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ABUNDANCE OF MICROPLASTICS IN *Rastrelliger* sp. FROM THE FISH LANDING PORT IN PALOPO CITY, SOUTH SULAWESI

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Abstract

Microplastic contamination in fish for consumption is a critical issue because of its potential to harm human health. This study aimed to analyze the abundance, shape, size, color, and type of microplastic polymers in mackerel (*Rastrelliger* sp.) obtained from the fish landing port in Palopo City. A total of 10 mackerel were randomly collected, and their gills, stomachs, and muscle tissues were extracted for analysis. Microplastic identification was performed using a stereo microscope and Fourier-transform infrared spectroscopy (FTIR). The average abundance of microplastics was 3.3 particles/individual fish, with microplastic characteristics dominated by fiber form (81.82%), dominant blue color (36.36%), and size of 1–5 mm. The distribution of microplastics was highest in the stomach, followed by the gills, and lowest in the muscles. FTIR analysis identified two types of polymers, namely polystyrene (PS) and polyethylene terephthalate (PET). These findings provide basic information regarding the presence of microplastics in mackerel consumed by the local community in Palopo City and emphasize the need for further studies that integrate aquatic environmental data to understand the sources and pathways of microplastic exposure more comprehensively.

Keywords: fish organs, FTIR, mackerel, microplastics, polymers

Kelimpahan Mikroplastik pada *Rastrelliger* sp. dari Pelabuhan Pendaratan Ikan Kota Palopo Sulawesi Selatan

Abstrak

Kontaminasi mikroplastik pada ikan konsumsi merupakan isu penting karena berpotensi membahayakan kesehatan manusia. Penelitian ini bertujuan menganalisis kelimpahan, bentuk, ukuran, warna, dan jenis polimer mikroplastik pada ikan kembung (*Rastrelliger* sp.) yang diperoleh dari Tempat Pelelangan Ikan Kota Palopo. Ikan kembung sebanyak 10 ekor dikoleksi secara acak, kemudian organ insang, lambung, dan otot diekstraksi untuk dianalisis. Identifikasi mikroplastik dilakukan menggunakan mikroskop stereo dan *Fourier Transform Infrared Spectroscopy* (FTIR). Hasil penelitian menunjukkan rata-rata kelimpahan mikroplastik sebesar 3,3 partikel/individu ikan, dengan karakteristik mikroplastik yang didominasi oleh bentuk fiber (81,82%), warna dominan biru (36,36%), dan ukuran 1-5 mm. Distribusi mikroplastik paling banyak terdapat pada lambung, diikuti insang, dan paling sedikit pada otot. Analisis FTIR mengidentifikasi dua jenis polimer, yaitu *polystyrene* (PS) dan *polyethylene terephthalate* (PET). Temuan ini memberikan informasi dasar mengenai keberadaan mikroplastik pada ikan kembung yang dikonsumsi masyarakat di Kota Palopo serta menegaskan perlunya studi lanjutan yang mengintegrasikan data lingkungan perairan untuk memahami sumber dan jalur paparan mikroplastik secara lebih komprehensif.

Kata kunci: FTIR, mikroplastik, ikan kembung, polimer, organ ikan

INTRODUCTION

Microplastics (MPs) are a current environmental issue of considerable concern, primarily because of the uncontrolled accumulation of plastic waste (Matavos-Aramyan, 2024). The presence of MPs in aquatic environments raises concerns about microplastic contamination in the human body. The entry of MPs into the human body has been associated with an increased risk of acute and chronic health effects, such as gastrointestinal disorders, inflammation, oxidative stress, cytotoxicity, neurotoxicity, and immune system disorders; however, the long-term effects of prolonged contamination are still not fully understood (Cañón-Bastidas *et al*., 2025; Bhuyan, 2022; Abbas *et al*., 2025).

Fishery products are a major source of microplastics in the human food supply chain (Rivera-Garibay *et al*., 2024). Microplastics are defined as plastic particles with diameters less than 5 mm (Priya *et al*., 2022). Owing to their extremely small size, microplastics can spread widely throughout the marine environment, particularly in surface waters (Mutuku *et al*., 2024). Consequently, these particles are frequently found in various marine fish consumed by humans, as microplastics can enter aquatic organisms through direct ingestion of contaminated water (active), ingestion of contaminated prey (passive) (Oza *et al*., 2024), and passive uptake through gill respiration that filters microplastics suspended in water (Hasanah *et al*., 2023; Ullah *et al*., 2026), thus allowing their accumulation in both migratory and sedentary species (Alberghini *et al*., 2023). Jabeen *et al.* (2017) detected microplastics in 100% of the examined marine fish and 95.7% of the examined freshwater fish, highlighting the widespread microplastic contamination of aquatic organisms.

Previous studies in Bone Bay waters have shown that microplastic pollution is detected in interconnected aquatic environments. Microplastics were detected in surface seawater along the coast of South Larompong, Luwu Regency, with an average concentration of 2.68 particles m^{-3}, indicating contamination in the western part of Bone Bay (Ningsih *et al*., 2022). Inland freshwater bodies flowing into Bone Bay are also important sources of microplastics. A study in Lake Towuti reported a high abundance of microplastics in the water column (7.36–26.28 items L^{-1}), dominated by blue-colored particles and fragments associated with anthropogenic activities, such as fishing and boating (Yusuf *et al*., 2022). Furthermore, microplastics have also been detected in the water column of Burau District, North Luwu, with an average concentration of 56.2 items m^{-3} and a relatively uniform spatial distribution, indicating widespread exposure to northern Bone Bay (Kama *et al*., 2021).

Palopo City, one of the coastal urban areas in Bone Bay, has a fish landing port that serves as a primary distribution center for local fishermen's catch (Susantri *et al*., 2019), with most of the marketed fish originating from Bone Bay waters (Marlinda *et al*., 2023). Fish consumption among Palopo residents is predominantly fresh seafood rather than processed products (Marwan *et al*., 2013), with per capita consumption increasing from 58 kg year^{-1} in 2018 to 60.03 kg year^{-1} in 2019 (Mustafa & Rahmatia, 2020). This high level of fish consumption underscores the importance of monitoring microplastic contamination in fish intended for human consumption to anticipate potential public health risks (Mir *et al*., 2025).

Although fish consumption practices generally remove organs such as the digestive tract and gills before cooking (Ciucă *et al*., 2025), the presence of microplastics in these tissues still serves as an indicator of microplastic exposure in fishing grounds (Piskuła & Astel, 2023), whereas their presence in edible tissues, such as muscle, has direct implications for microplastic exposure through the human dietary pathway. In this context, fish, as a seafood commodity, plays a crucial role in linking microplastic exposure in the aquatic environment with potential human health risks.

Although fish are free-moving pelagic organisms, fish are the dominant organisms landed at fish landing ports in South Sulawesi in general and in Palopo City in particular, with most of the catch coming from the waters of Bone Bay (Muhtar *et al.*, 2022). Thus, mackerel functionally represents the seafood consumed by people in this region. Supporting these concerns, microplastics have been detected in a sessile marine organism consumed by local people, namely, blood cockle (*Anadara granosa*), collected from the coastal waters of Palopo, with an average abundance of 0.591 particles g $^{-1}$ (Rahman *et al.*, 2024). However, despite evidence of microplastic contamination in the Bone Bay environment and in certain marine organisms, to date, no research has specifically examined the presence of microplastics in fish consumed in the Bone Bay region, particularly in Palopo City, South Sulawesi. Furthermore, most research on microplastics in fishery commodities in Indonesia has focused on Sumatra, Java, and Bali, whereas similar investigations in central Indonesia are limited.

Mackerel (*Rastrelliger* sp.) is a small pelagic fish that is generally abundant in Indo-Pacific waters (Limbong *et al.*, 2023; Manik *et al.*, 2024; Anabokay *et al.*, 2025) and widely consumed by Indonesians because of its high availability and relatively affordable price (Liviawaty *et al.*, 2023). Several studies have reported high levels of microplastic contamination in this fish. A study in Malaysia reported the presence of microplastics in 93.3% of mackerel samples, with an average of 3.07 particles in the digestive tract, 0.33 particles in the gills, and 0.34 particles in other edible tissues (Najihah *et al.*, 2025), and no data on microplastic contamination in water or sediment were reported in that study. In Indonesia, specifically in South Sulawesi, Sita *et al.* (2024) reported contamination of 0.21 particles/g in mackerel from the Beba Fish Landing Port (PPI Beba), Takalar Regency. However, to date, there is no specific data on similar conditions in mackerel sold at the Palopo City fish landing port.

Therefore, this study was conducted to fill the information gap regarding the presence of microplastics in mackerel (*Rastrelliger* sp.) in the Bone Bay region by analyzing the abundance of microplastics in the gills, stomach, and muscle. This study is the first to specifically assess microplastic contamination in fish species consumed in Bone Bay. The findings are expected to provide baseline information on the presence of microplastics in fish consumed in Palopo City. However, future studies should integrate microplastic measurements in aquatic environments, particularly in commercial fishing areas, to better quantify environmental exposure levels and strengthen the link between environmental contamination and microplastic accumulation in commercially important fish, thereby supporting public health protection and sustainable coastal ecosystem management.

MATERIALS AND METHODS

This study involved collecting samples in the field, handling samples, extracting microplastics, identifying and calculating the abundance of shapes, colors, and sizes of microplastics, analyzing microplastic polymers, and analyzing statistical data.

Fish Collection

Ten mackerel (*Rastrelliger* sp.) were randomly collected from the catch of fishermen at the Fish Landing Port (PPI) in Ponjarae Village, Wara District, Palopo City (Figure 1), during a one-day sampling period. This study consisted of 10 biological replicates (individual fish), with three repeated measurements conducted within each individual by analyzing three different tissues (stomach, gills, and muscle), resulting in a total of 30 tissue-level observations. The number of specimens was determined based on previous microplastic studies that applied similar sample sizes for organ-level microplastic analysis by Yona *et al.* (2021) and Hamdhani *et al.* (2023), which used 10 individuals per fish species for organ-specific microplastic analysis. Furthermore, this study was designed as a preliminary baseline assessment to detect the presence and distribution of microplastics in the organs

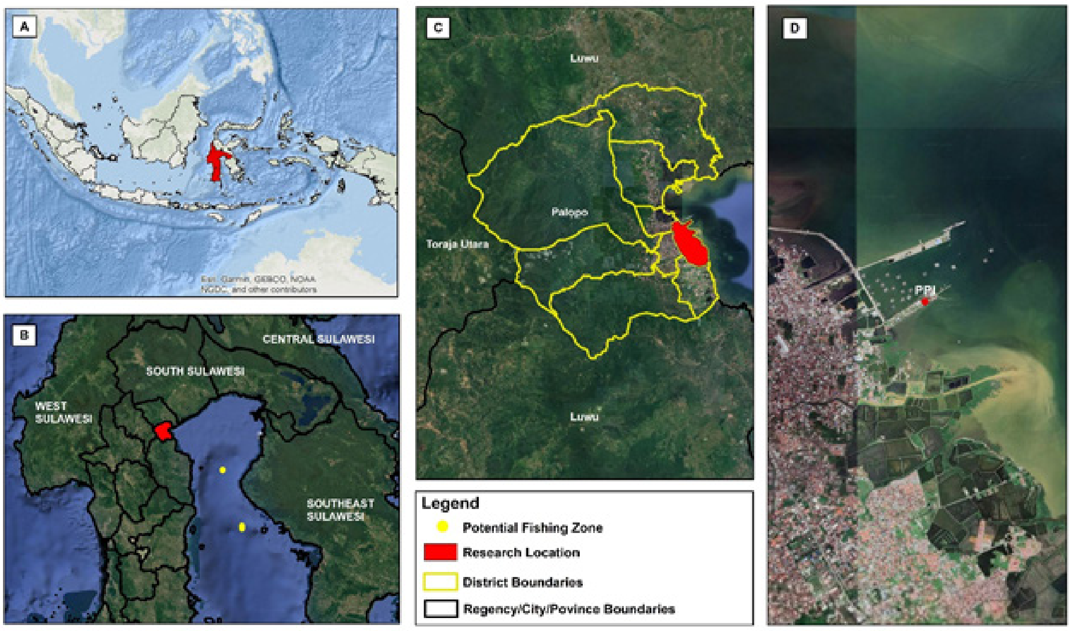


Figure 1 Location of the Fish Landing Port (PPI) in Palopo City and representative fishing grounds in Bone Bay. (A) Map of Indonesia showing the location of South Sulawesi Province; (B) administrative map of South Sulawesi Province showing Regency and City boundaries; (C) administrative map of Palopo City showing District boundaries; and (D) location of the Fish Landing Port (PPI) in Ponjarae Village, Wara District, Palopo City, which serves as a fish sampling location. Fishing grounds in Bone Bay are adapted from the spatial analysis of skipjack tuna fishing areas using fishing rods reported by Aswar *et al.* (2020)

of edible fish consumed from the Bone Bay fishing area, and not to estimate population-level contamination.

Each fish was treated as an independent biological replicate representing the natural individual variability at the time and location of sampling. No temporal replication was performed, and all samples were collected on the same day to reflect the contamination status of the fish at the time of landing. All fish samples were placed in labeled plastic bags, stored in a cooler, and transported to the laboratory for further analysis. A cooler was used to maintain the freshness of the fish during transport to the laboratory by maintaining the temperature below ambient conditions (Sormin *et al.*, 2016; Setiawan *et al.*, 2025). *Rastrelliger* sp. was chosen as the target species for this study because it is one of the most commonly caught and consumed fish species in the Bone Bay area. Furthermore, this species is considered representative of pelagic fish groups with a high potential for exposure to microplastics in the water column, making it relevant for evaluating the potential contamination of seafood consumed by the local community. Owing to logistical limitations and the exploratory nature of this study, the analysis focused on one representative species to provide baseline information for future multispecies investigations in the Bone Bay fishing area.

Microplastic Extraction

Morphometric parameters of the fish samples, including total length and body width, were measured using a ruler and weighed on an analytical balance with an accuracy of 0.1 g. The fish samples were then dissected to separate the gill, stomach, and muscle tissues using stainless steel surgical scissors. The stomach was removed by making a shallow straight incision from the anus anteriorly, passing through the mid-pelvic area, to open the peritoneal cavity (Jantz *et al.*, 2013). To remove the gills, a straight incision was made from the anus to the mouth area of the fish (Amponsah *et al*., 2024). Muscle tissue was collected by carefully cutting the flesh and removing the scales (Daniel *et al*., 2020). Gill, stomach, and muscle samples were weighed using an AND GF-300 balance with an accuracy of 0.001 g, then immersed in 10% potassium hydroxide (KOH) solution and incubated for 24 h at 60°C. The incubation process aims to accelerate the dissolution of organic matter (Rochman *et al*., 2015). After incubation, the samples were stored at room temperature for 1–2 weeks. The KOH solution dissolves the organic matter, allowing microplastics to be separated from biological tissue (Lopes *et al*., 2022).

Microplastic Identification

The extracted fish sample was poured into a petri dish (3–5 mL). Identification was performed visually using a stereoblue binocular SB.1902 microscope at 4.5× magnification using the zig-zag method. The microplastics present in the sample solution were then collected and transferred to a glass object for documentation (Rahman *et al*., 2024). Identification of the shape, color and size of microplastics refers to GESAMP (2016). The size of the microplastics was measured using the ImageJ software (Institute of Health, Bethesda, MD, USA, version 1.54h).

Microplastic Polymer Analysis

Microplastic particles identified using a Stereoblue Binocular SB.1902 microscope were transferred to a sterile glass slide and washed to remove any remaining KOH prior to Fourier-transform infrared (FTIR) analysis. The particle selection criteria for FTIR were size ≥300 µm (to allow for proper scanning), visible intact shape, and representation of the three organs analyzed (gills, stomach, and muscle) across all replicates. From 10 individual fish and three tissues each, we selected and analyzed stomach tissue from individual fish number 7, muscle tissue from individual number 9, and gill tissue from individual number 8. Fourier transform infrared (FTIR) analysis was used to determine the type of microplastic polymer in the selected fish tissue samples. In this method, FTIR emits infrared light, which is absorbed by the plastic polymer and re-emitted, producing a spectrum (Yona *et al*., 2021). FTIR analysis was performed using a Shimadzu IRSpiritX spectrophotometer (Shimadzu Corporation, Japan) in the range of 500–4,000 cm^{-1}, with a resolution of 0.5 cm^{-1} and 128 scans per spectrum.

A background spectrum was collected before each measurement, followed by baseline correction. The spectra obtained from the samples were then compared with the LabSolution IR reference spectral library. Polymer identification and confirmation were accepted only if they matched for more than 70%, following established FTIR-based validation criteria (Lefebvre *et al*., 2019). For spectral interpretation, special emphasis was placed on the fingerprint spectrum range (1,850–700 cm^{-1}), which exhibits characteristic absorption patterns to distinguish the types of polymers identified. These absorption characteristics were used as supporting evidence for polymer assignment. Spectra that did not meet the 70% similarity threshold or showed signs of organic contamination were classified as unidentified.

Data Analysis

Microplastic data in mackerel organs will be tested to determine significant differences in microplastic abundance between mackerel organs (stomach, gills, and muscles) using the SPSS software. Therefore, the normality of the data across all fish organs was first analyzed using the Shapiro–Wilk normality test. The Shapiro–Wilk test is recommended for testing normality in data with small to medium sample sizes (<50 data) (Sianturi, 2025; Habibzadeh, 2024). If the Shapiro-Wilk test results indicate that the data across all organs are normally distributed, a parametric test Repeated Measures ANOVA is used. If the data across all organs are not normally distributed, a nonparametric Friedmann test is used. The selection of this method is based on the characteristics of the research data, where each individual fish serves as the same experimental unit and measurements are carried out repeatedly on three different organs so that the resulting data are dependent (paired).

RESULTS AND DISCUSSION

Microplastic Abundance

The study found an average of 3.3 microplastic particles per individual in mackerel (*Rastrelliger* sp.). This value is lower than the microplastic abundance in mackerel from various other locations, such as Jakarta Bay, which had 8.8 particles per individual (Hanafi *et al.*, 2023), Padang City waters with 4.22 particles per individual (Edwin *et al.*, 2023), and Bali Bay with 5.03 particles per individual (Sarasita *et al.*, 2020). The relatively low abundance of microplastics in mackerel can be attributed to the size of the fish analyzed. Body length measurements revealed that all samples ranged from 15.1 to 18.5 cm, indicating that they are all immature (Pratama *et al.*, 2023). Mackerel can reach early sexual maturity (adulthood) at 20.91–21.14 cm for females and 21.07–21.32 cm for males (Kantun *et al.*, 2018).

Details of fish body morphometry and weight for each tissue are presented in Table 1. These morphometric conditions indicate that the fish analyzed likely had a relatively short duration of microplastic exposure, resulting in less than maximum microplastic accumulation in fish organs. According to previous studies, larger fish generally contain more microplastic particles (Horton *et al.*, 2024). Adult fish tend to ingest more microplastics measuring between 100 and 500 µm (Ding *et al.*, 2023), and larger fish are able to filter larger volumes of water (Sita *et al.*, 2024) and require more food and energy to maintain their active movement, which can then increase the likelihood of fish consuming microplastics (Lestari *et al.*, 2023).

Based on tissue type, the average microplastic abundance was 1.6±1.43 particles/ind in the stomach, 1.3±1.25 particles/ind in the gills, and 0.4±0.7 particles/ind in the muscle (Figure 2). The relatively high standard deviations observed in Figure 2 indicate high variability in microplastic abundance among individual fish. Although all samples are of the same species, individual differences in feeding activity, habitat use, and exposure to contaminated water may contribute to uneven microplastic distribution. Previous studies have also reported high variability in microplastic ingestion within the same fish species due to random feeding behavior and heterogeneous microplastic distribution in the aquatic environment. Furthermore, differences in the amount of food ingested and digestive status at the time of capture may influence the amount of microplastics detected in individual fish. Zeytin *et al.* (2026) also found high variability in the gut (26.8±18.7 MP/g), gills (9.8±9.4 MP/g), liver (0.6±1.5 MP/g), and blood (54.6±46.3 MP/g) of *Dicentrarchus*

Table 1 Morphometrics of mackerel and weight of each tissue

Fish samples	Fish body			Tissue weight (g)		
	Length (cm)	Width (cm)	Weight (g)	Stomach	Gill	Muscle
1	16.2	4.0	61	0.95	2.22	30.68
2	16.0	3.8	59	1.68	2.15	27.27
3	17.5	4.5	71	1.79	2.69	35.47
4	15.1	4.0	47	1.41	1.86	22.39
5	18.0	4.5	81	1.48	3.11	38.56
6	15.5	3.3	51	2.76	1.79	21.18
7	16.6	4.1	51	3.79	2.01	26.78
8	18.5	4.8	89	4.61	3.47	41.73
9	17.0	4.0	67	1.48	2.87	31.36
10	16.0	3.8	57	1.25	1.77	26.31

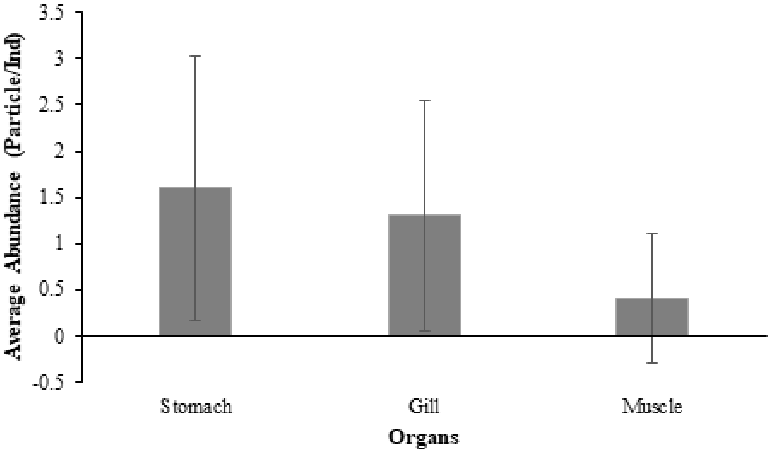


Figure 2 Microplastic abundance in each mackerel organs

labrax. Athukorala *et al.* (2024) also reported similar findings in the digestive tract of *Leiognathus splendens* (1.41±2.52), the gills of *Silago vincenti* (1.38±1.30 items/g wet tissue), and the gills of *Leognathus blochi* and *Siganus javus* (1.17±1.62 items/g wet tissue). This indicates that high interindividual variability in microplastic abundance is common in microplastic studies.

Furthermore, a review by Müller (2021) of 28 studies found that the majority used samples of fewer than 30 individuals per species, and eight studies used samples of fewer than ten individuals. This suggests that high variability between individual samples can lead to relatively high standard deviations, which is a common finding in fish microplastic studies. Statistical analysis using the Shapiro–Wilk test showed that only the stomach organ data met the assumption of data normality (p= .262), whereas the gill and muscle data did not ($p<0.05$); thus, justifying the use of the non-parametric Friedmann test. The Friedmann test results showed a significant difference in microplastic abundance among organs ($p=0.011$).

This finding suggests that microplastic exposure via the digestive tract is likely to be more prominent than through gill respiration, as microplastics were more frequently detected in the stomach than in the gills and muscles. This pattern is relevant to the findings of previous studies that reported high accumulation of microplastics in the digestive tract relative to gills (Aunurohim *et al.*, 2025; Pappoe *et al.*, 2022), although microplastics can also be absorbed into fish through predation and respiration (Devi *et al.*, 2022). Owing to the limitations of uncontrolled migratory behavior and limited sample size, these findings should be interpreted as an indication of the presence of microplastics in fish consumed from the Bone Bay area, rather than as a direct measure of contamination of the wider aquatic environment.

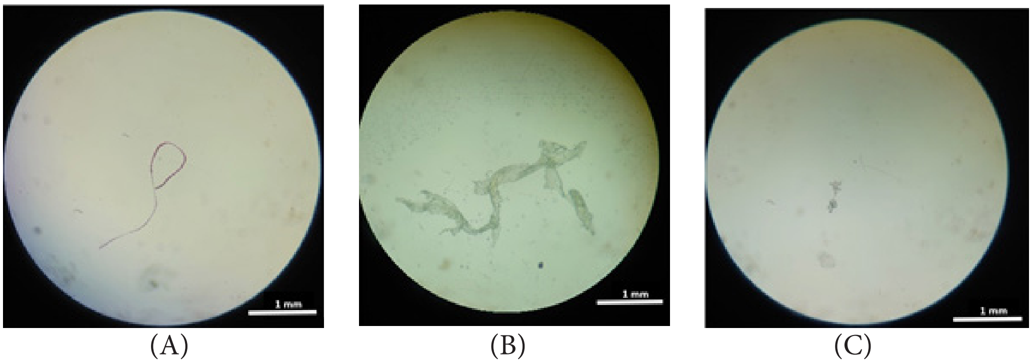
In general, microplastics enter the digestive tracts of marine organisms through two mechanisms: direct predation and/or indirect ingestion through prey that has already been contaminated with microplastics (Walkinshaw *et al.*, 2020). The size of microplastics similar to that of natural prey increases the likelihood of ingestion by fish (Takarina *et al.*, 2024). The primary food source for mackerel is small organisms such as phytoplankton, along with several additional food sources, including zooplankton, gastropods, worms, squid, anchovies, and shrimp (Hasibuan *et al.*, 2025). Furthermore, fish digestive enzymes are unable to digest microplastics (Wildan *et al.*, 2022), resulting in microplastics predominantly accumulating in the digestive tract. Microplastics can enter the gills due to the feeding habits and behavior of fish (Takarina *et al.*, 2024). According to Aye (2020), *Rastrelliger* sp. is a filter-feeding fish that lives near the surface. This results in the inadvertent absorption of microplastics through the gills and digestion from the surrounding water (Takarina *et al.*, 2024).

The presence of microplastics in fish muscle tissue is linked to their translocation into the tissue through the digestive process. The movement of microplastics from the digestive tract to other tissues, such as blood vessels, depends on the permeability of the digestive tract. This permeability determines whether microplastics can pass through barriers, such as the intestines, and enter the bloodstream. If microplastics successfully pass through the intestines, they can be distributed throughout the fish body via the circulatory system. Consequently, blood flow carries microplastics to various tissues, including muscle tissue (Hossain *et al*., 2023).

Microplastic Shape

The results of the study revealed three types of microplastics in mackerel (Figure 3), with fibers being the most abundant (81.82%), followed by fragments (12.12%), and films (6.06%). A total of 27 fiber particles were identified, distributed as follows: 15 in the stomach, nine in the gills, and three in the muscle, from a sample of 10 fish. In contrast, only four fragment particles were found: one in the stomach, two in the gills, and one in the muscle (Figure 4). Films were only found in the gills, with a total of two particles observed. These findings are in line with those of Barboza *et al.* (2020), who found 48% of microplastics in the digestive tract, 30% in the gills, and 22% in the muscle. Edwin *et al.* (2023) reported that fibers represented 94.74% of the dominant microplastics in mackerel.

The presence of microplastics in sessile blood cockles (*Anadara granosa*) has been reported previously, with fibers being the most abundant type (Rahman *et al*., 2024). Ningsih *et al.* (2022) also reported that fibers were the second most common form found in water bodies in South Larompong Waters. The predominance of fiber-shaped microplastics in this study likely reflects a broader pattern of microplastic contamination in the Bone Bay region. The presence of fiber microplastics in



(A) (B) (C)

Figure 3 Microplastics shape found in *Rastrelliger* sp. (A) fiber, (B) film, (C) fragmen

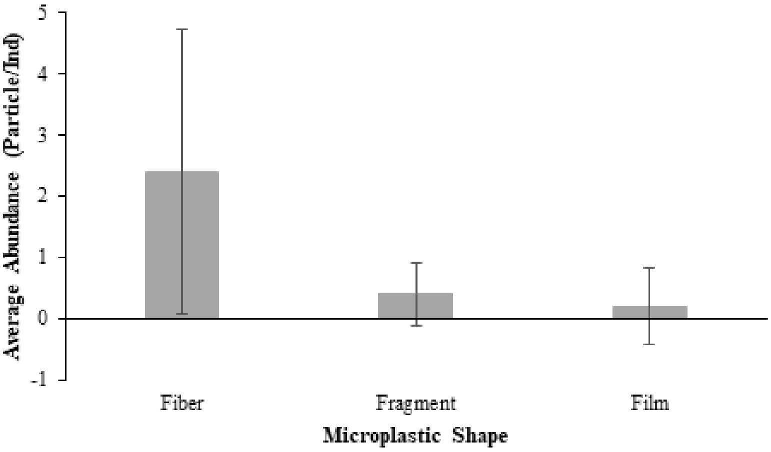


Figure 4 Abundance of microplastic shape in each mackerel

pelagic fish, such as *Rastrelliger* sp., and benthic organisms indicates that fiber microplastics are widely distributed in the waters of Bone Bay. The presence of fiber microplastics in Bone Bay is likely related to various anthropogenic sources and fiber morphology that allows for widespread distribution in the waters. Palopo City, as a coastal urban area around Bone Bay, contributes to the discharge of domestic wastewater, which can contribute to synthetic fibers in coastal waters (Zhou *et al*., 2023).

Furthermore, fishing activities in Bone Bay can be a significant source of fiber microplastics through the degradation of fishing gear, such as nets, lines, and fishing rods (Kasamesiri & Thaimuangphol, 2020). The semi-enclosed shape of Bone Bay can increase the trapping and accumulation of lightweight microplastic fibers carried by currents and river flows from the surrounding coast (Yarahmadi *et al*., 2024). In general, microplastic fibers are the most common type consumed by fish, followed by films and fragments (Widyastuti *et al*., 2023). The size and structure of these fibers are considered similar to those of natural prey in the food chain, indicating that fish may accidentally consume microplastics, such as fibers, films, and fragments (Walkinshaw *et al*., 2020). The abundance of microplastic fibers in Bone Bay waters is likely due to its elongated shape, which facilitates their transport by wind and currents, allowing them to settle in sediments and waterways (Harikrishnan *et al*., 2024; Alwi *et al*., 2025). In general, microplastic fibers originate from synthetic textile waste; one gram of textile waste can produce 4,900 to 640,000 fiber particles (Yang *et al*., 2023). In addition to synthetic textile waste, fibers can also originate from laundry wastewater and the degradation of fishing gear (Arat, 2024).

Fragments and films are two types of microplastics that are less abundant than fibers. Fibers are the most common form of microplastic found in aquatic environments, accounting for approximately 66–71% of the total, followed by fragments and pellets (Borriello *et al*., 2023). This suggests that the abundance of films is much lower. The findings of this study support this conclusion, showing that the prevalence of fragments and films is much lower than that of fibers, with films being very rare (Yona *et al*., 2019). Fragments are more frequently associated with bottom sediments owing to their higher density and irregular shape (Liu *et al*., 2019), whereas film-shaped microplastics tend to accumulate at the water surface because of their buoyancy (Takarina *et al*., 2022).

In contrast, microplastic fibers can be distributed throughout the water column, from the surface layer to the bottom (Wang *et al*., 2022). Their elongated shape and relatively low density prevent them from settling quickly and allow them to remain suspended in the water column for longer periods due to physical water movements such as currents and turbulence (Dittmar *et al*., 2024). The widespread distribution of fibers in the water column increases the likelihood of their ingestion by pelagic fish species, such as *Rastrelliger* sp., which interact with the surrounding water during feeding and respiration. Microplastic fibers also tend to be retained more in the digestive tract of fish than fragments and films because they readily adhere to organic matter (Lin *et al*., 2023). Chen *et al*. (2021) reported that 96% (n=632) of microplastics ingested by fish were fibers, while films and fragments accounted for only 3% (n=17) and 1% (n=8), respectively.

This dominance indicates that fibers are significantly more likely to persist in the digestive tract of fish. A potentially related finding by Ramsperger *et al*. (2023) suggests that fibers tend to adhere more readily to digestive tissues (such as the intestine), whereas fragments and films can more easily detach and ultimately be excreted in feces. However, it is important to note that Ramsperger *et al*. (2023) conducted their study on human intestinal tissue. Therefore, further research is needed to verify this possibility in fish.

Microplastic Color

Characterizing microplastic color is an important parameter in microplastic studies because it can provide information about potential sources, the aging process of plastics in the environment, and the interaction of plastics with chemical pollutants. Different colors of microplastics can indicate their origin, the duration they have been present in the aquatic environment, and their capacity to bind other hazardous contaminants (Rodlo *et al*., 2020; Zhao *et al*., 2022). In this study, blue microplastics were the most abundant color found in Rastrelliger sp., which is relevant to previous findings on marine organisms from the waters of Palopo and South Sulawesi (Rahman *et al*., 2024; Dullah *et al*., 2025). The dominance of blue microplastics indicates that the microplastics originated from synthetic textile fibers, fishing lines, and fishing nets, which are commonly used in fisheries (Rani, 2024).

These sources are particularly relevant for coastal urban areas, such as Palopo City, where domestic wastewater discharge and fishing activities can significantly contribute to the entry of microplastics into the marine environment. Blue-colored microplastics have a high affinity for adsorbing environmental pollutants, including heavy metals (e.g., Pb, Cd, Cu), polycyclic aromatic hydrocarbons (PAHs), and persistent organic pollutants (POPs), owing to their surface properties and prolonged exposure in aquatic environments (Suprayogi *et al*., 2024). Similarly, dark-colored microplastics, such as black particles, generally have higher levels of accumulated contaminants, including hydrophobic organic compounds and metal ions, which can alter their surface texture and increase their toxicity (Basri *et al*., 2021).

Once ingested by fish, these contaminant-rich microplastics can act as a medium for chemical transfer to biological tissues and potentially cause several bodily disorders, such as oxidative stress, inflammation, and cell damage (Bhuyan, 2022). White or transparent microplastics, the second most common microplastic color observed in this study, often originate from aged plastics, which are prone to surface degradation due to exposure to sunlight (photodegradation). Prolonged exposure to sunlight can cause oxidation and discoloration of polymers, thereby increasing surface roughness and adsorption of pollutants (Rodlo *et al*., 2020; Zhao *et al*., 2022). From a human health perspective, the presence of colored microplastics in edible fish tissues is a concern, as the consumption of contaminated seafood can lead to chronic exposure to microplastic particles and related chemical contaminants, potentially posing long-term risks to public health.

The relatively high standard deviation in the microplastic color abundance graph (Figure 5) indicates significant variability between individuals, a common finding in microplastic studies, particularly those involving biota. The same was true for microplastic abundance in each organ (Figure 2). This high variability may be due to differences in feeding selectivity and visual preferences among individual fish samples. Each fish species has distinct vision for recognizing microplastic colors, which can influence the fish's inadvertent ingestion (Horie *et al*., 2024). Okamoto *et al*. (2022) reported that the dominant microplastic colors ingested by clown anemonefish were red, yellow, and green.

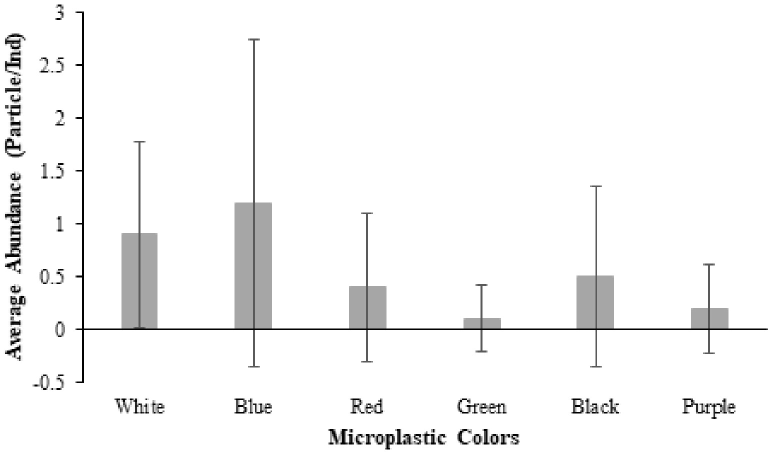


Figure 5 Abundance of microplastic colors in each mackerel organs

This study found that fish rely on color vision to recognize and select microplastics based on their preference for specific colors. These differences in visual preferences among fish species contribute to the attractiveness or disfavor of certain microplastic colors (Ríos *et al*., 2022). Furthermore, differences in microplastic color abundance are influenced by local sources and environmental aging processes, resulting in uneven exposure among organisms. A similar high variability in microplastic color data has been reported in previous studies and is considered a characteristic of microplastic contamination in marine organisms, not an indication of data uncertainty. Therefore, the color distribution results presented in this study should be interpreted as a description and indication of potential sources rather than as definitive population-level estimates.

Microplastic Size

Microplastic size significantly impacts the ecology and behavior of organisms. Smaller microplastics can persist longer in the water column, increasing the risk of ingestion by aquatic organisms (Ramakrishnan *et al*., 2025). Microplastic size analysis revealed that particles measuring 1–5 mm dominated, representing 26 particles or 78%, while particles smaller than 1 mm were only found at seven particles or 22% (Figure 6). This finding is relevant to the study by Nurhasanah *et al*. (2024), who reported a dominance of 1–5 mm microplastics at 81.68% and <1 mm size at 18.32%. The microplastic size findings in this study were significantly larger than those identified by Nawawi *et al*. (2025) in mackerel from the east coast of Peninsular Malaysia, where microplastic sizes ranged from 62.57 μm (0.06257 mm) to 236.87 μm (0.23687 mm). The findings of this study indicate that most microplastic particles are large (>1 mm) and are usually abundant in bottom sediments (Huang *et al*., 2022).

Microplastics can be categorized into two size groups: small (1 mm) and large (1–5 mm) (Edwin *et al*., 2023). In fish, mesoplastics (＞5 mm) are generally found (26%), followed by sizes of ＜1 mm (25.8%) and 1–5 mm (22.7%) (Hamed *et al*., 2023). The dominance of 1–5 mm microplastics in mackerel is likely due to the nature of these microplastics, which require a longer sinking time than particles ＜ 1 mm in size; therefore, it is possible that they can still be ingested by fish in the surface layer to the water column. Smaller particles (＜ 1 mm) tend to sink first, after approximately 18 days, whereas larger particles take longer to settle, approximately 50 days (Semcesen & Wells, 2021). In addition to sinking time, the dominance of 1–5 mm microplastics also indicates that the microplastic particles in this study mostly originated from primary sources of domestic plastic that have not had time to degrade.

The longer the duration of plastic exposure in water, the smaller the particle size, as the general rate of plastic surface degradation is approximately 469.73 μm per year (Maddison *et al*., 2023). From a human health perspective, the predominance of large microplastics (1–5 mm) does not necessarily imply a lower health risk than

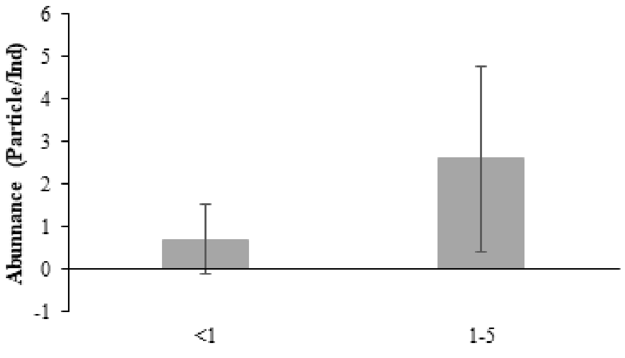


Figure 6 Abundance of microplastic particle size

smaller particles. Although larger particles tend to have greater difficulty penetrating the intestinal barrier than smaller microplastics or nanoplastics (Popa & Tabaran, 2025; Sharma *et al.*, 2022), they can still pose an indirect health risk if ingested through contaminated seafood. Larger microplastics can act as carriers for absorbed plastic additives and other environmental pollutants, such as heavy metals and persistent organic pollutants, which can be released into body tissues during digestion (Li *et al.*, 2025). Furthermore, the gastrointestinal tract can break down microplastic particles through mechanical and chemical processes, potentially producing smaller particles with higher bioavailability (Yousafzai *et al.*, 2025). Therefore, the predominance of large microplastics in edible fish tissues may constitute a secondary source of exposure to smaller microplastics and the toxic substances they carry, potentially leading to long-term human health effects through seafood consumption.

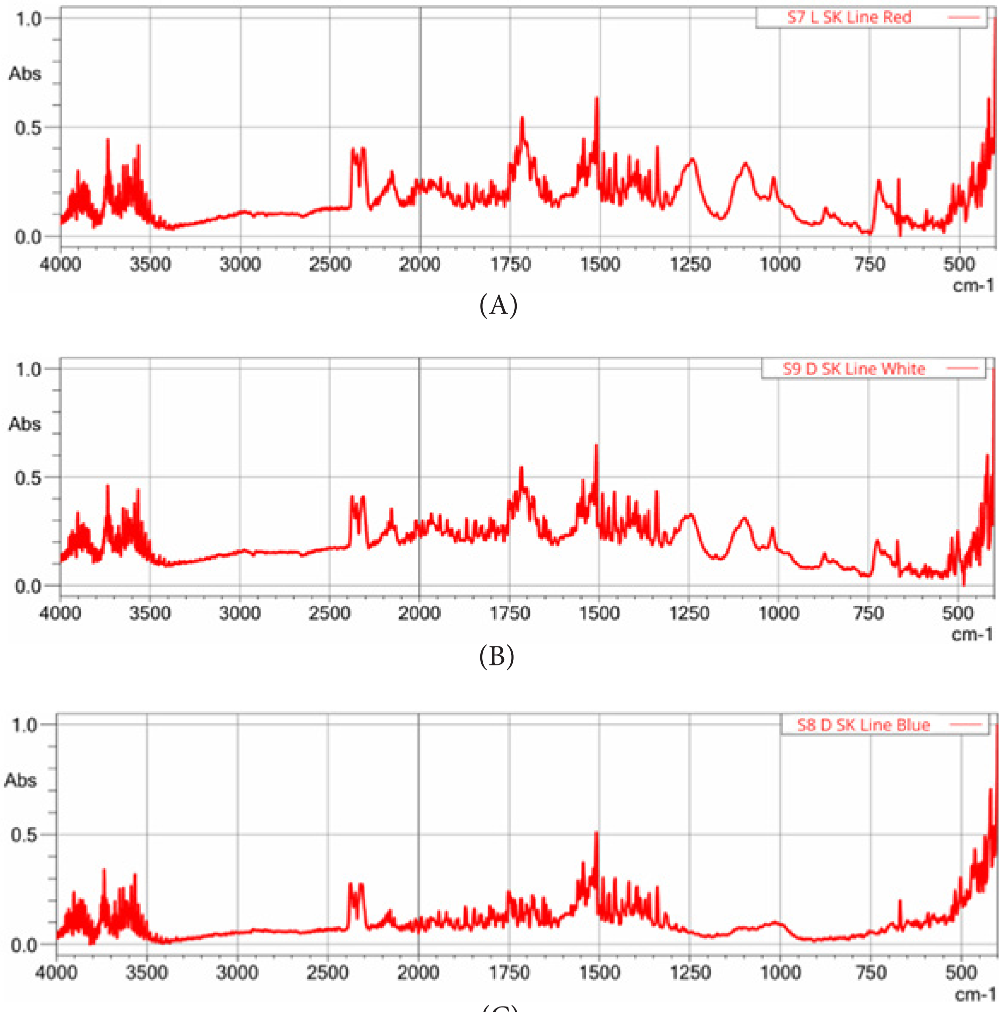
Microplastics Polymers

Polymers play a crucial role in determining the potential toxicity of various microplastics when they decompose into monomers (Yuan *et al.*, 2022). The most widely produced and used microplastic polymers globally include polyethylene (PE), polyethylene terephthalate (PET), polyamide (PA), polypropylene (PP), polystyrene (PS), polyvinyl alcohol (PVA), and polyvinyl chloride (PVC) (Ashrafy *et al.*, 2023; Andrady, 2017; Hayes *et al.*, 2021). Using an FTIR-based polymer identification approach, the spectra of the selected microplastic particles were compared with a reference spectral library, and the polymer types were assigned if there was a similarity or match of more than 70%, as recommended in previous microplastic characterization studies (Lefebvre *et al.*, 2019).

Based on the validated method with the reference library, two types of polymers were identified in Rastrelliger sp. tissue: PET and PS (Figure 7). PET was detected in gastric and muscle tissue extracts, whereas PS was identified in gill tissue. The horizontal axis of the graph shows the wavenumber in cm $^{-1}$ units, ranging from 4,000 to 500 cm $^{-1}$, which represents the absorption of infrared light produced by the vibration of molecular functional groups. The vertical axis shows the absorbance (Abs) or the intensity of infrared radiation absorption by the sample introduced; that is, the higher the absorbance value, the stronger is the absorption in that wavenumber range.

In this study, the PET spectrum showed characteristic absorption around the 1,710 cm $^{-1}$ band (Figures 7A and B), which indicates the presence of stretching vibrations of the carbonyl group (C=O) (Ivanova *et al.*, 2012) and the peak in the range of approximately 1,250–1,100 cm $^{-1}$indicates the stretching vibration of the C–O bond of the terephthalate group (OOC-C_6H_4-COO) (Silva *et al.*, 2019). In contrast, the spectrum obtained from gill tissue did not show any carbonyl absorption typical of PET but showed strong absorption at approximately 700 cm $^{-1}$ (Figure 7C), which is characteristic of aromatic ring vibrations in PS polymers (Ali *et al.*, 2025). According to Quevedo-López *et al.* (2024), the presence of a typical benzene group in PS polymers is indicated by absorption peaks at approximately 694 and 537 cm^{-1}.

Comparable polymer compositions have been reported for *Rastrelliger* sp. from Malaysian waters, where PET (2.81%) is present in lower proportions along with polymers such as rayon (68.88%), polyamide/PA (10.84%), polyethylene/PE (7.83%), and polyvinyl chloride/PVC (2.61%) (Najihah *et al.*, 2025). The presence of PET and PS in this study may reflect the dominant anthropogenic plastic sources, as PS is commonly used in disposable packaging materials because of its chemical stability and larger surface area (Siddiqui *et al.*, 2023), while PET is generally widely used in textile fibers, food packaging, and beverage containers because of its lightweight, transparent, and gas-permeable properties (Dhaka *et al.*, 2022; Kim *et al.*, 2025). These two types of polymers can have different toxicological effects on marine organisms. PS has been shown to cause severe liver and gill damage, skin lesions, and alteration of fish behavior (Hollerova *et al.*, 2023). This



(A)

(B)

(C)

Figure 7 FTIR spectra of selected microplastics particles extracted from (A) stomach tissue, (B) muscle tissue and (C) gill tissue of *Rastrelliger* sp.

suggests that the presence of PS in gill tissue can directly affect respiratory efficiency and physiological performance.

This study has several limitations that should be considered when interpreting the results. The relatively limited number of fish samples analyzed may limit the generalizability of the findings to the entire fish population in Bone Bay. However, we designed this study as a baseline for detecting the occurrence and distribution of organ-specific microplastics in commercially important fish species. We strongly recommend that future research use larger sample sizes, consider fishing seasons, and cover broader and more specific fishing areas to improve the statistical robustness and ecological representativeness of the waters.

CONCLUSION

This study confirmed the presence of microplastics in mackerel (*Rastrelliger* sp.) collected from the Palopo City Fish Landing Port. The results indicate that mackerel consumed by local communities is exposed to microplastic contamination originating from Bone Bay waters. Microplastics were detected in the stomach, gills, and muscle tissue, with the highest abundance found in the digestive organs. The presence of microplastics in edible tissues highlights a potential route of human exposure through seafood consumption. These findings provide baseline information on the presence of microplastic contamination in fishery resources in the Bone Bay region and emphasize the need for further studies with an expanded sample size and species coverage.

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