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REVIEW ARTICLE

Mitigation measures to avert the impacts of plastics and microplastics in the marine environment (a review)

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Abstract

The increasing demand for and reliance on plastics as an everyday item, and rapid rise in their production and subsequent indiscriminate disposal, rise in human population and industrial growth, have made the material an important environmental concern and focus of interest of many research. Historically, plastic production has increased tremendously to over 250 million tonnes by 2009 with an annual increased rate of 9%. In 2015, the global consumption of plastic materials was reported to be > 300 million tonnes and is expected to surge exponentially. Because plastic polymers are ubiquitous, highly resistant to degradation, the influx of these persistent, complex materials is a risk to human and environmental health. Because microplastics are principally generated from the weathering or breakdown of larger plastics (macroplastics), it is noteworthy and expedient to discuss in detail, expatiate, and tackle this main source. Macro- and microplastic pollution has been reported on a global scale from the poles to the equator. The major problem of concern is that they strangulate and are ingested by a number of aquatic biota especially the filter feeders, such as molluscs, mussels, oysters, from where it enters the food chain and consequently could lead to physical and toxicological effects on aquatic organisms and human being as final consumers. To this end, in order to minimise the negative impacts posed by plastic pollution (macro- and microplastics), a plethora of strategies have been developed at various levels to reduce and manage the plastic wastes. The objective of this paper is to review some published literature on management measures of plastic wastes to curb occurrence and incidents of large- and microplastics pollution in the marine environments.

Keywords Microplastics · Rise in plastic production and human population · Indiscriminate disposal · Environmental concern · Mitigation or management measures

Introduction

Plastic pollution has been a menace to our society for decades due to continued rise in human population combined with consumption, degradation through abiotic and oceanic factors (fragmentation due to ultraviolet radiation, mechanical abrasion, ocean temperature) and their sources and wide applications in every human endeavours: shipping, packaging, agriculture, automobiles, biomedical, telecommunication, building and construction, furniture, plumbing works, transportation, personal care products, aquaculture and fisheries, textile and clothing, etc. (Fig. 1) (Ismail et al. 2009; Vianello et al. 2013; Wright et al. 2013; Cózar et al. 2014; Turra et al. 2014). This is clearly evident in the Great Pacific Garbage Patch, a ring of marine litter, containing a large amount of plastic wastes, in the central North Pacific Ocean located between 135 and 155° W and 35–42° N (Moore et al. 2001). Around 4% of annual global crude-oil production is channelled and converted to plastic productions, of which thermoplastic resins constitute two thirds of it (Andrady 2003; British Plastics Federation 2008). Plastics are still in high demand in this modern era to improve the quality of life, but undoubtedly have changed the way we live (van Cauwenberghe et al. 2015). In coastal areas, the marine pollution of plastic is

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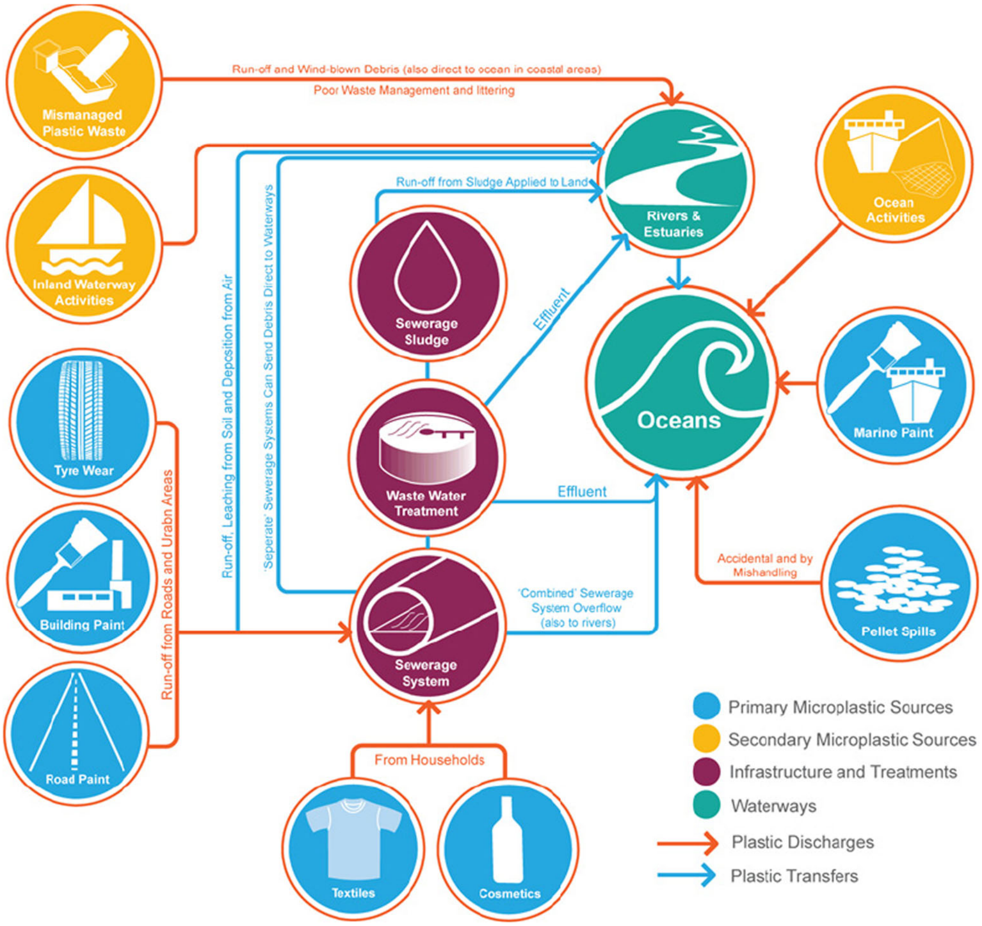


Fig. 1 Major microplastic sources and pathways to the environment (Eunomia 2015)

increasing at an alarming rate due to indiscriminate disposal by the consumers (beach visitors, tourists, shipping/maritime companies, fishery operators) with its continued growing production (Barboza and Gimenez 2015; Kiessling et al. 2017). It has been reported that all plastic materials if not incinerated may still be left littering around in the environment (Thompson et al. 2005). Records have shown that on a global scale, over 300 million metric tonnes of plastics (Fig. 2) are manufactured annually (from 2014 uptil date, 20% come from Europe) out of which 50% of this is disposed indiscriminately into the environment and about 4.8–12.7 million metric tonnes (MMT) end up in the marine ecosystem (water column, sediment and biological tissues) as microplastics (plastic materials < 1–5 mm, classified as primary and secondary), arising from deliberate production such as personal care products or degradation (due to chemical and physical ageing and other mechanisms) of larger plastic litter (Claessens et al. 2011; Cole et al. 2011; Goldstein et al. 2012; Andersson 2014; Law and Thompson 2014; Rochman and Browne 2013; Mathalon and Hill 2014; Jambeck et al. 2015; Singh and Sharma 2016; Auta et al. 2017). Several detailed studies of oceans near human-populated regions have evaluated the contribution of different sources of primary and secondary microplastics to the overall microplastic levels in the marine environment (Sundt et al. 2014; Essel et al. 2015; Lassen et al. 2015; Magnusson et al. 2016). It was generally concluded that the majority of microplastics in the marine environment are from secondary sources, breaking of larger plastic polymers (Waller et al. 2017; Jiang 2018). Microplastic pollution is increasing worldwide because of the difficulty in removing it from the environmental matrices due to its small size and less visibility (Auta et al. 2017). It is estimated that by 2050, an extra 33 billion tonnes of plastic will be added to our planet Earth, meaning that its environmental impact is likely to continue for decades (Rochman and Browne 2013; Wilcox et al. 2015). A recent study conducted by the 5 Gyres Institute estimated that about 5.25 trillion plastic particles are floating in the sea (Xanthos and Walker 2017). Plastics are found everywhere (including the Arctic and Antarctic regions) in our environments (soil/sediment, water-column, biota) in a wide variety of sizes ranging from metres to micrometres and have different routes of entering into various compartments of marine food webs (Barnes et al. 2009; Wright et al. 2013; Eriksson et al. 2013; Eriksen et al. 2014;

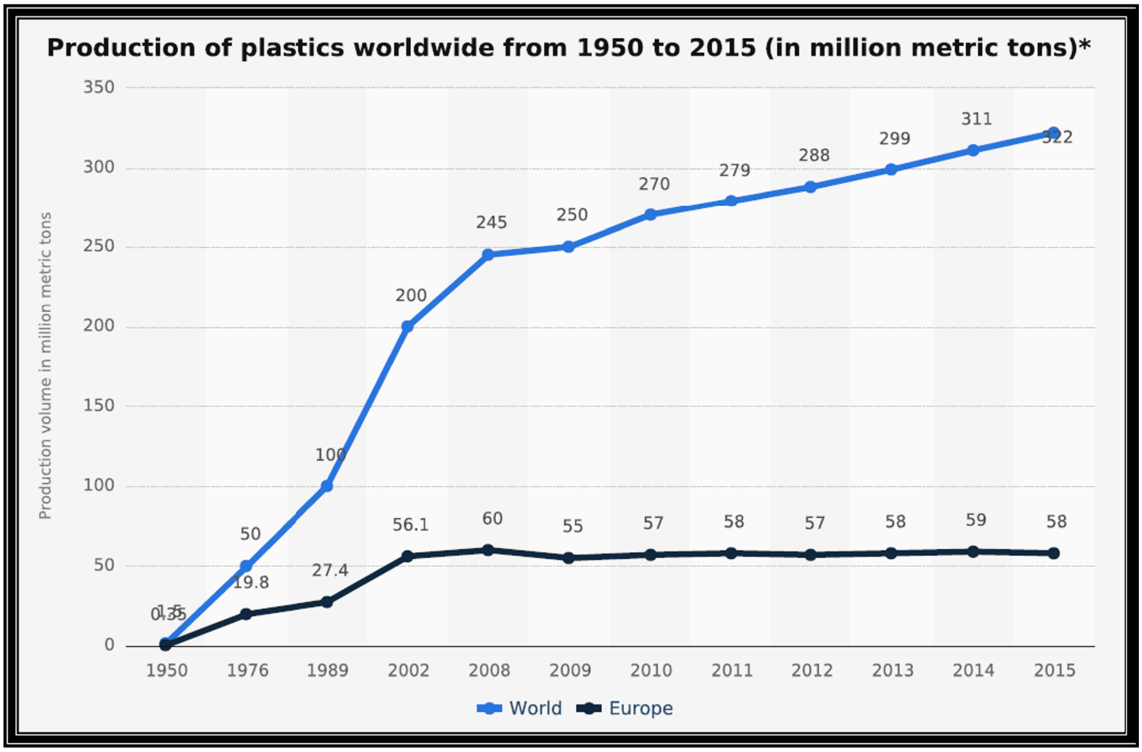


Figure 2 Production of plastics in Europe and worldwide from 1950 to 2015 (MMT) (Statista 2017)

Nuelle et al. 2014; Yang et al. 2015; Boucher et al. 2016; Alomar et al. 2016). The present situation of global plastic pollution is unacceptably alarming and demands stricter regulations on the use and handling (PlasticsEurope 2015b). Extreme weather conditions, like heavy rain, storms and wind, have also contributed and worsened the movement of microplastics from land into water bodies (Cole et al. 2011). Although the societal benefits of plastics are enormous, there are some environmental and socio-economic concerns associated with the material (Andrady and Neal 2009; van Cauwenberghe et al. 2015). For instance, the potential deleterious effects from ingestion (Fig. 3), digestive tract blockage, suffocation and biofouling in many aquatic biota resulting in endocrine disruption, behavioural modifications and changed metabolic processes, have elevated the urgent needs to evaluate the impact of plastics on the whole marine food chain and, ultimately, the consequences for humans as end consumers (Koch and Calafat 2009; UNEP 2011; Cole et al. 2011; Codina-García et al. 2013; Corcoran 2015; Galloway 2015; Anderson et al. 2016). Microplastics are in the same range as plankton, creating mistaken identity and uptake by predators (Browne et al. 2007). Many studies have quantified microplastics in aquatic biota. Wegner et al. (2012) and Von Moos et al. (2012) reported an increased pseudo-faecal deposit, reduced filter-feeding activity and inflammatory response of blue mussel (*Mytilus edulis*) after exposure to 30-nm nanopolystyrene particles. A steep decline in the European perch population has been attributed to the high pollution of the ocean with microplastics (Lönnstedt and Eklöv 2016). Organisms at the higher trophic levels (e.g. marine mammals) are not left out and have been found to ingest microplastics transported by prey items (Eriksson and Burton 2003). Microplastic particles approximately 1-mm in diameter were recorded in the guts of scat of fur seals and Hooker's sea lions (McMahon et al. 1999). They have also been reported to affect algal growth and impose toxicological effects on whales (Sjollema et al. 2015; Fossi et al. 2016). Incidents of entanglement by macroplastics have been widely reported for a variety of marine mammals, reptiles, birds and fish. It is estimated that between 57,000 and 135,000 pinnipeds and baleen whales globally are entangled annually (Butterworth et al. 2012). In many cases, it leads to acute and chronic injury or death (Allen et al. 2012; Nelms et al. 2015). Presently, concerted efforts are geared by the scientists to investigate the toxic exposure of human to plastic debris (microplastics) consumed or ingested by aquatic biota, fish, crustaceans and especially the bivalve molluscs, mussels, oysters, scallops, etc., with particular reference to plasticisers, trace metals, persistent organic pollutants (POPs) and stabilisers, which could impair our health after uptake from the seafood, such as disruption of thyroid and sex hormones (Lithner et al. 2011; Farrell and Nelson

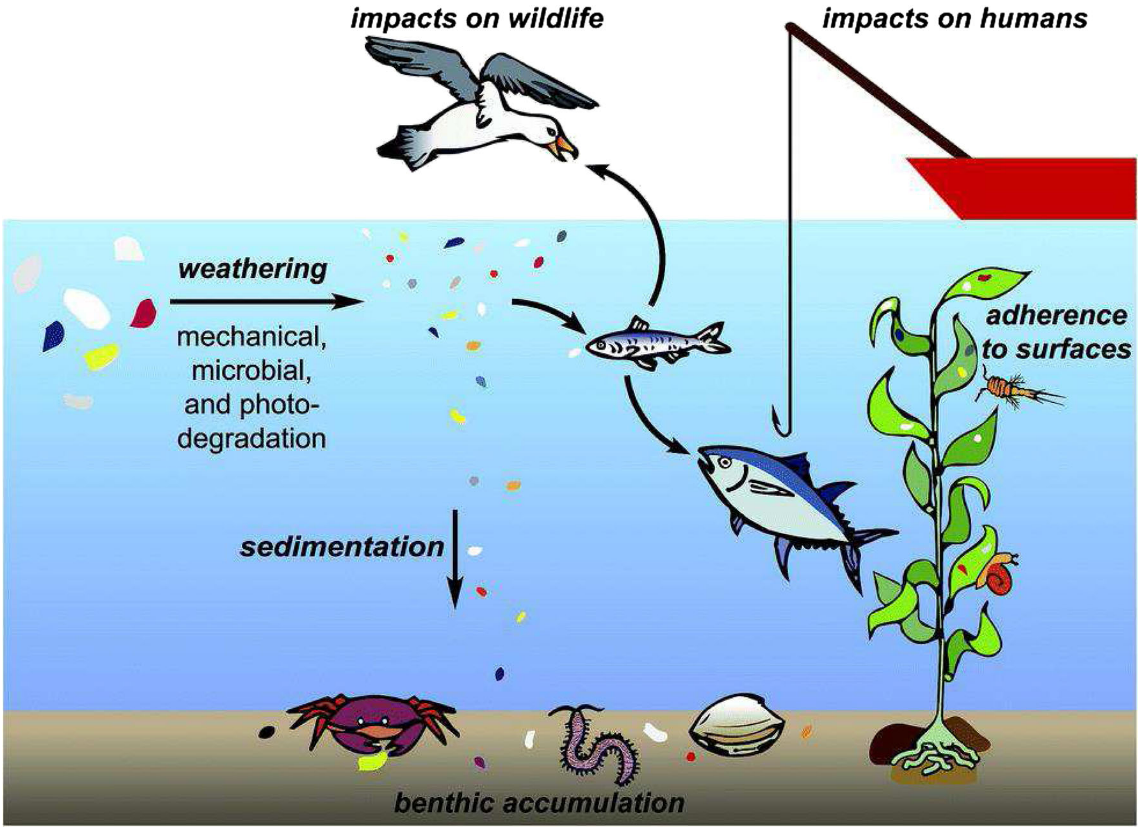


Fig. 3 Interactions of microplastic particles in the marine environment including environmental and biological links (solid arrows), which summarize potential trophic transfer (Bergmann et al. 2015; Lin, 2016)

2013; Mathalon and Hill 2014; Watts et al. 2014; Li et al. 2015; Singh and Sharma 2016). In addition to these, economic losses include the cost of non-action (loss of income) and the cost of action (e.g. beach cleanups). Marine plastic debris may cause a reduction in income as a result of reduced fishing days or reduced tourist numbers, if people are discouraged from visiting by the presence of litter. For instance, Hawaii and the Maldives are facing declines in tourist numbers and associated revenues due to marine litter, particularly plastics, that threaten to affect the reputation of islands as sought-after tourist destinations (Thevenon et al. 2014). On a global scale, plastic wastes have been estimated to cause an annual financial loss of $13.3billion (UNEA 2014).

To tackle the incidence of negative impacts imposed by microplastics, efficient plastic waste managements that are cost-effective, of high quality performance and eco-friendly are required and have been a subject of discourse at local, national, regional and international levels (Pettipas et al. 2016), due to the non-degradability of plastic wastes and toxicity associated with their leachates. The problem associated with management strategy has to do mainly with lack of scientific knowledge due to the limited number of studies (Cole et al. 2011; Bond et al. 2014). To make the situation worse, Seltenrich (2015) reported that no formal management plans to mitigate the incidence of microplastics are put in place in some regions of the world. Since the problem of plastic pollution in the ocean mostly originates from land-based activities, it is advisable to resolve the issue from the source.

The main goal of this manuscript is to review some of the current, advanced strategies in reducing the occurrence and menace of microplastics in the environment.

The commonly used strategies

While management practices have been directed towards macroplastics worldwide, little attention has been given to microplastics because it is an emerging topic and many people are unaware of its impacts thereby making force change difficult. Although the management strategies enumerated here are not exhaustive, they are illustrated as either a mandatory or voluntary entity and provide a general, snapshot picture of the framework of marine plastic particles.

Preventive and regulatory strategies

Preventive measures focus on the way of avoiding the generation of debris or preventing debris from entering the sea. These include source reduction, waste reuse, recycling and composting, waste conversion to energy, debris contained at points of entry into receiving waters and various waste management measures on land (Bergmann et al. 2015). Mitigating measures are concerned with the way plastic debris is disposed of. These measures are imperative and control regulations, and they overlap with preventive counterparts to avoid certain types of plastic debris from entering the sea.

Ecolabelling

Ecolabelling is an invaluable instrument or tool to prevent or reduce marine plastic pollution effectively (Pettipas et al. 2016; Auta et al. 2017). Microplastics take their source from three main domains: land, river and ocean (Galgani et al. 2015; Browne 2015; Jambeck et al. 2015). Walker et al. (2006) and Rovira (2006) reported that ~ 70–80% of the marine litters found in Halifax Harbour and Chilean mainland coast were of land-based origin, which indicates a domestic problem. Pettipas et al. (2016) argued that household plastic disposal is not easily regulated due to inadequate resources for auditing and that it is very difficult to trace waste origins in multi-industrial areas. They put forward that when common items are identified at the sea or along shorelines or beaches, this can help establish specific targets from which further actions can then be taken.

Ecolabelling identifies overall environmental performance and preference of a product within a product category based on life cycle considerations. It is borne out of the growing concern for environmental protection on the parts of governments, businesses and the general public. These labels cover thousands of products that can be regarded as “recyclable, eco-friendly, low energy and recycling contents”. Product categories under this are plastics, soap and detergents, batteries, textiles, cosmetics, packaging materials, drugs and electrical and electronic goods, among others. Its main objectives are to reduce adverse environmental impacts of products, to assist consumers to be environmentally conscious and responsible by providing information to take account of factors in their purchasing decisions and assist them to buy less harmful items and finally to improve the quality of the environment and sustainably manage our resources. The use of ecolabels is gaining ground in developed countries. For instance, the European Union, EU, and the UK have introduced ecolabels to some certain products to stop the growing concern of plastics ending up in our oceans. This strict, voluntary scheme is targeted for companies to use the label for their products (that generate less wastes and easily recycled) so as to gain public acceptance and marketability and its success depends on how many companies sign up (Puritz 2017). About 40,000 products hold the EU ecolabels from packaging materials, baby clothes to electrical and electronic devices. About 65% of the consumers who know the EU Ecolabel have trust in it. One example of ecolabel scheme is the “Nordic Swan Ecolabelled Disposables for Food” which is described as among the least environmentally harmful products to both human health and the environment. The products consist of a high proportion of recycled plastics, less dependent on fossil carbons. The disposables are designed to promote recycling. The label is used as a simple way of communicating environmental work and commitment to customers. The label clarifies the most important environmental impacts and shows how a company can cut emissions, resource consumption and waste management; therefore, it could be seen as a mark of quality. The ecolabels cover packaging items such as coffee cups, disposable tableware, cups, plates, cutlery, drinking straws, bags and films, bread bags, freezer bags, bags for fruits and vegetables. The ecolabel is a well-known, widely used and reputed trademark in the Nordic region (Denmark, Iceland, Finland, Norway and Sweden) and intending companies make application before they could be licenced to get the ecolabel for their products. Furthermore, in a large-scale study conducted in 2001 in Kassel, Germany, biodegradable plastic packaging with ecolabel on them were introduced into the local retail market (Klauss 2001). The primary aim of the scheme was to introduce biodegradable plastics that could be composted. The public was adequately educated and enlightened about the polymer, labelling, separation and collection. Householder surveys indicated that 82% of the population could clearly identify the ecolabel logo printed on the polymers and 90% supported the replacement of conventional plastic packaging with compostable counterparts. The success of the programme lies in the fact that it gained public support and commanded high demand for more of such packaging materials and a reduction in the amount of wastes to landfill and incineration (Song et al. 2009).

Recycling

Because of substantial amount of discarded plastic wastes in landfills and natural habitats worldwide, recycling provides one of the most important actions to reduce the impacts and also represents the most dynamic areas in the plastic industries (Hopewell et al. 2009). Recycling is a waste management strategy aimed at reducing environmental impact of wastes such as plastic polymers and resource depletion. Recycling of plastics is still on a low level around the world. According to the Ellen McArthur Foundation (2016), globally only 14% of plastic packaging is collected for recycling and even less is retained for a subsequent use due to losses in sorting and reprocessing. The recycling rate for plastic packaging varies in different countries, being around 20% in

France, 50% in Germany, Sweden, the Netherlands, Slovenia and Czech Republic in 2014 (Plastics Europe 2015), 7% in India (Singh et al. 2017), < 10% in the USA and 25% in China. To alleviate the vast amount of plastics entering the oceans, the recycling of plastic waste is crucial. Recyclability of plastics depends primarily on the type of plastic resin or the mix of resins and on technologies available for recycling (Dahlbo et al. 2018). Thermoplastics, including poly ethylene terephthalate, PET, polyethylene, PE and polypropylene, PP all have high potential to be mechanically recycled. Mechanical recycling of solid plastic wastes provides an environmental solution to the problem of indiscriminate disposal because it is generally eco-friendly and prevents waste of resources (Lazarevic et al. 2010; Wäger and Hischier 2015). This process involves presorting which can be done manually or automated (laser-introduced breakdown spectroscopy, Tribo-electric, X-ray fluorescence, Froth flotation, Magnetic density, hyper spectra imaging) to separate the plastic materials from non-plastic counterparts, glasses, papers, metals (Singh et al. 2017). The next step involves determining the chemical composition and colour of the plastics spectroscopically or using optical analysis. An extruder is finally used to process the flakes into granules which are melted to form new artefacts. Many governments have developed strategies to make recycling of plastic wastes easy and feasible by introducing a colour coding system in sorting the materials for collection. In this attempt, yellow bins are put in strategic places to collect any plastic wastes. To identify and separate specific types of plastics from one another, the American Society for Testing and Materials, ASTM, has developed a new 7-scale solid equilateral triangle systems for resin identification. For instance, triangles 01, 03, 05, 06 and 07 are for plastics of origins: polyethylene terephthalate, PET, polyvinyl chloride, PVC, polypropylene, PP, polystyrene, PS and others respectively. Although mechanical recycling of plastic wastes still remains the most preferable, it imposes a high operating cost of sorting, cleaning and separating the polymers (Singh and Sharma 2016), although Gu et al. (2016a,b) argued that it is economically viable as it saves up to 20–50% in terms of market prices. Seltenrich (2015) advised that the next generation of plastics could be designed biodegradable (made from carbon dioxide and carbon monoxide compounds and application of metal complexes as catalysts) to reduce their potential of accumulating in the marine environment. This technique provides a double benefit, binding unwanted greenhouse gases, while avoiding the competition with the human food supply. Life cycle analyses have been used to evaluate environmental benefits of mechanical recycling of plastics. It was gathered and concluded that it gives a net benefit in reduction of greenhouse gas emission as well as in landfill and energy consumption (Arena et al. 2003, Perugini et al. 2005). Recycling is gaining public awareness especially in advanced countries of the world. A recent market survey indicated that a significant, but not overwhelming, proportion of people place values on environmental issues in their purchasing power (Hopewell et al. 2009). This attribute could be that the people prefer buying packaging items that are recyclable. In a survey conducted in the UK and Australia in 2006, it is known that 57 and 80% of people participated in recycling schemes among the general population (NEPC 2001; WRAP 2008).

Bans and imposed fees

Strategic plans have been made by governments all over the world to ban the sale and use of lightweight bags and microplastic use in products. For instance, in Europe, Germany and Denmark were the early adopters of plastic bag bans over two decades ago (Xanthos and Walker 2017).

Complete ban or restriction and user fees from the sales and use of plastic bags (single-use) is one of the measures in the reduction of plastic wastes and their accumulation in the marine environment. At least over 30 countries in Asia, Africa, Europe, North America, South America and Oceania have partially or completely banned the use of plastic bags (Dikgang et al. 2012; Gold et al. 2014; EU 2014). Bangladesh was the first nation to outlaw polythene bags in 2002 followed by Myanmar, China and a number of African countries, including Eritrea, Mali, Mauritania and South Africa (Bergmann et al. 2015). In Canada, it is forbidden to manufacture and sell items containing microplastics except for personal care products (Legislative Assembly of Ontario 2015; Pettipas et al. 2016). In addition to this, natural health products and non-prescription drugs containing microbeads will be completely banned from the 1st of July, 2019 (Canadian Environmental Protection Act 2017). In the USA, only five states; Illinois, California (AB 888 in place), Minnesota, New York and Maine, have imposed bans on plastic bags and products containing microbeads whereas Colombia's plan is to reduce the use of plastic bags by 80% by the year 2020 with complete elimination 5 years afterwards (Bill Status of SB2727 2014; Casebeer 2015; California Legislative Info 2016; Auta et al. 2017; Xanthos and Walker 2017). Only three states (Northern Territory, Tasmania and South Australia) and some cities have been reported to ban the use or sales of plastic bags. It is hard to believe that no laws have been passed in New Zealand to ban the use of plastic bags (Clean Up Australia 2015). Most recently, the UK, the Netherlands Austria, Belgium, Luxembourg and Sweden governments announced their plans to ban microbeads in cosmetics and personal care products by the end of this year, 2017, so as to mitigate marine plastic pollution (UNEP 2015; UKDEFRA 2016). France imposed a total ban on the distribution of lightweight plastic bags at supermarket checkouts (Eastaugh 2016). UNCLOS/MARPOL/Honolulu Conventions reiterated complete ban of disposal of plastic wastes at sea by shipping vessels of all member states and signatories, but these regulations are weak due to poor monitoring and surveillance activities and enforcement (Aussendorf et al. 1995; Province of Nova Scotia 2011; UNEP and NOAA 2015). Bans are very effective because they disrupt consumers' behaviour by eliminating their choice and freedom and have been widely supported in Maine and Seattle, USA (Coulter 2009; Carrigan et al. 2011; Hoffman 2016; Wagner 2016). Effectiveness of the ban of plastic bag use could be seen when a substantial amount (levy) is to be paid by the consumers. This tends to change consumers' behaviour and plastic consumption patterns (Homonoff 2013). Rivers et al. (2017) were of the opinion that levying a very small fee on single-use plastic bags does not only regulate but also seeks to guide a preferred behaviour. Post adoption of ban and charged fee (of 5 cents) on plastics in Los Angeles, USA, reports gathered indicated that no plastic bags were distributed by the covered 72 retail establishments in the county (LA County 2012). According to the statistics released by the Welsh government in 2012, there was a drastic reduction in the use of plastic bags from 71 to 96% between 2011 and 2014 since a levy of 5 pence has been introduced (Welsh Government 2014). In Santa Barbara, Canada, following the imposition of a 10 cent fee on plastic bags, total consumption fell woefully by 89.3% (City of Santa Barbara 2016). A survey conducted in Portugal reported that after the imposition of a tax on plastic bags, there was a drastic reduction from the number of plastic bags consumed from 2.25 to 0.59 per person per shopping trip (Martinho et al. 2017). In Taiwan, the Environmental Protection Administration has placed bans on the use of plastic shopping bags and disposable tableware. This policy has been found effective in reducing the number of plastic bags used from 58.34 to 86% within 3 years of the ban, 2002–2005 (Environmental Protection Administration Executive Yuan 2013). On the contrary, the enactment of plastic-use banning scheme has not been successful in South Africa and some other countries because the levy charged was too small and also due to insufficient monitoring system on the ground (Dikgang et al. 2012). The introduction of user charges for single use of plastic bags have been introduced in some parts of the world, as found in the UK and Europe. The use of plastic bags at retailers has fallen drastically in Wales following the introduction of the charge (Neumann et al. 2013). In Ireland, coastal litter survey indicated that there was a drop in the number of plastic bags since 0.15 € user fee per bag was introduced. This is reflected in the consumers' behaviour with a decline in the plastic bag usage from 328 to 21 per capita (Neumann et al. 2013). In Scotland, an introduction of 5 pence on the use of plastic bags in 2014 has been found effective as evidence shows that there is a drastic fall in their usage by more than 80% since the charge was put in place (Howell 2016). In Luxembourg, a charge fee of 3 cents on plastic bags has reduced their usage by almost 85% since 2004 when it was introduced (Luxemberger Wort 2013).

Action plans and regulatory agreements to reduce the inputs of plastic from land- or sea-based sources

Several international conventions and agreements have been introduced to prevent or control the release of plastics and microplastics into the marine environments. The whole problem with plastic wastes could be considered as a "common concern for humankind" (Chavarro 2013).Therefore, this would require increased cooperation and common efforts (concept under international law) to tackle the issue and provide a long-lasting solution on a larger scale. Many of the regional conventions have helped to establish harmonised techniques, indicators and assessments and to implement joint litter reduction actions and measure their effectiveness but the only problem is their implementation, monitoring and enforcement (da Costa 2018).

The OSPAR convention

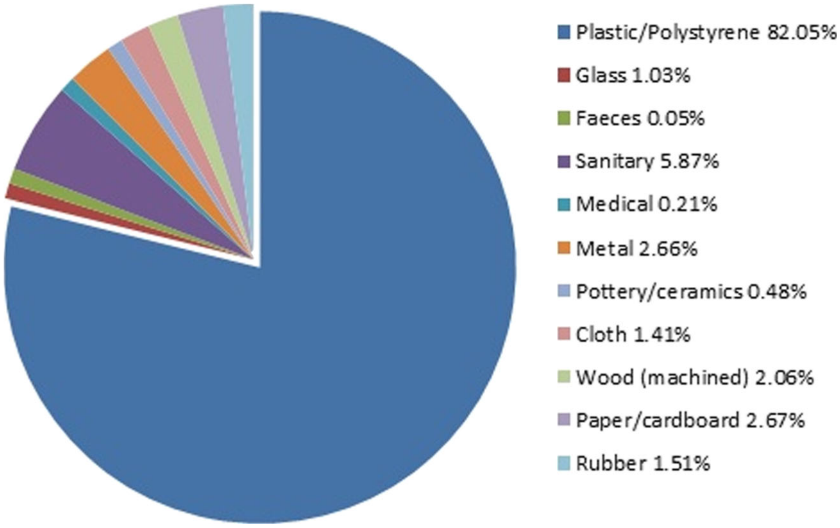
One major international instrument or agreement to reduce the inputs of plastics into the marine environment is the Action Plan on Marine Litter (OSPAR Convention 2014, see https://www.ospar.org/convention). The Convention came to force on 22nd September, 1992, binding and was signed and ratified by all of the contracting parties to the original Oslo or Paris Conventions (Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom of Great Britain and Northern Ireland) along with Luxembourg and Switzerland.

Marine litter covers any solid items which has been intentionally discarded, or unintentionally lost on beaches and on shores or at sea, including materials transported into the marine environment from land by rivers, draining or sewage systems or winds. Marine litter, originates from land- and sea-based sources, is largely based on prevailing, highly demanding human production and consumption patterns. Marine litter is mostly dominated by plastic accounting for over 80% of the items found on the seasurface, beaches and seabed in the OSPAR area of jurisdiction (Fig. 4).

The working areas of OSPAR are grouped into six: (1.) hazardous substances and eutrophication, (2.) Biological diversity and Ecosystems, (3.) Human Activities, (4.) Offshore Industries, (5.) Radioactive Substances, (6.) Cross-cutting Issues.

Its main objective is to substantially reduce marine litters in the area of jurisdiction (North-East Atlantic) to levels where properties and quantities do not cause any harm to the ecosystem by 2020. To execute this objective, Regional Action Plan (RAP) contains 55 collective and national actions to address both land and sea-based sources of marine litters (which fall under human activities section of the Convention) such as

Fig. 4 Marine Litter Composition in the North-East Atlantic (OSPAR 2014)



plastics, paper, rubber, wood and metals. The key action areas include waste from fishing industries, fines for littering at sea, fishing for litter, abandoned and lost fishing gears, reduction in single-use item, education and outreach, removal of microplastics from products, among others. All these action plans are categorised and summarised into four themes, as shown in Table 1. For instance, Fishing for Marine Litter is a simple idea which involves providing bags for participating boats to collect litter such as plastics that accumulate in the nets during fishing activities at Sea. It is a voluntary activity and harbours assist with bag distribution, waste handling and recycling. Currently, there are over 435 vessels and 50 ports involved in this scheme in the North-East Atlantic.

The HELCOM convention

The Baltic Sea as one of the most famous and important marine environments in the world is protected by the Helsinki Convention, which was adopted in 1992 by contracting states; Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. The convention covers the Baltic Sea and its catchment areas to reduce both land- and sea-based sources of pollution. In 2007, HELCOM Baltic Sea Action Plan was adopted covering four major areas of priority: eutrophication, hazardous substances, biodiversity and maritime activities. Our main concern out of these areas is the issue of marine litter which is a rapidly growing concern at sea, having large impacts on the environment, including socio-economic cost, threat to human health and inhabiting organisms in terms of entanglement, smothering, ingestion and mortality. HELCOM developed a regional action plan (RAP) (see http://www.helcom.fi/action-areas/marine-litter-and-noise) on marine litter which was adopted in 2015 with the sole aim of reducing marine litter and in the Baltic Sea by year 2025 and prevent harm to the coastal and marine environment. In the Convention, consumer behaviour was considered as the most important reason for plastic incident and occurrence in the Baltic Sea with contributions of 33 and 48% from tourism and household sources respectively. HELCOM Regional Action Plan for Marine Litter (Recommendation 36/1) sets standards for each member state to put the agreed commitments into actions (at regional and national levels) and to compulsorily include education and outreach on marine litter matters to reach the masses. These action plans on marine litter (related to plastics and microplastics) are summarised in Table 2.

Removing/cleaning-up strategy

Beaches are socio-ecological systems where socio-economic, ecological and physical dimensions or activities overlap (Lozoya et al. 2016). As a coastal interface, they are subjected to plastic pollution from land and sea, mostly associated with beach going, wind, tides and ocean currents (Thiel et al. 2013; Rech et al. 2014; Jambeck et al. 2015). Beach cleaning, which is a community-based approach that involves volunteers, has been described as an effective way to reduce large amounts of accumulation as well as prevent plastics from being washed into the ocean or seas. For instance, about 1271 and 912 plastic fragments and resins were collected from the sandy beach of Punta del Este in Uruguay during a survey (Lozoya et al. 2016). Similarly, about 2985 and 1940 particles per square meter of microplastics were the most common type of particles found and concentrated in the beach of Guanabara Bay in Brazil in summer and winter respectively (de Carvalho and Neto Baptista 2016). The Ocean Conservancy (2005) reported that over 60% of plastic wastes found on a shore in the US 2004 clean report originated from recreational activities. Removing plastic wastes from the beach (termed beach clean-up) and water column is a measure aimed to tidy up the marine environment and has been found very effective in reducing

Table 1 OSPAR Regional Action Plan for Marine Litters

RAP code	Theme	Action plan	Notes	Leading party/parties
30	A	Action to combat sea-based source of pollution	Harmonised system for port reception facilities. Ensure regional coordination and implementation of EU Directive 2000/59/EC in relation to MARPOL Annex V ship generated wastes	Belgium, Germany and the Netherlands
32	✓	✓	Enforcement of international legislation regarding all sectors. Identify best practice to manage ship generated wastes	Tbc ICG-ML
36	✓	✓	Develop best practice in relation to fishing industry on marine litter.	Sweden, the UK
38	✓	✓	Fines for littering at sea. Analyse penalties and fines for waste disposal offences at sea	Germany
39–41	B	Actions to combat land-based sources of pollution	Improved waste prevention and management practices by involving industry and authorities to develop best environmental practices including recycling	Germany, the Netherlands, Belgium
42–44	✓	✓	Incentives for responsible behaviour/Disincentives for littering	Germany, Ireland, Portugal, the Netherlands
46–49	✓	✓	Elimination, change or adoption of the products for environmental benefits such as phasing out the use of microplastics in personal care and cosmetic products	Belgium, Germany, the Netherlands, the UK, Portugal
52	✓	✓	Zero pellet loss by avoiding its loss along the plastic production chain	France, Germany, the Netherlands
53	C	Removal action	Implementation of Fishing for Litter initiative for vessels to land non-operational waste at harbours	Netherlands, the UK, Portugal
54–57	✓	✓	Cleaning environmental compartments such as beaches, inland water-ways. Reduction of abandoned, lost and otherwise discarded fishing gear (ALDFG). Identification of spot where ghost nets may pose threats	Germany, Portugal, Norway, ICG-ML.
58–60	D	Education and outreach	Develop marine litter assessment for education programs. Establish a database on good practice examples on marine litter measures. Develop a communication strategy	ICG-ML, Germany, OSPAR Secretariat

threats from microplastics (Andrady 2011). International coastal cleanups as well as waterway and ocean cleanups are organised worldwide on a yearly or biyearly basis, which involves many volunteers (Ocean Conservancy 2013). In an attempt to put an end to plastic pollution on Israel's beaches, in 2005, their Ministry of Environment launched a program called "Clean Coast" whose aim is to maintain beach cleanliness at all times by involving a joint venture of local authorities, polluters of the coasts, schools and youth movements (Alkalay et al. 2005, 2007). Beginning from 2008, a Foundation called the "Society of Wilderness" has conducted beach cleanups at 26 locations in Taiwan coasts and the number of participants have increased from 370 to 6945 within 2 years (2010–2012) (The Society of Wilderness 2013; Kuo and Huang 2014). Mouat et al. (2010) reported that over €18 million is spent each year by the UK municipalities to remove beach debris and this has increased operating costs by 37%. It is time-consuming, expensive and only a small fraction of the overall debris is captured and may not be feasible for primary microplastics, but effective for secondary microplastics emerging from the breakdown or weathering of macroplastics in water and sediments (Law and Thompson 2014; Ivar do Sul and Costa 2014; Kataoka and Hinata 2015; Newman et al. 2015). Kataoka and Hinata (2015) suggested that the best time to conduct beach cleanup is when there is availability of labour, good weather condition and adequate funding. For a significant effect to be realised, it was recommended that beach cleanup should be conducted every 2 years when the average residence time of the plastic litter is greater than the period of time over which it is being deposited.

Behavioural change strategy

There is a need for people to see a link between their plastic consumption patterns and the consequences in terms of environmental degradation. In one of the largest scientifically based assessments of public perceptions about plastic pollution conducted in Europe, it was gathered and reported that a large number of respondents were ignorant of the environmental issue, but were only aware of climate change and ocean acidification, thereby making the situation through behavioural change worse (Vignola et al. 2013). Educational outreach and public awareness programs must be set up by various governmental and non-governmental (NGOs) agencies to promote change (people's perception, behaviour,

Table 2 HELCOM Regional Action Plan for Marine Litters

Code	Action plan	Note	Operating level
RL1	General improved waste prevention and management	Prepare and agree on HELCOM guidelines on elements highlighting the impacts of marine litter	Regional
RL2	✓	Best practice routines to clean, collection systems that prevent litter from entering aquatic systems	✓
RL4	✓	Improved stormwater management to prevent microlitter such as microplastics from entering marine environment during natural events such as typhoons, cyclones, earthquakes, hurricane, etc	✓
RL6	Measures to tackle top items (micro-particles)	Establishment and overview of sources of primary and secondary microplastics and legal framework within which they operate	✓
RL7	✓	Promote best techniques and research in waste treatment plants to prevent the escape of microplastics to the marine environment	✓
RL10	✓	Define and implement instruments and incentives to reduce the use of plastic bags (levies, deposit fees, taxes, bans)	✓
RL11	✓	Establishment and development of deposit refund systems for bottles and containers	✓
RS5	Actions addressing waste related to fishing and aquaculture	Develop and promote best practices related to all aspects of waste management in fishing and aquaculture sectors	✓
RS6	✓	Develop and promote best practices to Abandoned, lost and otherwise discarded fishing gear (ALDFG)	✓
RS10	Remediation and removal measures	Mapping out historic grounds where ghost nets accumulate and pose a threat to the environment	✓
RS12	✓	Partnership with international organisations to encourage passive fishing for litter	✓
R1-R3 and NE1-NE6.	Education and outreach on marine litter	Developing materials and activities for educational programs and communication strategy on the issue of marine litter	Regional/national

mentality, orientation and perspective) in order to limit the indiscriminate disposal of plastic wastes into the environment (Miller 2005a, b; Nisbet et al. 2009; USEPA 2015; Auta et al. 2017). Raising awareness is a powerful, accelerating tool for voluntary measures and self-regulation of the masses and has the potential to reinforce legal and economic instruments by creating an understanding of the need and benefits of such measure and gaining support of the public (Sherrington et al. 2014). This approach has been found useful, especially in many developing countries that do not have effective waste management systems due to lack of infrastructures to cope with increased levels of plastic pollution (Koushal et al. 2014). Awareness and education campaigns targeting schools, communities and industry have been found successful in changing people's behaviours both in children and adults, especially in coastal areas to reduce single-use bags, including litter prevention, consumption and avoiding contamination of bags (Hardesty et al. 2014). For instance, in Australia, the Teach-Wild program was developed to train a large number of students, teachers and industry employees in a project concerned with marine debris such as plastics and this has helped build knowledge and skills and create and foster positive change attitudes by reducing plastic wastes in coastal areas of the region (Hardesty et al. 2014). The notion that "Change begins with you" at the grass-root levels must be our central focus on environmental management. People should see marine environment not only as common, but privately owned property that needs to be protected and well managed. They should stop littering beaches with plastic wastes during the visit. Mandatory ocean and environmental courses and outreaches must be introduced into our educational curriculum at various levels (primary, high and tertiary institutions) (Kershaw et al. 2011). Workshops, projects and campaigns on ocean management, conservation and protection must be organised for the students and people at large. Tran (2006) reported the importance of involving local populations in various developmental projects as seen in the case of people living on the Island of Holbox (Mexico) who see themselves as an integral part and solution to address various environmental problems confronting them. Wiener et al. (2015) also reported that the native people of Hawaii showed a very strong interest in adopting traditional ocean conservation measures. Furthermore, Kiessling et al. (2017) explained that the people of Rapa Nui (Chile) show the greatest concern for coastal litter and waste management on their island. This strong awareness and willingness of the citizens is traceable to their geographic location, cultural background, biodiversity and economy mainly depending on tourism, therefore, needs to be protected from outside pressure. Public awareness in the use of social media: advertisement, photos, stories and videos can help deliver messages quickly to a large number of people in their localities (Waters et al. 2009). Targeting children and youth is also seen as an effective way to promote positive behavioural change in the society, pursuing marine-related careers and help increase awareness (Hartley et al. 2015; McPherson 2015; Pettipas et al. 2016).

Biotechnology (a potential, promising approach)

Biotechnology offers a new potential approach for the management and complete or partial eradication of plastic pollution in our environment by producing bioplastics that are eco-friendly and can be degraded using micro-organisms or their components: enzymes, cutinases, lipases, esterases, peroxidases, hydroxylases, hydrolases, oxido-reductases (Chiellini and Solaro 1996; Friedrich et al. 2007; Negoro et al. 2012; Kalogerakis et al. 2015). These newly developed bioplastics have similar functionalities and properties and are believed to contribute less to environmental degradation as commonly found in conventional plastic counterparts (Song et al. 2009). Micro-organisms make use of plastic polymers as a source of nutrients (Russell et al. 2011). Laboratory studies have shown the effects of micro-organisms on different types of plastic polymers (biobased or petrochemical based) using hydrolytic or oxidation reactions, although most common plastics have been found recalcitrant to microbial breakdown under conditions that can favour this phenomenon (Krueger et al. 2015). Biodegradation of plastics is influenced by the characteristics of the polymer itself and environmental factors such as heat, light, humidity (Shah et al. 2008). The development and application of bioplastics have grown beyond original simple packaging to a more highly sophisticated application in biomedical and engineering fields. Bio- and petrochemical-based plastics are produced from renewable and non-renewable raw materials of biological and crude-oil origins, starch, vegetable fats and oils, petroleum, and have been tested to be completely or partially biodegradable (Krueger et al. 2015). For instance, polyhydroxyalkanoates, PHAs; polylactic acids, PLAs; poly (butylene adipate), PBA; poly (butylene succinate), PBS; poly (butylene adipate-co-butylene terephthalate), PBAT; and poly (capro lactone), PCL, are formed by melt poly-condensation using direct fermentation of blended starch and other raw materials and have been reported competing with several synthetic thermoplastic counterparts that dominate the market (Zhao et al. 2010). One study stated that bioplastics have the potential of replacing their petrochemical counterparts by 90% of the total polymer consumption as of 2007 (Shen et al. 2009). For instance, PHAs, polyesters produced as a storage material by bacteria, have been used to mass produce fully biodegradable bioplastics that can degrade into carbon dioxide and water under aerobic and anaerobic conditions (Urtuvia et al. 2014). Its biodegradation depends on prevailing environmental conditions such as moisture, temperature, degrading organisms and characteristics of the PHA materials (Tokiwa and Calabia 2004). Bilkovic et al. (2012) revealed that PHAs could degrade completely in seawater within a year in different salinity regimes. There is ongoing research to make use of simple raw materials such as sugar and plant oils for the production of PHAs (Jain et al. 2013). A new type of bioplastic has recently been developed from chitosan material, a polysaccharide, of crustacean shell and insect cuticles which has more advantage and the propensity of degrading within 2 weeks in environmental matrices (Ohta et al. 1999; Fernandez and Ingber 2014). A fabrication method has been developed to mass produce the chitosan bioplastic polymer from the waste products of seafood processing such as chitin-rich shrimp shells and mucoralean fungi. A recent study stated that bioplastics are not in commercial use today, but its demand will escalate in the future and will play a niche role in the global plastic market (European Bioplastics 2013; Krueger et al. 2015). They are still under developmental stage and presently not sustainable because they are expensive, non-availability of infrastructure to compost them and that they compete with lands needed for growing food for human consumption (Alvarez-Chávez et al. 2012; Philp et al. 2013; OECD 2013). Further research needs to be carried out and developed by chemical and plastic companies for cost-effective mass production of bioplastics using microbial metabolic pathways, a knowledge which could be tapped from modern molecular biology, microbial biotechnology and metabolic engineering (SBI Energy 2010; Iles and Martin 2013). Additionally, the environmental impact of bioplastics at the end of their life cycle has been a topic of debate, argument and discussion in the scientific communities (Yates and Barlow 2013). Several species of bacteria, fungi and consortia have been investigated and reported for their potential to biodegrade plastics (Zettler et al. 2013). These include various species of *Pseudomonas*, *Flavobacterium*, *Arthrobacter* and *Agromyces*, most of which are soil or sediment dwellers (Bassi 2017). This can be achieved in combination with other methods such as pre-treatment with temperature, radiation or light (photo) and chemicals (Sheik et al. 2015). Hadad et al. (2005) reported that gram-positive thermophilic soil bacterium, *Brevibacillus borstelensis*, could degrade branched-chain, low-density polyethylene, in combination with ultraviolet radiation. Yamano et al. (2008) showed that *Pseudomonas* strains could degrade nylon polymers with hydrolytic processes. Microbial breakdown of polyethylene with alkane hydroxylase enzyme of *Pseudomonas sp*. was confirmed by Yoon et al. (2012). Although polyethylene terephthalate, PET, is reported inert and recalcitrant to biodegradation (Muller et al. 2001), Ronkvist et al. (2009) showed enzymatic degradation (97% of low crystallinity of films) of the polymer using cutinase from soft rot fungus *Humicola insolens* within 4 days at 70 °C. Cutinase enzymes have been frequently used in PET hydrolysis and reported capable of depolymerising the polymer at least to a certain extent (Chen et al. 2010; Kawai et al. 2014). Negoro et al. (2012) demonstrated and reported the depolymerisation or catalytic breakdown of polymeric nylon from the oligomer hydrolase of *Agromyces*. Santo et al. (2013) used a crude cultured supernatant of *Rhodococcus ruber* and

Trametes versicolor to degrade polyethylene and nylon polymers with enzyme groups, Laccase. Biodegradation of polypropylene and polystyrene, which are widely used polymers, has received less attention because of scarce data. Brown rot fungus, *Gloeophyllum trabeum* has been reported to substantially degrade polystyrene (Krueger et al. 2015). Furthermore, biodegradability of plastic polymers could be improved by grafting the material with biodegradable polymers such as starch and lignin. Caruso (2015) also showed that *Pseudomonas putida* could degrade polyvinyl chloride, PVC. Most recently, Paco et al. (2017) reported that a marine fungus, *Zalerion maritimum*, cultured at 25 °C in seawater was capable of degrading polyethylene polymer, evidenced by the reduction of mass and size of the pellets. Jeyakumar et al. (2013) showed that there was a weight loss of polypropylene by 10% when blended or grafted with starch after 1 year incubation with fungi. Evidence of biodegradation of plastic polymers is clearly seen when there is a reduction in the average molecular weight and slight changes in Fourier transform infrared and nuclear magnetic resonance spectra. For instance, Deguchi et al. (1998) and Yamano et al. (2008) showed an NMR analysis of fungal and bacterial nylon-6,6 and 4 degradations yielding end products with end groups, –CH_3, –NHCHO and CHO and gamma-aminobutyric (GABA) oligomers as a result of oxidative cleavage of C–C, C–N and amide bonds. In addition, Yang et al. (2014) also recorded water soluble end products of microbial degradation of polyethylene, PE using mass spectrometry. The gravity of degradation of polypropylene polymer treated with *Bacillus spp.* strain 27 and *Rhodococcus spp.* strain 36 after 40 days inoculation showed various pores, a number of irregularities and eroded surfaces in the morphological structure of the matrix when observed under scanning electron microscopy, SEM, micrographs (Auta et al. 2018).

The current production capacity for bioplastics globally is about 350, 000 tonnes (Bioplastics 07/08), which represents less than 0.2% of conventional, petrochemical-based plastics, at approximately 260 million tonnes (Miller 2005a, b). However, the environmental performance benefits are not strong enough on their own to override the alternative use of conventional plastics. They also need to be cost-effective, fit for purpose and, ideally, provide unique benefits in use (Miller 2005a, b). Hence, bioplastic polymers have not yet realised their full potential. The costs of bioplastic polymers are generally still much higher than that of their traditional plastic counterparts (Petersen et al. 1999). For instance, most fall in the range 2–5€ per kilogrammes (Bioplastics 07/08) (compared with approximately 1.2€ per kilogrammes for major petrochemical polymers) and this is a major restriction for more widespread use. The costs could be brought down by optimising polymerisation and extraction of bioplastics through the genetic modification of plants. Methods for processing and extraction need further research and there may be stigma around genetically modified organisms, GMOs (Mooney 2009). Bioplastics are already on the market but their use is small (0.1 to 0.2% of total EU plastics). The technology to produce them on a large scale is still in its infancy and so is the research on their impacts. There is ongoing debate as to whether they actually degrade in natural habitats rather than under experimental conditions, particularly if they are present in large amounts (Song et al. 2009; Cho et al. 2011). It is also doubtful whether they will degrade in the marine environment where heat and pressure conditions are significantly different (O'Brine and Thompson 2010). Oxodegradable plastic bags have been found in use in some European countries, Germany, Denmark, France, Luxembourg, Switzerland (Zero waste Europe 2016).

Miscellaneous strategies

Extended producer responsibility (EPR**)** is an efficient waste management policy that is gaining recognition worldwide, especially in many advanced countries: Europe, Canada, Japan and South Korea, to help improve recycling and mitigate land-filling of plastic wastes (OECD 2014). The policy ensures that producers (plastic industries), manufacturers and importers of products and packaging are given sole legal responsibility for collection, recycling and end-of-life management of plastic waste materials (SCBD&STAP 2012). It is designed to make producers responsible for products found littering the public areas such as plastic and packaging wastes. EPR entails providing sufficient, accessible litter bins and recycling points to reduce land-based litter source entering the marine environments. EPR scheme is generally at a less advanced stage in developing countries (except for South Africa). Sweden, for instance, has a general product responsibility law covering plastic packaging items, tyres, automobile, furniture and electrical/electronic devices. The effect is that take-back requirement will accelerate the design of the products for recyclability and material consolidation as well as the use of materials that do not pose environmental issues or complicate recycle stream. EPR has been reported beneficial by increasing the collection and recycling plastic wastes, less budgetary and overall cost of waste management and design of environmental innovations by the government. The only setback confronting implementation of EPR scheme is the lack of enforcement mechanisms to make it work and incorporation of waste management into a new system that takes into consideration social issues such as employment.

Similarly, *provision of incentives* for responsible disposal, collection and recycling has been formulated and adopted in some advanced countries of the world to reduce the number of plastics found in the marine environment (from sea-based sources). For instance, a mandated retailer take-back approach has been operating in some places: New York, California, District of Columbia, Phoenix, Maine, in the USA, to provide free and convenient opportunities for customers to return single-use plastic bags for recycling (Wagner et al. 2013; McLaughlin 2016). A government-sponsored fishing gear buyback was operated in the Republic of South Korea for 10 years (2003–1013) where any recovered plastic polymer fishing line, rope or net are bought at the cost of US$10 per 100 l bag. The collected fishing gear wastes of plastic origin were incinerated and converted to energy. Over 700 tonnes of this waste was collected between 2007 and 2011 from 200 fishing vessels (IWC 2014). This incentive scheme would discourage fishers from discarding their fishing nets at sea and could encourage them to adopt and switching to the use of eco-friendly, biodegradable fishing gears (Kim et al. 2014).

Conclusions and recommendations

The issue of plastic pollution is escalating on a yearly basis on a global scale when compared with other issues such as climate change, ocean acidification, due to increased production, indiscriminate disposal practices by people and industries and inability of plastic wastes to degrade in the environment. It is universally agreed that macro- and microplastic pollution is a significant stressor to marine environments through unintentional faunal ingestion, strangulation and could contribute to the extinction of threatened species. Despite the existence of numerous interventions to resolve the issue, the problem still persists. This paper reviews current strategies to prevent or mitigate/curb plastic and microplastic pollutions and provides information helpful in the decision-making process. Among the strategies elaborated, positive human behavioural change is highly recommended as it can provide a long-lasting solution to the environmental problem. Promoting descriptive norms to influence behaviour has also been found to be extremely valuable in mediating community action and change (UK Cabinet 2011). Recycling is described as one strategy for end-of-life waste management of plastic products as it helps in improving the recovery rates and diversion from landfills. The United Nations Environmental Protection came up with a programme engaging over 40 million people from 120 countries to educate, set up awareness and encourage the use of recycling facilities (UNEP 2014). GESAMP (2015) advised all nations to take urgent efforts on decreasing the amount of plastic wastes entering our oceans by adopting "recycling" as the last stage of circular economy (reduce-reuse-recycle). Legislative measures (conventions) could also help a lot in mitigating the impacts of plastic pollution if they are strongly enforced and monitored and will have a wider coverage of the environment. Such legal, regulatory measures, have been proven effective (to some extent) in some places of the world, but there is urgent need for all stakeholders and parastatals involved to cooperate and address these issues in a meaningful way.

Although, it seems impossible to remove microplastics completely from our environmental matrices because of their small size and less visibility, biotechnology offers a promising and reliable approach to tackle plastic pollution that has prevailed in the world today. Bacteria are very opportunistic and can invade and adapt in any environment (Caruso 2015). Several strains of bacteria (*Staphylococcus*, *Pseudomonas*, *Rhodococcus*) have been effectively reported to degrade numerous plastic polymers such as polyethylene, polypropylene, polyvinyl chloride and polystyrene (Caruso 2015; Singh et al. 2016; Auta et al. 2018). Biodegradation process is an environmentally safe action programme that could ensure management of plastics without any side effects and wade off and favour natural cleaning of microplastics burdened environments. Advanced technology must be prioritised and researched on to develop new materials that are non-toxic, truly compostable, fully biodegradable and can be mass produced (and cost-effective) compared with and also retaining economic properties and performance characteristics as the conventional plastics. According to GESAMP (2015), the existence and utilisation of synthetic polymers persist in human markets and communities; mitigation measures will have to rely on bans, behavioural change, proper disposal of wastes, environmental education, incineration, beach cleanups and biotechnology. For instance, public awareness, ecolabelling, education and the imposed user fee for plastic bags have been found instrumental to change consumer behaviours, the number of single-use bags in circulation and enhance the support and success of regulatory measures. For instance, education has been posited as a powerful tool and building block to reduce plastic pollution, especially utilising children and youths as catalysts for change (Derraik 2002; Ryan et al. 2009).

Bans have been successfully implemented for microplastics, plastic bags and styrofoam in some countries like the USA and Rwanda. For instance, in 2015, California Microbead Ban was approved. The ban provides the strongest protection from plastic microbead pollution in the country. The bill encourages companies to replace and make use of natural alternatives such as walnut husks, apricot pits (Jiang 2018). Providing effective waste management facilities and extended producer responsibility and incentives are integrated approaches that can prevent plastic wastes from entering the marine ecosystems. Intensive or detailed research must be carried out to measure the positive impact of those strategies on a short and long run. Lastly, the occurrence and impacts of macro- and microplastic pollution in the future could be curbed now through multi-disciplinary approach across various spatial and temporal scales.

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