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New Surface Marine Microplastics for Colonization, Biofilm Formation and Biodegradation

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Abstract

We have known that microplastics (MPs) in the ocean are carriers of microbial dominated assemblages and rapidly are colonized by microbes when released into ocean. However, the role of microbial interactions with microplastics in marine ecosystems has been investigated in detail recently. The presence of microplastics in the marine environment has been raising global attention. Microparticles transport biofilm communities that are distinct from the surrounding environment. Although plastic-colonizing microorganisms are important for the fate of MPs in different ecosystems but its influence on the fate of microplastics is largely unknown. In this review, we focused on the establishment of plastic-specific biofilms (plastisphere); enrichment of pathogenic bacteria coupled to a vector function of microplastics; and the microbial degradation of microplastics in the marine environment. In addition providing a better understanding of plastisphere and biofilm expansion in marine environment, and discuss plastic biodegradation. Also, identification of potentially pathogenic "hitch-hikers" in the plastisphere considered.

Key words: Microplastics, Microorganisms, Biofilm communities, Microbial degradation.

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Introduction

Many plastics are produced annually and are known as important products in our society. They are cheap and wasted and cause profuse environmental problems (Geyer et al., 2017). Most of the produced plastics are not recycled, enter the oceans, and due to improper management have turned into a big environmental concern (Jambeck et al., 2015). Fungi, bacteria, algae, and protists can easily colonize the surface of the microplastics in the form of biofilms. The forming and developing of biofilms on the microplastic surfaces can change the morphology and physicochemical features of the microplastics. The plastic garbage by the living organisms, that are accumulated over time, change to biofouled (Thiel. 2005; Bixler, 2012). The organisms that are colonized on the surface of plastics include various microbial communities but they also include organisms such as; barnacles, bryozoans, and multicellular algae (Carpenter, 1972; De Tender., 2017). The organisms that colonize the floating plastic garbage expand all around the oceans (Gregory et al., 2009).

The microbial biofilms develop on plastic surfaces smaller than 1 mm in size are originated as plastisphere (Hartmann et al., 2019; Zettler et al., 2013). This term does not mean that these polymeric materials are actively selected for specified microbial communities, because, this item has remained unproven. Microplastics are widespread in the environment, especially the marine environment, due to hydrodynamic processes including transportation and ocean currents, in the large oceans uch as the Pacific Ocean (Law et al.,2014; Eriksen et al.,2013), the Atlantic Ocean (Cozar et al., 2017), Indian Ocean (Reddy et al., 2006), polar regions (Bergmann et al., 2016; Waller ., 2017), and the equator (do Sul et al., 2009), and from coasts (Claessens et al., 2011; Martin., 2017) to open seas (Taylor et al., 2016; Van Cauwenberghe et al., 2013). It was estimated that more than 15 trillion microplastics were present in the global ocean in 2014, weighing more than 93 thousand metric tons (van Sebille et al., 2015).There are plenty of debris in the great pacific garbage patch that 94% of it (Lebreton et al., 2018) are microplastics floating in the water.

Contamination of the oceans by the microplastics is a scientific concern that has resulted for excessive research in this area. The impact of microplastics on the health of by marine species such as fish(Lusher et al., 2013),mussels (Browne et al., 2008; Wegner.,2012), zooplanktons(Cole et al., 2013), seabirds(Rodriguez et al., 2012), sand hoppers(Ugolini et al., 2013) and worms (Browne et al., 2013) hasn't been clarified fully but there are some increasing evidence about the effect of microplastics in the marine environment that has risen environmental concern regarding this issue(Brandts et al., 2018.(In order to solve the problem , due to the presence of the microplastics and improving plastic waste management ,some efforts must be put into action. The present existing study is dealing with, offering a better understanding of the effects of microplastics on the marine ecosystems that are consisted of three parts: (1) the microplastics source and fate in the marine environments, (2) impacts of MPs on marine organisms, and (3) the bacteria and their impact on the degradation of microplastics in the existing environments.

1. Marine MPs' Sources

Variety of sources has a part in the marine microplastic pollution that are as below: a) inland-based, b) sea-based and c) air-based sources (Auta et al., 2017; Andrady. 2011; Saal, 2008). One of the main pathways for the microplasties entrance to the oceans are the rivers. (Lebreton et al., 2017). Almost %80 of the microplastic particles in the lands enter the oceans through the rivers (Auta, 2017; Mani, 2015). Some examples of these are the plastic debris in the sewage and municipal drainage systems. In addition, the left rubbish by the offshore tourists is entered into the marine ecosystems directly. (Browne et al., 2011; Barnes, 2009). The source of microplastic pollution regarding to the sea ere fishing and shipping industries (Bell, 2017; Watson et al., 2013). This way of microplastics entering the sea, is known as the main and most important (Thompson, 2004). Loss and damage of the fishing and shipping equipments can easily introduce the microplastic particles to the marine ecosystems (Al-Oufi et al., 2004; Thomas, 2006). On the other hand, the garbage that is discarded illegally by the ships on offshore platforms are known as the main source of a sea-based microplastic pollution In addition, airborne MPs are also important sources (Cai et al., 2017). Microplastics are divided into two groups by size: the primary microplasties that are particles having a size less than 5 mm in diameters and can enter directly into the ocean through the sewage effluent (Browne et al., 2011). The secondary microplastics that are large plastic particles and they are influenced by physical, biological and chemical processes and are broken down and degraded into smaller fragments and then enter the marine environments (Arias-Villamizar et al., 2018; Veiga et al., 2016). In addition, fiber and textile manufacture (Cesa et al., 2017). Secondary microplastics involve the breakdown of large plastic due to biological, chemical and physical degradation, which are characteristic of microbial biodegradation, photodegradation (solar ultraviolet radiation) and mechanical abrasion (wave action), respectively. Plastic debris in the ocean are subject to mechanical damage and photodegradation well as oxidative degradation, which break down fragile plastics into microplastics (Feldman et al., 2002; Wagner, 2014). Besides, microplastics can further degrade to Nano-scale plastic pieces. These microplastics and Nano plastics are more easily ingested and will have long-term adverse impacts on the marine environment, making them become a public concern in the future (Wegner et al., 2012).

2. Marine microplastics’ Fate

In general, plastic debris in any water body will eventually pass into the ocean. Microplastics, transported by water power and wind power, gradually migrate and diffuse deep through the ocean, eventually becoming as ubiquitous as they are today, ranging from the large ocean gyres (e.g., the Pacific Ocean (Law et al., 2014); the Atlantic Ocean (Cozar et al., 2017); Indian Ocean (Reddy et al., 2006) to the polar regions and equator, from densely populated areas to remote islands, and from beaches down to the abysses of the sea (Bergmann et al., 2016; Peeken et al., 2018; Claessens., 2011). Various shapes of plastic derbies are presents in these environments, with fibers are the most common form. Marine circulation, estuaries and other coastal areas are the ecosystems polluted by microplastics (Peters et al., 2016). Approximately 70% of microplastics is left in sediments, 15% floats in coastal areas and the remaining parts float on the surface seawate, since Some of microplastics are less dense and float on the sea surface and retain debris for a long time (Cozar et al., 2014; eisser, 2015). According to the surveys, there are only at least 7000 tonnes of plastic debris on the surface of the high seas, but at least 4.8 million tonnes of plastic debris enter the marine environment each year (Jambeck et al., 2015), which is inconsistent with data on surface plastics, suggesting that a significant number of plastics sinks to unknown depths. Microplastics have even been found on the seafloor at 2200–10,000 m depth, containing both high (Courtene-Jones et al., 2017) and low-density (relative to seawater) microplastics. This shows that the migration of microplastics is a active process, which may not only be carried to every part of these environments by physical effects such as crushing and deposition, but also through chemical processes such as oxidation or hydrolysis , and may also be carried to every part of the ocean through biological absorption, digestion and excretion. Weathering processes, biodegradation processes oxidative and hydrolytic degradation (Peng et al., 2018) and hetero-aggregation and biofilm formation (Woodall, 2014) could significantly affect the fate of microplastic pieces in the oceanic environment. Biological contaminations and deposition of plastics could control migration in marine environments (Zhang et al., 2017). Sedimentation and various physical factors such as light, salinity, water density, temperature, and viscosity simulate the effects of biological pollution and migration of microplastics. (Kooi et al., 2017). Many studies have also well focused on the particle size, shape, type, color and mesh size of microplastics. This information are helpful for further evaluating the plastic production plans and reduce the chemical production of plastics. (Tata et al., 2020).

3. Impacts on Marine Organisms of MPs

A plenty of literature has recently disscused the accumulation of microplastics in marine micro-

Table 1. Effects of microplastics and nanoplastics on marine organisms.
Yang, H., Chen, G., & Wang, J (2021).

Phyla	Species	Development	MP Size	Adsorption	MP Types	T Negative Effects
Bacillariophyta	*Chaetoceros neogracile*	spore, adult	50 µm	NA	PS	Particles decrease chlorophyll content, esterase activity, cell growth and photosynthetic efficiency of diatoms.
Aschelminthes	*Brachionus koreanus*	adult	0.05, 0.5, 6 µm	NA	PS	Inhibition of multiple resistance to p-glycoproteins and multidrug resistant proteins leads to increased toxicity and oxidative stress damage to membrane lipids.
Mollusca	*Crassostrea gigas*	embryo, larva, adult	50 µm	NA	PS	Particles reduce fertilization rate and development ability of embryo and larva.
	Mytilus galloprovincialis	Larva	140 ± 34.6 nm	Cbz	PS	Increased total oxidant status of digestive glands, influence neurotransmission, genotoxicity and lipid peroxidation.
		Adult	0.1–1 mm	pyrene	PE, PS	Alter immune response, lysosomal compartment, peroxisome, antioxidant system, and neurotoxic effects.
Arthropoda	*Artemia franciscana*	Larva	40, 50 µm	NA	PS	Impairment of feeding ability, behavioral ability and physiological conditions.
	Calanus finmarchicus	adult	particles: 10–30 µm fibers: 10 × 30 µm	NA	PA	Alter predation behavior, reduce fat storage, and affect growth and development
Chordata	*Danio rerio*	Embryo	average: 398 ± 54 µm minimum: 10 ± 2 µm	NA	PE	Produce cell death and affect energy metabolism.
			50, 200, 500 µm	Au	PS	Oxidative stress and inflammation reaction.
			44 nm	PAHs	PS	Energy metabolism.
		Larva	25 µm	NA	PS	Glucodermatin receptors disrupt glucose homeostasis, leading to abnormal larval activity.
		adult	44 nm	PAHs	PS	Energy metabolism.
			25 µm	Cu	PS	Inflammatory reaction.
			50 µm	BPA	PS	Neurotoxicity.
	Fish cell lines (SAF-1, DLB-1)	/	100 nm	NA	PS	Change the activity of superoxide dismutase and Glutathione S-transferase and the toxicity of drugs.

organisms through direct contact or food chain exposure to MPs. So these microorganisms use them as a feeding source, in this way MPs have negative effects on their development, metabolism, reproduction and cellular response, and so on (Mao et al., 2018). Plastics have toxic effects on marine ecosystem; depending on the types and sizes of microplastics they have different toxic effects on marine species, which are ultimately reflected in the physiological response of organisms and the damage they are supposed to [118 134] (Table 1). In addition, different microplastics also adsorb different pollutants, which contribute to further damage of living marine organisms (Wardrop et al., 2016; Teuten et al., 2009& Lusher, 2014).

4. Bacteria for Degradation of Marine Microplastics

4.1. Colonization of Microplastics by Bacteria

A wide range of studies reveal the differences between the bacteria living on organic particles with sea water (Oberbeckmann et al., 2018), on microplastics, and in a free state (Debroas et al., 2017). Bacterial cells located on the surfaces of microplastic are different from those in surrounding environments (Oberbeckmann et al., 2018). Enzymatic activities for degrading plastic would be interesting for the bioremediation process. Some bacterial phyla including Bacteroidetes, Proteobacteria, Cyanobacteria, and Firmicutes appear to colonize microplastics, indicating that these bacteria consider microplastics as an ecological niche for colonization. Taxa belonging to Bacteroidetes and Proteobacteria seem to be common by the core bacteria of the seafloor and subsurface plastisphere, and some photoautotrophic bacteria dominated the sub-surface environments (Dussud, 2018; Zettler et al., 2013).

4.2. Plastisphere as a New Niche for Marine Environment

Large-scale DNA sequencing technology gives a detailed image of the microbial populations of microplastics. Debris is usually described by the term plastisphere in marine biology research; they serve as various habitats for microbial colonies in aquatic environments besides accumulating organic pollutants (Oberbeckmann, 2014). The composition of plastisphere are complex and comprehensive. Different seasons, surrounding environment, polymer type, surface feature, and size of microplastics affect the variety of the colonizing bacteria (Reisser et al., 2014). Different studies show differences in microbial communities on microplastics from two different oceans, and the variety of bacteria living in water columns and those bacteria attached to microplastic debris (Amaral-Zettler et al., 2015). These studies show that heterotrophic bacteria survive longer than in aquatic environments, could rapidly colonize plastic surfaces (Webb et al., 2009).

Microplastic degradation

Marine microorganisms have been noticed as a possible solution to the plastic pollution problem in aquatic environments. A caution to understanding published research on the degradation of conventional polymers is that most studies to date have used pretreated polyethylene (which contains additives or has been exposed to UV light or other forms of thermal treatment) (Balasubramanian et al., 2010; Syranidou et al., 2017) prior to measuring degradation, so it is difficult to know whether the microbial activity to high-molecular weight polymers or smaller products generated by abiotic factors. As we have already mentioned, leaching of small molecules (low molecular- weight DOM) from plastics that have been incubated in seawater may stimulate microbial settlement and contribute to microbial metabolism. Microorganisms oxidize polymers intracellular, so the molecular weight (Mw) of the polymer must be low enough (<500 Mw) (Yoon et al., 2012) to pass through cell membranes. To this end, plastics that are hydrolysable (that is, with backbones consisting of components other than just C–C or C–H; for example, PET, polyurethane (PUR) and polycarbonate) are more likely to be substrates for microbial degradation in the environment than are the non- hydrolysable polymers most commonly encountered in the pelagic marine environment (polyethylene, polypropylene and expanded polystyrene) (Krueger et al., 2015). A class of enzymes that may be effective at degrading recalcitrant polymers such as polyethylene are those that degrade alkanes

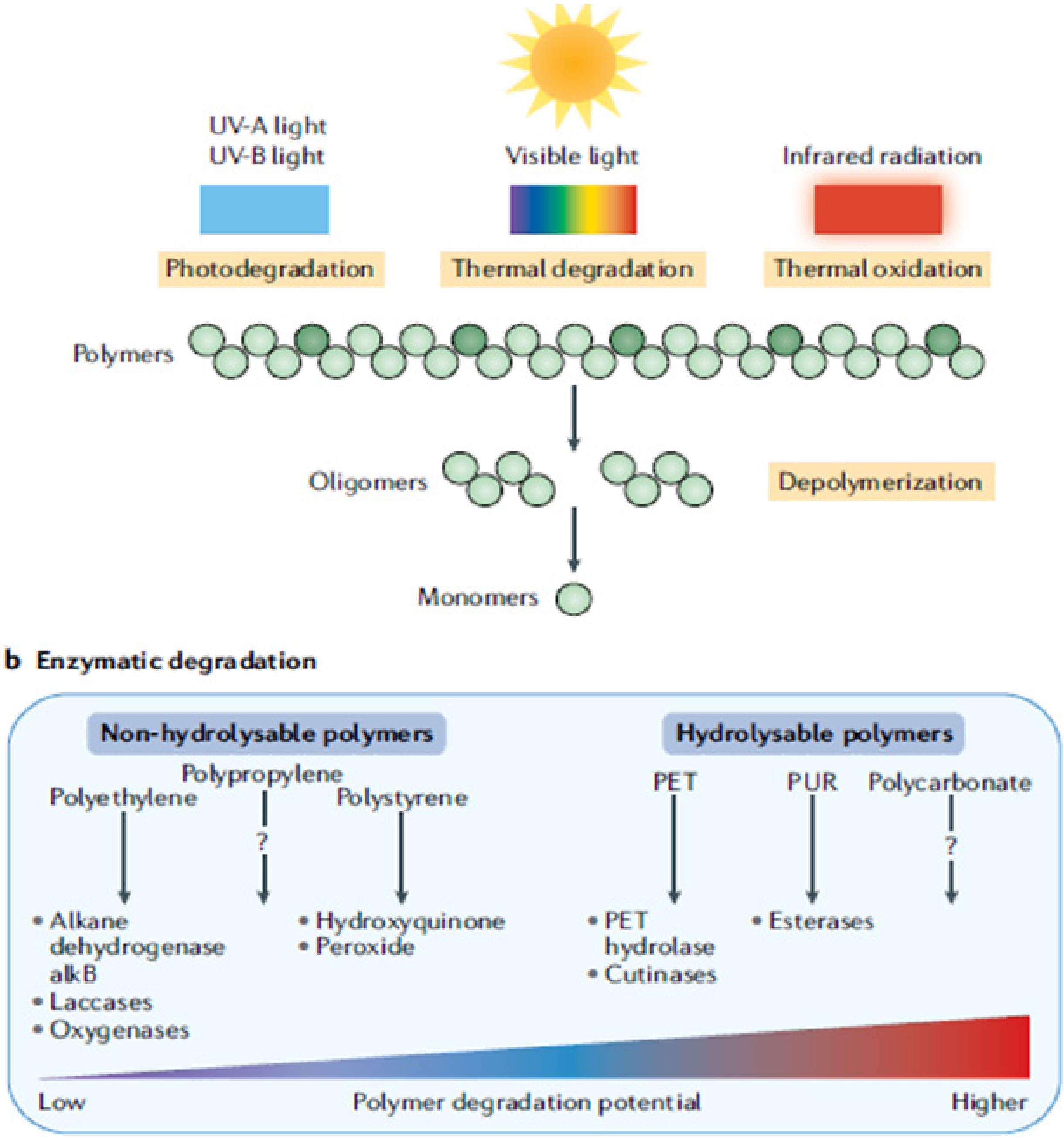

Fig1: Degradation of plastic materials. A: Microplastics degradation is usually due to physical, biological and chemical interactions. Our information about the biological processes is one of the strains and consortia that is reared in the laboratories and many of those strains are found in terrestrial environments. Thus, the schematic shown is a hypothetical model of the processes that cause the microplastics degradation in the marine ecosystems. The Floating plastic debris exposed to the sunlight are subjected to thermal degradation. The UV (ultravidet) light causes the breaking of the bands (band scission) and transforms them to monomers. One the other hand the radiation of the infrared results in thermal oxidation of the polymer chains. B: The way of biological degradation includes mechanical actions of the organisms that grow the cracks of the polymer and are enzymatic processes that can hydrolyze the polymer into oligomers and ultimately to monomers. Polyethylene, polypropylene, and expanded polystyrene contain very stable structure and are difficult to degrade, whereas polyethylene terephthalate (PET), polyurethane (PUR) and polycarbonate are more susceptible to hydrolysis and enzymes that catalyze these reactions (Krueger et al., 2015; Nakamiya et al., 1997& Akutsu et al., 1998): enzymes that can hydrolyze polypropylene and polycarbonate have not yet been reported.

such as hexadecane (Yoon et al., 2012). A mesophilic marine beach soil- derived Pseudomonas strain incubated with low- molecular-weight polyethylene (LMWPE) as a sole carbon source is often cited as the best example of the potential for biodegradation of polyethylene (Yoon et al., 2012). Although this and other studies hint at possibilities for microbial solutions to plastic pollution, LMWPE does not occur commonly in the marine environment, and conditions in the ocean result in very slow rates of degradation. Plastics that are hydrolysable (for example, polyamides, PET or PUR) may also be susceptible to preexisting degradation pathways present in microorganisms (such as extracellular hydrolases that are involved in the degradation of cellulose and proteins), but the environmental conditions often limit complete biodegradation. The discovery of PETase, an enzyme that hydrolyses plastic polymers such as PET, in the bacterium Ideonella sakaiensis (Yoshida., 2016), and the subsequent recovery of related enzymes from marine and terrestrial metagenomes in public databases(Danso et al., 2018), indicates that a PET- degrading capacity may be ubiquitous in those environments. However, incomplete microbial hydrolysis of plastic polymers or extreme oxidation through microbial biotransformation can lead to the generation of Nanoplastics. Although understudied, Nanoplastics may have the ability to be ingested by humans via the food chain. Once ingested by humans, microplastics of less than 150 µm have been shown to translocate across the gut epithelium into the lymphatic system, causing systemic exposure and eventually affecting human health (Hussain et al., 2011). However, it is important to note that the effect of nanoplastics on human health is underexplored.

Summary

Our planet is subject to human deeds, since then, studying these actions and activities has become important. Plastic substance are greatly notable for human beings and provide them many benefits, and have simplified life more than ever. Planet Earth has provided expanded habitats for the microbial communities (societies) (about 1030 microbial habitants) that can be a path to bio transform and degrade the plastic substances (Flemming et al., 2019). Oceans are dynamic systems but limited regarding the nutrients and biota and are continuously interacting with microplastics in all scales and do not have a stable condition, thus we cannot, consider the oceans as a continuous bioreactor with a constant temperature for degradation of the microplastics. Future studies are to comprehend the plastisphere role in the chemical biotransformation and physical modifications of the plastic garbage, the changing of size, density and oxidation of the polymers, are important issues to consider. There is no doubt that multiple approaches have an important role in decoding the changes done by microbial communities. In addition, can provide answers to many questions. Furthermore, future studies will be required in order to answer the many open questions in plastisphere research. For example, do the compounds that plastics emit in aquatic environments provide chemo- attractant plumes? If so, how do these plumes influence the initial plastisphere composition? Microbial biotransformation's of plastic debris may have a substantial role in the generation of micron- and sub- micron-scale polymer particles (McCormick., 2014).These nanoplastics could have implications for human health and food security, as they could be incorporated into tissues. Although this phenomenon is known to occur, it is still unclear to what extent nanoplastics pose a threat, if they do at all. It is clear that taking hundreds of millions of metric tons of hydrocarbons out of the Earth's interior and producing refractory materials that are allowed to escape into aquifers and marine systems has set up an 'experiment' for which we are only beginning to interpret the results.

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