Micro(nano)plastics: Unignorable vectors for organisms

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Abstract

Micro(nano)plastics, as emerging contaminants, have attracted worldwide attention. Nowadays, the environmental distribution, sources, and analysis methods and technologies of micro(nano)plastics have been well studied and recognized. Nevertheless, the role of micro(nano)plastic particles as vectors for attaching organisms is not fully understood. In this paper, the role of micro(nano)plastics as vectors, and their potential effects on the ecology are introduced. Micro(nano)plastics could 1) accelerate the diffusion of organisms in the environment, which may result in biological invasion; 2) increase the gene exchange between attached biofilm communities, causing the transfer of pathogenic and antibiotic resistance genes ; 3) enhance the rate of energy, material and information flow in the environment. Accordingly, the role of microplastics as vectors for organisms should be further evaluated in the future research.

Keywords: Micro(nano)plastics; Organism vector; Aggregation; Diffusion; Gene exchange; Energy flow

1. Introduction

Plastic pollution, a new type of emerging environmental pollution, has aroused increasing focuses in recent years (Law and Thompson, 2014). Plastic wastes are chemically stable, corrosion-resistant and difficult for biodegradation, which may exist for hundreds to thousands of years, causing continuous accumulation in the environment (Barnes et al., 2009; Hu et al., 2019). Under the condition of sunlight exposure, weathering, erosion and immersion, large plastics would be decomposed into small species (Auta et al., 2017). The release of plastic particles added to daily personal care products (including toothpaste, detergent, scrub and facial cleanser is also an important source of microplastic (Fendall and Sewell, 2009). When the particle sizes of plastic species have less than 5 mm, they are defined as microplastics (Thompson et al., 2004). Microplastics can be further broken down into nanoplastics in natural environments (Mattsson et al., 2013).

Microplastics could be easily and mistakenly eaten by zooplankton (Desforges et al., 2014), benthic animals (Poerger et al., 2010) and filter-feeding animals (Germanov et al., 2018) due to the small particle size and widespread distribution in the aquatic environment (Anderson et al., 2017; Kanhai et al., 2018; Schmidt et al., 2017; Wen et al., 2018; Xiong et al., 2018), even in polar regions (Obbard, 2018), which would affect the absorption of organisms for nutrients to endanger their growth and reproduction (Wright et al., 2013). Evidences suggested that microplastics can be accumulated in organisms (Li et al., 2015). Meanwhile, microplastics would also induce liver inflammation and change the metabolic pathways to organisms liver (Lu et al., 2016). When the size of microplastics reaches to the nanometer level, forming nanoplastics, its ability to invade the organism is further enhanced. Evidence showed that nanoplastics could penetrate the blood-brain barrier and eventually enter the brain groups (Chen et al., 2017; Kashiwada, 2006), which may have profound potential impacts on organisms.

Micro(nano)plastics, as a kind of particulate matter, can provide an attachment substrate for microorganisms, zooplankton, phytoplankton and protozoans to form a microbial community (Curren and Leong, 2018; Miao et al., 2019). Besides, due to the widespread distribution and constant drifting along with seawater, the microbial community may cause serious marine ecological effects such as the spread of pathogenic bacteria and resistant genes, biological invasion and the production of new species. As vectors of organisms, micro(nano)plastics are gradually being concerned to global scientists. The co-ecological effect of micro(nano)plastics and biology should be a hot issue in the further of micro(nano)plastic study. The main objective of this paper is to provide a summary of different function of micro(nano)plastics as vectors and their potential co-ecological effects of the micro(nano)plastics and biology on the environment, including aggregation, diffusion, and biological invasion.

2. Vectors for microorganisms

Micro(nano)plastics can adsorb organic and inorganic nutrients from water environment to attract the bacteria, viruses and other microorganisms to adhere on their surfaces (Frere et al., 2018). Microorganisms aggregate here to obtain more nutrients to improve the ability of bacterial energy. Micro(nano)plastics can also provide relatively stable habitats, helping microorganisms to resist environmental stresses and enhance microbial diffusivity (Oberbeckmann et al., 2015a). This function of micro(nano)plastics could enhance material circulation and energy transfer along the food chain, and may also be one of the reasons why microorganisms tend to adhere themselves to the micro(nano)plastic surface. Herein, we provide three aspects of evidence to introduce vector function of micro(nano)plastics for microorganisms.

Firstly, micro(nano)plastics can accelerate the diffusion of microorganisms in the environment. Micro(nano)plastics have strong floatability and mobility (Khatmullina et al., 2017), and can support the drift and long-term existence of surface microorganisms in the water. Micro(nano)plastics can diffuse the microbial community into a new habitat together under the ocean currents (Keswani et al., 2016). For example, several coral pathogens have been found in 95 plastics and debris from the Eastern Pacific Ocean (Goldstein et al., 2014). Additionally, higher levels of potential human pathogens frequently were observed in micro(nano)plastics from North Sea and North Atlantic furtherly (Kirstein et al., 2016). The abundance of pathogens is high on the micro(nano)plastics, which may serve as vectors for diffusion of certain bacterial communities. Due to the suitable conditions, a large number of alien species, especially toxic and pathogenic bacteria, may invade new habitats and multiply quickly in a short time. It will change and harm the local community structure and result in biological invasion, which may affect the safety of water quality and pose a potential threat to human health (Kirkpatrick et al., 2004; Kirstein et al., 2016; Zettler et al., 2013).

Secondly, micro(nano)plastics can increase the gene exchange between attached between biofilm communities, or between communities on biofilms and surrounding environment (Arias-Andres et al., 2018). As a result of the strong variability of bacterial genes, gene exchange between microorganism communities can occur through horizontal gene transfer in the environment (Broszat and Grohmann, 2014; Madsen et al., 2012; Molin and Tolkernielsen, 2003). Accordingly, new bacteria may be produced during the gene exchange. In particular, pathogenic and antibiotic resistance bacteria contain abundant pathogenic and antibiotic resistance genes, which may be transferred by multi pathways between communities on biofilms. It will cause outbreak of pathogenic and antibiotic resistant genes and lead to large-scale infection events in the environment.

Thirdly, micro(nano)plastics may speed up the spread of the antibiotic resistance genes and bacteria in the environment. Resistant gene and bacteria are often found in downstream waters of medical wastewater treatment plants (Karkman et al., 2017). Once a large number of resistance genes and bacteria enter the ocean system, it may induce the horizontal transfer of resistance genes between communities or the surrounding environment. The existence of micro(nano)plastics may enhance the transportation of antibiotic resistance genes and bacteria due to the strong floatability and mobility of micro(nano)plastics. Antibiotic resistance genes and bacteria may be transferred to different areas. The exchange of antibiotic resistance genes between communities or the surrounding environment and the existence of antibiotic resistance bacteria may cause huge uncontrollable disasters (Bloom et al., 2017; Long et al., 2015).

Overall, micro(nano)plastics can provide an attachment substrate for microorganisms to form a microbial community. Micro(nano)plastics not only act as vectors of microorganisms diffusion, but as vectors of gene exchange and transfer. However, the ecological effects of microplastics as microorganism vectors are not yet fully unknown. Therefore, it is necessary to investigate the abundance and species of microorganisms in micro(nano)plastics, to explore the diffusion mechanism of micro(nano)plastics as vectors, and to evaluate the ecological and environmental risks of micro(nano)plastics in further studies.

3. Vectors for planktons and animals

Compared with water body, micro(nano)plastics may be rich in nutrients due to the sorption of organic and inorganic matters from water environment. Micro(nano)plastics can provide relatively stable habitats for planktons in the marine environment (Carpenter and Smith, 1972; Oberbeckmann et al., 2015b). Planktons attached on micro(nano)plastic surface can obtain more foods, which may be one of the reasons why planktons are attracted to be attached on micro(nano)plastics. For predators, micro(nano)plastic particles rich in biofilms may be sufficient food sources for aquatic organisms. Therefore, we presume that not only the predation efficiency for organisms can be improved by feeding on micro(nano)plastics, but the rate of energy, material and information flow in the aquatic environment can be enhanced. We provide here three aspects of evidence to introduce our conjectures.

The first is that micro(nano)plastic particles provide more foods to predators. A lot of organisms, such as bacteria, planktons and microfauna, aggregate on the surface of micro(nano)plastics to form biofilms. Under the natural conditions, predators would preferentially select foods with more energy and nutrient to improve predatory efficiency (Steer et al., 2017; Vendel et al., 2017). The competition of zooplanktons and fish larvae is abnormally fierce in the marine environment, especially in oligotrophic waters (Carlson et al., 2002; Dodson, 1974). Therefore, micro(nano)plastics from the eutrophic waters to oligotrophic waters may carry more foods, thereby increasing the ingestion of micro(nano)plastics by zooplanktons and fish larvae and increasing their predation efficiency.

The second is that micro(nano)plastics may enhance the rate of energy, material and information flow in the aquatic environment. Micro(nano)plastics can provide abundant and comprehensive nutrients for predators to satisfy their demands. Protozoa can feed on bacteria and planktons, and high predators, such as fishes, feed on protozoa. Fishes not only can obtain a variety of nutrients from micro(nano)plastics and planktons, but gain more nutrients from protozoa. This process is called trophic upgrading, which improves the flow of energy, material and information of the micro-ecosystem along the food chain (Breteler et al., 1999; Hiltunen et al., 2017). Micro(nano)plastics aggregate organisms of different trophic levels and accelerate the trophic upgrading among them. Thus, the rate of energy, material and information flow may be accordingly enhanced in the aquatic environment through the trophic upgrading.

The third is that micro(nano)plastic particles possess similar activity characteristics with marine snow (Porter et al., 2018). It was confirmed that marine snow can provide habitats for microbial communities and also is a highly active center of photosynthesis, decomposition and nutrient regeneration (Alldredge and Silver, 1988). Many communities of zooplankton have been found in marine snow in sea waters (Bochdansky et al., 2016; Ivancic et al., 2018; Porter et al., 2018). Organisms tend to gather on marine snow because marine snow can provide abundant nutrients for them (Montgomery et al., 2016; Tansel, 2017). Owing to similar characteristics with marine snow (Porter et al., 2018), there is an inference that biofilms on micro(nano)plastics can also attract organisms to adhere, improve the predatory efficiency and enhance the rate of energy, material and information flow in the aquatic environment.

In short, micro(nano)plastic particles may have great potential to enhance the predation efficiency. However, toxic and harmful organisms may exist on micro(nano)plastic surface (Oberbeckmann et al., 2015a). These organisms and micro(nano)plastics themselves have adverse effects on the survival, growth and reproduction to organisms (Boerger et al., 2010; Cedervall et al., 2012). When predators emerge different degrees of damage causing energy intake reduction, they need to ingest more particles. Such a phenomenon might result in great damage to marine ecosystem. However, it is not yet fully understood that whether micro(nano)plastics rich in biofilms are preferentially eaten by marine predators. Consequently, relevant researches should be performed to understand and explore the relationship between the intake rate and the abundant existence of micro(nano)plastics and nutrient types.

4. Conclusion and recommendation

Micro(nano)plastics as organism vectors may accelerate the diffusion of organisms, improve the gene exchange among different species, speed up the migration of resistant bacteria and genes, inducing uncontrollable transmission of resistant bacteria and genes in the environment. Micro(nano)plastics may also cause biological invasion and serious ecological disasters due to the spread of harmful algae and pathogenic bacteria. Additionally, micro(nano)plastics may enhance the rate of energy, material and information flow of the aquatic ecosystem, but may result in damage to aquatic ecosystem. The research of micro(nano)plastics as vectors for organisms is a new topic. Many conclusions are still in the speculative stage, and there are barely scientific and sufficient information to confirm. Consequently, some experiments and studies should be carried out in the future:

(1) Identifying the main microbial communities, species composition in different water environments, and effects of microbial habitat on micro(nano)plastics.

(2) Exploring the adsorption mechanism of organisms on micro(nano)plastic vectors, the probability of gene exchange among species, the advantages of biological community structure and function, and the diffusion mechanism of pathogenic organisms attaching on micro(nano)plastics.

(3) Analyzing the impact of community accumulation in micro(nano)plastics on predators, and the selectivity of predators to foods at different environmental conditions.

(4) Establishing the ecological health risk assessment system of micro(nano)plastic pollution.

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Reference

Alldredge, A.L., Silver, M.W., 1988. Characteristics, dynamics and significance of marine snow. Progress in Oceanography 20, 41-82.

Anderson, P.J., Warrack, S., Langen, V., Challis, J.K., Hanson, M.L., Rennie, M.D., 2017. Microplastic contamination in Lake Winnipeg, Canada. Environmental Pollution 225, 223-231.

Arias-Andres, M., Klumper, U., Rojas-Jimenez, K., Grossart, H.P., 2018. Microplastic pollution increases gene exchange in aquatic ecosystems. Environmental Pollution 237, 253-261.

Auta, H.S., Emenike, C.U., Fauziah, S.H., 2017. Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. Environment International 102, 165-176.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos Trans R Soc Lond B Biol Sci 364, 1985-1998.

Bloom, G., Merrett, G.B., Wilkinson, A., Lin, V., Paulin, S., 2017. Antimicrobial resistance and universal health coverage. Bmj Global Health 2, e000518.

Bochdansky, A.B., Clouse, M.A., Herndl, G.J., 2016. Eukaryotic microbes, principally fungi and labyrinthulomycetes, dominate biomass on bathypelagic marine snow. Isme Journal 11.

Boerger, C.M., Lattin, G.L., Moore, S.L., Moore, C.J., 2010. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Marine Pollution Bulletin 60, 2275-2278.

Breteler, W.C.M.K., Schogt, N., Baas, M., Schouten, S., Kraay, G.W., 1999. Trophic upgrading of food quality by protozoans enhancing copepod growth: role of essential lipids. Marine Biology 135, 191-198.

Broszat, M., Grohmann, E., 2014. Horizontal Gene Transfer in Planktonic and Biofilm Modes.

Carlson, C.A., Giovannoni, S.J., Hansell, D.A., Goldberg, S.J., Parsons, R., Otero, M.P., Vergin, K., Wheeler, B.R., 2002. Effect of nutrient amendments on bacterioplankton production, community structure, and DOC utilization in the northwestern Sargasso Sea. Aquatic Microbial Ecology 30, 19-36.

Carpenter, E.J., Smith, K.L., 1972. Plastics on the Sargasso sea surface. Science 175, 1240-1241.

Cedervall, T., Hansson, L.A., Lard, M., Frohm, B., Linse, S., 2012. Food Chain Transport of Nanoparticles Affects Behaviour and Fat Metabolism in Fish. Plos One 7, e32254.

Chen, Q., Gundlach, M., Yang, S., Jiang, J., Velki, M., Yin, D., Hollert, H., 2017. Quantitative investigation of the mechanisms of microplastics and nanoplastics toward zebrafish larvae locomotor activity. Science of the Total Environment s 584–585, 1022-1031.

Curren, E., Leong, S.C.Y., 2018. Profiles of bacterial assemblages from microplastics of tropical coastal environments. The Science of the total environment 655, 313-320.

Desforges, J.P., Galbraith, M., Dangerfield, N., Ross, P.S., 2014. Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. Marine Pollution Bulletin 79, 94-99.

Dodson, S.I., 1974. Zooplankton Competition and Predation: An Experimental Test of the Size - Efficiency Hypothesis. Ecology 55, 605-613.

Fendall, L.S., Sewell, M.A., 2009. Contributing to marine pollution by washing your face: Microplastics in facial cleansers. Marine Pollution Bulletin 58, 1225-1228.

Frere, L., Maignien, L., Chalopin, M., Huvet, A., Rinnert, E., Morrison, H., Kerninon, S., Cassone, A.L., Lambert, C., Reveillaud, J., Paul-Pont, I., 2018. Microplastic bacterial communities in the Bay of Brest: Influence of polymer type and size. Environmental Pollution 242, 614-625.

Germanov, E.S., Marshall, A.D., Bejder, L., Fossi, M.C., Loneragan, N.R., 2018. Microplastics: No Small Problem for Filter-Feeding Megafauna. Trends Ecol. Evol. 33, 227-232.

Goldstein, M.C., Carson, H.S., Eriksen, M., 2014. Relationship of diversity and habitat area in North

Pacific plastic-associated rafting communities. Marine Biology 161, 1441-1453.
Hiltunen, M., Honkanen, M., Taipale, S., Strandberg, U., Kankaala, P., 2017. Trophic upgrading via the microbial food web may link terrestrial dissolved organic matter to Daphnia. Journal of Plankton Research 39, 861-869.
Hu, D., Shen, M., Zhang, Y., Zeng, G., 2019. Micro(nano)plastics: An un-ignorable carbon source? Science of the Total Environment 657, 108-110.
Ivancic, I., Paliaga, P., Pfannkuchen, M., Djakovac, T., Najdek, M., Steiner, P., Korlevic, M., Markovski, M., Baricevic, A., Tankovic, M.S., Herndl, G.J., 2018. Seasonal variations in extracellular enzymatic activity in marine snow-associated microbial communities and their impact on the surrounding water. Fems Microbiology Ecology 94.
Kanhai, D.K., Gårdfeldt, K., Lyashevska, O., Hassellöv, M., Thompson, R.C., O'Connor, I., 2018. Microplastics in sub-surface waters of the Arctic Central Basin. Marine Pollution Bulletin 130, 8-18.
Karkman, A., Do, T.T., Walsh, F., Mpj, V., 2017. Antibiotic-Resistance Genes in Waste Water. Trends in Microbiology 26, págs. 220-228.
Kashiwada, S., 2006. Distribution of Nanoparticles in the See-through Medaka (Oryzias latipes). Environmental Health Perspectives 114, 1697-1702.
Keswani, A., Oliver, D.M., Gutierrez, T., Quilliam, R.S., 2016. Microbial hitchhikers on marine plastic debris: Human exposure risks at bathing waters and beach environments. Marine Environmental Research 118, 10-19.
Khatmullina, L., Bagaev, A., Chubarenko, I., 2017. Microplastics in the Baltic Sea water: fibers everywhere, Egu General Assembly Conference.
Kirkpatrick, B., Fleming, L.E., Squicciarini, D., Backer, L.C., Clark, R., Abraham, W., Benson, J., Cheng, Y.S., Johnson, D., Pierce, R., 2004. Literature review of Florida red tide: implications for human health effects. Harmful algae 3, 99-115.
Kirstein, I.V., Kirmizi, S., Wichels, A., Garin-Fernandez, A., Erler, R., Löder, M., Gerdts, G., 2016. Dangerous hitchhikers? Evidence for potentially pathogenic Vibrio spp. on microplastic particles. Marine Environmental Research 120, 1-8.
Law, K.L., Thompson, R.C., 2014. Microplastics in the seas. Science 345, 144-145.
Li, J., Yang, D., Li, L., Jabeen, K., Shi, H., 2015. Microplastics in commercial bivalves from China. Environmental Pollution 207, 190-195.
Long, M., Moriceau, B., Gallinari, M., Lambert, C., Huvet, A., Raffray, J., Soudant, P., 2015. Interactions between microplastics and phytoplankton aggregates: Impact on their respective fates. Marine Chemistry 175, 39-46.
Lu, Y., Zhang, Y., Deng, Y., Jiang, W., Zhao, Y., Geng, J., Ding, L., Ren, H.Q., 2016. Uptake and accumulation of polystyrene microplastics in zebrafish (Danio rerio) and toxic effects in liver. Environmental Science & Technology 50, 4054.
Madsen, J.S., Burmã¸Lle, M., Hansen, L.H., Sã¸Rensen, S.J., 2012. The interconnection between biofilm formation and horizontal gene transfer. Fems Immunol Med Microbiol 65, 183-195.
Mattsson, K., Hansson, L.A., Cedervall, T., 2015. Nano-plastics in the aquatic environment. Environmental Science Processes & Impacts 17, 1712-1721.
Miao, L.Z., Wang, P.F., Hou, J., Yao, Y., Liu, Z.L., Liu, S.Q., Li, T.F., 2019. Distinct community structure and microbial functions of biofilms colonizing microplastics. Science of the Total Environment 650, 2395-2402.
Molin, S., Tolkernielsen, T., 2003. Gene transfer occurs with enhanced efficiency in biofilms and induces

enhanced stabilisation of the biofilm structure. Current Opinion in Biotechnology 14, 255-261.

Montgomery, Q.W., Proctor, K.W., Prairie, J.C., 2016. Effects of Phytoplankton Growth Phase on the Formation and Properties of Marine Snow, Agu Fall Meeting.

Obbard, R.W., 2018. Microplastics in Polar Regions: The role of long range transport. Current Opinion in Environmental Science & Health 1, 24-29.

Oberbeckmann, S., Löder, M., Labrenz, M., 2015a. Marine microplastic-associated biofilms - A review. Environmental Chemistry 12.

Oberbeckmann, S., Loeder, M.G., Gerdts, G., Osborn, A.M., 2015b. Spatial and seasonal variation in diversity and structure of microbial biofilms on marine plastics in Northern European waters. Fems Microbiology Ecology 90, 478-492.

Porter, A., Lyons, B.P., Galloway, T.S., Lewis, C., 2018. Role of Marine Snows in Microplastic Fate and Bioavailability. Environmental Science & Technology 52.

Schmidt, N., Thibault, D., Galgani, F., Paluselli, A., Sempéré, R., 2017. Occurrence of microplastics in surface waters of the Gulf of Lion (NW Mediterranean Sea). Progress in Oceanography.

Steer, M., Cole, M., Thompson, R.C., Lindeque, P.K., 2017. Microplastic ingestion in fish larvae in the western English Channel. Environmental Pollution 226, 250.

Tansel, B., 2017. Morphology, composition and aggregation mechanisms of soft bioflocs in marine snow and activated sludge: A comparative review. Journal of Environmental Management 205, 231-243.

Thompson, R.C., Ylva, O., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., McGonigle, D., Russell, A.E., 2004. Lost at sea: where is all the plastic? Science 304, 838-838.

Vendel, A.L., Bessa, F., Alves, V.E.N., Amorim, A.L.A., Patrício, J., Palma, A.R.T., 2017. Widespread microplastic ingestion by fish assemblages in tropical estuaries subjected to anthropogenic pressures. Marine Pollution Bulletin 117, 448-455.

Wen, X., Du, C., Xu, P., Zeng, G., Huang, D., Yin, L., Yin, Q., Hu, L., Wan, J., Zhang, J., Tan, S., Deng, R., 2018. Microplastic pollution in surface sediments of urban water areas in Changsha, China: Abundance, composition, surface textures. Marine Pollution Bulletin 136, 414-423.

Wright, S.L., Thompson, R.C., Galloway, T.S., 2013. The physical impacts of microplastics on marine organisms: A review. Environmental Pollution 178, 483-492.

Xiong, X., Zhang, K., Chen, X., Shi, H., Luo, Z., Wu, C., 2018. Sources and distribution of microplastics in China's largest inland lake - Qinghai Lake. Environmental Pollution 235, 899.

Zettler, E.R., Mincer, T.J., Amaral-Zettler, L.A., 2013. Life in the "plastisphere": microbial communities on plastic marine debris. Environmental Science & Technology 47, 7137-7146.