Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(5): 1323 – 1345 (2025)
www.ejabf.journals.ekb.eg

Microplastic Contamination in Commercially Important Fish from Labuan Bajo Fish Landing Site, Donggala, Central Sulawesi, Indonesia

Irsal Samitra[1], Shinta Werorilangi[2] and Andi Iqbal Burhanuddin[2]*

[1] Department of Marine Science, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, 90245, Indonesia

[2] Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, Indonesia

***Corresponding Author: irzalzamitra10@gmail.com**

ARTICLE INFO

Article History:
Received: April 21, 2025
Accepted: June 30, 2025
Online: Sep. 26, 2025

Keywords:
Economically important fish,
Microplastics,
Gastrointestinal tract,
Central Sulawesi,
Indonesia,
Food safety

ABSTRACT

The Labuan Bajo Fish Landing Station (PPI) serves as a key site for landing economically important fish species in Donggala Regency, Central Sulawesi, Indonesia. Given the rising concern over microplastic (MPs) contamination and its potential risk to food safety, this study investigated the abundance, characteristics (color, shape, and size), and polymer types of MPs in the digestive tracts of six commercially valuable fish species: *Rastrelliger kanagurta, Decapterus macarellus, Katsuwonus pelamis, Chanos chanos, Euthynnus affinis*, and *Thunnus albacares*. Sampling was conducted in August 2024 by purchasing 150 specimens (25 individuals per species) that were landed at the PPI Labuan Bajo. This study employed a descriptive quantitative method. Each fish underwent morphometric measurement and digestive tract dissection, followed by MPs extraction using 10% KOH digestion and stereomicroscopic analysis for particle identification. Microplastics were detected in 84–96% of the fish examined, indicating a high contamination prevalence. The highest mean abundance was observed in *R. kanagurta* (3.64 ± 0.35 particles/ind.) and *D. macarellus* (3.04 ± 0.47 particles/ind.). MPs were predominantly blue (49.9%), linear in shape (96.3%), and larger than 1mm in size (87.5%). Polymer analysis identified Nylon and polyethylene terephthalate (PET) as the most common types. These findings underscore the pervasive presence of MPs in fish from this region, with potential implications for human consumption. Future studies should explore MPs contamination in other tissues such as gills and muscle, and emphasize integrated waste management strategies to mitigate microplastic pollution in marine ecosystems.

INTRODUCTION

Donggala Regency, located in Central Sulawesi, Indonesia, encompasses the Palu City area and includes several surrounding small islands. With its expansive marine territory, Donggala supports a significant capture fishery sector, contributing notably to regional fishery production. One of the key facilities in this area is the Labuan Bajo Fish Landing Station (PPI), which functions as a hub for landing economically important fish species. In addition to fish landing activities, this site also facilitates the provision of fishing gear, marketing, and processing of fishery products **(Aminullah *et al*.,**

2021). However, the rapid growth of coastal population density and socioeconomic development has led to increased consumption of goods and services in coastal areas. This trend contributes to the growing issue of marine litter, particularly plastic waste.

The primary sources of marine debris in the region include industrial discharges, household waste from coastal communities, and urban runoff, much of which enters Palu Bay and ultimately disperses into the surrounding waters that serve as habitats for various fish species **(Hermawan *et al.*, 2022)**. Plastic waste in marine environments poses significant ecological risks. It is composed of diverse material types and sizes, ranging from macroplastics to microplastics (MPs). Due to environmental factors such as elevated temperatures, UV-B radiation, and mechanical forces, larger plastic fragments break down into smaller particles ranging from 5mm to 1µm in size, which are classified as microplastics **(Riani & Cordova, 2022; Cordova *et al*., 2024)**. These particles are persistent and resistant to degradation, and they can adsorb hazardous compounds, such as persistent organic pollutants (POPs), pesticides, and heavy metals. When ingested by aquatic organisms, MPs facilitate the bioaccumulation of toxic substances, which may be transferred through the food chain via biomagnification **(Rochman, 2015)**. Numerous marine organisms, including mollusks (clams and oysters), crustaceans (crabs), echinoderms (sea cucumbers), and various fish species, have been reported to ingest MPs **(Sharma & Chatterjee, 2017)**. MPs have also been detected in lower trophic organisms, such as zooplankton, indicating their widespread distribution in marine food webs **(Cole *et al*., 2013)**. The accumulation of MPs in aquatic organisms is a growing concern for ecosystem health and human food safety. Studies from different regions have documented the presence of MPs in commercially valuable fish species. For instance, research in the Red Sea, Saudi Arabia **(Baalkhuyur *et al*., 2018)**, and the North Ionian Sea of the Mediterranean **(Digka *et al.*, 2018)** confirmed MPs ingestion in various fish species. Similarly, **Lusher *et al*. (2013)** reported that 36.5% of 504 pelagic and demersal fish examined contained MPs in their digestive tracts. These findings suggest that fish may inadvertently ingest MPs mixed with organic matter or prey, thereby introducing plastics into the human food chain.

Microplastics in marine waters resemble phytoplankton **(Cordova *et al*., 2024)**, making them easily consumed by small fish, which are then preyed upon by larger fish and, ultimately, by humans. Laboratory studies have shown that ingested MPs can pass through the digestive tract and gills into the circulatory system **(Wright & Kelly, 2017)**, allowing them to reach various organs **(Rao, 2019)**. When accumulated in large amounts, MPs may block the digestive tracts of fish **(Browne *et al*., 2011)**. MPs pose serious health risks to humans when ingested directly or indirectly through the food chain. Studies have shown that alternative pathways of MPs consumption can lead to chromosomal abnormalities associated with infertility, obesity, and even cancer **(Sharma & Chatterjee, 2017)**. Furthermore, MPs have been linked to a range of physiological disorders, including metabolic imbalances, gastrointestinal disruption, kidney dysfunction, and reproductive impairment **(Aulia *et al.*, 2023)**. Given these potential health impacts, it is critical to investigate the presence of MPs in fish species that are commonly consumed by local communities. Therefore, this study is essential for quantifying the abundance and characterizing the physical properties (color, shape, and size) and polymer types of MPs found in economically important fish species landed at the Labuan Bajo Fish Landing Station, Donggala Regency, Central Sulawesi. The findings are expected to support community awareness and inform policymakers in formulating effective plastic waste management strategies, thereby helping mitigate environmental degradation and protect marine ecosystems in the region.

MATERIALS AND METHODS

Time and sampling location

The study was conducted in August 2024, with sample collection carried out at the Labuan Bajo Fish Landing Station (PPI) in Donggala Regency, Central Sulawesi, Indonesia. The site was selected because of its strategic role as a central hub for the landing of economically important fish species in the region. The preparation and analysis of samples were performed at the Marine Ecotoxicology Laboratory, Department of Marine Sciences, Faculty of Marine Sciences and Fisheries, Hasanuddin University, Makassar, South Sulawesi, Indonesia. The specific sampling locations within the PPI Labuan Bajo area are shown in Fig. (1).

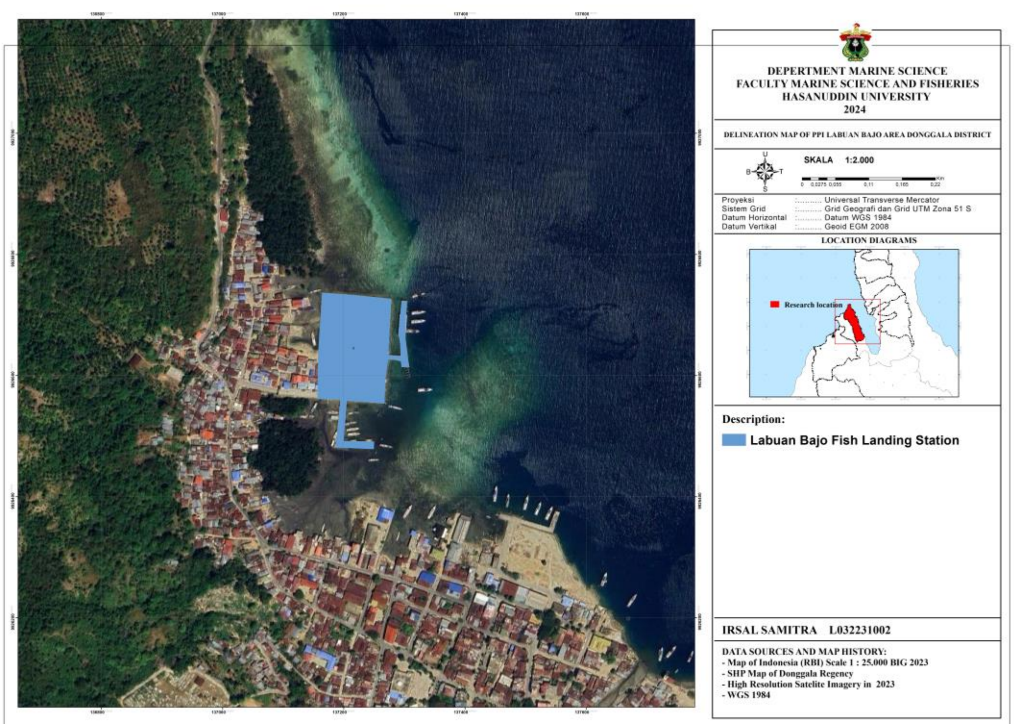


Fig. 1. Research sampling site at Labuan Bajo PPI, Donggala Regency, Central Sulawesi, Indonesia

This study examined six economically important fish species: *Decapterus macarellus, Katsuwonus pelamis, Thunnus albacares, Rastrelliger kanagurta, Euthynnus affinis,* and *Chanos chanos*. A random sampling method was employed to ensure representative data collection. 150 individual fish were sampled (N = 150), with 25 individuals collected from each species group (N = 25 per species). All specimens were immediately stored in insulated cool boxes containing ice to preserve freshness and prevent degradation of biological material before laboratory analysis.

Contamination prevention and quality control

To mitigate the risk of MPs contamination during the sampling process and subsequent laboratory analysis, a series of rigorous quality control procedures were implemented. All tools and materials used during the observations were meticulously cleaned and sterilized before use. The Petri dishes were maintained in a closed state throughout the study, except when samples were being transferred. In these instances, the Petri dishes were exposed to air for a maximum of 30s to mitigate the risk of airborne contamination. To assess and control potential contamination during visual MP observations, a procedural blank test was conducted based on a previously described method **(Wicaksono *et al.*, 2021)**. Three Petri dishes containing ultrapure water were positioned around the microscope and left open for 30min during the observation period. Following the visual identification of MPs in the fish samples, the contents of the control Petri dishes were examined under a microscope to detect incidental contamination. This approach ensured that any background contamination was identified and accounted for when interpreting the results.

Morphometric measurements and dissection procedures

Fish samples were first subjected to morphometric measurements, including total length (cm) and body weight (g), to obtain the basic biometric data. Following measurement, each fish was dissected to extract the digestive tract, specifically the stomach and intestines, as target organs for MPs analysis. The extracted organs were placed in labeled sample bottles for further processing. To isolate MPs, an alkaline digestion process was performed by adding a 10% potassium hydroxide (KOH) solution at a ratio of 1:3 (sample tissue weight to KOH volume), following the protocol adapted from **Rochman *et al*. (2015)**. The samples were then left to digest at room temperature for two weeks to ensure a complete breakdown of the organic material. After digestion, the resulting solution was filtered, and the remaining residue was transferred into clean petri dishes. MPs were visually identified using a Blue SB-1902 stereomicroscope. Each suspected MPs particle was photographed and analyzed using ImageJ software to determine the particle dimensions and morphology. Identification continued until the entire sample solution was examined to ensure the comprehensive recovery of MPs.

Analysis of microplastic abundance

The analysis of microplastic abundance in this study followed the method outlined by **Boerger *et al.* (2010)**, which quantifies microplastic particles per individual organism. This approach provides a standardized and meaningful measure to assess the level of contamination.

$$\text{Average abundance of MPs} = \frac{Number\ of\ microplastic\ particles\ (particles)}{Number\ of\ fish\ samples\ (Individuals)}$$

FT-IR analysis of microplastic polymer

Microplastic samples were selected based on a range of physical characteristics, including variations in color and shape, to ensure representative analysis. The selected MPs particles were analyzed using a Shimadzu IRSpirit-X 00236 Fourier Transform Infrared (FTIR) spectrometer equipped with a QATR-S accessory to determine the polymer composition. The analysis employed the Attenuated Total Reflectance (ATR) technique, which is particularly suitable for identifying polymers in larger-sized particles (>500 µm). FTIR analysis generates distinctive spectral fingerprints for each polymer type, allowing for the reliable differentiation of plastic materials from other organic and inorganic substances **(Baalkhuyur *et al*., 2018)**.

Data analysis

Data on microplastic characteristics were analyzed following the guidelines provided by **GESAMP (2019)**, focusing on the particle shape, size, and color. The observed MPs were categorized into size classes based on the classification scheme proposed **(Arias *et al*., 2019)**. To assess the abundance of MPs among different fish species, a one-way analysis of variance (ANOVA) was conducted, followed by Tukey's post-hoc test to determine statistically significant differences in the mean abundance of MPs. These analyses were performed using IBM SPSS Statistics 30.0 software (172). In addition, descriptive statistics of MPs' characteristics and polymer types were analyzed quantitatively using Microsoft Excel 2010. GraphPad Prism software version 9.0.2 (161) was used for graphical visualization and further statistical comparison.

RESULTS AND DISCUSSION

Visual observations of microplastics (MPs) under a negative control setup revealed minimal contamination, with only 2 blue, line-shaped MPs detected among 45 petri dishes, equating to a contamination rate of approximately 0.52%, which was considered negligible. In contrast, analysis of the actual fish samples showed that 90.6% of the individuals examined were contaminated with MPs. A total of 383 MPs particles were identified across all six fish species. Among these, *Rastrelliger kanagurta* exhibited the highest average MPs abundance, with 3.64 ± 0.35 particles per individual, followed by

Decapterus macarellus with 3.04 ± 0.47 particles per individual. Conversely, the lowest MP abundances were observed in *Euthynnus affinis* and *Thunnus albacares*, with averages of 1.88 ± 0.19 and 1.96 ± 0.17 particles per individual, respectively. The detailed results regarding MPs' abundance and characteristics are presented in Fig. (2). Additionally, the comparative data from previous studies on economically important fish in various regions, including Indonesia, are summarized in Tables (1, 2).

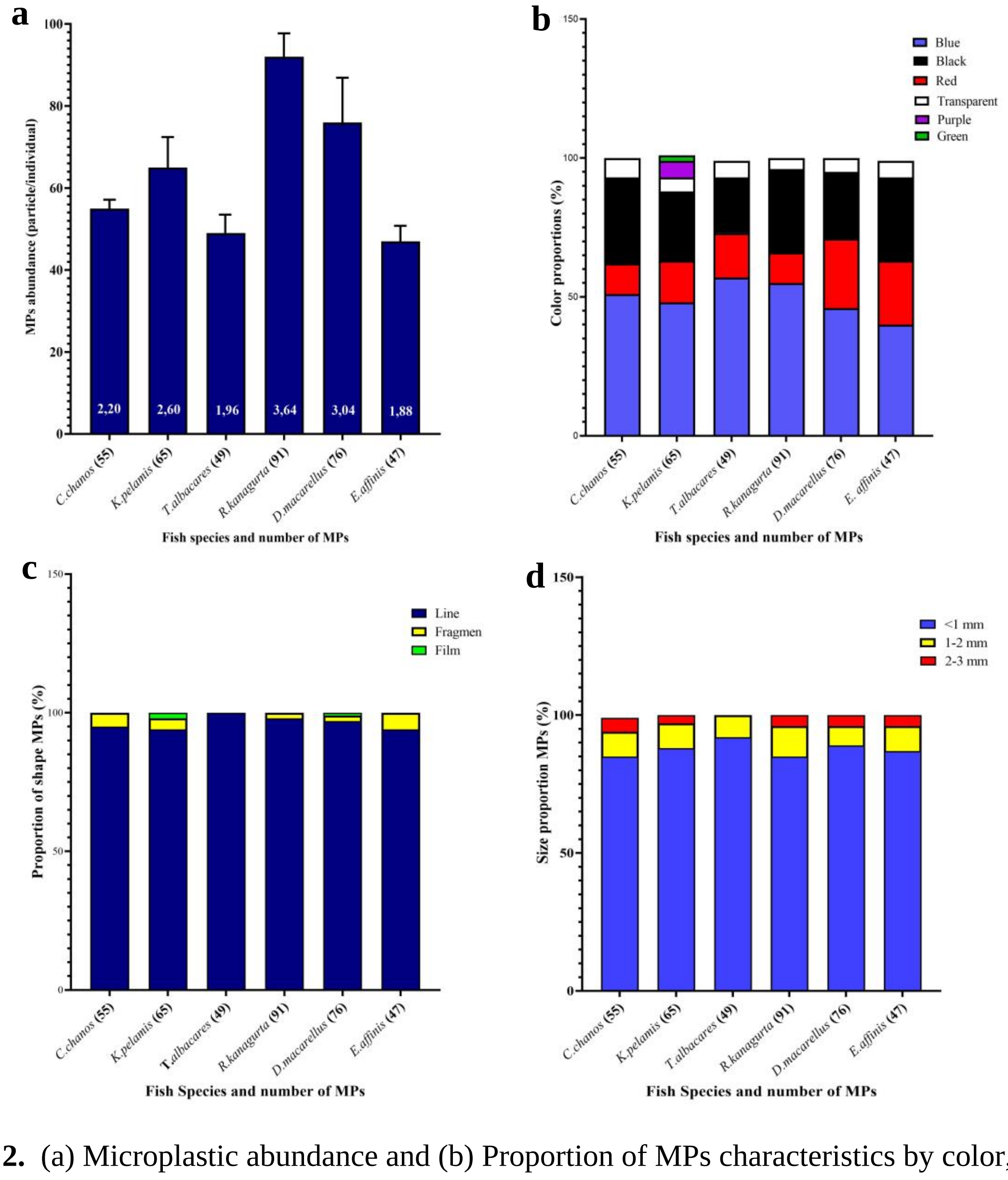


Fig. 2. (a) Microplastic abundance and (b) Proportion of MPs characteristics by color, (c) Shape, and (d) Size in economically important fish species

Table 1. Microplastic occurrence in fish species from selected study areas

Location	Species	Abundance of MPs in Biota (MPs/individual)	Reference
Yellow Sea, China	*Enchelyopus elongates*	1,2	**(Sun *et al.*, 2019)**
	Gadus macrocephalus	1,1	
	Ammodytes personatus	1,4	
Red Sea, Saudi Arabia	*Acanthurus gahhm*	1	**(Baalkhuyur *et al.*, 2018)**
	Epinephelus areolatus	1	
	Pristipomoides multidens	2	
Portuguese Offshore	*Alosa fallax*	1	**(Neves *et al*., 2015)**
	Argyrosomus regius	0,80±0,8	
	Boops boops	0,09±0,3	
Offshore Scottish Waters	*Pleuronectes platessa*	0,9 ± 1,79	**(Murphy *et al.*, 2017)**
	Platichthys flesus	0,8 ± 0,94	
	Limanda limanda	1,3 ± 1,67	
	Lepidorhombus whiffilagonis	0,1 ± 0,32	
North Ionian Sea (Mediterranean Sea)	*Sardina pilchardus*	1,8±0,2	**(Digka *et al.*, 2018)**
	Pagellus erythirinus	1,9±0,2	
	Mullus barbatus	1,5±0,3	
Inggris Strait Waters	*John dory zeus faber*	2,7± 0,10	**Lusher *et al*., (2013)**
	Trisopterus minutus	2,0± 0,10	
	Merlangius merlagus	1,75±0,10	
North Bay of Bengal, Bangladesh	*Harpadon translucens*	5,80 ±1,41	**(Hossain *et al*., 2019)**
	Harpadon neherus	8,72±1,54	
	Sardinella gibbosa	3,20±1,16	
Haizhou Bay, China	*Thryssa kammalensis*	22,21±1,70	**(Feng *et al*., 2019)**
	Cynoglossus semilaevis	13,54±2,09	

Table 2. Reported MPs abundance in economically important fish in Indonesia

Location	Species	Abundance of MPs Biota (MPs/individual)	Reference
PPI Labuan Bajo, Donggala Regency, Central Sulawesi	*Decapterus macarellus*	3,04±0,467	**Penelitian ini (2024)**
	Katsuwonus pelamis	2,6 ± 0,384	
	Thunnus albacares	1,96±0,17	
	Rastrelliger kanagurta	3,64±0,35	
	Euthynnus affinis	1,88±0,19	
	Chanos chanos	2,2±0,145	
Belawan Ocean Fishing Port, North Sumatra	*Rastrelliger Spp.*	2,30±1,30	**(Arisanti, 2023)**
Bali Strait Waters	*Trichiurus lepturus*	5,03±0,50	**(Sarasita *et al*., 2020)**
	Decapterus russelli	4,23±0,28	
	Sardinella lemuru	7,03±0,49	
Palu Bay Waters, Central Sulawesi	*Upeneus sulphureus*	3,58 ± 0,36	**(Hermawan *et al*., 2022)**
	Rastrelliger neglectus	1,84 ± 0,35	

	Carangoides coeruleopinnatus	1,67	
Bonto Manai Village, Pangkep Regency, South Sulawesi	*Chanos chanos*	3,5±2,87	**(Amelinda *et al.*, 2021)**
Baai Island Fishing Port, Bengkulu City	*Euthynnus affinis*	10,5±7,2	**(Purnama et al., 2021)**
Makassar Sea Waters, Indonesia	*Katsuwonus pelamis*	0	**(Rochman *et al.*, 2015)**
	Rastrelligar Kanagurta	1 (± 1.1), 0–3	
	Decapterus macrosoma	2.5 (± 6.3), 0–21	
	Spratelloides gracilis	1.1 (± 1.7), 0–5	
	Siganus argenteus	0,5 (± 0,7), 0–1	
	Lutjanus gibbus	0	
	Selar boops	0	
	Famili Carangidae	5.9 (± 5.1), 0–14	
TPI Tambak Lorok Semarang and TPI Tawang Rowosari Kendal	*Rastrelliger sp.*	25,2 dan 19,1	**(Senduk *et al.*, 2021)**
	Selaroides leptolepis	10,1 dan 8,4	

The results of microplastics (MPs) abundance in this study (Fig. 2a) align with those of **Hermawan *et al.* (2022)**, who reported the highest microplastic abundance of *Rastrelliger neglectus* in Palu Bay (1.84±0.35 particles/g), but are lower than those of **Hanafi *et al*. (2023)** for *Rastrelliger brachysoma* in Jakarta Bay (8.80±0.95 particles/ind. Similar contamination has also been reported in the Northern Ionian Sea **(Digka *et al*., 2018)** and the Yellow Sea **(Sun *et al*., 2019)**. In this study, *Rastrelliger kanagurta* (katombo fish) showed the highest abundance, likely because of its filter-feeding habits, group living in shallow coastal waters, and proximity to coastlines and settlements. Fishing and economic activities in Palu Bay further contribute to plastic waste input, including discarded and fragmented fishing nets and microplastics. The next highest contamination occurred in Layang (*D. macarellus*), a pelagic fish found from coastal areas to offshore waters of Palu Bay, with sources likely from household waste, nearby industries, and tourism. Feeding in both the water column and seabed increases the risk of ingesting microplastics directly or via the food chain, which accumulate in the digestive tract **(Khan *et al*., 2020)**. Other recorded pelagic species include the skipjack tuna (*Katsuwonus pelamis*), the tongkol (*Euthynnus affinis*), and the yellowfin tuna (*Thunnus albacares*), which inhabit tropical and subtropical waters from the surface to depths. *E. affinis* is typically caught 5–20 miles offshore, while *K. pelamis* and *T. albacares* are found from outside Palu Bay to the Makassar Strait. Previous studies have reported high microplastic levels in *K. pelamis* from the southern coast of Java 19 MPs/ind **(Andreas *et al*., 2021)** and Ternate 948 particles **(Lessy & Sabar, 2021)**. As fast-swimming species with wide-ranging movements, *K. pelamis*, *T. albacares*, and *E. affinis* are highly susceptible to microplastics from coastal waste and other anthropogenic sources transported offshore. *K. pelamis*, an opportunistic carnivore, may mistake microplastics for prey, whereas *T. albacares* showed a lower abundance than *Thunnus obesus* in

Wakatobi 12 MPs/ind **(Nur *et al*., 2021)** and *E. affinis* in Kupang 0.8 MP/ind **(Larasati *et al*., 2024)**. Contamination occurs via the ingestion of tainted plankton or small organisms, as well as microplastics floating or suspended in the water column, originating not only from Palu Bay but also across the Makassar Strait. *E. affinis* hunts in the epipelagic zone, where high microplastic concentrations increase the risk of ingestion. Studies have confirmed the presence of microplastics in the digestive tract, gills, and flesh of all three species. *C. chanos* is a demersal bottom feeder and omnivorous detritivore. High microplastic levels in this species likely result from the proximity of ponds to land, settlements, and fishing activities, with additional input from rivers and tides carrying synthetic fibers. Its feeding behavior, which involves sucking substrate or filtering mud, increases the risk of ingesting non-organic particles. The presence of microplastics is influenced by surrounding waste and human activities **(Eriksen *et al*., 2013)** as well as the consumption of contaminated prey **(Vandermeersch *et al*., 2015)**.

The observation of microplastic (MPs) colors in six fish species revealed blue as the most dominant color (49.9%), followed by black (26.6%), red (16.7%), transparent (5.50%), purple (1.04%), and green (0.52%) (Fig. 2b). The high abundance of blue MPs likely originated from residential and coastal activities involving blue fishing nets, ropes, bags, and gear, along with household waste carried by rivers into Palu Bay. Similar findings were reported by **Jiang *et al*. (2019)**, who noted that blue and transparent MPs are common in aquatic environments, resulting from riverine inputs. Fish that feed on zooplankton or transparent prey are more prone to ingest brightly colored MPs, including blue MPs **(Neves *et al*., 2015)**. **Ory *et al*. (2017)** noted that planktivorous fish often select microplastics resembling the blue pigment of their natural prey, such as copepods. *R. kanagurta*, which feeds on white, transparent, and blue plankton **(Boerger *et al.*, 2010)**, was found to contain microplastics of similar colors in its digestive tract. Black microplastics likely originate from urban, coastal, and industrial waste, such as single-use plastics, cables, tires, pipes, and packaging, entering water via drainage or runoff. Their UV resistance and heat absorption slow their degradation, enabling persistence and accumulation in marine environments. The prevalence of black MPs aligns with **Bellas *et al*. (2016)**, who found black to be the most common color in fish digestive tracts. Red microplastics in this study likely originate from household and port waste, including packaging, textiles, fishing lines, and hard plastics used in household goods, food packaging, and marine equipment. This aligns with **Lumban Tobing *et al.* (2020)**, who identified red MPs in edible fish from textiles, fishing lines, and ropes. Resembling small prey like shrimp or copepods, red MPs attract species such as skipjack tuna (*Katsuwonus pelamis*), *Rastrelliger kanagurta*, and bonito (*Euthynnus affinis*), increasing the likelihood of accidental ingestion. The dominance of transparent microplastics likely comes from degraded everyday plastics, such as bags, food packaging, and synthetic textile fibers. Resembling zooplankton, these particles can mislead pelagic fish like the skipjack tuna (*Katsuwonus pelamis*), *Rastrelliger kanagurta*, and the bonito (*Euthynnus* *affinis*). Color variation in MPs results from prolonged water exposure and sunlight-induced oxidation, which fades plastics into hues like blue, red, yellow, and green **(Browne *et al*., 2015)**.

Microplastics of various shapes were found in all economically important fish species analyzed, with line-shaped particles being the most dominant, followed by fragments and films (Fig. 2c). Microplastic lines dominated across species—*R. kanagurta* (97.8%), *D. macarellus* (97.4%), *K. pelamis* (93.8%), *C. chanos* (94.5%), *E. affinis* (93.6%), and *T. albacares* (100%). This dominance likely stems from urban and coastal waste, textile industries, and fishing activities, particularly nets and lines. Their thin, lightweight form allows them to float and be readily ingested by pelagic fish **(Barboza, 2019)**. Line-shaped MPs often originate from degraded bags, clothing, and textiles **(Strand *et al*., 2013)**, whereas fragments primarily originate from discarded single-use plastics, packaging, and styrofoam that break into irregular particles. **Dodson *et al*. (2020)** stated that microplastics with fragments originate from broken particles of plastic products with strong synthetic polymers and higher density, causing them to sink to the bottom of the sediment. The lower abundance of microplastic fragments compared to lines is likely due to their larger size or higher density, causing them to sink and remain near the seabed, thereby reducing their interaction with pelagic fish. Higher fragment counts were observed in *C. chanos*, which inhabit bottom waters where dense particles accumulate in sediments **(Priyambada *et al.*, 2023)**. Fragments typically originate from larger debris, such as thick plastic bottles and PVC pipes **(Priyambada *et al*., 2023)**. Additionally, they have also been reported in Portugal's northwestern coastal waters **(Rodrigues *et al*., 2020)**. Microplastic fragments appear as thick, opaque shards or irregular pieces, whereas films are transparent, thin, and thread-like with branched ends **(Suwartiningsih & Nafi'a, 2023**). In this study, films were found only in *D. macarellus* and *K. pelamis*, similar to the findings in the Bali Strait, where films occurred only in pelagic fish **(Sarasita *et al*., 2020)**. These films, originating from degraded single-use plastics such as packaging, feed bags, and fishing gear, are formed in coastal, estuarine, and deep-sea environments.

The MPs identified in this study varied in size, predominantly ranging from >1 mm to 3 mm (Fig. 2d). The most common size category was >1 mm, accounting for 87.5% of all MPs, followed by 1–2 mm (8.88%) and 2–3 mm (3.66%). The consistent size distribution across all fish species suggests a shared selectivity or ingestion pattern, likely influenced by the resemblance of small MPs to natural food particles such as plankton and dissolved organic matter **(Wright *et al*., 2013)**. Smaller MPs are more likely to be ingested due to their availability and similarity to prey items, especially in pelagic environments. According to **Filgueiras *et al*. (2020)**, factors such as fish body size and condition influence MPs ingestion, while **Wicaksono *et al*. (2021)** noted that smaller MPs are more easily translocated into tissue, posing greater physiological risks. A visual summary of MPs characteristics found in all economically important fish species sampled at Labuan Bajo PPI is presented in Fig. (3).

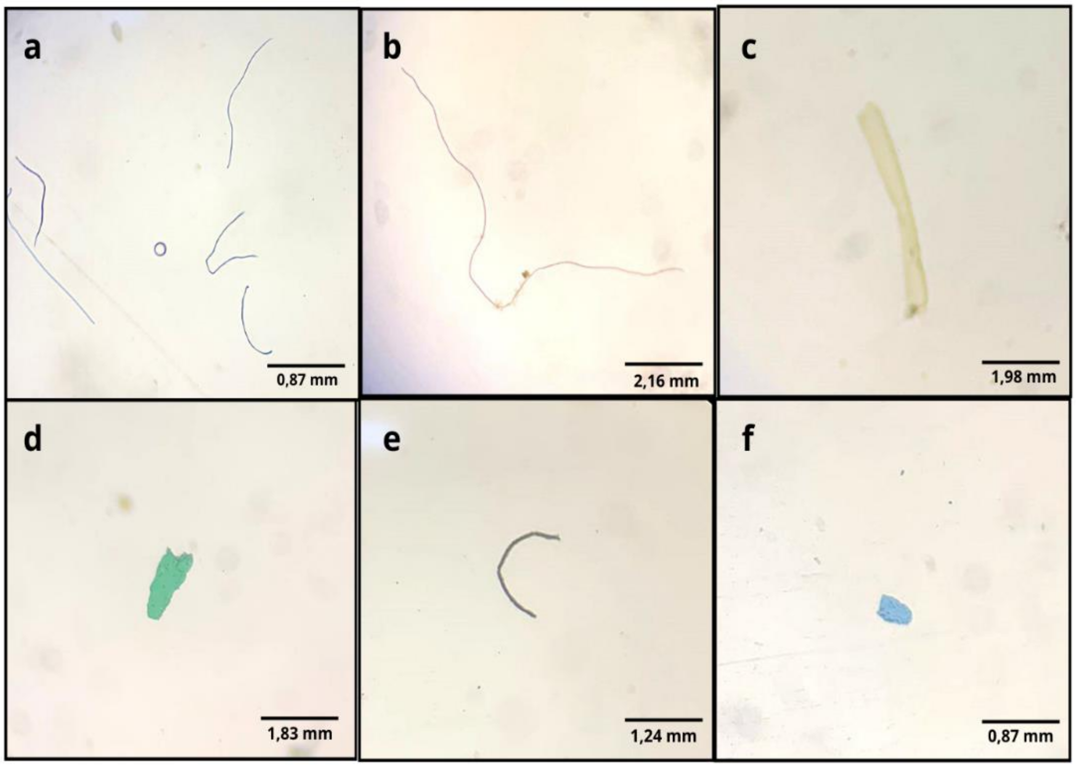


Fig. 3. Representative MPs characteristics found in economically important fish. (a) Blue and (b) red lines; (c)Transparent film; (d) Green fragment; (e) Black line; (f) and Blue fragment

Composition of microplastic polymers

The analysis identified eight distinct categories of polymers. Nylon and PET (polyethylene terephthalate) were the most prevalent, each comprising 33% of the microplastics found in economically important fish. These were subsequently succeeded by EVA (ethylene vinyl acetate) 11% and PMMA (polymethyl methacrylate) 7%. The following plastics were each responsible for 4% of the sample: polyvinyl chloride (PVC), polypropylene (PP), polymethylpentene (PMP), and polyethylene (PE). The detailed distribution is illustrated in Fig. (4).

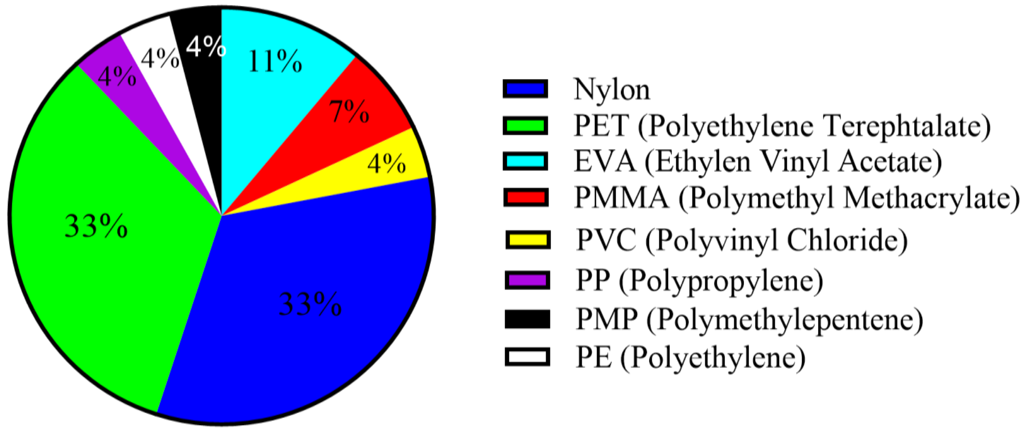
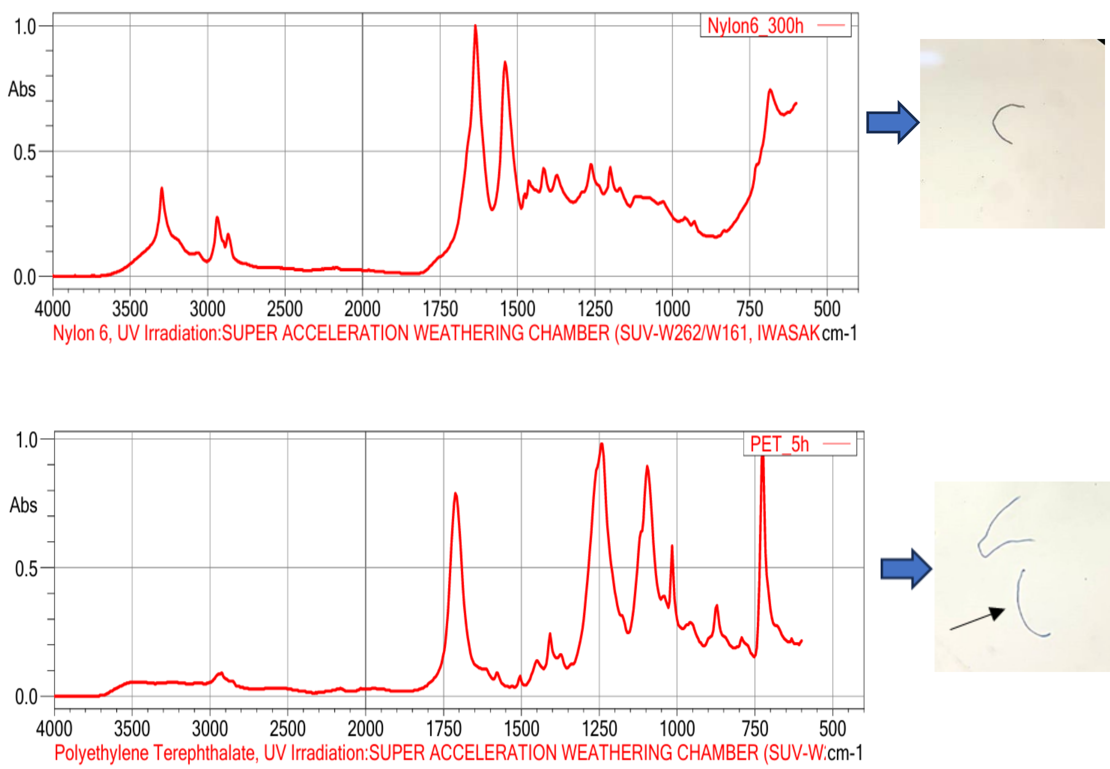
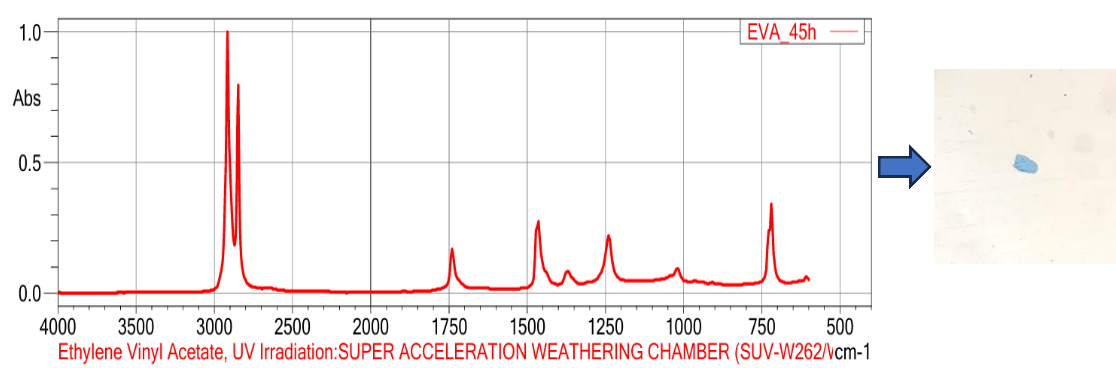


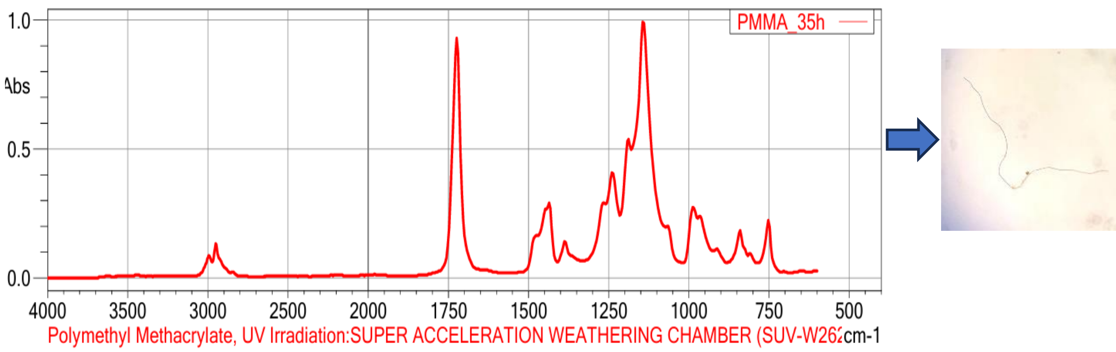
Fig. 4. Polymer microplastic composition in economically important fish species



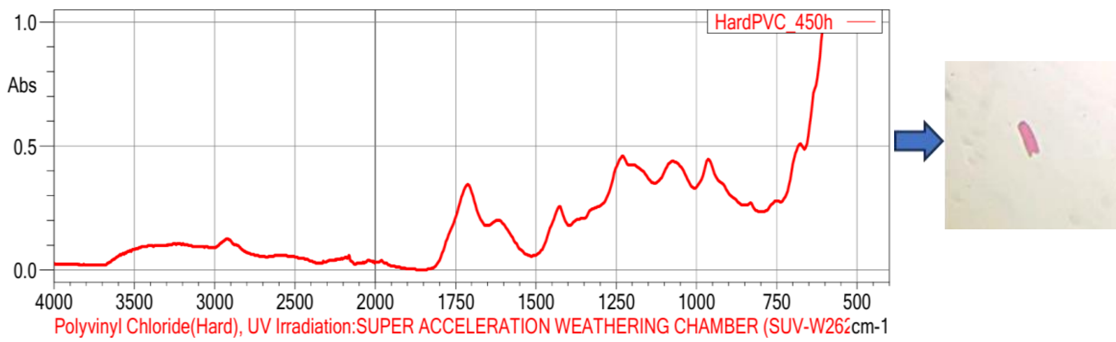
(b)



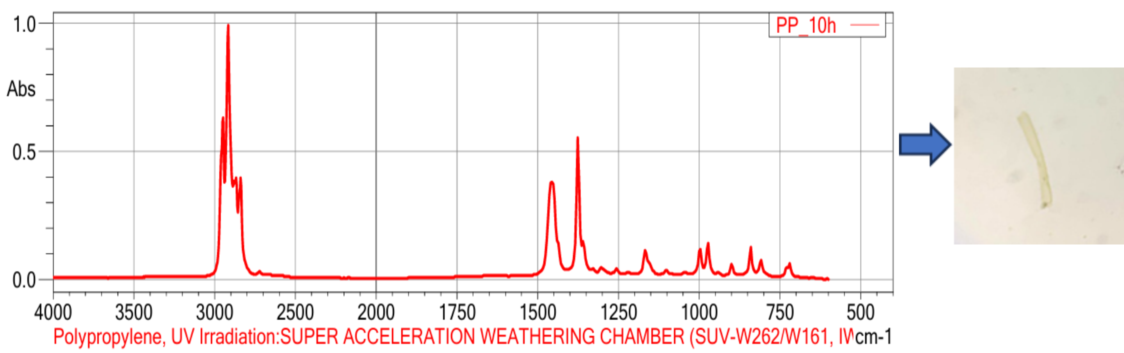
(c)


PMMA_35h
Abs
1.0
0.5
0.0
4000 3500 3000 2500 2000 1750 1500 1250 1000 750 500
cm-1
Polymethyl Methacrylate, UV Irradiation:SUPER ACCELERATION WEATHERING CHAMBER (SUV-W26

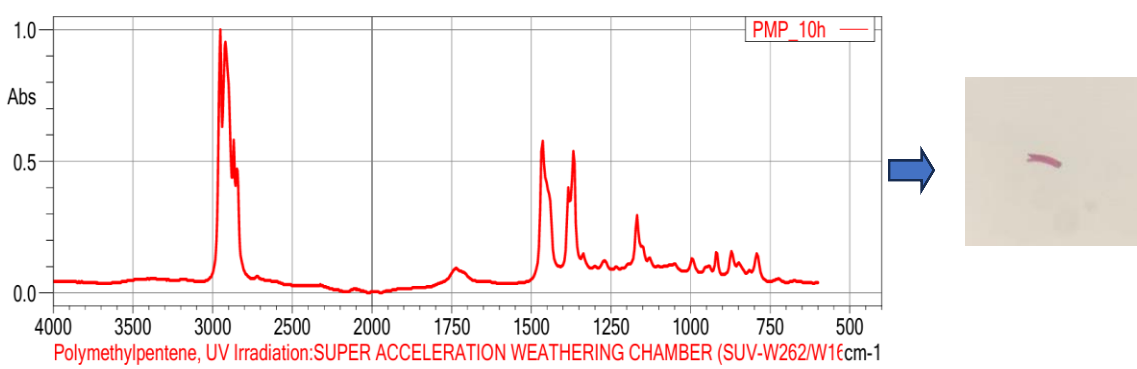
(d)


HardPVC_450h
Abs
1.0
0.5
0.0
4000 3500 3000 2500 2000 1750 1500 1250 1000 750 500
cm-1
Polyvinyl Chloride(Hard), UV Irradiation:SUPER ACCELERATION WEATHERING CHAMBER (SUV-W26

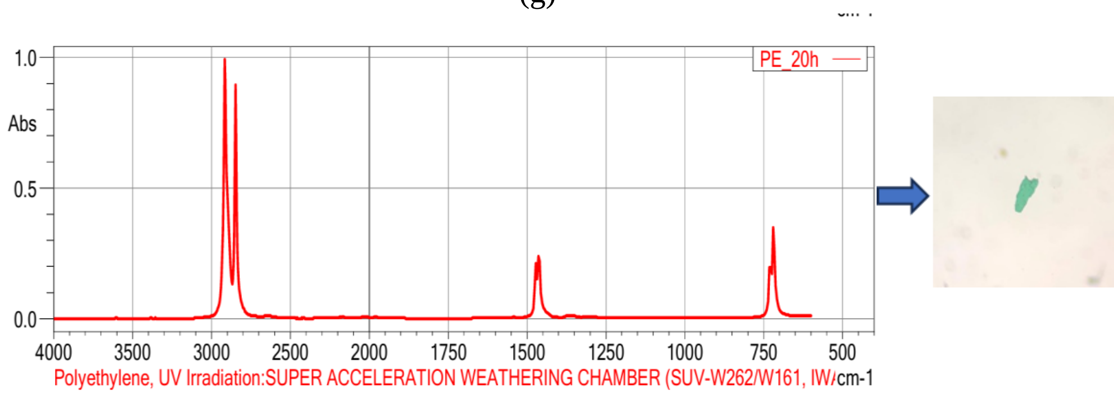
(e)


PP_10h
Abs
1.0
0.5
0.0
4000 3500 3000 2500 2000 1750 1500 1250 1000 750 500
cm-1
Polypropylene, UV Irradiation:SUPER ACCELERATION WEATHERING CHAMBER (SUV-W262/W161, I

(f)


PMP_10h
Abs
1.0
0.5
0.0
4000 3500 3000 2500 2000 1750 1500 1250 1000 750 500
cm-1
Polymethylpentene, UV Irradiation:SUPER ACCELERATION WEATHERING CHAMBER (SUV-W262/W1

(g)



(h)

Fig. 5. Result of FTIR spectrum analysis of MPs in fish species: (a) Nylon, (b) PET, (c) EVA, (d) PMMA, (e) PVC, (f) PP, (g) PMP, and (h) PE

Observations revealed varied microplastic polymer types across all economically important fish species (Fig. 4). *Rastrelliger kanagurta* contained PP, Nylon, and PET, indicating synthetic materials and textile waste. *Decapterus macarellus* had Nylon, EVA, PMMA, and PVC, reflecting diverse waste sources. *Katsuwonus pelamis* was dominated by Nylon, PET, and EVA, suggesting mixed synthetic and inorganic plastics. *Chanos chanos* mainly contained PET and Nylon, linked to textile waste or plastic bottles. *Thunnus albacares* was dominated by Nylon with PET, likely from textiles and plastic packaging. *Euthynnus affinis* contained Nylon, PET, PE, PMMA, and PMP, likely from packaging, construction, and coastal textile waste.

Nylon and PET (polyethylene terephthalate) were the most prevalent polymers, detected in all sampled fish species. They were associated with the dominant microplastic traits—blue, fiber-shaped (>1 mm). Likely sources include urban waste, textile industry effluents, and coastal fishing activities. Nylon typically derives from industrial fabrics, nets, ropes, cables, and carpets **(Vagholkar, 2016)**, while PET originates from densely populated areas, tourism, and single-use plastics such as bottles, packaging, and polyester clothing transported via rivers to the sea. High EVA exposure likely stems from local communities, fishing activities, and tourism, with common sources including flip-flops, beach shoes, and waterproof shoe soles **(Idowu *et al*., 2024)**. PMMA contamination may come from densely populated or tourist areas and shipbuilding, originating from acrylic-based products like windows, transparent roofs, billboards, outdoor furniture, electronics, aquariums, and stationery. PVC is linked to construction, industrial, and coastal activities, derived from items such as pipes, gutters, roofs, cables, hoses, bottles, buckets, and detergent containers. PP likely originates from industrial waste and discarded food containers, especially those for hot/cold drinks **(Fikri *et al*., 2024)**. PMP is associated with single-use waste from healthcare, cosmetics, and electrical industries, including synthetic leather, elastic rubber, medical tools, and lab supplies **(Tu *et al*., 2025)**. PE, both LDPE and HDPE, is primarily from single-use and lightweight plastics—LDPE from shopping bags, wrappers, and packaging; HDPE from caps, buckets, baskets, and durable plastic goods **(Crawford & Quinn, 2017)**.

Microplastic contamination concerning fish feeding habits

A total of 150 fish samples were collected from Labuan Bajo PPI. The species and their feeding habits are summarized in Table (3).

Table 3. Feeding habit characteristics of economically important fish species

Species	N	Food Habits	Length ± SE (range)(cm)	Weight ± SE (range)(g)	Contamination (%)
C.chanos	25	Omnivore	29,7 ± 0,211 28,0 - 32.1	251,0 ± 5,917 204,1 - 288,9	96%
R.kanagurta	25	Planktivora/ Omnivore	18,5 ± 0,256 15,7 - 20,0	75,4 ± 3,057 49,0 - 97,0	96%
T.albacares	25	Carnivore	28,7 ± 0,208 27,5 - 30,5	345,5 ± 6,783 298,2 - 405,1	84%
K.pelamis	25	Carnivore	30,4 ± 0,235 29,0 - 32,1	416,4 ± 8,880 315,4 – 510	88%
E.affinis	25	Carnivore	28,5 ± 0,275 30,6 - 25,5	344,6 ± 7,360 258,0 - 389,3	92%
D.macarellus.	25	Carnivore	19,9 ± 0,275 18,3 – 23,1	77,2 ± 2,532 62,0 – 98,0	88%

The highest MPs contamination was found in *R. kanagurta*, a planktivorous-omnivorous species. Its filter-feeding behavior, using gills to consume plankton and small particles, likely contributes to this **(Carbery *et al*, 2018)**. Since plankton can accumulate MPs, planktivorous fish may experience magnification through their diet **(Mardiyana & Kristiningsih, 2020)**. Studies also show that planktivores tend to have higher MPs loads than carnivores or herbivores **(Sánchez-Hernández *et al*., 2021)**. *C. chanos*, classified as an herbivore with omnivorous tendencies **(FAO, 2019; Jose & Radhakrishnan, 2023)**, showed higher MPs contamination than the carnivorous *T. albacares* and *E. affinis*, but lower than *D. macarellus* and *K. pelamis*. This may be due to its pond habitat, which is often near residential areas and prone to plastic pollution **(Ayuningtyas *et al*., 2019)**. Omnivorous fish are more vulnerable to MPs due to their varied diet and lower efficiency in expelling ingested MPs **(Zhang *et al*., 2021)**.

CONCLUSION

This study confirms the presence of microplastic (MPs) exposure in the digestive tracts of economically important fish landed at PPI Labuan Bajo, with contamination levels ranging from 84 to 96%. The highest MPs abundance was found in *R. kanagurta* and *D. macarellus*, particularly among planktivorous species. MPs identified were primarily lines, fragments, and films in colors such as blue, black, red, transparent, purple, and green, measuring <1–3 mm. Detected polymers included Nylon, PET, EVA, PMMA, PP, PE, PVC, and PMP. MPs' contamination raises serious food safety concerns and poses health risks to consumers. Further research is needed to examine MPs' accumulation in fish gills and flesh, alongside improved plastic waste management to reduce future marine pollution.

Acknowledgment: This research is part of projects titled Korea-Indonesia Marine Technology Cooperation Research Center (20220512), and Establishment of the Integrated Ocean Fisheries Technology Training Center and the Enhancement of Capacity Building in Indonesia (PG54000), which are funded by the Ministry of Oceans and Fisheries, Korea. The authors also thank the Marine Ecotoxicology Laboratory, Department of Marine Science, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, for supporting this research.

REFERENCES

Amelinda, C.; Werorilangi, S.; Burhanuddin, A.I. and Tahir, A. (2021). Occurrence of microplastic particles in Milkfish (Chanos chanos) from brackishwater ponds in Bonto Manai Village, Pangkep Regency, South Sulawesi, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *763*(1). https://doi.org/10.1088/1755-1315/763/1/012058

Aminullah, A. A.; Baskoro, M.S.; Imron, M. and Solihin, I. (2021). Technical and Operational Compliance of Donggala Fish Landing Base with Permen-Kp Ri Number Per.08/Men/2012 concerning Fisheries Ports. *Marine Fisheries : Journal of Marine Fisheries Technology and Management*, *12*(1), 113–123. https://doi.org/10.29244/jmf.v12i1.35032

Andreas, Hadibarata, T.; Sathishkumar, P.; Prasetia, H.; Hikmat, Pusfitasari, E.D.; Tasfiyati, A. N.; Muzdalifah, D.; Waluyo, J.; Randy, A.; Ramadhaningtyas, D. P.; Zuas, O. and Sari, A. A. (2021). Microplastic contamination in the Skipjack Tuna (*Euthynnus affinis*) collected from Southern Coast of Java, Indonesia. *Chemosphere*, *276*. https://doi.org/10.1016/j.chemosphere.2021.130185

Arias, A. H.; Ronda, A. C.; Oliva, A. L. and Marcovecchio, J. E. (2019). Evidence of Microplastic Ingestion by Fish from the Bahía Blanca Estuary in Argentina, South America. *Bulletin of Environmental Contamination and Toxicology*, *102*(6), 750–756. https://doi.org/10.1007/s00128-019-02604-2

Arisanti, G. (2023). Analysis of Microplastics in the Digestive Tract of Mackerel

(Rastrelliger sp.) at Belawan Ocean Fishing Port, North Sumatra. *Water and Marine Pollution Journal: Polu Sea*, *1*(1), 45–60. https://doi.org/10.21776/ub.polusea.2023.001.01.4

Aulia, A.; Azizah, R.; Sulistyorini, L. and Rizaldi, M. A. (2023). Literature Review: The Impact of Microplastics on Coastal Environments, Marine Life, and Potential Health Risks. *Indonesian Journal of Environmental Health*, *22*(3), 328–341. https://doi.org/10.14710/jkli.22.3.328-341

Ayuningtyas, W. C.; Yona, D.S. and Iranawati, F. (2019). Microplastic Abundance in Banyuurip Waters, Gresik, East Java [in Indonesia]. *Journal of Fisheries and Marine Research*, *3*(1), 41–45.

Baalkhuyur, F. M.; Bin Dohaish, E. J. A.; Elhalwagy, M. E. A.; Alikunhi, N. M.; AlSuwailem, A. M.; Røstad, A.; Coker, D. J.; Berumen, M. L. and Duarte, C. M. (2018). Microplastic in the gastrointestinal tract of fishes along the Saudi Arabian Red Sea coast. *Marine Pollution Bulletin*, *131*(December 2017), 407–415. https://doi.org/10.1016/j.marpolbul.2018.04.040

Barboza, L. G. A.; Lopes, C.; Oliveira, P.; Bessa, F.; Otero, V.; Henriques, B.; Raimundo, J.; Caetano, M.; Vale, C. and Guilhermino, L. (2020). Microplastics in wild fish from North East Atlantic Ocean and its potential for causing neurotoxic effects, lipid oxidative damage, and human health risks associated with ingestion exposure. *Science of the Total Environment*, *717*, 134625. https://doi.org/10.1016/j.scitotenv.2019.134625

Bellas, J.; Martínez-Armental, J.; Martínez-Cámara, A.; Besada, V. and Martínez-Gómez, C. (2016). Ingestion of microplastics by demersal fish from the Spanish Atlantic and Mediterranean coasts. *Marine Pollution Bulletin*, *109*(1), 55–60. https://doi.org/10.1016/j.marpolbul.2016.06.026

Boerger, C. M.; Lattin, G. L.; Moore, S. L. and Moore, C. J. (2010). Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. *Marine Pollution Bulletin*, *60*(12), 2275–2278. https://doi.org/10.1016/j.marpolbul.2010.08.007

Browne, M. A.; Crump, P.; Niven, S. J.; Teuten, E.; Tonkin, A.; Galloway, T. and Thompson, R. (2011). Accumulation of microplastic on shorelines woldwide: Sources and sinks. *Environmental Science and Technology*, *45*(21), 9175–9179. https://doi.org/10.1021/es201811s

Browne, M. A.; Underwood, A. J.; Chapman, M. G.; Williams, R.; Thompson, R. C. and Van Franeker, J. A. (2015). Linking effects of anthropogenic debris to ecological impacts. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1807). https://doi.org/10.1098/rspb.2014.2929

Carbery, M.; O'Connor, W. and Palanisami, T. (2018). Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health. *Environment International*, *115*(March), 400–409. https://doi.org/10.1016/j.envint.2018.03.007

Cole, M.; Lindeque, P.; Fileman, E.; Halsband, C.; Goodhead, R., Moger, J. and Galloway, T. S. (2013). Microplastic Ingestion by Zooplankton. *Environmental Science & Technology*, *47*(12), 6646–6655. https://doi.org/10.1021/es400663f

Cordova, M. R.; Iskandar, M. R.; Surinati, D.; Kaisupy, M. T.; Wibowo, S. P. A.; Subandi, R.; Ulumuddin, Y. I.; Purbonegoro, T.; Yogaswara, D.; Sani, S. Y.; Puspitasari, R.; Rositasari, R.; Riani, E.; Zheng, S.; Sun, X. and Wang, Z. (2024). Microplastic occurrence in sub-surface waters of the Indonesian archipelago. *Frontiers in Marine Science*, *11*(March), 1–16. https://doi.org/10.3389/fmars.2024.1362414

Crawford, C. B. and Quinn, B. (2017). Microplastic Pollutants. In *Microplastic Pollutants*. Elsevier. https://doi.org/10.1016/C2015-0-04315-5

Digka, N. Tsangaris, C.; Torre, M.; Anastasopoulou, A. and Zeri, C. (2018). Microplastics in mussels and fish from the Northern Ionian Sea. *Marine Pollution Bulletin*, *135*(February), 30–40. https://doi.org/10.1016/j.marpolbul.2018.06.063

Dodson, G. Z.; Shotorban, A. K.; Hatcher, P. G.; Waggoner, D. C.; Ghosal, S. and Noffke, N. (2020). Microplastic fragment and fiber contamination of beach sediments from selected sites in Virginia and North Carolina, USA. *Marine Pollution Bulletin*, *151*(January), 110869. https://doi.org/10.1016/j.marpolbul.2019.110869

Eriksen, M.; Mason, S.; Wilson, S.; Box, C.; Zellers, A.; Edwards, W.; Farley, H. and Amato, S. (2013). Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Marine Pollution Bulletin*, *77*(1–2), 177–182. https://doi.org/10.1016/j.marpolbul.2013.10.007

Feng, Z.; Zhang, T.; Li, Y.; He, X.; Wang, R.; Xu, J. and Gao, G. (2019). The accumulation of microplastics in fish from an important fish farm and mariculture area, Haizhou Bay, China. *Science of the Total Environment*, *696*, 133948. https://doi.org/10.1016/j.scitotenv.2019.133948

Fikri, I.; Riani, E. and Nedi, S. (2024). Types and Abundance of Microplastics in

Seawater and Sediment at Padang Beach Tourism Area, West Sumatra, Indonesia. *Environmental Forensics*, *0*(0), 1–11. https://doi.org/10.1080/15275922.2024.2432497

Filgueiras, A. V.; Preciado, I.; Cartón, A. and Gago, J. (2020). Microplastic ingestion by pelagic and benthic fish and diet composition: A case study in the NW Iberian shelf. *Marine Pollution Bulletin*, *160*(April), 111623. https://doi.org/10.1016/j.marpolbul.2020.111623

García, J.; Allen, S.; Allen, D. and Palacios-Mateo, C. (2020). Microplastic pollution in commercially important fish species from the Amazon River. *Environmental Pollution*, 258, 113697. https://doi.org/10.1016/j.envpol.2019.113697

GESAMP. (2019). *Guidelines for the monitoring & assessment of plastic litter in the ocean Reports & Studies 99 Ryan; Peter G; Turra; Alexander; Galgani; François; Kershaw; Peter John*. *99*(February).

Hermawan, R.; S Adel, Y.; Renol, R.; Syahril, M. and Mubin, M. (2022). Study of Microplastics in Fish Consumed by Communities in Palu Bay, Central Sulawesi. *Journal of Marine Research*, *11*(2), 267–276. https://doi.org/10.14710/jmr.v11i2.32321

Hossain, M. S; Sobhan, F.; Uddin, M. N.; Sharifuzzaman, S. M.; Chowdhury, S. R.; Sarker, S. and Chowdhury, M. S. N. (2019). Microplastics in fishes from the Northern Bay of Bengal. *Science of the Total Environment*, *690*, 821–830. https://doi.org/10.1016/j.scitotenv.2019.07.065

Idowu, G. A.; Oriji, A. Y.; Olorunfemi, K. O.; Sunday, M. O.; Sogbanmu, T. O.; Bodunwa, O. K., Shokunbi, O. S. and Aiyesanmi, A. F. (2024). Why Nigeria should ban single-use plastics: Excessive microplastic pollution of the water, sediments and fish species in Osun River, Nigeria. *Journal of Hazardous Materials Advances*, *13*(January), 100409. https://doi.org/10.1016/j.hazadv.2024.100409

Jiang, C.; Yin, L.; Li, Z.; Wen, X.; Luo, X.; Hu, S.; Yang, H.; Long, Y.; Deng, B.; Huang, L. and Liu, Y. (2019). Microplastic pollution in the rivers of the Tibet Plateau. *Environmental Pollution*, *249*, 91–98. https://doi.org/10.1016/j.envpol.2019.03.022

Jose, D. M. and Radhakrishnan, P. D. (2023). A Review on Aquaculture Important Fish Chanos Chanos, Forsskal 1775, The Milkfish. *Journal of Aquaculture In The Tropics*, *37*(1–4), 1–26. https://doi.org/10.32381/JAT.2022.37.1-4.1

Khan, F. R., Shashoua, Y.; Crawford, A.; Drury, A.; Sheppard, K.; Stewart, K. and

Sculthorp, T. (2020). "The plastic nile": First evidence of microplastic contamination in fish from the nile river (Cairo, Egypt). *Toxics*, *8*(2). https://doi.org/10.3390/TOXICS8020022

Larasati, G.; Wuri, D. A. and Kallau, N. H. G. (2024). Identification of Microplastics in Skipjack Tuna (Auxis Rochei) and Mackerel Tuna (Euthynnus Affinis) at the Oeba Fish Landing Base (PPI), Kupang. Journal of Veterinary Studies, *12*(1), 27–40. https://doi.org/10.35508/jkv.v12i1.12080

Lessy, M. R., and Sabar, M. (2021). Microplastics Ingestion by Skipjack tuna (Katsuwonus pelamis) in Ternate, North Maluku - Indonesia. *IOP Conference Series: Materials Science and Engineering*, *1125*(1), 012085. https://doi.org/10.1088/1757-899x/1125/1/012085

Lumban Tobing, S. J. B.; Hendrawan, I. G. and Faiqoh, E. (2020). Characteristics of Microplastics in Consumed Marine Fish Landed in Bali. Journal of Marine Research and Technology , *3*(2), 102. https://doi.org/10.24843/jmrt.2020.v03.i02.p07

Lusher, A. L.; McHugh, M. and Thompson, R. C. (2013). Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Marine Pollution Bulletin*, *67*(1–2), 94–99. https://doi.org/10.1016/j.marpolbul.2012.11.028

Mardiyana, M. and Kristiningsih, A. (2020). The Impact of Microplastic Pollution in Marine Ecosystems on Zooplankton: A Review. Journal of Environmental Pollution Control (JPPL), *2*(1), 29–36. https://doi.org/10.35970/jppl.v2i1.147

Murphy, F.; Russell, M.; Ewins, C. and Quinn, B. (2017). The uptake of macroplastic & microplastic by demersal & pelagic fish in the Northeast Atlantic around Scotland. *Marine Pollution Bulletin*, *122*(1–2), 353–359. https://doi.org/10.1016/j.marpolbul.2017.06.073

Neves, D.; Sobral, P.; Ferreira, J. L. and Pereira, T. (2015). Ingestion of microplastics by commercial fish off the Portuguese coast. *Marine Pollution Bulletin*, *101*(1), 119–126. https://doi.org/10.1016/j.marpolbul.2015.11.008

Nur, W.O.N.A.L.D.; Kantun, W. and Kabangnga, A. (2021). ANALYSIS OF MICROPLASTIC CONTENT IN THE INTESTINES OF BIG-EYED TUNA (Thunnus obesus) LANDED AT WAKATOBI FISHERY PORT. Journal of Tropical Marine Science and Technology, *13*(2), 333–343. https://doi.org/10.29244/jitkt.v13i2.34871

Ory, N.C.; Sobral, P.; Ferreira, J.L. and Thiel, M. (2017). Amberstripe scad

Decapterus muroadsi (Carangidae) fish ingest blue microplastics resembling their copepod prey along the coast of Rapa Nui (Easter Island) in the South Pacific subtropical gyre. *Science of the Total Environment*, *586*, 430–437. https://doi.org/10.1016/j.scitotenv.2017.01.175

Priyambada, G.; Kurniawan, B.; Sitompul, R.G. and Darmayanti, L. (2023). The abundance of microplastics in Siak tributary sediments in the watershed area, Pekanbaru City, Riau (Case Study Sago River). *Materials Today: Proceedings*, *87*, 272–277. https://doi.org/10.1016/j.matpr.2023.03.207

Purnama, D.; Johan, Y.; Wilopo, M.D.; Renta, P.P.; Sinaga, J.M.; Yosefa, J.M. and M.H.M. (2021). ANALYSIS OF MICROPLASTICS IN THE DIGESTIVE TRACT OF SKIPJACK TUNA (*Euthynnus affinis*) CAUGHT BY FISHERMEN AT THE FISHING PORT OF PULAU BAAI, BENGKULU CITY. Jurnal Enggano,*6*(1), 110–124.

Rao, B. M. (2019). Microplastics in the aquatic environment: Implications for post-harvest fish quality. *Indian Journal of Fisheries*, *66*(1), 142–152. https://doi.org/10.21077/ijf.2019.66.1.83125-20

Rochman, C. M. (2015). The Complex Mixture, Fate and Toxicity of Chemicals Associated with Plastic Debris in the Marine Environment. In M. Bergman, L. Gutow, & M. Klages (Eds.), *Marine Anthropogenic Litter* (pp. 117–140). Springer International Publishing. https://doi.org/10.1007/978-3-319-16510-3_5

Rochman, C.M.; Tahir, A.; Williams, S.L.; Baxa, D.V.; Lam, R.; Miller, J.T.; Teh, F.C.; Werorilangi, S. and Teh, S.J. (2015). Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. *Scientific Reports*, *5*(August), 1–10. https://doi.org/10.1038/srep14340

Rodrigues, S.M.; Almeida, C.M.R. and Ramos, S. (2020). Microplastics contamination along the coastal waters of NW Portugal. *Case Studies in Chemical and Environmental Engineering*, *2*(September), 100056. https://doi.org/10.1016/j.cscee.2020.100056

Sánchez-Hernández, L.J.; Ramírez-Romero, P.; Rodríguez-González, F.; Ramos-Sánchez, V.H.; Márquez Montes, R. A.; Romero-Paredes Rubio, H.; Sujitha, S.B. and Jonathan, M.P. (2021). Seasonal evidence of microplastics in environmental matrices of a tourist-dominated urban estuary in the Gulf of Mexico, Mexico. *Chemosphere*, *277*. https://doi.org/10.1016/j.chemosphere.2021.130261

Sarasita, D.; Yunanto, A. and Yona, D. (2020). Microplastics abundance in four different species of commercial fish in the Bali Strait. *Jurnal Iktiologi Indonesia*, *20*(1), 1. https://doi.org/10.32491/jii.v20i1.508

Senduk, J.L.; Suprijanto, J. and Ridlo, A. (2021). Microplastics in Mackerel (*Rastrelliger* sp.) and Horse Mackerel (*Selaroides eptolepis*) at Tambak Lorok Semarang Fish Market and Tawang Rowosari Kendal Fish Market. *Buletin Oseanografi Marina*, *10*(3), 251–258. https://doi.org/10.14710/buloma.v10i3.37930

Sharma, S. and Chatterjee, S. (2017). Microplastic pollution, a threat to marine ecosystem and human health: a short review. *Environmental Science and Pollution Research*, *24*(27), 21530–21547. https://doi.org/10.1007/s11356-017-9910-8

Strand, J.; Lassen, P,; Shashoua, Y. and Andersen, J. H. (2013). Microplastic particles in sediments from Danish waters. *ICES Annual Science Conference, 23 – 27 September 2013*, *September*, 4000.

Sun, X.; Li, Q.; Shi, Y.; Zhao, Y.; Zheng, S.; Liang, J.; Liu, T. and Tian, Z. (2019). Characteristics and retention of microplastics in the digestive tracts of fish from the Yellow Sea. *Environmental Pollution*, *249*, 878–885. https://doi.org/10.1016/j.envpol.2019.01.110

Suwartiningsih, N. and Nafi'a, N.M. (2023). Microplastics in the digestive tract of fish consumed from Supermarket X in Sleman Regency, DIY Province. National Seminar *VII*, *2030*, 655–666.

Tu, G.; Zheng, H; Yang, J.; Zhou, H.; Feng, C. and Gao, H. (2025). High-Performance Polyolefin Material: Synthesis, Properties, and Application of Poly(4-Methyl-1-pentene). *International Journal of Molecular Sciences*, *26*(2), 1–19. https://doi.org/10.3390/ijms26020600

Vagholkar, P.K. (2016). *Nylon (Chemistry , Properties and Uses) (Chemistry , Properties and Uses) Chemistry*. *November*.

Vandermeersch, G.; Van Cauwenberghe, L.; Janssen, C. R.; Marques, A.; Granby, K.; Fait, G.; Kotterman, M.J.J; Diogène, J.; Bekaert, K.; Robbens, J. and Devriese, L. (2015). A critical view on microplastic quantification in aquatic organisms. *Environmental Research*, *143*(2014), 46–55. https://doi.org/10.1016/j.envres.2015.07.016

Wicaksono, E.A.; Werorilangi, S. and Tahir, A. (2021). The influence of weirs on microplastic fate in the riverine environment (case study: Jeneberang River, Makassar City, Indonesia). *IOP Conference Series: Earth and Environmental Science*, *763*(1). https://doi.org/10.1088/1755-1315/763/1/012054

Wright, S.L. and Kelly, F.J. (2017). Plastic and Human Health: A Micro Issue? *Environmental Science and Technology*, *51*(12), 6634–6647. https://doi.org/10.1021/acs.est.7b00423

Wright, S.L.; Rowe, D.; Thompson, R.C. and Galloway, T.S. (2013). Microplastic ingestion decreases energy reserves in marine worms. *Current Biology*, *23*(23), R1031–R1033. https://doi.org/10.1016/j.cub.2013.10.068

Zhang, X.; Wen, K.; Ding, D.; Liu, J.; Lei, Z.; Chen, X.; Ye, G.; Zhang, J.; Shen, H.; Yan, C.; Dong, S., Huang, Q. and Lin, Y. (2021). Size-dependent adverse effects of microplastics on intestinal microbiota and metabolic homeostasis in the marine medaka (*Oryzias melastigma*). *Environment International*, *151*, 106452. https://doi.org/10.1016/j.envint.2021.106452