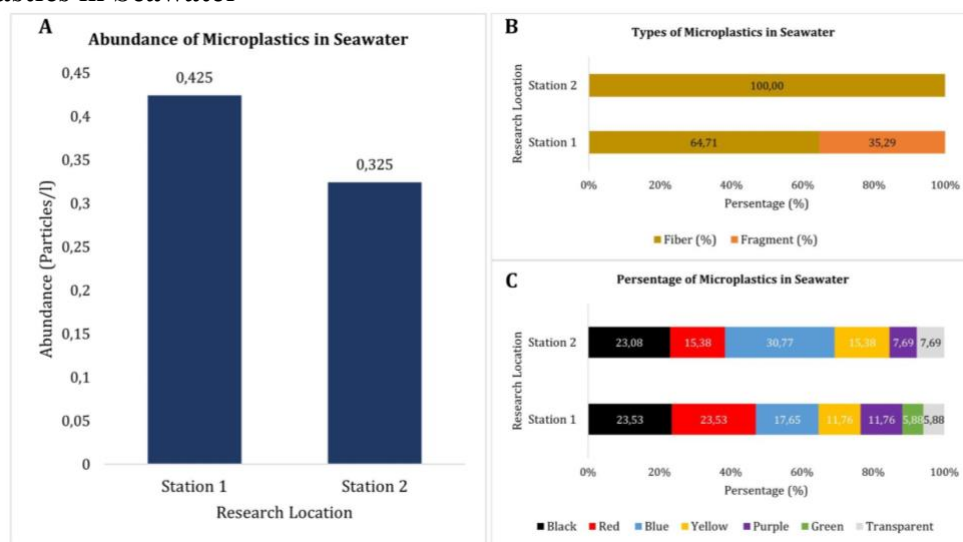


Figure 3. Variations in Seawater Microplastics Among Sampling Sites: a. Abundance; b. Types; c. Color Characteristics

The results of microplastic analysis at both sampling (Figure A) shows that Station 1 has a higher microplastic abundance of 0.425 particles/L compared to Station 2 at 0.325 particles/L. This difference may be due to Station 1 being located closer to the coastal area, which has a higher potential for microplastic contamination. The microplastics found at both stations were predominantly fiber-based. This suggests that the fiber particles may originate from various human activities. Fibers are typically generated during the washing of synthetic

clothing, where small fibers can detach and enter drainage systems, eventually accumulating in water bodies. According to Dris et al. (2016), a single clothing wash cycle can generate thousands of microplastic fibers that are discharged into the domestic wastewater system, these fibers can be carried by wastewater into rivers and eventually end up in the ocean (Tristanova et al., 2024).

Fiber microplastics may also originate from fishing activities. Fishing gear such as nets and fishing lines is commonly made of synthetic polymers that can degrade over time into microfibers (Pratita et al., 2022; Araújo et al., 2024). In addition, lost or abandoned fishing equipment, often referred to as “ghost fishing” represents a significant source of fiber pollution in aquatic environments (Araújo et al., 2024). Other studies also indicate that fiber-type microplastics are the most commonly found in water samples across various locations, including coastal areas and ports (Cordova et al., 2024). At Station 1, microplastics fragment accounted for 35.29%. Microplastics fragment typically originate from degraded macroplastics. This degradation process can occur due to exposure to ultraviolet (UV) light and interaction with microorganisms in the environment (Fatahi et al., 2021). Examples include plastic bags, beverage bottles, food containers, cooking utensils, and mobile phone accessories.

The color characteristics observed at both stations also varied. Black microplastics are often produced by the incomplete combustion of plastics. For example, black PE-PP fragments can form as a result of the burning of plastic waste, which is then transported into the ocean (Senduk et al., 2021; Liu et al., 2019). Red, blue, and other colored microplastics can originate from various types of plastic products such as textile clothing, food packaging, containers, and plastic household items (Ibrahim et al., 2023). Transparent microplastics are typically made from uncolored plastic products, such as water bottles, food packaging, or plastic wrap (Azzahra et al., 2024). The presence of microplastics in water bodies has the potential to disrupt the balance of marine ecosystems. Aquatic organisms may be exposed to microplastics, posing a risk of affecting the health of marine life as well as humans who utilize these marine resources.

Microplastics in the Hepatopancreas of Green Mussels

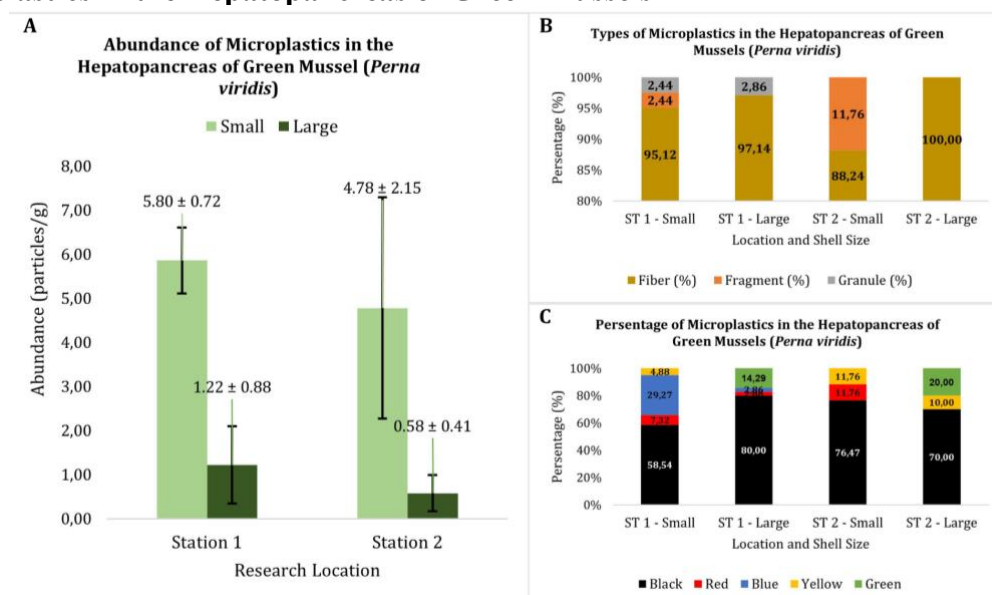


Figure 4. Comparison of Microplastics in the Hepatopancreas of the Green Mussels (*Perna viridis*) by Location and Size: a. Abundance; b. Types; c. Color Characteristics

Microplastics found in the hepatopancreas of green mussels (*Perna viridis*) showed a higher abundance in smaller individuals compared to large ones (Figure A). At Station 1, small mussels showed a microplastic abundance of 5.80 ± 0.72 particles/g, whereas large

mussels contained 1.22 ± 0.88 particles/g. A similar pattern was observed at Station 2, with values of 4.78 ± 2.15 particles/g in small mussels and 0.58 ± 0.41 particles/g in large mussels. These differences were statistically significant, as the results of the Shapiro-Wilk normality test indicated that the data for both size groups were normally distributed with a significance level of $p > 0.05$ (Small: $p = 0.472$; Large: $p = 0.138$), although the Levene's test for homogeneity of variances indicated non-homogeneous variances ($p = 0.042$; $p < 0.05$). However, the results of the One-Way ANOVA analysis still showed a highly significant difference in microplastic abundance between small and large mussels ($p < 0.001$), with an F-value of 40.26. To validate these results, the Mann-Whitney test also revealed a significant difference between the two groups ($p = 0.0039$; $p < 0.05$) indicating that body size has a significant effect on microplastic accumulation in the hepatopancreas.

The microplastics found in the hepatopancreas of green mussels were predominantly fiber-type particles (Graph B). At stations 1 and 2, the percentage of fiber-type particles ranged from 95% to 100%. In addition to fiber-type particles, fragments and granules were also found, though in smaller quantities. The dominance of fiber-type microplastics in all mussel samples aligns with conditions in the water, which are also dominated by the same type (Figure 3). According to Rizaldi et al. (2025) and Stelzer et al. (2025), fibers are often found in large quantities in the water, making them likely to enter the mussels' filtration system. Various studies on Bivalvia such as *Mytilus* and *Crassostrea* have also found microplastics within soft tissues, with fiber being the most dominant composition compared to other microplastic forms (Oanh et al., 2021; Wang et al., 2021; Parvaresh et al., 2024). Furthermore, black is the most dominant color, accounting for 58% to 80%. In addition to black, other color variations such as blue, red, yellow, and green were found (Graph C).

Green mussels are filter-feeding organisms with a high potential for exposure to microplastics. Small mussels have a relatively large body surface area compared to their body volume, resulting in more intensive interaction with the water and potentially increasing microplastic accumulation. This aligns with the research by Ruairuen et al. (2022), in which small mussels exhibited higher microplastic accumulation, which is believed to be influenced by their relatively greater filtering capacity. Research by Mohd Amin & Azman (2022) also indicates that high microplastic accumulation in small mussels is associated with a high proportion of microplastics in the water they consume. The hepatopancreas in green mussels plays a role in digestion and metabolism. Several studies indicate that mussels exposed to microplastics may experience tissue damage (Maharajan et al., 2011; Kaddissi et al., 2014), characterized by cellular vacuolization, hyperplasia, tubular regression, and necrosis (Rahim & Yaqin, 2022).

Polymer Identification (FTIR)

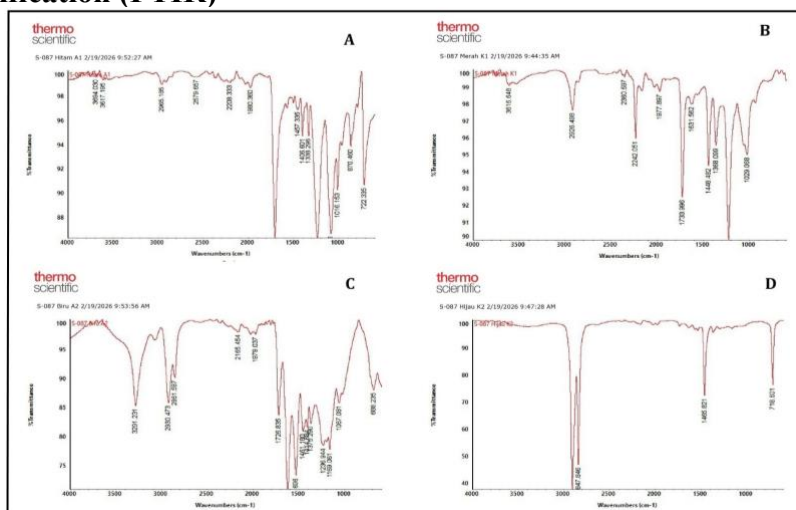


Figure 5. FTIR Spectra of Microplastics by Fiber Type: a. Polyester (Seawater, Station 1); b. Polyvinyl acetate (Hepatopancreas of Green Mussels, Station 1); c. Nylon & Spandex (Seawater, Station 2); d. Polyethylene (Hepatopancreas of Green Mussels, Station 2)

Based on the FTIR analysis results (Figure 5), Spectrum A shows absorption bands characteristic of polyester. This is indicated by the presence of an absorption band at a wavenumber of approximately 1711 cm^{-1} corresponding to the carbonyl group (C=O) stretching. This finding is consistent with the results of a study by Mishra et al. (2024), who reported that the peak at 1711 cm^{-1} indicates the presence of carbonyl groups in polyester that has undergone biodegradation due to changes in the polymer structure. Additionally, peaks were observed at 1240 cm^{-1} and 1090 cm^{-1} . These peaks indicate the presence of ester bonds (C-O), which are a characteristic structural feature of all types of polyester (Mishra et al., 2024). Polyester is lightweight, has high tensile strength, and offers optical transparency, making it highly popular in the textile and packaging industries (Dhaka et al., 2022). Furthermore, Waddell et al. (2020) note that synthetic fibers like polyester may contain chemicals such as dyes, plasticizers, and contaminants absorbed from the environment. These contaminants have the potential to transfer to organisms that consume them. Polyester has also been found in the digestive tracts of various marine organisms such as dolphins (Courville et al., 2024), penguins (Bessa et al., 2019), and blue crabs (Waddell et al., 2020).

Spectrum B shows a match with polyvinyl acetate (PVAc), as indicated by the presence of an absorption band at a wavenumber of 1734 cm^{-1} . According to Brock et al. (2017); Wei et al. (2012) and Miranda et al. (2008), the carbonyl (C=O) band appearing in the $1720\text{--}1740\text{ cm}^{-1}$ range is the most intense band in the PVAc spectrum. Additionally, the peak at 1230 cm^{-1} is associated with the (C-O-C) bond stretching of the acetate group (Brock et al., 2017; Miranda et al., 2008; Shamala et al., 2009). PVAc is widely used across various industrial sectors. For example, in wood adhesives, paper, packaging, and carpet coatings (Miranda et al., 2008; Jebrane et al., 2015).

Spectrum C shows an absorption band at a wavenumber of 3291 cm^{-1} indicating the presence of Amide A (N-H) stretching, which is characteristic of polyamide polymers such as nylon (Bake et al., 2021). Additionally, the peak at 1537 cm^{-1} is characteristic of the Amide II band, associated with the combination of N-H bending and C-N stretching vibrations. The absorption band in the region around 688 cm^{-1} also indicates the characteristic amide vibrations of the polyamide structure. This absorption pattern indicates that the primary component of the sample is nylon (Bake et al., 2021). However, in the C results, there is a strong absorption peak at 1726 cm^{-1} indicating carbonyl (C=O) stretching from urethane, which is characteristic of polyurethane polymers—the base material for spandex. This is supported by the presence of an absorption band in the $1236\text{--}1067\text{ cm}^{-1}$ region, which is commonly observed in polyurethane structures (Zhou et al., 2019). The FTIR results indicate that the sample is a polymer blend dominated by nylon with an additional spandex component.

Spectrum D shows main absorption bands at wavenumbers around 2914 and 2847 cm^{-1} . According to Silva & Wiebeck (2022), the absorption bands in the regions around $2915\text{--}2920\text{ cm}^{-1}$ and $2848\text{--}2850\text{ cm}^{-1}$ are the asymmetric and symmetric stretching bands of the methylene (-CH₂) group, which is the primary repeating unit in the polyethylene chain. Additionally, in the fingerprint region, an absorption band at approximately 718 cm^{-1} is the rocking band of the (-CH₂) group, which is characteristic of polyethylene (Silva & Wiebeck, 2022).

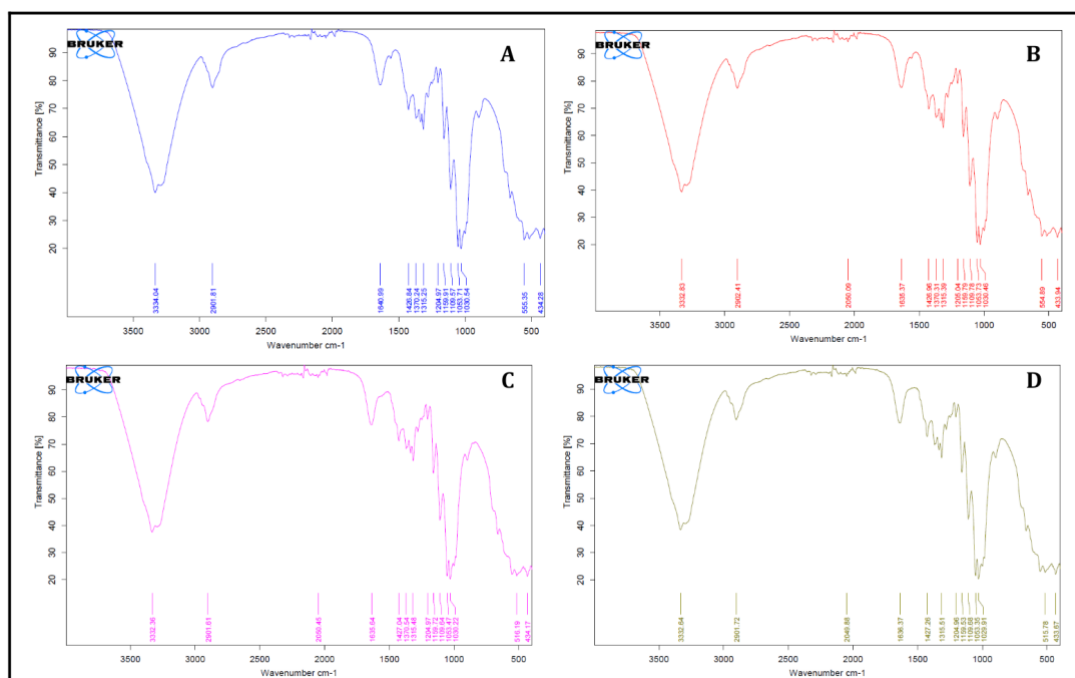


Figure 6. FTIR Spectra of Natural Cellulose Microfibers: a. Seawater from Station 1 (Black); b. Hepatopancreas of Green Mussels from Station 1 (Blue); c. Seawater from Station 2 (Yellow); d. Hepatopancreas of Green Mussels from Station 2 (Black)

In addition to microplastics, the analysis results also revealed the presence of cellulose microfibers in seawater samples and the hepatopancreas of green mussels at two stations (Figure 6). This was indicated by the presence of characteristic absorption bands at 1030 cm^{-1} and 1053 cm^{-1} associated with natural cellulose. According to Uçar et al. (1996), bands in the 1053–1058 cm^{-1} and 1030–1034 cm^{-1} ranges are associated with the (C-O-C) and (C-O) stretching modes. Both of these bands exhibit high intensity in natural fibers, indicating the presence of a dominant cellulose polysaccharide structure. According to Cai et al. (2019) as well, the 1060–1053 cm^{-1} wavelength range is a characteristic marker of natural cellulose such as cotton, sisal, and jute.

Consistent with the present study, several previous studies have shown that, in addition to microplastics, the majority of microfibers found are also made of natural cellulose (Huntington et al., 2020). Although derived from natural cellulose, this material still contributes to water pollution, as cellulose-based fibers can contain up to 27% of additional chemicals (Adams et al., 2021; Sanchez et al., 2018; Xue et al., 2017). Research by Santonicola et al. (2025) found that 80% of microfibers in commercial fish from the Adriatic Sea consisted of natural and synthetic cellulose. This indicates that microfibers, whether natural or synthetic, are commonly found in marine waters and aquatic organisms.

CONCLUSION

This research shows that microplastics are present in the waters of Gunung Jati, Cirebon, and have accumulated in the hepatopancreas of green mussels, with higher abundances at Station 1, which is closer to the coast. The types of microplastics found in the water and in the hepatopancreas of green mussels are dominated by fibers of varying colors. FTIR analysis results indicate that the detected microfibers consist of both synthetic and natural polymers. Microplastic accumulation in the hepatopancreas of green mussels is influenced by body size, with smaller mussels exhibiting higher accumulation levels compared to larger ones. This study demonstrates that green mussels have the potential to serve as bioindicators of microplastic pollution in marine waters and provide a foundation for

further research on the evaluation of microplastic impacts on marine biota, as well as for enhancing efforts to manage and control marine pollution.

REFERENCE

- Adams, J. K., Dean, B. Y., Athey, S. N., Jantunen, L. M., Bernstein, S., Stern, G., Diamond, M. L., & Finkelstein, S. A. (2021). Anthropogenic particles (including microfibers and microplastics) in marine sediments of the Canadian Arctic. *The Science of the total environment*, 784, 147155. <https://doi.org/10.1016/j.scitotenv.2021.147155>
- Araújo, F., Videla, E., Masi, B., & Silva, A. (2024). Subtidal benthic marine litter off the coast of Rio de Janeiro, Brazil. *Ocean and Coastal Research*, 72. <https://doi.org/10.1590/2675-2824072.23004>
- Azzahra, Y., Yulianto, B., & Ighwerb, M. (2024). Microplastic content in fish and sea water at Air Tawar Coast, Padang City, Indonesia. *Journal of Marine Biotechnology and Immunology*, 2(2), 13–18. <https://doi.org/10.61741/gnq8e649>
- Bağcı, I., Kukle, S., & Beļakova, D. (2021). Surface characteristics of sol-gel treated single jersey plated socks. *Journal of Engineered Fibers and Fabrics*, 16. <https://doi.org/10.1177/1558925021996711>
- Bessa, F., Ratcliffe, N., Otero, V., Sobral, P., Marques, J. C., Waluda, C. M., ... & Xavier, J. C. (2019). Microplastics in gentoo penguins from the Antarctic region. *Scientific Reports*, 9(1). <https://doi.org/10.1038/s41598-019-50621-2>
- Botterell, Z. L. R., Beaumont, N., Dorrington, T., Steinke, M., Thompson, R. C., & Lindeque, P. K. (2019). Bioavailability and effects of microplastics on marine zooplankton: A review. *Environmental Pollution*, 245, 98–110. <https://doi.org/10.1016/j.envpol.2018.10.065>
- Brock, F., Dee, M., Hughes, A., Snoeck, C., Staff, R. A., & Ramsey, C. B. (2017). Testing the Effectiveness of Protocols for Removal of Common Conservation Treatments for Radiocarbon Dating. *Radiocarbon*, 60(1), 35-50. <https://doi.org/10.1017/rdc.2017.68>
- Cai, H., Du, F., Li, L., Li, B., Li, J., & Shi, H. (2019). A practical approach based on FT-IR spectroscopy for identification of semi-synthetic and natural celluloses in microplastic investigation. *The Science of the total environment*, 669, 692–701. <https://doi.org/10.1016/j.scitotenv.2019.03.124>
- Cordova, M. R., Iskandar, M. R., Surinati, D., Kaisupy, M. T., Wibowo, S. P. A., Subandi, R., ... Wang, Z. (2024). Microplastic occurrence in sub-surface waters of the Indonesian archipelago. *Frontiers in Marine Science*, 11, 1362414. <https://doi.org/10.3389/fmars.2024.1362414>
- Courville, J. M., Borkowski, R., Sonnenberg, L., & Bielmyer-Fraser, G. K. (2024). A Quantitative Analysis of Microplastics in the Gastrointestinal Tracts of Odontocetes in the Southeast Region of the United States. *Environmental Toxicology and Chemistry*, 43(6), 1260-1273. <https://doi.org/10.1002/etc.5854>
- Dhaka, V., Singh, S., Anil, A. G., Naik, T. S. K., Garg, S., Samuel, J., ... & Singh, J. (2022). Occurrence, toxicity and remediation of polyethylene terephthalate plastics. A review. *Environmental Chemistry Letters*, 20(3), 1777-1800. <https://doi.org/10.1007/s10311-021-01384-8>
- Dris, R., Gaspéri, J., Saad, M., Mirande, C., & Tassin, B. (2016). Synthetic fibers in atmospheric fallout: A source of microplastics in the environment?. *Marine Pollution Bulletin*, 104(1-2), 290-293. <https://doi.org/10.1016/j.marpolbul.2016.01.006>
- Fatahi, M., Akdogan, G., Dorfling, C., & Van Wyk, P. (2021). Numerical study of microplastic dispersal in simulated coastal waters using CFD approach. *Water*, 13(23), 3432. <https://doi.org/10.3390/w13233432>
- Huntington, A., Corcoran, P. L., Jantunen, L., Thaysen, C., Bernstein, S., Stern, G. A., & Rochman, C. M. (2020). A first assessment of microplastics and other anthropogenic

- particles in Hudson Bay and the surrounding Eastern Canadian Arctic waters of Nunavut. *FACETS*, 5, 1–23.
- Ibrahim, F., Suprijanto, J., & Haryanti, D. (2023). Analisis kandungan mikroplastik pada sedimen di perairan Semarang, Jawa Tengah. *Journal of Marine Research*, 12(1), 144–150. <https://doi.org/10.14710/jmr.v12i1.36506>
- Jebrane, M., Cai, S., Panov, D., Yang, X., & Terziev, N. (2015). Synthesis and characterization of new vinyl acetate grafting onto epoxidized linseed oil in aqueous media. *Journal of Applied Polymer Science*, 132(24). <https://doi.org/10.1002/app.42089>
- Kaddissi, S. A., Simon, O., Elia, A. C., Gonzalez, P., Floriani, M., Cavalié, I., ... Legeay, A. (2014). How toxic is the depleted uranium to crayfish *Procambarus clarkii* compared with cadmium? *Environmental Toxicology*, 31(2), 211–223. <https://doi.org/10.1002/tox.22036>
- Kolandhasamy, P., Su, L., Li, J., Qu, X., Jabeen, K., & Shi, H. (2018). Adherence of microplastics to soft tissue of mussels: A novel way to uptake microplastics beyond ingestion. *Science of the Total Environment*, 610–611, 635–640. <https://doi.org/10.1016/j.scitotenv.2017.08.053>
- Li, Y., Tao, L., Wang, Q., Wang, F., Li, G., & Song, M. (2023). Potential Health Impact of Microplastics: A Review of Environmental Distribution, Human Exposure, and Toxic Effects. *Environment and Health*, 1(4), 249–257. <https://doi.org/10.1021/envhealth.3c00052>
- Liu, K., Wu, T., Wang, X., Song, Z., Zong, C., Wei, N., ... Li, D. (2019). Consistent transport of terrestrial microplastics to the ocean through atmosphere. *Environmental Science & Technology*, 53(18), 10612–10619. <https://doi.org/10.1021/acs.est.9b03427>
- Maharajan, A., Rajalakshmi, S., Vijayakumaran, M., & Kumarasamy, P. (2011). Sublethal effect of copper toxicity against histopathological changes in the spiny lobster, *Panulirus homarus* (Linnaeus, 1758). *Biological Trace Element Research*, 145(2), 201–210. <https://doi.org/10.1007/s12011-011-9173-z>
- Miranda, R., Balea, A., Blanca, E. S. d. I., Carrillo, I., & Blanco, Á. (2008). Identification of Recalcitrant Stickies and Their Sources in Newsprint Production. *Industrial & Engineering Chemistry Research*, 47(16), 6239–6250. <https://doi.org/10.1021/ie701718u>
- Mishra, S., Dash, D., & Das, A. P. (2024). Microbial Degradation of Polyester Microfibers Using Indigenously Isolated Bacterial Strain *Exiguobacterium* Sp.. *Clean - Soil Air Water*, 52(12). <https://doi.org/10.1002/clen.202300343>
- Mohd Amin, N. A., & Azman, S. (2022). Microplastic pollution in estuarine ecosystem at Sungai Laloh, Pasir Putih [Preprint]. *Research Square*. <https://doi.org/10.21203/rs.3.rs-1331548/v1>
- Mutlu, T., Eryaşar, A. R., Karaoğlu, K., Veske, E., & Gedik, K. (2025). Microplastics pollution in Gulf of Bandırma, Sea of Marmara: Biota and sediment. *Marine Pollution Bulletin*, 213. <https://doi.org/10.1016/j.marpolbul.2025.117667>
- Ningrum, I. P., Sa'adah, N., & Mahmiah. (2022). Jenis dan kelimpahan mikroplastik pada sedimen di Gili Ketapang, Probolinggo. *Journal of Marine Research*, 11(4), 785–793. <https://doi.org/10.14710/jmr.v11i4.35467>
- Nugroho, D. H., Restu, I. W., & Ernawati, N. M. (2018). Kajian kelimpahan mikroplastik di perairan Teluk Benoa Provinsi Bali. *Current Trends in Aquatic Science*, 1(1), 80–90.
- Oanh, D. T., Thuy, D. T., Huong, N. T. N., Quynh, H. T., Nguyet, V. T., Nam, P. N., ... Quynh, L. T. P. (2021). Efficiency assessment of microplastic extraction from green mussel *Perna viridis* Linnaeus. *Academia Journal of Biology*, 43(4), 55–66. <https://doi.org/10.15625/2615-9023/16153>
- Ogunola, O., & Palanisami, T. (2016). Microplastics in the marine environment: Current status, assessment methodologies, impacts and solutions. *Journal of Pollution Effects & Control*, 4(1). <https://doi.org/10.4172/2375-4397.1000161>

- Parvaresh, H., Enayati, S., Kerdgari, M., *et al.* (2024). The presence, abundance and characteristics of microplastics in some crustacean species: Blue swimmer crab (*Portunus armatus*), banana prawn (*Penaeus merguensis*), and in molluscs: Bivalve mollusc oyster (*Amiantis umbonella*) and razor shell (*Solen roseomaculatus*) on Bandar Abbas City shores, southern Iran [Preprint]. *Research Square*. <https://doi.org/10.21203/rs.3.rs-3804682/v1>
- Patty, S. I. (2013). Distribution Temperature, Salinity and Dissolved Oxygen in Waters Kema, North Sulawesi. *Jurnal Ilmiah PLATAX*, 1(3), 148–157. <https://doi.org/10.35800/jip.1.3.2013.2580>
- Phaksopa, J., Suksanghanangk, R., Keawsing, R., Tanapivatanakul, K., Asavakitikunal, B., Thammrongawasawat, T., & Worachananant, S. (2023). Assessment of microplastics in green mussel (*Perna viridis*) and surrounding environments around Sri Racha Bay, Thailand. *Sustainability*, 15(9), 1–19. <https://doi.org/10.3390/su15010009>
- Pratita, S., Gavintri, M., Rizkyta, A., Khasanah, L., Ponkiyawati, F., & Retnoaji, B. (2022). Study on the potential of sea urchin *Tripneustes gratilla* (Linnaeus, 1758) as a bioindicator of dangerous plastic pollution in the environment of Gunungkidul Beach, Yogyakarta. *IOP Conference Series: Earth and Environmental Science*, 1036(1), 012055. <https://doi.org/10.1088/1755-1315/1036/1/012055>
- Ragu Prasath, A., Sudhakar, C., & Selvam, K. (2025). Microplastics in the environment: Types, sources, and impact on human and aquatic systems. *Bioresource Technology Reports*, 29. <https://doi.org/10.1016/j.biteb.2025.102055>
- Rahim, N., & Yaqin, K. (2022). Histological alteration of green mussel *Perna viridis* organs exposed to microplastics. *Squalen Bulletin of Marine and Fisheries Postharvest and Biotechnology*, 17(1), 44–53. <https://doi.org/10.15578/squalen.597>
- Rahman, A., Sarkar, A., Yadav, O. P., Achari, G., & Slobodnik, J. (2021). Potential human health risks due to environmental exposure to nano- and microplastics and knowledge gaps: A scoping review. *Science of the Total Environment*, 757. <https://doi.org/10.1016/j.scitotenv.2020.143872>
- Ramli., Yaqin, K., & Rukminasari, N. (2021). Microplastics contamination in green mussels *Perna viridis* in Pangkajene Kepulauan waters, South Sulawesi, Indonesia. *Akuatikisile: Jurnal Akuakultur, Pesisir dan Pulau-Pulau Kecil*, 5(1), 1–5. <https://doi.org/10.29239/j.akuatikisile.5.1.1-5>
- Rizaldi, M. A., Azizah, R., Sulistyorini, L., & Ali, K. (2025). Environmental health risk analysis of microplastics due to consumption of squid and mussels at coastal area. *Environmental Analysis Health and Toxicology*, 40(1), e2025009. <https://doi.org/10.5620/eaht.2025009>
- Ruairuen, W., Chanhun, K., Chainate, W., Ruangpanupan, N., Thipbanpot, P., & Khammanee, N. (2022). Microplastic contamination in blood cockles and mussels in Bandon Bay, Suratthani Province, Thailand. *Trends in Sciences*, 19(7), 3073. <https://doi.org/10.48048/tis.2022.3073>
- Sanchez-Vidal, A., Thompson, R. C., Canals, M., & de Haan, W. P. (2018). The imprint of microfibrils in southern European deep seas. *PloS one*, 13(11), e0207033. <https://doi.org/10.1371/journal.pone.0207033>
- Santonicola, S., Volgare, M., Olivieri, F., Cocca, M., & Colavita, G. (2025). Natural and Regenerated Cellulosic Microfibers Dominate Anthropogenic Particles Ingested by Commercial Fish Species from the Adriatic Sea. *Foods* (Basel, Switzerland), 14(7), 1237. <https://doi.org/10.3390/foods14071237>
- Senduk, J. L., Suprijanto, J., & Ridlo, A. (2021). Mikroplastik pada ikan kembung (*Rastrelliger sp.*) dan ikan selar (*Selaroides leptolepis*) di TPI Tambak Lorok Semarang dan TPI Tawang Rowosari Kendal. *Buletin Oseanografi Marina*, 10(3), 251–258. <https://doi.org/10.14710/buloma.v10i3.37930>

- Shamala, T. R., Divyashree, M. S., Davis, R., ., K. S. K., Vijayendra, S. V. N., & Raj, B. (2009). Production and characterization of bacterial polyhydroxyalkanoate copolymers and evaluation of their blends by fourier transform infrared spectroscopy and scanning electron microscopy. *Indian Journal of Microbiology*, 49(3), 251-258. <https://doi.org/10.1007/s12088-009-0031-z>
- Silva, D. J. d. and Wiebeck, H. (2022). ATR-FTIR Spectroscopy Combined with Chemometric Methods for the Classification of Polyethylene Residues Containing Different Contaminants. *Journal of Polymers and the Environment*, 30(7), 3031-3044. <https://doi.org/10.1007/s10924-022-02396-3>
- Soon, T. and Ransangan, J. (2014) A Review of Feeding Behavior, Growth, Reproduction and Aquaculture Site Selection for Green-Lipped Mussel, *Perna viridis*. *Advances in Bioscience and Biotechnology*, 5, 462-469. [10.4236/abb.2014.55056](https://doi.org/10.4236/abb.2014.55056).
- Stelzer, R. S., Strauss, E. A., Lucas, J. R., Kleinheinz, G., & Christus, J. D. S. (2025). Rayon is the predominant microfiber in zebra mussels (*Dreissena polymorpha*) from a North American lake in the context of a global analysis of bivalves. *Water, Air, & Soil Pollution*, 236(10), 8248. <https://doi.org/10.1007/s11270-025-08248-9>
- Tantanasarit, C., Babel, S., Englande, A. J., & Meksumpun, S. (2013). Influence of size and density on filtration rate modeling and nutrient uptake by green mussel (*Perna viridis*). *Marine Pollution Bulletin*, 68(1–2), 38–45. <https://doi.org/10.1016/j.marpolbul.2012.12.027>
- Thompson, R. C., Swan, S. H., Moore, C. J., & Vom Saal, F. S. (2009). Our plastic age. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1526), 1973–1976. <https://doi.org/10.1098/rstb.2009.0054>
- Tian, R., Guan, M., Chen, L., Wan, Y., He, L., Zhao, Z., Gao, T., Zong, L., Chang, J., & Zhang, J. (2024). Mechanism insights into the histopathological changes of polypropylene microplastics induced gut and liver in zebrafish. *Ecotoxicology and Environmental Safety*, 280, 116537. <https://doi.org/10.1016/j.ecoenv.2023.116537>
- Tristanova, T., Ismanto, A., Widiaratih, R., Zainuri, M., Sugianto, D. N., Rochaddi, B., Ismuniarti, D. H., Wulandari, S. Y., Hernawan, U., Hadibarata, T., & Anindita, M. A. (2024). Modeling the fate of microplastics in the Sengkarang Estuary, Pekalongan City, Central Java, Indonesia. *Environmental Quality Management*, 34, e22239. <https://doi.org/10.1002/tqem.22239>
- Uçar, G., Staccioli, C. G., & Stoll, M. (1996). Chemical composition and ultrastructure of a fossil wood from the genus of ancestral Sequoia. *Holz als Roh- und Werkstoff*, 54(6), 411–421.
- Waddell, E. N., Lascelles, N., & Conkle, J. L. (2020). Microplastic contamination in Corpus Christi Bay blue crabs, *Callinectes sapidus*. *Limnology and Oceanography Letters*, 5(1), 92-102. <https://doi.org/10.1002/lo2.10142>
- Wang, R., Mou, H., Lin, X., Zhu, H., Li, B., Wang, J., ... Wang, J. (2021). Microplastics in mollusks: Research progress, current contamination status, analysis approaches, and future perspectives. *Frontiers in Marine Science*, 8, 759919. <https://doi.org/10.3389/fmars.2021.759919>
- Wei, S., Pintus, V., & Schreiner, M. (2012). Photochemical degradation study of polyvinyl acetate paints used in artworks by Py–GC/MS. *Journal of Analytical and Applied Pyrolysis*, 97, 158-163. <https://doi.org/10.1016/j.jaap.2012.05.004>
- Xue, J., Liu, W., & Kannan, K. (2017). Bisphenols, Benzophenones, and Bisphenol A Diglycidyl Ethers in Textiles and Infant Clothing. *Environmental science & technology*, 51(9), 5279–5286. <https://doi.org/10.1021/acs.est.7b00701>
- Zhou, J., Yang, Y., Qin, R., Xu, M., Sheng, Y., & Lu, X. (2019). Robust Poly(urethane-amide) Protective Film with Fast Self-Healing at Room Temperature. *Acs Applied Polymer Materials*, 2(2), 285-294. <https://doi.org/10.1021/acsapm.9b00807>