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Scoping Review on Microplastic Pollution in Aquatic Species Across Indonesian Waters

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Abstract

Microplastics (MP) pollution is an emerging environmental threat in aquatic ecosystems, with implications for both biodiversity and human health. As one of the world's largest archipelagic nations and a top contributor to marine plastic waste, Indonesia faces significant challenges related to MP contamination in its waters. This scoping review aims to map existing evidence on MP pollution among aquatic species in Indonesian waters. A comprehensive search was conducted in the PubMed database between April and May 2025, guided by the Population-Concept-Context framework. The review followed the PRISMA-ScR guidelines. Studies were included if they addressed MP pollution in aquatic organisms in Indonesia and were published in English. Data were extracted systematically, covering study characteristics such as MP types, sizes, shapes, colors, polymer composition, and detection methods. A total of 13 eligible studies were included. These studies examined MP contamination in various aquatic organisms, including fish, bivalves, sea urchins, and sandfish across freshwater, coastal, and aquaculture environments. Predominant MP shapes were fibers, fragments, and films, with sizes ranging from <math><100\ \mu\text{m}</math> to $5000\ \mu\text{m}$. The most frequently detected polymers were polyethylene, polypropylene, polystyrene, and polyvinyl chloride. Black was the most common color of MP, followed by blue. Filter feeders and species near polluted areas showed higher MP loads. The diversity in MP color, size, and polymer composition reflects a mix of land- and marine-based pollution sources. Differences in detection and limited health-impact data highlight the need for more consistent, in-depth research, emphasizing standardized protocols and further studies assessing biological and health impacts. This review points out the widespread presence of MP in aquatic species consumed by humans, raising significant concerns for seafood safety and environmental health in Indonesia. These findings highlight the urgent need for standardized analytical protocols and strengthened regulatory measures to address MP pollution, positioning it as an emerging environmental health priority in Indonesia.

1. INTRODUCTION

Microplastics (MP) are a growing environmental concern, posing risks to both ecosystem and human health, especially in marine environments (Pramaningsih et al., 2023). Defined as plastic particles ranging in size from 1 μm to 5 mm, MP accumulate in marine organisms, leading to human ingestion through seafood consumption, thereby signifying an increasing threat that requires immediate action (Hantoro et al., 2024; Luqman et al., 2021). Primary sources of MP in the marine environment include direct emissions from industrial processes and domestic use, such as microbeads in cosmetics and microfibers from synthetic textiles during washing (European Commission, 2025). Secondary sources result from the fragmentation of larger plastics exposed to UV radiation or physical wear (European Commission, 2025; Cole et al., 2011).

Indonesia is the world's largest archipelagic nation, located between the Pacific and Indian Oceans, with a population exceeding 285 million (Indonesia Population, 2025). As the second-largest fish producer globally, Indonesia's fisheries sector, including both marine and inland capture fisheries, along with aquaculture, plays a vital role in its economy (Henriksson et al., 2017). According to the South East Asian Fisheries Development Center in 2021, the fisheries sector contributed 2.77% to the gross domestic product, and per capita fish consumption was 35.26 kg. The Government of Indonesia has issued several regulations and legal frameworks at the national, provincial, and local levels. In 2017, Indonesia introduced the JAKTRANAS policy to manage household waste, aiming to reduce waste by 30% and treat 70% of solid waste by 2025, but it did not meet the targets (Maruf et al., 2019). In 2018, Presidential Regulation No. 35/2018 was issued to address plastic waste, focusing on social habit changes, reducing leakage, and promoting innovation in plastic production (Arifin et al., 2025). Indonesia's National Plan of Action (NPOA) on Marine Plastic Debris (2017-2025) highlights the need for integrated efforts, with the Coordinating Ministry for Maritime Affairs leading policy implementation (Maruf et al., 2019).

However, as a developing country, Indonesia has experienced rapid urbanization and industrial growth, leading to increased plastic consumption and poor waste management practices. Unfortunately, a major chunk of this waste ends up in the country's rivers and oceans (World Bank Group, 2021). As a result, Indonesia has become the second-largest contributor to marine plastic pollution, following China, with an annual emission of 0.27 to 0.59 million metric tons. This pollution not only harms the environment but also affects coastal economies by reducing tourism revenue and increasing cleanup costs, with the Asia-Pacific region losing around US \$1.265 billion annually (Maruf et al., 2019).

A recent study found that 105 Indonesian rivers account for 80% of global riverine plastic emissions into the ocean (Meijer et al., 2021). The main sources of land-based plastic pollution are the four islands of Java, Sulawesi, Bali, and Sumatra. MPs persist in marine environments for long periods and can be transferred from the environment to organisms, eventually making their way through the food web (Arifin et al., 2025). With Indonesia's vast coastline and significant fishing activities, this issue is even more concerning (Hantoro et al., 2019). Recent findings in Indonesia highlight the alarming presence of MP in seafood and human stools, indicating significant exposure among the population (Luqman et al., 2021). It is estimated that Indonesians have the highest intake of MP among nations, with seafood as one of the primary routes of exposure (Zhao et al., 2024).

However, there remains an extensive knowledge gap regarding the complex interactions among MP across species and ecosystems, the toxins they transport, and their effects on human health, highlighting the need for further research to fully understand these risks (Torre et al., 2019). Hence, given Indonesia's status as a significant contributor to marine plastic pollution, a review to inform future monitoring efforts, guide policy interventions, and support risk assessments related to MP contamination in aquatic ecosystems and food chains became necessary. Considering the heterogeneity in study designs, target species, detection techniques, and reported outcomes, a scoping review approach is well-suited to map the current evidence, identify knowledge gaps, and clarify methodological patterns. This scoping review aims to map existing evidence on MP pollution among aquatic species in Indonesian waters by synthesizing data on MP characteristics (type, size, shape, color, and polymer composition),

affected species, and the analytical methods employed in order to support research standardization, inform seafood safety risk assessments, and guide environmental policy development in Indonesia.

2. RESEARCH METHODS

The literature was searched using the advanced search functionality of the electronic literature database PubMed in May 2025. A pool of 128 articles was obtained from PubMed by combining the results of the broad individual keywords “Microplastics” and “Indonesia” in the initial search to uncover related literature. The keywords were searched across all fields, separated by the Boolean operator AND. The Population, Concept, Context (PCC) framework for determining the eligibility of studies for the research objective is presented in Table 1.

Table 1. The population, concept, context framework

Component	Description
Population	Aquatic organisms
Concept	Microplastics
Context	Indonesia

Eligibility criteria were established to include studies that meet the following inclusion criteria: (1) full-text research articles; (2) studies on microplastics in aquatic organisms; (3) studies conducted in Indonesia; and (4) studies reported in English. Studies were excluded if they (1) reported on MP in the aquatic environment, such as marine water or sediments without analyzing organisms, or (2) were systematic reviews, conference abstracts, editorials, or concept papers.

This scoping review was conducted and reported based on the guidelines outlined by Preferred Reporting Items for Systematic Reviews and Meta Analysis: extension for Scoping Reviews (PRISMA-ScR) (Tricco et al., 2018). After title and abstract screening, the eligibility of full-text articles was determined. A data charting form was created in an Excel sheet to extract relevant data items from the included studies systematically. The abstracted data items included study characteristics such as the name of the first Author, year of publication, study location, aquatic species investigated, sample size, sampling method, and organs analyzed. In addition, data on MP, such as detection methods used, MP shapes and size ranges, types of polymers identified, and findings, were extracted. The results were synthesized in a comprehensive summary table. All steps of the scoping review were conducted by one reviewer (AM).

3. RESULTS AND DISCUSSION

Study Selection

A total of 128 articles were identified in the initial search of the PubMed database (Figure 1). After title and abstract screening, 87 articles were discarded because they did not meet the stipulated inclusion criteria. The remaining 41 articles were eligible for full text screening and were reviewed in detail. However, 28 articles had to be excluded for the following reasons: studies reporting topics irrelevant to this review (n=3) and studies investigating irrelevant populations, including compartments of the aquatic environment such as water and sediments (n=25). Finally, 13 articles that met the inclusion criteria were selected for this scoping review.

Characteristics of the included studies

A summary of the key characteristics of the 13 included studies is presented in Table 2. All included studies were conducted between 2020-2025 in Indonesia. The primary aim of these studies was to assess the presence, characteristics, and potential biological impacts of MP in different aquatic species. These studies employed observational sampling approaches, typically involving point-in-time collections of fish, mussels, cockles, sea urchins, and sandfish from rivers, coastal waters, aquaculture sites, and

seafood markets in Indonesia. Most studies focused on MP detection in gills, digestive organs, or whole soft tissues, with sample sizes ranging from 10 to 300 aquatic individuals.

Across all studies, MP of various shapes, mainly fibers, fragments, and films, were detected, with particle sizes ranging from $<100\ \mu\text{m}$ to $5000\ \mu\text{m}$. Common polymer types included polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC). MP identification was primarily carried out using visual microscopy or stereomicroscopy, Fourier Transform Infrared (FTIR) spectroscopy for polymer identification, and in some cases, Gas Chromatography-Mass Spectrometry (GC-MS) was employed to identify plastic additives in MP.

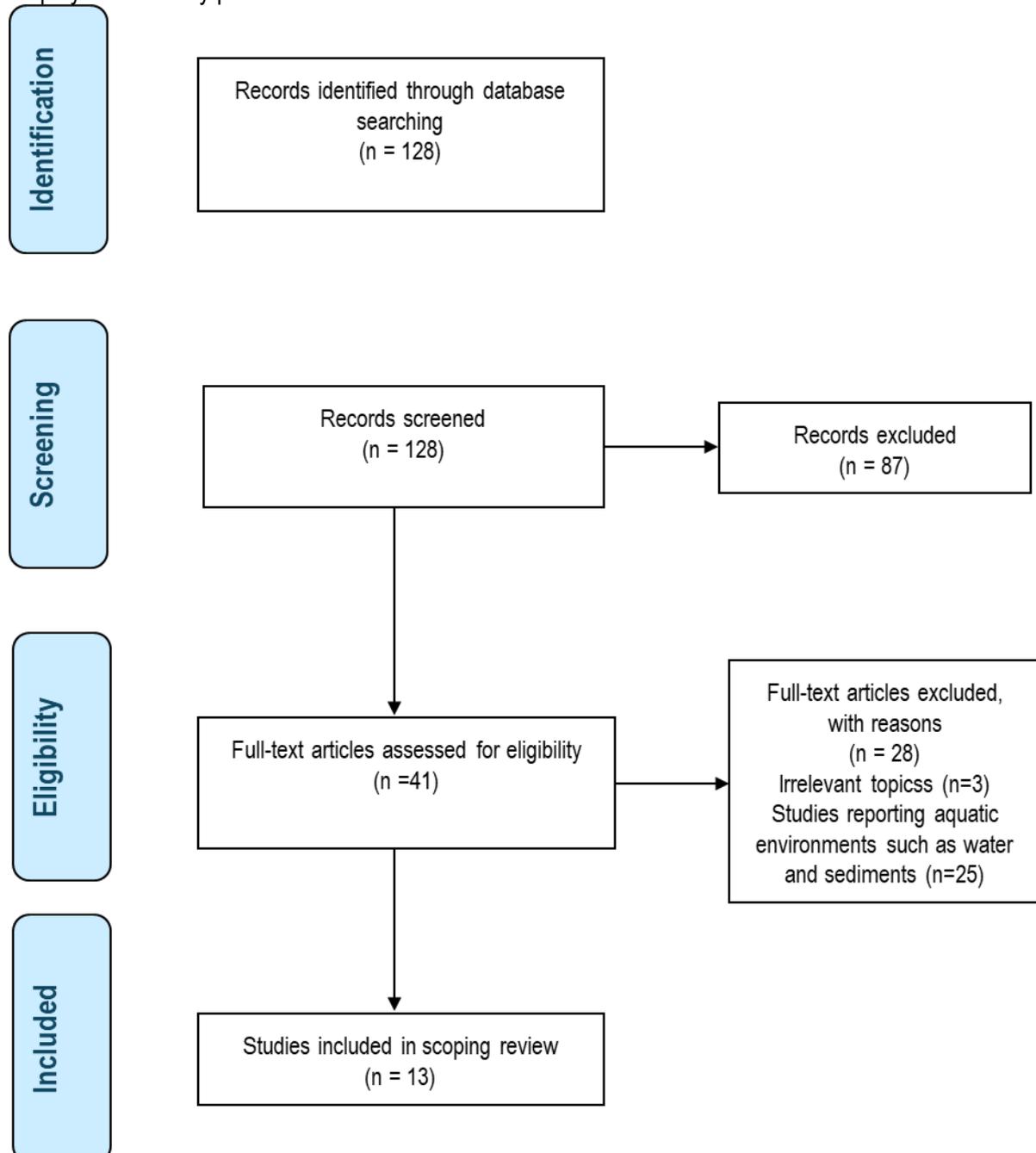


Figure 1. PRISMA flowchart of the selection of studies

Table 2. Characteristics of the included studies

Author, Year	Study location	Aquatic species, organs investigated, and MP abundance	Sample size, Sampling method	MP shape, MP size range	Polymer types identified	Detection method	Findings
Target organism: Green mussels							
Buwono et al. (2025)	Kalirejo coastal area, East Java, Indonesia	Green mussels (<i>Perna viridis</i>) Whole soft tissues At 1m sea depth: 160±15 particles/g, at 5m depth: 95±12.25 particles/g and at 10m depth: 50±8.66 particles/g	45 mussels per sampling round Manually collected from aquaculture racks.	Fragments, fibers, films. 55% MP: 500 µm–1 mm, 30% MP: 100–500 µm, 15% MP: >1 mm	Polyethylene, polyamide, polystyrene, polycarbonate, polyvinyl chloride.	Stereomicroscope and FTIR Spectroscopy for polymer identification	Fragments and polyethylene are dominant. A strong positive correlation ($R^2=0.75$, $p<0.05$, 95% CI) between water and mussel MP concentrations, with the highest MP abundance detected at 10 m depth of seawater.
Imidayanti et al. (2025)	Jakarta Bay, Indonesia	Green mussels (<i>Perna viridis</i>) Whole soft tissues (13.5 to 15.7 particles/ind)	300 mussels. Manually collected from traditional seafood markets in Jakarta.	Fibers, fragments, films, and pellets <100 µm.	Polyvinyl chloride, polyacrylonitrile, polycarbonate, polystyrene, polymethyl methacrylate, polyphenylsulphone, melamin-formaldehyde resin, polyethylene terephthalate, epoxy resin, polypropylene, polyvinyl acetate, polytetrafluoroethylene.	Stereomicroscope, FTIR spectroscopy for polymer identification, GCMS analysis for MP chemical composition.	Fibers were the dominant shape; black was the dominant color. MP abundance in cockle increased with an increase in shell length.
Imidayanti et al. (2023)	Jakarta Bay, Indonesia	Green mussels (<i>P. viridis</i>) Whole tissues (14 particles/ ind)	120 green mussels Direct collection from bamboo racks used in aquaculture.	Fibers, fragments, films <5000 µm	Polyurethane, polyimide, polyacrylonitrile, polycarbonate, polyphenylsulphone, polystyrene, polypropylene, acrylonitrile butadiene styrene, polyvinyl chloride, ethylene vinyl acetate, polytetrafluoroethylene, polymethyl methacrylate	Visual microscopy, FTIR spectroscopy	MP was detected in all green mussels sampled; fiber-shaped MP were dominant.
Target organism: Fish							
Noor et al. (2025)	Banten Bay, Indonesia	<i>Gambusia affinis</i> , <i>Stolephorus indicus</i> , <i>Scatophagus argus</i> , <i>Epinephelus coioides</i> , <i>Rastrelliger sp.</i> , <i>Parapenaeopsis sculptilis</i> , <i>Leiognathus sp.</i> Gills (7.85±3.45 items/ind) Digestive tract (4.95±2.15 items/ind)	21 fish from 7 different species Traditional fishing gear, 'bubu' and nets.	Fragments, filaments 20-4510 µm	Polyethylene terephthalate, polyvinyl chloride, polyester, polyurethane, ethylene propylene, polypropylene, polyethylene, polystyrene, polyphenylene sulfide.	Visual microscopy and analysis by FT-IR Spectroscopy.	Higher MP concentration in gills; fragments and smaller-sized MP were dominant; omnivorous species were more affected.
Marchellina et al. (2024)	East Java Coast, Indonesia	Spotted scat fish (<i>Scatophagus argus</i>) Gills (6.2±5.3 particles/ind) Stomach (9.1±8 particles/ind) Intestines (9.8±11.5 particles/ind)	120 fish Gillnets or fishing nets.	Fibers, fragments, films, and pellets 1000–<5000 µm	Ethene-vinylacetate, latex, polyamide, polypropylene, polyethylene, polyvinyl chloride, styrene-butadiene rubber, ethene-propene rubber.	Visual microscopy, FTIR spectroscopy for polymer identification, GCMS analysis for plastic additives.	Fibers were the dominant shape; black was the dominant color. There was a positive correlation between MP

Lestari et al. (2023)	Surabaya River, Indonesia	<i>Chanos chanos</i> , <i>Hemibagrus planiceps</i> , <i>Notopterus notopterus</i> (gastrointestinal tract- 186±130.81 particles/ind), <i>Oreochromis mossambicus</i> , <i>Pterygoplichthys pardalis</i> , <i>Rasbora argyrotaenia</i> (gastrointestinal tract- 358.75±121.98 particles/g wet weight), <i>Trichopodus trichopterus</i> (gills- 280.73±162.25 particles/g wet weight) gills and gastrointestinal tract	28 fish Fishing nets.	Fibers, fragments, films. Small MP (300–1000 µm) Large MP (1000–5000 µm)	Cellophane, Polyethylene-propylene, Low-density polyethylene, Polyvinyl chloride, polystyrene.	Dissection, wet peroxide oxidation, density separation, filtration; FTIR spectroscopy	abundance in intestines and fish length (p=0.025, 95% CI). MP concentration in gills decreased with age. Large, fiber-shaped, black-colored MPs were dominant; Cellophane was the dominant polymer; higher MP was found in gills than in the GIT.
Imidayanti et al. (2023)	Jakarta Bay, Indonesia	Mackerel (<i>Rastrelliger kanagurta</i>) gills (4.8±1.6 items/g) gastrointestinal tract (5.9±2.3 items/g)	120 fish 2-inch mesh gillnets.	Fibers, fragments, films. <100 µm	Latex, nylon, polycarbonate, polymethyl methacrylate, cellulose acetate, polyurethane, polystyrene, polytetrafluoroethylene.	Visual microscopy, FTIR spectroscopy	MPs that are fragment-shaped and black-colored were dominant.
Buwono et al. (2022)	Brantas River, East Java, Indonesia	Mosquito fish (<i>Gambusia affinis</i>) Entire fish body analyzed (Downstream 209.18±48.85 particles/g, Upstream 24.44±0.14 particles/g)	224 fish Collected using 0.2 cm mesh nets.	Fragments, fibers, films, pellets <100µm	Polyvinyl chloride, polystyrene, polyethylene, polycarbonate, polyamide	Visual microscopy, FTIR spectroscopy for polymer identification, GCMS analysis for plastic additives.	At the highest MP concentration downstream, Phthalic acid esters were dominant. Dominant shapes: Fiber upstream, Fragment downstream.
Riani et al. (2022)	Lampung and Sumbawa, Indonesia	Sandfish (<i>Holothuria scabra</i>) Viscera/internal digestive tract (2.01±1.59 particle/ind)	Sandfish: 28 from Lampung, 54 from Sumbawa Collected by local fishers/divers	Fragments, fibers, granules, foams 25.83% MP: 300-500 µm, 57.78% MP:500–1000 µm	Polyethylene, polypropylene, polyurethane, polyethylene terephthalate, polyamide, cellophane polystyrene, cellulose acetate, polyester, polybutadiene	Microscopic analysis, FTIR and µFTIR spectroscopy for polymer identification	MP were present in 89.02% of sandfish, with higher abundance in Lampung than in Sumbawa. Fragments and fibers of 300–1000 µm were dominant, and PE and PP were the most common polymers. A positive correlation between MP abundance in sediments and

Andreas et al. (2021)	Southern Coast of Java, Indonesia	Skipjack Tuna (<i>Euthynnus affinis</i>) Gastrointestinal tract (4 particles/ind)	10 fish Collected from traditional markets.	Filament (84%), Angular (11%), Round (5%) <250-5000 µm	Polybrominated Diphenyl Ethers	Stereomicroscopy, FTIR spectroscopy for polymer identification, GCMS analysis for plastic additive.	sandfish (R ² =0.49, 95% CI). MP were detected in Skipjack Tuna at all sampling locations, with filamentous MP dominant.
Cordova et al. (2020)	Ciliwung Estuary and North Jakarta Coastal Waters, Indonesia	Blue panchax fish (<i>Aplocheilichthys sp.</i>) Entire fish body analyzed (1.97 particles/ind)	60 fish samples Collected using larva nets.	Fibers, fragments, foam, granules 300–500 µm	Polyethylene, polypropylene, polystyrene, polyester, cellophane	Visual microscopy under a Nikon stereo microscope, FTIR spectroscopy for polymer identification,	MP were found in 75% of fish. Dominant forms were fibers and small-sized particles (300–500 µm), suggesting ingestion due to resemblance to food.
Target organism: Other aquatic species							
Rahmatin et al. (2024)	Coastal waters of East Java, Indonesia	Blood cockle (<i>Anadara granosa</i>) Whole soft tissues (27 particles/ind)	120 cockles Manual collection during low tide.	Fibers, fragments, films, and pellets 100–300 µm	Ethene-vinylacetate, latex, nitrile, nylon, polycarbonate, polymethyl methacrylate, polytetrafluoroethylene, polystyrene, polyvinyl chloride.	Visual microscopy, FTIR spectroscopy for polymer identification, GCMS analysis for plastic additives.	Fibers were the dominant shape; black was the dominant color. There was a positive correlation between MP abundance in sediment and cockle tissues (p=0.046, 95% CI).
Rahmawati et al. (2023)	Pari and Harapan Islands, Kepulauan Seribu, Indonesia	Sea urchins (<i>Echinodermata: Echinoidea</i>) Digestive tract (Pari island: 3.93±2.25 particles/g dry weight; Harapan island: 0.27±0.28 particles/g dry weight)	21 sea urchins Direct extraction by divers.	Fragments, fibers, films. <300–>1000 µm	Polyethylene, polyester, polypropylene	Visual microscopy and analysis by FT-IR spectroscopy.	Fragments were the dominant shape, with blue color MP in Pari and red in Harapan Islands, respectively. Higher MP abundance was found in Pari Island.

MP-Microplastics; FTIR-Fourier Transform Infrared; GC-MS-Gas Chromatography Mass Spectrometry

Buwono et al. (2025) conducted a sampling of green mussels in whole tissues from the Kalirejo coastal area, East Java. The dominant MP found was fragments, and the dominant polymer was PE. A strong positive correlation (R²=0.75, p<0.05, 95%CI) was noted between MP concentrations in mussel tissue and surrounding water. Irmidayanti et al. (2025) analyzed green mussels collected from seafood markets in Jakarta Bay. Fibers were the most dominant shape, and black-colored particles were most frequently observed. PS, PVC, and melamine-formaldehyde resin were detected as the dominant polymers. MP abundance increased with an increase in mussel shell length. In another study, Irmidayanti et al. (2023) examined green mussels collected directly from aquaculture racks in Jakarta Bay. Twelve types of polymers were identified, and all mussel samples contained MP, with fibers being the most dominant form.

Noor et al. (2025) investigated MP contamination in seven fish species collected from Banten Bay, Indonesia. MP were identified in each fish sampled, with an increased concentration in the gills compared to the digestive tract. Fragments and filaments were the predominant shapes. Nine types of polymers

were detected. Polyurethane (PU) and PVC were dominant in gills. MPs with smaller-sized particles and fragments were more prevalent in omnivorous species. Limitations of this study include a small sample size, restricted sampling sites, and sampling conducted at designated time points, which affect the accuracy and generalizability of the findings. Marchellina et al. (2024) assessed spotted scat fish collected from the East Java coast. MPs were extracted from the gills, stomach, and intestines. Eight different types of polymers were detected. MP concentrations in intestines positively correlated with fish length ($p=0.025$, 95% CI), while gill MP levels decreased with age.

Lestari et al. (2023) analyzed MP presence in freshwater fish from the Surabaya river. Particles were mainly fibers, black in color, and large-sized in the range of 1000-5000 μm . Cellophane was dominant. MP concentrations were higher in gills than in digestive tissues. Iridayanti et al. (2023) also conducted a study on mackerel from Jakarta Bay. Eight types of polymers were detected. Fragment-shaped, black-colored MP were most prevalent. Buwono et al. (2022) conducted a separate study in the Brantas River, East Java, analyzing mosquito fish. They concluded that it can be used to indicate the presence of MP in the river. MPs were extracted from whole bodies, with fragments and fibers being the main components detected. Phthalic acid was the dominant polymer. MP concentrations were highest downstream, with fibers upstream and fragments downstream.

Riani et al. (2022) analyzed sandfish from Lampung and Sumbawa. MP were present in 89% of the samples, mostly fibers and fragments. The major polymers detected were PE and PP. MP abundance was higher in Lampung, and sediment MP levels correlated with those in sandfish tissues. Andreas et al. (2021) studied skipjack tuna from traditional markets along Java's southern coast. MPs were identified in gastrointestinal tracts, with filaments being most dominant, followed by angular and round particles. Only one polymer type, polybrominated diphenyl ethers (PBDE), was reported. Cordova et al. (2020) investigated blue panchax fish from the Ciliwung Estuary and North Jakarta. MP were primarily fibers and small fragments, and 75% of the fish contained MP. The identified polymers included PE, PP, PS, and cellophane.

Rahmatin et al. (2024) examined blood cockles collected manually at low tide from coastal waters off East Java. Fiber-shaped black particles were dominant, and MP concentrations correlated with sediment contamination levels ($p=0.046$, 95% CI). MPs with hazardous plasticizers were also identified in the cockles. Rahmawati et al. (2023) investigated sea urchins from Pari and Harapan Islands in Kepulauan Seribu. MPs were extracted from the digestive tract, with fragments being dominant. The polymers identified were PE, polyester, and PP. Interestingly, the dominant MP color varied by location: blue in Pari and red in Harapan.

This scoping review provides a comprehensive synthesis of available studies on MP contamination in aquatic organisms across Indonesia, highlighting the complexity of MP pollution in the region. The included studies consistently demonstrate that MP are present in a wide range of freshwater, estuarine, and marine species, with contamination detected in nearly all tissue types examined, including gills, digestive tracts, and whole soft tissues. The widespread detection of MP indicates their pervasive nature and the rising ecological threat posed by plastic waste in aquatic environments.

A recurring observation across the studies was the consistent detection of MP in seafood species commonly consumed by humans. Filter-feeding organisms such as mussels and cockles exhibited particularly high MP burdens, reflecting their susceptibility to MP ingestion due to their feeding strategies (Hantoro et al., 2019). This is concerning from a food safety standpoint, as these species are often consumed whole, including their digestive and respiratory systems, where MP predominantly accumulate (Hantoro et al., 2024; Isfarin et al., 2024). In contrast, in species such as milkfish, larger MP particles were typically found in the gills and intestines, suggesting a lower risk of consuming filleted meat (Hantoro et al., 2024).

According to Septaria et al. (2025), *Codex alimentarius* was created as a globally accepted benchmark for food safety, and there are no specific Codex guidelines for MP in Indonesian seafood. Therefore, MP exposure through seafood remains an important and growing concern, particularly given the absence of clear consumption guidelines or regulations in Indonesia. Furthermore, fishery products

currently do not have an internationally recognized maximum level of MP. Several studies suggest that MP can cross intestinal barriers, enter the bloodstream, and accumulate in organs, potentially triggering inflammation, endocrine disruption, and long-term effects such as infertility, obesity, and cancer (Basri et al., 2021). The toxicological potential of MP is closely linked to their size, shape, and chemical composition (Hantoro et al., 2024). Smaller particles (<100 μm) were found to be more readily ingested and potentially more harmful due to their ability to penetrate cells and tissues (Hantoro et al., 2024; Isfarin et al., 2024; Pelegrini et al., 2023). Among shapes, fibers and fragments were most common, with fibers frequently dominating, especially in filter-feeding organisms (European Commission, 2025; Cole et al., 2011). Toxicity was reported to decrease in the order: spheres > fibers > fragments > beads (Hantoro et al., 2024). However, direct conclusions regarding human health effects cannot be drawn from the reviewed studies, as most investigations focused on detecting and characterizing MP exposure rather than toxicological outcomes. Consequently, potential health implications should be interpreted as inferred risks based on existing evidence rather than demonstrated effects.

Polymer composition also reflected a mixture of pollution sources. The most commonly identified polymers were PE, PP, PS, and PVC- all widely used in consumer products, packaging, and fishing materials. More complex polymers, such as polycarbonate and PU, and additives, such as phthalic acid esters and PBDEs, suggest contributions from industrial waste and highlight the chemical complexity of MP pollution. It is well established that MP can carry other pollutants, such as heavy metals and persistent organic pollutants, which increase pollutant concentrations in various aquatic organisms (Gola et al., 2021). These observations point to a mixed-source pollution profile, involving both land-based activities (e.g., waste mismanagement, wastewater discharge) and marine-based sources (e.g., fishing gear, boat coatings, aquaculture infrastructure).

Color analysis revealed that black was the predominant MP color observed, followed by blue. This pattern may indicate specific pollution sources. The dominance of black MP may indicate sources such as tire wear particles, degraded rubber, fishing gear and plastic packaging materials. Blue MP are commonly associated with synthetic textiles, rope and fishing nets. Color plays a key role in species-level susceptibility, as aquatic organisms ingest MP either by intentionally consuming plastic fragments that mimic natural food in size and appearance or by unintentionally swallowing particles during suspension, deposition or filter feeding (Rahmawati et al., 2023). The repeated presence of these colors highlights both human activity in coastal zones and the need for further research on color-mediated feeding behavior. Several environmental and biological variables were found to influence MP presence. MP concentrations tend to be higher in downstream areas and near aquaculture operations (Buwono et al., 2022). Additionally, factors such as species age, size and feeding habits were linked to differential MP loads, with omnivorous species often showing higher levels of ingestion (Rahmawati et al., 2023). These findings point toward a complex web of exposure pathways shaped by both ecological and anthropogenic factors.

When comparing the MP abundance reported in this review with global findings, it becomes evident that Indonesian green mussels exhibit considerably higher levels of MP contamination. In Jakarta Bay, Buwono et al. (2025) reported concentrations of 160 ± 15 particles/g at 1 m depth, 95 ± 12.25 particles/g at 5 m depth, and 50 ± 8.66 particles/g at 10 m depth. Similarly, Iridyanati et al. (2023) observed 14 particles per individual, while Iridayanti et al. (2025) reported 13.5–15.7 particles per individual. These findings stand in stark contrast to reports from other parts of the world, where levels are significantly lower. For example, Cho et al. (2018) documented only 0.97 ± 0.74 particles per individual mussels from South Korea, while mussels from Italy showed 4.53 ± 2.1 particles per individual (Quaglia et al., 2023). These differences highlight the particularly high exposure of Indonesian mussels to MP, which can be caused by higher plastic input into Indonesian coastal waters due to dense coastal populations and inadequate waste management; biological and physiological differences among mussel species that may influence feeding, filtration and retention of MP; and methodological variations in detection, digestion, and filtration protocols across studies (Iridayanti et al., 2025).

A similar trend is observed when comparing fish. Globally, fish from Australia were reported to contain 1.58 ± 0.23 pieces per individual, almost double that found in fish from Fiji (0.86 ± 0.14 pieces per individual) (Septaria et al., 2025). In contrast, this review found markedly higher concentrations in Indonesian fish. For instance, *Notopterus notopterus* contained 186 ± 130.81 particles per individual, while Spotted scat fish had 9.8 ± 11.5 particles/individual (Marchellina et al., 2024; Lestari et al., 2023). These values illustrate a wide interspecies variation, likely reflecting differences in feeding habits, trophic levels, habitat ranges and exposure pathways.

Overall, the findings suggest that MP contamination in Indonesian aquatic organisms, both mussels and fish, is substantially higher than in many regions globally (Figure 2). This not only highlights the severity of MP pollution in Indonesian waters but also emphasizes the urgent need for standardized methodologies to ensure comparability across studies. Without standardized protocols for sampling and quantification, it remains challenging to determine whether observed differences are primarily due to environmental pollution or to methodological biases.

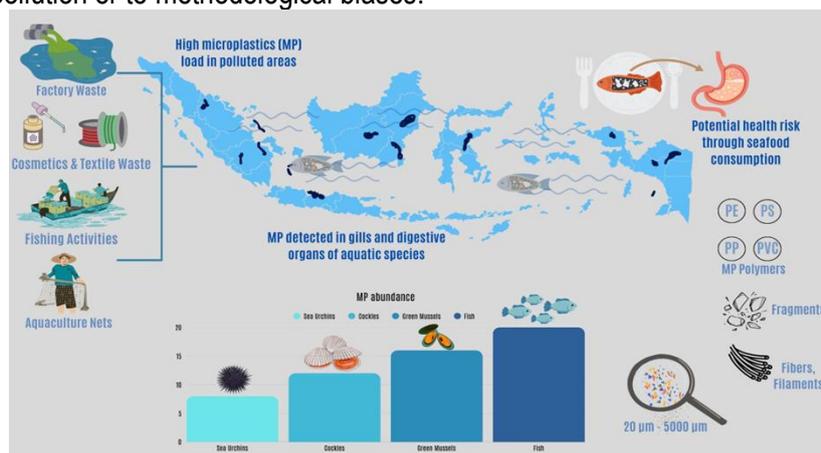


Figure 2. MP contamination in Indonesian aquatic organisms

Strengths and Limitations

To the best of our knowledge, this is the first scoping review focused exclusively on MP contamination in aquatic organisms within Indonesia. Guided by the PCC framework and the use of MeSH terms and Boolean operators, a thorough literature search was conducted to identify eligible studies from PubMed. The inclusion of studies spanning multiple geological formations, such as rivers, bays, estuaries, and open coasts, provides valuable insights into area-specific patterns of MP contamination. This review incorporated multiple taxonomic groups (e.g., fish, bivalves, echinoderms), providing broad ecological representation and allowing observations across feeding strategies and trophic levels. Furthermore, the included studies used advanced analytical methods, such as FTIR and GC-MS, to identify the composition of both polymers and additives, thereby enhancing the credibility of MP detection. Finally, the characteristics and findings of the included studies were systematically extracted and synthesized, allowing identification of trends in polymer types, particle morphology, and detection techniques used across studies.

Despite its strengths, the results must be interpreted cautiously due to limitations. Firstly, the lack of standardized protocols for sampling, digestion, and quantification of MP should be stressed, as these inconsistencies risk under- or overestimation of MP prevalence and contamination level. Additionally, most studies used point-in-time sampling, limiting insights into seasonal variability and the influence of episodic pollution events (e.g., monsoon-related runoff). Most studies focused solely on identifying and quantifying MP, with limited investigation into biological effects on both aquatic organisms and humans. The absence of such toxicological endpoints represents a major knowledge gap. Further, all stages of the review process, including screening, data extraction, and synthesis, were conducted by a single reviewer (AM). Although this approach ensured consistency in data handling, it may have increased the risk of selection and extraction bias. In line with the objectives of a scoping review, no formal quality

appraisal of the included studies was conducted, limiting the ability to conclude the strength of the evidence. Finally, it is possible that several relevant studies were missed, as the search was restricted to a single biomedical database (PubMed) and to articles published only in English.

4. CONCLUSIONS

This scoping review demonstrates that MP contamination is widespread across aquatic organisms in Indonesian freshwater, estuarine, and marine ecosystems. High MP burdens were consistently reported in commercially important and filter-feeding species, reflecting the pervasive presence of plastic-derived particles originating from consumer products, packaging materials, fishing gear, and aquaculture infrastructure. The dominance of polymers such as polyethylene, polypropylene, polystyrene, and polyvinyl chloride highlights the contribution of conventional plastic use and inadequate waste management to environmental contamination. Methodological heterogeneity across studies emerged as a key finding, limiting quantitative comparability and reinforcing the need for standardized research protocols.

Based on this evidence, policy interventions should prioritize reducing plastic inputs at their sources, particularly those associated with single-use plastics, fishing activities, and aquaculture operations. The promotion of sustainable alternatives, such as seaweed-based bioplastics, is relevant in this context, given Indonesia's extensive marine resources and the identified contribution of petroleum-based polymers to MP contamination. Strengthening regional collaboration within the Association of South East Asian Nations (ASEAN), implementing standardized monitoring frameworks, and supporting research on health risk assessment are critical steps toward mitigating MP pollution and protecting seafood safety in Indonesia. Educating the public on the health and environmental impacts of plastic waste is also crucial, particularly by integrating environmental education in schools and using social media to engage younger generations in reducing plastic use, which would have a lasting impact in the long run.

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