DOI: https://doi.org/10.54393/fbt.v3i03.77

FUTURISTIC BIOTECHNOLOGY

https://fbtjournal.com/index.php/fbt

Volume 3, Issue 3 (Oct-Dec 2023)

Review Article

Effects of Microplastics on Living Organisms and their Trophic Transfer: An Ecotoxicological Review

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ARTICLE INFO

Key Words:
Microplastics, Trophic Transfer, Eco-Toxicological Effects

How to cite:
Anjum, F., Azam, A., Faseeh, H., Bano, R., Latif, M., & Fahid, A. ul M. (2023). Effects of Microplastics on Living Organisms and their Trophic Transfer: An Ecotoxicological Review : Effects of Microplastics on Living Organisms . *Futuristic Biotechnology*, 3(03). https://doi.org/10.54393/fbt.v3i03.77

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Received Date: 13th November, 2023
Acceptance Date: 28th December, 2023
Published Date: 31st December, 2023

ABSTRACT

Plastic is used by individuals within many different fields, including the automotive, packaging, cosmetics, textile and apparel, agricultural, fisheries and industrial sectors. Nevertheless, it has become a hazard to our ecosystem due to its extended degradation and decadences in nature, unceasing rise in manufacture and consumption with the ever-increasing human population. Microplastics (MPs) can enter in both soil and aquatic environments through a variety of channels, including surface runoff, storm water runoff, river flow, and wastewater discharge. As a possible hazard to aquatic life, the existence and consumption of MPs has drawn significant attention throughout the world. These tiny plastic particles absorb various substances and emit harmful additives, serving as sinks for dangerous substances and enhancing their bioavailability, toxicity, and movement. Additionally, the trophic transfer or bioaccumulation of MPs in a variety of aquatic creatures presents a significant concern. MPs have the potential to seriously harm aquatic life, including reduced eating efficiency, physical side effects, impaired gill function, oxidative stress, neurological damage, suppression of immunity and developmental disruption.

INTRODUCTION

Water is an indispensable reserve on the earth, essential for all activities of human beings i.e. domestic, agricultural and industrial, as well as for all biological mechanisms and processes of non-humans, to sustain life [1-4]. Water is present on more than two thirds of the earth's surface, barely 0.1% of it being usable by people and other living things as fresh water. In spite of the conservation of fresh water resources, people are seriously damaging the natural ecosystems and polluting the water by discharging enormous amounts of different kinds of pollutants into natural water bodies of the world. These include inorganic wastes like heavy metals and organic wastes like pesticides, dyes, plastics, and pharmaceutical wastes [5-10]. Therefore, these noxious wastes, their types, their sources and techniques to mitigate them have gained the interests of researchers for the development of treatment techniques [11, 12]. Materials for packaging (39.5%), construction materials (20.1%), automobile components (8.6%), electrical devices (5.7%), and agricultural materials (3.4%) are just a few of the numerous industries that utilize plastics extensively. The remaining industries include home appliances, sporting goods, and other items [13]. Plastics gained importance and their large-scale plastic production started since 1950s [14]. Global plastic production was more than 300 million tons till 2013, and estimations reveal that till 2050 total plastic production will

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DOI: https://doi.org/10.54393/fbt.v3i03.77

surpass the range of 33 billion tons. Plastics come in a variety of materials, including low density polyethylene (LDPE), polymethyl methacrylate (PMMA), polyethylene terephthalate (PET), polystyrene (PS), polyvinyl chloride (PVC), polypropylene (PP), polyethylene (PE), and polyamide (PA) [15, 16]. Plastics are mostly derived from fossil fuels like natural gas, coal, and petroleum and are manufactured to satisfy the diverse requirements of final goods. Plastics have been significant in many important industries, including packaging, building and construction, transportation, electrical and electronic equipment, agricultural, medical, and sports, because of their adaptability, durability, and affordability. The world's plastic output has been steadily increasing over the past several decades and hit a yield of 335 million tons in 2016. Most plastics are made to be used in packaging, which might eventually be discarded. Plastic debris is building up at an uncontrollable rate as a result of the widespread use of plastic items, inappropriate disposal of plastic trash, and the refractory nature of plastic materials throughout marine and terrestrial environments [17, 18]. Rapid addition of plastic wastes in the natural ecosystems has raised global concerns [19, 20].

MICROPLASTICS (MPS)

Microplastic particles are minuscule plastic particles with a length of less than 5 mm. Research has revealed that MPs have deleterious effects on human health and the environment. Thompson and his colleagues initially used the term "microplastics" in 2004 while researching the UK's maritime plastic contamination. Thompson was 19 years old at the time. Since then, governing bodies, nonprofit organizations, scientists, and others have been interested in MPs. Plastic materials are relatively recent materials, developed in the latter part of the 20th century [21]. However, the environment is seriously threatened by their excessive manufacture and usage in a wide range of goods and industries [9, 22]. Primary MPs are defined as those that are purposefully made microscopic, such the cosmetic microbeads found in face cleansers [23].

Primary and Secondary Microplastics (MPs)

There are two categories of microplastics: primary and secondary. Primary MPs include plastic pellets (also called nurdles) used in industrial production, microbeads found in personal care items, and plastic fibers used in synthetic fabrics (like nylon). The primary particulates of plastics are released into the environment through a variety of means, (e.g., washing personal care products into wastewater systems from homes), inadvertent loss from spills during production or transportation, or abrasion during washing (e.g., laundering of clothing made with synthetic textiles). When bigger polymers are subjected to weathering—that is, when they are exposed to things like wave action, wind abrasion, and UV radiation from sunlight—secondary MPs are created.

Nano plastics

Nano plastics are tiny pieces of plastic that are less than 100 nm in at least two dimensions. Micro- and nano plastics are produced when weathering or fragmentations of bigger plastic waste occurs. Nano plastics are created when synthetic fibers break down when clothing is washed in textiles and when plastic products like expanded polystyrene deteriorate due to an expedited mechanical abrasion mechanism [24]. These nano plastics have a high surface area-to-volume ratio and are smaller in size, which makes them more prone to ingestion by primary food chain consumers like corals, phytoplankton, and zooplanktons. Additionally, their surfaces allow POPs to adhere, increasing the possibility of harmful effects. Because of their increased reactivity and availability than microplastics (MPs), nano plastics are particularly concerning since they represent a larger risk to biota. Their tiny size increases their potential of penetrance and damage, by making it easier for them to get enter into tissues and cells of remote organs of organisms [25]. The current analysis is distinguished by providing a more thorough overview of the biological consequences, migration, and microplastic contamination in aquatic ecosystems. It highlights the impact that MPs have on aquatic life, that was done by analyzing MPs as carriers and their transfer through the trophic levels. It also summaries the pollution status and MPs mobility in aquatic ecosystems worldwide. The breakdown and destiny of MPs in the aquatic ecosystems was also made clear. There is also a discussion of the difficulties in this subject as well as the current techniques for MP detection and analysis. At the conclusion of the current review, recommendations are made for further studies.

Table 1: Methods of Identification and analysis of Micro Plastics (MPs) in aquatic ecosystems

Technique	Detection	Advantages	Limitations	References
Visual analysis	MPs are identified through Physical and morphological appearance	MPs of big size ranges are identified.	Information related to the Chemical composition of MPS not given. High misidentification rate and time consuming	[26, 27]
Microscopy	Microscopy provides data by analyzing surface quality and structure of Mps	MPs of size ranges from 100 micron are identified by this technique	The limitation of microscopy in a sediment sample is the improper distinction between the light sediment particles	[28]

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Thermal analysis	Samples identification completely based on their thermal stability	In thermal environment information related to samples chemical and physical properties are provided in this technique	Analysis of smaller sized particles is difficult and lower size limits of particles	[29]
Fourier Transform Infrared spectroscopy FTIR	Detection of particles of size less than 10 micron	Minimum sample preparations, it can provide physical and chemical information of MPs	High cost, sensitive to the water vapors and organic impurities	[30, 31]
Scanning Electron Microscopy	Easily detect MPs of 1-5mm in size	Tt provides high resolution images of samples; different synthetic fibers can be detected	Samples need to be coated in presence of high vacuum coated samples are used for identification, detection of larger sized particles is done	[31]
Stereo-microscope	It can detect MPs up to 500micron in size	Low cost, easy to operate, it can provide morphological information of sample	-	[32]
Raman	Detect microplastics by providing information related to chemical composition of polymers, detection of the pigments and dyes can be done through this.	Detect samples, with minimal sample preparations, non-contact and nondestructive measurement	Time consuming, sensitive to fluorescent pigments and colors.	[33]
Analysis of C:H:N Ratio	Through C:H:N ratio and density analysis nature of Mps can be detected	Information related to origin and type of Plastics can be gathered though this technique	-	[34]

Environmental Fate of Micro Plastics

Microplastics are originated from various sources including fragments of larger plastic items formed through industries and microbeads of personal care items [35]. According to estimates, in year 2018, 348 million tons of plastic were produced worldwide [36]. Over 6,000 million tons of plastic litter were produced as of 2015, with over 80% of the debris being disposed of in landfills or dumped into the atmosphere (landfills, rivers and oceans) [13]. Globally, plastic litter deposition has been reported in a number of natural compartments [37]. These areas are prone to ongoing disintegration caused mostly by mechanical abrasion and UV radiation [17]. Regretfully, the fragmentation process is unable to entirely break down the plastic waste; instead, it converts it into a variety of tiny plastic particles, known as MPs, which are defined as tiny particles >5 mm in size [38]. Due to differences in shape and polymer densities, MPs can spread widely once they enter aquatic systems (surface water, the water column, and benthic sediment). This can increase MPs availability to aquatic biota inhabiting in various environments or trophic levels [39, 40]. Numerous aquatic animals, from tiny crustaceans to huge predatory mammals, have been shown to be affected through MPs ingestion [41]. Ingesting small particles of plastic not only damages the organisms that consume them by inducing inflammatory reactions and mechanical harm but it also offers a potential pathway for the introduction of certain dangerous substances into the aquatic food web, such as pathogenic microorganisms, pollutants immersed from the surrounding environment, and endogenous plastic additives [42, 43]. Moreover, food safety and human health may be at danger due to the widespread distribution of edible aquatic fauna consuming MPs [44].

Microplastics incorporation in Soil/Terrestrial Ecosystem

Microplastic pollution has attracted attention from scientists and public communities all over the world, with special attention towards the marine ecosystem disturbance [19]. The pervasiveness of MPs in seas and oceans has been indorsed mainly due to unending inputs and to continuous inputs from disintegration of larger plastic litter [19], the major portion of which is believed to originated from emissions on land [45]. Terrestrial ecosystems are more susceptible to the plastic incorporations as compared to aquatic ecosystems contaminations. Different estimates on MPs incorporations revealed that annual proportions of MPs from sewage sludge drained into agricultural land are more than the total amount of MPs currently present in the aquatic ecosystems worldwide [46]. MPs sequestration inside the soil effects soil structure, water holding capacities and soil bulk density [37]. Smaller size of MPs than soil particles are the reason of bulk shift of soil density of MPs contaminated soils [37]. After incorporating into the soil micro plastics effect and alter soil porosity, so effects soil aggregation and soil water dynamics [38]. Hydrophobicity and large surface area of MPs make possible the accumulation and aggregation of organic contaminants and heavy metals on its surface [47]. Lack of essential protocols and analytical techniques for the detection of MPs is the reason for the unavailability of appropriate monitoring data related to the

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distribution and occurrence of MPs in soil ecosystems, that is essential for systematic assessment of possible effects of these pollutants[32].

Table 2: Microplastics presence in aquatic species of different aquatic ecosystems of the world

Location	Region	Water bodies	Plastic type	Plastic size	References
Atlantic Ocean	North Sea Region	Marine	Macroplastics	>20mm Mesh	[48]
	Rio de la Planta	River	-	-	[49]
	Bay of Seine	Marine	Macroplastics	>20mm mesh	[48]
	Celtic sea	Marine	Macroplastics	>20mm	[48]
	Portuguese Coast	Marine	Microplastics	>5mm	[50]
	Giana	Estuary	Microplastics	1.65 -2.33mm	[51]
Baltic Sea	Baltic Sea	Marine	Macroplastics	>20mm mesh	[48]
Pacific Ocean	North Pacific Central Region	Marine	Microplastics & Macroplastics	0.35 - 4.76mm	[52]
-	North Pacific Inshore	River	-	-	[52]
-	North Pacific Offshore Region	River	-	-	[52]
-	South Pacific	Marine	Microplastics & Macroplastics	0.355 - 4.75mm	[53]
-	Water around Australia	Marine	Microplastics & Macroplastics	0.4 to 82.6mm	[54]
-	south sea of Korea	Marine	-	-	[55]
Mediterranean Sea	Gulf of Lion Region	Marine	Macroplastics	>10mm mesh	[48]
-	Adriatic Sea	Marine	Macroplastics	>20mm	[48]
South west England	Tamar Estuary	Estuary	Microplastics & Macroplastics	<1 to>5mm	[56]

Micro Plastics Ingestion by Aquatic Fauna

Micro plastic pollution in the aquatic system is highly and primarily related to the terrestrial ecosystem pollution. In aquatic ecosystems, micro plastics usually float on the surface of the water, dispersion in the different depth zones and MPs accumulation in the sediments make them reachable to the wide range of aquatic species living in habitats. The pervasive existence of MPs and their similarity to planktons due to same size ranges and appearance increase the likelihood MPs uptake by aquatic organisms [35]. Presence of MPs in aquatic organisms was confirmed by digestive tract and tissues analysis of large number of field- collected marine animals, including fish, Crustaceans, mammals, Turtles, Sea birds and so on [57-60, 43]. Studies revealed that once these MPs are gulped by aquatic organisms especially animals, feasibly the direct effects caused, the buildup of these lethargic particles in the digestive tract of organisms [61]. The accumulation of the gulped particles even blocks the digestive tract or the alimentary canal of aquatic animals which thereby results in diminished feeding needs due to deceitful repletion [62]. Studies on copepod *Centropages typicus*, crustacean *Nephrops norvegicus* and shore crab *Carcinus maenas* demonstrated that feeding rate of these tested organisms was reducing with accumulative addition of MPs [41, 63, 64]. Continual decrease in feeding lead to a variety of harmful effects on aqua fauna, for instance abridged body weight, growth inhibition, diminished mobility and reproductive system, diminished mobility, and even mortality [63, 65]. Physical damage of organs including digestive organs, metabolic changes due to enzyme changes in enzyme action, oxidative stress can be introduced into the body of aquatic organisms due to MPs ingestion [66, 63]. Breakdown of MPs into the tiny particles make the feasibility of MPs addition in the circulatory system of organisms. Long term retention and penetration of MPs into the phagocytic cells may introduce additional toxic effects and facilitate the transfer of MPs into predators of higher trophic levels [67].

Table 3: Effects of microplastic in take on aquatic organisms

Type of plastics	Organisms	Mechanism	Effects	References
Polyethylene	Bivalves (*Mytilus edulis*)	Ingestion	Aggregation in soft tissues	[44]
Polyethylene beads or polystyrene beads	Brine shrimp (*Artemia nauplii*)	Ingestion	Swelling and aggregation in liver	[68]
Polyethylene and polypropylene	Whale (*Balaenoptera Physalus*)	Ingestion	Increased toxicity symptoms	[69]
Microplastic spheres, fragments and fibers	grass shrimp (*Palaemonetes pugio*)	Ingestion	Stimulation of immune response	[70]
Micropolyvinyl chloride (mPVC)	Dinofagellates (*Karenia mikimotoi*)	Ingestion	Physical blockage, inhibition of growth, chlorophyll and photosynthesis	[23, 71]

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Polystyrene nano and microbeads	(*Paracyclopina nana*) Marine copepod	Ingestion	Decreased reproductive output, aggregation of microplastics in the body	[72]
Plastic litter	Sea birds (*Pelecanoides garnotii, ,Spheniscus humboldti, Pelecanus thagus, Phalacrocorax bougainvillii, Pelecanoides urinatrix and Larus dominicanus*)	Ingestion	Accumulation in stomach, starvation	[73]

Trophic Transfer of Microplastics (MPs) in the Food Chain

Presence of microplastics (MPs) have been confirmed through the filed collected aquatic organisms, that included the large vulturine animals (table). Bio accumulation is regarded an important pathway in the introduction of MPs in the body of the organisms. Presence of MPs were widely revealed from the scat analysis of Antarctic fur seal *Arctocephalus tropicalis* and *Arctocephalus gazelle*, possibly due to the fur seal consumption of a pelagic fish *Electrona subasper* that ingested MPs [74]. The capacity of polychaete larvae *Marenzelleria spp.* and copepods *Eurytemora affinis* to absorb 10 μm fluorescent polystyrene (PS) microspheres and then pass the ingested particles to pelagic mysid shrimps *Mysis mixta* was proven by Setälä and a co-researcher in 2014 laboratory [75]. According to Mattson *et al.*, PS Nanoparticles have the ability to go from algae (*Scenedesmus sp.*) to fish (*Carassius carassius*) to zooplankton (*Daphnia magna*) in a simulated aquatic food chain [76]. MPs have also been seen to migrate by trophic transfer between mussels (*Mytilus edulis*) and crabs (*Carcinus maenas*), ending up in the hemolymph and tissues of the latter [67]. According to Barnes *et al.*, and Hartmann *et al.*, environmental MPs are known to contain significant amounts of hazardous chemicals (such as absorbed contaminants and inherent plastic additives) [17, 77]. These chemicals are released after ingestion, assimilated in aquatic biota tissues and transmitted along the aquatic food chain [78, 79]. Using brine shrimp (*Artemia sp.*) nauplii and zebrafish (*Danio rerio*) as the foundation of a simple artificial freshwater food chain, researchers confirmed the process of trophic transfer in the lab [68]. They found that the absorbed chemical (benzo(a)pyrene) and MPs (1–20 μm fluorescent PE particles) may build up in shrimp and subsequently be transmitted to zebrafish. Regretfully, there are currently far too few of these kinds of studies related to Environmental MPs, that pose significant ecological risks, necessitating a comprehensive understanding of their role in bioaccumulation and bio-magnification within aquatic food webs using realistic scenarios.

Table 4: Biological effects caused by MPS on human

Biological effects caused by microplastics	Mechanism	References
Gut inflammation, transcriptional changes in the colon, inflammatory responses	Interactions between colonic epithelium of lumen side and MPS	[44]
Gut inflammations due to tumor necrosis factor-α, Interleukin-6 and NF-kb	Reduced crypt layer thickness, muscle, fat luminal surface, and mid-colon mucosa thickness; increased nucleotide-binding domain,	[81]
Gut dysbiosis, changes in human colonic microbiota, decreased levels of *Clostridium spp., Bifdobacterium spp., Enterobacteriaceae spp., and Staphylococcus sp.*	Biofilm formation due to colonic microbiota and microplastic adherence	[82]
Inflammatory bowel disease	Exposure of MPS is involved in retention of MPS that leads to progression of inflammatory bowel disease	[83]
Inhibition of human alveolar cells proliferation due to Potential toxicity	Significant changes in the morphology of lung cells due to exposure of MPS (1 μm)	[84]
Altering lung surfactant properties	The lung surfactant's phase behavior, surface tension, and membrane structure were altered by MPS.	[85]
Pulmonary inflammation and cytotoxicity	Disruption of lung epithelial barrier through oxidative stress and inflammation. Increased expression of interleukins-6 and interleukin-8.	[86]
Increased phagocytosis	Increased accumulation of macrophages and phagocytosis	[87]
Increased brain and body weight of offspring due to polystyrene exposure	High dosages of polystyrene nanoplastic (greater than 500 g/day) result in significant abnormalities in brain development.	[88]
Decreased birth rate and postnatal bodyweight	MPS can cause cell damage, that trigger inflammatory and immunological responses	[89]
Reduced testes weight and sperm count	Reduced testes weight and sperm countUnknown mechanism is involved in low fertility rate	[89]
Accumulation of MPS in the body of fetus	Microplastic exposure in the late-stage pregnancy causes accumulation of plastics in the fetal liver, kidney, brain and heart and even migration from maternal lungs to fetal lungs	[90]

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CONCLUSIONS

A wide variety of aquatic organisms is vulnerable to MPs exposure due to the widespread dispersion of MPs throughout the ecosphere. Studies conducted in the field and in the lab have shown how common it is for aquatic animals at various trophic levels of the aquatic food web to consume MPs. Exposure to MPs can have a range of negative consequences on aquatic biota, including humans, apex predators and primary producers. Studies on the toxicity of MPs have mostly concentrated on the potential harm of ingested MPs (together with related toxicants) to aquatic life, particularly marine taxa. On the other hand, relatively little is known about the effects of microplastic exposure on aquatic primary producers, the trophic transfer mechanism of MPs and related materials, and the potential health risks connected with consuming aquatic products.

Future Perspectives

The majority of research that are currently available on the consequences of MPs were carried out in labs, which may make them less applicable to real-world systems. Below are some suggested study goals to help better understand the ecological concerns that MPs pose to humans and aquatic organisms: While carrying out investigations on microplastic exposure, use concentrations that are appropriate for the environment, conduction of additional research to find out how aquatic primary producers are affected by MPs and what factors influence this, primarily focusing on the eco-toxicological consequences of MPs on freshwater species and higher order predators. Determine the part that MPs play in the trophic transfer of environmental pollutants and thoroughly assess the synthetic impacts of MPs and environmental toxicants. Conduct far reaching and extensive research on the elements influencing aquatic organisms' ability to distinguish MPs from other materials, as well as the toxicity and eventual disposal of MPs that are consumed by them. To determine the quantity of MPs that are ingested by humans through the eating of aquatic products, conduct comprehensive monitoring programs on the abundance of MPs in aquatic products. There is need to carry in-vitro studies to know behavior and the fate of MPs, and their role as pathogenic vectors of digestive tract diseases of human and in other aquatic predators. More importantly ecological risks caused by MPs need to be mitigated.

Authors Contribution

Conceptualization: FA, AA
Formal analysis: AUMF
Writing-review and editing: HF, RB, ML, AUMF
All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Source of Funding

The authors received no financial support for the research, authorship and/or publication of this article.

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