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Ecological Impacts of Microplastics in Coastal Environment

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Abstract

Microplastics (MPs) are a worldwide persistent insoluble micropollutant that significantly threatens the marine environment. Their ubiquitous presence has induced many adverse ecological impacts on the coastal and marine environments. Plastic particles that are less than 5 mm in size are termed MPs. Their small size and higher concentrations in the water surface and sediments have made them available for active and passive ingestion specially during foraging activities. MPs have affected marine biota, such as marine birds, mammals, turtles, fish, and mollusks to sensitive ecosystems such as coral reefs and algae communities, reducing biodiversity and altering the community structure of organisms in their natural habitats. Almost all the marine food sources, from shellfish to finfish, are contaminated with MPs. The toxic chemicals that MPs adsorb from the surrounding environment may lead to bioaccumulate along the food chains. Thus, impact food webs. The presence of MPs in food induces health implications in organisms, including humans, by leaching adhered toxicants into the body tissues. MPs present in coastal environment have to be managed, since their contamination will eventually lead to the bioconcentration of MPs in different trophic levels and will lead into biomagnification MP adsorbed toxic substances.

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1. Introduction

1.1 A global perspective on plastic and microplastic pollution

Plastic pollution is a worldwide persistent environmental challenge, which has invoked critical non-deleterious effects on both living and non-living components in the biosphere. Plastic pollution occurs due to various factors including improper disposal of plastic waste, inadequate recycling infrastructure, and the widespread use of single-use plastics (Iroegbu *et al*., 2021). Since, plastic is a man-made substance its density in the ecosystems positively correlates with the degree of human activities (Yin *et al*., 2021).

However, the persistence of plastics in remote and pristine areas indicate that plastic has invaded the areas where we see low human activities. This is mainly by means of both natural and artificial driven factors. Thus, breaks the limiting belief that the plastic pollution is confined mainly in the areas of high anthropogenic activities (Mihai *et al*., 2021**).** With the onset of the accumulation of plastic waste in the Anthropocene era, the plastic age has begun (Porta *et al*., 2021). The first record of plastics in the ocean appeared in the early 1940s (Carpenter *et al*., 1972) and has increased so far at an alarming rate (Jambeck *et al*., 2015; Jang *et al*., 2018). Land based plasitic litter contributes 80% of the plastics found in marine litter (Andrady, 2011). The estimated mass of land-based plastic waste that had been entering the ocean was 4.8 to 12.7 million metric tons (11%) in 2010 from 192 coastal countries (Jambeck *et al*., 2015). Also, an estimated 99.5 million metric tons of plastic waste was generated in coastal regions in 2010 (Jambeck *et al*., 2015). The biggest challenge is when it was found that the plastic could be further broken down into tiny particles termed microplastic (MP) due to both physical and chemical weathering processes.

Plastic debris less than 5 mm and greater than 1 µm is termed MP and has been considered a pollutant in its own right (Ryan *et al*., 2009). On the contrary, researchers have introduced many definitions for MPs: sizes less than 10 mm (Graham and Thompson, 2009), less than 5 mm (Barnes *et al*., 2009), within the size range of 2 – 6 mm (Derraik, 2002), less than 2 mm (Ryan *et al*., 2009) and less than 1 mm (Browne *et al*., 2007). However, the widely accepted and currently used size range is less than 5 mm and greater than 1 µm. The morphological and morphometric characteristics of MPs refer to their origin (primary or secondary), type (forms, filaments/threads, beads/pellets/nurdles and fragments), colour, and size. Relative to the origin, MPs are categorized as primary and secondary MPs. Plastics that are manufactured in a microscopic size are primary MPs. These plastics are used in cosmetics (Zitko and Hanlon, 1991), air-blasting media (Gregory, 1996), and pharmaceuticals (Wheate *et al*., 2021). Secondary MPs are tiny plastic fragments derived from the breakdown of larger plastic debris, both at sea and on land (Thompson *et al*., 2004; Ryan *et al*., 2009). Most of the marine MPs are fibers. Among the marine MP polymers, polyethylene (PE), polypropylene (PP), polystyrene (PS), polyamide (PA such as nylon), polyester (PES), and acrylic (AC) can be listed as the most common types (Cole *et al*., 2011). MPs have been found in over 90% of surface water samples worldwide, as well as in coastal and benthic sediments (Obbard, 2018). They are ubiquitous and are leached into marine ecosystems via different sources and routes. Mainly the high unidirectional flow of freshwater systems drives the movement of plastic and MPs into the oceans (Moore *et al*., 2002; Browne *et al*., 2010; Auta *et al*., 2017). Coastal tourism, recreational activities, commercial fishing, marine vessels, and marine industries (e.g. aquaculture, oil-rigs) are also sources of plastic and MPs that can directly enter the marine environment, posing a risk to biota. In addition, fishing gear is one of the most commonly noted MP sources in marine environments (Andrady, 2011). Moreover, shipping remains a dominant source of MPs in the marine environment as well (Derraik, 2002). The tropical oceans surround the Earth as an equatorial band between the Tropic of Cancer and the Tropic of Capricorn. It consists of sections from the Pacific, Atlantic Ocean, and the majority of the Indian Ocean. (Latif and Barnett, 1996). Highest density of plastic debri has been found in the central areas of North Atlantic and North pacific oceans (Alfaro Nunez, 2021). Thus, greater MP density would be predicted to be circulated in the Nothern hemisphere ocean basin. Also, when considering the Indian Ocean, it has been mentioned that the coastal soil and water in the North Eastern Indian Oceanic region has been highly contaminated with Mps of size 20 µm–6700 µm (Thathsarani *et al*., 2023). Many researches on MPs in open oceans that had been conducted thus far have mainly focused the tropical and subtropical ocean waters. Since the Ekman currents facilitate the plastic accumulation in all five subtropical ocean gyres (Alfaro Nunez *et al*., 2021), these will eventually serve as convergent zones for MPs. The North Pacific subtropical convergent zone where warm water from the South Pacific meets cooler water from the Arctic serves the great Pacific garbage patch. The great Pacific garbage patch which has become a severe complication is a gyre of plastic debris in the north-central Pacific Ocean, which also belongs to tropical waters. It is the largest accumulation of offshore plastic in the world. According to Lebroton (2018), 79 thousand tonnes of ocean plastic are floating inside an area of 1.6 million km^2 in this sub-tropical water body. In reality, these patches are almost entirely made up of MPs. Thus, it tends to release more MPs into tropical ocean waters than waters bound to temperate regions (Cole *et al*., 2011). Therefore, the adverse impacts of MPs are severely affected by the tropical marine and coastal environments (Lebreton *et al*., 2018).

Once the MPs are caught in the global ocean circulation system, they could travel far distances drifting along with the waters (Li and Tang, 2020). The presence of MPs has been confirmed in Polar water (Antarctic and Arctic regions), sediment, and sea ice (Munari *et al*., 2017; Obbard, 2018). MPs in Polar Regions have become an interesting finding since these regions are very thinly populated and are environments of extreme weather conditions. Human-mediated transportation and the natural long-distance transportation mechanisms would have been reasons for their accumulation in Polar Regions (Obbard, 2018; Mishra *et al*., 2021). Recently, it is shown that MPs could be transported worldwide through wind currents, ocean wave actions, algae, and seaweeds by providing possible substratum to adhere (Mishra *et al*., 2021). Irrespective of the locality, the consequences of plastic and MP pollution are directly attributed to human activities. Since, humans exploit resources from the marine environment at significant levels. Once the MP contamination levels in marine environments are investigated, it is always essential to analyse the consumer risks and the risk upon the inhabitants of these environments. Thus, monitoring practices and management policies of MPs related to the marine environment must be established. Further, MP pollution could be considered under the general cycle of polluter, pollutant and pollution concepts. If humans take measures to reduce this micro pollutant via MP monitoring measures, the pollution effects and its consequences experienced by humans could be managed. Figure 1 depicts the relationship between pollution and the MP pollutants. Therefore, the review article is focused on highlighting scientific knowledge in monitoring and management of marine food sources which could directly affect human health. The review briefs the overview of global MP pollution, describes the ecological impacts of MP pollution on marine ecosystems and MP contamination levels in different marine food sources.

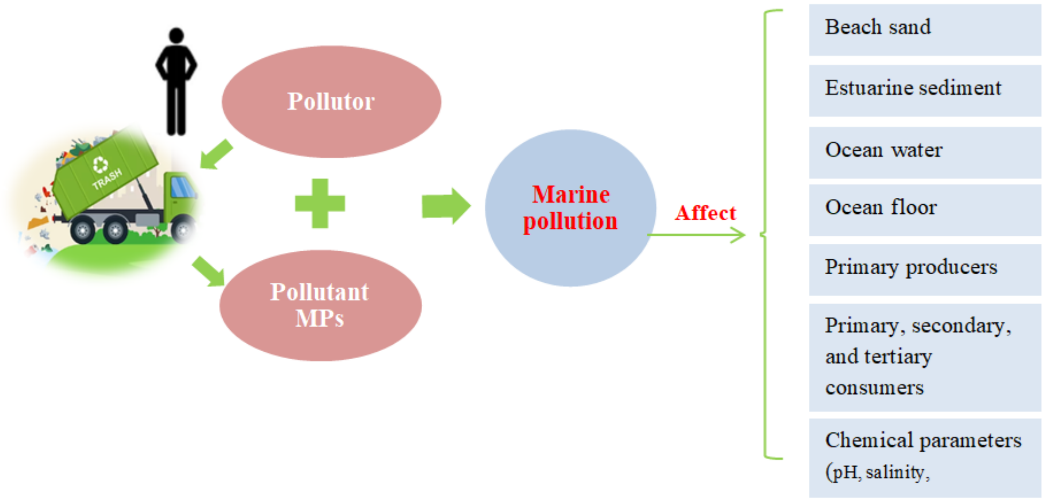

Figure 1: The biotic and abiotic marine environmental components that are affected by the MPs pollution.

2. Impacts of microplastic pollution on marine ecosystems

Microplastic pollution is invoking huge environmental toxic effects since they are considered potential vectors to carry the persistent organic pollutants (POPs) (Ng and Obbard, 2006), endocrine disrupting chemicals, water-soluble aqueous metals (Ashton *et al*., 2010) and hydrophobic organic contaminants (Rios *et al*., 2007), into the seawater, sediments and also into the body tissues of the marine organisms (Cole *et al*., 2011 and Nayanathara *et al*., 2023). Thus, it emphasizes the trophic transfer of MPs and bioaccumulation of the adhered toxic compounds finally moving into humans. The major impacts of MPs pollution on marine ecosystems will be bioaccumulation of MPs, bio-magnification of the adhered toxicants in the higher trophic levels of the marine food chains, biodiversity loss, habitat loss and fragmentation, less availability of food sources to chronic and acute effects of marine pollution and mass deaths of marine organisms etc. The following listed ecological impacts of MPs discuss their consequences on the marine ecosystems. The discussed impacts and the consequences are not isolated events. They are inter-related measures. Bioaccumulation and biomagnification could be considered as the major MP pollution impacts on marine fauna. Biomagnification is the accumulation of a chemical by an organism from water and food exposure that results in a concentration that is greater than would have resulted from water exposure only and bioaccumulation is a process of accumulation of chemicals in an organism that takes place if the rate of intake exceeds the rate of excretion.

2.1 Bioaccumulation and biomagnification of microplastics and associated chemical additives in marine ecosystems

Evidence of MPs present in the environment including coastal and marine environments goes back to 1940s. Since then, bioaccumulation of marine MPs has become a silent threat. Owing to their small size and presence in both pelagic and benthic ecosystems, MPs have the potential to be ingested by an array of marine biota. Microplastics can enter organisms through various pathways. The most prominent way is ingestion during feeding. Thus, they are retaining in the digestive tract. Moreover, filter-feeding animals will also ingest MPs through filtration of water, altering nutritional intake, growth, development, reproduction, and survival rate of the organism (Cole *et al*., 2011). These MP induced impairments may lead to detrimental consequences to wider community and eventually reduce the biodiversity (Carbery, 2018). The more the ocean waters allow matter to dissolve in it, the concentration of the seawater will get increased. Thus, this trend may result in dead seas and oceans with less wave action and lower biodiversity in the future. The bioaccumulation concept has been supported in numerous ways by the following research studies. Bioaccumulation is defined as the net uptake of pollutants including MPs (or chemical additives) from the environment by all possible routes and from any source. Routes of exposure to these pollutants are by means of contact, ingestion and respiration. The sources of MP contamination are the substratum such as water, sediment and prey (Miller *et al*., 2020). Bioaccumulation is linked with trophic transfer of MPs. Contamination of MPs in different trophic level is govern by the feeding pattern of the organism not by the trophic level of the organism. Therefore, when bioaccumulation is discussed under this section, MP concentrations of organisms in different trophic levels have been focused**.** Thereby, MPs retained in the macro primary producers up to the level of tertiary consumers are providing comprehensive information about bioaccumulation and biomagnification.

Seagrasses are one of the major macro primary producers in the coastal marine environment. They are natural MP trapping agents (Li *et al*., 2023). Seagrass beds acts as natural filters for MPs from the open ocean and act as sinks for MPs due to conditions, such as reduced water flow, increased settling rates and entrapment by blades that could favour retention of MPs (Kreitsberg *et al*., 2021). MPs have been found within the epiphytic layer of the autotrophic seagrass *Thalassia testudinum* at a quantity of 4.56 MPs individual^{-1} (Miller *et al*., 2020). Contamination levels of the surrounding sampling area such as surface water and sediment has not reported in this study. Therefore, the relationship between the trapped MPs by seagrass to the levels of MP concentration in their immediate water and sediment substratum are unknown. Studies have also indicated that seagrasses can elevate MP abundance in seagrass bed sediments by 2.1 to 2.9 times (Huang *et al*., 2020). Even though the studies that have been conducted to extract the adsorbed MPs from the leaves, the sediment deposition rate of MPs has been understudied. Rather than considering seagrass meadows as a natural barrier of MPs, the focus must be equally given to seagrass meadows conservation and to identify the potential hazards that MPs would eventually affect these primary producers over time. Not only seagrass beds but, the macro algae species also act as conduits for MP trapping and transportation from the open ocean to the sea shore environments (Aldana *et al*., 2024).

Representing the first trophic level, MP pollution has been documented in various species of macroalgae, including *Ulva prolifera*, *Ulva lactuca*, *Sargassum horneri*, *Sargassam crassifolium*, *Padina* sp. *Gracilaria lemaneiformis*, *Chondrus ocellatus*, and *Saccharina japonica* (Zhang *et al*., 2022; Atapattu *et al*., 2023). Of them, macro algal blooms of *Sargassam* sp., *Ulva* sp., *Enteromorpha* sp. etc. are heavily affecting the ocean basins and worldwide coastlines since 1970s. They cause the green tides and brown tides time to time and have been identified as one of the active agents of transporting pollutants such as MPs from a different region of origin to another region (Aldana *et al*., 2024). Of the studied species, *Sargassam* sp. has been widely studied for the contamination of MPs for their availability in both the seashore and in the pelagic zone. They act as a reservoir and transportation media for both macro and MPs in the marine environment. As *Sargassum* mats traverse the Atlantic Ocean and the Caribbean Sea, they entrap and transport plastic to coastal areas. According to Aldana (2024), in the pelagic *Sargassam* sp. scientists have analyzed MPs at monthly mean concentrations ranged from 3.5 to 15.3 MPs g^{-1} DW (Dry Weight). More than 90% of the algae have been extensively contaminated with fibers. The recorded colours were mainly blue, transparent and black. Another study has reported MP concentration to be 11.2–19.3 items/kg for fresh weight of *Sagassam* sp. (Joceylan *et al*., 2023). But, this value is significantly lesser than that of reported MP concentrations in Aldana (2024). The phenotypic properties of MPs that have been encountered from the seagrasses and seaweeds are in compliance with the morphological characteristics of the MPs found in the Open Ocean and marine fauna (Aldana *et al*., 2024).

Green algae *Ulva prolifera*'s distinctive tubular body and highly branched thallus enable it to retain high concentrations of MPs (Feng *et al*., 2020). The MP concentrations that have been tested along the migration pathways of green and gold tides of algal blooms in the Yellow China Sea have the following characteristics. It was found that *Ulva prolifera* has exhibited a higher abundance of MPs (0.065 ± 0.047 items/g^{-1} FW) and ratio of the MP abundance in macro-algae to that in seawater is (Rm/Rs = 97.33). These results imply that the MP trapped by the *Ulva* sp. is greater than that of the MP concentration in the water. The research team has also focused the MPs trapping levels of brown algae *Sargassam honeri*. The amount of MPs trapped by the *Ulva* sp. in this study was more than that of the MPs trapped by the *Sargassam* sp. (Zhang *et al*., 2022). Moreover, the MPs in *Ulva prolifera* has shown increased diversity in its bioconcentration characteristics such as shape, color and material than those in *Sargassam horneri*. The size of the MP particles that has been adsorbed by the *Ulva* sp. has been found to be smaller than that of the latter brown algae species. Slender long branches, fast growing biomass, hollow air sacs and soft epidermis may have allowed *Ulva prolifera* to load more MPs than *Sargassam honeri* (Zhang *et al*., 2022).

The values that have been discussed above were on pelagic macrophytes. But the values are different when moving from the open ocean to the shoreline where rocky shores are housed**.** As per Thathsarani *et al* (2023), the mean MPs contamination levels of rocky shore green algae *Ulva* sp. and brown algae *Sargassam* sp. were 0.101±0.011 items/g FW and 0.081±0.028 items/g FW, respectively. Since, the values are not significantly different among the species the authors have not circulated a sound conclusion on which algae species are more willing to trap more MPs respective to other algae species. But the MPs contamination levels mentioned in Thathsarani *et al* (2023) were high for both the algal species compared to Zhang *et al* (2022) and low than the MPs trapping values reported in Aldana *et al* (2024). The reason might be the heterogeneity of the selected marine ecosystem. The heterogeneity in the rocky shore may be due to the frequent mixing of water due to tidal fluctuations and may be due to the high wave action. According to Thathsarani *et al* (2023), the reasons for the research team to isolate less number of trapped MPs from the algae samples when compared to Aldana *et al* (2024) may be due to the increased detachment rate of MPs from the thalli for high wave action experienced during the South West monsoon season in the Morawala Negombo rocky shore and the algae have been mainly sampled from the low tide zone where water mixing was strong due to the harsh wave crashing against the rocky shore.

Majority of the studies that have been conducted on seaweeds and seagrass MPs, have not been able to reveal the contamination route or the exact MPs entry mechanism to the thalli. That is the MPs that have been found associated with these macrophytes might be the MPs in contact but not the thalli penetrated MPs. MPs will adsorb to the thalli and to the fronds. But, none of the research studies thus far have documented any thalli penetrated MPs. Therefore, when considering bioaccumulation of MPs in marine macrophytes, the concept is inapplicable for the MPs retained among the seagrass and seaweeds. Since, bioaccumulation directly refers to the absorbed pollutants and tissue accumulation of pollutants and not to the tissue adsorbed pollutants (Bryan and Darracott, 1979).

Moving in to the MP bioaccumulation status of other marine organisms representing different trophic levels, we observed an interesting trend. Filter feeders at any trophic level tend to bioaccumulate more MPs over non-filter feeders (De Benedetto *et al*., 2024). One of the researches that had been conducted in Morawala rocky shore Negombo, Sri Lanka was able to uncover the MPs concentrations present in filter feeding mollusks and grazers. Accordingly, the MPs concentration has been higher for filter feeding bivalves *Crassostrea* sp. and *Mytilus* sp. (1.453±0.554 items/g WW) than in the grazers such as *Patella* sp. and *Littorine* sp. (1.253±0.271 items/g WW). In this study filter feeding and grazing mollusks represented the second trophic level while algae represented the first trophic level. Of them, the mean MPs concentrations of mollusk tissue samples were high compared to the MPs trapped in green algae and brown algae samples at the same location (Thatsarani *et al*., 2023). Tracing the trophic levels of another study, on average, marine herbivores has been found to be contaminated with 4.55 ± 8.59 MPs per individual. According to Miller *et al* (2020), MPs uptake has been greatest in herbivores molluscs (6.97 ± 11.22 MPs individual^{-1}). Of them, herbivore filter feeders has demonstrated the greatest MPs accumulation (6.83 ± 11.04 MPs individual^{-1}) followed by browsers/grazers (0.96 ± 1.71 MPs individual^{-1}), scavengers (0.96 MPs individual^{-1}). The trend for MP retention results of the molluskan filter feeders are in compliance with Thathsarani *et al* (2023). The MP contaminated levels in the molluskan filter feeders reported by Thathsarani *et al* (2023) is lesser than the levels uncovered by Miller *et al* (2020). The other groups of organisms that represent the second and third trophic levels have revealed following MPs bioaccumulation status. For fish, the average MPs level is 0.83 ± 1.68 per individual and for arthropods the level is 0.44 ± 0.48 MPs per individual. Of the fish, selective planktivore species has exhibited 0.12 ± 0.15 MPs per individual. Much lower levels have been documented for species with different feeding strategies such as selective planktiovores and browsers/grazers. The size range of detected MPs was within 10 µm to 4.7 mm (Miller *et al*., 2020). In tertiary consumers, MP accumulation has been reported high for arthropods (8.15 ± 16.37 MPs individual^{-1}) not for birds or mammals. On average, MP bioaccumulation is highest for herbivores (trophic level 2) at 4.55 ± 8.59 MPs individual^{-1}, and lowest for tertiary consumers (Miller *et al*., 2020). Earlier, it has been reported that the higher MPs bioaccumulation was there in selective predators compared to deposit and filter feeders. But, this idea was denied after Bour *et al* (2018), suggested that the reasons for these results are limited sample size and the exclusion of microfibers.

At last, the MP body burdens reported for primary consumer species (mainly focused on mollusks) do not appear to support any relationship to the accumulated levels of MPs within the organisms and to the MP levels in the surrounding environments (Miller *et al*., 2020). That is, bioconcentration factors have not publicized. But, Thathsarani *et al* (2024) reported that the bioconcentration factor for the MPs in the *Corbicula fluminea* tissue samples to the MPs concentration present in the lagoon water to be 2.78 items/L. Thus, the clams have a high concentration of tissue MPs compared to water suggesting that the clams have come in contact with MPs not only by means of water but also through other substrate such as sediments (Thatsarani *et al*., 2024). Indeed, rather than biomagnification of MPs in trophic levels, the body burden of MPs by bioaccumulation in marine species appears to be more influenced by their feeding strategies. Filter feeders have on average a higher level of MP contamination than any of the other feeding strategy both *in situ* and laboratory-based studies, irrespective to the trophic level (Miller *et al*., 2020).

The studies that have been conducted thus far, could not reveal biomaginification of MPs and biomagnification of the chemical additives of MPs both *in situ* and laboratory exposure. Only three marine species across two trophic levels have been examined for the contamination of chemical additives associated with MPs found in their natural habitat (Hermabessiere *et al*., 2019; Miller *et al*., 2020). The examined additives that differed between the two trophic levels, with phthalates including benzyl butyl phthalate (BBP), diethyl phthalate (DEP), dimethyl phthalate (DMP), diethylhexyl adipate (DEHA), polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs), and polychlorinated biphenyls (PCBs) quantified in two species categorised as primary consumers. Only di(2-ethylhexyl) phthalate (DEHP) and dibutyl phthalate (DBP) were quantified in one species and categorised as secondary consumers. Bioaccumulation of chemical additives associated with MP uptake has been reported much less frequently than physical MP bioaccumulation, both *in situ* and in controlled laboratory experiments. Across all three marine species collected from the field, namely the clam *Cerastoderma edule,* the mussel *Mytilus edulis,* and the ascidian *Microcosmus exasperatus*, the concentrations of individual or combined phthalates were highest among the different chemical additives examined. (McGoran *et al*., 2018). It seemed that phthalates are primarily utilized as plasticisers and in turn commonly detected in the oceanic environments. Thus, it is not surprising to discover more phthalates as a chemical leachate in MPs detected from the tissues of the organisms. But, body burden of phthalates has not increased with MPs bioaccumulation across these species suggesting that the MPs concentration and the chemical leachate concentrations of MPs may not be directly and positively correlated with each other (Miller *et al*., 2020). Combined, these findings would precisely advocate that the environmental exposure to chemical additives affects bioaccumulation in marine organisms intensively than exposure to the plasticizers associated with MPs (Barboza *et al*., 2018). If the leaching of plasticizers from MPs to be accurately and realistically tested in a laboratory, it is always essential to include the environmentally relevant MP exposure characteristics. The colours, size, form of MPs in the marine environment have been considered as the potential factors responsible for the bioaccumulation of MPs (Thatsarani *et al*., 2024). We have to mention that the leaching of MPs into organisms is currently much unclear and requires further assessments for their bioaccumulation and biomagnification.

When the pollutants bioaccumulate within organisms, they get biomagnified over time along the food chains. Biomagnification related to MPs is simply defined as the increase in concentration of MPs or chemical additives due to trophic transfer from the lower trophic levels to higher trophic levels (Miller *et al*., 2020). According to the research that has been conducted thus far, bioaccumulated MPs on different trophic levels has not supported the *in-situ* biomagnification of MPs or associated chemicals within a marine food web. Even though the evidences support bioaccumulation in terms of both environmental and laboratory exposure, biomagnification has not yet been investigated targeting a specific marine food chain. It is advisable to test biomagnification of MP in a specific food chain under natural ecosystem exposure rather than examining under laboratory conditions. Laboratory exposure of MPs will be ideally supportive if the tested organisms are used for revealing altered physiological mechanisms due to MPs. If not, we suggest that it is always essential to uncover the real MPs contamination levels of the organisms of different trophic levels in a targeted marine ecosystem under the biotic and abiotic pressure of the ecological components.

According to Minderoo-Monaco commission on plastics and human health, MPs greater than 10 µm appear not to undergo biomagnification. Instead the chemicals adhered to plastics bioaccumulate in marine animals and biomagnify in marine trophic levels (Landrigan *et al*., 2023). In-order to confirm that MPs < 10 µm will dominantly undergo biomagnification, many oceanographic and environmental research are further warranted for proper scientific validation. In contrast, MPs biomagnification across a general marine food webs and food chains are not mainly been supported by the current field observations. Instead, trophic transfer of MPs has been tested with three to five trophic levels from isolated laboratory studies in unrealistic exposure conditions (Miller *et al*., 2020). Accumulation of MPs in a particular environment mandates a longer period of time. Thus, bioaccumulation tested in laboratory-based studies is far from acceptable as a realistic measurement due to difficulties in simulating oceanic ecosystems (Miller *et al*., 2020). Because of the unrealistic exposure, defining a proper size limit for the MPs bioaccumulation and bio-magnification could not be directly suggested based on the results of laboratory experiments (Miller *et al*., 2020). Miller *et al* (2020) has strongly suggested that MP biomagnification across a general marine food web was not truly supported by the literature under natural and laboratory exposure. In contrast, bioaccumulation and trophic transfer have been proven under both realistic and unrealistic exposure conditions. As an end note, this is to specify that the concepts of bioaccumulation and biomagnification of insoluble pollutants such as MPs may not be the same as those of soluble pollutants. Because these insoluble items may not alter the internal mechanisms in similar ways as the chemicals

2.2 Less biodiversity and biodiversity loss

Biodiversity loss due to MPs is a complex and emerging field of research, and while there is growing evidence suggesting its impacts, the full extent and mechanisms of these impacts are still being studied. The persistent nature of MPs and toxicity not only threatens the entire marine ecosystem but also the wildlife. (Ghosh *et al*., 2023). Ingestion of MPs, entanglement in animals and acting as a raft for non-indigenous species has drastically contributed for the death of marine mammals (whales, dolphins), coral reefs, reptiles like sea turtles, fish etc (Meaza *et al*., 2021). This eventually results in biodiversity loss (Thiel *et al*., 2018; Botterell *et al*., 2019). MPs will inhibit growth and development of juveniles, impact feeding and behavioral ability, induce reproductive and genetic toxicity. Thereby, lead to changes in biodiversity parameters (Li *et al*., 2021). Microplastics can alter species interactions and ecological processes, such as predator-prey relationships, competition, and nutrient cycling. Changes in these interactions can cascade through ecosystems, leading to shifts in community composition and biodiversity dynamics (Lusher *et al*., 2015).

Following research findings has validated the contribution of MPs to the species extinction and to the depletion of biodiversity. For the very the first time, Corinaldesi *et al*. (2021) research team replicated experiments in aquaria to explore the multiple impacts of MPs on the octocoral *Corallium rubrum.* It is a red coral and identified as a long lived habitat forming organism belonging to the *Corallium* genus. They are present almost in all altitudes from shallow water to deep sea habitats. When exposed to a series of MP types, corals preferentially ingested polypropylene. This in turn has caused many biological effects such as feeding impairment, mucus production and altered gene expression (Cornaldesi *et al*., 2021). Also, MPs have been able to alter the coral microbiome both directly and indirectly via tissue abrasions. Thus, proliferation of opportunistic bacteria has been stimulated. These effects in combination would suggest that MPs in different concentrations present in marine areas can eventually lead to the coral death. Also, other habitat forming suspension feeding species were also likely subject to similar impacts. Thus, will result mass mortalities in different species (Corinaldesi *et al*., 2021).

The last three years of secondary research on the responses of marine invertebrates to MPs have paved the way for the emerging field of macroecotoxicology. That is to relate and to discuss how the MPs as contaminants contribute to alter the fundamental ecological concepts in a particular environment (Moulatlet *et al*., 2023). Marine invertebrates are highly vulnerable to anthropogenic stressors because these are a sentinel group of species to study MPs. Accordingly, contaminants are more bioavailable at lower latitudes, where more species richness and diversity exist; this could potentially lead to more species being affected by MPs contamination (Moulatlet *et al*., 2023). MPs and plastic contamination have reduced the local species richness of macro and micro invertebrates in the intertidal shore and in the benthic inhabitant communities in mesocosms (Bringer *et al*., 2020).

Some studies have pointed out the changes in the frequency distribution of ecological traits. Crustaceans, swimmers, burrowers, smaller species, omnivores and deposit feeders have altered their niches in relation to performance traits (mortality and reproduction), functional traits (feeding and behavior) due to the MP contamination. Moreover, a reduction in body size of lobster species due to MPs exposure has been reported (Welden and Cowie, 2016).

For other aquatic taxonomic groups such as fish, MP effects have been associated with an overall decrease in growth and body size. Such information is not yet available for marine invertebrates. Nevertheless, invertebrates may suffer a reduction in energy budgets due to MPs, which could lead to negative changes in the frequency of common traits related to growth, reproduction and dispersal. Then, eventually leads into extinction and less biodiversity (Moulatlet *et al*., 2023). No specific research studies on MP-driven species extinctions or population decreases of threatened taxa have been published to yet. Research has put forwarded that the MPs will ultimately do alterations in population dynamics with the prevailing climatic changes. This may be based on the bioaccumulated MPs levels in the marine organisms and the MPs levels in the marine substratum (Yu and Sing., 2023). While these studies provide insights into the potential impacts of MPs on biodiversity, it is important to note that research in this field is ongoing, and further studies are needed to fully understand the long-term ecological consequences of MP pollution on marine and terrestrial ecosystems. Figure 2 depicts the graphical form of the discussed facts.

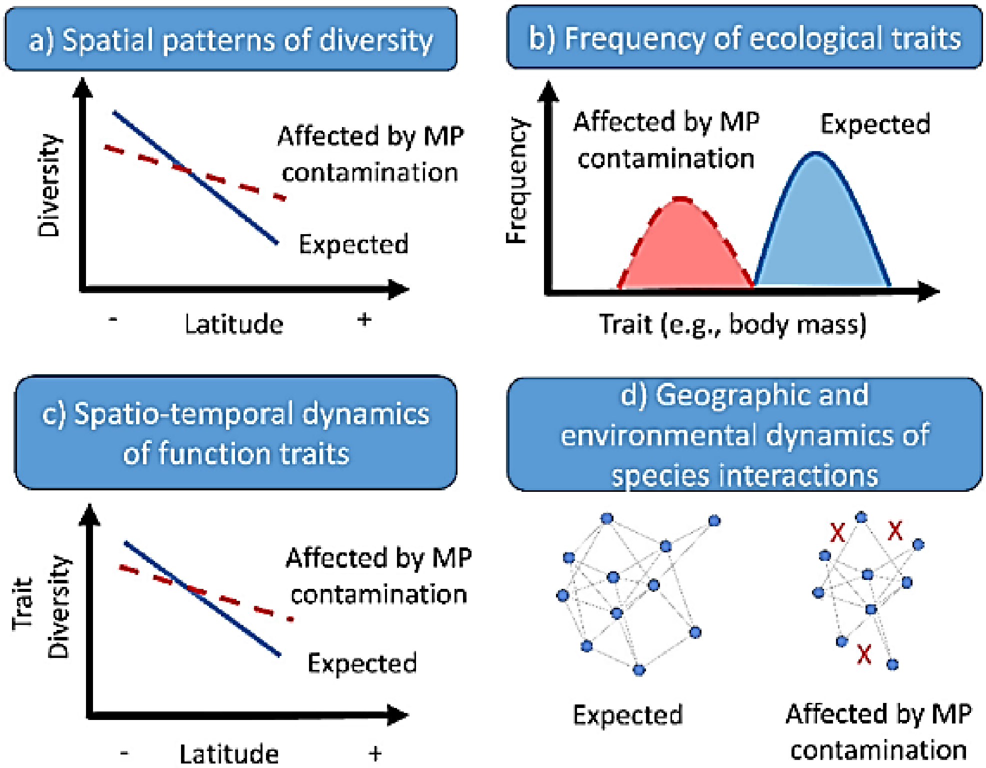

Figure 2: The upper plots (a, b, c and d) illustrate how diversity (taxonomic, functional traits or interactions represented in network affected by MPs contamination could potentially deviate from the expected macroecological patterns. Adapted from Moulatlet *et al*., 2023.

2.3. Altered habitat ecological functions

The marine environment is a system under increasing stress from MP pollution. Several scientists have taken approaches to assess whether there is a relationship between MP contamination and habitat loss and fragmentation of marine inhabitants. A change or alteration in land which causes an impact on ecosystems such as habitat loss could be defined as a habitat alteration. Theoretically it is very challenging to describe habitat alterations in terms of MPs. Since, MP is a contaminant its role in the habitat should be related to habitat ecological functions. Coral reefs, seagrass beds, mangroves, salt marshes, open ocean waters, deep sea and lagoons have been identified as major marine ecosystems contaminated with MPs (Thathsarani *et al*., 2023; Yu and Sing, 2023). Impaired ecosystem functions have been reported for coral reefs, seagrass beds, mangroves and for salt marshes (Yu and Sing, 2023).

Ecological impacts on ecosystem functioning of bivalve-dominated habitats have revealed the following alterations. The influence of MPs on the filtration rates of bivalves, inorganic nitrogen cycling, primary productivity of sediment dwelling microphytobenthos, and the structure of benthic assemblages have been hypothesized and tested. European flat oysters (*Ostrea edulis*) or blue mussels (*Mytilus edulis*) with intact sediment cores have been used for the outdoor experiment mesocosms. *Mytilus edulis* has elicited a significantly less filtration rate when exposed to 25 µg L^{-1} of the tested types of MPs and no effects have been observed on ecosystem functioning or the associated invertebrate assemblages post exposure of MPs. Contrast to *Mytilus edulis*, *Ostrea edulis*'s filtration rate has been increased when exposed to the same concentration of MPs. For them, porewater ammonium and biomass of benthic cyanobacteria has also decreased. These findings have highlighted that the potential of MPs to impact the functioning and structure of sedimentary habitats and show that such effects may depend on the dominant bivalves inhabitants (Green *et al*., 2017). It is exciting to state that MPs have also altered the Nitrogen cycling process in sediments which serve as organic carbon substrates for microbial communities. A microcosm experiment conducted using salt mass sediment amended with PE, PVC, polyurethane foam (PUF) or polylactic acid (PLA) has reinforced the above mentioned fact. The presence of MPs not only alters nitrogen cycle but also the sediment microbial community. As per their results, PUF and PLA amended sediments promote nitrification and denitrification while PVC inhibited both (Seeley *et al*., 2020). Coastal sediments support benthic microalgae that contribute to ecosystem functions such as primary production, nutrient recycling and sediment biostabilization. Also, these coastal environments are found to be contaminated with MPs. The coastline sediments have been dominated by PP, PY and PE MPs (Hope *et al*., 2021). Of them, fragments and fibers were the dominant form. Moreover, in sandy habitats porewater ammoniums recorded lower when fiber abundance and overall MP diversity were higher. The inclusion of porewater ammonium, organic matter content and pheophytins together with physical properties has explained a greater percentage of the variance in MP abundance-diversity for muddy habitats compared to sandy habitats. The results have emphasized that functionally different habitats should be examined separately to increase the understanding of MP-biota-function relationships along with the habitat eological functions (Hope *et al*., 2021).

Coral reefs are also a fascinating habitat which could provide number of micro habitats for many marine organsims. Coral reefs have been detected with MP pollution. Even though, corals do not represent a huge percentage of the marine environment they trap MPs and disproportionately enhance their accumulation. Coral reefs acts as a sink for MPs due to adhesion on reef building corals at distinct depths, ingestion of MPs by reef suspension feeders (sponges and ascidians), bioconcentration, reduction of sediment resuspension and seafloor turbulent energy due to marine forest architecture and diagenesis of Anthropocene sedimentary rocks containing MPs. Statistical results have shown that MP abundance for reef-building corals are higher than values found in reef sediments and especially in seawater (Soares *et al*., 2023). McCormick *et al* (2020) suggest that MPs consumption may avalanche the detrimental effects of coral reef degradation to impact the survival of newly recruited fish. Thus, shows how the organisms respond to the co-occurrence of local stressors such as MPs. As coral reefs are prone to MP accumulation and can become pollution hotspots.

2.4. Less availability of food sources

When the floral and faunal species diversity tends to decrease, the available food sources are decreasing. With less food availability both the interspecific and intraspecific competition for food will increase. In natural environments and commercial fisheries, MPs have the potential to reduce the increase of edible marine organisms via altered reproduction (Bilal *et al*., 2023). None of the studies conducted thus far, have directly communicated that MPs are responsible for the less availability of food sources. Instead, many studies have intensionally focused to the modulations in the reproduction and the growth parameters of the organisms (body size). Therefore, steady human consumption of MPs-amended marine food sources will increase multiple risks presented by plastic composites, exogenously formed adsorbents and their leachates. Thus, this will directly affect the marine food security. This section has been enfolded in this regard.

At present, it is only possible to determine the major marine contributors to overall dietary exposure of MPs. The marine food sources of interests are clams, mussels, shrimps, prawns, oysters and fish. The effect of PS MPs upon the reproductive efficacy of the marine oraganisms, have been dominantly studied. One of the studies has tested the 10 μm PS MP potential to alter the physiological functions of Manila clam. PS MPs has significantly increased the rates of respiration and excretion while significantly decreasing feeding and absorption efficiency, leading to a reduced amount of energy available for them to grow and ultimately inducing a slower growth. The dynamic energy budget model predicted that PS microplastic exposure for 200 days would cause lower shell/flesh growth rates and reproductive potentiality (Jiang *et al*., 2022). Moreover, 5 μm and 10 μm PS MPs together have been observed to enter and accumulate in Manila clam with strong detrimental effects on their physiological functions. Thus, the accumulation of MPs and their increased concentrations in marine ecosystems is certain to create consequences that compromise marine life or health, leading to less energy allocated for growth and reproduction (Choy *et al*., 2019). This evidence indicates that the abundance of MPs in any given marine ecosystem may adversely affect its biodiversity conservation, environmental health, ecosystem services and food security at large (Unuofin and Igwaran, 2023).

Global demand for marine food sources has become a huge challenge due to reduction of fishery areas and due to food safety hazards associated with both pre and post-harvest contaminations. The marine fish yields are stressed due to spread of marine contaminants activated by rising surface water temperature, transportation of microorganisms by marine vessels across the oceans, anthropogenic activities etc (Samarajeewa *et al*., 2023). Microplastics act as a plastishpere for these micro-organisms and eventually transfer the toxic chemical contaminants to the food fish (Thacharodi *et al*., 2024).

2.5 Contributes to chronic and acute effects of marine pollution and mass death of marine organisms

Organisms living in the marine environment may undergo both acute and chronic effects due to MP pollution. One-term exposure to high concentrations of pollutants can result in acute effects. Moreover, prolong and continuous exposure to low concentrations of pollutants can result in chronic effects (Krishnakumar and Periyadan, 2017). Discharge of untreated sewage and industrial effluents can impose chronic effects on marine biota by releasing mass amounts of MPs. Figure 3 provides examples of acute and chronic effects results mainly due to major marine pollutants. MPs also contribute to these effects more or less (Eltemsah *et al*., 2019; Suman *et al*., 2020).

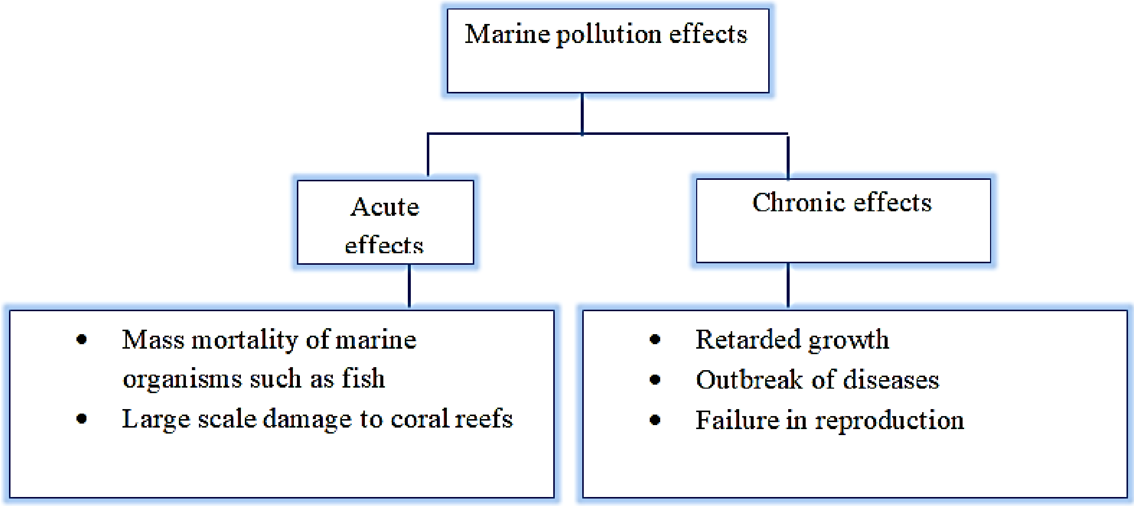

Figure 3: Acute and toxic effects upon marine organisms due to major marine pollutants

Conclusion

Microplastics represent a unique class of insoluble environmental pollutants that challenge conventional ecotoxicological assessment frameworks due to their hydrophobic properties and particulate nature. Unlike traditional dissolved contaminants, MPs persist as discrete solid particles in aquatic systems, requiring novel approaches to understand their environmental behavior and ecological implications. Particles smaller than 10 µm demonstrate particular concern due to their potential for biomagnification through marine food webs.This review has synthesized current understanding of MP ecological impacts in coastal environments, revealing multifaceted consequences that extend beyond simple contamination. Primary ecological impacts include biodiversity loss through altered species composition, habitat modification affecting benthic communities and spawning grounds, and impaired ecosystem functions such as nutrient cycling and primary productivity. Food web disruptions marked through reduced prey availability, altered predator prey dynamics, and compromised nutritional quality of marine organisms. Mass mortality events, particularly among filter feeding species, represent acute consequenses of MP contamination. Reproductive toxicity and behavioral impairements were also evident. The transfer mechanisms between environmental compartments whether water column, sediment, or biotaremain critical pathways for MP distribution to coastal inhabitants. However, significant knowledge gaps persist regarding bioaccumulation, bioconcentration, and biomagnification processes. Current research predominantly relies on laboratory based exposures that inadequately simulate natural environmental conditions, limiting our understanding of realistic biomagnification patterns through coastal food chains.The absence of standardized extraction and quantification methodologies hinders comparative assessments across studies, impeding accurate evaluation of bioaccumulation patterns across species and geographical regions. Long term monitoring programs are essential to establish baseline concentrations and temporal trends in MP contamination. Only through comprehensive understanding of these ecological impacts can region specific remediation strategies be effectively designed and implemented. Thus, offer the most promising pathway toward mitigating MP impacts in coastal environments while preserving marine ecosystem integrity.

Data Availability statement: All the data that have been compared in this review article has been included in the manuscript itself.

Conflict of interest: All authors have been declared that they have no conflict of interest upon the manuscript.

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