Review:

Status and Research Gaps of Microplastics Pollution in Indonesian Waters: A Review

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Received: March 10, 2022
Accepted: July 3, 2022

DOI: 10.22146/ijc.73485

Abstract: *This study is the first review of current research on microplastics (MPs) in the marine environments at the national scale in Indonesia from 2015 to 2022. This review was conducted to measure the environmental risk and highlight the waste management issue in Indonesian waters. Our literature study found that: (1) the MPs research was mainly conducted in the western part of Indonesia, especially in Java Island; (2) current research has primarily focused on coastal waters (98%) rather than the deep-sea area (2%); (3) the comparability of data is still hampered by difference in quality, about 67% of articles published have not carried out the polymer confirmation; (4) MPs concentrations reported on the articles that did not carry out the polymer identification tended to report higher MPs concentrations. Finally, we propose to have a standard guideline for MPs analysis at a national level and to do more research in the eastern part of Indonesia and deep-sea areas. Further research is required to fill research gaps on plastic distribution and density in deep-sea areas in the eastern part of Indonesia.*

Keywords: *MPs; seawater; marine sediment; marine biota; Indonesia*

INTRODUCTION

Plastics are widely used in packaging, followed by building and construction, automotive, electrical and electronics, agricultural household, leisure, and sport [1]. Plastic is preferred over other materials because it has several advantages: strong, light, cheap, easy to form, can be made transparent, and can be colored. In addition, it does not rust after being left in open air and water [2]. Since the first mass production started in the 1950s, plastic production rose to 368 million tons in 2019 [1]. Plastic fabrication is predicted to continue to grow along with the development of technological advances in plastic polymers. Most plastic products are single-use items designed to be thrown out after one time use. It is reported that 40% of plastic produced was plastic packaging that will only be used once [1]. If plastic waste is not adequately managed, it can end up in the ocean. Millions of tons of plastic entered the ocean from 192 coastal nations and are predicted to increase in connection with the increase in plastic production every year [3-5]. The ever-increasing amount of plastic waste in the oceans has attracted researchers worldwide to uncover the extent to which plastic pollution has entered the waters. Plastic waste has been detected in coastal areas of all continents, even in highly isolated areas such as the Arctic Ocean [6] and the Mariana deepest trough at a depth of 10908 meters in the Pacific Ocean [7].

Indonesia is the second-largest contributor to plastic waste in the world's ocean. Indonesia was estimated to produce 3.2 million tons of unmanaged plastic waste a year, of which about 1.29 million tons end up in the sea [4]. In 2017, the Ministry of Industry of the Republic of Indonesia estimated that every year, 4.8 million tons of plastic waste in Indonesia is considered mismanaged in various ways such as being openly burned (48%), dumped on land, in poorly managed official dumpsites (13%), or leaking into rivers, lakes and the ocean (9%) [8]. The latest report of the World Bank in 2021 showed that the number has increased to 4.9 million tons [9]. In a meeting of G20 leaders conducted in Germany, the Indonesian government has a target to decrease waste by reducing solid waste from its source by 30% and adequately handling 70% of solid waste by 2025, 70% of marine plastic litter by 2025 in order to minimize the impacts of plastic pollution. The basic strategy used to minimize plastic waste was by establishing a National Plan of Action (NPOA) on Marine Plastic Debris from 2017 to 2025 [8]. The main objective of this NPOA is to overcome the impacts of plastic waste pollution in the sea and reduce plastic waste in the sea by 70% in 2025. Since 2017, referring to this action plan, many activities have been organized to clean up beaches and rivers in various regions.

In the past decade, scientists have been concerned about microplastics (MPs) which are plastics under 5 mm in size that are often invisible to the naked eye [10]. This increasing concern is highly due to its significant impact on marine biota [11]. The small sizes of MPs can be mistaken as food for various marine species. As a result, MPs have been found in megafauna to planktonic marine biota [12-17]. MPs have been discovered in seawater, sediment, and marine biota in Indonesian waters. In order to explore the topic of MPs' studies in Indonesia, here, we reviewed publications regarding MPs' from Indonesian marine waters from 2015 to 2022. Subsequently, we also identified research gaps about MPs pollution in Indonesian waters. The data and information provide an overview of the degree of plastic pollution across Indonesia and the requirement for better marine environmental management and further research.

Data Collection and Review of Content

In this study, we collected the references (papers) from Indonesia that have been indexed in Scopus. Recent references published between 2015 (first MPs paper) and 2022 were retrieved using some keywords: "microplastic", "plastic", "debris", "litter", and "Indonesia". The references are reviewed critically, and the data collected from the references are entered into MS Excel for data analysis. The papers include 66 published articles (35 journal articles and 31 conference papers) (Fig. 1). The MPs assessment is focused on three major matrices: seawater, marine sediment, and marine biota. This article provides information on MP concentration from Indonesian marine waters, the sampling and extraction methods, the shape of MPs, and the plastic polymers identification. We also highlighted research gaps and management challenges regarding MP pollution in Indonesian waters.

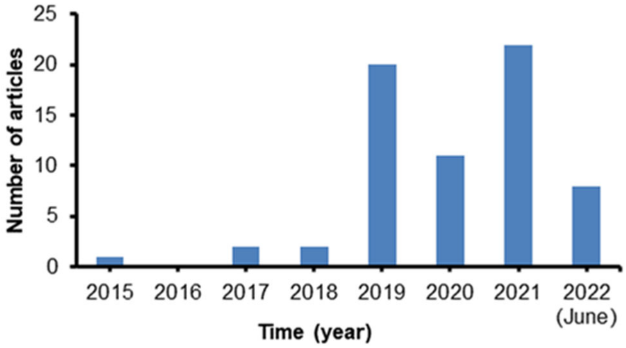

Fig 1. Number of papers on microplastics published between 2015 and 2022 (June) in Indonesia

RESULTS AND DISCUSSION

Determination of MPs in Indonesia

Sampling procedures

The instrument and methods used for collecting MPs for seawater, marine sediment, and marine biota in Indonesia have not been standardized. From the literature published in Indonesia, it was discovered that manta and plankton nets were commonly used to collect water samples in coastal waters with mesh sizes of 200 or 300 µm (Table 1). A new development has been conducted through simultaneous grading size samples in sea surface sampling. The water samples were directly divided into sizes 0.5 × 0.5 cm; 500–1000 µm; 300–500 µm; 100–300 µm [18]. In Indonesia, the volume of a water sample taken by plankton nets varied from 0.1 to 10 L. Relatively, no data was found regarding the volume of a water sample taken by a manta net. For the deep-sea waters, the water sample was collected using a rosette water sampler from certain layers with 10 L per layer [19]. Meanwhile, pipe, Ekman grab, and shovel was commonly used to collect the marine sediment samples, which varied from 100 to 1000 g (Table 2). Some studies used a transect (0.5 × 0.5 m; 1 × 1 m) to grab the sediment samples [20-23]. Marine biota was generally collected from the markets and in which the entire gastrointestinal tract was taken for MPs analysis. However, for the small biota (e.g., anchovies, *blue panchax* fish), the entire body of the biota was used [24-28]. The number of samples varied from 2 to 60 individuals. It is suggested that 50 or more individuals per research unit are defined as a suitable sample size for the number of biota samples [29]. Unfortunately, most studies in Indonesia have not exceeded this number of samples. Out of 39 studies, only three (7%) completed this threshold [24,30-31].

Laboratory methodologies for MP extraction

The methods and techniques to isolate MPs from other non-plastic materials such as biological tissues, organic matter, and other non-plastic materials were varied. There are four common types of digestion solutions used to extract and purify the MP from samples, namely acids (nitric acid (HNO_3), hydrochloric acid (HCl), per-chloric acid ($HClO_4$), etc.), bases (sodium hydroxide (NaOH), potassium hydroxide (KOH)), Oxidant (hydrogen peroxide (H_2O_2)), and enzymes (trypsin, proteinase K, etc.) [12-13,32-34]. However, H_2O_2 30% and KOH 10% were mainly used to remove non-plastic materials in most sample matrices (water, sediment, and biota) to digest biological tissues, organic matter, and other non-plastic materials without damaging the MPs. HNO_3, HCl, and NaOH were reported to alter plastic's physical state or cause the loss of some plastic-type features [32-33]. The other reagent that can be considered in the extraction process of MP is the enzyme solution. An enzyme (trypsin, proteinase-K) has the advantage of ensuring MPs integrity, short digestion time, and is less harmful to human and environmental health [32-33]. However, this method is rarely used because of the higher price compared to the chemical reagents. In Indonesia, MPs in the seawater and marine sediment samples were isolated mainly using the sodium chloride (NaCl) solution using the flotation separation method (density). However, few studies used H_2O_2 30% to purify the MPs in seawater and marine sediment, especially when the size of the MP of interest was less than 1 mm [19-20,24]. For larger MPs (1–5 mm) in beach sand and coastal sediment, the MPs were directly separated using a 1–mm^2 stainless steel sieve, followed by visual sorting [21].

Physical and chemical characterizations

In general, the MPs were physically categorized based on shape, size, color, and type of polymers under the observation of a stereomicroscope. To date, most MP research in Indonesia used visual identification based on size (< 200 µm, 200–500 µm, 500–1000 µm, 1000–5000 µm) and shape (fragment, fiber, foam, film, and granule). Regarding the color of MPs, most studies of MPs in Indonesia did not include the analysis of the color of plastics. The polymer type of the plastics can be further identified either by Fourier transform infrared spectroscopy (FTIR), thermal desorption gas chromatography with mass spectrometry (TDS-GC/MS), pyrolysis gas chromatography with mass spectrometry (Pyr-GC/MS), or Raman spectroscopy. Plastic polymer identification is a crucial protocol to examine the chemical characteristic of MP particles obtained from the visual calculation results (physical analysis) since it will highly be susceptible to misidentifying non-polymer fiber as a plastic material. This type of material is difficult to distinguish through microscopy alone. Additionally, the airborne contamination of fiber types is likely to happen in MP research if a proper cross-contamination protocol is not followed [35]. Previously, research on MPs in sediment samples from the North Sea measured using micro-FTIR showed that only 1.4% of particles visually resembling MPs came from synthetic polymers [36]. The literature data showed that most studies on MPs in Indonesia (over 60%) do not provide polymer analysis. This may be caused by the limited resources of analytical instrumentation that are not easily/readily available in Indonesia. We highlighted a tendency for the reported MPs value to be higher in articles that did not pass the plastic polymer conformation. Due to these cases, in regards to comparing studies in Indonesia with studies in other countries, we only included the articles that had performed the polymer identification test.

Size and unity

The commonly used units for the study of MPs in Indonesia were n/L (number per liter) for seawater, n/g (number per gram) for marine sediment, and n/ind (number per individual) for marine biota. Some studies that used transect to collect samples in the marine sediment expressed the MPs found with the unit item per m^2 or item per m^3 [21]. In Indonesia, the size of MPs was varied; however, most of the studies did not inform the specific size of MPs, but instead gave general size information of < 5 mm. Nonetheless, some studies classified the MPs in size ranges: < 0.1 mm; 0.3 to 0.5 mm; 0.5 to 1 mm; > 1 mm; and 1 to 5 mm [24,37-38].

Quality control

MP studies are very susceptible to contamination, such as airborne contamination, research equipment, and research materials. The airborne contaminant has been confirmed as fiber, which can indirectly contaminate the sample [35]. Some controls are highly recommended to minimize the contamination during analytical procedures in the laboratory. First, airborne contamination in the laboratory can be minimized by separating the sample processing process from other laboratory activities. Secondly, the air intake from the outside of the analysis room can be reduced by closing air vents to prevent contamination from outside. Thirdly, the destruction process should be carried out in a fume hood or laminar flow chamber to minimize airborne contamination sources [39]. Lastly, samples should always be kept closed to minimize exposure to air. Research equipment is also a significant source of contamination in MP research. Therefore, it is suggested to use metal and glass research apparatus rather than plastic research equipment. Another recommendation was to heat all the research apparatus at 450 °C for 5 h to remove all plastic before using it in MP analysis [40]. Washing research equipment repeatedly with distilled water has effectively removed plastic fibers up to 88 to 98%. However, an experimental study stated no significant difference between repeated rinsing of the research apparatus with heating at high temperatures [41]. In Indonesia, only a few studies provided information about quality control during the sampling and analysis in the laboratory, e.g., leaving a bare Petri dish or a sterilized filter paper near the sample during the digestion process until the identification is completed [24,37]. They also used either liquid water purified by a reverse-osmosis technique or double-distilled deionized water 3–5 times in their washing procedure, including during the sample clean-up and glassware/sample bottle washing. They found no MP contamination on the blank sample by applying these controls.

The Occurrence of MPs in the Marine Environment in Indonesia

MPs in seawater

A total of 26 data on MPs in seawater have been reported from 2017 to 2022. Among these, about 96% of the data reported was conducted in coastal areas, including estuaries, seagrass habitats, mangrove areas, and coral reef areas. However, we also identified that 48% of the articles did not identify the plastic polymer. The MP abundance in seawater of coastal areas in Indonesia ranged from 0.00004 to 110737 n/L (for the studies without polymer identification) and 0.000023 to 11100 n/L (for studies with polymer identification) (Table 1). The highest concentration of 11100 n/L was found in a small-scale estuary in Central Java [42]. The river receives a large amount of domestic waste without any treatment process. The type of polymer found was polyethylene where this plastic material is widely used in household goods which are easily degraded. We also observed that the value of MP tends to be higher in estuary areas and mangrove ecosystems. This might be due to the ability of mangrove branches and roots to act as trash traps in the water. Trapped trash tends to gest stuck in the mangrove area [43]. Meanwhile, the lowest MP concentration was found in the seagrass ecosystem area of the Sulawesi Island [44].

The MP concentration in the coastal areas of Indonesia varied widely. The MPs content with a polymer conformation in Sulawesi Island was 0.000023 up to 55 n/L, followed by 0.00046 ± 0.00025 n/L in Sumatra Island;

0.00054 in Bali Island and 0.00848 ± 0.00943 to 11100 n/L in Java Island (Table 1). The highest MPs content was found in a small-scale estuary in Central Java Island. It is remarkable that this value has far exceeded the MPs content in the estuary of Yellow River, China (930 n/L) [45], Changjiang Estuary, China (0.045 to 0.122 n/L) [46], Yangtse Estuary, China (4.13 n/L) [47], Goiana Estuary, Brazil 0.00026 n/L [48], Urban Estuary in South Africa (0.001 to 0.007 n/L) [49]and Tamar Estuary, England (0.00028 n/L) [50].

The first available data of MPs on the Indonesian deep-sea area was reported from the water column of Sumba waters (300 m) 0.044 ± 0.024.59 n/L [19]. These concentrations were far lower than in coastal areas. The MPs concentration reported in Indonesia is relatively lower than the average concentration of MPs in the world's open sea, which is 0.07 to 13.51 n/L [7,51]. The MPs concentration in Sumba Waters decreased in line with the depth and has relatively high concentrations in the thermocline area. Otherwise, the concentration of MPs in the Mariana Trench is linear with their depth levels [7].

MPs in coastal sediments

Studies regarding the concentrations of MPs in sediments have been carried out in Indonesian waters since 2017 (Table 2). Unfortunately, about 70% of the studies conducted did not carry polymer tests on the plastics found. The MPs abundance in marine sediment of coastal areas in Indonesia ranged from 2.96 to 111680 n/Kg dry weight (DW) (for studies without polymer identification) and 0 to 49000 n/Kg DW (for studies with polymer identification) (Table 2). The highest MPs concentration (49000 n/Kg) was found in Central Java [42]. This unrealistic value is found in a small-scale estuary used as a dumping area by the local community. Notably, this concentration is higher than in other regions around the world. For instance, the MPs found in Changjiang Estuary, China, was reported in the range of 20 to 340 n/Kg [52], Haihe Estuary, China (96.7 to 333.3 n/Kg) [53], Yondingxinhe Estuary, China (56.7 to 113.3 n/Kg) [53] and in coastal mangrove, Singapore (12 to 62.7 n/Kg) [54]. However, these findings were not consistent across Indonesia. Some studies also reported that MPs concentration in some estuaries in Indonesia was lower than in other regions. For instance, a lower concentration of MPs was found in mangrove sediment from Jakarta Bay in the range of 28.09 ± 10.28 n/Kg [37].

MPs in marine biota

Entanglement and plastic consumed by marine biota when consuming food have been frequently reported as the effects of large-sized plastics on wildlife and other aquatic biotas. Wildlife entangled in plastic may become immobile, bound, and eventually die. Animals that consume plastic may experience intestinal obstructions or even suffocate [2]. However, reports of microplastics in biota are far more widespread. Marine biota is more likely to consume smaller microplastics than larger macroplastics. Microplastics have been discovered in marine organisms of all sizes, from zooplankton to whales [12-17]. However, based on experiments in the laboratory, the presence of microplastics in the marine biota did not directly cause any deaths. Studies that documented mortality from exposure to microplastics found that the death of marine biota were typically caused by unreasonable intake of microplastics that also exceeds the expected concentration of microplastics in the environment [55-56]. Plastic can pass through the digestive tract but cannot be digested like food. This situation can change eating patterns, impede physical growth and physiological processes, and damage biota immunological systems [57-59]. It is recognized that exposure to microplastics in the biota can facilitate the entrance of hazardous chemicals into the biota [60].

MPs studies in Indonesia on biota have been conducted on various species such as fish (demersal and pelagic) and benthic biota (sea cucumber, shellfish, sea urchins) (Table 3 and Table 4). Thirty-eight papers report the presence of MPs and anthropogenic waste in marine biota. Of the 38 articles, only eight articles reported the polymer composition in their studies. Plastics are generally identified in the digestive tract. The MPs abundance in fish ranged from 0 to 246 and 0 to 688 n/ind (for studies with polymer identification) (Table 3). The highest MPs concentration was found in the anchovy species *Stolephorus* spp., which is caught in the waters around Sulawesi (688 n/ind) [61]. Based on

FTIR results, it was suspected that the type of MPs found was polystyrene, polyamide. Generally, the higher MPs concentration was recorded in the pelagic fish (Table 3). MPs studies on benthic biota have been reported on shellfish, sea cucumbers, and sea urchins. However, only three studies provided data with polymer identification. The MPs abundance in benthic organisms ranged from 0.5 to 2175 and 0.29 to 3.2 n/ind (for studies with polymer identification) (Table 4).

The MP content found in marine biota from Indonesia was significantly varied. The lower MP concentration in demersal fish were recorded from Sulawesi Island (0.17 to 0.8 n/ind) [44] and Jakarta Bay (1.97 n/ind) [24]. Both of these values were below MP content in fish estuarine from England (0.69 n/ind) [62] and China (2.5 n/ind) [63]. The low range of MPs on benthic biota was recorded in Sulawesi Island (0.29 to 0.5 n/ind) [64]. This range was lower than France (2.1 n/ind) [65], and Canada (6.1 to 15.4 n/ind) [66]. Nevertheless, few studies reported a much higher concentration in fish, for instance, 366 ± 3.51 n/ind in a small pelagic fish, *Stolephorus* spp. [26].

Research Gaps on MPs Research in Indonesia

We highlight the limited resources (expensive chemical reagents and analytical instrumentation that are not easily/readily available in Indonesia) that caused most studies on MPs in Indonesia (64%) not to provide polymer analysis. It is found that MPs concentration in most studies without polymer identification can be overestimated. Consequently, the MPs' concentration in Indonesian waters is widely varied. Furthermore, these studies did not provide the blank procedure during the sampling and laboratory analysis, so it is challenging to do

Table 1. The concentration of MPs in seawater of Indonesia

Location	Sampling devices	Volume sample (L)	MPs extraction	Concentration (n/L)	Shape dominancy	Chemical form	Quality control	Ref.
Bali	Manta net	*NI	H_2O_2 30%	0.00054 to 0.0007	Fragment	PP, PE, PS	Yes	[67]
Bali	Plankton net	35800	Gravimetrically	0.00004 to 0.00090	Film	NA	NA	[68]
ENT	Rosette sampler	10	H_2O_2 30%	0.044 ± 0.024	Fiber	NA	NA	[19]
ENT	Plankton net	1	H_2O_2 30%	2 to 28	Fiber	NA	NA	[69]
Java	Pipette	0.2	NaCl	156 ± 13.46	Fiber	NA	NA	[70]
Java	Plankton net	20	NaCl	13.15	Fiber	NA	NA	[71]
Java	Plankton net	20	NaCl	90.7 to 103.8	Fiber	NA	NA	[72]
Java	Plankton net	10	NaCl	15460	Film	NA	NA	[73]
Java	Plankton net	20	NaCl	248.5 ± 3.81	Fiber	NA	NA	[74]
Java	Manta net	*NI	H_2O_2 30%	0.66 to 3.00	Fragment	PP, PE	Yes	[75]
Java	*NI	5	NaCl	700 to 11100	Fiber	PP, PE	Yes	[42]
Java	*NI	20	H_2O_2 30%	0.38 to 0.61	Foam	PE, PS	Yes	[76]
Java	Manta net	*NI	H_2O_2 30%	0.00848 to 0.00937	Fragment	PE, PP, PS	Yes	[24]
Java	Manta net	270000	$ZnCl_2$	16.8 to 41.6 (in n/m^2)	*NI	PP, LDPE	NA	[77]
Java	Plankton net	20	NaCl	87626 to 110737	Fiber	NA	NA	[78]
Java	Manta trawl	0.15	NaCl	57530	Fiber	NA	NA	[79]
Java	Manta trawl	*NI	NaCl	70.9 ± 27.1	Film, fiber	PP, PE	Yes	[80]
Java	Plankton net	5000	*NI	12.6	Fiber	Nylon, PP, PS	NA	[81]
Molucca	Manta Net	21829	H_2O_2 30%	0.0146 to 0.4331	Fiber	NA	NA	[82]
Sulawesi	Vacum pump	10	$ZnCl_2$	7 to 55	*NI	PS	NA	[83]
Sulawesi	Manta net	*NI	$ZnCl_2$	0.000023	*NI	LDPE, PS	NA	[44]
Sulawesi	Neuston net	*NI	KOH 10%	0.00178 to 0.00183	Fiber	NA	NA	[84]
Sulawesi	Neuston net	*NI	H_2O_2 30%	0.056	Fragment	PS	NA	[85]
Sulawesi	Neuston net	10	Gravimetrically	6.9 to 7.7	Fiber	PS, PE	Yes	[86]
Sumatra	Plankton net	5	NaCl	283.9 ± 2.63	Fiber	NA	NA	[87]
Sumatra	Manta net	*NI	H_2O_2 30%	0.00046 ± 0.00025	Fragment	PE, LDPE, PP	Yes	[18]

*ENT: East Nusa Tenggara; NI: Not Informed; NA: Not Available; n/L: item per liter; n/m^2: item per meter square; PP: polypropylene, PS: Polystyrene; PE: polyethylene; LDPE: Low-Density PE

Table 2. The concentration of MPs in marine sediment of Indonesia

Location	Sampling devices	Volume sample (g)	MPs extraction	Concentration (n/Kg)	Shape dominancy	Chemical form	Quality control	Ref.
Java	Transect	250	H_2O_2 30%	28.09 ± 10.28	Foam	PP, PE	Yes	[37]
Java	Gravity corer	500	NaCl	800 to 49000	Fragment	PP, PE	Yes	[42]
Java	*NI	500	NaCl	31700	Film	NA	NA	[73]
Java	*NI	500	H_2O_2 30%	206.04 to 896.96	Fragment	NA	NA	[88]
Java	Transect	2000	NaCl	145 to 354	Fragment	NA	NA	[89]
Java	*NI	250	NaCl	87.4 to 99.88	Fiber	NA	NA	[78]
Java	Eckman grab	*NI	H_2O_2 30%	3.35 to 13.33	Fragment	PP, PE	Yes	[75]
Java	Grab sampler	*NI	NaCl	590	Fiber	PP, LDPE	*NI	[90]
Java	*NI	*NI	NaCl	18405 to 38790	Fragment	NA	NA	[91]
Java	Sediment grab	*NI	NaCl	82480 to 111680	Fiber	NA	NA	[72]
Java	Pipe	*NI	NaCl	169.2 ± 5.184	Fiber	NA	NA	[74]
Java	Smith-McIntyre	10 cm depth	NaCl	267 ± 98	Foam	CP, PS	Yes	[38]
Java	Grabs	500 to 1000	NaCl	920	Fiber	NA	NA	[71]
Java	Eckman grab	20	SI	34666 to 45066	Fiber	PE, PP, PS	NA	[92]
Java	Grab sampler	35 mL	$ZnCl_2$	0 to 8	Fiber	PP	Yes	[93]
Java	Van Veen grab	600 to 880	NaCl	166.9	Film, fiber	PP, PE, PS	Yes	[80]
Java	*NI	*NI	H_2O_2 10%	28500 to 43000	Film	NA	NA	[94]
Molucca	Transect	0.0125 m^3	gravimetrically	68.8 N/m^2	Film	NA	NA	[21]
Papua	Transect		H_2O_2 30%	1140 to 1998	Fiber	NA	NA	[20]
Sumatra	Transect	250	NaCl	11200 ± 263	Fiber	NA	NA	[23]
Sumatra	Transect	250	NaCl	3700 ± 0.28	Film	NA	NA	[87]
Sumatra	Shovel	250	NaCl	906	Film	NA	NA	[95]
Sumatra	*NI	100	NaCl	1976 to 2203	Fiber	NA	NA	[96]
Sumatra	Van Veen grab	250	H_2O_2 30%	72.64 ± 25.28	Fragment	PE, PP	Yes	[97]
Sulawesi	*NI	100	$ZnCl_2$	2.96 to 28.29	*NI	NA	NA	[83]
Sulawesi	*NI	120	$ZnCl_2$	14.6 to 50	Fiber	PE	NA	[64]
Sulawesi	Corer	100	$ZnBr_2$	195 ± 66.98	Fiber	NA	NA	[98]
Sulawesi	Transect	150	H_2O_2 30%	165 to 217	Fiber	NA	NA	[22]
WNT	Transect	1500	NaCl	116.41 ± 80.78	Fragment	NA	NA	[99]
WNT	Van Veen grab	250	H_2O_2 30%	44.19 ± 12.40	Fragment	PE, PP	Yes	[97]

*ENT: East Nusa Tenggara; NI: Not Informed; NA: Not Available; n/Kg: item per kilogram; n/m^2: item per meter square; n/m^2: item per meter cubic; PP: polypropylene, PS: Polystyrene; PE: polyethylene; LDPE: Low-Density PE; ABS: Acrylonitrile Butadiene Styrene; PC: Polycarbonates; CP: cellulose propionate; PVC: Polyvinyl Chloride; PA: polyamide

Table 3. The abundance of MPs in fish from Indonesia

Location	Species	Number of samples	MPs extraction	Concentrations	Physical shape	Chemical form	Quality control	Ref
ENT	*Stolephorus spp.*	15	NaOH	302 ± 1.0	Film	NA	NA	[25]
Java	*Mugil dussumieri*	15	HNO_3 65%	297	Fiber	NA	NA	[79]
Java	*Aplocheilus sp.*	60	H_2O_2 30%	1.97	Fiber	PP, PS	Yes	[24]
Java	*Various fishes*	25	HNO_3 65%	16.28	Fiber	NA	NA	[100]
Java	*Oreochromis mossambicus*	10	NaCl	4.30 ± 4.7	Fiber	NA	NA	[101]
Java	*Scatophagus argus*	35	NaCl	5.22 ± 4.3	Fiber	NA	NA	[101]
Java	*S. canaliculatus*	30	NaCl	17.97 ± 5.8	Fiber	NA	NA	[101]
Java	*Crenimugil seheli*	12	NaCl	8.42 ± 11.9	Fiber	NA	NA	[101]
Java	*M. cephalus*	27	NaCl	9.26 ± 6.1	Fiber	NA	NA	[101]
Java	*C.chanos*	10	NaCl	8 ± 6.3	Fiber	NA	NA	[101]
Java	*Anodontostoma chacunda*	10	NaCl	12.50 ± 6.7	Fiber	NA	NA	[101]
Java	*Abalistes stellaris*	30	NaCl	16.07 ± 11.05	Fiber	NA	NA	[101]

Location	Species	Number of samples	MPs extraction	Concentrations	Physical shape	Chemical form	Quality control	Ref
Java	*C. chanos*	6	HNO_3 65%	8.8 to 9.58 (n/g)	Fiber	NA	NA	[72]
Java	*C. chanos*	3	H_2O_2 30%	1.16 to 2.66	Fragment	PP, PE	Yes	[75]
Java	*Euthynnus affinis*	*NI	KOH 15%,	1 to 9	*NI	NA	NA	[102]
Java	*S. commersonnii*	15	H_2O_2 30%	1.87 ± 0.64	Fiber	NA	NA	[28]
Java	*S. insularis*	15	H_2O_2 30%	6.8 ± 1.62	Fiber	NA	NA	[28]
Java	*S. indicus*	15	H_2O_2 30%	3.66 ± 2.41	Fiber	NA	NA	[28]
Java	*S. indicus*	*NI	NaOH	246.10 ± 32.25	Fiber	NA	NA	[70]
Java	*S. fimbriata*	10	NaCl	14.6 ± 6.09	Fiber	NA	NA	[70]
Java	*Stolephorus* spp.	15	NaOH	42 to 131	Fiber	PP, PA	Yes	[61]
Java	*L. vitta*	3	NaCl	15 to 26	Fiber	NA	NA	[103]
Java	*Cephalopholis boenak*	2	NaCl	8 to 10	Fiber	NA	NA	[103]
Java	*C. formosa*	1	NaCl	8	Fiber	NA	NA	[103]
Java	*Plectorhinchus gibbosus*	1	NaCl	7	Fiber	NA	NA	[103]
Java	*Cyprinus* sp.	1	NaCl	11	Fiber	NA	NA	[103]
Java	*Genera Epinephelus*	20	HNO_3 65%	82.4	Fiber	NA	NA	[94]
Kalimantan	*Stolephorus* spp.	15	NaOH	130 ± 1.73	Fiber	NA	NA	[25]
Kalimantan	*Stolephorus* spp.	16	NaOH	366 ± 3.51	Fragment	PE, HDPE	NA	[26]
Molucca	*Epinephelus fuscogutattus*	29	NaCl	3.07	Fragment	NA	NA	[31]
Molucca	*E. coioides*	36	NaCl	2.64	Fragment	NA	NA	[31]
Molucca	*E. suillus*	65	NaCl	1.51	Fragment	NA	NA	[31]
Molucca	*S. canaliculatus*	47	NaCl	2.47	Fragment	NA	NA	[31]
Molucca	*Synanceia*	27	NaCl	5.93	Film	NA	NA	[31]
Molucca	*Scarus psittacus*	16	NaCl	2.25	Fragment	NA	NA	[31]
Molucca	*Stolephorus* spp.	15	NaOH	277 ± 1.15	Fiber	PA	Yes	[61]
Papua	*Stolephorus* spp.	15	NaOH	59 to 290	Fiber	HDPE, PA	Yes	[61]
Sumatra	Various fishes	25	KOH 10%	62.96	Film	NA	NA	[104]
Sumatra	*Stolephorus* spp.	15	NaOH	246 to 645	Fiber	PS, PS, HDPE	Yes	[61]
Sulawesi	*Oreochromis niloticus*	5	KOH 10%	0			NA	[34]
Sulawesi	Family Carangidae	7	KOH 10%	5.9 ± 5.1	Fragment	NA	NA	[34]
Sulawesi	*S. argenteus*	2	KOH 10%	0.5 ± 0.7	Fragment	NA	NA	[34]
Sulawesi	*S. fuscescens*	2	KOH 10%	0			NA	[34]
Sulawesi	*S. canaliculatus*	3	KOH 10%	0.3 ± 0.6	Fiber	NA	NA	[34]
Sulawesi	*Lutjanus gibbus*	5	KOH 10%	0.00			NA	[34]
Sulawesi	*Katsuwonus pelamis*	9	KOH 10%	0			NA	[34]
Sulawesi	*Rastrelliger kanagurta*	9	KOH 10%	1 ± 1.1	Fragment	NA	NA	[34]
Sulawesi	*Decapterus macrosoma*	17	KOH 10%	2.5 ± 6.3	Foam	NA	NA	[34]
Sulawesi	*Spratelloides gracilis*	10	KOH 10%	1.1 ± 1.7	Fragment	NA	NA	[34]
Sulawesi	*S. canaliculatus*	10	KOH 10%	0.8	*NI	LDPE, Nylon, PS	NA	[44]
Sulawesi	*Gerres longirostris*	10	KOH 10%	0.5	*NI	LDPE, Nylon, PS	NA	[44]
Sulawesi	*Selaroides leptolepis*	14	KOH 10%	0.43	*NI	LDPE, Nylon, PS	NA	[44]
Sulawesi	*Lethrinus ornatus*	12	KOH 10%	0.17	*NI	LDPE, Nylon, PS	NA	[44]
Sulawesi	*Oreochromis niloticus*	25	KOH 10%	1.6 to 3.5	*NI	NA	Yes	[84]
Sulawesi	*Megalops cyprinoides*	12	KOH 10%	1.83 to 3.5	*NI	NA	Yes	[84]
Sulawesi	*Barbonymus gonionotus*	23	KOH 10%	0.91 to 2	*NI	NA	Yes	[84]
Sulawesi	*Chanos chanos*	50	KOH 10%	3.5 ± 2.87	*NI	NA	Na	[30]
Sulawesi	*Stolephorus* spp.	15	NaOH	95 to 688	Fiber	PS, PA	Yes	[61]
WNT	*Stolephorus* spp.	16	NaOH	88 ± 2.89	Fiber	PP, PS, LDPE, Nylon	NA	[27]
WNT	*Stolephorus* spp.	15	NaOH	48 ± 2.31	Fiber	PS	Yes	[61]

*WNT: West Nusa Tenggara; NI: Not Informed; NA: Not Available; n/ind: item per individual; n/g: item per gram; PP: polypropylene, PA: polyamide; PS: Polystyrene; PVC: Polyvinyl Chloride; HDPE: High-density polyethylene

Table 4. The abundance of MPs in benthos from Indonesia

Location	Species	Number of samples	Mps Extraction	Concentrations (n/ind)	Physical shape	Chemical form	QC	Ref.
Java	*Perna viridis*	30	HNO_3 65%	23	Fiber	NA	NA	[71]
Java	*Littoraria scabra*	10	HNO_3 65%	75.5	Fiber	NA	NA	[105]
Java	*Metopograpsus quadridentata*	9	HNO_3 65%	328.56	Fiber	NA	NA	[105]
Java	*Telescopium telescopium*	27	HNO_3 65%	764.81	Film	NA	NA	[73]
Java	*Anadara granosa*	15	HNO_3 65%	618.8 ± 121.4	Fiber	NA	NA	[74]
Java	*Diadema setosum*	15	HNO_3 65%	1,786 to 2,175	Fiber	NA	NA	[78]
Java	*Holothuria leucospilota*	15	HNO_3 65%	8.44 (n/g)	Fiber	NA	NA	[106]
Java	*Paracaudina sp*	20	KOH 10%	289 to 1380	Fiber	NA	NA	[107]
Java	*Dolabella auricularia*	8	HNO_3 65%	40.1 to 73.7 (n/g)	Fiber	NA	NA	[108]
Java	*Placuna placenta*	6	H_2O_2 30%	1	Fiber	PP, Nylon	NA	[81]
Sumatra	*A. granosa*	10	HNO_3 65%	434 ± 97.05	Fiber	NA	NA	[23]
Sumatra	*Cerithidea obtusa*	*NI	HNO_3 65%	167 ± 16.01	Film	NA	NA	[87]
Sumatra	*Laevistrombus turturella*	*NI	HNO_3 65%	489	Film	NA	NA	[95]
Sumatra	*H. scabra*	28	H_2O_2 30%	3.21 ± 0.07	Fragment	PE, PP	Yes	[97]
Sumatra	*Various species*	*NI	H_2O_2 30%	32 to 52	Fiber	NA	NA	[109]
Sulawesi	*Marcia hiantina*	22	KOH 20%	1.10 to 3.08	Fiber	NA	NA	[110]
Sulawesi	*Tripneustes gratilla*	17	KOH 10%	0.53	*NI	NA	NA	[64]
Sulawesi	*Pinna* sp.	6	KOH 10%	0.5	*NI	NA	NA	[64]
Sulawesi	*Pinctada* sp.	12	KOH 10%	0.3	*NI	NA	NA	[64]
Sulawesi	*Cypraea tigris*	10	KOH 10%	0.3	*NI	NA	NA	[64]
Sulawesi	*Nudi Branch*	6	KOH 10%	0			NA	[64]
Sulawesi	*Tripneustes gratilla*	14	KOH 10%	0.5	*NI	LDPE, PS	NA	[44]
Sulawesi	*Cyprea tigris*	14	KOH 10%	0.36	*NI	LDPE, PS	NA	[44]
Sulawesi	*Pinctada* sp.	14	KOH 10%	0.29	*NI	LDPE, PS	NA	[44]
Sulawesi	*D. setosum*	10	KOH 10%	23.70 ± 2.99	Fiber	NA	NA	[98]
WNT	*H. scabra*	54	H_2O_2 30%	1.39 ± 0.86	Fragment	PE, PP	Yes	[99]

*NI: Not Informed; NA: Not Available; n/ind: item per individual; n/g: item per gram; PS: Polystyrene; LDPE: Low-Density polyethylene; PA: polyamide

comparative studies among other studies across Indonesia.

The MPs' research in Indonesia primarily focused on the western part of Indonesia (65%), including Java Island. About 50% of studies were conducted on Java Island (Fig. 2). Over 60% of data came from the western part of Indonesia. Meanwhile, research conducted in the eastern part of Indonesia were predominantly in rural areas and small islands that are very vulnerable to marine plastic waste due to limited waste management. Over 70% of plastic pollution in Indonesia originates in rural regions and small to medium-sized cities [8-9]. It is reported that plastic waste in mangrove areas of small islands such as the Ambon Island (Molucca) negatively impacts mangrove health [43]. Plastic waste is trapped in mangrove areas due to limited waste management on small islands.

It is also observed that limited data is available regarding the distribution of MPs in Indonesia's deep-sea waters. The lack of study in the deep-sea area of Indonesia is something that is worth noting. Essentially, if we refer to the deep-sea's definition as a sea with a depth of more than 200 meters vertically and horizontally [111], then 68% (4.1 million km^2) of Indonesia's marine area is classified as deep-sea waters [112]. Although very limited data is available from the deep sea area, several studies predicted potentially large quantities accumulating in the deep sea ocean. This is expected after a higher concentration of MP is found in line with their depth [7,112]. It is reported that the increase in the value of MP in the water column and marine sediment in Mariana Trench is in conformity with its depth [7]. However, our knowledge about microplastic pollution from deep-sea oceans is relatively

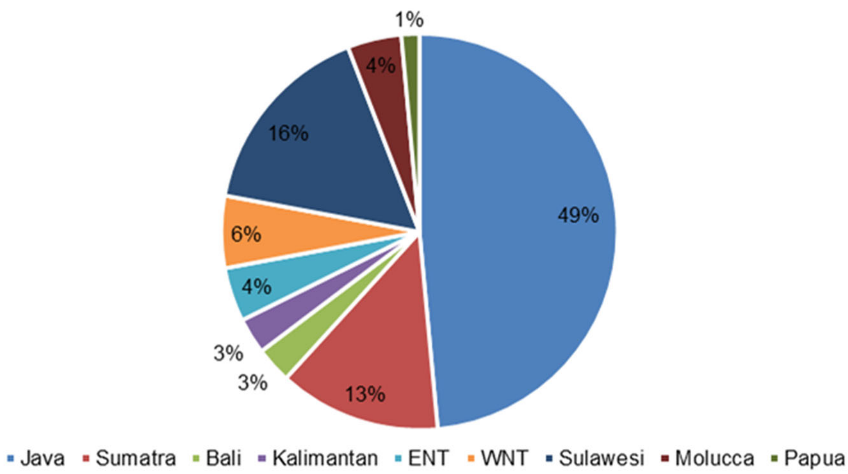

Fig 2. Number of papers on microplastics published between 2015 and 2022 (June) in Indonesia based on locations

little. We need more data from deep-sea areas.

This brief review also highlights that the dominant research in Indonesia is still related to the distribution and concentration of MPs. Information on MPs fate analysis until it reaches the body of organisms or humans and research related to the mechanism of transportation of microplastics does not appear to be widely available in Indonesia. Furthermore, due to the higher MPs concentration in Indonesian waters in some locations, we proposed to do research about remediating MP from the environment. The MPs remediation technologies such as electrocoagulation, sediment-MP isolation (SMI), cellulose nitrate filter membrane, fluidization and flotation, nanoparticle and sol-gel method have been widely used in the remediation of MPs [114].

■ CONCLUSION

This brief review summarizes the milestones that have been made in microplastic research in the Indonesian waters over the last decade. Lack of polymer analysis in the research in Indonesia due to the limited resources (expensive chemical reagents and analytical instrumentation that is not easily/readily available) led to many unconfirmed studies regarding the type of polymer, thus can also undermine the result. It is noteworthy that most studies on MP in Indonesia (64%) do not provide polymer identification and lack a blank/control procedure during the sampling until the identification process, thus impeding data quality. Consequently, the estimation of MP concentration is overestimated, and comparative studies are challenging. The MP research was mainly conducted in the western part of Indonesia, especially on Java Island. Data and information about MP pertaining to the eastern part of Indonesia are very limited. Current research has primarily focused on coastal waters rather than the deep-sea area. Thus, we propose to have a standard guideline for MPs analysis at a national level and future work should focus on conducting more research in the eastern part of Indonesia, which is mainly dominated by deep-sea areas.

■ ACKNOWLEDGMENTS

The authors thank Dr. Muhammad Reza Cordova from the Research Center for Oceanography, National Research and Innovation Agency (BRIN) and Dr.rer.nat. Yasman, M.Sc. from Universitas Indonesia (UI) for providing helpful comments on earlier drafts of the manuscript. The authors would like to thank the 2022-2023 Hibah PUTI Q2 of Universitas Indonesia (NKB-656/UN2.RST/HKP.05.00/2022) and LIPI COREMAP-CTI 2021–2022 (17/A/DK/2021) for funding this study.

■ AUTHOR CONTRIBUTIONS

Corry Yanti Manullang: Writing – original draft, Writing – Review & editing, Conceptualization, Resources, Investigation, Methodology, Analysis. Rafidha Dh Ahmad Opier: Data curation. Suyadi, Mufti Petala Patria, Agus Haryono, Sabiqah Tuan Anuar:

Supporting the study and revising the substantial content.

REFERENCES

[1] Plastics Europe, 2020, *Plastics–the Facts 2020*, https://plasticseurope.org/knowledge-hub/plastics-the-facts-2020/, accessed on 1 March 2021.

[2] Thevenon, F., Carroll, C., and Sousa, J., 2014, *Plastic Debris in the Ocean: The Characterization of Marine Plastics and their Environmental Impacts, Situation Analysis Report*, IUCN, Gland, Switzerland.

[3] Geyer, R., Jambeck, J.R., and Law, K.L., 2017, Production, use, and fate of all plastics ever made, *Sci. Adv.*, 3 (7), e1700782.

[4] Jambeck, J., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., and Law, K.L., 2015, Plastic waste inputs from land into the ocean, *Science*, 347 (6223), 768–771.

[5] Meijer, L.J.J., van Emmerik, T., van der Ent, R., Schmidt, C., and Lebreton, L., 2021, More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean, *Sci. Adv.*, 7 (18), eaaz5803.

[6] Lusher, A.L., Tirelli, V., O'Connor, I., and Officer, R., 2015, Microplastics in Arctic polar waters: The first reported values of particles in surface and sub-surface samples, *Sci. Rep.*, 5 (1), 14947.

[7] Peng, X., Chen, M., Chen, S., Dasgupta, S., Xu, H., Ta, K., Du, M., Li, J., Guo, Z., and Bai, S., 2018, Microplastics contaminate the deepest part of the world's ocean, *Geochem. Perspect. Lett.*, 9, 1–5.

[8] Government Republic of Indonesia, 2020, *Indonesia's Plan of Action on Marine Plastic Debris 2017-2025*, https://maritim.go.id/konten/unggahan/2018/03/NAP_Marine_Plastic_Debris_Indonesia_Summary.pdf, accessed on 1 August 2021.

[9] World Bank, 2021, *Plastic Waste Discharges from Rivers and Coastlines in Indonesia*, Marine Plastics Series, East Asia and Pacific Region, Washington DC.

[10] GESAMP, 2015, *Sources, fate and effects of microplastics in the marine environment: A global assessment*, Eds. Kershaw, P.J., IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, Rep. Stud., GESAMP No. 90, 96 p.

[11] Kühn, S., Bravo Rebolledo, E.L., and van Franeker, J.A., 2015, "Deleterious Effects of Litter on Marine Life" in *Marine Anthropogenic Litter*, Eds. Bergmann, M., Gutow, L., and Klages, M., Springer International Publishing, Cham, Switzerland, 75–116.

[12] Besseling, E., Wegner, A., Foekema, E.M., van den Heuvel-Greve, M.J., and Koelmans, A.A., 2013, Effects of microplastic on fitness and PCB bioaccumulation by the lugworm *Arenicola marina* (L.), *Environ. Sci. Technol.*, 47 (1), 593–600.

[13] Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., and Galloway, T.S., 2013, Microplastic ingestion by zooplankton, *Environ. Sci. Technol.*, 47 (12), 6646–6655.

[14] Desforges, J.P.W., Galbraith, M., and Ross, P.S., 2015, Ingestion of microplastics by zooplankton in the northeast Pacific Ocean, *Arch. Environ. Contam. Toxicol.*, 69 (3), 320–330.

[15] Md Amin, R., Sohaimi, E.S., Anuar, S.T., and Bachok, Z., 2020, Microplastic ingestion by zooplankton in Terengganu coastal waters, southern South China Sea, *Mar. Pollut. Bull.*, 150, 110616.

[16] Sun, X., Li, Q., Zhu, M., Liang, J., Zheng, S., and Zhao, Y., 2017, Ingestion of microplastics by natural zooplankton groups in the northern South China Sea, *Mar. Pollut. Bull.*, 115 (1-2), 217–224.

[17] Wieczorek, A.M., Croot, P.L., Lombard, F., Sheahan, J.N., and Doyle, T.K., 2019, Microplastic ingestion by gelatinous zooplankton may lower efficiency of the biological pump, *Environ. Sci. Technol.*, 53 (9), 5387–5395.

[18] Syakti, A.D., Hidayati, N.V., Jaya, Y.V., Siregar, S.H., Yude, R., Suhendy, S., Asia, L., Wong-Wah-Chung, P., and Doumenq, P., 2018, Simultaneous grading of microplastic size sampling in the Small Islands of Bintan water, Indonesia, *Mar. Pollut. Bull.*, 137, 593–600.

[19] Cordova, M.R., and Hernawan, U.E., 2018, Microplastics in Sumba waters, East Nusa

Tenggara, *IOP Conf. Ser.: Earth Environ. Sci.*, 162, 012023.
[20] Marei, I.C.A., Saleh, F.I.E., Manullang, C.Y., Soamole, A., and Rehalat, I., 2021, Occurrence and distribution of microplastics in the beach sediment of Anday Beach, West Papua (Indonesia), *IOP Conf. Ser.: Earth Environ. Sci.*, 944, 012070.
[21] Manullang, C.Y., 2019, The abundance of plastic marine debris on beaches in Ambon Bay, *IOP Conf. Ser.: Earth Environ. Sci.*, 253, 012037.
[22] Widiastuti, I.M., Serdiati, N., and Tahya, A.M., 2021, Study of microplastic sediment abundance in Palu Bay, Central Sulawesi, Indonesia, *AACL Bioflux*, 14 (5), 2857–2865.
[23] Fitri, S., and Patria, M.P., 2019, Microplastic contamination on *Anadara granosa* Linnaeus 1758 in Pangkal Babu mangrove forest area, Tanjung Jabung Barat district, Jambi, *J. Phys.: Conf. Ser.*, 1282, 012109.
[24] Cordova, M.R., Riani, E., and Shiomoto, A., 2020, Microplastics ingestion by blue panchax fish (*Aplocheilus* sp.) from Ciliwung Estuary, Jakarta, Indonesia, *Mar. Pollut. Bull.*, 161, 111763.
[25] Ningrum, E.W., and Patria, M.P., 2019, Microplastics and mercury detection on anchovy from Alor and Balikpapan harbors, Indonesia, *2019 IEEE R10 Humanitarian Technology Conference (R10-HTC)(47129)*, November 12-14, 2019, Depok, Indonesia, 254–257.
[26] Ningrum, E.W., Patria, M.P., and Sedayu, A., 2019, Ingestion of microplastics by anchovies from Talisayan harbor, East Kalimantan, Indonesia, *J. Phys.: Conf. Ser.*, 1402, 033072.
[27] Ningrum, E.W., and Patria, M.P., 2019, Ingestion of microplastics by anchovies from east Lombok Harbour, Lombok Island, Indonesia, *AIP Conf. Proc.*, 2120 (1), 040002.
[28] Guntur, G., Asadi, M.A., and Purba, K., 2021, Ingestion of microplastics by anchovies of the Madura Strait, Indonesia, *AACL Bioflux*, 14 (3), 1163–1170.
[29] ICES, 2015, OSPAR request on development of a common monitoring protocol for plastic particles in fish stomachs and selected shellfish on the basis of existing fish disease surveys, *ICES Special Request Advice Northeast Atlantic and Arctic Ocean*, 1–6.
[30] Amelinda, C., Werorilangi, S., Burhanuddin, A.I., and Tahir, A., 2021, Occurrence of microplastic particles in milkfish (*Chanos chanos*) from brackishwater ponds in Bonto Manai Village, Pangkep Regency, South Sulawesi, Indonesia, *IOP Conf. Ser.: Earth Environ. Sci.*, 763, 012058.
[31] Al Muhdhar, M.H.I., Sumberartha, I.W., Hassan, Z., Rahmansyah, M.S., and Tamalene, M.N., 2021, Examination of microplastic particles in reef fish food in Ternate Island waters, Indonesia, *Jordan J. Biol. Sci.*, 14 (4), 853–858.
[32] Catarino, A.I., Thomson, R., Sanderson, W., and Henry, T.B., 2017, Development and optimization of a standard method for extraction of microplastics in mussels by enzyme digestion of soft tissues, *Environ. Toxicol. Chem.*, 36 (4), 947–951.
[33] Cole, M., Webb, H., Lindeque, P.K., Fileman, E.S., Halsband, C., Galloway, T.S., 2014, Isolation of microplastics in biota-rich seawater samples and marine organisms, *Sci. Rep.*, 4 (1), 4528.
[34] Rochman, C.M., Tahir, A., Williams, S.L., Baxa, D.V., Lam, R., Miller, J.T., Teh, F.C., Werorilangi, S., and Teh, S.J., 2015, Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption, *Sci. Rep.*, 5 (1), 14340.
[35] Dris, R., Gasperi, J., Mirande, C., Mandin, C., Guerrouache, M., Langlois, V., and Tassin, B., 2017, A first overview of textile fibers, including microplastics, in indoor and outdoor environments, *Environ. Pollut.*, 221, 453–458.
[36] Shim, W.J., Hong, S.H., and Eo, S.E., 2017, Identification methods in microplastic analysis: A review, *Anal. Methods*, 9 (9), 1384–1391.
[37] Cordova, M.R., Ulumuddin, Y.I., Purbonegoro, T., and Shiomoto, A., 2021, Characterization of microplastics in mangrove sediment of Muara Angke Wildlife Reserve, Indonesia, *Mar. Pollut. Bull.*, 163, 112012.

[38] Falahudin, D., Cordova, M.R., Sun, X., Yogaswara, D., Wulandari, I., Hindarti, D., and Arifin, Z., 2020, The first occurrence, spatial distribution and characteristics of microplastic particles in sediments from Banten Bay, Indonesia, *Sci. Total Environ.*, 705, 135304.

[39] Claessens, M., Van Cauwenberghe, L., Vandegehuchte, M.B., and Janssen, C.R., 2013, New techniques for the detection of microplastics in sediments and field collected organisms, *Mar. Pollut. Bull.*, 70 (1-2), 227–233.

[40] Zhao, S., Ward, J.E., Danley, M., and Mincer, T.J., 2018, Field-based evidence for microplastic in marine aggregates and mussels: Implications for trophic transfer, *Environ. Sci. Technol.*, 52 (19), 11038–11048.

[41] Song, J., Hou, C., Zhou, Y., Liu, Q., Wu, X., Wang, Y., and Yi, Y., 2020, The flowing of microplastics was accelerated under the influence of artificial flood generated by hydropower station, *J. Cleaner Prod.*, 255, 120174.

[42] Khoironi, A., Hadiyanto, H., Anggoro, S., and Sudarno, S., 2020, Evaluation of polypropylene plastic degradation and microplastic identification in sediments at Tambak Lorok coastal area, Semarang, Indonesia, *Mar. Pollut. Bull.*, 151, 110868.

[43] Suyadi, S., and Manullang, C.Y., 2020, Distribution of plastic debris pollution and it is implications on mangrove vegetation, *Mar. Pollut. Bull.*, 160, 111642.

[44] Tahir, A., Soeprapto, D.A., Sari, K., Wicaksono, E.A., and Werorilangi, S., 2020, Microplastic assessment in seagrass ecosystem at Kodingareng Lompo island of Makassar City, *IOP Conf. Ser.: Earth Environ. Sci.*, 564, 012032.

[45] Han, M., Niu, X., Tang, M., Zhang, B.T., Wang, G., Yue, W., Kong, X., and Zhu, J., 2019, Distribution of microplastics in surface water of the lower Yellow River near estuary, *Sci. Total Environ.*, 707, 135601.

[46] Zhao, S., Wang, T., Zhu, L., Xu, P., Wang, X., Gao, L., and Li, D., 2019, Analysis of suspended microplastics in the Changjiang Estuary: Implications for riverine plastic load to the ocean, *Water Res.*, 161, 560–569.

[47] Zhao, S., Zhu, L., Wang, T., and Li, D., 2014, Suspended microplastics in the surface water of the Yangtze Estuary System, China: First observations on occurrence, distribution, *Mar. Pollut. Bull.*, 86 (1-2), 562–568.

[48] Lima, A.R.A., Costa, M.F., and Barletta, M., 2014, Distribution patterns of microplastics within the plankton of a tropical estuary, *Environ. Res.*, 132, 146–155.

[49] Naidoo, T., Glassom, D., and Smit, A.J., 2015, Plastic pollution in five urban estuaries of KwaZulu-Natal, South Africa, *Mar. Pollut. Bull.*, 101 (1), 473–480.

[50] Sadri, S.S., and Thompson, R.C., 2014, On the quantity and composition of floating plastic debris entering and leaving the Tamar Estuary, Southwest England, *Mar. Pollut. Bull.*, 81 (1), 55–60.

[51] Courtene-Jones, W., Quinn, B., Gary, S.F., Mogg, A.O.M., and Narayanaswamy, B.E., 2017, Microplastic pollution identified in deep-sea water and ingested by benthic invertebrates in the Rockall Trough, North Atlantic Ocean, *Environ. Pollut.*, 231, 271–280.

[52] Peng, G., Xu, P., Zhu, B., Bai, M., and Li, D., 2017, Microplastics in freshwater river sediments in Shanghai, China: A case study of risk assessment in mega-cities, *Environ. Pollut.*, 234, 448–456.

[53] Wu, N., Zhang, Y., Zhang, X., Zhao, Z., He, J., Li, W., Ma, Y., and Niu, Z., 2019, Occurrence and distribution of microplastics in the surface water and sediment of two typical estuaries in Bohai Bay, China, *Environ. Sci.: Processes Impacts*, 21 (7), 1143–1152.

[54] Mohamed Nor, N.H., and Obbard, J.P., 2013, Microplastics in Singapore's coastal mangrove ecosystems, *Mar. Pollut. Bull.*, 79 (1-2), 278–283.

[55] Oliveira, M., Ribeiro, A., Hylland, K., and Guilhermino, L., 2013, Single and combined effects of microplastics and pyrene on juveniles (0+ group) of the common goby *Pomatoschistus*

microps (Teleostei, Gobiidae), *Ecol. Indic.*, 34, 641–647.
[56] Rist, S.E., Assidqi, K., Zamani, N.P., Appel, D., Perschke, M., Huhn, M., and Lenz, M., 2016, Suspended micro-sized PVC particles impair the performance and decrease survival in the Asian green mussel *Perna viridis*, *Mar. Pollut. Bull.*, 111 (1-2), 213–220.
[57] Derraik, J.G.B., 2002, The pollution of the marine environment by plastic debris: A review, *Mar. Pollut. Bull.*, 44 (9), 842–852.
[58] Wright, S.L., Thompson, R.C., and Galloway, T.S., 2013, The physical impacts of microplastics on marine organisms: A review, *Environ. Pollut.*, 178, 483–492.
[59] von Moos, N., Burkhardt-Holm, P., and Köhler, A., 2012, Uptake and effects of microplastics on cells and tissue of the blue mussel *Mytilus edulis* L. after an experimental exposure, *Environ. Sci. Technol.*, 46 (20), 11327–11335.
[60] Rochman, C.M., Hoh, E., Kurobe, T., and Teh, S.J., 2013, Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress, *Sci. Rep.*, 3 (1), 3263.
[61] Ningrum, E.W., and Patria, M.P., 2022, Microplastic contamination in Indonesian anchovies from fourteen locations, *Biodiversitas*, 23, 125–134.
[62] Horton, A.A., and Barnes, D.K.A., 2020, Microplastic pollution in a rapidly changing world: Implications for remote and vulnerable marine ecosystems, *Sci. Total Environ.*, 738, 140349.
[63] Jabeen, K., Su, L., Li, J., Yang, D., Tong, C., Mu, J., and Shi, H., 2017, Microplastics and mesoplastics in fish from coastal and fresh waters of China, *Environ. Pollut.*, 221, 141–149.
[64] Tahir, A., Samawi, M.F., Sari, K., Hidayat, R., Nimzet, R., Wicaksono, E.A., Asrul, L., and Werorilangi, S., 2019, Studies on microplastic contamination in seagrass beds at Spermonde Archipelago of Makassar Strait, Indonesia, *J. Phys.: Conf. Ser.*, 1341, 022008.
[65] Phuong, N.N., Poirier, L., Pham, Q.T., Lagarde, F., and Zalouk-Vergnoux, A., 2018, Factors influencing the microplastic contamination of bivalves from the French Atlantic coast: Location, season and/or mode of life?, *Mar. Pollut. Bull.*, 129 (2), 664–674.
[66] Davidson, K., and Dudas, S.E., 2016, Microplastic ingestion by wild and cultured Manila clams (*Venerupis philippinarum*) from Baynes Sound, British Columbia, *Arch. Environ. Contam. Toxicol.*, 71 (2), 147–156.
[67] Suteja, Y., Atmadipoera, A.S., Riani, E., Nurjaya, I.W., Nugroho, D., and Cordova, M.R., 2021, Spatial and temporal distribution of microplastic in surface water of tropical estuary: Case study in Benoa Bay, Bali, Indonesia, *Mar. Pollut. Bull.*, 163, 111979.
[68] Germanov, E.S., Marshall, A.D., Hendrawan, I.G., Admiraal, R., Rohner, C.A., Argeswara, J., Wulandari, R., Himawan, M.R., and Loneragan, N.R., 2019, Microplastics on the menu: Plastics pollute Indonesian manta ray and whale shark feeding grounds, *Front. Mar. Sci.*, 6, 679.
[69] Kisnarti, E.A., Ningsih, N.S., Putri, M.R., Hendriati, N., and Box, C., 2021, Microplastic observations in the waters of Labuan Bajo-Gili Trawangan, Indonesia, *IOP Conf. Ser.: Earth Environ. Sci.*, 925, 012043.
[70] Hardianti, E., Wardhana, W., and Patria, M.P., 2021, Microplastic abundance in anchovy *Stolephorus indicus* (Van Hasselt, 1823) in the Lada Bay, Pandeglang, Banten, *J. Phys.: Conf. Ser.*, 1725, 012050.
[71] Fathoniah, I., and Patria, M.P., 2021, Abundance of microplastic in green mussel *Perna viridis*, water, and sediment in Kamal Muara, Jakarta Bay, *J. Phys.: Conf. Ser.*, 1725, 012042.
[72] Priscilla, V., and Patria, M.P., 2019, Comparison of microplastic abundance in aquaculture ponds of milkfish *Chanos chanos* (Forsskål, 1775) at Muara Kamal and Marunda, Jakarta Bay, *IOP Conf. Ser.: Earth Environ. Sci.*, 404, 012027.

[73] Putri, F.T., and Patria, M.P., 2021, Microplastic in mangrove horn snail *Telescopium telescopium* (Linnaeus, 1758) at mangrove ecosystem, Rambut Island, Jakarta Bay, Indonesia, *J. Phys.: Conf. Ser.*, 1725, 012045.

[74] Ukhrowi, H.R., Wardhana, W., and Patria, M.P., 2021, Microplastic abundance in blood cockle *Anadara granosa* (Linnaeus, 1758) at Lada Bay, Pandeglang, Banten, *J. Phys.: Conf. Ser.*, 1725, 012053.

[75] Sembiring, E., Fareza, A.A., Suendo, V., and Reza, M., 2020, The presence of microplastics in water, sediment, and milkfish (*Chanos chanos*) at the downstream area of Citarum River, Indonesia, *Water, Air, Soil Pollut.*, 231 (7), 355.

[76] Cordova, M.R., Purwiyanto, A.I.S., and Suteja, Y., 2019, Abundance and characteristics of microplastics in the northern coastal waters of Surabaya, Indonesia, *Mar. Pollut. Bull.*, 142, 183–188.

[77] Syakti, A.D., Bouhroum, R., Hidayati, N.V., Koenawan, C.J., Boulkamh, A., Sulistyo, I., Lebarillier, S., Akhlus, S., Doumenq, P., and Wong-Wah-Chung, P., 2017, Beach macro-litter monitoring and floating microplastic in a coastal area of Indonesia, *Mar. Pollut. Bull.*, 122 (1-2), 217–225.

[78] Huseini, D.R., Suryanda, A., and Patria, M.P., 2021, Comparative analysis of microplastic content in water, sediments, and digestive traces of sea urchin *Diadema setosum* (Leske, 1778) on Untung Jawa Island and Tidung Island, Seribu Islands, Jakarta, *IOP Conf. Ser.: Mater. Sci. Eng.*, 1098, 052051.

[79] Rahmawati, N.H.F., and Patria, M.P., 2019, Microplastics dissemination from fish *Mugil dussumieri* and mangrove water of Muara Teluknaga, Tangerang, Banten, *J. Phys.: Conf. Ser.*, 1282, 012104.

[80] Takarina, N.D., Purwiyanto, A.I.S., Rasud, A.A., Arifin, A.A., and Suteja, Y., 2022, Microplastic abundance and distribution in surface water and sediment collected from the coastal area, *Global J. Environ. Sci. Manage.*, 8 (2), 183–196.

[81] Tielman, E.M., Indriana, L.F., Widowati, I., and Ambariyanto, A., 2022, Presence of microplastics in windowpane oyster *Placuna placenta* and the waters from the Tambak Lorok Coastal Area in Central Java, Indonesia, *IJMS*, 27 (1), 53–60.

[82] Manullang, C.Y., Opier, R.D.A., Suyadi, S., Rehalat, I., Soamole, A., and Tatipatta, W.M., 2022, Floating microplastics on the sea surface of semi-closed and open bays of small islands, *AACL Bioflux*, 15 (1), 454–61.

[83] Tahir, A., Taba, P., Samawi, M.F., and Werorilangi, S., 2019, Microplastics in water, sediment and salts from traditional salt producing ponds, *Global J. Environ. Sci. Manage.*, 5 (4), 431–440.

[84] Wicaksono, E.A., Tahir, A., and Werorilangi, S., 2020, Preliminary study on microplastic pollution in surface-water at Tallo and Jeneberang Estuary, Makassar, Indonesia, *AACL Bioflux*, 13 (2), 902–909.

[85] Kama, N.A., Rahim, S.W., and Yaqin, K., 2021, Microplastic concentration in column seawater compartment in Burau, Luwu Regency, South Sulawesi, Indonesia, *IOP Conf. Ser.: Earth Environ. Sci.*, 763. 012061.

[86] Sawalman, R., Putri Zamani, N., Werorilangi, S., and Samira Ismet, M., 2021, Spatial and temporal distribution of microplastics in the surface waters of Barranglompo Island, Makassar, *IOP Conf. Ser.: Earth Environ. Sci.*, 860, 012098.

[87] Fitri, S., and Patria, M.P., 2019, Microplastic contamination on *Cerithidea obtusa* (Lamarck 1822) in Pangkal Babu mangrove forest area, Tanjung Jabung Barat District, Jambi, *AIP Conf. Proc.*, 2168, 020075.

[88] Yona, D., Sari, S.H.J., Iranawati, F., Bachri, S., and Ayuningtyas, W.C., 2019, Microplastics in the surface sediments from the eastern waters of Java Sea, Indonesia, *F1000Research*, 8, 98.

[89] Asadi, M.A., Hertika, A.M.S., Iranawati, F., and Yuwandita, A.Y., 2019, Microplastics in the sediment of intertidal areas of Lamongan, Indonesia, *AACL Bioflux*, 12 (4), 1065–1073.

[90] Firdaus, M., Trihadiningrum, Y., and Lestari, P., 2020, Microplastic pollution in the sediment of Jagir Estuary, Surabaya City, Indonesia, *Mar. Pollut. Bull.*, 150, 110790.

[91] Manalu, A.A., Hariyadi, S., and Wardiatno, Y., 2017, Microplastics abundance in coastal sediments of Jakarta Bay, Indonesia, *AACL Bioflux*, 10 (5), 1164–1173.
[92] Azizi, A., Setyowati, W.N., Fairus, S., Puspito, D.A., and Irawan, D.S., 2021, Microplastic pollution in the sediment of Jakarta Bay, Indonesia, *IOP Conf. Ser.: Earth Environ. Sci.*, 930, 012010.
[93] Utami, D.A., Reuning, L., Konechnaya, O., and Schwarzbauer, J., 2021, Microplastics as a sedimentary component in reef systems: A case study from the Java Sea, *Sedimentology*, 68 (6), 2270–2292.
[94] Mardiansyah, M., Utomo, A.B., and Putri, L.S.E., 2022, Microplastics in grouper fish (*Genera epinephelus*) gastrointestinal tract from Pramuka Island, Seribu Islands, Indonesia, *J. Ecol. Eng.*, 23 (3), 194–205.
[95] Al Hamra, A.J., and Patria, M.P., 2019, Microplastic in gonggong snails (*Laevistrombus turturella*) and sediment of Bintan Island, Kepulauan Riau Province, Indonesia, *AIP Conf. Proc.*, 2202, 020079.
[96] Amin, B., Galib, M., and Setiawan, F., 2020, Preliminary investigation on the type and distribution of microplastics in the west coast of Karimun Besar Island, *IOP Conf. Ser.: Earth Environ. Sci.*, 430, 012011.
[97] Riani, E., and Cordova, M.R., 2022, Microplastic ingestion by the sandfish *Holothuria scabra* in Lampung and Sumbawa, Indonesia, *Mar. Pollut. Bull.*, 175, 113134.
[98] Sawalman, R., Werorilangi, S., Ukkas, M., Mashoreng, S., Yasir, I., and Tahir, A., 2021, Microplastic abundance in sea urchins (*Diadema setosum*) from seagrass beds of Barranglompo Island, Makassar, Indonesia, *IOP Conf. Ser.: Earth Environ. Sci.*, 763, 012057.
[99] Asadi, M.A., Ritonga, Y.A.P., Yona, D., and Hertika, A.M.S., 2019, Vertical distribution of microplastics in coastal sediments of Bama Resort, Baluran National Park, Indonesia, *Nat. Environ. Pollut. Technol.*, 18 (4), 1169–1176.
[100] Efadeswarni, E., Andriantoro, A., Azizah, N., and Saragih, G.S., 2019, Microplastics in digestive tracts of fishes from Jakarta Bay, *IOP Conf. Ser.: Earth Environ. Sci.*, 407, 012008.
[101] Hastuti, A.R., Lumbanbatu, D.T.F., and Wardiatno, Y., 2019, The presence of microplastics in the digestive tract of commercial fishes off Pantai Indah Kapuk coast, Jakarta, Indonesia, *Biodiversitas*, 20 (5), 1233–1242.
[102] Andreas, A., Hadibarata, T., Sathishkumar, P., Prasetia, H., Hikmat, H., Pusfitasari, E.D., Tasfiyati, A.N., Muzdalifah, D., Waluyo, J., Randy, A., Ramadhaningtyas, D.P., Zuas, O., and Sari, A.A., 2021, Microplastic contamination in the Skipjack Tuna (*Euthynnus affinis*) collected from Southern Coast of Java, Indonesia, *Chemosphere*, 276, 130185.
[103] Susanti, N.K.Y., Mardiastuti, A., and Hariyadi, S., 2022, Microplastics in fishes as seabird preys in Jakarta Bay area, *IOP Conf. Ser.: Earth Environ. Sci.*, 967, 012033.
[104] Amin, B., Febriani, I.S., Nurrachmi, I., and Fauzi, M., 2020, Microplastics in gastrointestinal track of some commercial fishes from Bengkalis waters, Riau Province Indonesia, *J. Phys.: Conf. Ser.*, 1655, 012122.
[105] Patria, M.P., Santoso, C.A., and Tsabita, N., 2020, Microplastic ingestion by periwinkle snail *Littoraria scabra* and mangrove crab *Metopograpsus quadridentata* in Pramuka Island, Jakarta Bay, Indonesia, *Sains Malays.*, 49 (9), 2151–2158.
[106] Wicaksono, K.B., Patria, M.P., and Suryanda, A., 2021, Microplastic ingestion in the black sea cucumber *Holothuria leucospilota* (Brandt, 1835) collected from Rambut Island, Seribu Islands, Jakarta, Indonesia, *IOP Conf. Ser.: Mater. Sci. Eng.*, 1098, 052049.
[107] Amin, B., Rukim, M., and Nurrachmi, I., 2021, Presence of microplastics in sea cucumber *Paracaudina* sp from Karimun Island, Kepulauan Riau, Indonesia, *IOP Conf. Ser.: Earth Environ. Sci.*, 934, 012053.
[108] Priscilla, V., Sedayu, A., and Patria, M.P., 2019, Microplastic abundance in the water, seagrass, and sea hare Dolabella auricularia in Pramuka Island,

Seribu Islands, Jakarta Bay, Indonesia, *J. Phys.: Conf. Ser.*, 1402, 033073.

[109] Idris, F., Febrianto, T., Hidayati, J.R., Rajib, R., and Nugraha, A.H., 2022, Microplastic abundance in sea cucumber at seagrass ecosystem of Bintan Island and surrounding area, Indonesia, *IOP Conf. Ser.: Earth Environ. Sci.*, 967, 012009.

[110] Wicaksono, E.A., Werorilangi, S., and Tahir, A., 2021, Microplastic occurrence in Venus clam *Marcia hiantina* (Veneridae) in Tallo Estuary, Makassar, Indonesia, *AACL Bioflux*, 14 (3), 1651–1657.

[111] Rogers, A.D., 2015, Environmental change in the deep ocean, *Annu. Rev. Environ. Resour.*, 40, 1–38.

[112] Indonesian Institute of Sciences, 2019, *Academic draft of Research Center for Deep-Sea*, Indonesian Institute of Sciences, Ambon.

[113] Woodall, L.C., Sanchez-Vidal, A., Canals, M., Paterson, G.L.J., Coppock, R., Sleight, V., Calafat, A., Rogers, A.D., Narayanaswamy, B.E., and Thompson, R.C., 2014, The deep sea is a major sink for microplastic debris, *R. Soc. Open Sci.*, 1 (4), 140317.

[114] Chellasamy, G., Kiriyanthan, R.M., Maharajan, T., Radha, A., and Yun, K., 2022, Remediation of microplastics using bionanomaterials: A review, *Environ. Res.*, 208, 112724.