Contamination of Marine Environment by Floating, Drifting and Precipitating Microplastics in the Ocean: Potential Menace to Marine Species, Ecosystems and Human Health

TAKEMURA Noriyoshi

Faculty of Law, Toin University of Yokohama

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1. Introduction

Plastic debris has now become the most serious problem affecting the marine environment, according to Thevenon et al., not only for coastal areas of developing countries that lack appropriate waste management infrastructures, but also for the world's oceans as a whole because slowly degrading large plastic items generate microplastic particles (smaller than 1 to 5 mm) which spread over long distances by wind-driven ocean surface layer circulation. Growing scientific and public awareness is fueling global concern regarding the impact of plastic ingested by marine species and the accumulation of plastics in coastal and remote areas of oceans in trash gyres (Thervenon *et al*. 2014: 9; Bethge).

They continue that it is well recognized that drifting plastic debris has several adverse effects on marine species and ecosystems. However, there is still a lack of precise knowledge about the quantity, sources, transport, accumulation and fate of plastics in the oceans. The most visible and disturbing impact of marine plastic pollution is the ingestion, suffocation and entanglement of hundreds of marine species. Floating plastics, presently the most abundant items of marine litter, also contribute considerably to the transport of non-indigenous (alien) marine species thereby threatening marine biodiversity and the food web. These floating particles accumulate toxic pollutants on their surface during their long-residence time in polluted seawater and can therefore represent a concentrated source of environmental pollution, or serve as a vector for toxic pollutants that accumulate in the food webs (bio-accumulation of contaminants) (Thevenon *et al*. 2014: 9; Darraik 2002).

They conclude that the globally emerging environmental, economic and health risks related to plastic pollution require immediate international attention. It is time to take regional- and global-level actions against the entry of plastics into the ocean. There is also an urgent need to monitor the type and quantity of marine plastics as well as to better assesses the impacts of plastic pollution on marine environments, species and ecosystems (Thevenon *et al*. 2014: 9; Moore *et al*. 2012; Decker 2014).

TAKEMURA Noriyoshi : Professor, Faculty of Law, Toin University of Yokohama, 1614 Kurogane-cho, Aoba-ku,Yokohama, Japan 225-8503

In this paper, present situation of plastic debris, especially microplastics, in the world's oceans is cleared and what should be done is considered [1) 2)].

2. Plastic Debris in the Ocean

2.1 Assessing the extent of the problem

Kershaw *et al*. assess the extent of plastic debris problem in the oceans as follows. The ocean has become a global repository for much of the waste we generate. Marine debris includes timber, glass, metal and plastic from many different sources. Recently, accumulation and possible impacts of microplastic particles in the ocean have been recognized as an emerging environmental issue. Some scientists are increasingly concerned about the potential impact of releases of persistent bio-accumulating and toxic compounds (PBTs) from plastic debris. At the same time, fishing and tourism industries in many parts of the world are affected economically by plastic entering nets, fouling propellers and other equipment, and washing up on beaches. Despite international efforts to stem the flow of plastic debris, it continues to accumulate and impact the marine environment. To reduce the quantity of plastic entering the ocean, existing management instruments need to be made more effective and all aspects of waste treatment and disposal need to be improved (Kershaw *et al*. 2011: 21; Cole *et al*. 2011: 2596; Cózar *et al*. 2014: 10239; Andrady 2011: 1602–1603. 2009; Thompson *et al*.; Teuten *et al*. 2009).

Although monitoring, surveillance and research focusing on plastic and other types of marine litter have increased in recent years, they complain about present situations and makes their suggestion, a comprehensive set of environmental indicators for use in assessment has been lacking, as have related social and economic indicators. These types of indicators could include trends in coastal population increase and urbanization, plastics production, fractions of waste recycled, tourism revenue, waste disposal methods, shipping tonnage and fishing activities. Indicators also provide a means to measure the effectiveness of mitigation measures, such as improved waste management and the introduction of economic measures (Kershaw *et al*. 2011: 23; Ivar do Sul *et al*. 2014: 361).

2.2 Physical and chemical impacts

Then they mention physical and chemical impacts of plastic debris that environmental damage due to plastic and other marine debris can be defined as mortality or sub-lethal effects on biodiversity through physical damage by ingestion; entanglement in 'ghost nets' (fishing nets lost or left in the ocean) and other debris; chemical contamination by ingestion; and alteration of community structure, including the importation of alien species. Exposure of plastic debris to the variety of physical, chemical and biological processes in oceans results in fragmentation and size reduction. In general, potential chemical effects are likely to increase with a reduction in the size of plastic particles while physical effects, such as the entanglement of seals and other animals in drift plastic, increase with the size and complexity of the debris (Kershaw: 25).

Microplastics are ubiquitous in the ocean, contain a wide range of chemical contaminants, and can be ingested by marine organisms. However, the lack of certainty about the possible role of microplastics, as an additional vector for contaminants taken up by organisms, calls for caution and further research (Kershaw *et al*. 2011: 75, 28; GESAMP 2015: 30, 48; Thevenon *et al*. 2014: 27, 29, 31–32).

3. Presence of Microplastics in Water and Fishes of Easter Island

3.1 Plastic Polution in the South Pacific Subtropical Gyre

Martinez et al. insist that we should be on the watch for floating and drifting plastic debris in the South Pacific Ocean as well as in the North Pacific Ocean. In the South Pacific, after a longer time period of drift, floating marine debris accumulates in the eastern-center region of subtropical gyre from where they do not escape. We should wonder what happens to those accumulated detritus. As the horizontal convergence upper layer induces a vertical divergence in the lower layer, are some of the dislocated plastic fragments trapped? Do they sink? Do they accumulate in the sediments at the bottom of the oceans? (Martinez *et al*. 2009: 1353–1354)

It is difficult to estimate the damages in the eastern-center region of the subtropical gyre since there is only one island, Easter Island, and no surveys carried out in the region (in 2009). People should worry about the same happening in the South Pacific Ocean, and care should be brought regarding the increasing plastic products and other detritus that are released by our polluting way of life (Martinez *et al*, 2009: 1353–1354; Eriksen *et al*. 2013: 71–72).

3.2 Undesirable items from far away and thread for marine lives and human health

Ory *et al*. made a valuable research on microplastics around the Easter Island, and analyze the problems caused by them. Winds and currents of the Pacific Ocean had brought to the shore of the islands living organisms for millions of years, allowing life to flourish on one of the most remote island of the world. Nowadays, however, winds and currents also bring undesirable items from far away: microplastics.

They explains that microplastics also originate from the degradation of larger plastic object which, once released in the ocean by human activities (urban waste, industry, fishing), gradually degrade in smaller fragments under the combined effects of the sun, temperature and microbial activity. Floating plastics may drift for years and over thousands of kilometers within oceanic gyres, which are zones where currents converge and at the center of which plastic particles accumulate in high abundance. Five main subtropical gyres exist in the world: Rapa Nui is located in the center of the South Pacific gyre.

In addition to the esthetical problem of the presence of microplastics in one of the clearest waters of the world, they continue, these tiny particles are a threat for marine wild life because they may be ingested by various marine organisms, such as fishes. Once ingested, microplastics may cause inflammation and physical lesions to the digestive system and reduce the amount of food taken by the animals. Mycroplastics also contain hazardous chemical elements or may accumulate at their surface contaminants present in the seawater. These contaminants may be transferred to the tissues of the fishes and, in turn, to humans who eat the fishes. The effects of microplanstics on human health are still unclear, but they may represent a threat for communities where fish is an important source of food, such as in Rapa Nui.

3.3 Researches and solutions to the problem caused by microplastics

They explain their researches and solutions as follows. Members of the Nucleus Millenium Ecology and Sustainable Management of Oceanic Islands (ESMOI) of the Universidad Catolica del Norte in Coquimbo went to Rapa Nui for 6 weeks between March and April 2015. The goal of this study was to quantify the amount of maicroplastics in superficial water, subtidal sand and fish stomachs at different sites around the coasts of the islands.

They continue that the first results of this study confirmed a high abundance of microplastics in surface waters around the coasts of the islands. Most of the microplastics found were brittle and tarnished, indicating that they had spent a long time floating at the surface of the ocean. Few plastics were found in the sand surrounding coral and rocky reefs, which signifies that microplastic input from Rapa Nui is limited. These observations support the fact that the microplastics found around the coasts of Rapa Nui originate far away from countries surrounding the South Pacific Ocean and large fishing vessels operating in the open ocean. Almost all the stomachs of planktivorous fishes (*i.e.* feeding on tiny organisms living in the water column), such as the ature (amberstrip scad, Decapteruas muroadsi), contained at least one microplastic fragment, with a maximum of six particles found in a single individual. Interestingly, a high proportion of these microplastics were of similar size and colour (transparent and blue) as planktonic crustaceans, very abundant in our water samples and often also found in the fish stomachs. Planktivorous fishes may thus mistakenly ingest microplastics instead of their natural prey, which makes them very micronatural prey (Joret *et al*. 2003; Boersema 2011).

4. Dynamic and Complex Effects of Microplastics on Ecosystem, Food Chain, and Humans

4.1 Dynamic and complex effects on ecosystem, food chain and humans

Depending on the amount and size of the particles, according to GESAMP, different functional groups may be directly affected by microplastics, compromising ecological process and ecosystem function. Adsorption of microplastics in the organism surface, e.g. algae and zooplankton, was demonstrated to reduce the photosynthetic and feeding rate, respectively. However, what this effect at the base of the food chain could mean for the productivity and resilience of ecosystems in the long term is unknown. Considering that amount of plastics entering the ocean is increasing, plastic degradation produces smaller particle sizes, smaller particles are supposed to be more toxic, and the effect of microplastics at the higher levels of organization is supposed to increase, it is possible to suppose an increasing impact of microplastics on marine systems. However, due to their complexity, with species-specific and generalized response from the biota to the presence of microplastics, with external and internal exposures and with physical and chemical effects, which are not well understood, the direction of this effect is hard to be predicted (GESAMP 2015: 52).

On the other hand, GESAMP explains dynamic and complex effects on food chain and humans. The potential accumulation of microplastics in the food chain, especially in fish and shellfish (species of molluscs, crustaceans and echinoderms) could have consequences for the health of human consumers (GESAMP 2015:52; Seltenrich 2015).

4.2 Biomagnification of chemical contaminants in the food chain

From the viewpoint of biomagnification, Rochman analyzes chemical contaminants in the food chain. The long-range transport, persistence and global dynamics of plastic debris are key aspects to understanding the ultimate fate of this material and any potential impacts of plastic debris on marine ecosystems. The addition of plastic to the marine environment adds a novel medium for chemical contaminants to interact with, and it is important to understand how plastic debris should be considered in future environmental fate. Plastic debris is a novel environmental matrix and it plays a potential role in helping to mediate the fate and distribution of chemical contaminants globally. Specifically, plastic debris is a sink and a source for chemical contaminants in the marine environments and it may facilitate the global transport of chemicals in the marine environment and the transport of chemicals into marine foodwebs (Rochman 2015: 124–125, 130; Thevanon *et al*. 2014: 33).

5. Uncertainty and Complexity in Kinetics and Thermodynamics of Interaction between Marine Debris, Toxic Chemicals and the Food Web

5.1 Plastic debris, toxic chemicals and the food web

Engler explains the uncertainty and complexity in Kinetics and Thermodynamics of Interaction between Marine Debris, Toxic Chemicals and the Food Web. Some plastic debris acts as a source of toxic chemicals: substances that were added to the plastic during manufacturing leach from plastic debris. Plastic debris also acts as a sink for toxic chemicals. Plastic sorbs persistent, bioaccumulative, and toxic substances (PBTs), such as polychlorinated biphenyls (PCBs) and dioxins, from the water or sediments. These PBTs may desorb when the plastic is ingested by any of a variety of marine species. This broad look at the current research suggests that while there is significant uncertainty and complexity in the kinetics and thermodynamics of the interaction, plastic debris appears to act as a vector transferring PBTs from the water to the food web, increasing risk throughout the marine food web, including humans (Engler 2012: 12302).

He continues that no one is sure how long traditional plastics persist in the environment, but rates may be as slow as just a few percent of carbon loss over a decade. Plastic objects typically fragment into progressively smaller and more numerous particles without substantial chemical degradation. Furthermore, although much of the marine debris research focuses on floating plastic debris, it is important to recognize that not all plastic floats. Depending on the density of the material and the presence of entrapped air, marine debris may float or sink. After some amount of time in the ocean, floating plastic debris may become sufficiently fouled with biological grows that it sinks. As a result, plastic debris will be found throughout the water column, but largely concentrated near the surface and on the ocean floor (Engler 2012: 12302, 12304, 12308–9).

5.2 Potential solutions, no single solution and many opportunities

Engler offers potential solutions that among the challenges in addressing marine debris is that the greatest impacts are largely invisible from the origin of the debris (fugitive loss, litter or other improper disposal). Another significant challenge is that marine debris arises from sources around the world. Unilateral action by one country will be helpful, but cannot solve the problems presented by marine debris. Debris dropped anywhere on earth may end up being transported via surface water to the ocean where it may be carried vast distances before it settles to the bottom. Furthermore, plastic debris is simply too widely dispersed to effectively clean it up. Even in the ‘Great Pacific Garbage Patch’ there are only a few kilograms of plastic per square kilometer of ocean. This is roughly equivalent of a few teaspoons of plastic pieces spread over a football field and trying to clean it all up with tweezers. Reversing the impacts of plastic debris will take sustained efforts and novel technologies (Engler 2012: 12309).

In addition, he insists that there is no single solution to the risk posed by plastic marine debris and toxic chemicals in the ocean. While there are limited, if any, viable options to clean up plastics or toxics already present in the oceans, there are many opportunities to prevent more plastics and toxics from being released. Plastic reduction strategies will have to include low-tech solutions to reduce littering, such as behavior change, and high-tech solutions, such as new, biodegradable resins, as well as public policy options. Public policies may include limiting trash in water discharges by, for example, physical trapping debris before discharging effluent to surface water, financial incentives to increase reuse or recycling, such as plastic bag fees, or even incentives for ambitious system-wide redesign of plastic manufacturing-use-disposal cycles to 'close the loop' for resins (Engler 2012: 12310; McKinsey & Company *et al*. 2015).

6. Conclusions

In the end, we can conclude as follows. Large amounts of plastic debris enter the ocean every year, where it slowly fragments and accumulates in convergence zones. Scientists are concerned about the possible impact of small plastic fragments (microplastics) in the environment. The role of plastics as a vector for transporting chemicals and species in the ocean is as yet poorly understood, but it is a potential threat to marine species, ecosystems and human health (Kershaw *et al*. 2011: 21).

Marine plastic debris has major direct and indirect harmful effects on the marine biota and wildlife. Problems associated with absorption and entanglement of plastic debris include ingestion of specific plastic items by animals that mistake plastic waste for prey, and to a lesser extent consumption of pelagic fish and other prey that have plastic particles in their guts. Accumulation of plastic debris in the marine environment can result in habitat degradation whereas floating plastics create new habitats and enable transport of invasive (alien) species over long distances. Finally, plastics contain toxic substances that were added to the polymers during the production process. Marine plastics accumulate toxic pollutants present at the sea surface and serve as a potential transport vector for chemical contaminants of concern. Although pollution by plastics is increasingly recognized worldwide as a major threat to marine biota, the effects of oceanic plastic debris on marine organisms and food webs, community structure, and ecosystems are still poorly understood (Thevenon *et al*. 2014: 27).

According to Thevenon *et al*., future ecotoxicological studies are needed to assess the harmful effects of plastic marine ingestion, especially regarding the transfer of adsorbed pollutants and additives towards high trophic levels in the food web. There are increasing number of scientific studies focusing on the bioaccumulation of the chemical associated to plastic debris and about their potential to affect organisms ranging from zooplankton to top predator fish species. Consequently, inadvertent plastic material ingestion represents a threat for marine organisms living in polluted waters, with possible public health concerns for the consumption of fish and seafood living in polluted waters enriched in microplastics. These recent findings strengthen the need for a better assessment of the extent of marine plastic pollution (characteristics, sources, accumulation zones, transport pathways and sedimentation), as well as the necessity to regulate the manufacturing of polymer substances and plastic additives at an international level (Thevenon *et al*. 2014: 33).

At last, it is certain that contamination of marine environment is a serious, potential menace not only to our generation but also to next and future generations, and we should put in serious efforts to tackle microplastic problems.

[Notes]

1) This article is based on the two papers. One is titled "Contamination of Marine Environment by Floating Plastic Debris: Potential Threat to Marine Species, Ecosystems, and Human Health," and presented at the 15th Annual Conference of the European Soci-

ety of Criminology, Porto, Portugal, 2-5 September, 2015. The other is titled "Plastic Debris in the Ocean: A Potential Threat to Marine Species, Ecosystems, and Human Health," and presented at the 71st Annual Meeting of the American Society of Criminology, Washington D.C., U.S.A., 18–21 November, 2015.

2) This article is also a part of results of 'Research on Environmental- and Eco-crimes by Progress of Scientific Technologies and Development of Societies and Measures against Them 2015-2019' supported by the Grant-in-Aid of Scientific Research by Japanese Ministry of Education, Culture, Sports, Science and Technology.

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〔一般研究論文〕
Contamination of Marine Environment by Floating, Drifting and Precipitating Microplastics in the Ocean: Potential Menace to Marine Species, Ecosystems and Human Health
海洋浮遊・漂流・沈殿プラスティックごみによる海洋環境の汚染
——海洋生物、生態系、人間の健康に対する潜在的脅威——
TAKEMURA Noriyoshi

訂正表

頁	左右	行	誤	正
67	左	38	away: microplastics.	away: microplastics (Ory: 5).
67	右	12	the South Pacific gyre.	the South Pacific gyre (Ory: 5).
67	右	29	… in Rapa Nui.	… in Rapa Nui (Ory: 6).
67	右	41	of the islands.	of the islands (Ory: 7).
68	左	26-27	… prey (Joret et al. 2003 ; Boersema 2011).	… prey (Ory : 7-8 ; Joret *et al.* 2003 ; Boersema 2011).
72	左	35		Thompson, R.C., S.H. Swan, C.J. Moore and F.S. vom Saal (2009). “Our plastic age.” *Philosophical Transactions of the Royal Society* B364: 1973-1976.

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