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# A Reviewon Plastic Pollutionin MarineEnvironment

**Poonam Poonia, Loveena Gaur**

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## ABSTRACT

Production and distribution of plastics continue to increase both in developed and developing countries. Plastic pollution in marine environment was reported nearly 50 years ago. Plastic debris has been found in all major marine habitats worldwide. Micro-plastics are the major among plastic debris and have emerged as a threat as well as eco-toxicological and ecological risk for marine habitats. Hazardous and deleterious effects were seen on marine biota as animals ingest plastic debris and get entangled. Measuring or forecasting this issue is a complex and challenging task due to technical limitations and uncoordinated assessment campaigns. Acting to tackle this issue requires adequate metrics to guide and prioritise action at different levels, ranging from sound product design and efficient regional infrastructure, to adequate policies and enforcement. In this review paper, we reflect on the extensive literature on the sources and effects of marine litter, current knowledge on the effects of policies and other actions that are taken worldwide to mitigate and prevent pollution and the recommendations for initiatives, policies and strategies.


Poonam Poonia,*
Assistant Professor, Department of Zoology, Jai NarainVyas University, Jodhpur 112001, Rajasthan,India

Loveena Gaur
Department of Zoology, Jai NarainVyas University, Jodhpur112001, Rajasthan,India
Email :poonam.poonia@yahoo.com
*Corresponding author

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## INTRODUCTION

Plastics are synthetic organic polymers. The plastic material is used for various purposes in everyday life and due to which this material is continuing with great demand over past three decades (Hansen 1990). Plastics are characterized by their low cost, high durability, light weight and strength. They are used in great number of applications, ranging from clothing, household and personal goods and packaging to construction materials resulting in plastic pollutionin environment in various sizes (Am. Chem.Counc.2015). The smallest forms are called micro-plastics categorized further into primary micro-plastics (occur as micro-plastics by design) and secondary micro-plastics (formed by degradation of larger plastic waste) (Soloman and Palanisamiet al. 2016). The plastic pollutants are present in the form of spheres, pellets, irregular fragments and fibers in freshwater, deep oceans and sediments (Alomar et al. 2016).It is estimated that about 70-80% plastic contaminants originate from land based resources which are transported to seas and oceans by rivers (Jambeck et al. 2015). These contaminants can be easily seen as piles of trash on coastlines, marine mammals entangled in fish nets, or sea birds bellies filled with bottle caps, colorful shreds of plastic (UNEP 2014). Estimations are done that accumulative potential of plastics will be in the range of 250 million tons by 2025 in marine environment (Wright and Kelly 2017). Major aspect of plastic pollutant is occurrence of micro-plastics in aquatic ecosystem and the toxic effect of this isthreatening the aqua-life (Avioet al. 2016, Haward 2018).

The first reporting of plastic pollution in marine environment was outlaid nearly 50 years ago (Law 2017). Production and distribution of plastics continue to increase both in developed and developing countries. From 1950s, the plastic production increased almost 200 times, from 1.5 million tons to 300 million tons in 2015 (Wright and Kelly 2017). The threat of plastic contaminations in marine environment hasnot given considerable attention and seriousness about its toxicologyis recently recognised (Stefatos et al. 1999). Plastic debris in seas and oceans has seriously harmed and even killed the large number of marine species, mainly by entanglement, ingestion of plastic litter. Even the plastic pellets and scrubbers are reported to be dangerous for their survival (Derraik 2002).

Worldwide, seafoodconstitutes more than 20% of food intake (by weight) for 1.4 billion people (19% of the global population) (Golden et al. 2016). Marine plastic pollution reduces the efficiency and productivity of commercial sea food market as are widely ingested by marine species especially by the fishes (shell fishes) that are consumed as food. Consumption of such fishes causes high health risk to the consumers as POPs are concentrated in the flesh of sea foods (Beaumont et al. 2019).

In this review we have set out to explore the pollution by plastic in marine environment, sources of plastic pollution, impact and threats of plastic pollution on marine habitat, sinks of plastics in marine environment, remedial measures (solutions to minimize and degrade plastic pollutants) and recommendations for initiatives, policies and strategies.

**Plastic pollution**

Any undesirable changes in physical, chemical and biological aspect in environment having hazardous or deleterious effect on living organisms and their habitat is known as pollution. Among the various types of pollution plastic pollution is most hazardous one, affecting all life forms of land air, water. Plastic pollutionisthe accumulationofplasticobjectsandparticles(plastic-bottles, bags and micro-beads)inthe earth's environment that adversely affects wildlife, wildlife habitat, and humans(Parker et al.2018). Plastics that act as pollutants are categorized into micro, meso, or macro debris, based on size (Hammer et al. 2012). Plastics are inexpensive and durable and as a result levels of plastic production by humans are high (Hester and Harrison 2011). However, the chemical structure of most plastics renders them resistant to many natural processes of degradation and as a result they are slow to degrade. Together, these two factors have led to a high prominence of plastic pollution in the environment(Le Guern 2020).

Plastic pollutants are classified mainly as primary and secondary micro-plastics. Primary microplastics-size ranges from 1nm to <5nm, manufactured through process of extrusion or grinding. It is used as raw materials for plastic pellets, microbeads associated with industrial spillages, for cosmetics, cleaning products and drug vectors. Secondary microplastics formed during degradation of macroplastics due to mechanical, photolytic and chemical degradation of bigger plastics fragments in water environment (Gracaet al. 2017). The eco-toxicity of plastic pollutants depends on physical and chemical properties of plastics such as particle size, shape, surface area, crystallinity, polymer type and chemical additives. There are seven main classes of produced plastics. These are polyethylene (PE),polypropylene (PP), polyvinyl chloride (PVC),polystyrene (PS),polyamide (PA),polyurethane (PUR), polyethylene- terephthalate (PET) (Soloman and Palanisami 2016,Gracaet al. 2017).

The specific gravity of plastics ranges from 0.91 (PE) to 1.5 (PA), therefore depending upon the type of material and size, plastic pollutants can sink to bottom or float on the surface (Avioet al. 2016). Plastic pollutants have hydrophobic nature thus absorbs dangerous organic and inorganic contaminants like heavy metals, personal products, pharmaceutical, polychlorinated biphenyls (Soloman and Palanisami 2016). The degradation of plastic pollutants is very slow therefore persisting for longer time in marine habitats and become available to marine biota (Lalglbauer et al. 2014).

Marine plastic pollution is now considered as global problem of all the ocean regions. The maximum plastic pollution has been reported in the subtropical gyres. These gyres are highly polluted with surface plastics. Among which the North Pacific Ocean gyre, Great Pacific Garbage Patch, carries about 45-129 thousand tonnes of plastic waste and this quantity is still increasing exponentially (Lebreton et al. 2017). Plastic enters into seas and oceans indirectly through the riverine and coastal sources and also directly by disposal (fishing gear and other items) at marine environment (Horton and Dixon 2018, Lebreton et al. 2018, Windsor et al. 2019).

Waluda et al. (2020) surveyed beached marine debris at two locations in the Scotia Sea, in the Southwest Atlantic sector of the Southern Ocean. They recovered10,112 items (101 kg:1996 onwards) from Main Bay, Bird Island, South Georgia in the Northern Scotia Sea between October 1989 and March 2019. Off the items recovered 97.5% by number; 89% by mass was the only plastic. Similarly debris items were collected, 1304 items with a mass of 268 kg, from three beaches between 1991 and 2019, during the austral summer attSigny Island, South Orkney Islands, located in the Southern Scotia Sea and within the Antarctic Treaty area. Among the items recovered plastic items was about 84% by number and 80% by mass.

**Sources of plastic pollution in marine biota**

There are various sources of plastic pollutants which can be distinguished as waste water treatment plants, cargo shipping, fisheries, human waste from beaches and urban run-off (Stolte et al. 2015, Graca et al. 2017,Wright and Kelly 2017). Mintening et al. (2017) detected micro-plastics ranging from 0 to 50 micro-plastics/cubic meter in size >500 micrometer and 10 to 9000 micro-plastics/cubic meter in size <500 micrometer micro-plastics. Weathering and degradation of plastics in marine water has resulted in their brickling and micro-cracking, yielding micro-particles that are carried into water by wind or wave actions and concentrate persistent organic pollutants by partition. Consequently, micro-plastics laden with high levels of POP's are ingested by marine biota (Andrady 2011). Micro-plastics are pieces of marine debris 5mm enters from sources including direct input of small pieces such as exfoliating beads used in cosmetics and as a consequence of the segmentation of larger plastic debris. Resin pellets were among the first plastic debris reported in the ocean (Carpenter and Smith 1972) and have been detected in the sea worldwide (Hirai et al. 2011). Waste water treatment plants are the main source of micro-plastics in aquatic environment (de Costa et al. 2016). Carr et al. (2016) stated that micro-plastics are removed in primary treatment zone via solids skimming and sludge settling processes thus suggesting that minimal load of micro-plastics are found in the effluents from both secondary and tertiary wastewater treatment plants. Efficiency of wastewater treatment can be 99.9% leading an average discharge of one micro-plastic for every 1400 liter of effluent. Synthetic fibers from clothing are the bigger issue than micro-plastics because they are not completely removed even after advanced treatment. 1900 fibers are released in single washing from a single polysterfiber. Tourist activity during summer could be a major entry of synthetic fibers. Tourist activity on the beaches leaving behind various plastics such as bottle cans, straws, bottle caps, packaging materials, wrappers, toys is also source of plastic pollution (Stolte et al. 2015).

It has been reported that approximately 135,400 tons of plastic fishing gear and 23,600 tons of plasticpackaging material had discarded into the sea by the world's fishing fleetin1975 (Cawthorn 1989, DOC 1990). Horsman (1982) found that ships are main source of plastic debris contaminationandreported that merchant ships are dumping 639,000 plastic containers each day around the world. These plastic litters though river flow and municipal drainage systems are reached to the large water bodies of sea and oceans (Williams and Simmons 1997). Ross et al. (1991) reported that recreation and land-based sources are adding about 62% of the total litter in the harbour. According to recent study, microplastics are falling on sea floor, being carried by bottom currents and gets accumulated at certain points in ocean. These points have been coined as microplastic hotspots by some authors. Microplastic hotspots has the highest concentration of plastics as they contain upto 1.9 million pieces of plastic per square meter (Alberts 2020).

**Impacts and threats on marine biota**

Replacement of natural materials by synthetic materials (plastics) in manufacturing of fishing nets, line and all sorts of everyday items resulted in their discardation and transport to most remote areas like ocean shorelines and water causing hazardous effects in marine biota (Laist and Liffmann2000). deCosta (2016) suggested that micro-plastics interact with persistent organic pollutants (POPs) and contaminate marine biota when ingested affecting food web. Micro-plastics and Nano-plastics have unique feature of getting transferred easily in marine ecosystem, across different trophic level inside food web and inside different tissues of animals. There is also risk of contamination by chemicals associated with plasticsin the animals that ingest plastic. These substances are persistent, bioaccumulative and toxic (Rochman et al. 2015).

Various studies have reported lethal effect of ingestion of microplastics on faunas such as fishes, invertebrates and vertebrates of marine ecosystem (de Souza Petersen et al. 2016, Hurley et al. 2017,Reynolds and Ryan 2018, Horton et al. 2018,Redondo-Hasselerharmet al. 2018, Windsor et al. 2019). Ingestion of plastics by marine animals has been reported for the reduced growth and reproduction, change in their behavior, starvation due to gut obstruction (Gall andThompson 2015). Studies of Gall and Thompson (2015) showed that about 233 species of marine vertebrates (seabirds, mammals, fish, turtles) were affected by ingestion, among which sea turtles have shown a maximum record of plastic ingestion. Faure et al. (2015) reported ingestion rate of plastic up to 12.5% in birds and fish in French and Swiss waters. Other than ingestion of plastic debris, entanglement or stucking of plastic item is also a big issue. Fish, Sharks, Turtles, and many vertebrates have been reported to lethally entangled in plastic wastes such as abandoned fishing gear (Gall and Thompson 2015, van Emmerik and Schwarz 2020).

Fishing gear has been shown to cause tissue abrasion and breakage when colliding with sessile vertebrates in coral reef ecosystem and variety of plastic and non-plastic debris items in sea bed have caused changes to ecological assemblages and death due to suffocation. Seabed debris acts as a barrier, preventing light penetration (Uneputty and Evans 1997), reducing the exchange of oxygen and preventing delivery of settling organic matter to sediments, with consequences for marine life (Green et al. 2015). Ingestion of plastic debris in marine animals inhibits the secretion of digestive enzymes, lowers the stimulus for feeding, disturbs secretion of steroid hormone levels, effect ovulation process, causes internal injury and also causes reproductive failure (Azzarello and Van-Vleet 1987). Even death has been shown in small fishes and sea birds due to blockage of intestinal tract (Zitko and Hanlon 1991).As micro-plastics are capable of absorbing organic contaminants, metals and pathogen from environment into organisms thus exacerbates its toxicological profiles as they interact to induce greater toxic effects. Micro-plastics increase dysregulation of gene expression required for control of oxidative stress and activating stress and activating the expression of nuclear factor E2-related factor (Nrf) signalling pathway in marine vertebrates and invertebrates resulting in oxidative stress, immunological responses, genomic instability, disruption of endocrine system, neurotoxicity, reproductive abnormities, embryo-toxicity and trans-generational toxicity (Alimba and Faggio 2019). Ingestion of plastics by sea birds and sea turtles began as early as the 1960s. The potential impacts included entanglement by debris, leading to injury to marine biota such as Albastross, fulmars, shearwaters and petrels by mistake considers them as food and gets affected. About 44% of seabirds have reported for ingestion ofplastic litter and sea turtles with plastic bags and fishing lines. According to Moore(2008)plastic debrishas affected about 267 worldwide species. In recent studies plastic ingestion has now been documented for 233 marine species which includes 100% marine turtles, 36% seals, 59% whales, 59% seabirds as well as 92 species of invertebrates (Kuhn et al. 2015).

Ingestion of plastic particles has reported to affect the certain physiological metabolism in migrating red phalaropes (*Phalaropusfulicarius*) by lowering the fat deposits, hindering migration cognition and their reproductive behavior on breeding grounds (Connors and Smith1982). In a case study by Bourne and Imber (1982) at isolated Chatham Islands (New Zealand) a white-faced storm-petrel (Pelagodroma marina) found dead at a breeding site and was found with empty stomach and gizzard packed with plastic pellets.The chicks of Laysan albatrosses (*Diomedeaimmutabilis*) in the Hawaiian Islands has also reported with the plastic debris in their upper gastrointestinal tract (Fry et al. 1987). Ryan (1988) through the experiment on domestic chickens (Gallus domesticus), postulates that in sea birds feeding with plastic loads had reduced their fitness by reducing the ability of food consumption. A study carried out by Moser and Lee (1992) at coast of North Carolina in the USA on 1033 birds found that about 55% of the species were reported with plastic load in their guts. They also reported that some seabirds confuse plastic pellets with their prey, as they had selected some specific shape and color of plastic item. In early study on various species of fishes, Carpenter and Smith (1972) observed specifically white plastic debris in their gut. Ingestion of white plastic debris was also exclusively reported in loggerhead sea turtles (Carettacaretta in the Central Mediterranean). Turtles also have been reported to confuse polythene bags, drifting in oceans, with their prey items and they target them as food (Gramentz 1988, Bugoni et al. 2001). Balazs (1985) found about 79 turtles gut full with various types of plastic debris. In a New York O'Hara et al. (1988) reported turtle swallowed with 540 m of fishing line. Endangered green sea turtle (*Cheloniamydas*) on the south of Brazil was studied by Bugoniet al. (2001) and found that 60.5% of examined turtles (38 turtles) had ingested plastic debris. Similarly 75.9% of loggerhead sea turtles (*C. caretta*) (54 turtles) were found with plastic debris in their digestive tracts by Tomas et al. (2002).

Tarpley and Marwitz (1993) reported death of a young male pygmy sperm whale (*Kogiabreviceps*) in Texas, USA and revealed that first two stomach compartments of whale was completely occupied by plastic debris (bread wrapper, a corn chip bag and more plastic sheets).Similarly large piece of plastic, that blocked its digestive tract, was reported responsible for the death of an endangered West Indian manatee (*Trichechusmanatus*) in 1985 in Florida (Laist 1987). Secchi and Zarzur (1999) also blamed on a bundle of plastic threads found in the whale's stomach for the death of Blainville's beaked whale (*Mesoplodondensirostris*) in Brazil.Ingestion of plastic debrishas been reported inatleast 26 species of cetaceans (whales, dolphin, porpoise) (Baird and Hooker 2000).

Micro plastic have been reported to affect the living of invertebrates of crabs and carps. Brains of velvet swimming crab (*Necorapuber*) has been identified with the microplastic in the study of Crooks et al. (2020) and they had suggested that this could impact crucial survival behaviors. Mattsson et al. (2017) had reported that microplastics also transfers from blood to brain of Crucian carp (*Carassiuscarassius*) and suggested that impairment of brain disturbs the feeding and swimming. In recent studies Crump et al. (2020) investigated the effect of microplastics on the hermit crab shell selection, after they kept in tanks with and without microplastics. They observed impairedshell selectionbehavior in hermit crabs. They suggested reason that microplastics inhibited the cognition aspect in crabs. The reason for which may be contributed to that microplastics enter the brain of crabs and carp and that potentially disrupts the gathering of information, assessments, decision-making and finally the behavioral responses of selection of shell (Crooks et al. 2019, Mattsson et al. 2017).

**Remedial measures**

Between 1960 and 2000 the world production of plastic resins has increased 25 folds while its recovery is less than 5%. The successful management of the problem requires a comprehensive understanding of both marine debris and human behavior. Knowledge to consumers may help them to make appropriate choices in using and disposing waste items. For successful prevention marine pollution, education and outreach programs, strong laws and policies, governmental and private enforcement are the building blocks to overcome the problem. Plastic industry can play role in educating its employees and customers and searching for technological mitigation strategies (Sheavly and Register 2007). Some remedial measures including material reduction, design for end-of-life recyclability. Development of bio-based feed-stocks, strategies to reduce littering, the application of green chemistry life cycle analyses and revised risk assessment approaches will be most effective through combined actions of public, industry, scientist and policymakers (Thompson et al. 2009).

Rationally 15 bacteria (GMB1- GMB15) were isolated by enrichment technique. GMB5 and GMB7 were selected for further studies based on their efficiency to degrade the high-density polyethylene (HDPE) and identified as Arthrobacter species and *Pseudomonas* sp. respectively. Assessed weight loss of HDPE after 30 days of incubation was nearly 12% for Arthrobacter species and 15% for Pseudomonas species. The bacterial adhesion to hydrocarbon assay showed that cell surface hydrophobicity of Pseudomonas sp. is higher than Arthrobacter species. Both fluorescein diacetate hydrolysis and protein content of biofilm was used to test the viability and protein density of biomass. The results suggested that both Arthrobacter species and Pseudomonas species were proven efficient to degrade HDPE albeit the latter was more efficacious (Balasubramanian et al. 2010).

**Recommendations**

If this global problem is translated to regional and national levels then global commitment and goals provide a good basis for measures around the world. Solutions for this issue will only be effective if the problemis context specific and if local conditions are taken into account, as there are large global differences in the causes of plastic pollution at land and sea. The measures to deal with the marine litter problem has been supported by scientific research including understanding of the sources, fate and effects and customized to the local situation. Most important measure is to identify risk hotspots for both macro-plastics and micro-plastics (Kershaw and Rochman 2016).Well-defined protection goals are needed that are currently absent at many levels. Various authors are in opinion that removal of plastics in the ocean needs to be carried out in places where efforts are ecologically most effective, places more closer to the shores (Shermannand Van Sebille 2016) and not in the middle of the Pacific gyres where impacts on marine animals maybe limited (Wilcox et al. 2015).

To predict the possible effects to marine life and guide the design of effective and resource-efficient management measures risk assessment models can be helpful (Shermannand Van Sebille 2016).There isan ample example that shows that market-based instruments and legislation, such as waste management policies, bans on certain products (plastic bags and other items) can be very effective (Martinhoet al. 2017). Strategies like taxes and chargeson plasticbags have proven to be successful in both developed and developing countries.Market-based items such as-bottle deposit refund schemes and container deposit schemes were shown to be effective too (Hardesty et al. 2014,Gitti et al. 2015).Veiga et al. (2016) suggested that the marine litter problem may stimulate sustainable economics and lifestyles. Plastic solid waste management strategies can involve recycling (Singh et al. 2017), reuse or upcycling (recycling to improve a materials value) (Braungart et al. 2013), extended producer responsibility and redesigning products (for example to make them less hazardous) (Singh et al. 2017). A move towards sustainable and resilient societies may be needed to increase awareness within society of all stakeholders, such as producers, consumers and governments. Awareness rising can be change-oriented like the 'Beat the Micro-bead' campaign "Beat the Micro-bead 2017"resulted in the announcement by manufacturers to stop using microbeads in the cosmetic products. United States of America passed a federal law to ban microbeads in rinse-off personal care products in 2018 (Kershawand Rochman 2016, Rochman et al. 2015). There could also be ways like legislation and measures to reduce the use of plastics for restricting the use of single-use plastics in all sectors. The Clean Seas global campaign on marine litter by United Nations Environment (UN Environment) also aims at worldwide elimination of micro-plastics in cosmetics and the excessive, wasteful usage of single-use plastic by the year 2022.

However, apart from environmental knowledge, skills to turn plans into action and in the right context are also required (Naustdalslid 2011). For school children education has been demonstrated to be important, as it increased their understanding and stimulated them to come into action (Hartley et al. 2015). Higher education for sustainable development also reflects on the complexity of behavior and decisions in a future-oriented and global perspective of responsibility (Barth and Burandt 2013). Open education in the form of Massive Open Online Courses (MOOCs) has attracted many institutions and learners worldwide with its goal to make education available to a global and massive audience (Kalz 2015). The MOOC on Marine Litter, as part of the Clean Seas Campaign (UN Environment 2017), calls on actors to work on change-oriented solutions; on governments that are urged to pass plastic reduction policies; on private sector enterprises to commit to improving plastic waste management and work on circular economy principles (re-design, re-use, recycle, recover plastics and phase out non-recoverable plastics) and on the general public to reduce their plastic footprint(Leire et al. 2016).

## CONCLUSION

Plastic pollution in marine and coastal environment is a challenging restoration and governance issue. This marine plastic pollution is transboundary and therefore governance solutions are complex. It gives an example of an environmental restoration challenge where successful governance and environmental stewardship would likely result in healthier global oceanic ecosystem. Still there are many issues and challenges need to be considered and addressed about the marine plastic pollution.

Standardized methodology and sampling are lacking in detection quantification and characterization of plastic debris in marine environment. Systematic observations are not extensive or long enough to determine plastic distribution on coast lines, in water column, in sediments and sea floor which will be required for determining the size- frequency distribution of plastic debris, from nanoparticles to large debris. We need to understand in which human attitudes and behavior can be influenced to reduce the sources of plastics pollutants in the environment. Even if the discharge of pollutants suddenly stopped, harm to organisms would continue for many decades due to long life of plastics. To limit the harmful impact of plastic debris various actions such as efficient waste water treatment, waste disposal, recycling of plastic materials are urgently required. Education and public involvement in understanding the problem, integration and harmonization of science discipline and usage of innovating biodegradable plastics and other alternatives are also mandatory approach.Holistic approach that utilizes scientific expertise, community participation, and market based strategies is needed to significantly reduce global plastic pollution problem.

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