Review paper

A cognitive review on microplastics and their effects on marine ichthyofauna

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Abstract: Microplastics are a composite group of copiously reorganized, imitated organic particulates that pollute a variety of ecosystems. It is an emanation pollutant that has attracted widespread recognition due to its very small size (<5 mm). Awareness of the waste plastics pose to marine ecosystems developed gradually through the 1960s and 1970s. But nowadays they are ubiquitous occurring globally in each and every marine domain and their distribution is affected due to changes in plastic composition and environmental conditions. Furthermore, MPs are routinely identified in the gastrointestinal tract of aquatic organisms worldwide. The comparably smaller size of MPs makes it easy for the particle to enter the food chain. An overview of microplastic pollution is debated in the present paper which includes the history, categories and sources of MPs, usage in fisheries and aquaculture, uptake in different aquatic organisms, along with significant challenges and abatements measures.

Keywords: Fibers; Fragments; Ingestion; Microplastics; Ubiquitous

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1. Introduction

Today world without plastics or synthetic organic polymers seems unimaginable, as it used in many areas of society starting from the packaging of food products to textiles and automobile industries, fishing gear, and medical devices. Among other things, versatile use of plastics is due to properties like lightness, durability, strength, and low-cost. However, these same properties make synthetic materials such a large environmental problem. Global production of plastics has exponentially increased from 1.5 million tonnes (MT) in 1950 to 367 MT in 2020 (Figure 1) and demand for plastics estimated to increase to 600 MT by 2025 and reach 1000 MT by 2050 (Lusher et al., 2017; Tiseo, 2022). Compared to previous year (2019) the plastic production in 2020 declined by 0.3% due to COVID-19 impacts on the industry (Tiseo, 2022). Production of almost 79% of the plastic products discarded into the environment and these plastic wastes are further fragmented and turned to smaller-sized litter. Microplastics are of notable issue among the plastic pollution in the world both for the environment and animals/human health predominantly owing to their smaller size, paucity of technology available to quantify the smallest microplastics in the environment, and their possibility to effect the marine biota and humans.

Microplastics (MPs) came to be designate as tiny fragments of plastic having size of <5 millimeters with no lower limit established (GESAMP, 2016). They are scrap greater than 5 millimeters in size, while fragments having size range between 1 and 100 nanometer were designated as nanoplastics (Koelmans et al., 2015; EFSA, 2016). Currently, these small fragments are conceded as inescapable contaminant and in the last decade they are experiencing a significant amount of research and programme awareness. Fragmentation of larger plastic debris result into these MPs or may be transferred into the water column or soil earlier as micro or nano-sized particles. Prepared pellets and constituents of various products including pieces of fishing gear, polythene bags, water bottles, ear buds, toothbrush, synthetic textiles, car tyres, paints, cosmetics and sanitary products and other idiomatic and automatic equipments are examples of MPs (GESAMP, 2016). Necessarily, MPs includes extremely diversified group of an assemblage of particles that differ in their properties such as shape, size and chemical constituents (Andrady, 2017). Being ubiquitous nature of MPs, they are found in all the habitats including marine and coastal areas (Figure 2). In the late 1960s the first record of interactions between persistent litter and marine organisms were reported in the scientific literature. The ingestion of plastic items by *Laysan Albatrosses* has been reported along the northwest Hawaiian Islands (Kenyon and Kridler, 1969). More than 70 albatross chicks have died due to plastics in their stomach in 1966. In the 1970s, several reports have published their observations on microplastic pellets in marine environments (i.e. the raw material in plastic production) and during 1970s the first poll of microplastic ingestion were identified in birds (Carpenter and Smith, 1972; Carpenter et al., 1972; Gregory, 1977). Thereafter finally during 1990s, it was clear that the MPs consumption had a toxic effect on different species and during 2000s consequences were reported for human health (Vegter et al., 2014; Chae and An, 2017). "Microplastics" term was proposed by Thompson et al. (2004) and they revealed that microscopic plastic pieces and fibers are ubiquitous oceanic contaminants. Like larger plastic items, MPs are now observed all around the oceanic floors, encompassing deep sea sediments (Van Cauwenberghe et al., 2013). Though MPs contamination perceived as a concern of worry in the 1990s, several earlier investigation on plastics in marine and coastal environments concentrated on macroplastics and the uncertainty they cause to the animals (Vegter et al., 2014). Even with the compound information about the deleterious effects of MPs, prosecution of law and policy for the management left in its incunabulum.

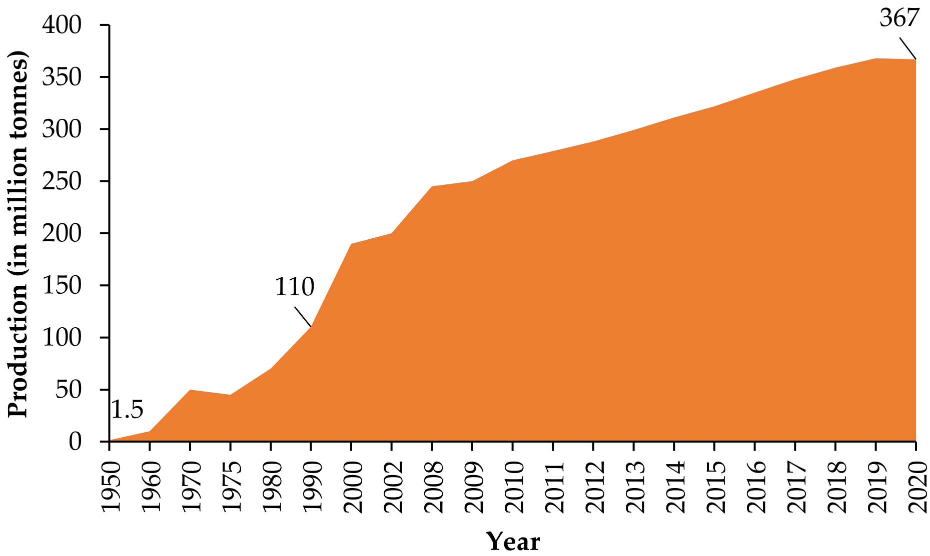

Figure 1. World-wide production of plastic from 1950 to 2020

Figure 2. Spread of macroplastics in the coastal environment (Photo credit: Nitin Suyani)

2. Categories and sources of microplastics

The most important characteristic of the type of microplastics is the size, because it displays the effects of MPs in different organisms. Decomposition of larger plastic fragments form small particles of plastics termed as microplastics (>100 nm and <5 mm) or nanoplastics (<100 nm) (Lobelle and Cunliffe, 2011). Likewise accumulation of MPs in the organism is also depend on the age, developmental stage, gender, occurrence in the trophic level, etc. (Nguyen et al., 2019). Schematic diagram of classification of MPs is presented in Fig. 3. Researchers tend to use five main categories for different shape of MPs, even if the nomenclature used differ between research groups (Figure 3). Colors are frequently reported over a wide spectrum because color differentiation is subjective and identification of MPs visually cannot be based on color alone. Primary and secondary MPs are categorized based on the source of occurrence. Primary MPs are those particles that are intentionally produced at the microscale for different industrial applications having size range below 5 mm. This includes pellets used in the production of larger plastic items, such as microbeads included in cosmetics or used in industrial processes. Secondary MPs are the by-products obtained from breakdown of larger products due to weathering of debris on shorelines and in the sea, UV induced brittleness and later fragmentation of plastics, or from washing of synthetic textiles (Andrady, 2017). They may originate, such as, from the abrasion of tires in road traffic. The source of secondary MPs is via breakdown of mesoplastics (5 to 25 mm) and macroplastics (>25 mm).

Degradation mechanisms of plastics in the environment are broadly classified into biodegradation and non-biodegradation (Rouch, 2019). Non-biodegradation of plastics chiefly encompass degradation through physical means, decomposition, thermal oxidation and hydrolysis (Andrady, 2011). Breakdown of plastics through physical means is an important process for disintegrating large sized plastic wastes into fragments because it is principally modulated by weathering and sea waves. Hydrolysis is a bond-breaking reaction converting long polymers into shorter polymer. Photo-degradation through exposure to ultraviolet light is the most productive method of plastic degradation in the environment. All the deterioration methods would mortify the structure, alter the mechanical properties of long polymers and increase the implicit surface area of plastics during their various chemical and physical reactions and their reciprocity with microorganisms (Lucas et al., 2008). Biodegradation of plastics to form nanoplastics occurs through the action of microorganisms (Trishul and Mukesh, 2010). Due to various types of intra and extra-cellular enzymes secreted by the microorganisms the breakdown of long polymer chains will convert the smaller fragments of various size and structure, finally forming nanoplastics. They are very small particles having size of <1 μm are explicitly laborious to determine and analyze at environmentally suitable concentrations and in biological forge (Valsesia et al., 2021).

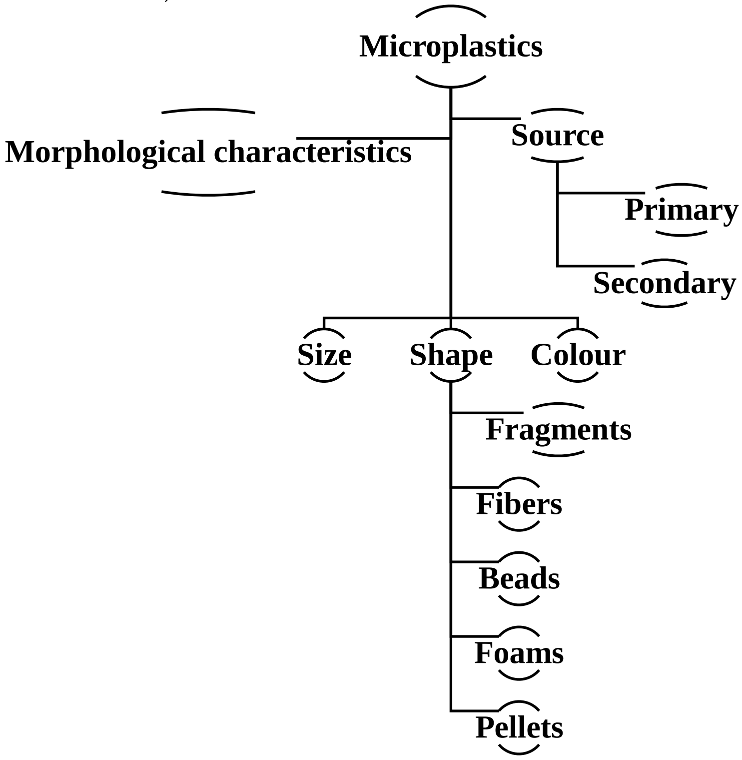

Figure 3. Classification of microplastics

3. Plastic use in fisheries and aquaculture

3.1. Capture Fisheries

Plastics have made a significant place in all the traceable point of the fishing channel starting from harvesting of resources to final consumption. Plastics are used in preparation of various fishing nets and twines and in different types of fishing gears. They are also utilized for packaging of various frozen, chilled and value added fishery products. Fish meal and different by-products are also been packaged in different types of plastics materials. Though material used for different process vary based on the utility and durability of the products and operation procedures. Different types of polymers used are polyethylene, polypropylene, expanded polystyrene, polyvinyl chloride, polyamide and polyethylene terephthalate. Polyethylene is also used in seafood processing units for covering the fishes at the time of preservation and storage and for further export in international markets (Patel et al., 2020).

3.2. Aquaculture

Culture practices of different fish and shellfish vary depending on the species and environment. Different types of aquaculture practices include traditional rope cultures to modern intensive and recirculating aquaculture and cage farming systems (Lusher et al., 2017). In fish farming, plastics are used in different systems like in cage culture system it is used in the fabrication of cage, mesh screens, drain pipes, etc., in case of pond culture system it is used for bird fencing, biosecurity measures, plastic paddlewheel aerator, pond plastic lining (p-lining), crates as well as for feed and feed supplement packaging. Plastic materials are also used when harvesting is done and fish packaging and transportation to the various fish processing units. In mariculture farming practices all the structures like cage, raft and rope are primarily made of plastics which are kept afloat by different buoyant plastic buoys. From small domestic facilities to highly technical systems everywhere plastics are used. Due to cheap and durable properties of plastics and are easily obtained and maintained, they are extensively used in small domestic facilities to highly technical systems everywhere.

4. Uptake routes of microplastics in fishes

MPs may be uptake by a range of marine organisms by a number of active and passive pathways which include the confusion of microplastic particles ingestion with prey, accidental uptake while foraging and trophic transfer through the food chain, but a holistic understanding of influencing factors is still lacking (Roch et al., 2020). Ingestion of MPs is presumed to be the prime divulgence route for different marine species because they may confounded with prey, but ingestion through passive water filtration and deposit-feeding activity also occur (Naji et al., 2018). After ingestion, several types of adverse effects encountered because MPs were absorbed and distributed to different cells and tissues through the circulatory system (Chae and An, 2017; Foley et al., 2018). Furthermore, MPs as well as the chemicals they contain may be transferred from marine prey to predators. Aquatic animals unassertively ingest MPs because of their impotence to differentiate between food and MPs. The small size of microplastic particles, enchanting color, and buoyancy of the plastic particles make them flawless candidates as food for fish (Rao, 2019).

Ingestion of microplastic was observed in a wide range of ichthyofauna including finfish, bivalves (clams, mussels, and oysters) and crustaceans (shrimps and crabs) (Table 1). Shrimp is one of the highly demanded crustaceans because it fetches higher prices compared to fish and mollusks (Suyani et al., 2019) and thus due to MPs ingestion quality of the shrimp will fall and eventually leads to loss. It has been noted that >690 marine species belonging to different trophic levels are found contaminated with MPs (Gall and Thompson, 2015; Lavers and Bond, 2017). Apart from the species caught from natural populations, the ingestion of MPs have been reported from the species cultured in the various confined conditions such as bivalves (oysters, mussels and clams) reared in estuarine and coastal lagoons are vulnerable to devouring MPs because of the contaminated water and sediment areas (Lusher et al., 2017; Cheung et al., 2018; Renzi et al., 2018). Further, aquaculture systems where fish and shellfish fed with formulated feed pellets may also be contaminated with MPs present in the ingredients used for preparation of pelleted diet3. The occurrence of plastic fragments in fish and shellfish purchased from local fish markets for consumption were reported by several authors (Li et al., 2015; Neves et al., 2015; Rochman et al., 2015; Karami et al., 2017). The study conducted by Shylaja et al. (2018) reported that 97% by weight and 99% by the number of the composite flotsam in the Vembanad stake net fisheries (Kerala) formed of plastic items. Scientist and Researches of Central Marine Fisheries Research Institute (CMFRI) have observed and analyzed the plastic ingestion in different commercially important marine fishes of India like sardine, mackerel, anchovy, ribbon fishes, and also in the carcasses of sea birds and stranded cetaceans. This affirmation markup concerns about the ingestion of MPs by humans through the consumption of marine species contaminated with these particles as food and the potential effects on human health.

Table 1. Occurrence of microplastics in marine ichthyofauna

Species name	Location	Size range	Types of particles	Levels of MPs	References
Crustaceans					
Crangon crangon	Southern part of North Sea and English channel	> 20 μm	Synthetic fibers	63%	Devriese et al. (2015)

Aristeus antennatus	Western Mediterranean Sea	1 - >5 µm	Fibers	0-100%	Carreras-Colom et al. (2018)
Penaeus semisulcatus	Musa estuary, Persian Gulf	<100 - >1000 µm	Fibers	7.8 particles / shrimp	Abassi et al. (2018)
Parapenaeopsis hardwickii	North-west coast of India	-	Fibers	62.22%	Kumar et al. (2018)
Charybdis longicollis	Mediterra-nean Sea	-	-	25%	Stasolla et al. (2015)
Nephrops norvegicus	West coast of Scotland	-	Filaments	83%	Murray and Cowie (2011)
Panulirus polyphagus	North-west coast of India	-	Fibers	41.07%	Kumar et al. (2018)
Mollusks					
Venerupis philippinarum	British Columbia	-	Fibers, films, fragments	90%	Davidson and Dudas (2016)
Crassostrea gigas	California, USA	>500 µm	Fibers	-	Rochman et al (2015)
Mytilus spp.	Scottish coast	200 - >2000 µm	Fibers	-	Catarino et al. (2018)
Perna perna	Santos Estuary, Brazil	-	Fibers	26.7%	Santana et al. (2016)
Pinctada radiate	Coastal water of Persian Gulf, Iran	10 - 5000 µm	Pellets, fibers, fragments, film	-	Naji et al. (2018)
Marine finfish					
Sardinops neopilchardus	Australian waters	-	Polystyrene, polyethylene, polyvinyl chloride, polypropylene and poly(methyl	2.9 mg/g	Ribeiro et al. (2020)

			methacrylate)		
Trachurus trachurus	English channel	1000 - 2000 µm	Fragments, fibers, beads	28.6%	Lusher et al. (2013)
Clupea harengus	Baltic sea	100 - >5000 µm	Fibers, fragments	21%	Beer et al. (2018)
Engraulis japonicus	Tokyo Bay	10 - 500 µm	Fragments, filaments, foam, beads	77%	Tanaka and Takada (2016)
Epinephelus areolatus	Red Sea coast	1900 µm	Fibers, fishing thread, film	20%	Baalkhuyur et al. (2018)
Mugil cephalus	Hong Kong coast	<2000 - >5000 µm	Fibers, fragments	60%	Cheung et al. (2018)
Rastrelliger kanagurta	Eastern Indonesia	>500 µm	Fragments, monofilament, film	56%	Rochman et al. (2015)
Sardinella longiceps	Indian Coast	500-3000 µm	Fragments	60%	Sulochanan et al. (2014)
Saurida tumbil	Musa estuary, Persian Gulf	<100 - >1000 µm	Fibers, fragments	13.5%	Abassi et al. (2018)
Scomber japonicus	Mediterranean Sea	>9.07 µm	Nylon, Fibers, hard plastic	71%	Guven et al. (2017)
Sparus aurata	Mediterranean Sea	>9.07 µm	Nylon, fibers, hard plastic	44%	Guven et al. (2017)
Sphyraena jello	Northeast of Persian Gulf	<100 - 5000 µm	Fibers, fragments	100%	Akhbarizadeh et al. (2018)
Sardina pilchardus	Spanish Mediterranean coast	-	Natural fibers	14-15%	Compa et al. (2018)
Thunnus albacares	Arabian Sea	3 cm	Piece of plastic carry bag	-	Sajikumar et al. (2013)
Priacanthus hamrur	Bay of Bengal	<500 - <5000 µm	Film and fiber	3.8 particles / fish	Ghosh et al. (2021)

Setipinna tenuifilis	Bay of Bengal	<500 µm	Film, fiber, foam and pellet	3.8 particles / fish	Ghosh et al. (2021)
Stolephorus commersonnii	Mud bank, Kerala	1.14 – 2.5 µm	Threadlike MPs	37.5%	Kripa et al. (2014)

5. Environmental fortuity of microplastics

It is estimated that nearly 70% of marine trash are settled down to the bottom sediment of the ocean (Wu et al., 2019). MPs is believed to enter the ocean once it reaches any water-body. Due to its light weight, accumulation of MPs is higher in the surface waters. Globally around 7000 to 35000 tons of plastics is estimated from the ocean surface layer (Cozar et al., 2014). Apart from the accumulate in oceanic gyres and shallow water sediments, deep-sea sediments are a potential sink of MPs. Obbard et al. (2014) proposed that the polar sea ice may also represent a major historic global sink of MPs. The fate of plastic debris in the aquatic environment is strongly affected by various weathering processes like photooxidation, hydrolytic degradation, and biodegradation. Those processes gyrate plastic fragmentation into smaller particles and concomitantly change the condition of the MPs and their hydrodynamic behaviors (Ter Halle et al., 2016; Lambert and Wagner, 2016). MPs ingested by organisms may either be excreted as waste or translocated into tissues, making trophic transfer and accumulating in food chain. Thus there are two major effects posed by MPs are toxic effects and bioaccumulation and bioavailability.

Due to potential toxicity as well as durability and persistence, MPs present an increasing threat to the environment and the ecosystems (Hidalgo-Ruz et al., 2012; Lusher et al., 2014). In addition, several studies have suggested the potential roles of MPs as vectors of other toxic chemical contaminants (Avio et al., 2015). Thus it is crucial to understand the toxicity of MPs for environmental impact assessment study. MP uptakes by organisms such as lugworms, mussels, amphipods, barnacles, sea cucumbers, and fish have been documented, but their toxicity has not yet been fully understood yet. Internal abrasion, cogging feeding appendages and reduced feeding and physical condition are the potential effects of physical hazard posed by MPs. Most notably, after ingestion, MPs may transfer and release toxic chemicals hence, their toxic effects may be more severe with chemical injury compared to physical hazard (Wardrop et al., 2016). Due to limited studies on ecological effects of MPs, there is an increasing concern that the accumulation of MPs may affect the functioning of marine ecosystems. Eggs, embryos, and larvae of aquatic organisms are particularly vulnerable to MPs due to their limited ability to regulate their internal environment (Sussarellu et al., 2016). Biological toxicity analysis shows that the potential toxicity from MP exposure can induce disturbance of energy and lipid metabolism as well as oxidative stress (Deng et al., 2017). Lower trophic creatures (e.g., zooplanktons and invertebrates) can ingest and accumulate MPs, realizing the trophic transfer and accumulation in food web. Nevertheless, only few studies focus on the bioaccumulation of MPs and their associate pollutants in organisms. It is most likely that there are interactions between organism and MPs because of the widespread presence of MPs in the environment (Collignon et al., 2012). Thus accumulation and bioavailability of MPs in the food chain increase when their sizes decrease. Nevertheless, what makes scientists more interested is that there is a potential for MPs to enhance the bioavailability of pollutants adsorbed on MPs surface.

6. Abatement measures

- There is menacing need for generating data of occurrence of MPs in the sediment water and animals as evidence for framing food quality regulations.
- In place of synthetic plastic polymers different biodegradable plastic materials are used to minimize the plastic menace.

- Avoid utilization of plastic products identified as primary sources of MPs.
- Develop, execute, monitor and evaluate a coordinated marine waste reduction strategy.
- Prohibit use of microbeads in household cleaning and personal care products.
- Avoid purchasing products containing microbeads.
- Source reduction of plastics is the foremost and the only option through which we can prevent the MPs pollution in the aquatic environment.
- Regular assessment of fate of MPs in different fishery products and foodstuffs is required.
- Continuous monitoring programs is required to evaluate the presence of MPs in environment.
- Substantial reduction in the release of plastic in the aquatic environment is required.
- Superior waste management practices are required by establishing recycling infrastructure.
- Awareness in the local fishermen about the serious impact of MPs in the seafood security is required by organizing different awareness programmes and workshops.
- Strengthen local education by different awareness programs such as "Beat Plastic Pollution", "Say No to Plastic", etc.
- Reinforce and fortify product alteration for recyclable substitute to plastic polymers.
- Promote six R's (reduce-redesign-remove-reuse-recycle-recover) strategy.
- Minimize leakage of plastics to the environment at each stage of the plastic lifecycle train.
- Standardization of protocol for estimation of MPs is required.
- Innovations are required to prepare different alternative and ecofriendly plastic products from different natural resources like seaweed.
- Legislation / policy / strict law is required to avoid the dumping of plastics and plastics based products in the coastal and oceanic environments.
- Regional, national and international collaboration is required to beat the plastic and MPs pollution.
- Collaboration between the central and state institutes are required to address the impact of MPs among the local stakeholders.

7. Conclusion

No doubt that microplastic pollution has reached to a harrowing situation. With the increasing coastal population and lack of proper solid waste management protocols, the amount of solid waste entering the coastal waters is immeasurable. Currently, they are a ubiquitous contaminants in aquatic environments and detected in all the niches starting from beach sediments, water surface, water column, and deep-sea sediments. The analysis and management of MPs in the oceans is the greatest environmental challenges of the 21st century because of potentially hazardous chemicals released by MPs like plastic monomers and additives or adsorb toxic pollutants from the marine environment. Thus future research should focus on microplastic monitoring techniques along with the supply chain. Nevertheless, awareness program should be carried out starting from village level to urban level and we have to work for a permanent solution to this problem. Mitigation in the use of plastics, proper solid waste management programs, development of infrastructural facilities to deposit and degrade non-degradable litter in public locations and coastal cleanup programmes can some of the alternative ways to reduce and combat MPs pollution. Marine remnants should not be disregarded; if neglected, it can completely demolish the natural resources and the subsistence depending on aquatic ecosystems.

Conflict of Interest: The authors have no conflict of interest to declare.

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