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REVIEW PAPER

The environmental effects of microplastics on aquatic ecosystems

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Abstract

Purpose of review: Contamination of aquatic ecosystems by plastics under 5 mm in size, which are classified as microplastics (MPs), is becoming increasingly serious, and research on the ecotoxicity of MPs is needed. In this study, we aimed to present solutions to the problem of MPs through a review of the current state of research on the definition of MPs, usage, leakage, toxicity, and domestic and overseas circulation of plastics.
Recent findings: Long-term exposure to MPs results in ecotoxicity. MPs not only deliver chemical substances within organisms, but also act as mediators for chemicals or other contaminants in aquatic environments. Co-exposure to MPs and chemical contaminants has been reported to increase toxicity in several organisms.

Keywords: Microplastic, Ecotoxicity, Environmental risk management, Polypropylene

Introduction

Plastics have diverse uses in modern industrial society due to their light weight, excellent durability, and easy moldability[1,2]. In 2016, 335 million tons of plastic were produced, which were used in various industries including packaging (39.9%), construction (19.7%), and electronics (6.2%)[3].

However, the fact that plastics are not degraded after use has been highlighted as a problem in the treatment of waste[4]. In particular, contamination of aquatic ecosystems caused by plastics under 5 mm in size, classified as microplastics (MPs), is becoming increasingly serious, and MP release has recently become a global issue[5].

Two types of MPs are known to be released in ecosystems (Figure 1). First, primary MPs are produced by manufacturing plastic to a size of less than 5 mm, which are then released as "microbeads" that have been prepared for a specific purpose, such as "rinse-off" cosmetics[6,7].

Secondary MPs are plastics that are exposed to the environment after being used and then shrink to a size of less than 5 mm as a result of physical, chemical, or biological degradation[7]. Plastics of 1 cm^2 in size can degrade to the nm scale under irradiation by ultraviolet A (UV-A) in sunlight[8,9].

There have been reports that MPs that leak into the environment can potentially affect human health[10].

As a result, the European Chemical Agency (ECHA) has warned of the dangers of releasing MPs into the environment from products in circulation in the EU in January 2018, and is currently implementing their 'Strategy on Plastics in the Circular Economy' as a follow-up measure[6].

However, there are still no policies for controlling distributions that consider the effects of MPs on the environment in South Korea. Therefore, there is a need for environmental risk assessment and management of MPs.

In this study, we aimed to present solutions through a review of the current state of research on the definition of MPs, current usage, environmental leakage, toxicity, and domestic and overseas circulation of plastics.

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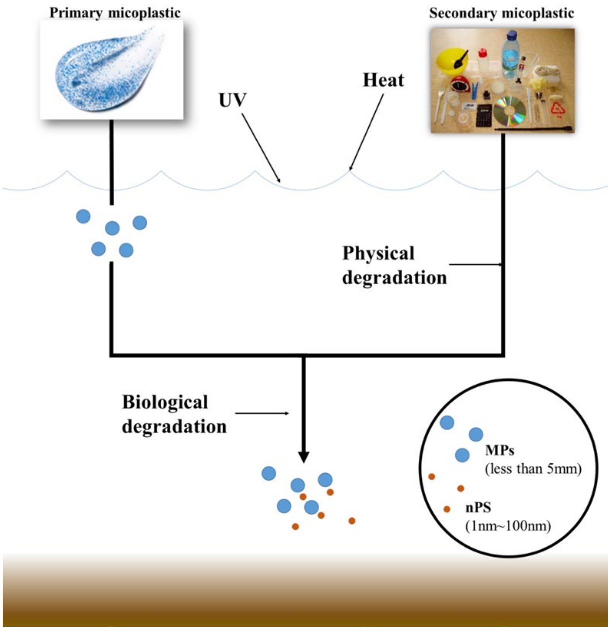

Figure 1. Degradation of plastic debris in aquatic environments.

Microplastic definition

MPs are plastics with a diameter of less than 5 mm. In this study, plastics with a diameter of 1-100 nm are defined differently as nanoplastics (NPs)[11]. Degradation of plastic polymers can proceed through biotic or abiotic pathways[12]. In general, abiotic degradation begins before biodegradation, via thermal or hydrolytic degradation, or by exposure to ultraviolet light in the environment[12]. The smaller polymer fragments formed by abiotic degradation can permeate the cell membrane and can be biodegraded within microbial cells by intracellular enzymes[12,13]. For most plastics, the surface is degraded first by chemical or enzymatic exposure, and so the degradation of MPs, which have a relatively large surface area, is faster than that of larger plastics[14].

Use of plastics and environmental leakage

Excluding 2011, domestic plastic production has maintained 12 years of continual growth at an annual average of 3.2%, from 10.9 million tons in 2005 to 15.5 million tons in 2016[15]. Meanwhile, plastics account for approximately 9% (4,242 tons/day) of the total daily domestic waste (45,560.3 tons) in Korea (Figure 2). The majority of this waste (50.4%) is incinerated, 30% is recycled, and 19.6% is put in landfills[16]. Recyclable plastics that are properly separated as recyclable waste are 100% recycled, however, a large proportion of these are incinerated as a result of not being properly separated[16].

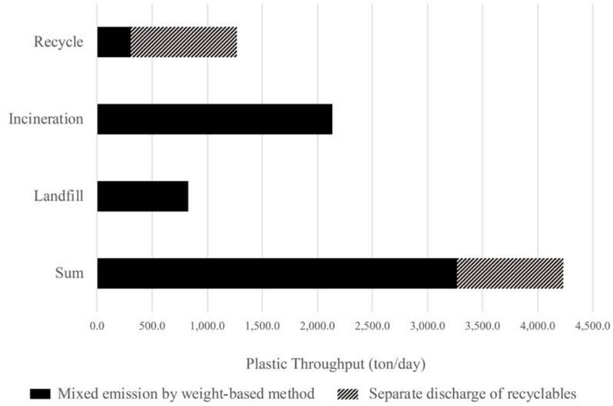

Figure 2. The status of the emission and disposal of plastics in municipal waste. Ministry of Environment, National waste generation and disposal status (2017).

Plastic use is showing persistent increasing trends globally as well, with production of plastics growing from 322 million tons in 2015 to 335 million tons in 2016 (Figure 3), and increasing from 58 million tons to 60 million tons in Europe during the same period[17]. Asia is responsible for 50% of plastic production, with China accounting for 29% of global production[17].

The most common use for plastics is packaging. In particular, packaging accounts for 39.9% of the European plastic market, and the most commonly used plastic is polypropylene (PP)[18].

Since January 2018, the ECHA has demanded information on MP particles that have been "intentionally added" to products or that are used in a wide range of products placed on the EU market. In July 2018, the ECHA published a memo on substance identification, and a potential range of limitations on the use of MPs, restricting the use of "intentionally added" MPs[6].

The ECHA reported that 2-5% of plastic production migrates into the ocean, and that some of this is in the form of MPs[18].

Of the MPs that enter marine ecosystems, only 20% are introduced by marine activities, and the other 80% consist of MPs that have been leaked from the land[19], Waste processing is one of the major sources of MP release[20-25].

Plastic that enters the environment is degraded into micro-nano sizes by physicochemical action, UV, and microbes[26]. In an experiment using 7 types of macromolecule, all of the macromolecules were degraded in water to form MPs. All of the macromolecules used in the experiment were degraded to form particles of 30

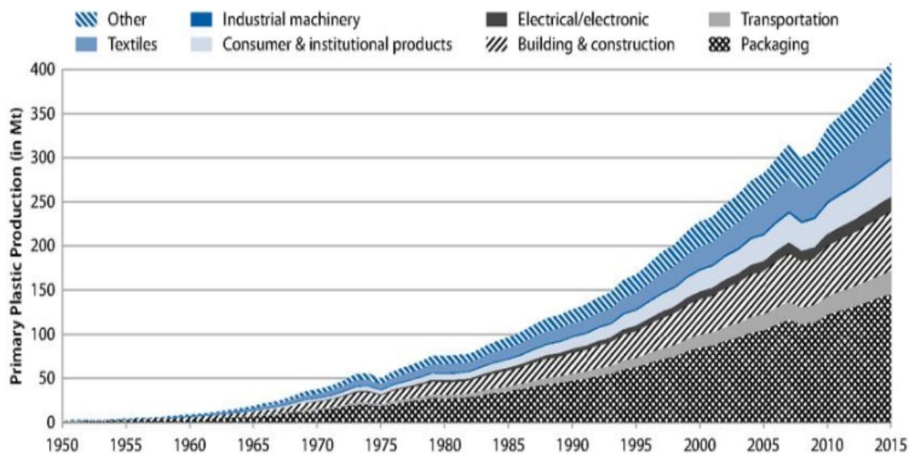

Figure 3. Global production of primary plastics (in million metric tons) according to the industrial use sector from 1950 to 2015[18].

nm-60 μm. Polystyrene (PS) and polylactic acid (PLA) showed especially active formation of nano-sized particles. The degradation process is initiated by breaking the macromolecular chain at the polymer surface. Most plastics tend to absorb high-energy radiation in the ultraviolet part of the spectrum. This increases the reactivity of the electrons, resulting in oxidative scission or other forms of degradation. When plastics are heated, the ductility and brittleness are decreased via molecular scission due to heat, which causes chalking and cracking, thus making the plastic biodegradable[4].

Toxicity of microplastics

MPs are difficult to identify, and are readily ingested by aquatic organisms because of their microscopic size. Since MPs have a larger relative surface area compared to large plastic particles, they are able to adsorb and transport much more organic matter[27].

MP exposure has been found to cause growth impairment[27-31], behavioral impairment[32], reproductive impairment[27,33,34], feeding impairment[35-39], reduced survival[40,41], and increased mortality[34,42] in aquatic organisms[43](Table 1).

In the toxicity profile of MPs, short-term exposure does not seem to have a major biological effect. However, there are numerous studies showing toxicity from long-term exposure.

Mark A. Browne (2008) exposed mussels to PS MPs, and observed MP accumulation in the digestive system. MPs accumulated in the circulatory fluid of muscles, and were detected in the lymph and blood cells, and phagocytic activity was significantly higher on days 3 and 6 than on days 23 and 24[40]. N. Von Moos (2012) injected *Mytilus edulis* L. with high-density polyethylene (HDPE, size 0-80 μm) and observed a decrease in lysosome stability and an increase in granular cell tumors after 6 hr. Complete destruction of lysosomes was observed after 96 hr of MP exposure. In addition, MPs were detected in digestive epithelial cells, and were found to enter cells by endocytosis[44].

MPs also affect reproduction. In a study by Sussarellu *et al.* (2016), male oysters showed a 23% decrease in sperm motility and females showed reduced oocyte numbers compared to those of a control group following exposure to PS MPs at a concentration of 0.0002%. In addition, this trend was observed to persist, with the second generation also showing delayed growth[27].

In an experiment on the long-term exposure of *Eriocheir sinensis* to fluorescent PS MPs, absorption and accumulation was detected in the gills, liver, and intestines, and liver injury and oxidative stress were observed[45].

MPs carry materials to other organisms or locations, acting as a mediator for chemical contamination and contaminants in aquatic environments[46,47]. Co-exposure to MPs and chemical contaminants has been reported to cause severe toxicity in several organisms[48-51]. In a long-term toxicity experiment using zebrafish (*Danio rerio*), when given feed that contained MPs and persistent organic pollutants (POPs, PCBs, BFRs, PFCs, and methylmercury), the zebrafish showed higher levels of hepatocyte vacuolization than the zebrafish that consumed feed containing only POPs. In particular, zebrafish that consumed MPs and POPs together developed skin abnormalities[52].

The toxicity from co-exposure to MPs and other chemicals is affected by the size of the MPs[53]. When *D. magna* were co-exposed to phenanthrene and MPs, the

Table 1. Environmental toxicity of MPs in organisms.

Particle (materials)	Particle size (diameter)	Test organisms	Toxicity type	References
HDPE	0-80 μm	*Mytilus edulis L.*	Tumor	43
PE	10 μm to 27 μm	*Hyalella azteca*	Growth inhibition Increased mortality	28
	10 μm to 27 μm	*Idotea emarginata*	Growth inhibition	29
	1-μm, 100-μm	*Daphnia magna*	Behavioral disorder	32
PLA, HDPE, PVC	<1 mm	*Arenicola marina*	Eating disorder	35
PS	10 μm-2 mm	*Scleractinian coral*	Eating disorder	36
	~70 nm	*Scenedesmus obliquus, Daphnia magna*	Reproductive disorder	33
	2, 4-16 μm	*Mytilus edulis L.*	Reduced survival rate Increased phagocytic activity	42
	50 nm	*Mytilus edulis*	Reduced survival rate	41
	55 nm, 110 nm	*Daphnia magna, Thamnocephalus platyurus, Pseudokirchneriella subcapitata,* and *Vibrio fischeri*	Reduced survival rate	42
	70 nm-20 μm	*Crassostrea gigas*	Growth inhibition	30
	20 μm	*Echinoderm*	Eating disorder	37
	0.05, 0.5, and 6-μm	*Telmatogeton japonicus*	Reproductive disorder Increased mortality	34
	24, 27 nm	*Scenedesmus* sp., *Daphnia magna, Carassius carassius*	Behavioral disorder	53
	100 nm	*Daphnia magna*	Eating disorder Increased mortality	38
	0.05, 0.5 and 6 μm	*D. tertiolecta*	Growth inhibition	31
	2 and 6 μm	*Crassostrea gigas*	Growth inhibition Reproductive disorder	27
	0.5 μm	*Eriocheir sinensis*	Liver damage	40
UPVC	130 μm	*Arenicola marina*	Eating disorder Inflammation	39

HDPE: High-density polyethylene; PE: Polyethylene; PLA: Polylactide; PVC: Polyvinylpyrrolidone; PS: Polystyrene; UPVC: Unplasticised Polyvinyl Chloride

group exposed to 50 nm NPs showed higher toxicity and bioaccumulation than the group exposed to 10 μm MPs. In an acute toxicity experiment, the *D. magna* exposed to 50 nm NPs developed severe injuries to the thoracopods, which are essential to swimming, creating water currents for filter feeding, and accumulation of particles on the surface of the thoracopods. After long-term exposure, phenanthrene remained in the brain, bones, and intestines, and adhesion to the carapace was observed[54].

MPs show more severe effects as the level of the consumer in the food chain increases. When *Daphnia* were fed algae that had been administered NPs, and the *Daphnia* were then fed to crucian carp (*Carassius carassius*), significant differences were detected in the muscle tissue of the carp, and MPs were also detected in the gills. The carp showed lower activity than a control group, and also showed differences in the color of cerebral and muscle tissue. The brain had a soft, white, swollen appearance[55].

In an experiment by Yooeun Chae (2018) spanning 4 trophic levels (*Chlamydomonas reinhardtii*, *D. magna*, *Oryzias sinensis*, and *Zacco temminckii*), accumulation in the body was visually observed to be affected by the trophic level following exposure to fluorescent MPs with a mean diameter of 51 nm. In this study, NPs were found to cause impairment of liver tissue morphology, lipid metabolism, embryos, and organ activity. Although we investigated short-term exposure to a much higher doses of NPs than would be observed in nature in this study, exposure to NPs in natural environments is long-term, and the results of this study warn about the possibility of accumulation within the body[56].

Solutions & Conclusion

Plastic processing techniques are being developed with a shift towards the use of ultrafine particles. This is similar to the trends with other chemicals, which are moving in the direction of increased use efficiency via the advancement of nano-techniques.

The ecological effects of the environmental leakage of chemicals have been recognized as a global problem. Active control policies for MPs are also being implemented in a number of countries, mostly in the EU, by labeling products with information regarding the safety and ecological effects of MPs.

In Korea, the Ministry of Environment has recently been implemented guidelines to reduce the use of plastics, but these do not address MPs. These guidelines are still similar to other environmental campaigns that are targeted to the general public.

Thus, there is a need for more active policies regarding MPs. This, in turn, requires surveys of the MP substances that are currently in domestic circulation. In addition to MP substances being produced domestically, imported MPs will also need to be investigated, as is currently implemented in the Act on Registration, Evaluation, etc. of Chemicals. In addition, given the diversity typically found in production, MPs should be controlled by hazard assessments, as are conducted for chemical substances.

In particular, like the concept of lifecycle assessment (LCA) that was introduced for chemicals, a system needs to be introduced for the assessment and control of MPs throughout their whole lifecycle, including production, consumption, and disposal. This is because advances in processing techniques have led to plastics, which are a major part of daily human lives and have been developed into new substances that can accumulate in the body and permeate cells. The issue is even more urgent in the current system where products, including fresh foods, are distributed worldwide.

Informative environmental marking of products from the production stage could be implemented with modern electronic information technology, and could help to advance environmental control policies in Korea.

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Conflict of Interest Jiwon Ha & Min-Kyeong Yeo declare that they have no conflicts of interest.

Human and animal rights The article does not contain any studies with human and animals, and this study was performed following institutional and national guidelines.

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