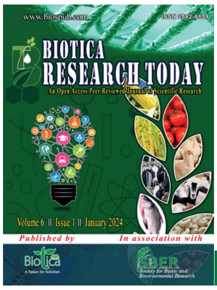

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Micro and Nanoplastics Invasion Everywhere - Will it Take A Toll on Aquatic Organisms?

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Abstract

Among various pollutants, plastic pollution in aquatic environments has a profound impact due to its extensive use and non-biodegradable nature. In 1950, global plastic production was a mere 1.5 million metric tons. However, by 2020, production had surged to a staggering 367 million metric tons. Larger plastics degrade into smaller fragments, known as microplastics (MPs) (<5 mm), and even finer particles called nanoplastics (NPs) (<100 nm or <0.01 µm), driven by environmental forces. Microplastics have been discovered throughout the globe, from oceans to land to air. Astonishingly, recent research has identified microplastics even within the human body. Given their resemblance to food particles, aquatic organisms may ingest these and once ingested, microplastics can induce physiological, hematological, endocrine, metabolic, reproductive, and teratogenic effects in aquatic organisms. Notably, microplastics and nanoplastics exert substantial influence on primary producers within aquatic ecosystems. The intricate interplay of plastic pollution within aquatic ecosystems necessitates comprehensive research and immediate action to mitigate its far-reaching consequences.

Keywords: Co-toxicity, Microalgae, Microplastics, Nanoplastics

Introduction

Among various pollutants, plastic pollution has a significant impact in aquatic environment because of its wide usage and non-biodegradable nature. A world without plastics may be challenging to imagine in today's scenario. Initially, plastic was hailed as a remarkable scientific invention, but over time, it has turned into a significant environmental threat on a global scale. Plastic materials have become the first choice of humankind among all other man-made substances for their cost-effectiveness, lightweight nature, durability, longevity and excellent thermal and electrical insulation properties. In 1950, the global production of plastic was a mere 1.5 million metric tons, but by 2020, it had surged to a staggering 367 million metric tons (Statista, 2021). Predictions even indicate that it could reach an astonishing 33 billion tons by 2050. After use, the final destination of these plastic wastes is the ocean, which has become giant garbage bins for all types of plastics. Plastic pollution and its influence on aquatic systems have attracted the scientific community's interest in recent years, particularly concerning microscopic-sized plastic particles. Once entered into the environment, larger plastics are broken down into smaller ones, such as microplastics (MPs) (<5 mm) and nanoplastics (NPs) (<100 nm or <0.01 µm) (Galloway *et al.*, 2017) under various environmental forces including wind action, wave action, UV radiation, photodegradation, mechanical abrasion and microbial activities (Figure 1). Based on the polymer, these tiny plastics were divided into seven basic types: polyamide (PA), polypropylene (PP), polyethylene (PE), polystyrene (PS), polyvinyl chloride (PVC), polyurethane (PUR) and polyethylene terephthalate (PET). MPs and NPs are utilized in a wide range of personal care products like face creams, sunscreens, cosmetics, scrubbers, toothpaste, handwash, *etc*. In the environment, it persists for a very long time and may pose risk to the biotic communities.

Occurrance in the Aquatic Environment

Over the years, global plastic production has seen a substantial increase. However, despite this massive output,

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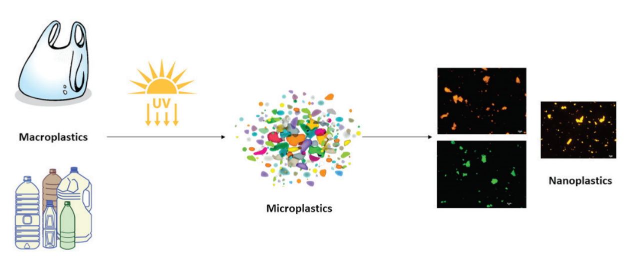

Figure 1: Formation of Micro and Nanoplastics from macroplastics

a mere 9% of the plastic manufactured is recycled, while 12% is incinerated, leaving a staggering 79% to accumulate in natural ecosystems (Geyer *et al.*, 2017). Approximately 2,69,000 tonnes of plastic have been discovered in surface waters worldwide, with an estimated 5 trillion plastic particles believed to be present in the world's surface waters (Eriksen *et al.*, 2014). These minute plastic fragments have been identified in oceans across the globe, from the busiest Pacific Ocean to the remote Arctic Ocean. It's been observed that around 1.5 trillion microplastics have infiltrated the water and been ingested by marine species, endangering their lives. In recent years, the abundance of MPs has increased significantly, surging 21 times and reaching levels of 15 to 311 million tonnes in sediment samples from the Indian Ocean. Specific areas, like the Mediterranean and the Yellow Sea, have been identified as hotspots for marine microplastic pollution. The presence of MPs/ NPs is influenced by various factors, including tourism, aquaculture, industrial discharge rates and sewage treatment facilities. Researchers have uncovered a strong positive correlation between MPs and fishing activity and a modest connection with tourism-related activities. It has been well-documented that MPs/NPs can accumulate within the various organs of aquatic animals and even breach the blood-brain barrier of fish. These plastic particles have been detected in the gastrointestinal tract, gallbladder, liver, pancreas, heart, brain and tissues of various commercially valuable aquatic organisms.

Fate of MPs/ NPs

Plastics already replaced conventional and natural materials due to their various beneficial properties and low manufacturing cost. Unfortunately, it does not decompose after usage and remains in the natural environment for a long time. Primary microplastics are produced for intended work and can enter the water body directly or unintentionally. After entering the environment, primary microplastics undergo various physical and chemical changes, eventually breaking down into secondary microplastics. MPs/ NPs eventually end up in the ocean (Figure 2). They entered the marine ecosystem through three principal routes: soil pathways, water pathways and wind pathways. The water pathway is the primary route. NPs and MPs are light enough to travel great distances and deposit straight in the ocean due to wind action. Storms and cyclones have the potential to carry larger plastic litter into the ocean. Soil-borne plastic litter, such as agricultural films, fertilizer and pesticide packing materials may end up in the oceans due to surface

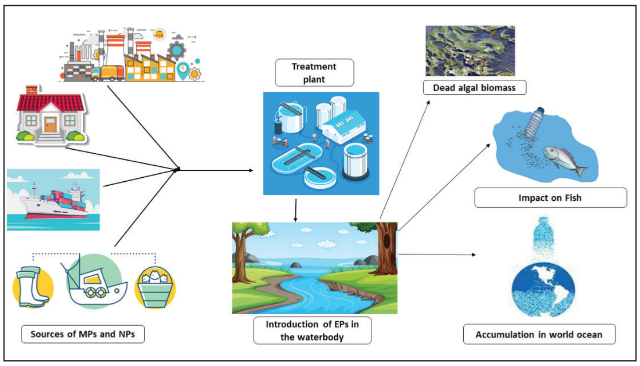

Figure 2: Fate of MPs/ NPs

runoff and tidal washing. Rivers collect plastic debris from various sources, including sewer overflows, soil runoffs, air (dust) precipitation and tourist garbage and transport it to the seas.

Impacts

1. Ingestion and Accumulation of MPs/ NPs

The primary route through which aquatic organisms uptake microplastics and nanoplastics is ingestion, primarily because of smaller plastic particles are consistently mistaken for food. Studies have uncovered that even planktonic larvae have the capacity to ingest both MPs and NPs. Remarkably, MPs have been identified in the saliva of diverse aquatic creatures, including mammals, aquatic birds and fish. NPs, on the other hand, have been discovered within the gastrointestinal tract, gallbladder, liver, pancreas, heart, brain and tissues of a range of aquatic organisms such as mussels, zebrafish, zooplankton, oysters, sea urchins, fish embryos and larvae. Ingesting minute plastic fragments and fibers might result in intestinal obstructions. After ingestion MPs/ NPs not only cause adverse effects on the organisms but also have the capacity to accumulate inside the various organs of the exposed animal. The main cause of the accumulation is its hydrophobic nature. Prolonged retention inside these organisms, microplastics can accumulate at lower trophic levels, potentially initiating a cascading impact on marine food webs. Interestingly, secondary micro (nano) spheres have demonstrated a greater capacity for accumulation than primary or virgin particles. The extended presence of microplastics in prey species increases the likelihood of their transfer to predators over time.

2. Effect on Aquatic Animals

In a marine environment, the distribution of microplastics and pollutants might seriously affect seafood as a protein source. Recent laboratory bioassays have illustrated that exposure to MPs and NPs is associated with a wide range of ecotoxicological consequences in fish and other commercially important aquatic species. These plastic particles exert effects on various physiological, hematological, endocrine, metabolic, reproductive and teratogenic processes. Generally, these small plastic elements lead to a decrease in fish growth and feeding rate, also affecting their swimming behavior. Filter-feeding organisms, such as clams and oysters, experience a reduction in their filtering capacity at elevated concentrations of MPs/ NPs. In shellfish, MPs reduced the shell length and width of the organisms. Tiny plastic particles also adversely affect the immune system of the animal. It degrades the primary granules and weakens the neutrophil extracellular traps, which are working against pathogens. NPs cause several metabolical changes in the host body such as changes in the distribution pattern of cholesterol in various organs of the body and altered fatty acid to cholesterol ratio of blood serum. MPs and NPs induced teratogenicity in the fish shellfish. Larval malformation was observed and the survival rate was decreased under MPs and NPs treatment. In addition, when MPs and NPs exposed to brooder or yolk it was observed that traces of plastics were present inside the organs of the larvae. It confirms that these plastics can cross through the placenta. Elevated levels of antioxidant enzymes such as SOD, CAT, POD and MDA indicated that the exposed animal is under stress.

3. Effect on Microalgae

NPs have the potential to harm aquatic ecosystems by disrupting the physiological balance of microalgae, a key component of the aquatic food chain. Algae, which are chlorophyll-containing, photosynthetic unicellular or multicellular organisms, play a vital role in the global carbon cycle. Research has indicated that both MPs and NPs have detrimental effects on microalgae. These effects include a decrease in growth rate, hindered photosynthesis efficiency, reduced pigment production, alterations in biochemical compositions and changes in enzymatic activity. For instance, a study observed a 57% growth inhibition of the microalgae *Dunaliella tertiolecta*, along with a reduced photosynthesis rate (Sjollema *et al.*, 2016). Furthermore, there were several-fold increases in antioxidant enzymes (SOD, POD, CAT and MDA), suggesting that microplastics can induce oxidative damage to algal cells. Plastic fragments can also disrupt esterase activity and lipid content in microalgae. Morphological observations using scanning electron microscopy (SEM) and transmission electron microscopy (TEM) revealed that NPs and MPs can adhere to the surface of microalgae, remaining attached even after exposure to environmental forces. This result indicates that these smaller plastics can potentially enter the food chain through microalgae and increase the complexity of microalgal cells. The adverse impact varies depending on the type of microalgae, the characteristics of the microplastics, the duration of exposure, the presence of additives and environmental conditions, among other factors. It has been reported that smaller-sized microplastics, such as nanoplastics, tend to be more toxic than larger microplastics.

4. Co-Toxicity of MPs/ NPs

Microplastics and nanoplastics act as a substrate or as a platform for many foreign elements [heavy metals, polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs)] in the water body. In aquatic environments, many pollutants particularly hydrophobic materials used MPs/ NPs as a vector to enter the organism's body. Primary plastics, when undergoing a continuous weathering process, the surface properties get altered and even sometimes they acquire charge, and this lead to the sorption process. For example, one of the common surface modifications is the addition of carbonyl functionalities, which as a result increases the sorption rate of triclosan-like chemicals. Along with the surface modification, many other factors determine the sorption rate such as water pH, temperature, salinity, load of organic contaminants, type of polymers, particle size, crystallinity, area-to-volume ratio, eco-corona formation and biofilm production. Adsorbed pollutants can be released in the organisms' digestive systems or other tissues, leading to additional toxic effects beyond those caused by microplastics alone. Pollutants can travel through the food chain through the transfer of MPs and NPs. It increases the chance of the interaction of many pollutants and the biological organism. Recent studies on aquatic organisms reported that their synergestic effect is more harmful than individual.

Conclusion

Plastic waste can enter the aquatic environment through water, air and soil pathways. Reaching the environment, plastics are fragmented into smaller micro-and nanoplastics, posing risk to the ecosystem and biotic communities. MPs have been isolated from the surface water to the ocean basin; it was even identified from remote locations. There are also reports of plastic particles in human blood, indicating that all organisms are at risk from microplastics. Unlike macroplastics, micro and nanoplastic can enter into the animal body and can be distributed through the circulatory system. Primary producers of the ecosystem are greatly affected by MPs and NPs. Though the information is scanty, it was reported that MPs/ NPs can produce synergistic effects with other pollutants of the environment. It may work as a vector for the contaminants to the organisms. So future research should be focuses on the combined effects of MPs/ NPs with other contaminants. Moreover, it is high time to establish an effective framework to reduce the use and discharge of plastics into the aquatic ecosystem.

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