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Review article

Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions

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ABSTRACT

The presence of microplastics in the marine environment poses a great threat to the entire ecosystem and has received much attention lately as the presence has greatly impacted oceans, lakes, seas, rivers, coastal areas and even the Polar Regions. Microplastics are found in most commonly utilized products (primary microplastics), or may originate from the fragmentation of larger plastic debris (secondary microplastics). The material enters the marine environment through terrestrial and land-based activities, especially via runoffs and is known to have great impact on marine organisms as studies have shown that large numbers of marine organisms have been affected by microplastics. Microplastic particles have been found distributed in large numbers in Africa, Asia, Southeast Asia, India, South Africa, North America, and in Europe. This review describes the sources and global distribution of microplastics in the environment, the fate and impact on marine biota, especially the food chain. Furthermore, the control measures discussed are those mapped out by both national and international environmental organizations for combating the impact from microplastics. Identifying the main sources of microplastic pollution in the environment and creating awareness through education at the public, private, and government sectors will go a long way in reducing the entry of microplastics into the environment. Also, knowing the associated behavioral mechanisms will enable better understanding of the impacts for the marine environment. However, a more promising and environmentally safe approach could be provided by exploiting the potentials of microorganisms, especially those of marine origin that can degrade microplastics.

Capsule: The concentration, distribution sources and fate of microplastics in the global marine environment were discussed, so also was the impact of microplastics on a wide range of marine biota.

Contents

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1. Introduction

Coastal and marine areas are constantly under continuous and increasing pressure from the activities of humans. Pollutants such as pesticides, persistent organic pollutants (POPs), hydrocarbons, heavy metals, plastics and microplastics impact the marine ecosystem. The high dynamic nature of the coastal areas makes up the physicochemical properties of freshwater environments, estuaries and lagoons with the oceanographic characteristics of adjoining seas. Hence, the evaluation of contamination and remediation of coastal and marine environments are one of the most complex and current issues in ecotoxicology and environmental management. Marine litter has become a global environmental problem affecting all parts of our oceans (Shim and Thompson, 2015). It originates mainly from activities on land, and causes health economic and environmental problems that arise as a result of poor waste management practices and lack of standard infrastructure. Marine litter load in seas is a rising issue due to the biological and ecological consequences (Alomar et al., 2016).

Plastic makes up about 80 to 85% of marine litter. Plastics became the fastest growing segment of the municipal waste stream between 1950 and 2003, and its global production has increased significantly over the past decades [1.7 million tonnes in the 1950s to 299 million tonnes in 2014 (PlasticsEurope, 2015; United Nations Environment Programme, UNEP, 2015)]. The trends of production, consumer-use patterns and demographics all point to a further increase of plastic use in the future. Only <5% of plastic material has been recovered and this has led to the accumulation of plastics in the marine environment (Sutherland et al., 2010). Plastics enter the aquatic environment in a wide range of sizes (Hidalgo-Ruz et al., 2012; Cole et al., 2011). Most commonly used plastics do not ever fully "go away" but rather breakdown into smaller fragments under ultraviolet (UV) light and relatively low temperatures (GESAMP, 2015), and referred to as microplastics (Cole et al., 2011).

Microplastics are tiny ubiquitous plastic particles smaller than five millimeters (5 mm) in size and originate from two sources; those that are manufactured purposely for particular industrial or domestic application such as exfoliating facial scrubs, toothpastes and resin pellets used in the plastic industry (primary microplastics), and those formed from the breakdown of larger plastic items under ultraviolet radiation or mechanical abrasion (secondary microplastics) (IMO, 2015). These small plastic particles enter the marine environment through several activities on land and in the marine environment. Microplastic beads present in facial cleansers, synthetic clothing, toothpaste, and scrubs get into the marine ecosystem through domestic and industrial drainage systems and wastewater treatment plants (Cole et al., 2011; Murphy et al., 2016). Also, larger plastic particles from waste dumps that have been broken down into smaller fragments can be transported into seas which cause microplastic pollution (Alomar et al., 2016).

Microplastics are dispersed throughout the world's ocean. Often found in shorelines, seabed sediments, beaches, wastewater effluents (Gallagher et al., 2015) and even frozen ice, some float on surface waters (Lusher et al., 2015a,b). Some are found within the Artic and the Antarctic, transported by ocean currents, and wind (Cole et al., 2011; Eriksen et al., 2014; IMO, 2015; Van Cauwenberghe et al., 2015a,b; Setälä et al., 2015; Alomar et al., 2016; Ferreira et al., 2016). The small size of microplastics makes them easily available for ingestion by a wide range of organisms in the marine environment. Bivalves, zooplankton, mussels, fishes, shrimps, oysters, copepods, lugworms, and whales have been reported to ingest microplastics (Cole et al., 2013; Lusher et al., 2015a, b; Ferreira et al., 2016). This poses a great risk to the organisms as the ingestion of these tiny plastic particles have been reported to cause pathological stress, false satiation, reproductive complications, blocked enzyme production, reduced growth rate, and oxidative stress (Sutton et al., 2016; Fossi et al., 2016). Microplastics can also adsorb toxic chemicals from surrounding sea water which can be transferred into the food chain (Reisser et al., 2014). Studies have reported that microplastics have been detected globally in growing numbers in rivers and lakes and at very high levels. Microplastics are mainly composed of polyvinyl chloride (PVC), nylons and polyethylene terephthalate (PET), which are more likely to sink, and polyethylene (PE), polypropylene (PP) and polystyrene (PS), which are more likely to float. Other polymers include; polyvinyl alcohol (PA), and polyamide (PA) (Avio et al., 2016; Carr et al., 2016). These plastics persist in the environment due to resistance to degradation by microorganisms (Yoshida et al., 2016). The presence of these small plastic particles has been observed at the surface of oceans, water columns, and in deep sea sediments worldwide (Van Cauwenberghe et al., 2015a,b). Microplastics have recently been identified as an important emerging global problem which affects marine organisms and even humans (Sutherland et al., 2010; Caruso, 2015; Wang et al., 2016). There has been a significant increase in the concentrations of microplastic particles in the surface waters of oceans within the last four decades and concern about the potential impact on the marine environment has increased during the past few years. Scientific investigations about the impact of microplastics on ecosystem have increased, along with public interest (GESAMP, 2015; Shim and Thompson, 2015).

Several studies have demonstrated that marine organisms can take up microplastics often with great consequences as that can accumulate in the tissues, serve as vehicles for transport of pathogens, adsorb and accumulate toxic pollutants. Microplastics have the potential to cause many adverse effects such as cancer, impaired reproductive activity, decreased immune response, and malformation in animals and humans. Pollution of the marine environment by microplastics is a potential health and economic problem. Prevention and possible management measures have been listed as a challenge because these particles are very small and hard to visualize, which makes their manual removal very difficult, if not impossible. The persistence of microplastics will continue to increase. Reports have it that by the year 2050, there will be more microplastics in our oceans than fish (World Economic Forum, 2016).

A pollution source needs a name and an address, but difficulty arises in assigning a name and address to microplastics pollution as microplastics drifting into the ocean usually come from a mix of different sources, originate from different locations and are emitted at different times. Identifying the original sources and classes of both plastics and microplastics will aid in providing possible ways to decrease the entry of microplastics into the aquatic environment. In view of these, the review aim to discuss the mechanism of generation (sources) and routes which aid microplastics entry into the marine environment, to address the fate and behavior of microplastics in the marine environment, and to determine the impact of these tiny particles on the marine ecosystem. Furthermore, it presents a concise environmental distribution of microplastics globally, analyzes and discusses various prevention and management strategies proposed by both the private and government sectors, and offers possible control and remediation measures that can be adopted to solve the menace of microplastics pollution.

2. Sources of microplastics

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). They are found in everyday use products such as facial scrubs, paints, etc. (primary microplastics), or from the breakdown of larger macroplastic debris under environmental conditions (secondary microplastics) (Andrady, 2011; Wagner et al., 2014).

2.1. Primary microplastics

Primary microplastics are microplastics that are manufactured for particular industrial or domestic applications to be of a microscopic size. They include plastic particles used in facial cleansers, tooth paste, resin pellets and cosmetics like shower/bath gels, scrubs, peelings (Cole et al., 2011), eye shadow, deodorant, blush powders, make up foundation, mascara, shaving cream, baby products, bubble bath lotions, hair coloring, nail polish, insect repellents and sunscreen (Castañeda et al., 2014; Fendall and Sewell, 2009; Cole et al., 2011; Costa et al., 2010; Duis and Coors, 2016), others include synthetic clothing, abrasives found in cleaning products, drilling fluids, and air-blasting media (Gregory, 1996; Alomar et al., 2016). These consumer products are characterized as “open use” since they are intended to be washed off and end up in drains (Castañeda et al., 2014). The use of microplastics in medicine as vectors for drugs has increasingly been also reported (Patel et al., 2009). Virgin plastic production pellets (typically 2–5 mm in diameter) are also considered as primary microplastics, although their inclusion within this category has been criticized (Andrady, 2011; Costa et al., 2010; Wagner et al., 2014). Microplastic “scrubbers”, used in exfoliating hand cleansers and facial scrubs, have replaced traditionally used natural ingredients, such as oatmeal, ground almonds, and pumice (Fendall and Sewell, 2009). The use of exfoliating cleansers containing plastics has risen dramatically since the patenting of microplastic scrubbers within cosmetics in the 1970s (Fendall and Sewell, 2009). For example the presence of polyethylene and polypropylene granules (<5 mm) and polystyrene spheres (<2 mm) in a cosmetic product has been reported (Gregory, 1996). Typically marketed as “micro- beads” or “micro-exfoliates”, the plastics vary in composition, size and shape depending upon the product. More recently, Fendall and Sewell (2009) reported an abundance of irregularly shaped microplastics, typically <0.5 mm in diameter with a mode size <0.1 mm, in another cosmetic product. Chang, 2013 on the other, reported polyethylene beads found in facial cleansers to range from 60 to 800 μm and estimated that approximately 5000 g of microplastics was going into the waste stream on a yearly basis due to usage. Primary microplastics have also been produced for use in air blasting technology). This process involves blasting acrylic, melamine or polyester microplastic scrubbers at machinery, engines and boat hulls to remove rust and paint. As these scrubbers are used repeatedly until they diminish in size and their cutting power is lost, they often become contaminated with heavy metals (e.g. Cadmium, Chromium, and Lead) (Cole et al., 2011).

2.2. Secondary microplastics

Larger plastic debris on sea and land over time fragment into smaller particles when exposed to the elements until they end up as microplastics (Norwegian Environment Agency, 2015). These types of microplastics are referred to as secondary microplastics. A culmination of physical, chemical and biological processes reduce the structural integrity of macroplastic debris, thereby leading to fragmentation (Cole et al., 2011). A combination of several environmental factors (such as sunlight and temperature), and the properties of the polymer (size, density) influences the disintegration of macroplastic debris. Exposure of larger plastic debris to ultraviolet (UV) radiation from the sun causes photo- degradation of plastics. The ultra violet radiation in the sun causes oxidation of the polymer matrix which leads to the cleavage of bond (Cole et al., 2011; Andrady, 2011; GESAMP, 2014; Mailhot et al., 2000; Lucas et al., 2008; Wagner et al., 2014). Microplastic production by fragmentation into smaller sizes is most effective on beaches due to high UV light, physical abrasion by waves, oxygen availability (Cole et al., 2011; GESAMP, 2014), and turbulence (Barnes et al., 2009). With time, they turn brittle, forming cracks and “yellowing” (Andrady, 2011; Cole et al., 2011). Once these fragments submerge into surface waters, or deep environments, cooler temperatures and reduced UV light renders the breakdown slow (GESAMP, 2014). The breakdown continues until the fragments become smaller over time and become microplastic in size (Rios et al., 2007; Ryan et al., 2009; Cole et al., 2011). As large plastic items breakdown into microplastics, their abundance in the marine environment increases, which possibly enhance the potential impacts to wildlife. As particle size decreases, the diversity of organisms that can ingest the debris increases. Thus, the smaller plastics particles are easier to ingest, thereby increasing the susceptibility, enhanced leaching, desorption and adsorption potentials of the microplastics (Law and Thompson, 2014; Shim and Thompson, 2015).

Both microplastic types (primary and secondary) exist in marine ecosystems at high concentrations. It has been estimated that about 245 tonnes of microplastics are produced each year which end up in water bodies where they become ingested and incorporated into the bodies and tissues of marine organisms (Morris, 2015; Grossman, 2015).

3. Routing microplastics into ocean waters

Microplastics enter the marine environment via different pathways (terrestrial and marine-based activities) as shown in Fig. 1 (Lee et al., 2014; Alomar et al., 2016). The microplastics beads present in cosmetics such as scrubs, toothpastes, air-blasting media, and in clothing can enter the aquatic environment through industrial or domestic drainage systems. Similarly, synthetic fibers from clothing produce microplastic sheds that are washed into water or wastewater treatment plants as effluents (Murphy et al., 2016). Wastewater treatment works (WWTW) located on the River Clyde in Glasgow releases about 65 million microplastic particles into the receiving water on a daily basis. Gouin et al. (2011) reported that the US population emits about 263 tonnes yr^{-1} polyethylene microplastics, mainly from the usage of personal care products. They estimated the per capita consumption of microplastics to be 2.4 mg/person day-1. This invariably makes up 25% of plastics in the North Atlantic subtropical gyre.

Microplastics also get into the marine environment via storm sewers, wind, and currents (Zalasiewicz et al., 2016; Murphy et al., 2016). Some are transported out to sea via runoff (Cole et al., 2011), while the degradation of macroplastic debris is another source and the route is often sea recycling ports and landfills where adverse weather situations aid in macroplastic dumping at sea shores. Sewage sludge is another possible source of microplastic pollution as it contains more microplastics than effluent which are transported into the aquatic ecosystem (Leslie et al., 2012; Alomar et al., 2016). The size of microplastics (<5 mm) and associated low density contributes to the widespread transport and distribution across larger distances by currents (Eriksson et al., 2013; Eerkes-Medrano et al., 2015). These small marine plastics are abundant and are widespread in all aquatic habitats across the world (Reisser et al., 2014; Cole et al., 2014; Eerkes-Medrano et al., 2015).

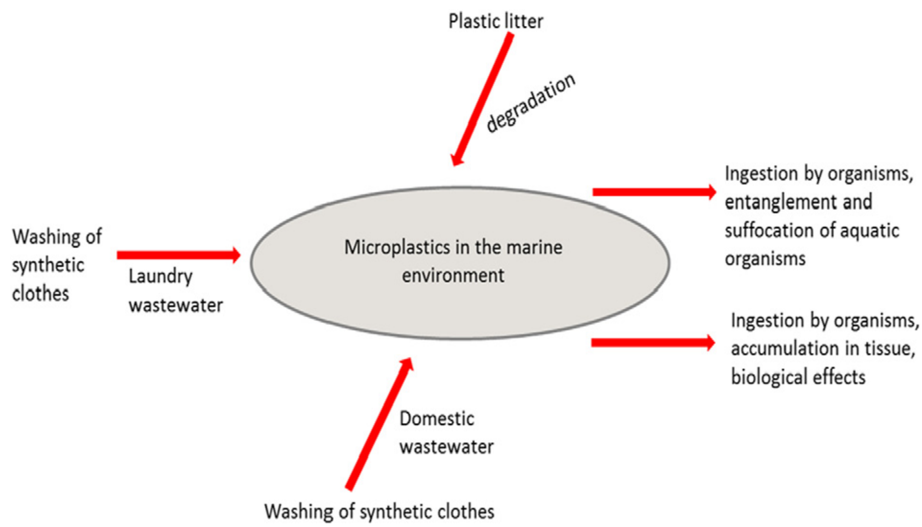

Fig. 1. Sources of microplastics in the marine environment.

Microplastics exist on beaches, seabed sediments surface waters, and in a wide diversity of marine organisms such as sea birds, fishes, bivalves, mammals and crustaceans (De Witte et al., 2014; Gauquie et al., 2015). Another route through which microplastics could get into oceans is through the feces of zooplankton. This has been proven through the study of Cole et al. (2016) were they exposed zooplankton (*Calanus helgolandicus* and *C. typicus*) to 20.6 μM polystyrene microplastics (1000 microplastics mL^{-1}). On exposure, the organisms readily fed on the microplastics which passed through the gut, became encapsulated in the feces and were egested. Following egestion, the feces sank to the base of the exposure vessel and were subsequently ingested by the larger copepod. The study demonstrated that microplastics can be indirectly ingested through the consumption of fecal pellets, proving that fecal pellets are a source of microplastics in the marine environment. It has been estimated that out of 269 million tonnes from 5.25 trillion particles globally, 92% are microplastics and these microplastics are a hundred times less on the sea surface than expected, supporting the understanding that most microplastics sink down to marine sediments (Eriksen et al., 2014). Some have been found frozen in the ice of the Arctic sea which has become a global sink for microplastics (Obbard et al., 2014; Zalasiewicz et al., 2016).

4. Microplastics in the environment

4.1. Microplastics in marine sediments

Microplastics with density greater than that of sea water sink down in sediments where they accumulate (Woodall et al., 2014; Alomar et al., 2016), while those with low density float on the sea surfaces (Suaria and Aliani, 2014). Increase in density, through biofouling by organisms in the marine environment can result in sinking of microplastics. As biofouling progresses, the density of the plastic material also increases and once the density becomes greater than that of sea water, the plastic material sinks to the bottom of the sea (Andrady, 2011; Reisser et al., 2013; Jorissen, 2014). Marine sediments have the potential to accumulate microplastics (Nuelle et al., 2014), and have demonstrated long-term sinks for microplastics (Cozar et al., 2014). Very high concentrations of microplastics now occur within marine sediments; such plastics can make up 3.3% of sediment weight on heavily impacted beaches (Van Cauwenberghe et al., 2015a, 2015b; Boucher et al., 2016). It is a fact that deep sea areas, submarine canyons, and marine coastal shallow sediments are sinks for microplastics (Alomar et al., 2016; Pham et al., 2014).

4.2. Microplastics in mangrove sediments

Mangrove accumulates carbon, nutrients and sediments; hence, it is often referred to as “enhancer of sedimentation” (Valiela and Cole, 2002). The deposition of sediments into mangroves occur from different sources; allochthonous sediments - these are sediments that come from external sources such as terrestrial or oceanic sources, and the autochthonous sources which are sediments that are re-suspended (Adame et al., 2010). As with sediments in other aquatic environments, microplastics similarly accumulate in mangrove sediments. In a study conducted by Nor and Obbard (2014) to study the prevalence of microplastics in mangrove habitats of Singapore, microplastic particles were extracted using the floatation technique. The plastic particles extracted were smaller than 20 μm and contained polypropylene, polyvinyl chloride, nylon and polyethylene. The concentration of the microplastics ranged from 12.0–62.7 particles per dry sediment. The presence of these different polymers of microplastics may be due to the degradation of marine macroplastic debris which could have accumulated in the mangroves. The distribution of microplastics in mangroves located in Peninsular Malaysia recorded about 418 items of different microplastic polymers ranging from polystyrene foams to plastic pellets (Jayanthi et al., 2014). Smith (2012) recorded a total of 3349 items m^{-2} in mangrove dominated areas of Papua New Guinea out of which 263 items were small plastic pieces. Fig. 2 shows microplastics of different sizes, color, and shape excavated from mangrove sediments in Peninsular Malaysia.

5. Global microplastics distribution in the marine environment

Microplastics are carried and dispersed throughout the world's oceans; at shorelines, beaches, in seabed sediments, and on surface waters from the Arctic to the Antarctic where they concentrate at remote locations (IMO, 2015). The distribution in the marine environment is influenced by the density of the particles, location of the sources and conveyance with ocean currents and waves (Kukulka et al., 2012; Magnusson et al., 2016). The buoyant and persistent natures of microplastics allow them to become easily and widely dispersed via hydrodynamic processes and ocean currents (Carvalho and Baptista Neto, 2016).

Investigations on the presence of microplastics in the marine environment started in the 2000s. Recently, research has shown that microplastics have ubiquitously permeated the aquatic ecosystem, and even the Polar Regions are not left out (Lusher et al., 2015a,b; Barnes

Fig. 2. Microplastics in different sizes and color from mangrove sediments in Peninsular Malaysia.

et al., 2009), the deep sea (Claessens et al., 2013), and the mid-ocean islands (Ivar do Sul et al., 2013). About two billion microplastic fragments were estimated to have entered the Californian coastal waters in just over a period of three days via two rivers (Moore et al., 2005). Reddy et al. (2006) discovered a concentration of 81 ppm microplastics in sediments at an intertidal site near a shipwreck yard in India. Microplastic particles distribution on the surface and sub-surface areas of the Arctic waters, south and southwest of Svalbard, Norway has been estimated to range between 0 and 1.31 particles m^{-3} and 0 and 11.5 particles m^{-3}, respectively (Lusher et al., 2015a,b). The composition of the particles suggested that they may have resulted from the breakdown of macro debris or from sewage and wastewater. High concentrations of microplastics (770 and 3300 items kg^{-1} dry weight) have been reported in sediments in the Wadden Sea and the Rhine estuary, respectively, with about 400 items reported in the Coastal harbor sediments of Belgium. Isobe et al. (2015) investigated the concentrations of microplastics in the East Asian Seas around Japan and a total particle count of about 1.72 million pieces km^{-2} (10 times greater than in the North Pacific and 27 times greater than in the world oceans) were recorded. In South Africa, microplastic densities in beach sediment ranged from 340.7–4757 particles m^{-2}, while those in the water column ranged between 204.5 and 1491.7 particles m^{-3}, which were governed by water circulation (Nel and Froneman, 2015). Studies were conducted to quantify microplastic debris in sand beaches in Peninsular Malaysia and a total of 2542 pieces (265.30 g^{-2}) of small microplastic debris were collected from six beaches (Fauziah et al., 2015). Microplastic concentrations ranged from 8 to 9200 particles m^{-3} in offshore pacific waters, and increased to 6, 12, and 27-folds in West coast Vancouver Island, Straights of Georgia and Queen Charlotte Sound, British Columbia, Canada, respectively (Desforges et al., 2013). An average microplastic density of 20,264 particles km^{-2} has been recorded in Lake Hovsgol, Mongolia (Free et al., 2014). Lusher et al. (2014), investigated the levels of microplastics in the Northeast Atlantic Ocean and the average microplastic abundance was calculated as 2.46 particles m^{-3}. The study was the first to report the ubiquitous nature of microplastic pollution in the North Atlantic Ocean. Study was carried out on the distribution, abundance and possible discharge of microplastics via treated municipal wastewater in urban estuaries. It was observed that the wastewater treatment facilities discharged about 7 million microplastic particles daily whereas, those found in the Midwest and Northeast US recorded a total of 2 million particles daily. In total, 56 million microplastic particles were discharged into the San Francisco Bay. The distribution of microplastics in the surface waters of San Francisco bay ranged from 15,000–2,000,000 particles km^{-2} (Sutton et al., 2016). Studies have reported that Denmark emits about 21,500 tonnes of microplastics on a yearly basis which arise from both primary and secondary sources, about which 2000 to 5600 tonnes are discharged into sewage yearly from tyres and textiles (Lassen et al., 2015). Norway on the other hand generates approximately 8000 tonnes yearly (NEA, 2015). Eriksen et al. (2013) in their studies used SEM/EDS analysis for the microscopic and elemental analysis of particles from samples of the Great Laurentian Great Lakes of the United States. Particles >1 mm were more easily identified as plastics and were therefore, excluded from the SEM/EDS analysis. However, an average abundance of 43,000 microplastic particles km^{-2} were recorded and such included particles <5 mm. Antunes et al. (2013) reported that the average marine debris along the Portuguese coastline was 2421 items m^{-2} which computed to 362 g^{-2}; 98% were plastics (2397 items m^{-2}, 283 g^{-2}) and were 4 mm in diameter. The most dominant class of plastic marine debris was resin pellets, representing 53% of the total marine debris collected (1289 items m^{-2}, 30 g^{-2}). Resin pellets are small cylindrical granules of about 2–7 mm in size (Andrady, 2011). Microplastic samples were identified and quantified using FTIR and SEM in the beach samples of the Chinese Bohai Sea. The range of microplastics abundance from three (3) sampled locations was 63–201 items kg^{-1} most of which consisted of fragments and sheets and belonged to the polyethylene (PE) group of plastics (Yu et al., 2016).

The statistics of microplastic distribution in the world's aquatic environment is very troubling as the concentrations are very high; hence, creates a concern especially as it relates to impact of such enormous distribution on aquatic life. Table 1 shows the distribution of microplastics (in percentage) and their concentrations in the marine environment.

6. Effects of microplastics

6.1. Interaction with marine biota

As the abundance of microplastics increases, its bioavailability to marine organisms also increases. The color, density, shape, size, charge, aggregation and abundance of these tiny plastic particles affect their potential bioavailability to marine organisms (Wright et al., 2013; Van Cauwenberghe et al., 2015a,b). Biological interactions of microplastics with marine biota are key to understanding the movement, impact and fate of microplastics in the marine environment (Clark et al., 2016).

Recently, several studies on the ingestion of microplastic particles by marine biota has increased with most of the studies carried out in controlled laboratory experiments. The ingestion of microplastic particles has been observed in oceanic regions globally in a wide range of marine organisms (Ferreira et al., 2016; Setälä et al., 2015; Devriese et al., 2015; Green, 2016). Ingestion of microplastics by marine organisms in most cases is accidental because the particle is often mistaken for food, although some can be specifically targeted by some organisms (Lönnstedt and Eklöv, 2016). Studies have been carried out on microplastic ingestion by marine organisms and most of the studies come from the analysis of stomach contents (Rochman et al., 2013; Fossi et al., 2016; Cole et al., 2013; Caron et al., 2016; Rehse et al., 2016). Microplastics, when ingested by marine organisms, cause chemical and physical harm. The consumption of microplastics by marine organisms may cause mechanical effects such attachment of the polymer to the external surfaces thereby, hindering mobility and clogging of the digestive tract, or the effect could be chemical such as inflammation, hepatic stress, decreased growth (Setala et al., 2016). The consumption of microplastics is common to a wide range of marine organisms representing different trophic levels including invertebrates, especially lugworms (Green et al., 2016; Besseling et al., 2012), mussels (von Moos et al., 2012; Avio et al., 2016), barnacle; sea cucumbers, amphipods and zooplankton (Rehse et al., 2016; Cole et al., 2013; Goldstein and Goodwin, 2013), and fish-eating birds, fishes, turtles, and mammals (Ferreira et al., 2016; Batel et al., 2016; Fossi et al., 2016; Caron et al., 2016), which can interfere with the food chain as microplastics ingested by organisms in the lower trophic level including zooplankton and copepods, could pass up the food chain when lower trophic organisms

Table 1
Microplastic distribution in the world oceans.

Marine environment	Distribution (%)	Concentration	Reference
North East Atlantic Ocean	89	2.46 particles m^{-3}	Lusher et al. (2014)
Arctic Polar Waters	95	0–1.31 particles m^{-3}	Lusher et al. (2015a,b)
Laurentian Great Lake	20	43,000 particles km^{-2} to 466,000 particles km^{-2}	Eriksen et al. (2013)
Jade Bay, Southern North Sea	70	1770 particles L^{-1}	Dubaish and Liebezeit (2013)
Northwestern Atlantic	60	2500 particles km^{-2}	Law et al. (2010)
Portuguese Coast	53	332–362 itemsm^{-2}	Antunes et al. (2013)
Mediterranean Sea	74	0.90 $\pm$ 0.10 microplastics g^{-1}	Alomar et al. (2016)
Yangtze Estuary and East China Sea	90	0–144 particles m^{-3}	Zhao et al. (2014)
Beaches of Guanabara Bay, Southeast Brazil	56	12–1300 particles m^{-2}	Carvalho and Baptista Neto (2016)
Swedish Coast	–	150–2400 particles m^{-3} to 68,000–102,000 particles m^{-3}	Lönnstedt and Eklöv (2016)
Chinese Bohai Sea	–	63–201 items kg^{-1}	Yu et al. (2016)

are fed upon by organisms in the higher trophic level (Hollman et al., 2013).

Microplastics contain organic pollutants, either 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). Adsorption is both a physical and chemical behavior. Physical adsorption is dependent on the great specific surface area and Van der Waals' force, while chemical adsorption is mainly due to greater affinity of organic pollutants for hydrophobic surfaces of the microplastics compared to seawater (Teuten et al., 2007; Wang et al., 2016). The large surface area to volume ratio of microplastics makes them liable to contamination by water borne-contaminants such as persistent organic pollutants (POPs), metals (Ashton et al., 2010; Cole et al., 2011), and endocrine disrupting chemicals (Ng and Obbard, 2006). These chemicals are found in high concentrations in the sea surface microlayer, where low density microplastics also exist in large numbers (Teuten et al., 2009). Organochlorine pesticides such as dichlorodiphenyl trichloroethane (DDTs), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) can sorb to the hydrophobic surface of the microplastics. The sorption capacity of microplastics is influenced by the type of polymer and its state (whether it is glassy or rubbery). Proof of pollution by microplastics has been reported by several studies. Hirai et al. (2011) and Ogata et al. (2009) reported that the global concentration of POPs in marine plastic pellets was 1–10,000 ng g^{-1}. Marine microorganisms have been found to metabolize persistent organic pollutants that have been sorbed unto microplastics. For example, the assimilation of polybrominated diphenyl ethers from microplastics by *Allorchestes compresa* was reported by Chua et al. (2014). The organisms were found to have ingested about 45 particles which got assimilated into the tissues. Wardrop et al. (2016) also reported the assimilation of polybrominated diphenyl ethers by fish into the tissues. Aquatic sediments also serve as potential sinks for metals entering into the aquatic environment where they sorb unto microplastics. Antifouling paints, fuel combustion, and industrial waste are major sources of heavy metals that enter the marine environment (Deheyn and Latz, 2006; Brennecke et al., 2016). Studies have reported the ability of microplastics to sorb trace metals from the aqueous environment (Rochman et al., 2013; Boucher et al., 2016; Brennecke et al., 2016). Heavy metals such as aluminum (Al), copper (Cu), silver (Ag), zinc (Zn), lead (Pb), iron (Fe) and manganese (Mn), have been detected on plastic production pellets sampled in the seawater (Ashton et al., 2010; Holmes et al., 2012). Microplastics that have been covered with POPs and heavy metals may be carried across the oceans and easily contaminate other ecosystems (Zarfl and Matthies, 2010). Further, the material may be ingested by marine biota which is transported along the food chain (Eerkes-Medrano et al., 2015). Similarly, Brennecke et al. (2016) examined the adsorption of zinc (Zn) and copper (Cu), that had been leached from an antifouling paint to polyvinyl chloride fragments and virgin polystyrene beads in seawater, and both metal ions were adsorbed by the microplastics. These toxic chemical contaminants have a wide range of harmful effects such as causing cancer and endocrine disruption, birth defects, immune system problems, and child development issues (Teuten et al., 2009; GESAMP, 2010; Setala et al., 2016). Additives that are harmful and have the ability to leach into the environment may also be present in microplastics which have proven transfer potential across the aquatic food chain, and to cause harm to marine organisms that ingest them (Nobre et al., 2015; Setala et al., 2016).

Ingestion of microplastics by organisms can occur through ventilation processes. That is, the uptake of small particulate matter into the gill chamber onto the gills by water movement through the base of the limbs of the organism (Watts et al., 2014). Studies on marine ingestion of microplastics explained toxic implications especially on *Pomatoschistus microps* (Oliveira et al., 2013; Luís et al., 2015; Ferreira et al., 2016), zebra fish (*Danio rerio*) (Khan et al., 2015), whales (Fossi et al., 2016; Lusher et al., 2015a,b), microalgae (Sjollema et al., 2015), and on cod, dab, flounder, and the pelagic fish species (mackerel and herring) from the North and Baltic Sea (Rummel et al., 2016).

6.2. Microplastics in fish

Studies have reported the presence of chemicals in fish tissues which are the same chemicals that form plastics. Predator-prey interaction enhances the transfer of the toxic chemicals in greater concentrations since toxic chemicals from multiple sources can accumulate in the body (Andrady, 2011; Wang et al., 2016).

Concerns about the transfer of microplastics and harmful chemicals between trophic levels have resulted in laboratory studies being carried out to demonstrate the impacts of microplastics on marine biota. Several studies have also been undertaken to prove that microplastics are a peril for fish as mortality is prevalent before reaching maturity due to microplastic ingestion. Batel et al. (2016) investigated the transfer of microplastics and potential harmful substances between different trophic levels in the marine environment. In the study, *Artemia* sp. nauplii were subjected to high concentrations of microplastics (1.2×10^6 mg^{-2}), and were found to have ingested and accumulated microplastic particles which ranged in size from 1 to 20 μm, in high concentrations and these were subsequently transferred to zebrafish which fed on the nauplii. Although some of the accumulated microplastic particles were excreted out of the organisms, some got retained within the epithelial cells and the intestinal villi. It was also observed from the study that the microplastic particles acted as a vector for the transfer of associated persistent organic pollutant benzo [a] pyrene (BaP) from the nauplii to the zebra fish, and the substance was retained in the intestinal tract. However, no physical harm was observed in both nauplii and zebrafish. The study clearly proved that microplastics and associated harmful substances can be transferred along food chains across various trophic levels. Rochman et al. (2013) investigated the effect of toxic chemicals that had been sorbed on microplastics in marine fish (*Oryzias latipes*). From the study, the fish ingested and bioaccumulated the harmful chemical substances which resulted in pathological and oxidative stress, and the inflammation of the liver. Several other studies have been carried out on microplastic ingestion by different fish species. About 18% of top predators in the central Mediterranean Sea; swordfish (*Xiphias gladius*), bluefin tuna (*Thunnus thymus*), and albacore (*Thunus alalunga*) were found to have ingested micro, *meso* and macro-plastic debris ranging in sizes, <5 mm, 5–25 mm, and 25 mm, respectively (Romeo et al., 2015). Lusher et al. (2013) found microplastics in 36.5% of the gastrointestinal tracts of pelagic and demersal fish. The range of plastic particle abundance was 1–15 pieces per fish. A total of 351 pieces of plastic particles were identified using FT-IR Spectroscopy. Neves et al. (2015) reported the presence of microplastics in 63.5% of benthic fish and 36.5% pelagic fish species with a total of 73 microplastics identified from the stomach contents of the fish. In a different study carried out on the uptake and effect of microplastics by zebra fish, most of the plastic particles (5 μm in diameter) were seen to have accumulated in the gills, gut and liver while those that were 20 μm in diameter could only accumulate in the fish gut and gills. Hence, the accumulation of the plastic particles caused inflammation and lipid accumulation in the fish liver. It was also observed that the microplastics induced oxidative stress, and altered the metabolic profiles of the fish liver which disturbed the lipid and energy metabolisms (Lu et al., 2016).

In an experiment to investigate the transfer of persistent organic pollutants sorbed unto microplastics from personal care products, the rainbow fish (*Melanotaenia fluviatilis*) were exposed to microbeads that had been sorbed with polybrominated diphenyl ethers (PBDEs) and monitored at 0, 21, 42, and 63 days. Exposed fish were found to have accumulated high concentrations of PBDEs (ca. 115 pg g^{-1} ww d^{-1}) in the tissue after ingestion (Wardrop et al., 2016). The Baltic Sea is reported to be heavily polluted with high concentrations of microplastics (7000–10,000 particles m^{-3}). 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, and altered the feeding and behavior, and even affected the olfactory senses that enhanced susceptibility to killing by predators. This brings to our understanding to the fact that the impacts of microplastics ingestion goes beyond the immediate effect on the fish's digestive system. Hence, the study revealed that the fish preferred to hunt and feed on microplastic particles rather than on natural food. The preference of polystyrene microplastic particles to natural food could be attributed to the size and shape of the polystyrene microplastics which may have made them appropriate for ingestion as has been reported by Moore et al. (2005). Also, the color of the polystyrene microplastic particles could have contributed to their likelihood of ingestion as color is one of the characteristics of microplastics that attract prey (Wright et al., 2013). There was a steep decline in the European perch population which the study attributed to the high pollution of the sea with microplastics (Lönnstedt and Eklöv, 2016).

6.3. Microplastics in other marine biota

The issue of microplastic ingestion is not restricted to fish alone; zooplankton and sea turtles are also susceptible to microplastics. Outdoor mesocosm studies were carried out on the effect of microplastics on the health and biological functioning of the European flat oyster (*Ostrea edulis*) and on the structure of associated macrofauna. The organisms were subjected to low and high doses (0.8 μg L^{-1} and 80 μg L^{-1}) of biodegradable and conventional microplastics for a 60 day period. After exposure, it was observed that the respiration rates of *Ostrea edulis* were elevated in response to high doses of polylactic acid (PLA) microplastics which indicated that the oysters were under stress. Similarly, the abundance and biomass of associated benthic organisms which included periwinkles (*Littorina* sp.), isopod (*Idotea balthica*), and the peppery furrow shell clam (*Scrobicularia plana*) reduced. The reduction was attributed to reduced reproductive output and mortality due to microplastic ingestion and reduced feeding (Green, 2016). Desforges et al. (2015) investigated microplastic ingestion by two ecologically important zooplankton in the North Pacific marine food web; the calanoid copepod (*Neocalanus cristatus*), and the euphasiid (*Euphasia pacifica*) using acid digestion method to assess the ingestion of microplastics by the zooplankton. Microplastic ingestion were 1 particle per every 34 copepods and 1 particle per every 17 euphasiids, with the euphasiids having the highest ingestion of microplastic particles (816 ± 108 μm) than in the copepods (556 ± 149 μm). The results proved that organisms at the lower level of the marine food web ingest microplastic particles which could be attributed to accidental or deliberate ingestion of microplastics by the organisms as microplastic particles can be mistaken for food (Rochman et al., 2013). The study raised concern about potential risks to organisms in the higher trophic level as microplastic particles ingested by zooplankton can be biomagnified to organisms at higher trophic levels (humans included). An example is the salmon fish of the Northwest coast or North America which has been reported to feed heavily on euphasiids and copepods.

Cole et al. (2016), demonstrated the effect of polystyrene microbeads on the feeding, function and fertility of the marine copepod; *Calanus helgolandicus*. The copepods were exposed to 75 mL^{-1} of polystyrene beads and 250 μg C L^{-1} of cultured algae. It was observed that the copepods exposed to the microplastics ingested fewer algal cells which resulted in 11% reduction in algal cells and a significant reduction in carbon biomass (40%). Prolonged exposure resulted in death of some of the copepods, fewer egg productions, and decreased reproductive output which affected hatching. The studies proved that copepods exposed to microplastics suffer energy depletion overtime, and impede feeding in copepods. The results were comparable with Kaposi et al. (2014) and Lee et al. (2013) that also proved that the survival of zooplankton may be impacted by exposure to high concentrations of microplastics.

Filter feeding organisms are very important components of the marine food web and their decline in the aquatic environment could pose severe threats to many trophic levels. The bioavailability of microplastics and harmful organic pollutants (bisphenol A, polybrominated diphenyl ethers, DDT, etc.) which adhere to microplastics and eventually bioaccumulate in marine biota when ingested is of great concern considering the large volume of microplastics particles that enter the aquatic environment. There is a growing fear that the toxic chemicals could cause infertility, genetic disruption, poisoning, reduced feeding, and increased mortality in marine organisms and in humans if ingested in very large quantities (Hollman et al., 2013; Galloway, 2015; Report of the NJDEP-Science Advisory Board, 2015). The uptake of microplastics by marine biota and associated impacts are shown in Table 2.

6.4. Microplastics in sea salt

Abiotic sea products are a source of food for humans and there is a possibility that the presence of microplastics in the sea could lead to the contamination of sea products and potential transfer to humans. One of such products is sea salt. The presence of microplastics in sea salt has recently been proven through the study by Yang et al. (2015) that detected 7–204 particles kg^{-1}, 550–681 particles kg^{-1} and 43–364 particles kg^{-1} of microplastics in 15 brands of rock/well salts, sea salt and lake salt, respectively. The microplastics found were polyethylene, cellophane and polyethylene terephthalate. This demonstrates that along with fish and shellfish (seafood), table salt also appears to be contaminated by microplastics.

7. Fate of microplastics ingested by marine organisms

Different studies did demonstrate that microplastics can be taken up by different marine organisms and once ingested;

- Can be eliminated out of the organism through excretion or production of pseudofaeces, thereby having no long-lasting effect on the organism (Browne et al., 2008).

Table 2
Uptake of microplastics by marine organisms and associated impacts.

Organism	Plastic type	Concentration	Mechanism of uptake/effect	Reference
Shore crab (*Carcinus maenas*)	polystyrene	107 microspheres L^{-1}	Ventilation & ingestion (uptake and retention through gills)	Watts et al. (2014)
Bivalves (*Mytilus edulis*, *Crassostrea gigas*/*Macoma bathica*, *Mytilus trossulus*	Polyethylene/polystyrene microbeads	250 beads mg L^{-1}	Ingestion/accumulation in soft tissues	Van Cauwenberghe and Janssen (2014); Setala et al. (2016); von Moos et al. (2012).
Microalgae	Polystyrene		Ingestion/affected growth	Sjollema et al. (2015)
Marine fish (*Pomatoschistus microps*, *Artemia nauplii*, *Danio rerio*, *Oryzias latipes*)	Polyethylene/polystyrene beads	1.2×10^6 particles mg^{-1} and 12 mg L^{-1}, 0.5 mg - 2.5 particles mg^{-1}	Ingestion/pathological stress/inflammation of liver/oxidative stress/lipid accumulation in liver	Ferreira et al. (2016); Batel et al. (2016); Lu et al. (2016); Rochman et al. (2013)
Whales (*Balaenoptera physalus*, *Mesoplodon mirus*, *Megaptera novaeangliae*)	Polyethylene/polypropylene/Polyvinyl chloride/Polyethylene terephthalate/nylon		Ingestion/increase in toxi- cological	Fossi et al. (2016); Lusher et al. (2015a, 2015b); Besseling et al. (2015)
Demersal (cod, dab, flounder/pelagic fish (herring & mackerel)	polyethylene	54 particles mg^{-1}	Ingestion	Rummel et al. (2016)
Zooplankton (*Centropages typicus*, *Daphnia magna*)	Polystyrene beads	4000 mL^{-1} & 400 mg L^{-1}	Ingestion/decreased algal feeding/causes immobilization	Cole et al. (2013); Rehse et al. (2016)
Sea turtles	Polypropylene/polyethylene	–	Ingestion	Caron et al. (2016)
Gooseneck barnacles (*Lepas* sp.)	Polyethylene/polystyrene/polypropylene	–	Ingestion	Goldstein and Goodwin (2013)
Brown shrimp (*Crangon cragon*)	Microplastics	0.68 ± 0.55 g^{-1} w.w (200–1000 μm)	Ingestion	Devriese et al. (2015)
Mussel (*Mytilus edilus*), amphipods (*Allorchestes compressa*)	Polyethylene/polystyrene/microbeads	2.5 g L^{-1} (0–80 μm), 0.51 g L^{-1} (2 μm and 9 μm)	Ingestion/inspiration/formation of granulocytomas and lysosomal membrane destabilization/vector for accumulation of POPs	von Moos et al. (2012); Avio et al. (2016); Browne et al. (2008); Chua et al. (2014).
European flat oysters (*Ostrea edulis*)	Polylactic acid	0.8 μg L^{-1} & 80 μg L^{-1}	Ingestion/elevation of respiration rates	Green (2016)
Lugworm (*Arenicola marina*)	Polylactic acid/polyethylene/polyvinyl chloride/polystyrene	1.4–707 & 250 μm, 2.5–316 & 112.9 μm, 8.7–478 & 143.5 μm	Ingestion/increase in metabolic rates, production of less fecal casts/affect fitness	Green et al. (2016); Besseling et al. (2012).
Copepod (*Calanus helgolandicus*, *C. cristatus*, *Euphasia pacifa*)	Polystyrene	75 particles mL^{-1}	Ingestion/reduced feeding, decreased reproduction, fewer egg production	Cole et al. (2016); Desforges et al. (2015)

- Microplastics can remain within the organism and translocate between tissues as Hall et al. (2015), and Van Cauwenberghe and Janssen (2014) found in bivalves and scleractinian corals, respectively.
- Microplastics can be retained and have negative effects on the organisms that ingest them. Laboratory studies have shown the adverse effects of microplastic ingestion. Microplastics can increase toxicological stress in fin whales (Fossi et al., 2016) and affect algal growth (Sjollema et al., 2015). It is known to cause liver toxicity and inflammation, and cause the accumulation of lipids in the liver of fish (Lu et al., 2016). Microplastics can also serve as vector for the assimilation of persistent organic pollutants (POPs) and heavy metals by marine organisms and the environment (Chua et al., 2014; Brennecke et al., 2016), and reduce the feeding activity of invertebrates (Besseling et al., 2012).
- Lastly, organisms that have ingested microplastics and have microplastics inside them may subsequently be fed upon by other higher animals in the food web thereby, transferring the microplastics to other animals in the trophic level.

8. Various management strategies for microplastic pollution

Plastic production has followed an exponential increase for several decades and it seems inevitable that the abundance of microplastic particles will continue to increase in years to come. As an emerging pollutant of great concern, there is little or no public and private sector awareness of the possible detrimental dangers posed by microplastics and nanoplastics as compared to macroplastics. To decrease the entry of microplastics into the aquatic environment, the original sources and classes of plastics and microplastics entering the marine environment need to be identified. Also, creating public awareness through education at the public, private, and government sector will go a long way to raise awareness about microplastics. Ivar do Sul et al. (2013) provided the first in-depth exploration of the effects of microplastics on the marine environment and biota. They drew the attention of the scientific community on the monitoring of contaminated pellets so as to determine temporal patterns of the various toxic chemicals that could aid decision-making for future works.

Concern about microplastics has led to the development of management guidelines by several organizations. For example, The United Nations Expert Panel of the United Nations Environmental Programme (UNEP) has called for immediate action to rid the oceans of microplastics as they have noted that microplastics are consumed by a large number of marine organisms, and that this inflicts both physical and chemical harm on them. Therefore, UNEP has come up with a program engaging over 40 million people from 120 countries and has set up educational measures to create awareness and promote the decrease of plastic use, encourage recycling, and evaluate disposal facilities (UNEP, 2014; Caruso, 2015). Similarly, the United Nations Environment Program/Mediterranean Action Plan (UNEP-MAP), the Oslo/Paris convention (for the protection of the marine environment of the North-East Atlantic (OSPAR), and the Baltic Marine Environment Protection Commission-Helsinki Commission (HELCOM) have developed guidelines for assessing marine litter including microplastics. The plan includes organizing several workshops to encourage capacity building and spreading of good practices among individuals. The plastic industry in 2011 came up with a Joint Declaration of the Global Plastics Associations for solutions on marine litter which comprised programs to reduce litter and commitment to support a number of litter assessment. Non-

Governmental Organizations (NGOs) have also come up with programs aimed at raising awareness and help to quantify the extent of microplastics pollution and the effects at the national, regional and international scale. All are aimed at creating a safe environment for marine life and for humans. The Plastic Disclosure Project (PDP) intends to reduce the environmental impact of plastic wastes by encouraging companies to use plastics more efficiently and intelligently and creating awareness on methods for daily use of plastic materials.

The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) advocates for all nations to lead urgent efforts on decreasing the amount of plastics entering the ocean by adopting the reduce-reuse-recycle circular economy (3-Rs) as this will represent a cost-effective way of reducing the quantity of plastic objects and microplastics particles entering and gathering in the ocean (GESAMP, 2015). In 2015, the California Microbead Ban, AB 888 was approved. The ban is to provide the strongest protections from plastic microbead pollution in the country, which include the banning of all types of plastic microbeads. The bill encourages companies to use natural alternatives such as walnut husks, sea salt and apricot pits. AB 888 plans to ban the sale of products containing plastic microbeads by the year 2020 (Casebeer, 2015).

8.1. Possible solutions

8.1.1. Exploiting microbes for the remediation of microplastic contaminated environments

Pollution of the marine environment by microplastics has now become so widespread, and their persistence continues to increase as they seem to be extremely difficult to remove manually because of small size and less visibility. Also, the rate at which microplastics enter the environment supersedes the rate of removal. Identifying the possible origins of sea and land-based sources for plastics and microplastics will go a long way to allowing mitigation methods to be better developed. However, a more promising approach could be provided by utilizing microbes that are able to degrade microplastic polymers in a process called biodegradation. Biodegradation is the process by which microorganisms are employed for the degradation of a synthetic polymer. Microbes utilize the polymer as a source of carbon and energy (Caruso, 2015). Bacteria are very opportunistic and can invade and adapt in any environment. Several bacteria species have been reported to degrade plastic polymers. For example, Singh et al. (2016) reported the degradation of polyethylene by *Staphylococcus* sp., *Pseudomonas* sp., and *Bacillus* sp., isolated from soil. Similarly, Asmita et al. (2015) isolated microbes from different soil samples that had the potential to degrade polyethylene terephthalate (PET) and polystyrene (PS). The isolates included species of *Aspergillus niger*, *Pseudomonas aeruginosa*, *Bacillus subtilis*, *Staphylococcus aureus*, and *Streptococcus pyogenes*. *Rhodococcus ruber* was found to have the ability to degrade polystyrene in a study carried out by Mor and Sivan (2008). This bacteria species was found to have produced biofilm which helped it to improve the degradation of polystyrene. Microorganisms isolated from Andhra Pradesh and Telangana areas in Hyderabad were reported to possess the ability to degrade polyethylene using the clear zone and weight loss method of assay, indicating that the isolates could be potential microplastic degraders (Deepika and Jaya, 2015). These microbes could be harnessed as an environmentally safe way to degrade microplastics. Such microbes could then be applied to the treatment of sewage wastewater as this could limit inputs from domestic uses. They could also be exploited for the remediation of contaminated environments. Also, the degradation of polyvinyl chloride (PVC) by *Pseudomonas putida* has been reported (Caruso, 2015). Other bacteria that can degrade plastic polymers include *Brevibacillus borstelensis*, *Streptomyces* sp., *Pseudomonas stutzeri*, and *Alcaligenes faecalis*. These organisms produce extracellular polymer degrading enzymes which are able to degrade polymers (Ghosh et al., 2013; Caruso, 2015; Trivedi et al., 2016).

9. Conclusion

Microplastics are very small particles of plastics that find their way into the marine environment through two main sources; cosmetic products and generally when larger plastic debris is weathered into smaller pieces. Usually, this type of plastic enter the marine ecosystem via rivers, drainage systems, runoff from wastewater treatment plants, and by the action of wind, current, and waves. Microplastics are distributed in the oceans globally where accumulation takes place. The distribution in large quantities is common to water columns, surface waters, and sediments of Europe, Asia, Africa, and North America. Due to the relative small size, microplastics are easily ingested by marine organisms and have been found to accumulate in tissues, circulatory system, and brain. The extent to which microplastics represent a hazard to the entire ecosystem is pronounced with the degree of ingestion by a wide range of marine biota and the existence in sea salt. This is of considerable concern because microplastics can cause significant harm to marine organisms and humans. Microplastics reduce the recreational, esthetic and heritage value of an environment and it seems inevitable that these particles will continue to increase in the coming years as ways to do away with the presence have not been feasible. Reducing the problem of microplastics cannot occur without involving the general public, the socio-economic sectors, tourism and companies specializing in waste management. In addition, research avenues are being tested on bacteria of marine origin which have properties that could degrade marine microplastics. Such bacteria could then be applied in the remediation of contaminated environments. Harnessing microbes for the degradation of microplastics is a promising and environmentally safe action plan that will enable the management of microplastics without negative effects, and eventually favor the natural cleaning of contaminated environments.

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