Microplastics: Emerging Pollutants for Indonesian Marine and Fishery Environment

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Abstract: Pollution of microplastics (plastic particles <5 mm) is becoming global concern, including Indonesia. Microplastics may present in the aquatic environment as a consequence of plastic macrodebris pollution. Microplastics are mainly contributed from the degradation of plastic debris with additional sources from cosmetic ingredient and other polymer applications. Concern on microplastic pollution in Indonesian marine and fishery ecosystem is relatively new, as the first study was just started in 2015 compared to that of globally in 2004. Similarly, studies on macroplastic (marine litter) in Indonesia was started in 1997, while in other parts of the world has been conducted since 1969. Based on the studies which are so far conducted predominantly around Java Island, Indonesian waters are among potential ecosystem for macro and microplastic pollution, either delivered from local terrestrial area or possible transported from international waters. Since microplastics may be exposed to seafood in concerned study areas, they may pose adverse effects, either to seafood species or human health. Established global and national legislation and action plans need to be implemented practically in order to protect Indonesian waters from massively pollution of macro and microplastic, as well as developing bio-technology alternatives and enhancing social responsibilities.

1 INTRODUCTION

Microplastic pollutions in the aquatic environment have been attracting global attention, including Indonesia. The problem on microplastic in the coastal marine environment, for example, could not be separated from the trend of marine debris pollution, in particular plastic litters distributed in the oceans. This is due to the increasing quantity of plastics application in many areas of modern usages, such as for clothing, packaging, storage, transportation, construction and various applications of consumer goods. A study estimated more than 5.25 trillion pieces of plastic debris (over 250,000 tons) afloat across the sea (Jambeck *et al*., 2015). Additionally, a study revealed that plastic litter in the ocean during 2010 was approx. 4.8-12.7 Mio Tons with Indonesia is suggested as the second largest producer of marine debris after China i.e. 0.22 Mio Tons/year as 0.48-1.29 Mio Tons of which are plastic litters (Erikssen *et al*., 2014).

UNEP (2009) defined marine debris as any persistent, manufactured or processed solid material discarded, disposed -off or abandoned in the marine and coastal environment. Those amounts of such debris are delivered from terrestrial sources entering the marine environment mainly through rivers (Libreton *et al*., 2017), industrial and urban effluents, and run off of beach sediments and neighbour fields. The other part could be resulted from direct inputs, such as off shore activities such as maritime transportation, capture fishery and litter released from tourism activities. With regards to the marine litter composition, plastic debris has become predominantly of the waste that accumulates on shorelines, ocean surface or seafloor. Plastic bags, fishing equipment, food and beverage packaging are the most common items and contribute more than 80% of litter stranded on beaches, sea surface or seafloor (Topçu *et al*., 2013; Thiel *et al*., 2013; Ramirez-Llodra *et al*., 2013; Galgani *et al*., 2015; Duhec *et al*., 2015; Peng *et al*., 2018; Rech *et al*., 2018).

As the global plastic production has significantly increased from approx. 2 Mio tons in 1950 to 380-415 Mio tons in 2015, it is estimated an amount of 6.300 Mio tons of plastic waste was generated by the end of 2015 (UNEP, 2009; Webb *et al*., 2013). Of these

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wastes, 9% has been recycled, 12% was incinerated and the rest of 79% will accumulate in the environment, about 3-10% (8-12 Mio tons) of which leaks into waterways and ends up in the marine environment. They are composed predominantly by coastal mismanaged waste (60-70%) and the rest are from either terrestrial mismanaged waste, plastic pellet or fishing gear (Webb *et al*., 2013). Over a period of time and environmental exposures, plastic litter will decompose at various rate depend on the polymer materials, molecular weight (MW), type of functional group, hydrophobicity, and crystallinity (Wilkes & Aristilde, 2017).

Microplastics are fragmented plastics less than 5 mm in diameter generated during the decomposition of macroplastic caused by abiotic factors (UV radiation, temperature, physical stress) or biotic factors (biodegradation process) which can transport over long distances in the ocean, persist in the seabed or bioaccumulate in aquatic organisms. There is also a concern that plastic litter have a significant influence on marine fauna due to entanglement, suffocation, and disruption of digestion in birds, fish, mammals, and turtle, while microplastic shows as source of toxic chemicals such as persistent organic pollutants (POPs), phthalates and bisphenol A (Bryant *et al*., 2016; Tekman *et al*., 2017). Furthermore, free radical compounds may be produced during plastic degradation and when react with oxygen will form peroxy-radicals that promote significant deleterious consequences on the health of not only marine organisms but also enter the further food chain (Da Costa *et al*., 2018). This paper reviews the current research on the microplastics pollution in Indonesian aquatic environment, including the accumulation in seafood species. Further discussion is focused on the related issues, such as potential harmful of microplastic to marine organism and human health, related global and local regulations as well as some aspects to be concerned in the future.

2 MICROPLASTIC IN INDONESIAN WATER

The first study on plastic pollution in the environment and in living organism was reported previously (Kenyon & Kridler, 1969). Based on an investigation in Laysan Hawaii, they found plastic materials including caps of bottle and tube, broken pieces, toys, and polyethylene bags among indigestible materials in albatross carcass. Additionally, a number of plastic exposures were also investigated in 1970s in different part of the world such as in Sweden (Holmström, 1975), Northwestern Atlantic (Colton *et al*., 1974), New Zealand Beach (Gregory, 1978), Great Gull-New York (Hays & Cormons, 1974), Pacific Ocean (Wong *et al*, 1974), Narragansett Bay (Cundell, 1973), New England (Buchanan, 1971; Carpenter *et al*, 1972). However, the term marine plastic debris become familiar in a decade later during the 1984 Workshop on the Impacts and Fate of Marine Debris held in Honolulu-Hawaii in particular by Shomura and Yoshida (1985). Previously, marine debris has been identified and explained in different terms such as man-made objects (Venrick *et al* 1973; Shaughnessy 1980), man-made debris (Feder *et al*., 1978), synthetic debris (Balazs, 1979), plastic litter (Merrell, 1980), and floating plastic debris (Morris, 1980). In fact, the term of marine debris covers not only plastic, but also metals, glass, and other materials (rubber, textiles, lumber). However, studies showed that plastic revealed the majority (more than 80%) of marine litter (e.g. Topcu *et al*., 2012; Thiel *et al*., 2013; Ramirez *et al*., 2013; Galgani *et al*., 2015; Duhec *et al*., 2015; Peng *et al*., 2018; Rech *et al*., 2018).

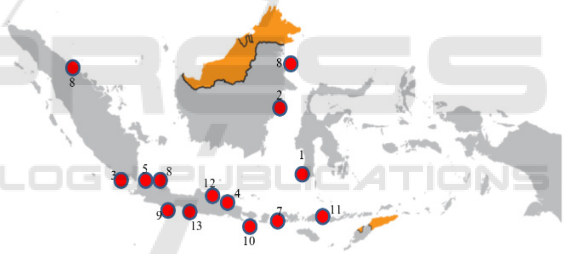

Figure 1: Overview of studies on microplastic in Indonesian waters (1: Rochman *et al*., 2015; 2: Dewi *et al*., 2015; 3: Cordova & Wahyudi, 2016; 4: Cordova *et al*., 2019; 5: Falahudin *et al*., 2017; 7: Cordova & Hermawan., 2018; 8: Dwiyitno *et al*,. 2018; 9: Septian *et al*., 2018; Ismail *et al*., 2019; 10: Nugroho *et al*., 2018; 11: Hiwari *et al*., 2019; 12: Asadi *et al*., 2019; 13: Syakti *et al*., 2017).

In response to the issue of marine debris pollution, Thompson *et al*. (2004) investigated the occurrence of microplastic in sediment samples from Plymouth-UK. This is known as the first study on microplastic exposure in aquatic environment. Additionally, Browne *et al*. (2011) reported the first time of microplastic global distribution on shorelines. In Indonesia, study on plastic litter in aquatic environment was started by Uneputty & Evans (1997). However, instead of microplastic they only identified macroplastic pollution on surface water and seafloor of Ambon Bay. Additionally, another study (Rachman *et al*. 2015) reported the first study of microplastic in Indonesian water based on the exposure in 11 fish species collected from fish market in Makassar. They found that plastic debris (0.1-4.5 mm) was identified in the gut of 21 out of 76 (28%) fish samples at concentration of up to 21 particles/individual. Afterward, a number of studies were conducted in different regions of Indonesian waters either in water, sediment or seafood species as presented in Table 1.

Based on the established studies concerning microplastic pollution in Indonesian waters (Table 1), the studies were so far predominantly conducted around Java Island (53%). With refer to the compartment, sediment and water are the predominantly (77%) samples for microplastic studies and only 3 out of 13 studies investigated microplastic exposure in seafood species (Rochman *et al*., 2015; Dwiyitno *et al*, 2018; Ismail *et al*., 2019). It can be seen that coastal environment around Java Island (in particular Jakarta, Banten, and Lamongan Bays) are relatively more polluted by microplastic compared to other coastal as performed by microplastic pollution in sediment samples (Table 1). This may indicate that these regions are more polluted by plastic litter, especially from terrestrial sources. Microplastic concentration in sediment samples also corresponds to that in seafood samples, suggesting the bioaccumulation uptake via food web as revealed by earlier study (Karlsson *et al*., 2017).

Based on a study conducted by Rochman *et al*. (2015), plastic fragments were predominantly shape (60%) identified in fish gut from Makassar markets, followed by foam (37%), film (2%) and filament (1%). This finding is in contrast to that in fish gut from USA, showed 80% fibers, 10% film, and fragments, foam, filament at the same frequency of 3.3%. Microplastic composition in fish gut from Makassar also corresponds to that in 2 fish species (*Trichiurus* sp. and *Johnius* sp.) from Pangandaran Bay as reported by Ismail *et al*. (2019 revealed 49.74% fragments, 27.46% film and 22.8% fibers. Similar to the result from Makassar and Pangandaran (Rachman *et al*., 2015; Ismail *et al*., 2019), fragmented microplastic was also predominantly identified in fish and mussel from Jakarta Bay (Dwiyitno *et al*., 2018). Fibers and fragments are the most commonly microplastic shape in seafood species around the world (de Sa *et al*., 2018). Kingfisher (2011) suggested that source of plastic fibers may be contributed from fishing activities in the sea or emission from laundry and textile activities on the land. On the other hand, plastic fragments could be resulted from decomposed macro plastic polymers of consumer products (such as beverage bottles and plastic gallons) fishing nets, fiber lines, or industrial raw materials (Tanaka & Takada, 2016).

Table 1: Microplastic in different regions of Indonesian waters.

No	Location	Sample	Concentration	Ref*)
1	Makassar	*Oreochromis niloticus* *Katsuwonus pelamis* *Rastrelliger kanagurta* *Decapterus macrosoma* *Spratelloides gracilis* *Carangidae* *Siganus argente* *Siganus fuscesce* *Siganus canaliculatus* *Lutjanus gibbus* *Selar boops*	0 part/individual 0 part/individual 0-3 part/individual 0-21 part/individual 0-5 part/individual 0-14 part/individual 0-1 part/individual 0 part/individual 0-1 part/individual 0 part/individual 0 part/individual	1)
2	Muara Badak,	Sediment	57-91 part/kg dw	2)
3	Lampung	Sediment	0-14 part/cm^3	3)
4	Surabaya	Water	0.38-0.61 part/L	4)
5	Banten	Sediment	101-431 part/ kg dw	5)
6	Cilacap coast	Water	0.27-0.54 part/m^3	6)
7	Sumba,NTT	Water	70-120 part/m^3	7)
8	Kupang,NTT	Surface water	0-0.05 part/m^3	8)
9	Pangandaran	Sediment	26-68 part/kg	9)
10	Pangandaran	*Trichiurus* sp. *Johnius* sp.	4-28 part/indv 2-14 part/indv	10)
11	Benoa Bay	Water Sediment	0.43-0.58 part/m^3 0-113 part/kg	11)
12	Lamongan	Sediment	144-353 part/kg	12)
13	Jakarta Bay	Water Sediment Fish Mussel	29 part/m^3 (max) 420 part/kg (max) 20 part/indv (max) 50 part/indv (max)	13)

*) Reference:
1) Rochman *et al*. (2015); 2) Dewi *et al*. (2015); 3) Cordova & Wahyudi (2016); 4) Cordova *et al*. (2019); 5) Falahudin *et al*. (2017); 6) Syakti *et al*. (2017); 7) Cordova & Hermawan (2018); 8) Hiwari *et al*. (2019); 9) Septian *et al*. (2018); 10) Ismail *et al* (2019); 11) Nugroho *et al*. (2018); 12) Asadi *et al*. (2019); 13) Dwiyitno *et al*. (2018)

In line with sediment sample, microplastic concentration in surface water of Jakarta Bay is the most abundance in comparison to that of other coastal in Indonesia (Table 1). Based on the a study of Cordova *et al*. (2019), foams are the most commonly microplastic in surface water of Surabaya Coast, followed by fragments, pellets, and fibers. Foams are typically result of fragments or pieces of styrofoam (Tanaka & Takada, 2016; Zhou *et al*., 2018), indicating the source from domestic waste. However, different result was performed from surface water in Sumba (East Nusa Tenggara) which was dominated by fiber plastics (45.45%), followed by granule (36.36%) and other plastic form (Cordova & Hernawan, 2018). Similar result was performed in the other region in East Nusa Tenggara (Kupang) which was dominated by fragment and fiber plastics, followed by pellets and film (Hiwari *et al*., 2019). Fragment plastic was also the most abundance mikroplastic in surface water at Benoa Bay, followed by film and fibers (Nugroho *et al*., 2018).

Referring to other region of the world, the present of plastic fibers as the main microplastic form (60–70%) was found in the Rhône and Têt Water in the Mediterranean Sea, followed by foams and films (Constant *et al*., 2018). On the other hand, another study in the Northern Ionian Sea, Mediterranean Sea showed fragment plastic was the most dominant form (99.7–100%) in surface water (Digka *et al*., 2018). In a study conducted in Cilacap Coast, Syakti *et al*. (2017) reported that microplastics in surface water were composed by different polymers i.e. polystyrene, polypropylene, low density polyethylene (LDPE), and other polymers. Another study on macroplastic assessment in Jakarta Bay revealed that polyethylene and polypropylene are the most plastic litter identified in surface water, followed by polyethylene terephthalate (PET), polystyrene, polyvinyl and other plastic polymers (Dwiyitno *et al*., 2018). Accordingly, microplastic fragments are more dominant in surface water of Jakarta Bay than non-fragment one.

3 POTENTIAL HARMFUL OF MICROPLASTIC

The presence of microplastics contaminant in the aquatic environment must be taken into account due to the potential risk to either aquatic organisms consuming the microplastics or human health through food chain. Studies showed that different types of conventional plastic demonstrate different decomposition rate, and consequently to the degraded microplastic. The most commonly polymers applied in plastic material include polyethylene/PE, polypropylene/ PP, polyethylene terephthalate/PET, polystyrene/PS, polyvinyl chloride/PVC, polycarbonate/PC, polyamides/PA/ nylon), acrylics, polylactic acid/PLA, polyurethanes/PU and cellulose acetate/CA (Plastics Europe, 2016). Physico-chemical properties such as molecular weight, density, melting temperature, young are modulus, glass transition temperature and water absorption may influence the decomposition rate (Webb *et al*., 2013). The Marine Conservancy estimated the decomposition rates of CA around 1-5 years, PE 20 years, PS 50 years, PET/PETE 400 years, and PA/nylon around 600 years (Andrady, 2015).

Plastic debris, including microplastics, can be ingested by various aquatic organisms across food chain and become global concern (Lusher *et al*. 2013). In general, microplastic ingestion can lead to decreased nutritional status and bioaccumulation of hydrophobic organic compounds that sorb to the microplastic particles in the water and desorb in the gut (Cole *et al*., 2015; Rochman *et al*., 2014). This could threat the seafood biodiversity and food security. Boerger *et al*. (2010) found that fish in North Pacific Central Gyre consume microplastics of an average size of 1–2.79 mm. another study found that *Oryzias latipes* (Japanese medaka fish) eats less than 0.5 mm polyethylene fragments (Rochman *et al*., 2013). Similarly, previous study observed microplastics of 100–1000 μm in fish stomach from Giglio Island (Avio *et al*., 2017). Güven *et al*. (2017) revealed that microplastics were found in the intestine of some Mediterranean Sea fish. Studies showed that shellfish such as bivalve molluscs tend to be important source of microplastic exposure at present is via (shellfish). As filter feeding species, bivalves are directly exposed to microplastics via pumping surrounding water column and retaining particles from suspension on their gills for subsequent ingestion. It is of concern that depuration may excrete microplastics in the bivalves with different rate (28-46%) depend on polymer type, size, concentration, time and the presence of other contaminants (Wood *et al*., 2018; Birnstiel *et al*., 2019).

The presence of microplastic in aquatic ecosystem demonstrated to reduce population growth, and reduced chlorophyll concentrations in the algae. This affects to a reduced body size and severe alterations in reproduction of *Daphnia* species, lowering of numbers and body size of neonates, while the number of neonate malformations among neonates rose to 68% of the individuals (Besseling *et al*., 2014; Aljaibachi & Callaghan, 2018). Further exposure of microplastics to marine life showed brain damage and behavioural abnormalities in fish, oyster fertility, hepatic stress, oxidative damages (Sussarellu *et al*., 2016; Barboza *et al*., 2018; Mattsson *et al*., 2017). Although the study was carried out on fish, the repercussions of human exposure to plastic particles must be better understood. The smaller of plastic particles may penetrate deeply into organ tissue (EFSA, 2016) and the translocation of plastic particles from the gut to the lymphatic system has furthermore been observed in different species (Browne *et al*., 2008; Brennecke *et al*., 2015).

A number of studies reported that microplastic may release potentially toxic substances into the water such as from chemical additives and polymer derivatives. Additionally, plastic pellets tend to absorb toxic metals (e.g. As, Cd, Cu, Cr, Co, Fe, Pb) and dangerous hydrophobic contaminants (like brominated flame retardants/BFRs, PAHs, PCBs, dioxin, and DDT) from surrounding water (Hirai *et al*., 2011; Engler *et al*., 2012; Holmes et. al., 2012; Rochman *et al*., 2014). Plastic additive such as BPA is also known as endocrine disrupting compounds (EDCs) which is commonly associated with sex ratio imbalances, disruption in fertility cycles, immune disorders, as well as delayed neurodevelopment in children and hormone-related cancers (Bergman *et al*., 2013).

Phthalates, often known as plasticizers, are used in plastics to increase flexibility of plastic which are also categorized as EDCs. They are also used as solvents and can be found in various products, ranging from vinyl on floors, to cosmetics and toys. Even though phthalates are metabolized in the body and the metabolites could pass out of the body through urine, health concern is raised regarding the developmental and/or reproductive toxicity (Meeker *et al*., 2009; CDC, 2013). BFRs such as polybrominated diphenyl ethers/PBDE are commonly used in plastic products such as fire proof electronics, synthetic foams and textiles, and plastic furniture, have also raised concern globally. Sensitive populations such as children and pregnant women are thought to be at higher risk of exposure, and some BFRs have been found in human breast milk (Birnbaum & Staskal, 2004). BFRs are believed to impair neurological behavior, developing immune systems, and thyroid hormones (Darnerud, 2003).

Nonylphenols ethoxylates (NPE) are antioxidants and plasticizers commonly used for the production of plastics and other applications such as paints, pesticides, detergents and personal care products (Sussarellu *et al*., 2016; Barboza *et al*., 2018). In the environment, NPE produces intermediate products known as nonylphenol (NP) which is considered as endocrine disruptors and their use is prohibited in the European Union due to the possible adverse effects to the environment and human health (Engler, 2012; Rani *et al*., 2015). NP has been found to leach out from plastic bottles to the water content (Loyo-Rosales *et al*., 2004). Moreover, effluents from a waste water treatment plants are the major source of NP and NPE in the environment (Soares *et al*., 2008).

4 LEGISLATION AND FUTURE CONCERN FOR SEAFOOD SAFETY

Seafood represents an essential source of protein in Indonesia, contributing 13.36 % of total protein source, which is higher than non-seafood animal protein/meat and poultry (9.99%). In average, national fish consumption is approximately 47.34 kg/person/year correspond to 11.65 Mio tons of seafood/year. Seafood also important commodity for 2.6 Mio local fisherman with annual fish production of 23.51 Mio tons comprising of 7.07 Mio tons (30.5%) from capture fishery and 16.11 Mio tons (69.5%) from aquaculture with export volume 955 thousand tons or 5,200 Mio USD (MMAF, 2018). For that reason, seafood safety is an increasingly important issue with respect to microplastics, in particular to support the governmental campaign such as "*Gemar Makan Ikan*" ("Eating Fish") campaign in elevating seafood consumption in the region.

A number of legislations have been established by Indonesian government in order to support the quality and safety assurance of seafood products either for domestic or export markets. Governmental Law No.18/2012 chapter IV, for example, states that central and local government obliges to assure the safety of food at all supply chain. Additionally, chapter 7 of the law No.45/2009 asks the Ministry of Marine Affairs and Fisheries (MMAF) to prevent the contamination and destruction of marine and fishery resources, including the environment. Another decree No.52A-/KEPMEN-KP/2013 deals with the requirements of quality assurance and safety of seafood products in production, processing and distribution. The decree elaborates the general structure and hygiene requirements of the whole chain including during fishing, landing, storage, fish markets, as well as the food security and health standards.

With regard to microplastic contaminant in seafood an aquatic environment, there is general regulation either in Indonesia or globally. However, a number of legislation instruments have been established in order to reduce the risk and protect marine environment from plastic litter accumulation. During the London Convention in 1972, United Nations agreed to control ocean dumping, followed by the International Convention for the Prevention of Pollution from ships (MARPOL). Additionally, Annex V of MARPOL was introduced in 1988 with the intention of banning the dumping of most garbage and all plastic materials from ships at sea. A total of

122 countries have ratified the treaty. Furthermore, a number conventions were held resulted more implementing agreements to combat plastic pollution to marine and coastal environment, such as Oslo and Paris conventions in 1972 and 1974 for controlling marine pollution in the north-east Atlantic Ocean around Europe. Numerous cooperative efforts have also been held, such as a Protocol on Integrated Coastal Zone Management, involving 21 countries bordering the Mediterranean Sea, as well as the European Union, approved in 2008. Under the UNEP, the Global Partnership on Marine Litter (GPML) was launched in June 2012 at Rio de Janeiro-Brazil (UNEP, 2019). Specifically, UN-SDGs accommodate marine pollution and marine litter under the 14th Goal i.e. conserve and sustainably use the oceans, seas and marine resources for sustainable development (UN, 2019).

For national level, different countries have generated their legislation concerning marine debris, such as US Marine Debris Program, Marine Plastic Pollution Research & Control Act, UK legislations on garbage from ships & PRFs, beach clean-up & awareness, Scotland Marine Litter Strategy, and Taiwan's Marine Pollution Control Act. In 2003, the government of Taiwan released a system that plastic bags are no longer available in markets without charge. However, Bangladesh is known as the first country to ban plastic bags in 2002. In 2005, French parliament passed legislation to prohibit all non-biodegradable plastic bags, followed by China's parliament to impose a ban to supermarkets from providing free plastic bags less than 0.025 mm in thick since January 2008. In Indonesia, marine debris issue has been regulated in Presidential Regulation No.16/2017 concerning Marine Policy; No.97/2017 concerning National Policy and Strategy on Waste Management; No.83/2018 concerning Marine Debris. Indonesia has also established Action Plan on Marine Plastic Debris 2017-2025 focusing on the reduction of 70% marine plastic by 2025. However specific legislation on microplastic pollution either in marine environment or seafood product is not established yet.

Currently, biotechnology and innovation has been challenged for the mitigation alternative in reducing plastic debris pollution. Biodegradable plastics have been produced as sustainable option to replace demand and consumption of plastic in many countries, including Indonesia since they break down much faster than conventional plastic. As the result, studies on biodegradable plastic, as well as investigation for the solution of traditional plastic waste problem are encouraged such as plastic-consuming or degrading microorganisms and discovery of new kind of biodegradable plastic material (Shah *et al*., 2008; Web *et al*., 2013; Urbanek *et al*., 2018). Noteworthy, public education is another key point in changing community behaviors and awareness such as to over-consume plastics, discard and thus pollute, need to be promoted to the fullest. A number approaches have been promising and well implemented to succeed in reducing plastic problem such as recycling and zero waste concept as well as extend producer responsibility that have been implemented in many countries.

5 CONCLUSIONS

A number of studies showed that Indonesian waters are among potential ecosystem for macro and microplastic pollution, either delivered from local terrestrial area or transported from international waters. Many of literatures have revealed adverse effects of microplastic exposure, either to aquatic ecosystem, seafood species as well as the possibility to human health. Concentration of microplastic in marine and fishery ecosystem has to be concern as they may pose adverse effects, either to seafood species or the possibility to human health. Established global and national legislation and action plans need to be implemented practically in order to protect Indonesian waters from massively macro and microplastic pollution, as well as developing biotechnology alternatives and enhancing social responsibilities.

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