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A review of macro plastic pollution in marine environment

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Abstract

Despite its vital importance, we are currently treating our ocean like an enormous dump particularly for plastic wastes. We have collected global level information, compiled data from national level studies and included regional studies pertaining to Andaman and Nicobar islands. More than 320 million tons of plastics are produced globally each year, and for this reason, the introduction of plastic waste into the marine environment is a global concern, causing direct and indirect impacts on ecosystems, marine fauna, and local economies. This review discusses the marine pollution by macro plastics (> 0.5 cm dia) encompassing (i) types of plastic commonly found in the oceans; (i) the global distribution of marine plastic debris in the world's oceans; (ii) threats to wildlife and the environment; and (iii) international / regional agreements and initiatives to prevent and combat plastic debris in the world's oceans.

Keywords : *Plastic pollution, Large debris, Entanglement, Ingestion, Regulation*

Introduction

Marine litter is defined as "any waste, discarded or lost material, resulting from human activities, that has made it into the marine environment, including material found on beaches or material that is floating or has sunk at sea" (Cheshire et al., 2009). The marine debris is a menace to the environment. In a survey conducted from the Arctic to the Antarctic, 20-80% of the debris items collected from 30 islands were anthropogenic debris (Barnes, 2002).It is known to affect about 693 species, out of which 17% are listed in the IUCN Red List (Gall and Thompson, 2015). The fauna and flora existed in the marine habitats are affected severly by human introduced debris from the plastic compounds (Critchell and Lambrechts, 2016).

The characters of the plastics such as lightweight, durable, high thermal and electrical inulation properties, strong and inexpensive causes serious environmental threat (Ryan et al., 2009, Thompson et al., 2009a, Thompson et al., 2009b; Koushal et al., 2014). Due to their efficiency and performance, there is a gradual increase in the usage of plastic (Andrady and Neal, 2009). The plastic industry is one of the largest and fastest-growing manufacturing industries in the world (Vegter et al., 2014) with about 260 million tons of plastic usage annually (Thompson et al., 2009a). Daily life of a human being entangled with plastic in one form or other and in worldwide, almost a million plastic bags consumed per hour (Andrady and Neal, 2009; Koushal et al., 2014). The data in the year 2018 suggestd that 360 million tons of plastic were produced globally with half of it as single-use plastic (Dharmamony, 2018). Asia contributed to 51% of global plastic production in 2018 with China topping the list with 108 million tons (Plastics Europe, 2019). The polyethylene and polypropylene composition plastic are commonly used (Worm et al., 2017). The global production of polyethylene was 140 million tons per year (Sivan, 2011).

Plastic in Marine Environment

Plastic pollution or littering is one of the biggest environmental challenges humans face today (Dharmamony, 2018). It accounts for the major portion of marine litter worldwide (Derraik, 2002; Moore, 2008; Kaladharan et al., 2017; Dharmamony, 2018) and single-use plastic provide a significant contribution to it (Xanthos and Walker, 2017). As reported by Jambeck et al., (2015), based on the year 2010 data, 192 countries were produced 275 million tons of plastics and 4.8 to 12 million metric tons entering in to the ocean as a debris (Fig. 1). Based on several studies on the persistence, size, composition and effect on the environment, there are two categories of plastics viz, '**macroplastics**' (larger plastic materials greater than 0.5 centimeters in diameter) and **microplastics** (smaller particles less than 0.5 centimeters).

Fig. 1. Plastic debris in marine environment

Coastal and marine environments act as an ultimate sink of plastic debris (Vennila et al., 2014). It is predicted that by 2050, there will be more plastic in oceans than fishes unless we find a solution for single-use plastics (Dharmamony, 2018). The commercial production of plastic commenced during the year 1950's from then to till date, the debris of the plastic omnipresent in every environment of earth, including atmosphere (Gall and Thompson, 2015; Barnes et al., 2009; Vennila et al., 2014). Coastal currents, wind direction, and tidal patterns as well as the size, weight, and density of plastic influence the distribution of plastic pollutants across the oceans (Cundell, 1974; Browne et al., 2010; Eriksen et al., 2014). Merchant ships dispose of significant amounts of litter wastes including plastic, into the sea (Horsman, 1982). During the years 2007 to 2013, 24 marine expeditions found that 4291 items of fishing buoys and 1116 foamed polystyrene under the most heavy (58.3%) floating plastic debris (Eriksen et al., 2014).

The summary of studies on plastaics in marine are (Fig. 2),

- The vast majority – 82 million tonnes of macroplastics and 40 million tonnes of microplastics – is washed up, buried or resurfaced along the world's shorelines.
- Much of the macroplastics in our shorelines is from the past 15 years, but still a significant amount is older suggesting it can persist for several decades without breaking down.
- In coastal regions most macroplastics (79%) are recent – less than 5 years old.
- In offshore environments, older microplastics have had longer to accumulate than in coastal regions. There macroplastics from several decades ago – even as far back as the 1950s and 1960s – persist.
- Most microplastics (three-quarters) in offshore environments are from the 1990s and earlier, suggesting it can take several decades for plastics to break down.

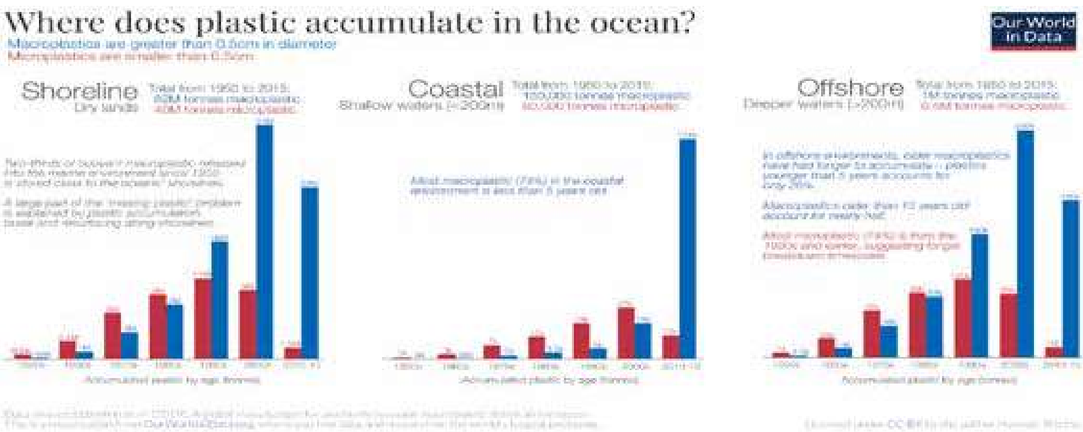

Fig. 2. Marine plastics – source and accumulation (Ref: Lebreton et al., 2019)

Each polymer differs in its time of degradation (Palmisano and Pettigrew, 1992). The degradation of plastic in the ocean is a slow process due to its cooling capacity (Dharani et al., 2003) and complete degradation of plastic might take even hundreds of years (Moore, 2008). They either float on the sea or sink to the bottom and stay for years or even decades (Laist, 1987). The plastic can temporarily break into fragments, which can increase the concentration of microplastic (Thompson et al., 2009b; Browne et al., 2010; Eriksen et al., 2014; Koushal et al., 2014; Vegter et al., 2014), their wider dispersal and their impacts in the environment (Palmisano and Pettigrew, 1992; Engler, 2012).

Impacts and Threats to Marine Life

The accumulation of plastic debris through different environment can impact adversely on marine systems (Ryan, 2015). A large number of marine animals affected by entanglement or ingestion of plastic debris, i.e., over 260 species viz. zooplanktons, fishes, seabirds, sea turtles, corals, crustaceans, bivalves, mammals, etc. (Laist, 1987; Laist, 1997; Derraik, 2002; Dharani et al., 2003; Moore, 2008; Todd et al., 2010; de Stephanis et al., 2013; Cozar et al., 2014) (Fig. 3). As reported by Hall et al. (2015), the Great Barrier Reef Scleractinian corals *Dipsastrea pallida* showed the ingestion of microplastics. Later, Allen et al. (2017) found that the chemosensory cues are the driving force responsible for the feeding of plastics by Scleractinian corals, as a part of his experiment on plastic ingestion by *Astrangia poculata*. The seabirds, especially young and immature birds are more often vulnerable to plastic pollution as they normally ingest floating plastic mistaking for food (Moore, 2008; Thompson et al., 2009b; Van Franeker and Law, 2015). As predicted by Wilcox et al., (2015) during the year 2050, 95% of humans and 99% of all seabird species will have ingested plastic.

The larger surface area of plastics can undergo biofouling and host a wide size range of organisms, which can aid as a dispersion tool, especially for invader species (Derraik, 2002; Reisser et al., 2014; Cozar et al., 2014; Gall and Thompson, 2015). Plastic contains and absorbs hydrophobic organic pollutants (or plasticizers) like PCB, phthalates and bisphenol A (Carpenter and Smith, 1972; Dharani et al., 2003; Oehlmann et al., 2009; Teuten et al., 2009; Thompson et al., 2009a; Koushal et al., 2014; Jayasiri et al., 2015). PCB ranging up to 5 parts per million are being absorbed from the surrounding seawater by plastic (Cundell, 1974). The absorption and adsorption, release of toxic elements like antimony, cadmium, chromium, lead, tin, etc., can contaminate the marine waters and sediment (Nakashima et al., 2012). Further, these absorbed and adsorbed chemical also make more complex mixture of chemical pollutants on marine environment (Rochman, 2015). The contaminants from plastic pose a threat to the animals that ingest them (Derraik, 2002; Teuten et al., 2007; Teuten et al., 2009) as they can bioaccumulate and transfer up the food chain (Engler, 2012; Vennila et al., 2014). The organic pollutants can cause damage to the reproductive system, hormone functioning, thyroid functioning, carcinogenic effects and can even cause genetic aberrations (Oehlmann et al., 2009; Koushal et al., 2014).

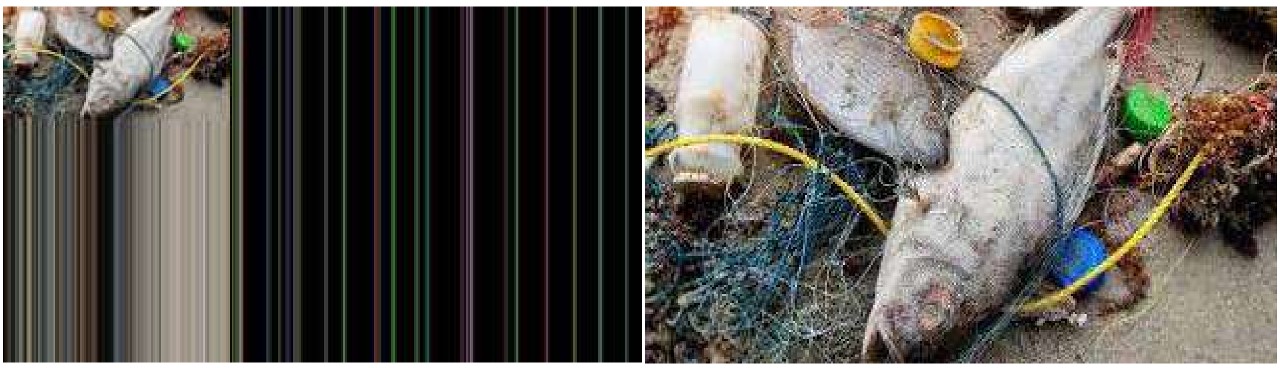

Fig. 3 Effect of plastics on marine life (entanglement)

Global Scenario

The Carpenter and Smith (1972) work on plastic in the marine environment was considered as a pioneering work. This study found out that the Sargasso Sea surface had 3500 pieces and 290gm per square kilometer plastic. Scott (1972) found that the ocean currents transported seaborne plastic pollutants of foreign origin to isolated stretches of the shoreline in Scotland. Velander and Mocogni (1999) compared ten sampling methods for estimating beach litter and found a huge amount of litter accumulation near the vegetation line across all the stations. A review of 13 different sampling protocols used across the world to survey marine litter was made by Cheshire et al. (2009) and they provided a set of standard methodologies and datasheets for marine litter sampling and monitoring. Ryan et al. (2009) reviewed methods used for sampling beach surveys and boat surveys for plastic litter estimation and suggested to use a 50m wide belt for beach litter sampling. The floating plastic debris was sampled using the Neuston surface nets to estimate its concentration (Carpenter and Smith, 1972; Cozar et al., 2014; Eriksen et al., 2014; Van Franeker and Law, 2015). ATR FT-IR (Attenuated Total Reflectance Fourier Transform-Infrared Spectroscopy) technique has been used for identifying the polymer composition of plastic marine debris (Jung et al., 2018). Comparision of data on plastics, the number and mass of plastic debris items are considered significant (Ryan et al., 2009).

Marine debris of different locations of the world was studied extensively. 72% of debris collected from Hawaiian archipelago were plastic particles and their concentration was found to be higher towards the high tide line (McDermid and McMullen, 2004). The samples collected from the strandline of Tamar estuary, NE Atlantic, Polyethylene and Polypropylene (Browne et al., 2010) were the dominant polymers. McIlgorm et al. (2011) estimated $1.26 billion annual damage to the marine industry in the Asia-Pacific region due to marine debris during the 2008 term. Nakashima et al. (2012) collected about 974 plastic samples (26.5 kgs) from Ookushi Beach, Nagasaki, Japan using random quadrat (2m x 2m) sampling. The Spanish marine waters were studied for plastic pollution by Cozar et al. (2014). The convergence zone of each of the five large subtropical gyres accumated 7,359 plastic items (Malaspina 2010), and a minimum of 5.25 trillion floating plastic particles weighing about 268,940 tons (Eriksen et al., 2014). Walther et al. (2018) found a total of 9,04,302 items weighing 1,31,358.3 kg from Taiwan coast in the 12-year period from 2004 to 2016, out of which 90% was plastic. A questionere was prepared with a set of 16 priority questions, as suggested by 26 researchers from around the world, to address the plastic pollution by future researchers (Vegter et al., 2014).

Lebreton et al. (2012) found that the plastic debris accumulated larger level in Northern hemisphere and lesse in Southern hemisphere, based on the transport, distribution, and accumulation of floating marine debris. Potemra (2012) also compared and suggested a few ocean models to study the drifting marine debris. Critchell and Lambrechts (2016) evolved based on the different marine debris study models, quantity of debris, the rate at which plastics sink, resuspension of beached plastics and their source location, the degradation of macroplastics into microplastics at sea and their processes.

Indian Scenario

Indian Ocean coast concern, out of 20 countries, 10 countries are releasing waste into the oceans (Veerasingam et al., 2017). India uses about 15 million tons of plastic annually (Dharmamony, 2018). Plastic shopping bags are one of the main sources of plastic wastes in India (Koushal et al., 2014). In 2002, Legislation was passed to ban <20 μm thick plastic bags, followed by <50 μm thick bags in the year 2005 (Xanthos and Walker, 2017). Indian coastal region, Odisha coast showed the lowest beach litter (0.31 g/m^2) and highest in Goa coast (205.75 g/m^2) (Kaladharan et al., 2017).

Sridhar et al. (2009) collected five samples each from hind dune and mid dune across the beaches in Karnataka and found 22 types of plastic debris (Low-Density Polyethylene and Polystyrene were common). Ganesapandian et al., (2011) quantified the marine litter of Gulf of Mannar along top wet strandline parallel to the beach and found that plastic accounted for 48% of total litter. Kaladharan et al., (2012) collected data on plastic debris from 32 beaches and trawl grounds of eight coastal centers of India gravimetrically along line transects in beaches and from trawling vessels after each haul. Jayasiri et al., (2013) collected samples from the high-tide mark on the beach shore and found an average of 7.49 g and 68.83 items of plastics per square meter from four recreational beaches of Mumbai. The mean concentration of polycyclic aromatic hydrocarbons (9,202.30 ± 114.89 ng g^{-1}) as well as the median concentrations of polychlorinated biphenyls (37.08 ng g^{-1}) and organochlorine pesticides (104.90 ng g^{-1}) in the plastic pellets from Mumbai coast were also significantly high, indicating oil pollution in the Mumbai coastal region as the petrogenic sources (petroleum hydrocarbons) were predominant over pyrogenic sources (Jayasiri et al., 2014; Jayasiri et al., 2015). A mature female specimen of Bigeye Thresher Shark *Alopias superciliosus* collected from Cochin Fisheries Harbor, Kerala, during a gillnet operation at a depth of 200m off Ratnagiri coast, was reported to ingest transparent plastic cover (Diana Benjamin et al., 2014). A total of 44.89% of marine debris accumulated in vegetation line of Marina beach, Chennai (Arunkumar et al., 2016). Around 8.8 million tons of plastic debris dumbed in the ocean by 254 beaches of India, in every year (Kaladharan et al.,, 2017). Nallathanni Island, Gulf of Mannar, coral reef regions shows that plastic debris are the major component of the deposits (Krishnakumar et al., 2018).

Sridhar et al., (2009) identified food-based litter as a major source of plastic pollution in India, while Ganesapandian et al., (2011) report fishery as the major source of plastic litter, followed by tourism. Household items, bottles, and plastic covers are major plastic litter observed on Nallathanni island, Gulf of Mannar (Krishnakumar et al., 2018).

Sampling strategies varied greatly among the researchers. 1m^2 quadrat along 100m line transect was used for collection by Sridhar et al. (2009) and Kaladharan et al. (2012) while 50cm^2 quadrat was preferred by Jayasiri et al. (2013). Ganesapandian et al. (2011) used a wider area of 100$m^2$for collecting samples. Kaladharan et al. (2017) collected triplicate rope quadrat samples of 10$m^2$with 100m intervals.

Andaman and Nicobar Archipelago

The study on plastic debris in Andaman and Nicobar Islands was initiated by Dharani et al. (2003), assessing the magnitude and impacts of marine debris along the coasts of Nancowry and Great Nicobar, with a huge amount of plastic litter originating from adjacent countries. Their finding was later supported by Das et al. (2016) and Sahu and Baskar (2019) with the **majority of debris recorded were originating from adjacent countries like Thailand, Malaysia, Indonesia, Myanmar, China, Cuba, etc., and not of Indian origin**. Mohan and Dhivya (2013) studied on the six-year trend (2003-2008) of plastic waste distribution on Sunset Bay, Colinpure, Port Blair, and found a 400% increase. This study further reported that shoreline/recreational-related debris and ocean/waterway-related debris were highest in Andaman, while smoking-related debris was minimal. Seetharaman et al., (2015) compared the impact of city effluents on water and oysters (*Crassostrea rivularis*) using a polluted area [Phoenix Bay Jetty] and an unpolluted area with least human interference [North Wandoor] and found poor water quality parameters in waters of the polluted area with the high microbial load.

Kaladharan et al., (2017) reported Andaman as extremely littered region in their study where 47% of total debris collected from Andaman was plastic, which included single-use sachets and carrier bags, soft drinks bottles, sachets of edible oils, beverages, detergents, toothpaste, cases of cosmetics, ice cream containers, PET bottles, etc. Sahu and Baskar (2019) collected plastic litter bottles from 5 beaches of Great Nicobar Island and found that 97.8% of bottles were of foreign origin from the countries like Malaysia (40.5%), Indonesia (23.9%) and Thailand (16.3%). Over and above, they also found the debris contribution from the countries like Singapore, Philippines, Vietnam, India, Myanmar, China, and Japan. They identified a continuous increment of litter on beaches and mangroves of the Andaman Islands. Dharani et al., (2003), Das et al., (2016) and Sahu and Baskar, (2019) reported sea-based debris as a major source of litter in Great Nicobar.

Preventive Measures and Recommendations

Like the problem, finding a solution is also a multifaceted process. Beach cleanups are proposed by most of the literature (Dharani et al., 2003; Moore, 2008; McIlgorm et al., 2010; Vegter et al., 2014) but litter cleanup operation is expensive and is having practical difficulties. It is true that good, quality data can help to plan better management strategies as well as help in updating global and national datasets (Cheshire et al., 2009). However, in India, the existing literatures suggested that continuous monitoring of the marine debris is lacking, which lead to deficient data base for the effective action for preventing measures.

It is essential to reduce the plastic waste by the way of curb the single-use plastics (Jambeck et al., 2015). Switch to eco-friendly, biodegradable alternatives that contain no toxic chemicals and which breaks down easily in the environment without any negative impacts (Dharmamony, 2018). Recycling of waste food into biopolymers (which use renewable biomass instead of oil) can reduce the use of non-biodegradable plastic (Thompson et al., 2009b). Establish the incentive system to reduce the use of plastic along with high tax for plastic materials inturn increase the cost of plastic materials are advised. Further, more recyclable packaging should be encouraged (Kaladharan et al., 2017). Deposit-Refund schemes and Take-back schemes are implemented in several countries to promote the returning of plastic waste and can prevent it from getting dumped in the environment. Devices to capture plastic debris like debris booms and litter traps on storm water drains can prevent plastics from reaching to the rivers and oceans (Moore, 2008; McIlgorm et al., 2010).

Fishery related debris act as a major source of plastic related to entanglement. Finding new technologies to decrease the potential for gear loss can aid in reducing the problem (Laist, 1997). The universal 3 'R's: Reduce, Reuse, Recycle, remains a widely advocated solution to reduce the plastic waste and additionally, a 4th and 5th 'R' viz. Recover and Redesign are also proposed (Thompson et al., 2009b; Engler, 2012; Koushal et al., 2014; Kaladharan et al., 2017). Encourage to use the plastic debris as a recycle materials for the fishery products and advise the fishing community to collect the debris to the shore during their operations (Dharani et al., 2003). Controlling the use of disposable single-use plastics, plastic straws, and plastic beverage bottles are also advocated (Dharmamony, 2018). Suggested for the integrated waste management systems for waste collection, disposal, and treatment methods (Worm et al., 2017). The attitude of giving importance to short-term economic gain over the protection of the environment should change in Asian regions (Todd et al., 2010).

Littering is primarily a behavioral issue (Andrady and Neal, 2009). The simplest and effective solution for plastic problem is thus managing the discard behavior in humans (Cheshire et al., 2009). Only education can bring change to their littering behavior (Derraik, 2002; Vennila et al., 2014). Educate the community for the environmental consequences of marine debris which produce a significant difference (Arunkumar et al., 2016). But the message needs to be built on accurate scientific information and should be brought to the public and decision-makers through traditional as well as social media, conferences, press, websites, and advertising (Vegter et al., 2014). It also essential to reduce the production of plastic (Ryan, 2015). Global cooperation is recommended and a new innovative strategy needs to be conceived to address this global issue.

The incineration of plastic shouldn't be practiced as it releases metal-corroding and air-polluting fumes and chemicals (Cundell, 1974). However, as reported by Balasubramanian (2010), who identified and isolated fifteen bacteria by enrichment technique from the Gulf of Mannar, which include two bacteria (*Pseudomonas* sp. and *Arthrobacter* sp.) with a potential of degrading High-Density Polyethylene (HDPE) in in-vitro condition. This methodology should not stop at the laboratory level and scaleup is needed for largescale use in the sustainable environmental activities. In summary, the general steps to manage the marine plastic problems are,

- Reduce our plastic dependency
- Increased producer responsibility
- Increase fees and taxes on polluting plastics
- Increased waste management where the problem is greatest

- Implementation of the zero vision for ocean plastic
- Increased mapping, surveillance and research
- Stop the flow of plastic waste into the sea
- Increased funds and co-operation for clean-up

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