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Journal of Fisheries Science
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REVIEW

The Ecotoxicological Effects of Microplastics on Primary Producers in the Marine Environment

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ARTICLE INFO

Article history
Received: 21 May 2020
Accepted: 11 June 2020
Published Online: 31 July 2020

Keywords:
Microplastics
Marine
DOC
Microorganisms
Ecological impact
Ecotoxicology

ABSTRACT

Plastic debris is an emerging environmental threat all over the world. But its effect and distribution in the marine ecosystem is barely known. Microplastics abundance in the marine vegetated area is about 2 to 3 times higher than the bare site in the ocean. Although seagrass meadows trap huge amount of microplastics over the ocean floor, a considerable amount of microplastics are also sink incorporating with the marine aggregates from the epipelagic zone of the ocean. Scavenging of microplastics by diatom aggregation decreases the sinking rate of them rather than cryptophyte. As we know, marine snow is the leading carbon source for zoobenthos, but the ubiquitous presence of microplastics damages cell of different microalgae which may alter the food webs of marine ecosystems. Additionally, microplastics releases immense amount of dissolved organic carbons (DOC) in the surrounding seawater that stimulates the growth of heterotrophic microorganisms as well as their functional activity. Plastic debris result in outbreaks of disease in the marine environment and coral reefs are highly affected by it. When coral reef comes in contact with microplastics, the disease infestation rate of the reef increases massively. Three major disease *viz*., skeletal eroding band, white syndrome and black band of coral reef causes approximately 46% of reef mortality due to microplastics consumption. Due to complex structure and size, the corals accumulates huge amount of microplastics that increases growth of pathogens by hampering the coral immune system. Existing scientific evidence presents that exposure of microplastics in aquatic environments triggers a wide variety of toxic insult from feeding disruption to reproductive performance, disturbances in energy metabolism throughout the ocean. The present review focused on the ecotoxicological effect of microplastics on primary producers of ocean, its uptake, accumulation, and excretion, and its probable toxicity with risk assessment approaches.

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 DOI: https://doi.org/10.30564/jfsr.v2i2.1906

1. Introduction

The invention of plastics has achieved a crucial status, with extensive industrial, commercial, municipal and medicinal applications in contemporary society. Marine ecosystems are subjected to peculiar types of anthropogenic pollutants including plastics, nanoparticles, radionuclides, hydrophobic pollutants etc. Plastics incorporate with an enormous variety of polymer types, including polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinylchloride (PVC), polyamides (PA), polyethylene terephthalate (PET) and so on that contaminate both marine and freshwater ecosystems. Accumulation of these plastic contaminants for time after time creates a risk to the aquatic health and living organisms [1,2]. In last sixty years, plastic production has grown very rapidly, and globally where more than 288 million tonnes of plastic production was recorded in 2012 [3]. Due to its cheap prize, durability and flexibility it is used for making several types of fishing gear that are responsible for microplastics pollution in ocean in different ways [4-6]. Due to indiscriminate waste disposal and effluent of wastewater plastic debris are entering into the oceanic environment and may remain several centuries to mineralize [7]. According to the National Oceanic and Atmospheric Administration (NOAA), particles ignored portion from any kind of plastic debris and smaller than 5mm in size are considered as microplastic [8]. These are microscopic plastic fibres, fragments and beads that comprises 1-5 µm size in diameter [9, 10]. Depending on their origin microplastics has been divided into two categories. Firstly, the primary microplastics that originates from textiles, paints, cosmetics, household wastewater as well as from different plastic industries; and secondly, the secondary microplastics that are departed from the macro plastic (bigger in size >5mm) by dint of physical abrasion [9]. As plastic debris and microplastics had been observed in all over the ocean across the world from epipelagic layer to bottom floor of the ocean and also in the different levels of the trophic web [10-16]. The low density microplastics, polystyrene, polyethylene and polypropylene are usually found in the surface layer of the water column, while the high-density plastics polyamides and polyvinylchloride are tends to sink to the bottom. Sometimes, due to environmental disturbance like storms and currents of water of pelagic region creates vertical mixing of these particles within the oceanic environment [17,18]. Several studies revealed that the concentration of microplastics are very high in the urban coastal area, oceanic gyres and convergence zone of the ocean [19-22]. A study performed by Van-Cauwenberghe et al. [23] showed that a total of 10,000 particles m^{-3} microplastics covered the Belgian coast whereas about 102,000 particles m^{-3} are found in the Swedish coastal water body [24]. Another study on the North Pacific gyre revealed that small plastic particles exceed the phytoplankton in mass [25]. Moreover, Shim et al. [26] found fibers as the most dominant microplastic in the subtidal zone of ocean.

2. Plastics and the Marine Ecosystem

Ecological effects of microplastics on marine ecosystem are well studied [12,27]. Due to high sorption capabilities the microplastics contaminants absorb miscellaneous chemical substances of the epipelagic zone of ocean and transfer into the food webs or marine ecosystems [28]. In many places, microplastics contain high levels of toxic substances [29,30]. For example, at Brazil coast heavy metals adhere to microplastics was found [31,32]. At present, wetland playing an important role to support biodiversity and nutrient cycling, but also a microplastic transmission center of the global ecosystem [33,34]. Mangrove forests, seagrass meadows, saltmarshes and other marine and coastal vegetated area makes blue carbon ecosystem, which stores a significant amount of carbon in plant biomass as well as sediments [35]. The seagrass meadows of the wetland and blue carbon ecosystem plays a significant role in global carbon absorption and mitigate climate change [36]. Seagrass controls the velocity of water flow and enhances particles retention and sedimentation [37-39]. Seagrass meadows trap the particulate things recommend that it may also trap microplastics significantly [40]. The Dissolved Organic Carbon (DOC) pool of the ocean is one of the Earth's biggest, old and refractory [41-44] carbon pool (662Pg C) [45] and almost the same as the atmospheric carbon in size (828Pg C) [46]. Mainly phytoplankton derives DOC which enters the microbial food web and helps micro-heterotrophic organisms to grow [45, 47]. In this review, the term DOC used for biologically available dissolved organic carbon taken by heterotrophic bacteria in the daytime. Plastics release of DOC in the ambient seawater, as well as the biodegradation processes and its effects, are not much studied [48].

Lower plastic concentration in the sea surface than expected [49,50] suggests that majority of the plastics sinks to the bottom [51]. A higher density of the particles is not always true for their vertical fluxes. Because ocean dynamics can mix the bottom and surface particles to the water column [52]. But, sinking occurs because of the particles density most of the time [1] and biofouling (e.g. colonization of microorganisms) process could change the density and reverse their buoyancy [53] and microalgae had found to be attached with microplastics [54]. When

  DOI: https://doi.org/10.30564/jfsr.v2i2.1906

algae become stressed (e.g. nutrient and light limitation) or get concentrated the release polysaccharides [55-57] to form sticky transparent exopolymer particles (TEP) [56,58] which helps to form cell aggregation. Microplastics incorporates these aggregates [59], which could create a vertical sinking of microplastics [60]. Thus phytoplankton and the upper trophic level grazers are mostly relying on these marine aggregates, this microplastic incorporation could have a considerable impact on the organisms which are ingesting [12,27,61-64]. Occurrence and abundance of plastic litters in marine environment are shown in Table 1.

Table 1. Abundance of plastic litters in marine environment

Saline area	Location	Abundance of microplastics	Methods of detection
North Shore Channel [65]	USA	1.94 items/m^3 at upstream – 17.93 items/m^3 downstream	Scanning Electron Microscope Analysis
Clyde sea [66]	North and West Scotland	Average weight of fibers from lobster gut 0.28–0.68 mg	FTIR Spectroscopy
Southern Ocean [67]	Fremantle to Hobart	44 pieces of microplastic, excluding fibers and expanded polystyrene, were collected over 5 sampling stations; Total particle counts along the sampling stretch is 100,000 pieces km^{-2}	Stereoscopic microscope; visual identification
Goa beaches [68]	India	Total of 3000 pellets	FTIR coupled with attenuated total reflectance (ATR) for polymer composition
Bohai sea [69]	China	0.33 ± 0.34 particles/m^3	Micro-Fourier transform infrared spectroscopy

Additionally, the coral reef is one of the most diversified ecosystems on earth which is threatened by disease [70]. The pathogens containing by plastic continuously trigger the diseases and increases vulnerability to the coral reef [71]. For instance, genus *Vibrio* colonizes on the polypropylene of marine water [54] and this devastating pathogenic bacterium creates white syndrome disease on corals [72]. As microplastic debris sinks frequently to the bottom and the previous studies on microbial rafting [73] suggests that plastic colonization level on coral reef ecosystem may very high.

3. Seagrass Meadows Traps Microplastics

Vegetated area microplastic abundance is much higher in than that in the bare site in both study area [40] (Figure 1). This was the first documentation of seagrass meadows traps and have high particle retention [39]. Seagrass beds create high roughness in the bottom layer and increase boundary friction which reduces the water flow [74]. The water flow is 2-10 times less in the vegetated area, sediments do not resuspend much and results in high sediment and organic particles accumulation [39,75-80].

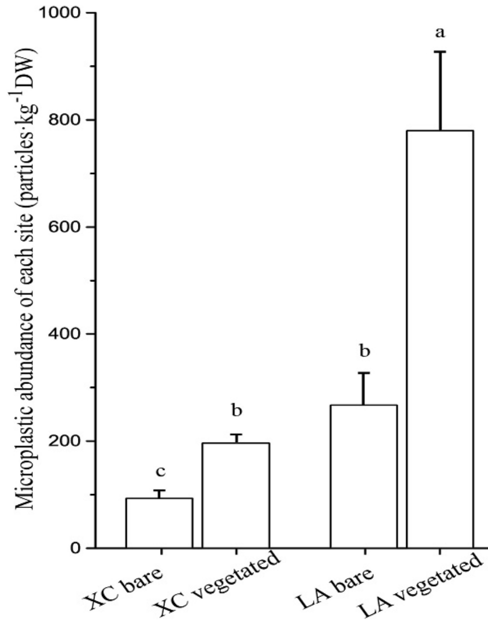

Figure 1. Microplastic abundance in the vegetated and bare site of the study area [40]

Seagrass canopy loss the particle's momentum by trapping particles through leaves and sinks them under the bed [74,81]. In a similar way, the microplastic could be trapped in the vegetated area due to less flow in the bottom and caught by leaves. There could be more accumulation of stacked sediments when leaves are buried [40]. The intertidal mudflats have lower physical turbulence where microplastic abundance is higher than from the exposed area [82] which is the similar findings by Huang et al. [40]. Another fact that the microplastic trapping by blue carbon ecosystem can explain their accumulation, like the mangrove of the Arabian Gulf and Red Sea [83]. Hence, seagrass meadows may be considered as the storage of microplastic of the marine environment [40], the anthropogenic contaminants can affect the living organisms of that ecosystem.

4. Microbial Activity

High- and low-density polyethylene (HDPE and LDPE), polypropylene (PP) and packaging polyethylene (PE) had been used for the experiment shows that these types of plastics leaches major part DOC when first contact with the seawater. During the experiment within first 200h almost half of the leached DOC has lost [48] (Figure 2).

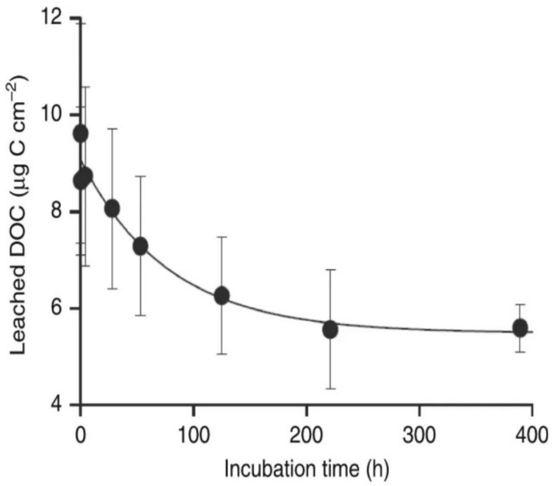

Figure 2. Loss of DOC over time using LDPF [48]

Karapanagioti and Klontza [84], documented the plastics sorption and desorption capacity, thus plastics could reabsorbed the leached DOC until it gets equilibrium [48]. Organic compounds sorption by plastics can be very fast. Because, Bakir et al. [85] found that floating polyethylene reabsorbs organic pollutants and gets equilibrium within 24 to 48 hours. However, other experiments documented more than 20 days [84]. In Romera-Castillo et al.[48] study it reached after 200 hours and may be with including DOC already been in the water. In nature, there could be a competition between bacteria and plastics to absorb natural DOC as bacterial abundance increased over time in the experiment (Figure 3) which may disrupt the other trophic level process [48].

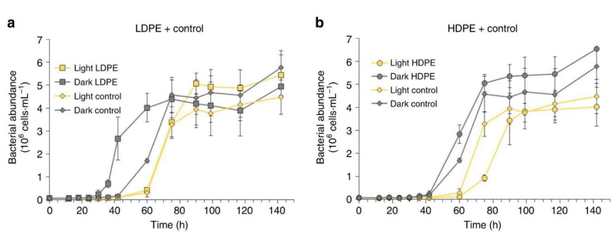

Figure 3. Bacterial abundance during the incubation with plastic leachates (cell mL-1) during the incubation of DOC leached from the plastics [48]

Carbon cycle and microbial activity influences by DOC leaching from plastics. The bioavailable DOC was higher in the dark than in the light (artificial solar radiation). Bacterial community stimulates in the dark condition (Figure 3), indicates they utilizes DOC than in the light condition [48]. Because, the radicles produce by plastics photo degradation [86] which could inhibit the growth of bacteria [87]. But, in the higher plastic concentrated area leaching DOC and their microbial activity could be significant in the near shore area or subtropical gyres [48].

5. Distribution and Impact on Microalgae

The Cryptophyte *Rhodomonus salina* and the diatom Chaetoceros neogracile aggregates were exposed to microplastic. *R. salina* aggregates showed eighteen times more affinity for microplastic beads than *C. neogracile* [60]. One reason could be *R. salina* aggregates are more permeable and small particles get more encountered through the aggreagtes [88]. Again, extracellular polymeric substance (EPS) of algae establishes hydrogen bond with the particles to facilitate hetero aggregation [89,90] with the interaction of the algal cells [91] (Figure 4). This kind of hetero aggregation may cause physical damage, membrane structure may alter [92], even cause damage of cell wall [29]. Besides, micro particles could cause light attenuation and reduce the nutrient uptake and gas exchange ability of algae which may consequent adverse impact on algal photosynthesis and respiration [89].

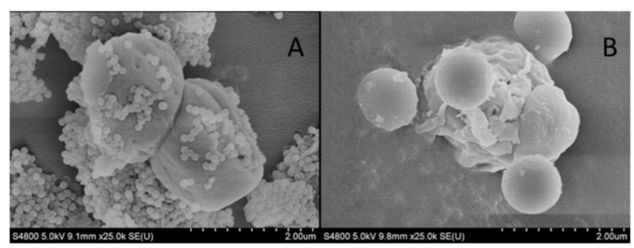

Figure 4. Algae and microplastic aggregation (Hetero aggregation). *Chlorella pyrenoidosa* (A) exposed to 0.1 µm PS microplastics (100 mg/L) and (B) exposed to 1.0 µm PS microplastics (100 mg/L) [91]

Incorporation with the microbeads the density of *R. salina* aggregates get higher and sinking rate increased than *C. neogracile* aggregates. In contrast, *C. neogracile* incorporates with low density microplastics and the overall density of the aggregates reduced [60]. The microbeads incorporating with the phytoplankton aggregates suggests that these aggregates potentially act as microplastic sinking and responsible for distribution [60]. Lack of plastic in the surface ocean [49, 50] and particles higher concentration in the bottom [51] can be explained by this. Phytoplankton aggregates contain microplastics and it may have a significant impact on the marine organisms [60]. Because, microplastics could be more approachable and ingested by the zoobenthos associated with the phytoplankton aggregates [27] as the filter feeders rely mostly on marine snow as carbon source [60]. And this may result in more microplastics access to the food chain [93]. Thus, it poses a serious threat to the biota and eventual ecological niche imbalance. Impacts of microplastics on different marine biota are shown in Table 2.

  DOI: https://doi.org/10.30564/jfsr.v2i2.1906

Table 2. Observed ecotoxicity of microplastics in marine algal community

Algae	Microplastics size/concentration	Duration of Exposure	End points	Observations
Tetraselmis chuii (Microalgae) [94]	fluorescent red polyethylene microspheres (1–5 μm - 0.046 to 1.472 mg/l), Copper conc. Ranging from 0.02 to 0.64 mg/l,	96h	Growth inhibition	no significant growth rate inhibition
Skeletonema costatum (Diatom) [69]	polyvinyl chloride (PVC) microplastics of 1 μm and 1 mmsize	96h	Growth inhibition	39.7% growth inhibition in 1 μm particle exposure; no effects on algal growth in 1 mm size. Significant adsorption and aggregation
Rhodomonas baltica (Microalgae) [95]	fluorescent polystyrene particles (1–5 μm)	60 min	Uptake and motility	Increased uptake; bio-fouling formation

6. Coral Disease

About 17 genera of reef forming corals were found in contact with the plastics in different Asia-pacific regions [96]. Intensity of causing disease increases from about 4% to about 89% in presence of plastic debris [96] (Figure 5). Altizer et al. [97] demonstrate that terrestrial pollutants outbreak diseases in the marine environment and about 80% of the marine plastic waste comes from land [92]. It is also in consideration that disease effect differs in the different reef building corals in presence of plastic debris (Figure 5).

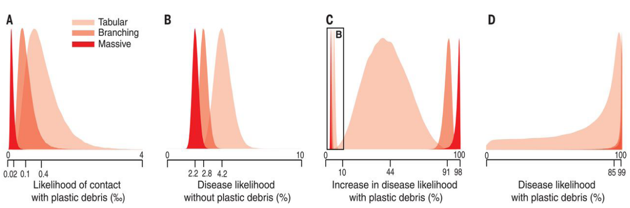

Figure 5. Coral morphological complexity influences the risk of plastic debris and disease. Tabular type corals are more likely to contact with plastic debris and affected by disease [96]

Because, corals with more structural complexity are the microhabitats for the organisms associated with coral reefs forming disease [96]. Lamb et al. [96] found three major diseases which cause rapid coral reef mortality: white syndromes (17% mortality), skeletal eroding band (24% mortality) and black band disease (5% mortality). Plastics not only cause physical damage of the corals, one of the major reasons could be abundance of pathogens and microbial activity in the high plastic concentrated area [48]. Plastic also inhibits light penetration into the water which is essential for some coral forming organisms could be another reason of global coral reef decreasing.

7. Conclusion

The distribution of plastic debris is higher in the vegetated bottom area that at the sea surface in the ocean. Seagrass and other plants act as filters for trapping the plastics. Plastic debris creates shading and triggers a favourable environment for microbial growth in the plastic concentrated area. Additionally, microplastics incorporate with marine snow sinks down and threating the overall biodiversity as it can cause damage of microalgal cell and disease to heterotrophic organisms. At present coral reefs are in very vulnerable to plastic contamination. But, how and what types of diseases causing to the other marine living organisms is not studied at all. It could be very important to do further research on that specific area (e.g. effects of microplastic on marine heterotrophic organisms). Most of the scientists believe that only the proper plastic waste management with strict law can stop this devastating marine pollution.

Authors' Contributions

All authors had searched and contributed to the article writing. Mahibul Islam and Mahmudul Hasan had designed the paper structure and contributed to editing; Bhaskar Chandra Majudmar and Sulav Indra Paul had revised the article. All authors read and approved the final manuscript.

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DOI: https://doi.org/10.30564/jfsr.v2i2.1906

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