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Microplastic contamination in the gut and gills of commercial marine fish

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ABSTRACT

BACKGROUND AND OBJECTIVES: In recent decades, there has been significant advancement in scholarly research focused on detecting pollutants in marine environments and assessing the potential risks associated with seafood, particularly marine fish. The advancement has been predominantly influenced by the detection of microplastics, which have the ability to permeate food webs via both direct and indirect pathways. Microplastic pollution poses a substantial health risk to organisms at all levels of the food chain, including humans, who are top consumers. Despite the global concern, there is a lack of extensive research on microplastics in fish in Indonesia. The reliance of coastal communities in Indonesia on marine resources raises concerns regarding the potential impact of microplastic contamination. This study sought to assess the extent of microplastic pollutants in commercially caught marine fish from Jakarta Bay, a densely populated and industrialized coastal area accommodating more than 35 million inhabitants.

METHODS: The study was conducted at five nearby fresh seafood markets in the northern part of Jakarta, where marine fish specimens were collected between December 2023 and January 2024. In total, 160 samples were gathered, with 20 individuals representing each of the eight diverse marine fish species. The approved protocol for extracting microplastics, which incorporates biological digestion, density separation, and microplastic identification, was strictly followed, although some adaptations were made as the process unfolded. Preventative actions were enacted in order to decrease the risk of microplastic cross-contamination.

FINDINGS: It was determined through analysis that 93.75 percent (150 out of 160) of the fish studied contained microplastics, which were detected in samples obtained from both the gut and gill samples. On average, each fish had 3.65 ± 2.34 particles per individual, or approximately 0.12 ± 0.21 particles per gram. Microplastics were found in 81.25 percent of gut samples and 79.38 percent of gill samples. The abundance of microplastics in gut (1.79 ± 1.19 particles per individual) was slightly lower than in gills (1.86 ± 1.30 particles per individual). The variance in microplastic content between the two organs did not reach statistical significance. Fish with carnivorous feeding habits demonstrated a higher average microplastic content when contrasted with those utilizing omnivorous and planktivorous feeding strategies. Fish living in the benthopelagic region tended to have slightly more microplastic particles than those in benthic coastal water and pelagic coastal water. Most of the microplastics detected in commercial marine fish were in the size range of 2000-5000 micrometers, with the majority being in the form of fragments and fibers. The study also pinpointed seven specific polymer classifications, which consist of polyethylene, polypropylene, polystyrene, nylon, polyester, polybutadiene, and polyethylene terephthalate.

CONCLUSION: The escalating levels of microplastics in the environment present a substantial threat to food security, marine ecosystems, and human health. It is imperative to develop a standardized risk assessment mechanism utilizing advanced tools and methodologies to quantify the levels of microplastics in the environment and living organisms as the study moves forward. It is imperative that both capture fisheries and aquaculture undergo thorough assessments of risks and hazards. This study underscores the significance of monitoring plastic waste in the Greater Jakarta area and its adjacent coastlines. Further study is essential to evaluate the magnitude of plastic pollution in fish tissues that are consumed by humans, and to assess the potential consequences for food safety.

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96	8	1

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INTRODUCTION

In recent decades, there has been a notable rise in the desire for seafood, mainly because of its plentiful nutritional perks. Seafood offerings boast high levels of energy, protein, omega-3 fatty acids, polyunsaturated fatty acids, and vital vitamins and minerals (Gunning *et al.*, 2016; Teixeira and Silva, 2024). The consumption of seafood has been linked to numerous health benefits, such as the ability to lower the likelihood of developing specific illnesses (Inanli *et al.*, 2020; Samadi *et al.*, 2019). The presence of environmental pollutants in seafood can compromise these benefits and pose potential health risks to consumers. One such emerging contaminant is microplastics, defined as plastic fragments measuring less than 5 millimeters (mm) (Vriend *et al.*, 2021). These microplastics may be derived from primary sources, which are manufactured on a minuscule level, or from secondary sources, which are created by the breakdown of larger plastic objects (Omeyer *et al.*, 2022). While the impact of plastic consumption by marine organisms has been extensively studied, the specific toxic effects of microplastics on these organisms and the potential implications for human health still need to be fully understood (Oza *et al.*, 2024 In recent years, academic studies have advanced quickly in the identification of contaminants in oceanic settings and assessing the possible dangers linked to seafood, particularly marine fish (Zakiah *et al.*, 2024a). This progress has been fueled by the emergence of microplastics, which can enter food chains through direct and indirect pathways (Omeyer *et al.*, 2023). Consequently, the presence of microplastic pollution poses a significant threat to the health of organisms across various trophic levels, encompassing apex predators such as humans (Sathish *et al.*, 2020). The presence of contaminants in aquatic ecosystems can be assessed using fish as bioindicators, highlighting their crucial role (Cordova *et al.*, 2020; Javad Sajjadi Shourije *et al.*, 2023; Vadivelu *et al.*, 2020). The rate at which pollutants accumulate in fish is influenced by several factors, including the availability and concentration of contaminants in water, the organism's physiology, feeding behavior, environmental conditions, and the duration of exposure (Vendel *et al.*, 2017). Pollutant accumulation can vary among different organs in fish (Miranda *et al.*, 2022). The escalating issue of microplastic pollution in marine ecosystems presents a substantial risk to the intricate equilibrium of the aquatic food web (Toussaint *et al.*, 2019). The diminutive plastic particles, frequently confused as food by marine creatures, infiltrate various tiers of the ecosystem, ranging from microscopic plankton to sizable (Cordova *et al.*, 2020). As smaller organisms consume microplastics, these particles build up in their tissues and are passed on to predators, causing the magnification of toxins up the food chain (Omeyer *et al.*, 2022). Ultimately, the consumption of seafood contaminated with these potentially dangerous microplastics and their accompanying toxins poses a risk to human well-being. The prevalent existence of microplastic pollution highlights the critical necessity for implementing effective mitigation strategies in order to safeguard marine ecosystems and human health (Ajith *et al.*, 2020). Toxic contaminants associated with microplastics can have significant impacts on marine organisms. Human exposure to toxic microplastics through the consumption of contaminated seafood may lead to the development of severe physiological disorders (Ajith *et al.*, 2020). Various studies have highlighted the potential impact of microplastics on human health, with their presence detected in samples such as urine, feces, breast milk, and blood (Barceló *et al.*, 2023; Paul *et al.*, 2024; Pironti *et al.*, 2023). It is imperative to perform a comprehensive risk assessment to gain insight into the potential risks associated with diverse types of microplastic polymers. Extensive research has been undertaken internationally to investigate microplastic contamination in fish, with recent studies in Indonesia shedding light on the accumulation of microplastic pollutants in fish (Manullang *et al.*, 2023). Despite the increasing global concern, research on microplastics in fish - especially in commercially important species - is remarkably limited in Indonesia. The fact that Indonesia is one of the main producers and consumers of seafood, with coastal communities heavily dependent on marine resources, makes this condition a cause for concern. The insufficiency of comprehensive data on microplastic pollution in Indonesian waters poses a challenge to the understanding of the risks to human health and the coastal and marine ecosystems. Urgent efforts are required to increase research endeavors to evaluate the extent of microplastic pollution in Indonesian fish, pinpoint hotspots and sources of contamination, and develop effective mitigation strategies to protect this

crucial food source and its livelihoods. The aim of this research was to analyze the quantities of microplastic contaminants in commercially valuable edible marine fish sourced from Jakarta Bay, a densely populated and industrialized coastal region that is inhabited by over 35 million people (BPS DKI Jakarta, 2021). The study involved quantifying and characterizing microplastics present in the gills and gut of selected commercial marine fish species, providing valuable insights not previously explored. The findings help to advance the understanding of microplastic pollution in commercially valuable marine fish and stress the critical nature of implementing successful plastic waste management strategies. The risk assessment of the identified polymers could lay the groundwork for further research into the potential impacts of microplastics on human health. The primary objectives of this investigation are twofold: a) to determine whether the concentration of microplastics in the gills and gastrointestinal tracts of commercially harvested marine fish in Jakarta Bay exceeds global averages, likely as a result of inadequate waste management practices; b) to ascertain whether larger microplastic fragments and fibers are the predominant types, indicative of the prevalent process of microplastic fragmentation in the region. This study aims to measure and characterize microplastics found in the gills and gut of specific commercially important marine fish species, providing new insights that have not been previously explored. This study also seeks to understand the level of microplastic pollution in commercially significant marine fish and highlight the importance of enacting successful plastic waste management tactics. The study was conducted in North Jakarta, Indonesia, at the end of 2023 and the beginning of 2024.

MATERIALS AND METHODS

Among the various studies carried out in Indonesia, this particular study stands out as one of the few that concentrate on commercially valuable. Through these methodological approaches, a holistic understanding of the marine environment and the prevalence of microplastics can be achieved. The study methods include area studies to describe the area's characteristics, sampling procedures, microplastic recovery processes from fish samples, extraction and identification of microplastics, quality assurance/ quality control procedures, and data analysis.

Study area

Five nearby fresh seafood markets in the northern area of Jakarta were selected as the study locations: Cilincing, Kalibaru, Nizam Zachman, Muara Angke and Kamal Muara (Fig. 1). These markets are situated administratively in North Jakarta, which covers an area of 7,133.51 square kilometer (km^2), including a 6,979.4 km^2 marine area and a 146.66 km^2 land area with a coastline extending 32 kilometers (km). More than 22,000 fishermen, hailing from regions such as Cirebon, Indramayu, Bekasi, and Banten, reside in this region, and can be classified as either resident or migrant fishermen. Traditional fishing gear is predominantly employed in this area, with fishing excursions typically lasting for a day near residential areas surrounding Jakarta Bay. The region is home to a large number of small capture fishing vessels, most of which are under 10 gross tonnage (GT) in size.

Field sampling

Marine fish samples were obtained at the designated study areas during the period spanning December 2023 and January 2024. Established techniques were employed to analyze microplastics in seafood, with strict adherence to standardized methods during the collection, processing, and laboratory procedures (Cordova *et al.*, 2020; Karami *et al.*, 2018; Lusher *et al.*, 2017; Walkinshaw *et al.*, 2020). classified based on their dietary preferences, including omnivores, carnivores, and plankton feeders, as well as their preferred feeding locations, such as pelagic, benthopelagic, and benthic zones. These include *Mugil* spp. (Grey mullet, omnivorous, benthic feeding zone), *Netuma thalassina* (Giant catfish, omnivorous, benthopelagic feeding zone), *Chirocentrus dorab* (Dorab wolf-herring, carnivorous, pelagic feeding zone), *Saurida tumbil* (Lizardfish, carnivorous, benthopelagic feeding zone), *Lutjanus malabaricus* (Malabar blood snapper, carnivorous, benthopelagic feeding zone), *Leiognathus* spp. (Pony fish, carnivorous, benthic feeding zone), *Rastrelliger kanagurta* (Indian mackerel, plankton feeder, pelagic coastal water) and *Decapterus russelli* (Indian scad, plankton feeder, pelagic coastal water). This study collected a total of 160 samples, consisting of 20 specimens for each category of marine fish species. The data presented in Table 1 provides details about different types of fish, such as their average total

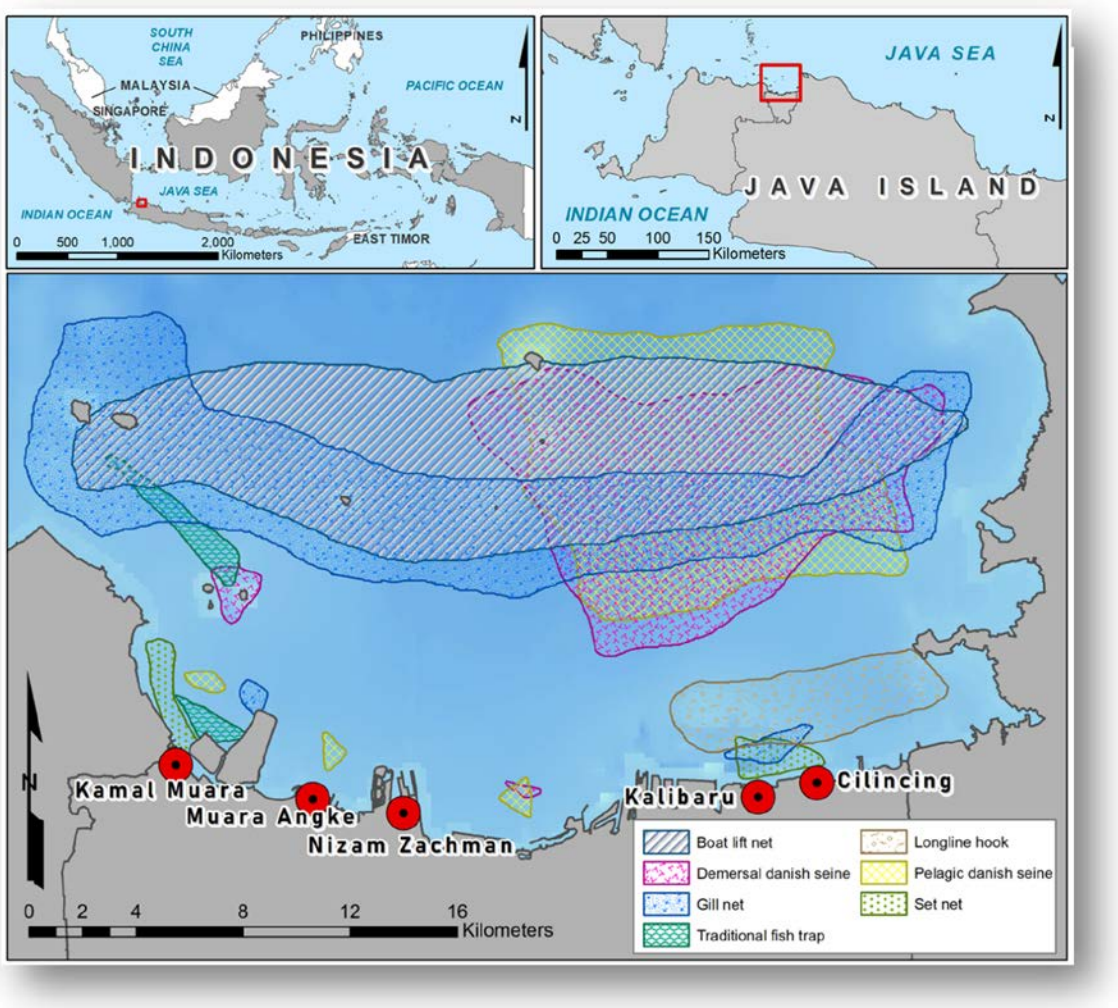

Fig. 1: Geographic location map of the study area along with sampling points and fishing areas in Jakarta Bay, Indonesia

length and weight, feeding habits, and the range of habitats they occupy. Data on fishing locations and techniques were obtained through interviews with fishermen who brought their catch to the fish auction site at the seafood market within the study region. The fish samples were stored in ice box coolers with regular ice, ensuring temperatures stayed below 4 degrees Celsius (°C) before undergoing processing within 24 hours (h) to retain their freshness.

Laboratory analysis and quality assurance/quality control

Upon reaching the laboratory and in sterile condition, the fish specimens were rinsed using ultrapure water and were measured for their length and weight. Subsequently, the fish's intestines and gills were inspected to help with the extraction of microplastics. The focus on these organs is due to their initial interaction with microplastics. Microplastics ingested by marine organisms accumulate in their digestive systems, while those inhaled accumulate in their gills (Horton *et al.*, 2018). The accumulation of microplastics in the gastrointestinal system presents a notable threat to the well-being of these organisms. Microplastic particles released through feces can accumulate in the sediment of water bodies and serve as a source of nutrition for other organisms (Botterell *et al.*, 2019). These extracted gut and gill samples were then placed in a clean glass container. The established protocol for extracting microplastics,

Table 1: Characteristics and microplastic abundance of selected commercial fish from seafood markets in northern Jakarta.

No.	Common name	Species name	Feeding habits	Feeding areas	Length centimeter (cm)	Weight gram (g)	Microplastic	
							Particles/ind	Particles/g
1	Dorab wolf-herring	*Chirocentrus dorab*	carnivorous	pelagic coastal water	34.28 ± 6.75	179.46 ± 99.41	5.00 ± 2.45	0.04 ± 0.04
2	Indian mackerel	*Rastrelliger kanagurta*	plankton feeder	pelagic coastal water	21.68 ± 2.54	105.25 ± 34.96	1.45 ± 0.94	0.02 ± 0.01
3	Indian scad	*Decapterus russelli*	plankton feeder	pelagic coastal water	17.76 ± 2.08	20.79 ± 6.36	1.50 ± 0.83	0.08 ± 0.05
4	Grey mullet	*Mugil spp*	omnivorous	benthic coastal water	14.00 ± 2.50	28.10 ± 14.71	2.90 ± 1.55	0.15 ± 0.12
5	Lizardfish	*Saurida tumbil*	carnivorous	benthopelagic	28.40 ± 1.57	167.01 ± 30.76	4.75 ± 2.05	0.03 ± 0.01
6	Giant catfish	*Netuma thalassina*	omnivorous	benthopelagic	59.03 ± 5.68	2350.61 ± 637.67	2.85 ± 1.60	0.001 ± 0.001
7	Malabar blood snapper	*Lutjanus malabaricus*	carnivorous	benthopelagic	40.84 ± 5.99	721.37 ± 295.67	5.40 ± 2.35	0.01 ± 0.01
8	Pony fish	*Leiognathus spp.*	carnivorous	benthic coastal water	7.57 ± 0.69	9.54 ± 2.61	5.35 ± 1.73	0.60 ± 0.24

which includes biological digestion, density separation, and identification of microplastics, was implemented in accordance with previous guidelines, with specific modifications made during the process (Cordova *et al.*, 2020; Karami *et al.*, 2018; Lusher *et al.*, 2017; Riani and Cordova, 2022). Briefly, the gut and gill of the fish specimen were moved to 125 milliliter (mL) clean test tubes (Pyrex®) and dried in a sterile oven at 50°C for 48-72 hours to remove water content. Fenton's reagent, composed of 30 percent (%) hydrogen peroxide (H_2O_2) (40 mL, Emprove® Merck Millipore) and 10 milligrams per milliliter (mg/mL) ferrous sulfate (Fe_2SO_4) (20 mL, Emsure® Merck Millipore), was introduced into the test tube, to break down the biogenic materials in the samples. After being left in a controlled airflow environment overnight, the samples underwent heating in a water bath at 50°C for a period ranging from 72 to 96 hours. Subsequent to this step, microplastics from each sample were sorted based on density using a high-density zinc chloride (ZnCl2) solvent of analytical grade sourced from Pudak Scientific. Following this process, all samples were placed onto sterile cellulose nitrate filter paper (gridded, Merck Millipore) for the purpose of visual examination. Particles on the filter paper were pinpointed thoroughly through an examination using a microscope (Olympus CX31) with a Sony IMX307 camera. Particles were identified according to the subsequent criteria: uniform shape, lack of particle division, and the nonexistence of biological or cellular characteristics. The size limit for detection in this study was 200 micrometers (µm), slightly smaller than the 212 µm size fraction limit used in a previous study on four environmental matrices (Lao and Wong, 2023). At this point, 20% (119 out of 584) of visually identified microplastic particles had their chemical composition verified using Attenuated Total Reflectance - Fourier transform infrared spectroscopy (ATR-FTIR) (The Agilent Cary 630 FTIR with ATR diamond accessories and MicroLab Expert software). A systematic random sampling method was employed to gather particles for chemical composition analysis, ensuring that the stomach and gill contents of the fish sample were adequately represented. The least microplastic detected under a microscope using the ATR-FTIR procedure measured at 205.6 µm, while the largest was recorded at 4999.7 µm. FTIR analysis was conducted with a resolution of 4/cm and 32 scans spanning the 650–3000/cm spectral range. Polymer identification relies on observing specific

peak patterns in various spectral regions (De Frond *et al.*, 2021; Löder and Gerdts, 2015; Riani and Cordova, 2022). The results of the chemical composition analysis were compared against polymer standard references provided by Agilent, Thermo-scientific, and Shimadzu, as well as the FLOPP spectral library of plastic particles and plastic standard references from the Research Center for Geosciences at the University of Bayreuth in Germany. Measures have been put in place to prevent potential cross-contamination of microplastics. During the collection and analysis of samples, the researchers wore protective gear such as 100% cotton clothing, medical masks, and latex gloves. Every piece of glassware and surgical equipment received meticulous washing and rinsing using ultrapure water. Sterile filtration paper was utilized to purify all chemical solutions such as H_2O_2, Fe_2SO_4, and $ZnCl_2$, ensuring the elimination of residual microparticles. During the extraction process, procedural blanks (n = 5) were filled out by positioning open beaker glass containers near the samples until the final identification procedures were carried out. The control samples did not show any signs of cross-contamination.

Data analysis

The statistical software PAST4 (version 4.17) was used to perform statistical analysis and generate visual representations of the data. Quantities were measured in particles per individual fish (particles/ind) and particles per gram of fish (particles/g). The Kruskal-Wallis test, a non-parametric statistical analysis method, along with Mann-Whitney pairwise post hoc comparisons, was applied to explore and compare the prevalence of microplastics in different fish species, their feeding habits, and feeding areas. Statistical significance was determined at a significance level of 0.05.

RESULTS AND DISCUSSION

The data on microplastic in commercially caught marine fish from Jakarta Bay provides valuable insights for stakeholders and policymakers. It can help prioritize specific types and categories of plastics to effectively reduce marine plastic debris in the Greater Jakarta area. The data can contribute to assessing recent initiatives aimed at reducing marine plastic debris from various sources.

Abundance and occurrence of microplastic

A total of 160 fish samples were obtained from 5 diverse fishing markets in Jakarta for the purpose of this investigation, and it was determined that 93.75% (150 out of 160) of the fish were found to contain microplastics, which were identified in both the gut and gill samples. Fish are essential for ecosystems, widespread, and serve as both a valuable food source for humans and popular research subjects (Miller *et al.*, 2021; Wesch *et al.*, 2016). As of 2017, reports indicated that almost 800 species had been documented to consume microplastics (Vendel *et al.*, 2017), and this number is expected to increase in the future (Cordova, 2020). The level of microplastic contamination identified in this study (93.75%) was markedly greater in comparison to studies in Spain, Japan, South Africa, the United Kingdom (UK), India, Mexico, the North Sea, and Australia (Bellas *et al.*, 2016; Cannon *et al.*, 2016; Foekema *et al.*, 2013; Herrera *et al.*, 2019; Karuppasamy *et al.*, 2020; Lusher *et al.*, 2013; Naidoo *et al.*, 2016; Phillips and Bonner, 2015; Tanaka and Takada, 2016). Microplastics were detected in fish samples ranging from 1% to 80% across various studies. Notably, a study conducted in Jakarta revealed that nearly all commercial marine fish samples were contaminated with microplastics. Other studies in the Canary Islands, Spanish Atlantic and Mediterranean coasts reported that 17.50-78.30% of fish samples were contaminated with microplastics (Bellas *et al.*, 2016; Herrera *et al.*, 2019). The findings from the study conducted in Tokyo Bay, Japan, revealed that 77.00% of the fish samples analyzed were found to be contaminated with microplastics (Tanaka and Takada, 2016), and 73.00% of fish samples were contaminated in South Africa (Naidoo *et al.*, 2016). Fish samples collected from the English Channel exhibited a reduced level of microplastic contamination, amounting to 36.50% (Lusher *et al.*, 2013). This study results show a much higher proportion compared to the Bay of Bengal at 8.95% (Karuppasamy *et al.*, 2020), the Gulf of Mexico at 8.20% (Phillips and Bonner, 2015), the North Sea at 2.61% (Foekema *et al.*, 2013), and Australia at 0.30% (Cannon *et al.*, 2016). Table 1 provides details regarding microplastic contamination in each fish sample species. The average number of particles per individual was 3.65 ± 2.34 particles/ind, or approximately 0.12 ± 0.21 particles/g (mean

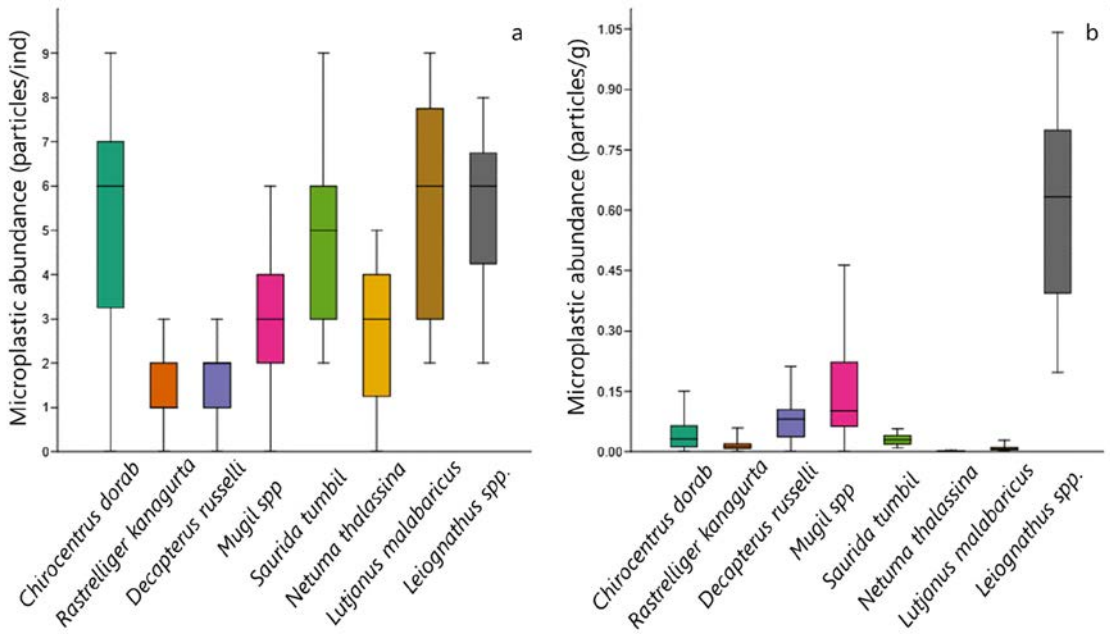

Fig. 2: The abundance of microplastic in commercial marine fish for each species in terms of particles/ind (a) and particles/g (b)

± standard deviation). The presence of microplastics was identified in 81.25% (130 out of 160) of the gut samples and 79.38% (127 out of 160) of the gill samples, as determined through the examination. Some fish showed exclusively microplastic contamination in their guts (22 out of 160) or gills (22 out of 160). The microplastic content in the digestive system (1.79 ± 1.19 particles/ind) was slightly lower than that in the gills (1.86 ± 1.30 particles/ind), but the variance between the levels found in these two organs was not significant (p=0.8673The presence of microplastics was identified in 81.25% (130 out of 160) of the gut samples and 79.38% (127 out of 160) of the gill samples, as determined through the examination (Cordova *et al.*, 2020; Horton *et al.*, 2018; Su *et al.*, 2019; Toussaint *et al.*, 2019). The ingestion and inhalation of microplastics may result in the formation of physical blockages in the intestines and gills of fish, which can disrupt their immune system and make them more vulnerable to pathogens and cytotoxic substances (Du *et al.*, 2022; Lyu *et al.*, 2020). Among the species sampled, *Lutjanus malabaricus* had the highest abundance in terms of microplastics per individual, followed by *Leiognathus* spp., *Chirocentrus dorab*, *Saurida tumbil*, *Mugil* spp., *Netuma thalassina*, *Decapterus russelli*, and *Rastrelliger kanagurta* (Table 1 and Fig. 2a-b). The eight commercial fish species examined in this research are exclusively located in coastal regions. Consequently, they exhibit a higher accumulation of microplastics in their digestive system and gills in comparison to fish that inhabit the open ocean (Nithin *et al.*, 2022; Pozo *et al.*, 2019). The statistical analysis indicated notable variances across the majority of fish species, barring a small number of outliers. The tests indicated that the levels of microplastics per individual did not vary significantly between specific pairs of fish species: *Chirocentrus dorab* and *Saurida tumbil* (p=0.5289), *Lutjanus malabaricus* (p=0.6229) and *Leiognathus* spp. (p=0.8147), *Rastrelliger kanagurta* and *Decapterus russelli* (p=0.7409), *Mugil* spp. and *Netuma thalassina* (p=0.9231), *Saurida tumbil* and *Lutjanus malabaricus* (p=0.3319) as well as *Leiognathus* spp. (p=0.2413), and between *Lutjanus malabaricus* and *Leiognathus* spp. (p=0.7733). In the post-hoc test for microplastic abundance per gram, results were not significantly different between *Chirocentrus dorab* and *Saurida tumbil* (p=0.5792) and between *Rastrelliger kanagurta* and *Lutjanus malabaricus* (p=0.0720). The present study extensively examined the prevalent occurrence of microplastic contamination in diverse

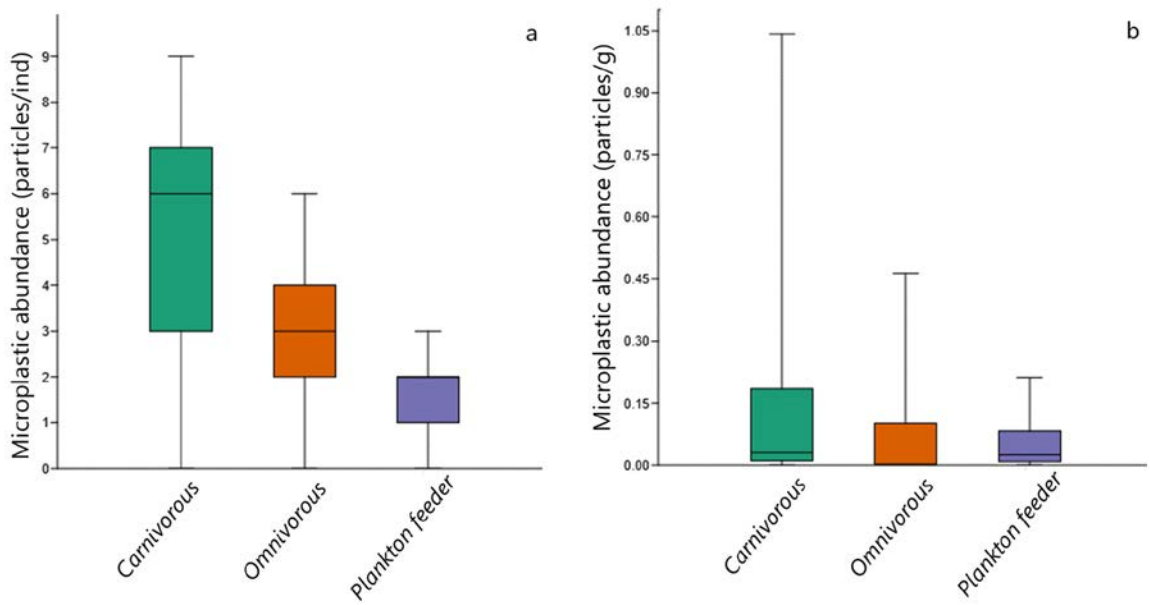

Fig. 3: The abundance of microplastic in commercial marine fish for each feeding habits in terms of particles/ind (a) and particles/g (b).

fish communities, encompassing specimens obtained from natural habitats as well as those raised for commercial purposes in coastal and marine environments (Khan *et al.*, 2024; Makhdoumi *et al.*, 2023; Oza *et al.*, 2024). The results of this study are consistent with and support previous studies carried out in countries with waste management systems similar to Indonesia, such as Cebu Island in the Philippines (Abiñon *et al.*, 2020), Chennai in India (Ineyathendral *et al.*, 2023), and Guangdong in China (Zhang *et al.*, 2020). Previous studies have similarly identified elevated concentrations of microplastics in fish populations targeted for commercial fishing activities. (Abiñon *et al.*, 2020; Ineyathendral *et al.*, 2023; Zhang *et al.*, 2020). It is anticipated that the prevalence of microplastic pollution in fish populations will persistently rise in the foreseeable future, as indicated by current trends.

Microplastics in commercial fish from different feeding habits and feeding areas

The analysis revealed that fish with carnivorous feeding habits exhibited a greater mean microplastic abundance (5.13 ± 2.14 particles/ind; 0.17 ± 0.28 particles/g) compared to those with omnivorous (2.88 ± 1.56 particles/ind; 0.07 ± 0.11 particles/g) and planktivorous (1.48 ± 0.88 particles/ind; 0.05 ± 0.05 particles/g) feeding strategies (Fig. 3). Subsequent statistical analysis revealed notable variations in microplastic abundance across the three distinct feeding habits observed in the fish samples. Significance was observed in the comparison of microplastic levels per individual within each feeding groups (Fig. 3a). Upon examination at a per-gram level of fish tissue, notable variances were solely detected between carnivorous and omnivorous species. It is noteworthy that no distinctions were identified between carnivorous and planktivorous species (p=0.2789), and similarly, there were no variances between omnivorous and planktivorous fish (p=0.6268) (Fig. 3b). The analysis of microplastic particles per individual and per weight of fish tissue reveals an interesting pattern in the feeding areas of fish (Table 1). Fish with feeding areas in the benthopelagic region show a slightly higher microplastic particle count (4.33 ± 2.27 particles/ind) compared to those in benthic coastal water (4.13 ± 2.04 particles/ind) and pelagic coastal water (2.65 ± 2.29 particles/ind). Further statistical analysis indicates a significant difference between fish in pelagic coastal water and those in other feeding areas, while there is no significant difference between benthopelagic and benthic coastal water (p=0.7925) (Fig. 4a). When considering microplastic accumulation per gram of

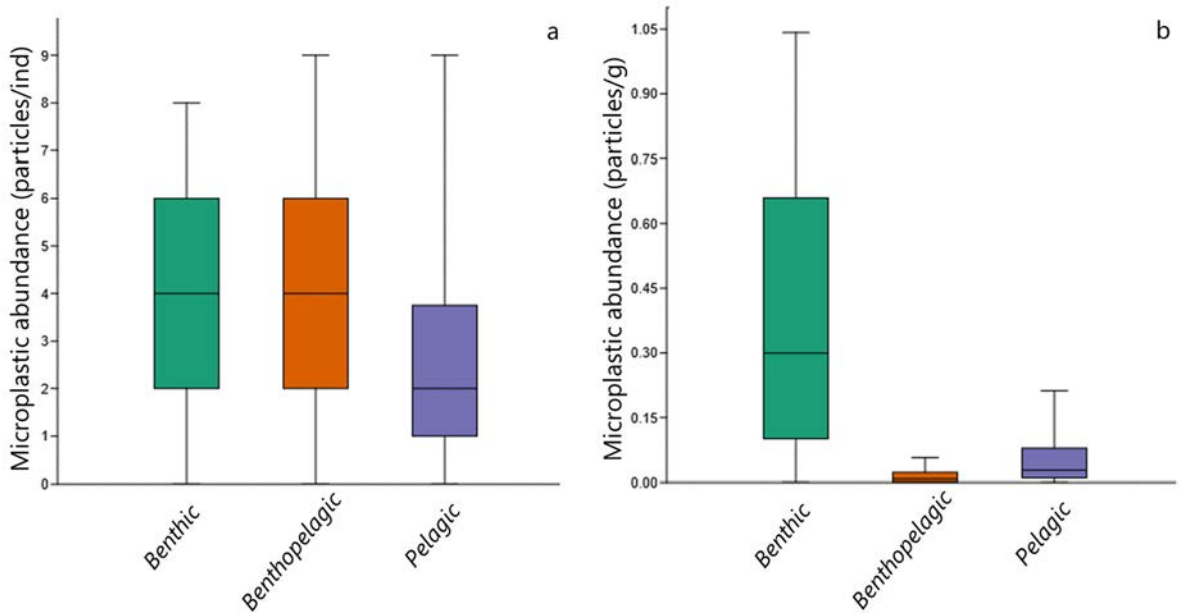

Fig. 4: The abundance of microplastic in commercial marine fish for each feeding areas in terms of particles/ind (a) and particles/g (b).

fish tissue, fish in benthic coastal water (2.65 ± 2.29 particles/g) have the highest accumulation in the gut and gill compared to pelagic coastal water (0.05 ± 2.05 particles/g) and benthopelagic coastal water (0.01 ± 0.01 particles/g). Statistical analysis indicates notable variations in microplastic concentration per gram of fish tissue among the different feeding zone (Fig. 4b). The research indicates that fish are consistently at risk of ingesting microplastics, irrespective of their taxonomic categorization, habitat characteristics, feeding behaviors, or foraging locations (Khan *et al.*, 2024; Makhdoumi *et al.*, 2023; Oza *et al.*, 2024). The findings of this study indicate that fish species exhibiting carnivorous feeding behaviors and those that search for food in benthic areas display elevated levels of microplastic pollution. These feeding-related factors seem to influence the accumulation of microplastics within the fish's body (Ineyathendral *et al.*, 2023). Certain studies indicate that dietary patterns could potentially exert a greater influence on the presence of microplastic pollution than habitat selection (Zhang *et al.*, 2020). This may be because microplastics resemble the natural prey of fish, causing carnivorous species to inadvertently consume these particles. As a result of biomagnification (Cordova *et al.*, 2020; Lyu *et al.*, 2020), Fish exhibiting carnivorous feeding habits are prone to amassing elevated levels of microplastics as they progress through the trophic hierarchy of the food chain. (Justino *et al.*, 2023). Microplastics' low buoyancy enables them to remain afloat on the water's surface, presenting a danger to nektonic organisms (Lopes *et al.*, 2020). This is particularly concerning in the eutrophic and heavily (Cordova and Nurhati, 2019; van der Wulp *et al.*, 2016), organic material can adhere to microplastics (Karbalaei *et al.*, 2018), causing them to sink into the water column and eventually reach the seafloor. Human population density and urbanization have been shown to have a significant impact on riverine inputs (Cordova *et al.*, 2024a; Jeyasanta *et al.*, 2020). The 13 major rivers flowing into this area are strongly suspected to be the primary source of these microplastics (Cordova *et al.*, 2022c, 2021a; Cordova and Nurhati, 2019). Improper management of municipal waste disposal sites, surface runoff, and improper handling of plastic waste by individuals and industries are additional sources of pollution (Cordova *et al.*, 2023a; Harikrishnan *et al.*, 2023). The tourism industry, as well as shipping and fishing activities in North Jakarta, significantly contribute to the plastic contamination of the coastal environment (Watkins *et al.*, 2015).

Characteristics of microplastic in gut and gills

ssessed the properties of microplastics, encompassing their dimensions and configuration, in particles derived from marine fish samples sold in North Jakarta (Figs. 5, 6, and 7). The range of detected length sizes was 205.6 - 4999.7 µm (specifically for gut 205.6 - 4989.5 µm and gill 233.3 - 4999.7 µm). Commercial fish were found to have a greater concentration of larger microplastics in their gut and gill. Among the four size groups (200-500 µm, 500-1000 µm, 1000-2000 µm, and 2000-5000 µm), the majority of microplastics from commercial marine fish were found in the 2000-5000 µm size class, which accounted for 61.99% of the total microplastics found. The other three categories, namely the 200-500 µm, 500-1000 µm, and 1000-2000 µm classes, accounted for 7.36%, 10.96%, and 19.69% of the observed microplastics. The statistical analysis demonstrated a substantial variation in size when comparing the 2000-5000 µm group with other size ranges. In contrast, there were no substantial distinctions within the other size groupings. In contrast, there were no substantial distinctions within the other size groupings. The analysis of microplastic characteristics based on shape, as depicted in Figs. 5, 6, and 7, revealed the predominance of fragments (36.13%) and fibers (33.56%) over foam (15.58%) and granules (14.73%). This pattern of microplastic shape dominance was consistently observed across different fish species (Fig. 5), feeding habits, and feeding areas. According to the statistical analysis, notable distinctions were identified exclusively among fragment shapes, foam, and granules, with no statistically significant disparities observed among the other shapes. The statistical analysis did not detect any significant differences in microplastic shapes based on the feeding habits and feeding areas of commercial fish species examined. The ingestion of microplastics by fish occurs as a result of their resemblance to natural prey in terms of shape and size (Barboza *et al.*, 2020; Lehtiniemi *et al.*, 2018). In this study, microplastic fragments and fibers were the most commonly detected forms. The spread of these microplastics is strongly connected to the local human behaviors, particularly fishing operations and the release of domestic and industrial wastewater (Sathish *et al.*, 2020; Zakiah *et al.*, 2024a). This study revealed that both of these microplastic varieties were widespread in the Jakarta River, suggesting that the main origin of microplastics in the region is the

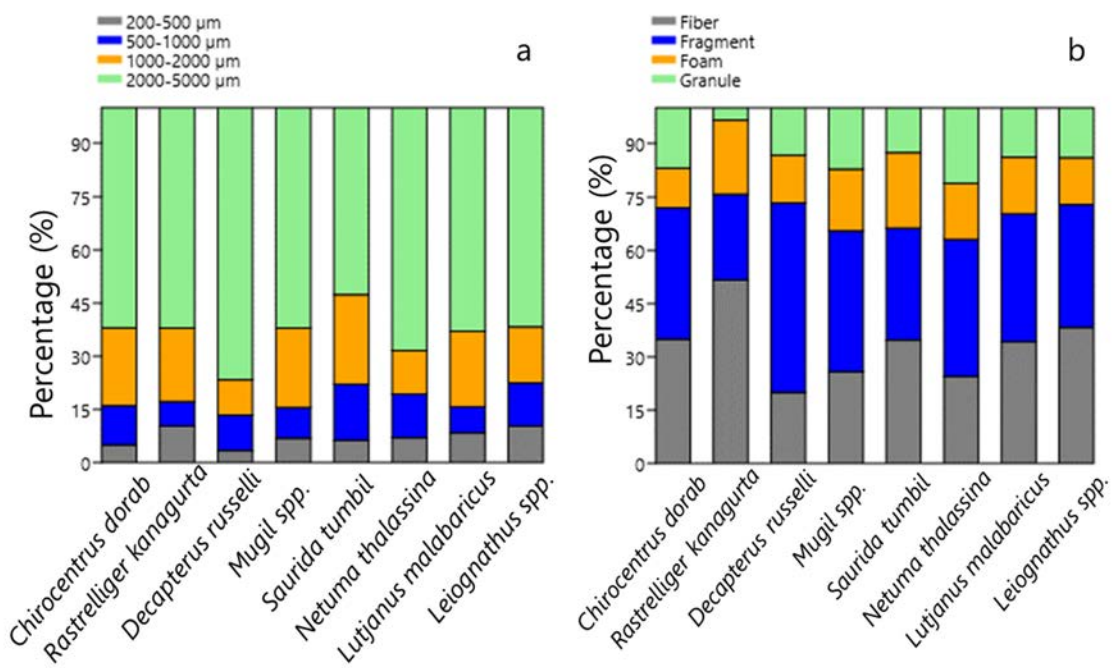

Fig. 5: The characteristic of recovered microplastic from commercial marine fish for each species in terms of size (a) and shape (b)

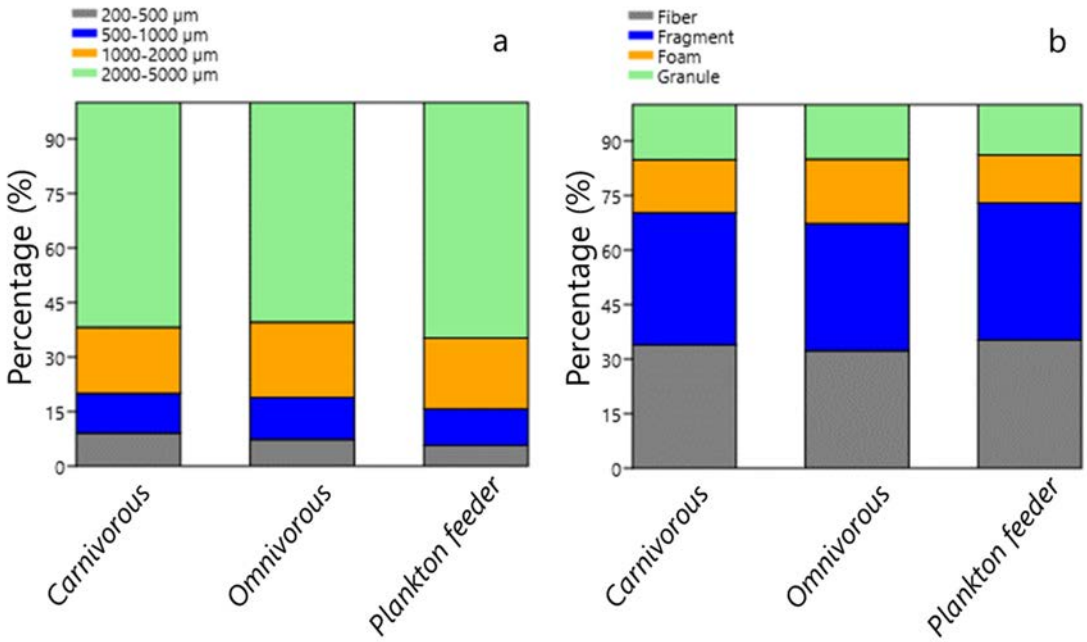

Fig. 6: The characteristic of recovered microplastic from commercial marine fish for each feeding habits in terms of size (a) and shape (b)

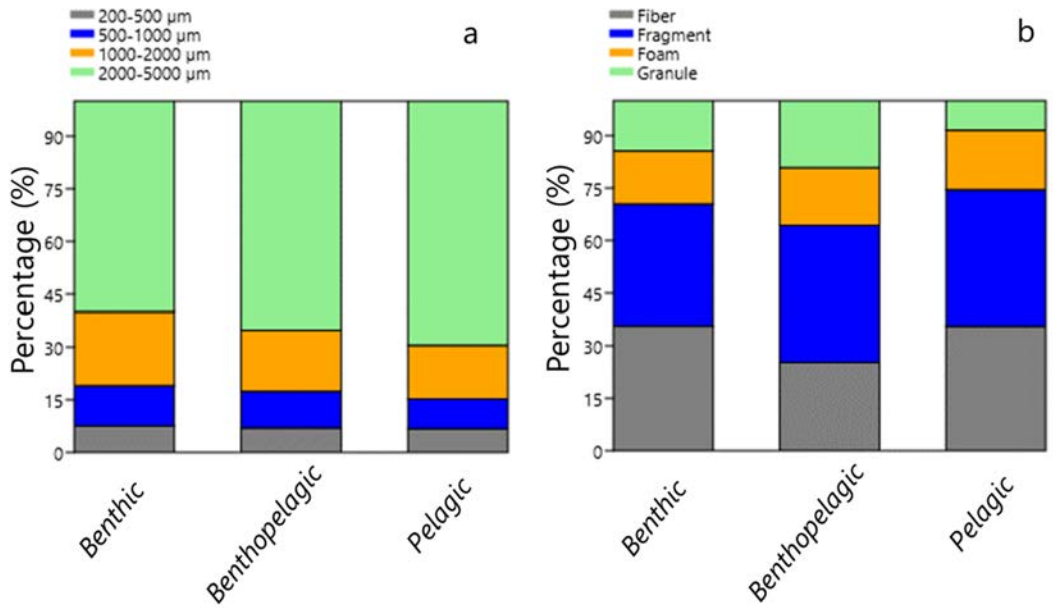

Fig. 7: The characteristic of recovered microplastic from commercial marine fish for each feeding area in terms of size (a) and shape (b)

waste that flows into Jakarta Bay, especially single-use plastic waste (Cordova *et al.*, 2024b, 2022c, 2022a). The high levels of microplastic fragments and fibers in the environment pose a risk of contaminating commercial fish in Jakarta. According to the study, the prevailing variety of microplastics retrieved were of a larger scale, indicating that bigger plastic fragments have deteriorated in the environment to produce microplastics (Cordova *et al.*, 2023b; Simon-Sánchez *et al.*, 2022; Zakiah *et al.*, 2024b).

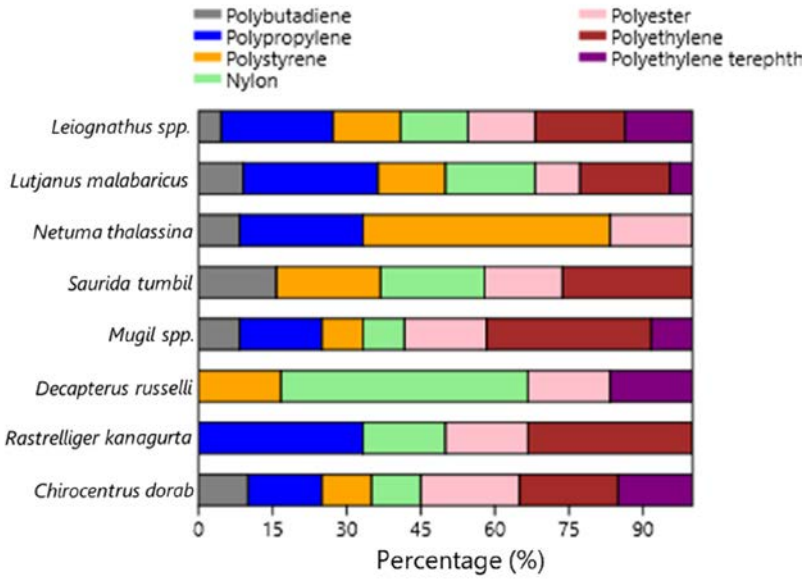

Fig. 8: Proportion of polymer types detected in each commercial fish species

The Jakarta Bay area was also notable for the abundance of visible microplastics, indicating a significant source of plastic pollution in the region (Cordova *et al.*, 2021a; Cordova and Nurhati, 2019). The results back up previous studies on microplastics in this region, providing additional evidence that microplastics come from larger plastic objects that have degraded in the environment. Smaller microplastics have a more pronounced adverse impact on aquatic species as their larger surface area enables them to absorb higher levels of hydrophobic organic contaminants, posing a serious threat (Li *et al.*, 2020). The amount of microplastics consumed by organisms rises proportionally with environmental contamination and the organism's size, highlighting the risk of substantial bioaccumulation and biomagnification of these pollutants across the food chain (Krause *et al.*, 2021; Nithin *et al.*, 2022). As microplastics continue to proliferate at higher rates worldwide, it is essential to emphasize the necessity for meticulous monitoring and enhanced plastic waste management.

Chemical composition of recovered microplastic in gut and gills

A chemical composition analysis (Fig. 8) was conducted on 119 microplastic particles, selected from the 584 total microplastic particles obtained. The examination revealed the presence of 7 distinct polymer groups, namely Polyethylene (19.33%), Polypropylene (17.65%), Polystyrene (16.81%), Nylon (15.13%), Polyester (15.13%), Polybutadiene (8.40%), and Polyethylene terephthalate (7.56%). The findings indicate that the marine fish species studied are likely to ingest microplastics without discrimination, as there is no dominant polymer type present, suggesting a lack of ability to selectively avoid consuming plastic particles. The seven types of polymers identified in this study - polyethylene, polypropylene, polystyrene, nylon, polyester, polybutadiene, and polyethylene terephthalate - have relatively lower densities than seawater, allowing them to disperse within the water column (Cordova *et al.*, 2021b; Huang *et al.*, 2022; Int-Veen *et al.*, 2021). Density does not play a major role in the distribution of plastic in aquatic ecosystems, but many polymers have a tendency to stick to organic materials, resulting in the accumulation of microplastics in sediments (Crawford and Quinn, 2017). Various environmental factors, such as wind, currents, internal waves, and seawater temperature, can influence the vertical distribution of microplastics, making it easier for marine fish to ingest them (Enders *et al.*, 2015; Y. Li *et al.*, 2020; Xu *et al.*, 2020; Zhang, 2017). Fish living near the

water's surface may face direct exposure to low-density polymers, while those at the bottom could encounter microplastics during settling or swimming upwards. Further investigation is warranted. The specific polymer types identified in this study suggest that they come from single-use plastic sources. It is probable that the seven types of polymers come from different single-use consumer products, fishing gear, clothing and textiles, vehicle tires, and plastic bottles used by the people in the greater Jakarta area (Cordova *et al.*, 2022b, 2021a, 2021b; Cordova and Nurhati, 2019). This indicates that the microplastics found in the marine environment and commercial fish species mainly result from improper disposal or management of these common plastic materials.

Risk assessment of microplastic

The presence of microplastics in aquatic ecosystems carries substantial risks, as these tiny plastic particles can have adverse effects on human health, the environment, the economy, and ecosystem health (Agamuthu *et al.*, 2019; Lee, 2015). When microplastics enter the environment, they can release additives from the production process, such as phthalates and bisphenol A (Sulistyowati *et al.*, 2022; Wright and Kelly, 2017). Additionally, they have the ability to soak up and spread different types of pollutants, like persistent organic pollutants, heavy metals, and invasive species (Brennecke *et al.*, 2016; Herrera *et al.*, 2022; Imhof *et al.*, 2013; Lee *et al.*, 2014). These contaminants may enter marine-based products, such as commercial marine fish, potentially posing a significant threat to food safety. The capacity of seafood to accumulate microplastics has been the subject of numerous studies. Determining whether microplastics in seafood can adversely affect human health remains a topic requiring further research. Nevertheless, the data indicates that these pollutants pose a substantial obstacle that requires additional investigation and precautionary actions. The ingestion of microplastics by humans can occur through the consumption of commercially available marine fish (Collard *et al.*, 2017). While there are potential health dangers associated with microplastic pollution, fish and other seafood are vital for maintaining a healthy and balanced diet (Barboza *et al.*, 2018). Although this study did not identify microplastics in fish flesh, their gills and digestive systems can act as additional sources of microplastic exposure. It is estimated that individuals may consume around 17 microplastic particles per week solely from fish meal consumption (Akhbarizadeh *et al.*, 2018). With Indonesia's average weekly fish and fishmeal consumption at 0.35 kg and 0.01 g (BPS, 2024) respectively, the escalating trend raises concerns about the heightened risk of microplastic exposure from seafood intake. The results of this study highlight the critical importance of enhancing comprehension regarding the potential impacts of microplastics, especially those originating from seafood, on human health. The presence of microplastics in commercial marine fish poses potential risks to human health through dietary exposure (Agamuthu *et al.*, 2019; Lee, 2015). The transfer rate of microplastics from fish to humans is currently under investigation. Ingesting contaminated seafood could potentially cause the accumulation of these particles in human tissues (Akhbarizadeh *et al.*, 2018). Microplastics have the ability to attract harmful chemicals, such as persistent organic pollutants and heavy metals, which can adhere to their surfaces. The leaching of these pollutants into the human body has the potential to disrupt endocrine function, induce oxidative stress, and elevate the likelihood of developing chronic diseases (Brennecke *et al.*, 2016; Herrera *et al.*, 2022). Microplastics themselves may trigger inflammatory responses and cellular damage, raising concerns about their long-term health effects (Brennecke *et al.*, 2016; Herrera *et al.*, 2022; Imhof *et al.*, 2013; Lee *et al.*, 2014). The presence of microplastics in commercial marine fish highlights a significant environmental risk to marine ecosystems. Fish frequently confuse microplastics for food, resulting in consumption and possible malnourishment from deceptive satiation (Cordova *et al.*, 2021b). Ingested microplastics can cause physical harm to internal organs, obstruct digestive tracts, and impair feeding behavior. Microplastics can accumulate in the food chain, with larger predators consuming contaminated prey, resulting in the biomagnification of these particles and associated toxins (Cordova *et al.*, 2021b; Huang *et al.*, 2022; Int-Veen *et al.*, 2021). Disrupting trophic interactions can lead to changes in ecosystem structure, ultimately affecting the overall health and resilience of marine environments (Omeyer *et al.*, 2022). It is important to note that this study has potential limitations, such as only sampling a limited number of locations within fresh seafood markets in the northern part of Jakarta

during specific periods. The extent of microplastic pollution may not be accurately reflected in this study. The research results do not offer a comprehensive evaluation of microplastic contamination levels in the fish samples when compared to existing guidelines or acceptable contamination thresholds (Priya *et al.*, 2022). The ongoing study necessitates further extensive research to gain a clearer understanding of this issue. The dynamics of the bay and seasonal variations could also influence the distribution of microplastics. Concentrating only on commercially significant fish species for sampling may not provide a comprehensive understanding of the complete influence of microplastics on the bay's ecosystem. It is suggested to increase the number of sampling sites and frequency to obtain a wider spatial and temporal representation of Jakarta Bay. It is also recommended to evaluate the potential socioeconomic consequences of microplastic contamination in Jakarta Bay, considering its impact on fisheries, tourism, and human health. Exploring additional marine organisms at lower trophic levels may provide valuable insights into the wider ecological consequences.

CONCLUSION

The study aimed to gauge the extent of microplastic pollution in commercial marine fish organs in the North Jakarta region. The findings indicate that microplastics are commonly found in the digestive systems and respiratory organs of these fish, with more than 93% of samples showing the presence of these contaminants. The findings of this study indicate that microplastics were detected in a significant proportion of the gut and gill samples of commercial marine fish examined, with 81.25% of gut samples and 79.38% of gill samples containing these pollutants. Interestingly, some fish exhibited exclusive microplastic contamination in either their guts or gills. The microplastic content in the digestive system was marginally lower compared to the gills, however, the difference in levels between these two organs was not deemed slightly lower than in the gills, the variance between the levels found in these two organs was not statistically significant. Further analysis revealed that the abundance of microplastics in the gut and gill of the sampled fish varied across different species. This study highlights that microplastics tend to gather in the gills and gastrointestinal tract as their main accumulation sites, before being carried to other regions of the organism's body. The study found that fish with carnivorous feeding habits exhibited a greater mean microplastic abundance than those with omnivorous and planktivorous feeding strategies. This pattern was also observed in the analysis of microplastic particles per individual and per weight of fish tissue, with fish from the benthopelagic region showing a slightly higher microplastic particle count than those in benthic coastal water and pelagic coastal water. This study brings attention to the fact that microplastics tend to amass in the gills and gastrointestinal tract as their primary accumulation sites, before being transported to other areas of the organism's body. The distribution of these microplastics is closely tied to local human activities, such as fishing operations and the discharge of domestic and industrial wastewater. Interestingly, the analysis did not reveal any dominant polymer group, with the seven types of polymers identified - polyethylene, polypropylene, polystyrene, nylon, polyester, polybutadiene, and polyethylene terephthalate - suggesting that the fish do not possess the ability to avoid consuming plastic particles selectively. More investigations are necessary to establish the level of plastic contamination in fish tissues that are consumed by humans, along with the potential threats to food safety. Since fish gills and guts are often removed before human consumption, it's important to understand the implications of ingesting microplastics through whole fish. This study highlights the importance of monitoring plastic waste in the Greater Jakarta region and its surrounding coastlines. This study holds immense importance in the worldwide examination of microplastic contamination in commercially caught marine fish. It offers essential insights into microplastic contamination in Jakarta Bay, a densely populated area with extensive fishing activity, furthering our understanding of the scope of this issue. The study highlights the significance of poor waste management and the use of single-use plastics in exacerbating the issue of microplastics, particularly in fast-growing areas, by identifying their types and sources. This local analysis reinforces the need for worldwide efforts to mitigate plastic pollution, highlighting the importance of implementing effective waste management strategies and promoting responsible consumption to protect marine ecosystems and

the human food supply. Plastic pollution poses a significant threat to food security, safety, marine ecosystems, and human health due to the increasing levels of microplastics in the environment. With the progression of research, it is crucial to implement a uniform risk assessment system utilizing cutting-edge tools and methodologies for evaluating microplastic concentrations in the environment and organisms. It is imperative for both capture fisheries and aquaculture to undergo thorough risk and hazard evaluations to guarantee the safety and longevity of seafood production.

AUTHOR CONTRIBUTIONS

Nurhasanah, the corresponding author, has contributed to interpreting the results, preparing the manuscript and leading funding and project acquisition. Hasrianti participated in data analysis and interpretation and helped in writing the manuscript. L. Hakim participated in data analysis and interpretation and helped write the manuscript. E. Riani designed the field sampling and contributed to the data analysis and interpretation of the results. M.Y. Iswari prepared the map and performed data analysis and interpretation. M.R. Cordova is the main contributor to this manuscript, contributed to supervision, study design, laboratory analysis, and data analysis and led the writing of the manuscript.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. The ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS

%	Percent
°C	degree Celsius
µm	Micrometer or micron
/cm	A reciprocal centimeter (or wavenumber)
ATR-FTIR	Attenuated Total Reflectance - Fourier Transform Infrared Spectroscopy
cm	Centimeter
e.g.	Exempli gratia (for example)
Fe_2SO_4	Iron(II) sulfate or ferrous sulfate
g	gram
GT	Gross tonnage
h	hours
H_2O_2	Hydrogen peroxide
ind	individual
kg	Kilogram
km	Kilometer

km^2	square kilometer
mL	milliliters
mm	millimeters
particles/ind	Particles per individual
particles/g	Particles per gram
p-value	probability value
spp	species pluralis
UK	United Kingdom
$ZnCl_2$	Zinc chloride

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