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Plastic Pollution of the Oceans: A Review of Marine Plastic Pollution and Its Environmental Impacts

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Abstract

The invention of plastic played a significant role in advancing human civilization. Plastic products have become an integral part of human lives. However, the usage of plastics generates a huge amount of waste. Studies indicate that about 79% of the plastic the world has ever produced returned into the environment as waste. A significant part of this waste enters the oceans through various pathways. In recent years, the plastic pollution status of the oceans has grown exponentially, and plastic litter represents around 70% of all the pollutants in the oceans. Plastic debris has been linked to the deaths of over a million seabirds and marine animals combined every year. Long exposure to sunlight and saltwater break down plastics into microplastics. Microplastics resemble planktons and are thus consumed by sea animals including commercially important fish and shellfish populations. Studies suggest that microplastics can cause sublethal to lethal impacts on sea lives. Microplastic accumulation has been observed in marine animals at various levels of the food web. This observation could indicate that microplastics may potentially impact human food safety through the consumption of seafood. Unfortunately, there isn't enough data to establish the long-term impacts of microplastic pollution. This paper will discuss the current status of global plastic pollution with its environmental impacts.

Keywords: Ocean plastic pollution, microplastic, plastics in pelagic organisms, ocean gyres, garbage patch.

1.0 Introduction

Plastics are synthetic polymers of extremely long, repetitive molecules that are primarily made of carbon. Some examples of these polymers are polyethylene, polyvinylchloride (PVC), and nylon. The word plastic derives from the Latin word "plasticus" and the Greek word "plastikos", both meaning "able to be molded" (ACS, 1993). Plastics are light-weight and malleable substances and can be molded into shapes to produce a wide range of consumer products. Because of its low cost, light weight, versatility, and mass availability, plastic became popular with the manufacturing and packaging industries and is associated with almost every aspect of our lives - from water bottles to aircraft or even spaceships.

Plastic was first invented in 1856 by Alexander Parkes, a British metallurgist, who named it Parkesine. However, the beginning of the plastic industry dates to 1907 when Leo Baekeland, a Belgian-American chemist, produced the first synthetic plastic called Bakelite (Knight, 2014). Bakelite was resistant to heat and electricity. These properties helped Bakelite to gain popularity in the defense, electrical, and automotive industries (ACS, 1993). Bakelite production was labor intensive (Knight, 2014) and with the innovations of alternative plastic materials, demand for Bakelite dropped. However, Baekeland's work led to the innovation of some significant commercial products, such as polystyrene, polyester, polyvinyl chloride, and nylon in 1929, 1930, 1933, and 1995, respectively (Knight, 2014).

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Due to cheaper production costs, mass availability and versatility, plastic-made products became a significant part of human lives over a short time span. In 1950, the global plastic production was about 2 million MT (Metric Ton). Over the next few decades, plastic industry had a rapid expansion, and by 2015, the annual global plastic production reached about 381 million MT (Geyer *et al*., 2017; Ritchie and Roser, 2018) (Figure 1A). The estimated amount of plastic the world has ever produced is about 8.3 billion MT (Figure 1B), and about 79% of total plastic produced has been stored in landfills or dumped into the environment directly (Rhodes, 2018). As a result, plastic waste has become a major environmental concern and a threat for the ecosystems. However, long-term effects of plastic pollution on human health is yet to be determined. This paper will discuss various aspects of ocean plastic pollution and its environmental impacts.

2.0 Plastics in the environment

With the rapid increase in plastic usages, environmental plastic pollution is growing in an exponential manner, causing one of the most challenging environmental issues. Geyer et al. (2017) reported that most of all the plastic produced were discarded and accumulated in landfills and only about 30% was in use. In another report, it has been estimated that out of the 8.3 billion MT of plastic ever produced, about 6.3 billion MT of plastic waste was generated between 1950 and 2015. About 9% of this waste has been recycled, 12% has been incinerated, and 79% has been stored in landfills or dumped into the environment directly (Rhodes, 2018).

Although scientists warned about plastic pollution in the 1970s, it didn't catch the attention of the broader community until recently. More literature on environmental plastic pollution has been published in the past 5 years than in the previous 50 years before them (Cirino, 2019). Data suggests that a lot of non-recycled plastic eventually ends up polluting the oceans; some estimates suggest that this could reach 4.8 to 12.7 metric tons every year. It is not surprising that wealthier and highly populated countries generate the most plastic waste. But even though some countries have safeguards in place, discarded plastics still enter rivers and oceans.

Data from 2010 indicated China was the number one producer of plastic waste with estimates reaching

Figure 1: (A) Annual and (B) Cumulative global plastic production, 1950-2015: Data illustrates a sharp rise in plastic production over the past 50 years (Credit: Ritchie and Roser, 2018).

59.8 million tons generated per year. However, the amount thought to enter oceans and streams is less than the number two producer of plastic waste, the United States. The U.S. produces 37.83 million tons of plastic waste per year and 275,000 tons of this is estimated to enter rivers and oceans yearly. The number three through ten producers of plastic waste in 2010 were respectively Germany, Brazil, Japan, Pakistan, Nigeria, Russia, Turkey and Egypt (Dorger, 2019). In 2018, China, Indonesia, Philippines, Vietnam, and Sri Lanka were identified as the top five plastic polluters, responsible for producing 56% of global plastic waste (Rhodes, 2018).

3.0 Plastics in the Oceans

Plastic contamination of the oceans is currently an extremely visible form of pollution which started to draw human attention in the 1970s (Law, 2017). Due to a rapid increase in pollution status and its visible nature, this issue has quickly captured the attention of both the general public and the scientific community. A simple visit to a sea beach, where empty water bottles, beach toys, fishing gear, and other plastic debris are readily observed, will show the magnitude of the pollution. Additionally, reports of entangled marine fauna in abandoned fishing nets or ingestion of plastic contaminants by seabird and other marine animals are also well documented and enormously shocking (Wilcox *et al*., 2015; Bjorndal *et al.*, 1994; Brandao *et al*., 2011; Browne *et al*., 2008 and 2011; Choy and Drazen, 2013; Davison and Asch, 2011; Rothstein, 1973; Jacobsen *et al*., 2010; Fry *et al*., 1987).

Presence of plastic wastes has been documented in virtually all marine environments (Choy *et al*., 2019), and a report from the UK Government Office for Science suggests that 70% of all pollutants in the oceans are made of plastics (Thompson, 2017). Plastic waste that enters the oceans is mostly generated in coastal areas within 50 kilometers of the shoreline (Ritchie and Roser, 2018). Eriksen *et al.* (2014) reported an estimated 5 trillion pieces of floating plastic materials in the oceans, weighing over 250,000 tons.

3.1 How Do Plastics Get into the Oceans?

Single-use plastic items that are thrown into the trash make about 50% of the global annual plastic production (Sloactive, 2019). Most managed trash is dumped into landfills and only a small part of that is being recycled. Mismanaged trash is tossed into the open environment. In 2015, the estimated global mismanaged plastic waste production ranged between 60 and 99 million MT (Lebreton and Andrady, 2019).

About 20% of the plastic debris that is polluting the oceans, comes from marine sources. The remaining 80% is terrestrial in origin and carried to the oceans by rivers (Sloactive, 2019). Data from other studies indicate that each year, rivers carry about 1.15 to 2.41 million metric tons of plastic to the oceans and about 67% of all plastic carried to the oceans is contributed by major Asian rivers (Lebreton, 2017). Regrettably, thus far, very few studies have been conducted to evaluate plastic pollution status of freshwater as compared to marine environments. Nonetheless, to appropriately evaluate river plastic emissions to oceans, information on freshwater plastic pollution is essential. Although, the most plastic polluted rivers are in Asia, only about 14% of the plastic pollution studies have been carried out in Asia (Blettler *et al*., 2018). The authors recommended that major focus should be given to study most polluted rivers in the world, particularly, in countries with rapid industrial expansion and poor waste management. This will be helpful to assess the role of rivers in ocean plastic pollution.

It is projected that by 2025, 155 million MT of plastic will enter our oceans every year (Parker, 2015). Another study estimated that in 2010 alone, about 275 million MT of plastic waste was generated in 192 coastal countries of which 4.8 – 12.7 MT entered the ocean (Jambeck *et al*., 2015).

3.2 Oceanic Gyres and Garbage Patches

Gyres are massive circular ocean currents, generated by the earth's rotation, wind pattern, and landmasses surrounding the oceans. They can include hundreds of kilometers of open waters with about 100 meters in depth (National Geographic, 2014). Gyres help circulate the oceans and maintain oceanic conveyor belts. In the Northern Hemisphere, water rotation is clockwise, and in the Southern Hemisphere, it is anticlockwise. There are five

massive Gyres found in the North Atlantic, South Atlantic, North Pacific, South Pacific, and Indian oceans (Figure 2A), and they are: The North Pacific Subtropical Gyre, South Pacific Subtropical Gyres, North Atlantic Subtropical Gyre, South Atlantic Subtropical Gyres, and the Indian Ocean Subtropical Gyre (NOAA, 2019). Along with these major Gyres, there are minor gyres found in the Atlantic, Pacific, and Indian oceans (Beachapedia, 2015). Oceanic debris is pulled into these Gyres and over time, the debris forms into large masses and become garbage patches.

3.3 The Great Pacific Garbage Patch

Among the garbage patches, the largest one was discovered in 1997 by Captain Charles Moore (Parker, 2018). This 600,000 square mile garbage patch is in the North-Central Pacific Ocean between Hawaii and California (Sharma and Polan, 2018) (Figure 2B). It is estimated that this garbage patch contains about 1.8 trillion pieces of plastic materials. About half of this patch consists of plastics from fishing nets and other fishing gear generated from intense fishing activities surrounding that region, and the other half is made of other plastic materials from other sources. For the past 70 years, this garbage collection has been growing at an exponential rate (Sharma and Polan, 2018).

According to a 2015 report, the Great Pacific Garbage Patch could contain an estimated range of 15-51 trillion microplastic particles, with an estimated weight between 93-236 thousand MT (van Sebille *et al*., 2015).

3.4: Plastics and the Marine Ecology

Our knowledge of the long-term effects of plastic pollutants in the marine environment is limited. However, since these pollutants are reported to interact with marine animals (Rothstein, 1973; Boerger, 2010; Murray and Cowie, 2011; Lusher *et al*., 2012; Vandermeersch *et al*., 2015; Wilcox *at al*., 2015; Lamb *et al*., 2018; Cirino, 2019), it is expected that they will understandably affect marine ecology.

Accumulation of plastic particles in sea birds was reported in 1973 (Rothstein, 1973). A risk analysis study with 135 species of seabirds revealed that 90% of these birds had ingested plastics. Studies also predicted that this number may reach as high as 99% among all bird species by 2050 unless effective plastic waste management protocols are in place (Cirino, 2019; Wilcox *et al*., 2015). According to UNESCO (United Nations Educational, Scientific and Cultural Organization), every year, over a million sea birds and more than 100,000 marine animals

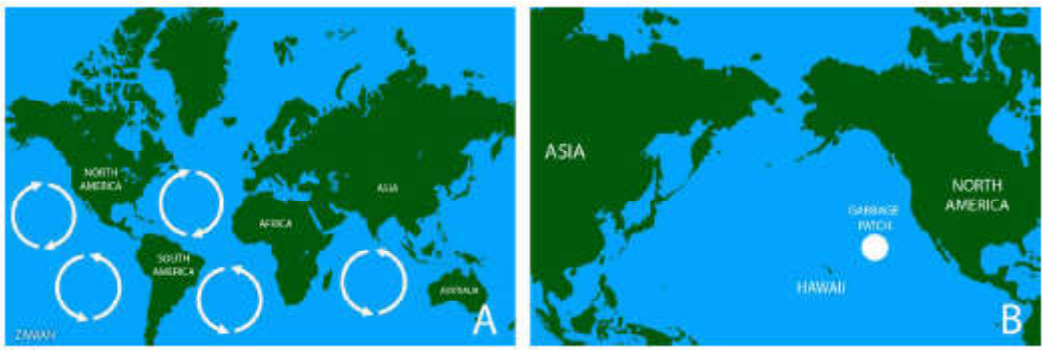

Figure 2: (A) The five major Gyres in the oceans, (B) The Great Pacific Garbage Patch located between California and Hawaii.

Figure 3: Plastic pollution affecting marine lives (Source: Google, 2019)

die from plastic debris-related causes (UNESCO, 2017) (Figure 3).

A recent study indicates plastic wastes in oceans can also promote microbial growth and cause outbreaks of disease in coral reefs. The risk of disease could be increased by 4% to 89%. This research also estimates that over 11-billion pieces of plastic are associated with the coral reefs of the Asia-Pacific and this number could be 40% higher by 2025 (Lamb *et al*., 2018).

Plastics are photodegradable materials and they break down into microplastics with the action of sunlight and saltwater. Microplastics are <5 mm in size (Vandermeersch et al, 2015) with dimensions as small as a few microns (Van Cauwenberghe et al., 2013) and in the oceans, they originate from degradation of plastic debris. Microplastic distribution in the marine environment depends on the size and density of the particles. Lighter particles remain afloat in ocean water, while heavier particles sink and settle in the sediments. Additionally, bioaccumulation of microplastics in marine organisms may redistribute microplastics within the ocean water columns (Clark *et al*., 2016). Therefore, the presence of microplastics is ubiquitous in the marine environment and the pollution status has gradually widened throughout the seas and oceans. Microplastics have been detected in beach sediments to deep-sea sediments, ranging in depth from 1100 to 5000 meters (Van Cauwenberghe *et al*., 2013; Qie *et al*., 2015; Clark *et al*., 2016), and even in polar ice (Obbard *et al*., 2014). Ocean gyres also hold large amounts of microplastics (van Sebille *et al*., 2015). However, at present, we don't have enough information on the distribution and long-term effects of microplastics in the marine environment.

A study of Monterey Bay pelagic ecosystem reveals that microplastics are present throughout the pelagic water with the highest concentration between 200-600 meters. The study also reported transfer of microplastics through the marine food webs and suggested that deep sea water column and the animal community could be the largest reservoir of the microplastics (Choy *et al*., 2019).

Microplastics are mistaken for and often outnumber planktons and are thus consumed by pelagic animals. Microplastics are reported to deliver sub-lethal to lethal impacts on the marine organisms (Wright *et al*., 2013; Nelms *et al*., 2015; Wilcox *et al*., 2015). Several studies have reported accumulation of microplastics in zooplankton, mollusks, crustaceans, and fish (Vandermeersch *et al*., 2015; Boerger, 2010; Lusher *et al*., 2012, Murray and Cowie, 2011), and thus it has the potential of entering the marine food webs, suggesting potential impact on food safety and human health through the consumption of seafood. Clark *et al*. (2016) suggested that marine microplastics that are actively consumed by commercially important fish and shellfish, are fated for human consumption. However, not enough data is available to establish the effects of microplastics on human health.

4.0 Discussion and Conclusion

Currently, the world is inhabited by over 7.5 billion people, and the global population growth is exponential. It can be easily predicted that with the expansion of the human population, the demand for plastic production will also increase, and with the rising demand for plastic production, additional amounts of plastic wastes will also be produced. In 2015 alone, an estimated 302 million MT of plastic waste was produced (Ritchie and Roser, 2018). Without effective recycling programs in place, macro and microplastic litters will continue to rise, posing increasing threats to both terrestrial and marine ecosystems. United Nations Environmental Program (UNEP) has recognized this pollution issue and adopted a resolution to encounter marine plastic pollution through public awareness, effective waste management programs, and governmental oversights (UNEP, 2016).

Despite all the adverse effects of plastic pollution, it is evident that we cannot imagine a plastic-free life as plastics provide us with numerous advantages. Plastic is a versatile material, inexpensive, lightweight and is being used in food packaging, electronics, medical devices, automotive, and products of daily necessities. Moreover, the production of plastic materials is energy efficient and thus can help reduce carbon footprint (UNESCO, 2017).

Reducing plastic pollution could be a challenging but not an impenetrable task. It requires rather a commonsensical approach. We must limit our plastic production and compensate it by optimizing the recycling of disposable plastics. This would undeniably limit the plastic wastes entering the environment and help restrain pollution. Norway, Switzerland and some European Union states are reported to recycle over 80% of their used plastics (UNESCO, 2017), whereas, the world-wide plastic recycling rate is only about 9% (Rhodes, 2018). Additionally, we should also seriously consider using biodegradable packaging materials including bioplastics or biodegradable polymers (Reddy et al, 2013; Luckachan and Pillai, 2011; Arikan and Ozsoy, 2015; Jabeen *et al*., 2015) as substitutes for plastics. At the initial stage, using biodegradable plastics may show some disadvantages such as inadequate availability and higher costs, but such disadvantages will be eased over the time by mass productions of such materials.

One recent situation has thrown a wrench into recycling efforts. For several years, the United States and other countries sold millions of tons of plastic trash to China to be recycled. In fact, approximately 70% of plastic waste from the entire planet went to China. Although several Chinese companies made millions from resale of the processed materials, in 2018 the Chinese government stopped the import of trash. This caused plastic waste to be shipped to countries either not equipped to process or properly dispose of it (Joyce, 2019). Obviously, countries need to become self-sufficient in terms of dealing with their own plastic waste.

The current state of plastic pollution and its ecological impacts are solely a man-made crisis fueled by human ignorance. This is also a reflection of our irresponsible behavior against the environment. Human addiction to single-use plastic items is a major contributor to the plastic waste crisis the world is facing today. With proper strategies and actions, this problem could have been solved years ago (Cirino, 2019).

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