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Strategies for Response and Mitigation of Marine Environmental Damage Caused by Plastic Debris

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Abstract : *Environmental damage caused by marine plastic debris occurs and has become a major contributor to marine pollution. This study analyzed the current state of marine plastic debris pollution and proposed essential strategies to reduce damage. To assess the current state of pollution arising from marine plastic debris, this study investigated the properties of plastic debris, reviewed case studies of ecological impacts, and examined the inflow and distribution of marine plastic debris. The results of this study indicate that the major deleterious effects of marine plastics are entanglement and ingestion. In addition, the amount of plastic waste entering the sea was estimated to be 230 Mt in 2015 and may increase to 554 Mt in 2050. In this study, three key strategies were proposed to reduce damage and preserve the ecosystem, including: 1) removing plastic debris in the marine environment, 2) limiting the release of plastic debris to the marine environment, and 3) preventing damage to humans and marine life from plastic debris. To minimize the environmental damage caused by marine plastic debris, the proposed response strategies should be implemented in parallel.*

Keywords : *Marine plastic debris, Marine pollution, Environmental damage, Ecological impact of marine plastic debris, Inflow and distribution of marine plastic debris, Strategies for response and mitigation*

1. Introduction

Marine debris is an environmental issue globally that accounts for a significant portion of marine pollution. The main sources of marine debris, among which 60% to 80% come from land, shoreline and recreational activities, ocean/waterway activities, smoking-related activities, dumping activities, and medical/personal hygiene (Ocean Conservancy, 2010). Moreover, marine plastic debris accounts for 60% - 80% of marine debris and 90% - 95% of marine litter (Derraik, 2002).

The level of pollution caused by marine plastic debris is severe, and is expected to rapidly worsen if the current dependency on plastic continues (Jambeck et al., 2015; Geyer et al., 2017). For marine life, entanglement and ingestion are two of the major deleterious effects of marine plastics (Arnould and Croxall, 1995; Laist, 1997; Moore et al., 2009; Allen et al., 2012; Kühn et al., 2015). In addition to affecting organisms that have directly ingested plastics, plastic ingestion affects the entire ecosystem by accumulating in the food chain (Ryan, 1988; Lee et al., 2001; Mato et al., 2001; Rochman et al., 2013).

Despite the severity of pollution caused by marine plastic debris, there is a still lack of comprehensive research on the process of generation and inflow of plastic debris and the mechanism of ecosystem damage. To assess the severity of pollution caused by marine plastic debris, this study analyzed the risks posed by plastic debris, as well as its impact on the ecosystem and inflow and distribution. The corresponding need for action was assessed based on the results, and strategies for efficient management were presented.

2. Risks of marine plastic debris and impact on ecosystem

Marine plastic debris exists in various sizes, ranging from sub-millimeter to as large as a few centimeters (Fig. 1). Among marine plastics, small plastic pieces that can be observed under a microscope are called “microplastics,” a term that first emerged in “Lost at sea: Where is all the plastic?” (Thompson et al. 2004). Microplastics were later defined as plastic pieces smaller than 5 mm in diameter that are readily ingestible by biota, thereby threatening the ecosystem (GESAMP[1], 2015). Microplastics are classified into primary and secondary microplastics depending on

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1) GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) is a group of independent scientific experts that provides advice to the UN system on scientific aspects of marine environmental protection (GESAMP, 2020).

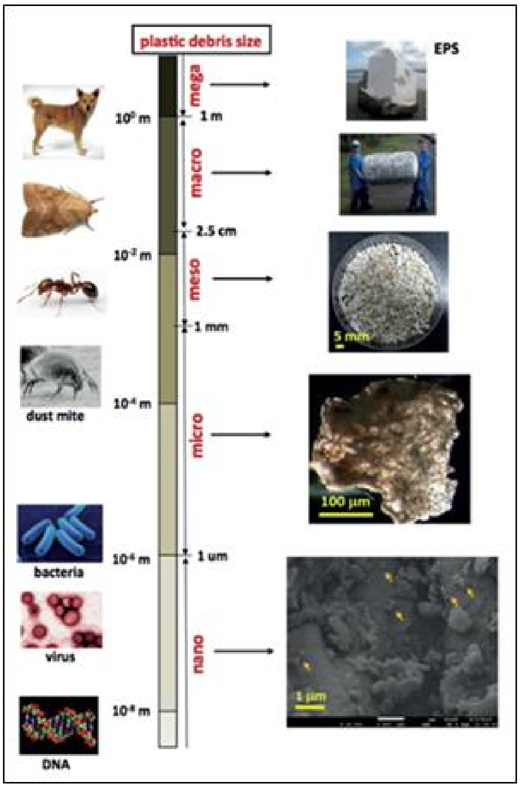

Fig. 1. Size range of plastic objects observed in the marine environment and comparisons with living materials (GESAMP, 2015).

how they are manufactured. Primary microplastics include grains used to blast clean surfaces, plastic powders used in plastic moldings, microbeads used in cosmetics, nanoparticles used in various industrial processes, and pellets used as raw materials for plastic products (GESAMP, 2015). When plastic litter is exposed to the environment, it is broken down into smaller particles via ultraviolet light-induced photodecomposition, fragmentation due to wave forces, and biodegradation process (GESAMP, 2015). While secondary microplastics transform into microplastics as a result of weathering process over long periods, primary microplastics are released into the ocean as sewage discharge immediately after use (Fig. 2). Thus, primary microplastics are considered to have a far more rapid and significant contribution to marine pollution than secondary microplastics.

Entanglement is one of the key deleterious effects of marine plastic debris on marine life and often occurs the result of lost or abandoned fishing gear, in a process known as “ghost fishing” (Fig. 3). The percentages of species with records of entanglement are 100% of marine turtles (7 of 7 species), 67% of seals (22 of 33 species), 31% of whales (25 of 80 species), and 25% of seabirds (103 of 406 species) (Kühn et al., 2015). Compared with the study by Laist (1997), the total number of bird, turtle, and mammal species associated with entanglement increased from 89 (21%) to 161 (30%) from 1997 to 2015, respectively (Kühn et al.,

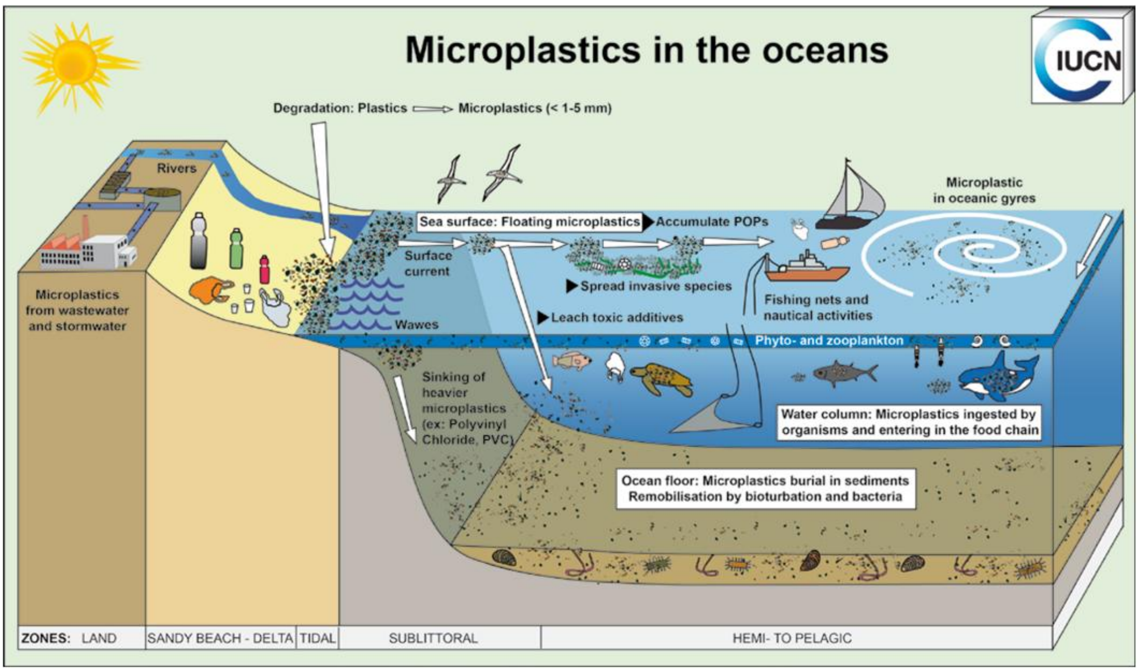

Fig. 2. Schematic showing the main sources and movement pathways of plastics debris in the oceans (Thevenon, 2014).

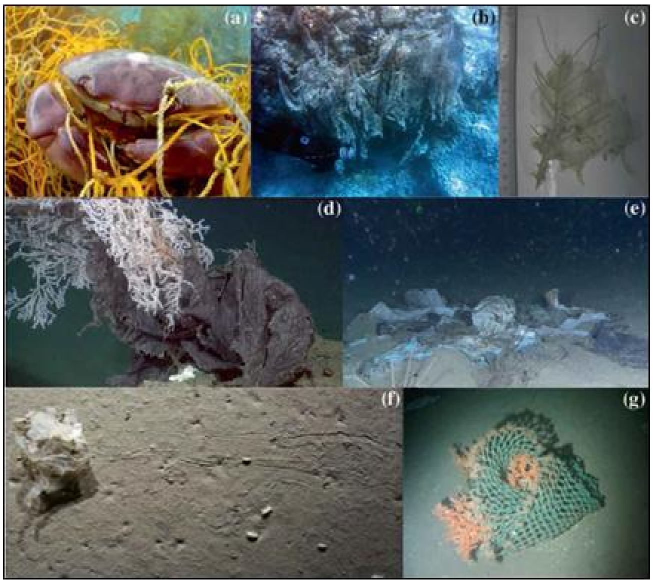

Fig. 3. Effects of litter on organisms on the seafloor. a) Crab entangled in derelict net, b) fishing net wrapped around coral, c) plastic fragment entangled in trawled sponge (*Cladorhiza gelida*). d) rubbish bag wrapped around deep-sea gorgonian, e) Mediterranean soft-sediment habitat smothered with plastic litter, f) evidence of plastic fragment causing disturbance and biogeochemical changes at the sediment, and g) cargo net entangled in a deep-water coral colony (Kühn et al., 2015).

2015). Marine life entangled in plastic debris can neither find food nor escape from predators, and as a result, die from starvation or drowning (Laist, 1997). Even if these creatures do not face immediate death, they experience serious impairment in their physical ability and ability to find sustenance because of injuries (Arnould and Croxall, 1995; Laist, 1997; Moore et al., 2009; Allen et al., 2012).

Another harmful effect of marine plastic debris on marine life is ingestion (Fig. 4). The percentages of species with records of ingestion are 100% of marine turtles (7 of 7 species), 59% of whales (47 of 80 species), 36% of whales (12 of 33 species), and 40% of seabirds (164 of 406 species) (Kühn et al., 2015). Compared with the study by Laist (1997), the total number of bird, turtle, and mammal species associated with ingestion increased from 143 (33%) to 233 (44%) from 1997 to 2015, respectively (Kühn et al., 2015). The ingestion of plastic debris occurs when marine organisms mistake plastics for food. For instance, marine turtles often mistake clear, flimsy plastic debris for jellyfish

Fig. 4. Plastic ingestion by Northern fulmars (Kühn et al., 2015).

(Bugoni et al., 2001; Tourinho et al., 2010). The ingestion method may also cause some organisms to ingest plastic debris by mistake. Specifically, pursuit-diving seabirds ingest more plastic debris than surface-seizing birds (Day et al., 1985; Azzarello and Van Vleet, 1987; Ryan, 1988; Tourinho et al., 2010).

The ingestion of plastic debris by marine life can have both direct and indirect negative effects. The blockage of food and fluid in the digestive system may cause digestive or respiratory conditions and, in severe cases, can lead to death. Further, the elution of harmful substances or organic pollutants from ingested plastics within the body may promote inflammation and liver stress and decrease the rate of growth. During the use or degradation of plastic products, chemical substances may leak into the surrounding environment (Rochman et al., 2013). Specifically, the concentration of persistent organic pollutants (POPs)[2] in plastics has been found to accumulate 105 – 106 times higher than the ones in the surrounding seawater (Mato et al., 2001). Meanwhile, an indirect impact of plastic debris ingestion is that it not only accumulates in organisms that have directly ingested plastics but also impacts the entire ecosystem through the food chain. In particular, when marine

2) Persistent organic pollutants (POPs) are chemicals of global concern due to their potential for long-range transport, persistence in the environment, ability to bio-magnify and bio-accumulate in ecosystems, as well as their significant negative effects on human health and the environment (WHO, 2020).

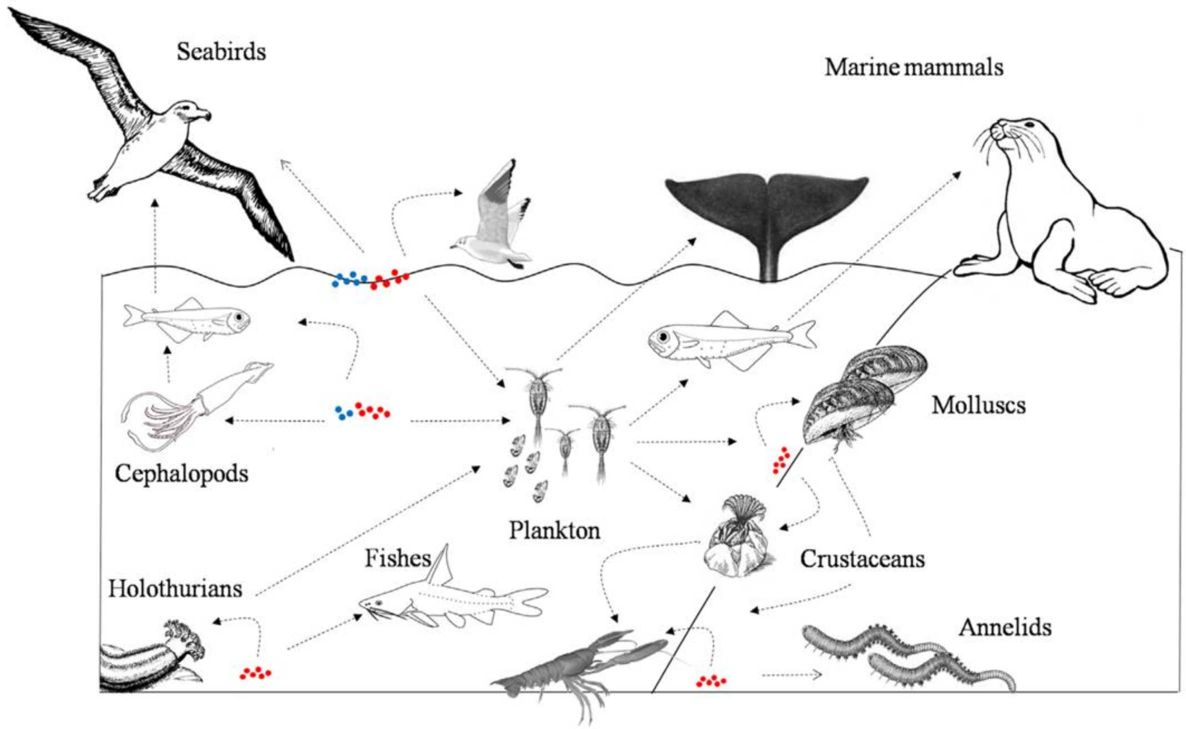

Fig. 5. A conceptual model of the potential trophic routes of microplastics across marine vertebrate and invertebrate groups (Ivar do Sul and Costa, 2014). The blue dots denote polymers that are less dense than seawater (i.e., Polyethylene (PE) and Polypropylene (PP)) and the red dots denote polymers that are more dense than seawater (i.e., Polyvinyl Chloride (PVC)). The dashed arrows represent the hypothesized microplastic transfer.

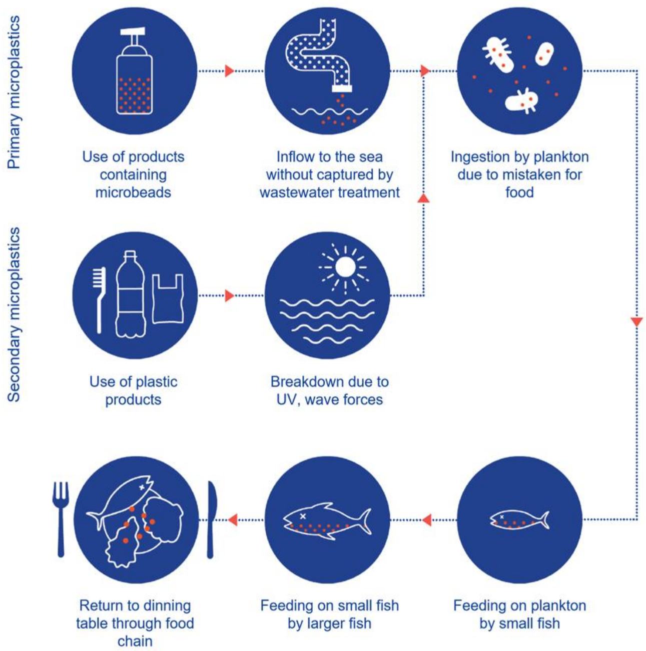

Fig. 6. Journey of microplastics (Captions translated from Korean, published by Park (2016)).

life at the bottom of the food chain ingests microplastics, organisms higher up the food chain will experience a higher concentration of harmful substances and POPs (Fig. 5). This can result in the illness or death of the entire food chain, ultimately affecting humans (Fig. 6).

3. Inflow and distribution of marine plastic debris

The world's annual plastic production has increased 200 fold from 1950 to 2015, from 2 Mt to 380 Mt, respectively. The amount of plastic produced during this period was estimated to be approximately 8,300 Mt (Geyer et al., 2017). In 2015, the amount of plastic waste generated was estimated to be 6,300 Mt, of which 567 Mt (9%) was recycled, 756 Mt (12%) was incinerated, and 4,977 Mt (79%) was placed in landfills or the natural environment (Geyer et al., 2017). Assuming this trend continues, the amount of plastic waste produced in 2050 will be 33,000 Mt, of which 12,000 Mt of plastic waste may be left to accumulate in landfills or the natural environment (Geyer et al., 2017).

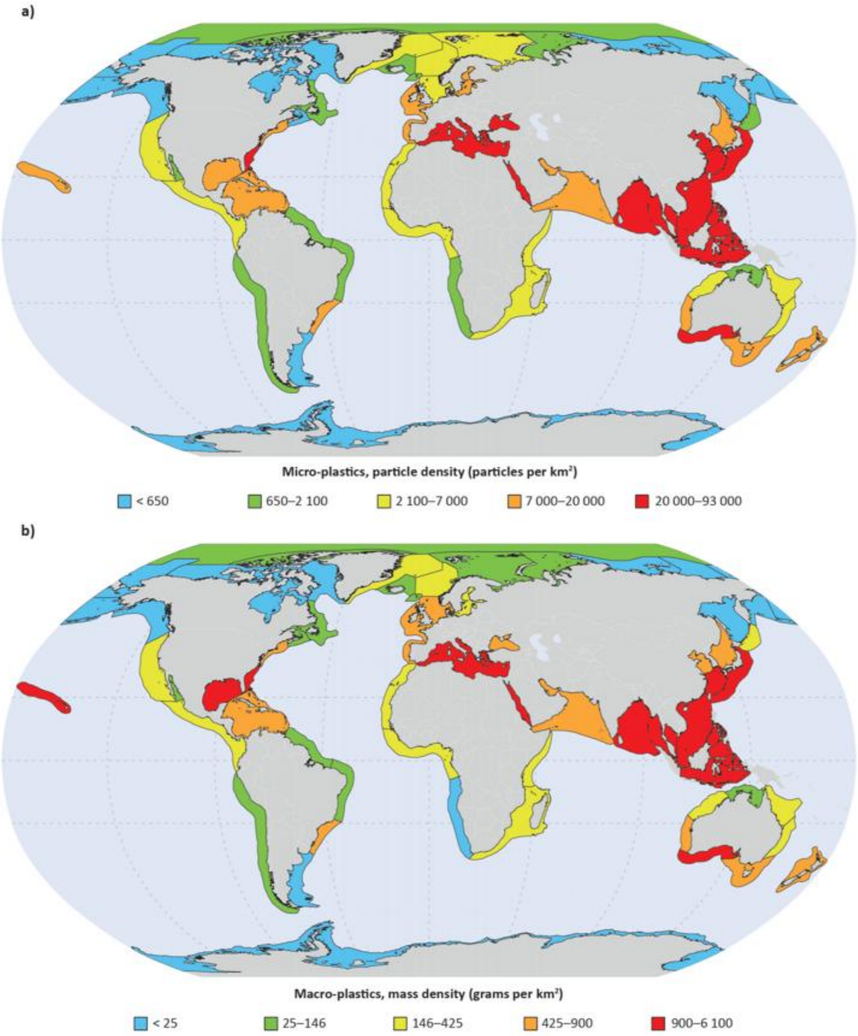

Fig. 7. Spatial distribution of the relative abundance of floating (a) microplastics and (b) macroplastics in 66 Large Marine Ecosystems (LMEs) based on model estimates (Kershaw and Lebreton, 2016). LMEs were separated into five categories of relative abundance based on model estimates using proxy sources, according to Eriksen et al. (2014) and Lebreton et al. (2012).

In a survey concerning plastic waste introduction into seas within 50 km of residential areas for 192 coastal countries, the amount of plastic waste entering the ocean ranged from 4.8 Mt to 12.7 Mt, with an average of 8.0 Mt (Jambeck et al., 2015). This corresponds to 1.7% to 4.6% of the total plastic waste, or 275 Mt, produced in the surveyed areas. Applying this trend to the study by Geyer et al. (2017), the amount of plastic waste entering the ocean in 2015 was presumed to be 230 Mt and may increase to 554 Mt by 2050. Meanwhile, a study of 1494 rivers with an outlet to the sea showed that the annual range of plastic debris entering the sea was 0.000247 Mt 16.7 Mt (average of 0.39 Mt), and that ten rivers contributed 75% of this waste (Schmidt et al., 2017a). Among these ten rivers, China's Yangtze River recorded a maximum load of 1.5 Mt, which is three times higher than the total contribution of the remaining nine rivers (Schmidt et al., 2017b).

Plastic debris introduced into the ocean via shores or rivers is carried by currents and spread globally. Numerical model simulations have demonstrated that the world's marine plastic debris is distributed, as shown in Fig. 7 (Kershaw and Lebreton, 2016). Specifically, marine plastic debris is distributed along coastal areas, with high concentrations in the Mediterranean Sea,

Fig. 8. Waste hierarchy, according to the Zero Waste International Alliance (ZWIA, 2020).

Indian Ocean, and northwest Pacific Ocean. Depending on the current, marine plastic may concentrate not only along the coasts but also as patches in the ocean (Kershaw and Lebreton, 2016). With a help of numerical model simulation, it was found that a marine plastic patch[3)] in the subtropical waters between California and Hawaii has an area of 1.6 million km2 and contains 0.79 Mt of marine plastic debris Lebreton et al. (2018).

4. Response strategies for marine plastic pollution

Currently, the three strategies that should be implemented to mitigate marine plastic pollution are to remove plastic debris already existing in the marine environment, to suppress the release of new plastic debris into the marine environment, and to prevent damage to humans and marine life from plastic debris.

The first strategy of removing plastic debris already existing in the ocean involves removing macroplastics as this will also contribute to the suppression of the production of secondary microplastics, which usually results from the weathering of large plastic debris. For this purpose, countries worldwide should quickly collect coastal debris for on land handling. Further, countries neighboring high seas or regional seas should actively cooperate to collect debris that has spread through waters beyond territorial seas.

Meanwhile, to suppress the release of plastic debris into the marine environment as a second strategy, policies should be implemented to minimize the use of plastics and to encourage the 3Rs (reduce, reuse, and recycle). The United Nations Environment Programme (UNEP, 2011) Governing Council decision 25/8 on waste management requested litter management policies to "shift from an end-of-pipe approach in waste management to an integrated waste management approach." Accordingly, countries should strive to achieve "zero" plastic debris by adopting a waste management hierarchy (Fig. 8) and integrated solid waste management (UNEP, 2011), including the principles of the 3Rs.

Finally, the last strategy involves assessing the risks of plastics and minimizing the damage caused to humans and marine life. While harmful effects caused by plastic toxicity are well known, there are also the secondary risks associated with the release of plastic into the ocean, including the chemical reactions of plastics with seawater, and the accumulation of plastic in the food chain. Thus, there is still much to explore regarding the introduction of primary microplastics into marine ecosystems and the potential related hazards. Therefore, to reduce the damage caused to humans and animals, it is necessary to first determine the risks of microplastics.

5. Summary and conclusions

Marine debris is an environmental issue that accounts for a significant portion of marine pollution. To assess the problem of environmental pollution arising from marine plastic debris and develop countermeasures, this study investigated the properties of plastic debris, ecological impact case studies, as well as the inflow and distribution of marine plastic debris. Based on the results, strategies were proposed to minimize the damage caused by marine plastic debris.

Marine plastic debris is classified by size into macroplastics and microplastics; the latter of which can be again classified into primary and secondary microplastics, depending on how they were manufactured (GESAMP, 2015). The major deleterious effects of marine plastics include entanglement and ingestion. Marine organisms can become entangled in plastic debris within ghost gear, which limits their physical abilities and can lead to death (Laist, 1997). Meanwhile, the ingestion of plastic debris can directly cause digestive problems and indirectly produce adverse effects through chemical reactions. In particular, these indirect effects are more critical when microplastics are involved, as they can affect not only the ingested organism but also impacting the entire ecosystem via the food chain (Ryan, 1988; Lee et al., 2001).

3) This patch is known as the Great Pacific Garbage Patch (GPGP).

The annual amount of plastic debris entering the ocean through coastal countries averaged 8.0 Mt in 2010 (Jambeck et al., 2015), and the amount entering through rivers was found to be 0.39 Mt (Schmidt et al., 2017a). Further, based on the amount of plastic waste entering the sea in 2015 (230 Mt), 554 Mt of plastic waste may enter the sea in 2050. Plastic debris is carried by currents and is distributed globally (Lebreton et al., 2012; GEMSAMP, 2015). It is noted that even plastic waste patches have been observed in some oceans (Lebreton et al., 2018).

The three strategies proposed to reduce marine plastic debris environmental pollution are to: 1) remove plastic debris already existing in the marine environment, 2) suppress the release of plastic debris into the marine environment, and 3) prevent plastic debris from causing damage to humans and marine life.

Marine plastic debris is a major cause of marine pollution, and its devastating effects may worsen with the increased use of plastics. Specifically, regarding microplastics, there is still much to learn about inflow, movement within the ecosystem, and hazards posed to humans and marine life. Thus, to minimize the environmental damage of marine plastic debris, the proposed response strategies should be implemented in parallel. In addition, it is important to raise public awareness regarding the risks of marine plastic debris and to implement effective policies for marine debris management.

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