

MICROPLASTICS POLLUTION IN THE AQUATIC ECOSYSTEMS AND ITS EFFECTS ON AQUATIC FAUNA

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ABSTRACT

Microplastics (<1mm) has been recognized as a ubiquitous component of marine debris and they possess major threat to both planktonic and higher organisms (fish, sea birds, sea mammals, and sea turtles) in the aquatic environment that ingest it. Microplastics are found in everyday use products (primary microplastics) such as facial scrubs, and paints or from the breakdown of larger plastic debris under environmental conditions (secondary microplastics) such as polyesters and acrylic. The behaviour of microplastics can be classified into physical, chemical and biological behaviours. The quantity of accumulating plastic waste that is available to enter the ocean from land is of great concern and it is predicted to increase by an order of magnitude without waste management infrastructure improvements by 2025. This review describes the sources and fate of microplastics in the aquatic environment and its effects on aquatic organisms that ingest them. It also highlights possible solutions to this global issue.

Keywords: Microplastics, Aquatic ecosystems, Fish and Plankton

INTRODUCTION

Adequate water is already a limiting resource in many parts of the world. In no time, it will become even more limiting due to increased population, urbanization, pollution and climate change (Jackson *et al.*, 2001). Water body is any accumulation of water that is significant on a planet's surface (Langbein *et al.*, 1995). Basically, water bodies can be classified into 3 categories based on salinity. This includes; marine water bodies, (30-35‰), brackish water bodies (0.5-30‰) depending on the season) and fresh water bodies (<0.5‰). However, these ecosystems have been polluted with microplastics. Several works has widely addressed and confirmed the presence of these substances in both aquatic and terrestrial ecosystems (Browne *et al.* 2011; Rillig 2012). The wide presence of MP seen is due to an increase in plastic production and use by a fast growing human population with unequal proper management techniques and strategies (Plastics Europe 2008; Mason *et al.* 2016). This ubiquitous presence has contributed to enriching persistent organic pollutants (POPs, such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and toxic metals from aquatic environments according to Teuten *et al.* 2009, Hidalgo-Ruz *et al.* 2012a). More so, MP particles act as carrier to pathogenic microorganisms in the aquatic ecosystems (Gregory *et al.* 2009). For the above highlighted reasons the review of this important issue is necessary in the global sustainable goal of safeguarding the aquatic ecosystems.

MICROPLASTICS POLLUTION

According to National Oceanic and Atmospheric Administration (NOAA), microplastics can be defined as small plastic

particles in the environment that are less than 1mm in diameter (Arthur *et al.*, 2009). They are the commonest component of marine debris (Wright *et al.*, 2013) and they are threats to many planktonic and benthic organisms in the aquatic environment since they occupy similar size fraction to sediments. They have been reports of trophic transfer of polystyrene microplastics from macro zooplankton to meso-zooplankton that had previously ingested polystyrene microplastics (Setälä *et al.* 2014). For instance through their degradation in sea recycling ports and landfills and finally through the faeces of zooplankton (Cole *et al.*, 2016), they get to feeding chain. It is through this trophic feeding pattern that other invertebrates and fish with other feeding mechanisms and habitats have microplastics consumption in both vivo and in vitro pattern (Graham and Thompson, 2009; Hall *et al.* 2015; Neves *et al.* 2015). Further studies have also shown that MPs are available in lakes, lakeshore sediments as well as pelagic microplastics in rivers and the ingestion of microplastics by freshwater fauna (Free *et al.*, 2014).

Microplastics sources

Browne *et al.* (2011) described microplastics composition, abundance, and their impacts in the ocean including their sources (primary and secondary). Most consumer products are intended to be washed off after use and end up in drains, hence, they are characterized as "open use" (Castañeda *et al.*, 2014). Microplastics enter the marine environment through different pathways (terrestrial and marine-based activities) which can be through industrial or domestic drainage systems. According to Murphy *et al.*, 2016 microplastics get into the marine environment via currents, storm sewers, wind and through runoffs (Cole *et al.*, 2011).

Primary Microplastics sources

They are found in everyday use products (primary microplastics) such as facial scrubs, paints. For example plastic particles used in cosmetics, abrasives found in cleaning products, shower/bath gels, scrubs, peeling sand facial cleansers, tooth paste, resin pellets, synthetic clothing, drilling fluids, and air-blasting media, eye shadow, deodorant, blush powders, make up foundation, mascara, shaving cream, baby products, bubble bath lotions, hair colouring, nail polish, insect repellents and sunscreen (Duis and Coors, 2016).

Secondary Microplastics sources

Secondary microplastics arise from the breakdown of larger plastic debris under environmental conditions. Their fibers may reach more than 100 fibers per litre of effluent and those from washing clothes are mainly made of polyesters, acrylic, and polyamide (Browne *et al.*, 2011). They have long staying times in freshwater systems, since fibers similar to those in household sewage effluent have been found to be dominant at sewage disposal sites (Zubris and Richards, 2005).

Microplastics behaviours

Microplastics particles in the aquatic environment are made up of particles that differ in size, specific density, chemical composition, and shape (Duis and Coors, 2016). The behaviours of microplastics can be physical, chemical or biological.

Physical behaviours of Microplastics

Migration of plastic debris into the ocean can be through synthetic polymers, such as polyethylene and polypropylene since they are buoyant, (Andrady, 2011), also Polymers like PVC that are denser than seawater can be transported by underlying currents (Engler, 2012) or through ocean tide, ocean current, tsunami and wind. Secondly, sedimentation occurs as a result of increase in density of floating plastic debris environment. Plastic samples from the ocean have revealed the presence of nitrogen through the elemental analysis, the nitrogen was absent in virgin polyethylene and polypropylene; this is an indication of biofouling ((Moret-Ferguson *et al.*, 2010). As plastic debris neutrally drifts or slowly sink particles, the plastic debris would reach seawater density and enter the water column through biofouling (Cozar *et al.*, 2014), which may result in sedimentation and accumulation that can be either temporary or spatial. This is as a result of insufficient treatment capacity, accidental inputs, littering, illegal dumping and coastal human activities which cause large amount of microplastics to end up as marine debris (Hopewell *et al.*, 2009).

Chemical behaviours attached to Microplastics

The degradation of microplastics can be classified into photo-oxidative degradation, thermal degradation, ozone-induced degradation,

mechanochemical degradation, catalytic degradation and biodegradation owing to different causes, (Singh and Sharma, 2008). Degradation of polymer containing substance involves a change in its properties such as tensile strength, colour, and shape of polymer or polymer-based products under the influence of environmental factors such as heat, light, and chemicals (Wang *et al.* 2016). Plastics such as LDPE (Low Density Polyethylene), HDPE (High Density Polyethylene) and PP (Polypropylene), degrades in the ocean environment with physical abrasion such as wave action and sand grinding. Furthermore, Wang stated that when plastics are exposed to solar UV radiation would result in photo-degradation, embrittlement and fragmentation. Another chemical behaviour is adsorption of organic pollutants and metals, which are added during plastic production (Diethylhexyl phthalate (DEHP) or absorbed from sea water thereby serving as scavengers and transporters of organic contaminants (Bakir *et al.*, 2014). Microplastics could absorb Persistent Organic Pollutants (POPs) such as Dichlorodiphenyltrichloroethane (DDTs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) with reported concentrations ranging from 1 to 10,000 ng/g plastic pellet (Ogata *et al.*, 2009). The documentation of presence of metals on plastic debris is rare mainly because of a common understanding that plastics are relatively inert towards aqueous metals meanwhile Ag, Cd, Fe, Co, Cr, Cu, Ni, Pb, Sb, Zn, Al, Mn, Hg, Mo, Sn and U uptake by plastics have been recently reported (Ashton *et al.*, 2010; Turner, 2010; Holmes *et al.*, 2012).

Biological behaviours

The biological behaviours of MPs can be studied using three different paradigms; the ingestion, translocation and biodegradation. Aquatic Organisms such as barnacles, *Nephrops norvegicus* (crustacean), amphipods, mussels, lugworms, sea cucumbers, ingests microplastics due to their small size (Murray and Cowie, 2011). According to Laist, (1997) at least 267 species, including 43% of all marine mammal species, 86% of all sea turtle species, 44% of all seabird species, have been affected by plastic debris. Through translocation plastic debris is reported in the gut content of fishes, only to be egested in the form of faeces and further absorbed into the epithelial lining of the gut by phagocytosis (Browne *et al.*, 2007) to other tissues from estuaries pelagic and demersal habitats (Lusher *et al.*, 2013). The high molecular weight, together with its hydrophobicity and lack of microbial species capable of metabolizing polymers in nature makes plastics extremely resistant to biodegradation, with the exception of biopolymers (cellulose and chitin). However, several works have identified few microbial strains capable of biodegrading polyethylene (Bhattacharya

et al., 2010), polyvinyl chloride (Shah *et al.*, 2008) and polystyrene).

Degradation of Microplastics

Plastics are extremely resistant to biodegradation with the exception of biopolymers (such as cellulose and chitin) due to the high molecular weight, hydrophobicity and lack of microbial species that can metabolize polymers in nature (Wang *et al.* 2016). The mechanisms involved in biodegradation is complex due to the interaction of different oxidative processes which are caused by the oxygen presence in the air either by the microorganisms or by the combination of the two (Glass and Swift, 1989). The process of biodegradation is characterized by formation of biofilm, weight loss of polymers and visual pits. This process of biofilm formation on the plastic surface seems to be the favorite mode of growth of plastic degrading bacteria (Gilan *et al.*, 2004; Sivan *et al.*, 2006; Mor and Sivan, 2008; Balasubramanian *et al.*, 2010). Through incubation biodegradation of plastics commences (Harshvardhan and Jha, 2013).

Aquatic ecosystems microplastics pollution has become so widespread, and their persistence continues to increase as their removal manually seems to be extremely difficult owing to their small size and less visibility. In the quest to reduce MPs pollution microbes that are able to degrade polymers in a process called biodegradation are used, the approach involves the use of microorganisms secrete enzyme polyhydroxyalkanoates depolymerases which helps in plastic degradation (Mukherjee and Chatterjee, 2014). Polymers are utilized by microbes as a source of carbon and energy (Caruso, 2015) thus, they can serve as biodegraders. Several bacteria species have been reported to degrade plastic polymers. For example, degradation of polyethylene by *Bacillus sp.*, *Pseudomonas sp.*, and *Staphylococcus sp* isolated from soil has been reported by Singh *et al.* (2016). Caruso, (2015) also reported the degradation of polyvinyl chloride (PVC) by *Pseudomonas sputida*, plastic polymers by the following bacteria; *Brevibacillus borstelensis*, *Streptomyces sp.*, *Pseudomonas sstutzeri*, and *Alcaligenes faecalis*. Microbes that were isolated from different soil samples which had the potential to degrade polyethylene terephthalate (PET) and polystyrene (PS) have been reported by Asmita *et al.* (2015). The isolated species of *Aspergillus niger*, *Pseudomonas saeruginosa*, *Bacillus subtilis*, *Staphylococcus aureus*, and *Streptococcus pyogenes*. *Rhodococcus ruber* have the ability to degrade polystyrene by production of biofilm which helped in improving the degradation of polystyrene (Mor and Sivan, 2008). The method of using microbes is an environmentally safe way to degrade microplastics thus limiting input of microplastics from domestic uses.

Microplastics Effects on Fish

Studies have shown that microplastics are injurious to fish, according to Ramos *et al.*, (2012) microplastics ingestion in fish have led to prevalent mortality before maturity. Batel *et al.*, (2016) looked into the transfer of microplastics and potential harmful substances between different trophic levels in the marine environment by subjecting *Artemia nauplii* to high concentrations of microplastics ($1.2 \times 10^6 \text{ mg}^{-2}$) and they were found to have ingested and accumulated microplastic particles ranging from 1 to 20 μm , in high concentrations. This disturbed the lipid and energy metabolisms of the fish (Lu *et al.*, 2016). The European perch (*Perca fluviatilis*) exposed to 90 μm polystyrene microplastic particles ingested and accumulated the polystyrene microplastics which resulted in decreased growth, hindered hatching, altered the feeding and behaviour, and even affected the olfactory senses that enhanced susceptibility to killing by predators (Lönngstedt and Eklöv, 2016, Auta *et al.*, 2017). Microplastics have no long-lasting effect on the organism, but when retained in the body it has negative effects on the organisms that ingest them. They are found to increase toxicological stress in fin whales (Fossi *et al.*, 2016) and affect algal growth (Sjollemma *et al.*, 2015). According to Hall *et al.*, (2015) MPs have been found in bivalves and scleractinian corals, and has the tendency of remaining within the organism and translocate between tissues. They can also serve as vector which helps in transferring heavy metals and persistent organic pollutants (POPs) to marine organisms and the environment (Brennecke *et al.*, 2016) hence, reduction in the feeding activity of invertebrates (Besseling *et al.*, 2012). Higher animals in the food web may feed on organisms that have microplastics inside them thereby, transferring the microplastics to other animals in the higher trophic level (Wang *et al.* 2016). Microplastics can also cause the accumulation of lipids in the liver of fish due to the liver toxicity and inflammation (Lu *et al.*, 2016). When retained in the body, microplastics can be harmful to aquatic animals (fish, plankton) (Murray and Cowie, 2011).

Possible ways of reducing microplastics pollution

Since the issue and challenges of MPs cannot be totally avoided, strategies to solve the menace should focus on source control methods, remediation and clean up. The outlined points below according to Wu *et al.* (2017) have proven efficient; i. Removal of plastic microbeads from personal care products. Through US Microbead Free Waters Act of 2015, the US government banned the sale of personal care products containing plastic microbeads, effective on 2017. Other regions such as Canada, Australia, and several European countries have also queued in and encouraging

phase outs or bans of plastic microbeads which are major source of microplastics.

ii. Use of biodegradable materials. Biodegradable/biocompatible plastics such as polylactatide (PLA), polyhydroxyalkanoates (PHA) and others are commercially available and can replace traditional plastics for many applications.

iii. Enforcement of plastics reuse, recycle and recovery. The need for improvement of solid waste infrastructure and management will decrease plastic debris entering rivers and the ocean, this will in the long run decrease the rate of microplastics accumulation.

iv. Improved method of waste water treatment and management so as to remove microplastics efficiently and to prevent microplastics from entering surface waters, such as rivers and the ocean. This involves modification of filters within washing machines to preventing microplastics fibers from entering sewer.

v. Development of clean-up and bioremediation technologies. The microbial biodegradation of petroleum-based plastics, especially Polyethylene (PE), Polypropylene (PP) and Polystyrene (PS), has been evaluated since the 1970s while some fungi biodegrade Polyurethane, PE, PP and PS are on the other hand non-biodegradable without heat or UV pretreatment hence has the tendency to persist in natural environments for hundreds of years Wu *et al.* (2017). Through biodegradation methods of using PE, PS and Polyester (PET). Bacterial strains of *Bacillus* and *Enterobacter asburiae* degrading PE and *Exiguobacterium* degrading PS were isolated from the guts of pest insect larvae of *Plodia interpunctella* (waxworms or Indian moth) and *Tenebrio molitor* (mealworms) respectively (Yang *et al.* 2014, Yang *et al.* 2015). PS foam is completely mineralized in mealworms' gut within 12–24 h (Yang *et al.* 2015). PET degraders found in PET contaminated soils include strains of *Ideonella sakaiensis* (Yoshida *et al.* 2016).

CONCLUSION

Microplastics are products of humans daily use items that once they find their ways into water bodies have no benefits to both fish and other aquatic organisms but instead havoc. It is evident through this review that microplastics have brought a lot of damages into the aquatic biota globally. Due to their small sizes, they are easily ingested by aquatic organisms, thus causing decreased growth and alteration in the feeding and behaviour patterns of the organisms which may ultimately result to mortality. They also serve as vector which helps in transferring heavy metals and persistent organic pollutants (POPs) to marine organisms and the environment. To this effect there is need to create awareness to this human ill treatment to the water bodies by proffering solutions to microplastic pollution reduction; hence, the idea of

biodegradation and bioremediation which involves the use of microbes.

REFERENCES

- Andrady, A.L., (2011): Microplastics in the marine environment. *Mar. Pollut. Bull.* 62, 1596–1605. Arthur, Courtney; Baker, Joel; Bamford, Holly (January 2009): "Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris". NOAA Technical Memorandum.
- Arthur, C., Baker, J., Bamford, H., (2009). Proceedings of the International research Workshop on the 632 Occurrence, Effects and Fate of Microplastic Marine Debris. NOAA Technical Memorandum 633 NOS-OR&R-30, pp. 49.
- Ashton, K., Holmes, L., Turner, A., 2010. Association of metals with plastic production pellets in the marine environment. *Mar. Pollut. Bull.* 60, 2050–2055.
- Asmita, K., Shubhamsingh, T., Tejashree, S., (2015): Isolation of plastic degrading microorganisms from soil samples collected at various locations in Mumbai, India. *Curr. World Environ.* 4 (3), 77–85.
- Bakir, A., Rowland, S.J., Thompson, R.C., (2014): Enhanced desorption of persistent organic pollutants from microplastics under simulated physiological conditions. *Environmental Pollution Journal*, 185, 16–23.
- Balasubramanian, V., Natarajan, K., Hemambika, B., Ramesh, N., Sumathi, C.S., Ballent, A., Purser, A., de Jesus Mendes, P., Pando, S., Thomsen, L., (2012): Physical transport properties of marine microplastic pollution. *Biogeosci. Discuss.* 9, 18755–18798.
- Batel, A., Linti, F., Scherer, M., Braunbeck, T., (2016): The transfer of benzo(a)pyrene from microplastics to *Artemia nauplii* and further to zebrafish via trophic food web experiment-CYP1A induction and visual tracking of persistent organic pollutants. *Environmental Toxicology Journal of Chem.*
- Besseling, E., Wegner, A., Foekema, E.M., van den Heuvel-Greve, M.J., Koelmans, A.A., (2012): Effects of microplastics on fitness and PCB bioaccumulation by the lugworm *Arenicola marina* (L.). *Environ. Sci. Technol.* 47 (1):593–600.
- Bhattacharya, P., Lin, L., Turner, J.P., Ke, P.C., (2010). Physical adsorption of charged plastic nanoparticles affects algal photosynthesis. *J. Phys. Chem. C* 114 (39), 16556–16561.

- Brennecke, D., Duarte, B., Paiva, F., Cacador, I., Canning-Clode, J., (2016): Microplastics as vectors for heavy metal contamination from the marine environment. *Estuar. Coast. Shelf Sci.*:1–7 <http://dx.doi.org/10.1016/j.ecss.2015.12.003>.
- Browne MA, Galloway T, Thompson R (2007) Microplastic—an emerging contaminant of potential concern? *Integr Environ Assess Manag* 3:559–561.
- Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., (2011): Accumulation of microplastic on shorelines worldwide: sources and sinks. *Environ. Sci. Technol.* 45, 9175–9179.
- Caruso, G., (2015): Plastic degrading microorganisms as a tool for bioremediation of plastic contamination in aquatic environments. *Pollution Effects and Control* 3, 112.
- Castañeda, R.A., Avlijas, S., Simard, M.A., Ricciardi, A., (2014): Microplastic pollution in St. Lawrence River sediments. *Can. J. Fish. Aquat. Sci.* 70:1767–1771. <http://dx.doi.org/10.1139/cjfas-2014-0281>.
- Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., (2011): Microplastics as contaminants in the marine environment: a review. *Mar. Pollut. Bull.* 62 (12), 2588–2597.
- Cole, M., Lindeque, P.K., Fileman, E., Clark, J., Lewis, C., Halsband, C., Galloway, T.S., (2016). Microplastics alter the properties and sinking rates of zooplankton faecal pellets. *Environ. Sci. Technol.* 50:3239–3246.
- Cozar, A., Echevarría, F., Gonzalez-Gordillo, J.I., Irigoien, X., Úbeda, B., HernandezLeon, S., Palma, A.T., Navarro, S., García-de-Lomas, J., Ruiz, A., Fernandez-dePuelles, M., Duarte, C.M., (2014). Plastic debris in the open ocean. *Proc. Natl. Acad. Sci.* 111 (28), 10239e10244.
- Duis, K., Coors, A., (2016). Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. *Environ. Sci. Eur.* 28 (2).
- Engler, R.E., (2012): The complex interaction between marine debris and toxic chemicals in the ocean. *Environ. Sci. Technol.* 46 (22), 12302-12315.
- Fossi, M.C., Marsili, L., Bains, M., Giannetti, M., Coppola, D., Guarranti, C., Caliani, I., Minutoli, R., Lauriano, G., Finoia, M.G., Rubegni, F., Panigada, S., Bérubé, M., Ramirez, J.U., Panti, C., (2016): Fin whales and microplastics: The Mediterranean Sea and the sea of Cortez scenarios. *Environ. Pollut.* 209, 68–78.
- Free, C.M., Jensen, O.P., Mason, S.A., Eriksen, M., Williamson, N.J., Boldgiv, B., (2014): High-levels of microplastic pollution in a large, remote, mountain lake. *Mar. Pollut. Bull.* 85 (1), 156-163.
- Glass, J.E., Swift, G., (1989). Agricultural and synthetic polymers: biodegradation and utilization. *ACS Symp. Ser.* 433, 9e64.
- Graham, E.R., Thompson, J.T., 2009. Deposit- and suspension-feeding sea cucumbers (Echinodermata) ingest plastic fragments. *J. Exp. Mar. Bio. Ecol.* 368, 22-29.
- Gregory, M. R. Environmental implications of plastic debris in marine settings – entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philos. Trans. R. Soc., B* 2009, 364, 2013–2025.
- Hall, N.M., Berry, K.L.E., Rintoul, L., Hoogenboom, M.O., (2015): Microplastic ingestion by scleractinian corals. *Mar. Biol.* 162, 725–732.
- Holmes, L.a, Turner, A., Thompson, R.C., 2012. Adsorption of trace metals to plastic resin pellets in the marine environment. *Environ. Pollut.* 160, 42-48.
- Hopewell, J., Dvorak, R., Kosior, E., (2009): Plastics recycling: challenges and opportunities. *Phil. Trans. R. Soc. B Biol. Sci.* 364, 2115e2126.
- Jackson, R. B., Carpenter, S. R., Dahm, C. N., McKnight, D. M., Naiman, R. J., Postel, S. L., and Running, S. W. (2001). Water in a changing world. *Ecological applications*, 11(4), 1027-1045.
- Laist, D.W., (1997): Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe, J.M., Rogers, D.B. (Eds.), *Marine Debris Sources, Impacts and Solutions*. SpringerVerlag, New York, pp. 99-139.
- Langbein, W.B.; Iseri, Kathleen T. (1995): “Hydrologic Definitions: Stream”. *Manual of Hydrology: Part 1. General Surface-Water Techniques (Water Supply Paper 1541-A)*. Reston, VA: USGS.
- Lönnstedt, O.M., Eklöv, P., (2016): Environmentally relevant concentrations of microplastic particles influence larval fish ecology, ecotoxicology. *Science* 352, 6290.
- Lu, Y., Zhang, Y., Deng, Y., Jiang, W., Zhao, Y., Geng, J., Ding, L., Ren, H., (2016): Uptake and accumulation of polystyrene microplastics in zebra fish (*Danio rerio*) and toxic effects in liver. *Environ. Sci. Technol.* 50, 4054–4060.