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Microplastic contamination in pelagic fishes from the east coast of Peninsular Malaysia

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Abstract

Microplastic contamination in marine environments is a growing concern, particularly in fish species consumed by humans. This study investigates the presence and characteristics of microplastics in the livers of Indian mackerel (*Rastrelliger kanagurta*) and yellowtail scad (*Atule mate*) collected from Pahang and Kelantan. The abundance of microplastics was quantified for each species at each location, with the total count normalized by the number of fish analyzed following the extraction and identification process. Microplastic identification was conducted using a Stereoscopic Microscope, while polymer composition was determined through ATR-FTIR spectroscopy. The microplastic abundance recorded was 0.067 particles per fish. The microplastic identified were predominantly fragments and filaments in red, black, and grey colors. The polymers found were poly(diallyl phthalate) (PDAP), poly(butylene terephthalate) (PBT), polypropylene (PP), poly(cyclohexylenedimethylene terephthalate) (PCT), and high-density polyethylene (HDPE). The finding of microplastics in fish livers provides preliminary evidence of contamination and suggests direct exposure of these vital organs. This raises serious concerns about potential contamination in other crucial organs, including the gills, gastrointestinal tract, tissues, and even the brain. This highlights the need for further research on microplastic exposure pathways and its ecological implications along the east coast of Peninsular Malaysia.

Keywords: Microplastic pollution, Indian mackerel, yellowtail scad, marine contamination, fish organ, polymer degradation

Introduction

Malaysians heavily depend on marine fish as their main source of protein. Fisheries contributed 0.8% to the gross domestic product in 2021 and an average consumption of 34.08 kg per capita (SEAFDEC, 2022). However, the pervasive issue of microplastic contamination poses a threat to both human health and marine ecosystems. A study by Wootton et al. (2021), indicates a concerning prevalence of plastic ingestion among global fish populations, with 49% of sampled fish containing an average of 3.5 plastic pieces per individual.

Despite this, investigations into microplastic abundance have predominantly focused on the muscle, gills and gastrointestinal tracts of fish (Abbasi et al., 2018; Piskuła & Astel, 2023; Menéndez et al., 2023), neglecting crucial organs like the liver. The liver plays a vital role in filtering blood, detoxifying harmful substances, and maintaining metabolic functions in fish (Bruslé & i Anadon, 2017). The accumulation of microplastics in this organ suggests prolonged exposure and potential health implications for the fish (Bakieva et al., 2024). Unlike the gills and gastrointestinal tract, which offer pathways for microplastic expulsion through breathing and excretion, the liver retains these contaminants, posing a higher risk of bioaccumulation and adverse health effects (Lu et al., 2016). Consequently, assessing the abundance of microplastics in marine fish, especially in livers, is important for understanding the overall health status of marine fish and evaluating the safety of consuming them.

This research addresses a critical environmental and public health issue by focusing on the extent of microplastic contamination in the liver of Indian mackerel and yellowtail scad from Pahang and Kelantan. Indian mackerel and yellowtail scad are economically valuable species in Malaysia, widely consumed by local communities. Assessing microplastic contamination in these fish is crucial for evaluating potential risks to human health and food safety. The study aims to analyze the abundance and types of microplastics present in fish livers, providing crucial data on contamination levels and assessing the associated risks to human consumers. Given that Malaysia is one of the largest producers of plastic waste, the findings of this study are particularly relevant to addressing the impact of plastic pollution on the country's coastal waters.

The results of this study will provide important information on the extent of microplastic pollution in fish, which is crucial for understanding its impact on fish health and, by extension, human health. This information will be crucial for policymakers, environmental agencies, and the public health sector to develop and implement effective strategies to mitigate the environmental and public health risks associated with microplastic pollution in seafood. By contributing specific data on microplastics in marine commercial fish species, this study will help promote sustainable fisheries practices, improve waste management strategies, and mitigate the environmental impacts of plastic pollution in Malaysia's marine environments.

Methods

Study area

The study samples were collected from two key locations along the east coast of Peninsular Malaysia: LKIM Kuantan in Pahang and LKIM Tok Bali in Kelantan (Figure 1). Both sites are significant fisheries hubs under the Lembaga Kemajuan Ikan Malaysia (LKIM) where most of the fish from the east coast of Malaysia and the South China Sea landed at these ports. Both fishing ports are situated at the South China Sea which is also one of the most heavily trafficked and high with development and industrial activities in the world (Sany et al., 2018; Ezraneti et al., 2024).

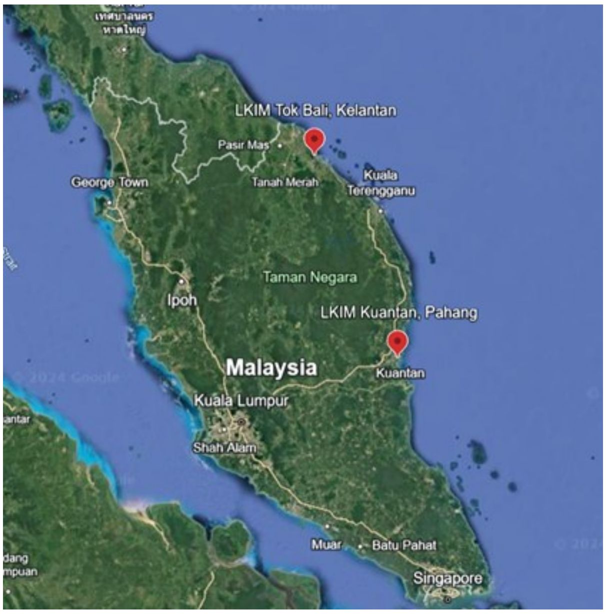

Figure 1. Map of selected sampling sites along the east coast of Malaysia.

Sample collection

At each sampling location, 30 fish samples of similar size of Indian mackerel and yellowtail scad were collected. These resulted in a total of 120 samples. Fish collected were covered with aluminium foil and kept in separate plastic zip for each sampling location. Then, it was placed in an ice box during transportation to the laboratory. After arrival at the laboratory, the fish were rinsed with distilled water to avoid contamination from microplastics in the air during the shipping and transfer of fish from the ice box to the freezer. The fish were then kept in a freezer at -20 °C until the next analysis.

Sample preparation and microplastic extraction

Dissection process

The fish that had been frozen in the freezer was retrieved and thawed at room temperature before the microplastic extraction stage. Following thawing, fish biometrics such as standard lengths, total lengths and total wet weight were calculated. The standard length was taken from the fish's mouth to the tail muscle, while the total length was taken from the mouth to the tail (Foo et al., 2022). The liver of the fish was dissected using surgical devices such as a scalpel and surgical scissors. Each liver was weighted with an electronic balance for the microplastic abundance assessment. To eliminate any airborne contamination, all dissection procedures were performed in the enclosed area of the microplastic laboratory.

Depuration process

The samples underwent a depuration process, which involved washing the liver parts with distilled water and using forceps to remove any externally attached plastics. This ensured that only microplastics present within the tissue were retained for digestion and analysis procedures (Lusher et al., 2017).

Digestion process

Each sample was digested individually to dissolve the organic matter and isolate the resistant materials. A 10% potassium hydroxide (KOH) solution was used to denature proteins and break the chemical bonds in the fish liver samples. As a strong base, 10% KOH proved to be the most effective method for removing microplastics from biological samples (Rochman et al., 2015; Dehaut et al., 2016). The solution was prepared with a ratio of 1g of liver to 10 ml of KOH solution (Karami et al., 2016). For each digestion session, a total of 31 Schott bottles, including the control, were incubated overnight at 60 °C in the oven with 60 ml of 10% KOH.

Filtration process

All the digested samples were vacuum filtered using Whatman GF/C filters (1.2 μm pore size, 47 mm diameter) with a porcelain Büchner funnel. The filter paper was then placed into a glass petri dish and dried in an oven at 60 °C.

Microplastic identification and analysis

The identification of microplastics was determined using a stereoscopic microscope (Nikon SMZ2745). The characteristics of the microplastics were studied for classification purposes such as types of polymers, size, shape, and color. In addition, the verification of the polymers was analyzed using the ATR Fourier Transform Infra-Red spectrometry (FTIR). The polymers identified with a search score > 0.60 were taken as results (Woodall et al., 2014).

Contamination prevention

Contamination prevention measures were crucial to maintain quality assurance throughout the process. All work surfaces, glassware, and equipment were carefully cleaned with 70% ethanol and rinsed with distilled water before use. Tools and samples were covered with aluminum foil to protect them from contamination. Nitrile gloves and cotton laboratory coats were worn at all times during processing and analysis. All procedures were conducted under a laminar airflow hood to minimize contamination from airborne particles. Additionally, field blanks were used during the digestion process to detect any potential contamination, and the microplastics found in the blanks were subtracted from the final results.

Data analysis

The abundance of microplastics was calculated for each species at each location (e.g., Indian mackerel from Pahang, Indian mackerel from Kelantan) by summing the total number of microplastic particles found across all fish samples for that species at that location. This total was then divided by the number of fish examined (30 samples per species per location) to determine the average number of microplastic particles per fish, expressed as particles ind^{-1} (Hidayati et al., 2023; Boerger et al., 2010). The data were analyzed descriptively, and the shapes, sizes, colors, and polymer compositions of the microplastics retrieved were expressed as percentage distributions for each species and location.

Results

Microplastic abundance

The abundance of microplastics found in fish liver at Pahang and Kuantan was recorded in Table 1. The liver samples of two fish species have resulted in a total of 28 particles. Only six particles were identified by FTIR analysis as polymers. The reported findings were based on a search score from the polymers library that exceeded 60% similarity. The amount of polymer found in the collected control samples was designated a contaminant and subtracted from the study's final conclusion.

Table 1. The abundance of microplastics in fish livers from Pahang and Kelantan.

Location	Fish sample	MPs particles	MPs abundance (particles ind^{-1})
Pahang	Indian mackerel	2	0.067
	Yellowtail scad	2	0.067
Kelantan	Indian mackerel	2	0.067
	Yellowtail scad	0	0

Microplastics size

The size range of microplastics detected was from 62.57 μm to 236.87 μm. The smallest microplastic detected was 62.57 μm found in Indian mackerel from Pahang, while the largest was 236.87 μm, found in the Indian mackerel from Kelantan (Figure 2).

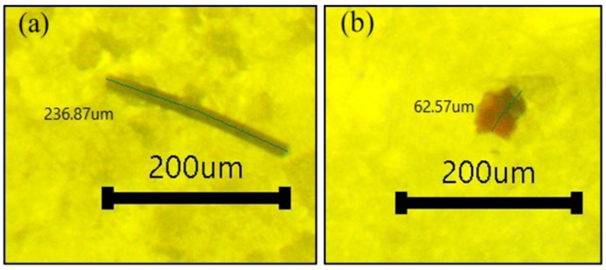

Figure 2. The largest (a) and the smallest (b) Size of MPs found in fish liver.

Microplastics shape

The shape of microplastics found in the fish liver can be categorized into filaments and fragments (Table 2 and Figure 3). Fragment-shaped microplastics were the most dominant type found in both species in Pahang and Indian mackerel from Kelantan, while filament-shaped microplastics were only found in Indian mackerel from Kelantan.

Table 2. Shapes of microplastics found in fish liver from Pahang and Kelantan.

Location	Filament	Fragment	Total
Pahang	0	4	4
Kelantan	1	1	2

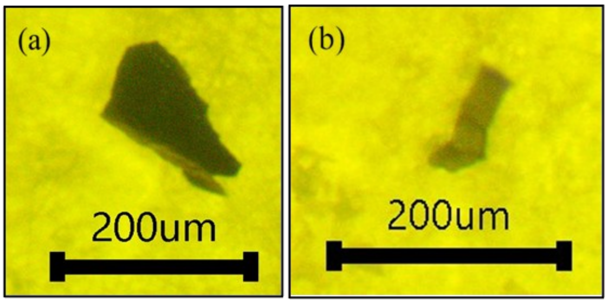

Figure 3. Fragment-shaped (a) and filament-shaped (b) of MPs found in fish liver.

Microplastic color

The color distribution of microplastics found in Indian mackerel and yellowtail scad for Kelantan and Pahang were black, red, and grey (Figure 4 and Figure 5).

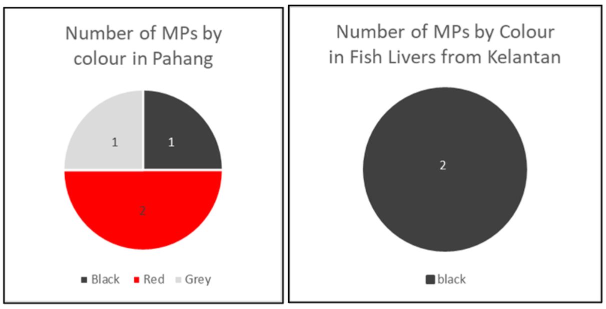

Figure 4. Numbers of microplastics by colour in fish livers from Pahang (left) and Kelantan (right).

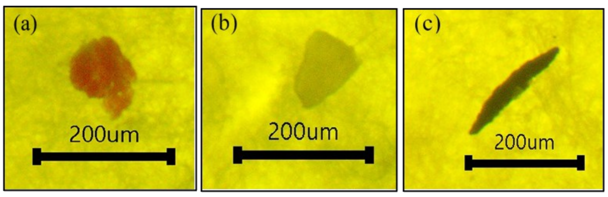

Figure 5. Colours of MPs found in fish liver were red (a), grey (b), and black (c).

Type of polymer

Several types of polymers were identified in the fish samples from Pahang and Kelantan (Figure 6). The polymers found include poly(diallyl phthalate) (PDAP, Figure 7), poly(butylene terephthalate) (PBT, Figure 8), poly(cyclohexylenedimethylene terephthalate) (PCT, Figure 9), polypropylene (PP, Figure 10), and high-density polyethylene (HDPE, Figure 11). The presence of these polymers suggests the variety of plastic products entering marine environments, with different types of plastics being contaminated by the fish.

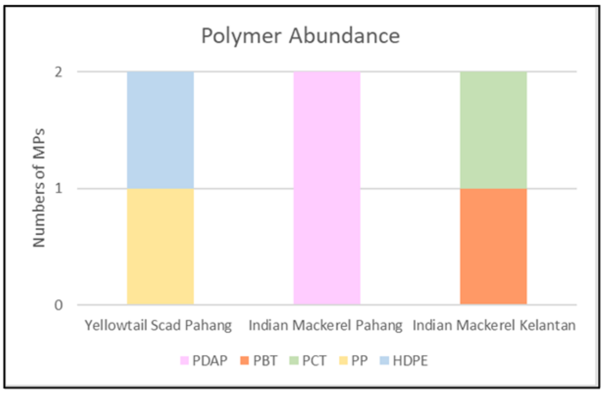

Figure 6. Abundance of MPs polymers found in fish livers.

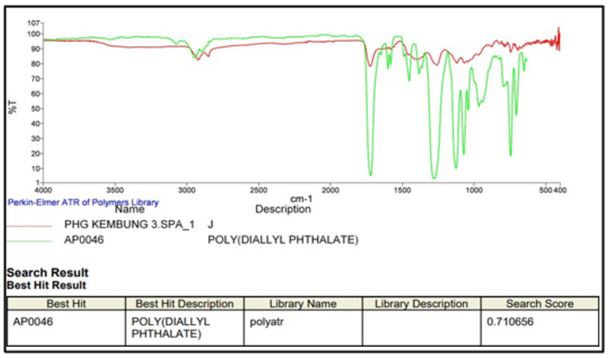

Figure 7. Comparison of polymer spectrum and the suggested MPs spectrum for poly(diallyl phthalate) (PDAP).

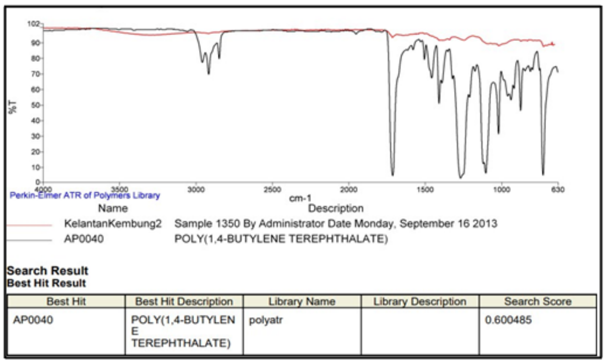

Figure 8. Comparison of polymer spectrum and the suggested MPs spectrum for poly(butylene terephthalate) (PBT).

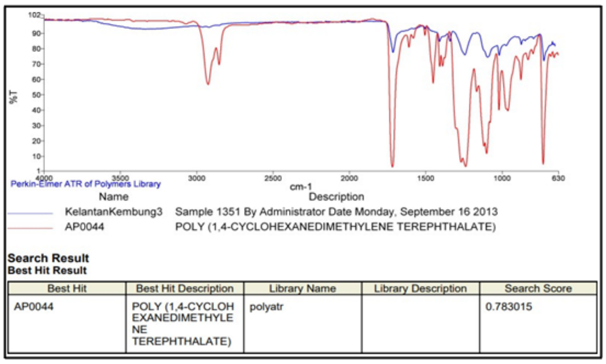

Figure 9. Comparison of polymer spectrum and the suggested MPs spectrum for poly(cyclohexylenedimethylene terephthalate) (PCT).

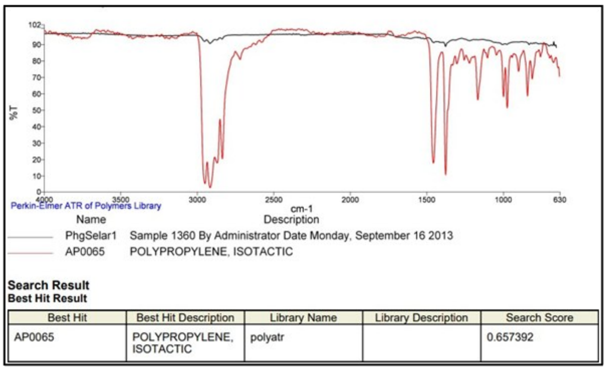

Figure 10. Comparison of polymer spectrum and the suggested MPs spectrum for polypropylene (PP).

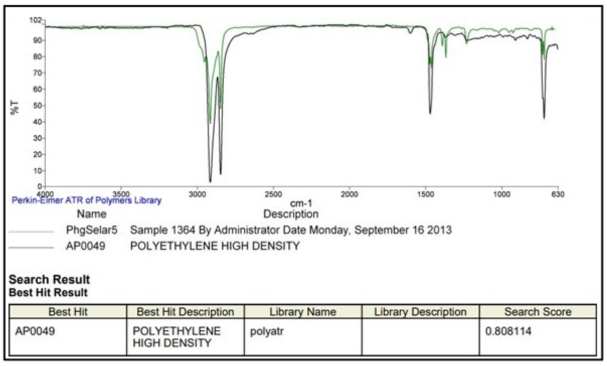

Figure 11. Comparison of polymer spectrum and the suggested MPs spectrum for high-density polyethylene (HDPE).

Discussion

Microplastic abundance in fish liver

The number of microplastics particles discovered in fish liver was small where only 2 particles were found from 30 samples for both species in Pahang and in Indian mackerel from Kelantan. Compared to previous research by Collard et al. (2017) and Avio et al. (2015), which reported 1–2 microplastic particles per liver, the microplastic abundance in this study is considerably lower. The microplastic abundance in both species and locations ranges from 0.00 to 0.067 particles per individual fish. The abundance was observed in Indian mackerel and yellowtail scad from Pahang and Indian mackerel from Kelantan (0.067 particles·ind^{-1}). However, no microplastic particles were detected in the liver of yellowtail scad from Kelantan. This could be due to the sample size of 30 fish per species may not have been sufficient to detect contamination in this species. A larger sample size, such as 60 fish, could provide more accurate results by increasing the chances of detecting microplastics.

The variation in microplastic abundance can be linked to species behavior and distinct environmental factors affecting each region. Indian mackerel is a highly migratory pelagic species (Wujdi et al., 2022). This means that individuals found in Pahang and Kelantan may have been exposed to microplastics from other regions before being caught. Additionally, Indian mackerel are pelagic filter feeders, meaning they actively consume plankton and other particles suspended in the water column (Nath, 2015). This feeding behavior increases their likelihood of ingesting microplastics, which explains why microplastic particles were found in Indian mackerel from both locations.

In contrast, yellowtail scad have different feeding behaviors. Juveniles mainly consume copepods and shrimp parts, while adults feed on fish and cephalopods (Knuckey et al., 2008). This diet may result in a lower likelihood of ingesting microplastics compared to Indian mackerel, which filter-feed directly from the water column. Future studies could explore whether differences in feeding strategies influence microplastic ingestion rates in these species.

Both Pahang and Kelantan are located along Malaysia's east coast, bordering the South China Sea, which is one of the busiest shipping routes globally. Ships passing through the South China Sea may release plastic waste either accidentally or illegally, which eventually fragments into microplastics. Studies have confirmed the presence of microplastics in the South China Sea (Cui et al., 2022; Zheng et al., 2023). Additionally, microplastics in open oceans are heavily influenced by ocean currents (Cui et al., 2022). Hence, microplastics originating from other countries bordering the South China Sea, such as Vietnam, China, and Thailand, can be transported by these currents and deposited along the coastlines of Pahang and Kelantan (Nguyen et al., 2023).

In Pahang, particularly in Kuantan, the presence of industrial activities such as petrochemical production, oil refining, and shipping may significantly contribute to microplastic contamination. As a major multi-cargo port, Kuantan experiences high maritime traffic, which increases the risk of plastic waste entering the marine environment through shipping-related activities, accidental spills, and improper waste disposal (Yap et al., 2021). Furthermore, urban runoff from Kuantan's rapidly expanding residential and commercial areas introduces microplastics into the marine ecosystem. These factors align with findings by Khalik et al. (2018), which reported a high abundance of microplastic particles in Kuantan's seawater. This explains the finds of microplastic in both Indian mackerel and yellowtail scad from Pahang.

Meanwhile, microplastic pollution in Kelantan may be influenced by fishing activities, riverine inputs, and agricultural runoff. Saipolbahri et al. (2020) reported microplastics have been found in surface water and sediments throughout the Kelantan coastline. Tok Bali, a significant fishing hub, likely contributes to microplastic pollution through the discarding or degradation of fishing gear such as nets and lines. The Kelantan River serves as a major transport pathway for plastic waste originating from upstream urban and agricultural areas, ultimately reaching the South China Sea. Microplastics may also originate from tourism activities and the degradation of plastics used by fishermen for capturing fish or selling goods (Saipolbahri et al., 2020).

The microplastic abundance found in fish livers in this study was relatively low, at 0.067 particles per individual fish. In comparison, microplastic pollution has been widely detected across various ecosystems, including estuaries, beaches, marine and freshwater bodies, coastal and offshore areas, agricultural soils, and even the atmosphere (Noor et al., 2024). The eastern states of Peninsular Malaysia includes Terengganu, Kelantan, and Pahang contribute significantly to plastic waste, generating approximately 0.71 kg per capita daily (Sulaiman et al., 2023). In Kuantan microplastic concentrations in water have been reported between 0.13 and 0.69 particles per liter (Khalik et al., 2018). These findings suggest that while microplastic contamination is evident in the environment, its presence in fish livers remains relatively low.

Microplastic characteristic in fish liver: Size, shape, and color

The average size of the particles present in the liver was similar to the findings of other researchers : 214µm to 288 µm (Jovanović et al., 2017), 123µm to 438µm (Collard et al., 2017) and 200µm to 600 µm (Avio et al., 2015). Particle size significantly affects how microplastics travel to the liver. In several vertebrate species, particles smaller than 5 µm may traverse intestinal cells (enterocytes) by transcytosis and enter the circulatory system, while particles ranging from 5 to 150 µm are absorbed through the intestinal villi via persorption (Kaur et al., 2024;). Larger particles are more likely to remain in the liver, while small particles are more likely to be removed from the liver through circulation (Jovanović et al., 2017). However, the exact mechanism of microplastic translocation across fish liver remains unclear.

The microplastics found in fish livers from Pahang and Kelantan exhibited significant size variations, with Pahang samples containing smaller particles and Kelantan samples having larger ones. Pahang's coastal waters may experience stronger wave energy and ocean currents due to its proximity to Kuantan Port and its exposure to open waters of the South China Sea. Strong waves and currents increase the physical breakdown of plastic debris, leading to smaller microplastic particles. In contrast, Kelantan's waters, especially near Tok Bali, may experience weaker currents due to the influence of the Kelantan River estuary. Rivers typically deposit larger particles into the ocean, as there is less mechanical force to break them down before they reach the marine environment. This means that plastics entering the ocean near Pahang are subjected to harsher conditions, fragmenting them into smaller pieces, while in Kelantan, larger plastic debris may persist longer before breaking down.

The dominance of fragment-shaped microplastics aligns with findings from other studies in Malaysia, where fragments are frequently identified as a common type of microplastic found in seawater (Khalik et al., 2018), sediment (Saipolbahri, 2020), and fish (Foo et al., 2022). Microplastics in the marine environment undergo changes in their physical characteristics due to various factors. UV radiation from sunlight exposure can break down the chemical structure of plastics through photodegradation, leading to the formation of smaller particles (Andrady, 2011; Wei et al., 2020). Additionally, mechanical forces such as wave action and collisions can fragment larger plastic pieces into smaller microplastics (Wei et al., 2020). Fragment-shaped particles are often formed through the breakdown of larger plastic items, such as plastic containers, packaging materials, and cleaning products (Zhang et al., 2023; Derraik, 2002). The abundance of fragment-shaped particles in Pahang aligns with the findings of Khalik et al. (2018), who reported that fragmented shapes accounted for 50.8–66.1% of total microplastics at Kuantan Port, potentially explaining their dominance in the current study.

Meanwhile, the decomposition of used fishing gear and clothing can contribute to the presence of filament-shaped microplastics in the environment (Cesa et al., 2017). The presence of these particles is likely linked to poorly managed plastic waste and uncontrolled disposal practices near coastal areas, which lead to plastic degradation and the introduction of microplastics into marine ecosystems (Biswas & Ganguly, 2025).

In Pahang, microplastics were predominantly red, followed by black and grey. This suggests that the red particles may originate from specific types of plastic products commonly used or discarded in the region. In contrast, all microplastics found in Kelantan were black. The black microplastics could indicate the presence of particular plastic materials that degrade into this color or the influence of specific local environmental factors. Plastic manufacturing industries often introduce a variety of colors to differentiate and attract consumers to their goods. However, the originally colored microplastics, like red and green, often lose their vibrant hues and become opaque or black after being ingested by marine organisms. This color change occurs as the degradation process alters the plastic's original pigmentation (Etzrodt, 2022). Additionally, many plastic products are commonly produced in black, which could explain the high percentage of black microplastics observed in this study.

Type of Polymer contained in fish liver

Poly(diallyl phthalate) (PDAP) was detected in Indian mackerel from Pahang, indicating that this polymer specifically contaminates this species. Indian mackerel are schooling fish, suggesting that their contamination might be linked to their feeding patterns in areas with high levels of plastic pollution. PDAP falls under the category of phthalic acid esters (PAEs), commonly known as phthalates. These are widely used plasticizers, making up to 40% of final plastic products, as they enhance the flexibility and durability of plastics (Zhang et al., 2023; Paluselli & Kim, 2020). PDAP is commonly used in electrical components, cables, wires, construction materials, furniture coatings, toys, food-contact materials, packaging, and medical devices (Net et al., 2015). Studies by Kingsley and Witthayawirasak (2020), Paluselli and Kim (2020), and Paluselli et al. (2018) reported the presence of PDAP in seawater, floating between the bottom water layer and the bed sediment. This position in the water column makes PDAP accessible to marine organisms, increasing the likelihood of ingestion and contamination. Additionally, a study by Hu et al. (2016) found that PAEs tend to accumulate in fish kidneys, gills, bile, liver, and muscle. While the study did not specifically investigate PDAP, it is reasonable to assume that PDAP, as a type of PAE, might follow similar pathways. This suggests that PDAP accumulates in the liver of Indian mackerel from Pahang, reflecting its potential impact on marine ecosystems and organisms.

Polypropylene (PP) is a versatile thermoplastic polymer extensively used in various industries due to its toughness, rigidity, and resistance to heat. Common applications of PP include food packaging, plastic straws, ropes, fishing gear, and single-use plastic items (Rahmawati et al., 2023; Hidayati et al., 2023). In this study, PP microplastics were detected in yellowtail scad collected from Pahang waters. PP particles has been found in seawater (Khalik et al., 2018), sediments (Ezraneti et al., 2024), coral species (Miskon et al., 2024) and fish (Ezraneti et al., 2024) at Kuantan Pahang suggested that the coastal zones of Kuantan are particularly vulnerable due to industrial activities and the maritime operations at nearby ports.

PP is also used in the production of face masks (Wang et al., 2021). Since the COVID-19 pandemic, face masks have been used daily, and it has been reported that around 1.56 billion face masks entered the oceans in 2020 (Ma et al., 2022). As these masks degrade, they contribute to marine plastic debris, and the PP they contain can lead to contamination of the ocean environment through the release of microplastics and other harmful substances.

Meanwhile, high-density polyethylene (HDPE) is a durable and robust polymer widely used in manufacturing plastic products such as milk jugs, shampoo bottles, grocery bags, plastic containers, and fishing equipment (Hidayati et al., 2023). Moreover, poly(butylene terephthalate) (PBT) and poly (cyclohexylenedimethylene terephthalate) (PCT) are thermoplastics polyester commonly used in industries for their durability and versatility in producing automotive parts, electrical components, industrial fabrics and consumer products (Turner & Liu, 2012). These HDPE, PBT and PCT polymers may enter the marine environment through improper waste disposal, industrial runoff, and degradation of plastic products.

Previous studies on microplastic (MP) contamination in Malaysia and neighboring regions have commonly reported polyethylene (PE), polypropylene (PP), polystyrene (PS), polyamide (PA), and poly(vinyl chloride) (PVC) as the dominant polymer types in marine water, sediments, and fish tissues (Ezraneti et al., 2024; Noor et al., 2024; Hidayati et al., 2023; Rahmawati et al., 2023). These polymers are widely used in packaging, textiles, and consumer products, making them the most prevalent microplastics in aquatic environments.

However, the polymers found in this study are uncommon compared to previous research, except for PP and HDPE. The presence of PDAP, PBT, and PCT may likely come from industrial discharge or localized pollution rather than general plastic waste. Their properties, such as buoyancy and degradation rate, may affect their accumulation in fish livers. Biological factors like selective ingestion and metabolism could also influence the types of MPs detected. This highlights the need for further research on site-specific pollution sources and their impact on fish contamination.

Future studies should focus on including a wider variety of commercial fish species to get a better understanding of how microplastics affect different types of marine life. More sampling sites along the east coast of Peninsular Malaysia, like Terengganu and Johor, should be considered to see how microplastic pollution varies in different areas. Expanding the study to include both pelagic and demersal fish species will offer insights into how contamination varies between open-water and bottom-dwelling habitats. Furthermore, the potential source of microplastics identification is suggested to be further studied by recording all anthropogenic activities being held along the coastal area of Pahang and Kelantan waters. Contamination prevention is crucial in this study as the microplastics particles may be presented in the air and fill the whole research area.

Conclusions

This study confirmed the presence of microplastics (MPs) in the fish livers of Indian mackerel and yellowtail scad from Pahang and Kelantan. The objective of determining the abundance of microplastics in the livers of Indian mackerel and yellowtail scad from Pahang and Kelantan was achieved.

The abundance of microplastics ranged from 0.00 to 0.067 particles per individual fish, with 0.067 particles·ind^{-1} observed in Indian mackerel and yellowtail scad from Pahang and Indian mackerel from Kelantan. The presence of MPs in the fish liver highlights contamination and suggests these organs have been directly affected by microplastic particles. This also raises concerns that other organs, such as the gills, gastrointestinal tract, tissues, and brain, may similarly be contaminated.

Microplastic polymers found in the livers were categorized by size, shape, color, and type. Fragment-shaped and black-colored microplastics were the most abundant. FTIR analysis identified polymers such as PDAP, PBT, PCT, PP, and HDPE. This revealed varying contamination in marine fish from Pahang and Kelantan.

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Authorship contribution

Ain Waznin Nuha Ahmad Nawawi: Conceptualization, methodology, data collection, laboratory analysis, writing–original draft preparation; writing–review and editing. **Riri Ezraneti:** Laboratory analysis, data collection. **Mohd Fuad Miskon:** Conceptualization, methodology, Writing–review and editing. **Juliana Mohamed:** Conceptualization, methodology, writing–review and editing, supervision, Project administration. All authors reviewed and approved the final manuscript and are responsible for the integrity and accuracy of the work.

Data availability

Datasets generated during and/or analysed throughout the present study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare no conflict of interest.

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