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Impact of Microplastic (MP) Pollution in Seagrass Ecosystem

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Abstract

Seagrass ecosystems are one of the vital coastal habitats that claim numerous ecological, economic, and social benefits. However, this unique underwater ecosystem is facing threats from MP (MP) pollution which is an emerging global concern. MPs are tiny, fragmented plastic bits (5mm) found all over the world. Plastics, used in daily life are frequently blindly discarded into the ocean by humans, causing harm to the marine ecosystem by lowering its quality. Since MPs can persist in the environment for a prolonged period, they can harm the environment and are difficult to eradicate. They are used by marine species, which results in their assimilation, biomagnification, and bioaccumulation in the trophic levels. The existing documentation and research on MP accumulation in seagrass habitats is remarkably limited. Additionally, taking into account more than a decade of research (from 2000 to 2023), none of the research that came out before 2017, demonstrated the severity of the issue and devoted efforts to address and manage the problem. India, is one among the nations having significant seagrass habitats. If prompt attention isn't paid to tackling MP pollution in marine systems, it will eventually result in the disruption of seagrass beds. This review paper synthesizes current knowledge on the biological and chemical impact of MP pollution in seagrass ecosystems. This review article gives a brief idea about the seagrass ecosystems and their global as well as Indian distribution. It also explores the sources, distribution, and destiny of microplastics in various ecosystems, together with their potential ecological and biological consequences on seagrass and their associated organisms. Additionally, the paper discusses mitigation strategies and identifies critical research gaps, emphasizing the need for comprehensive studies to understand and mitigate the continuing effect of MPs on seagrass ecosystems.

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Introduction

Seagrasses, a distinctive array of marine angiosperms that have been crafted to live completely submerged in the sea, have a tremendous impact on the physico-chemical as well as biological systems of ocean, performing as environmental engineers.[1] Seagrasses cover approximately 0.1-0.2% of the world's oceans and form extremely productive environments that show a censorious part in the marine environment. Despite being considered one of the most prevalent marine plants, seagrasses have received little attention in research. In recent years, widespread ignorance about the ecosystem services of seagrasses has resulted in massive damage to them. The habitat of seagrass is under constant danger from human activities. Dredging, fishery, anchoring, nutrient enrichment, the effects of coastal constructions, predator–prey alterations, and the negative effects of climate change all contribute to ubiquitous seagrass loss. MP pollution is another significant threat to the seagrass ecosystem, and MPs have been noticed in abundance in marine ecosystems.[2] MPs can enter food webs through consumption once they are in the environment and can bioaccumulate in higher levels of trophic interaction. Even though their aggregation has been discovered in seagrass ecosystems, little priority has been paid to the consequences of MPs on seagrass beds. MP pollution poses a noteworthy risk to seagrass ecosystems, with possible repercussions for biodiversity, ecological services, and coastal communities. Addressing this issue requires a multidisciplinary approach, including research, management, and policy interventions.

This review provides insight into understudied seagrass ecosystems, which are currently decreasing in area and are challenged as a consequence of numerous anthropogenic impacts and MP pollution. This review aims to combine existing research on the impact of MP pollution on seagrass ecosystems.

Materials and Methodology

Using the authoritative scientific information repositories "Scopus" (https://www.scopus.com) and "ISI Web of Science" (http://apps.webofknowledge.com), a comprehensive systematic assessment of the literature has been performed. Google Scholar has been used for further investigation (https://scholar.google.com). Every noteworthy as well as crucial reported research regarding the topic has been analyzed between 2000 and 2024 (Fig 1). To make sure that the effects of plastic litter are included in articles about the seagrass ecosystem, two independent analyses have been carried out by combining the terms "MP" and "impact of plastic litter" with "seagrass." The following is how boolean logic have been subjected to keywords: [(MP*seagrass)* OR distribution of seagrass* OR plastic* type of MPs* OR of MPs fate* OR marine plastic pollution* OR seagrass beds* OR effect of trapping* OR seagrass ecosystems* OR effect*] AND [(Plastic waste* seagrass) OR marine plastic pollution* OR types of plastics* OR fate of plastics* OR seagrass communities* trapping effect* OR coastal ecosystems*,OR effect*]

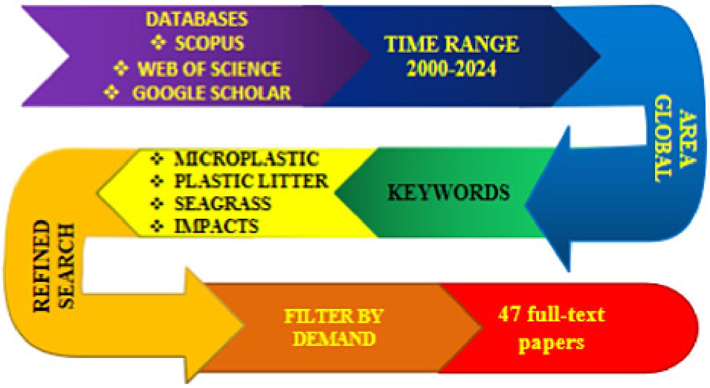

Fig. 1: Bibliographic investigation flowchart

All together 47 whole-text publications were reviewed, which represent the outcome of this investigation. After evaluating every study, a final screening was done to ensure that every article taken into consideration had a direct connection to MP contamination of seagrass ecosystems.

Seagrass ecosystem

Seagrasses, that are the only marine angiosperms, found all over the world's temperate and tropical shorelines. They are the one and only sunken marine flora with an underground root and rhizome system. Seagrasses play significant ecosystem functions in marine habitats and can grow in large meadows that support a broad level of biodiversity. Seagrasses are an important marine environment, and their accomplishments in commercial fisheries, sediment accumulation and maintenance, ocean ecosystem dynamics, and so on have a significant impact on mankind.[3] Seagrasses are recognized as keystone species in several narrow lagoons and estuaries, by offering sophisticated vegetation as well as increased rates of primary production for both ecologically and commercially important species

Seagrass Distribution

Although seagrasses makeup only 0.1 - 0.2% of the ocean's surface, they constitute a crucial environment. Seagrass species composition is minimal (about sixty species), but a few varieties can cover hundreds of miles of coastal area. Seagrasses have been found in 191 nations and six worldwide bioregions extending temperate and tropical seas.[4] Global assessments of seagrass three-dimensional distribution range from 177,000 to 600,000 sq km in the peer-reviewed studies.[5]

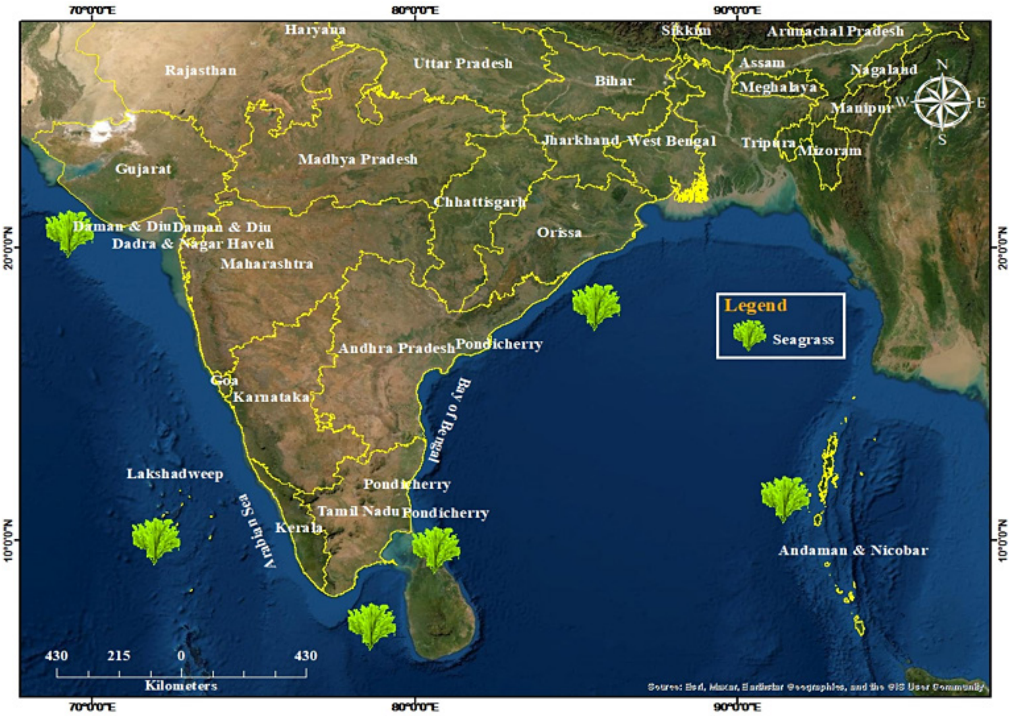

Fig. 2: Indian seagrass distribution

India is regarded as one of the nations that have significant seagrass resources, within the five global locations which possess a substantial seagrass diversity. India's entire seagrass area is calculated to be 517 km^2 with a total of 16 seagrass species *(Cymodocea rotundata, Cymodocea serrulata, Halodule uninervis, Enhalus acoroides, Halodule pinifolia, Halophila beccarii, Halophila ovalis, Halophila decipiens, Halophila minor, Halophila stipulacea, Ruppia maritima, Thalassia hemprichii and Syringodium isoetifolium)* distributed along coastal regions, belongs to seven genera *(Enhalus, Cymodocea, Ruppia, Thalassia, Halophila, Syringodium, and Halodule)* and four families.[6,7]

Regions like Palk Bay and the Gulf of Mannar (fourteen species), the Andaman and Nicobar Islands (twelve species), the Lakshadweep Islands (ten species), Odisha (eight species), and Gujarat (eight species) are the major coastal belts along the Indian coast with higher diversity of seagrasses (Fig 2).[6]

Along the shores of India, the greatest species richness were documented in Tamil Nadu (fourteen varieties), and in island habitat, 9 varieties of sea -grass have been identified, with Andaman and Nicobar Islands exhibiting the greatest seagrass diversity.[8] Seagrass ecosystems along the coasts of India are increasingly imperiled primarily by anthropological activities including MP pollution, a globally prevalent environmental issue that has garnered quite extensive focus lately.

Seagrass Meadows as a MP Sink

MPs are developed in coastal habitats by commercial fishing, transportation through winds, tides, rivers, industrial effluent discharges, and sewage.[9] Seagrass ecosystems exhibit several mechanisms that facilitate MP sequestration. These include the physical entrapment of MPs within seagrass canopies, sediment trapping, and adhesive properties of seagrass leaves. Additionally, the intricate root systems of seagrasses can bind MPs, preventing their resuspension in the water column. These mechanisms collectively add to the efficient elimination of MPs from the marine waters and their subsequent deposition in seagrass sediments.[10] However, increased MP deposition can be lethal in the seagrass environment. Seagrass meadows are currently facing numerous threats as a result of human action, including harmful fishing practices, coastal construction, eutrophication, sediment loading, and pollution. Among these potential risks, MP pollution is becoming more and more of a concern to the valuable ecosystem. Nowadays seagrass ecosystem acts as a sink for MPs here majority of plastic waste has accumulated (Fig 3).

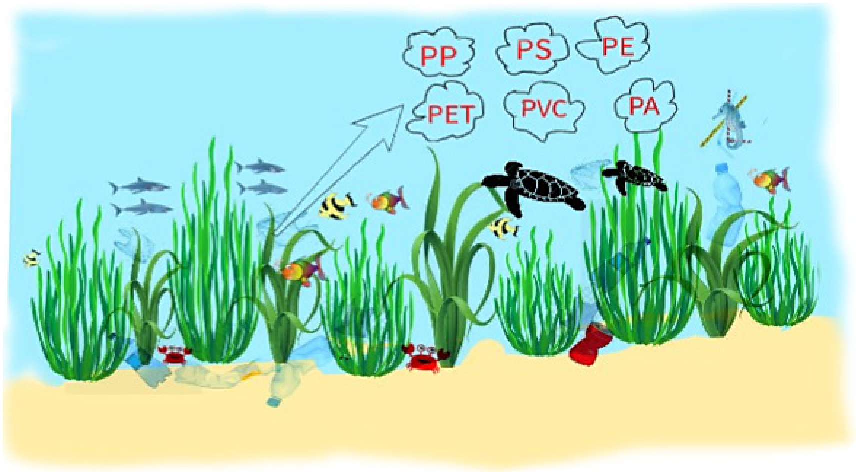

Fig. 3: Seagrass beds as MP sink

MPs can be attached to the surfaces of seagrass leaf blades, boosting their absorption rate to marine herbivores. Numerous investigations have explored how seagrass foliage can accumulate MP particles, offering yet another pathway for increasing their concentration in seagrass meadows.[11,12] Interestingly, hydrodynamic effects of seagrasses influence the increase in finer particle sedimentation, and this can be substantiated by various studies demonstrating the existence of MPs in seagrass sediments, notably in shallow coastal environments.[13,14]

MPs: Their Origin and Types

Thompson et al. developed the notion of MPs in 2004, establishing MP to be a tiny plastic litter of 20 mm size.[15] MPs are categorized as primary or secondarymicroplastics.[16] Primary MPs are generated for a wide range of purposes such as pharmaceutic vectors, private hygiene items, beauty products, sanitizing agents, basic supplies for other plastic products and so on, whereas secondary MPs are generated by decomposing large plastic materials through various sophisticated factors such as Ultraviolet radiation, tides, wind, heat, and physical abrasion.[17] However, the onsite degradation of bigger pieces of plastic trash in the ecosystem represents the most possible reason for the foundation of the huge percentage of MPs.[18]

According to our finest perception and awareness, numerous investigations on the origin, abundance, and toxicity of MPs in nature have been conducted.[19-21]

Fate and Transport of MPs

MPs enter seagrass ecosystems through multiple pathways, including coastal runoff, sewage discharge, and atmospheric deposition. These particles are highly durable, leading to their persistence in the environment. Knowing the causes and distribution of MPs in seagrass ecosystems is vital for effective management and mitigation. MPs can adhere to seagrass leaves and stems or become buried in sediments. Their fate within seagrass ecosystems is affected by a number of variables like hydrodynamics, seagrass morphology, and microbial degradation. Investigating the behavior and pathways of MPs within these ecosystems is vital for figuring out their ecological impact. Natural factors like winds, water currents, gyres, river runoff, canal inputs, and human activities such as water treatment plants that discharge waste water comprising MPs all influence the worldwide supply and richness of MPs.[22-24] Plastics are deteriorated and weathered in the surroundings by a wide range of external variables (like photocatalytic oxidation, thermochemical oxidation, biological degradation, and physical detrition induced by sand, rocks, tides, and waves to construct MPs and even nano-plastics. It can reach isolated places spanning from tropical regions to temperate to polar regions. Because MPs can be found in all ecosystems, we cannot conclude that the ocean will be their final resting place. Because of intense fragmentation and sedimentation, it can get into the food chain and initiate ingestion by a broad array of living creatures,[25] eventually reach the human body. Current research has found that this silent killer is present in human blood,[26] human feces,[27] human placentae[28] and even in human breast milk.[29]

All marine habitat is contaminated by MPs and their intensity is increasing in the coming decades.[30] The research world paid little attention to the early informations of plastic trash in the ocean waters in 1970s.[31,32] With gaining evidence on the probable repercussions of MPs, the issue received considerable and consistent research attention in the past years, with most research being concerned with the entanglement of marine mammals and other organisms. According to various reports, a wide range of plastic materials can be found in marine environments (Table 1).

Table 1: Plastic debris in marine environment18 (Andrady, A. L. 2011)

S.No	Plastic Types	Commodity and typical source
1	Low density polyethylene LDPE LLDPE	Plastic films, bread bags, wraping covers
2	High density polyethylene HDPE	Grocery bags,shampoo and body lotion bottles
3	Polypropylene	Rope, bottle caps, straw,food trays
4	Polystyrene PS	Bait containers, foam cups, plastic utensils, food containers Foamed Floats, take away packagings
5	Nylon	Netting materials
6	Thermoplastic -polyester	Plastic beverages bottles
7	Polyvinyl chloride (PVC)	Plastic films, softdrink bottles, cups
8	Cellulose Acetate	Cigarette filter

The emergence of MPs in oceans can be associated to two prominent reasons: (a) direct creation via land runoff and (b) degrading or breakup of meso and macroplastic fragments. Several MPs, particularly constructed micro and nanoparticles of plastics being used in commercial commodities, enter the oceans immediately through runoff.[33] Many other ecological as well as human made variables impact the dissemination and abundant supply of MPs in different marine environments. Seagrass meadows are known to filter and lock debris by lowering the water flow rate, enabling contaminants to settle on the sand surface. As a result, seagrass beds could prove effective as long-term sinks for waste materials. Polyamide (PA), Polyethylene Terephthalate (PET), Polyvinyl Chloride (PVC) , Polyethylene (PE), Polypropylene (PP), and Polystyrene (PS) are different kinds of MPs found in the seagrass ecosystem and among these polyethylene (PE), polyethylene terephthalate (PET), polyamide (PA), polypropylene (PP) are the prevalent MP worldwide.[34]

Impacts of MP Pollution on Seagrass Ecosystem

Seagrasses are found globally and are highly productive and commercially beneficial coastal habitats. Regretfully, seagrass meadows, like other marine habitats, face numerous regional, native, and worldwide consequences because of three major issues: eutrophication, overexploitation, and the ruination of physical and biological habitat. These effects, combined with pollution, have caused substantial alterations in the arrangement of marine biota, as well as local and even worldwide loss of biodiversity. MPs have recently emerged as a new ecological disaster in the seagrass ecosystem. Seagrasses are sensitive to a variety of manmade pressures, including ongoing exposure to marine debris, including MP. The surfaces of small MP pieces could hold dreadful organisms and serve as disease carriers in the seagrass ecosystem, causing a reduction in seagrass diversity.[36] Increased MPs in the seagrass ecosystem may harm epiphytes and seagrasses by light blocking, as well as stimulate local toxin accumulation, disrupting physiological functions. Furthermore, MPs can interfere with the seagrass microbiome, influencing nutrient cycling by blocking diazotroph dinitrogen fixation, restricting microbial processes, and lowering root nutrient uptake.[2]

The functioning of seagrass ecosystems may be adversely affected by the introduction of seagrasses to microplastics in ecosytem. Seagrass ecosystems are seriously threatened by MPs, which have the potential to change the habitats' chemical equilibrium and have an impact on the biological processes of seagrasses and the organisms that rely on seagrass ecosystem. For example, it may have a negative impact on seagrass development by growing the rate of foliage damage, enhancing seagrass oxidative pressure, and influencing phenol production. Seagrass beds are destroyed since MPs exert physical stress by attaching to seagrass leaves, hindering their ability to photosynthesize effectively. This interference leads to reduced growth and overall vitality of seagrass beds, which are indispensable habitats for many marine organisms.[36] MPs have the potential to alter seagrass structure, including rhizome length and biomass, and to decrease meadow plant coverage. By encouraging the growth of non-native macroalgae in the meadows, MP deposition may lessen the habitat for seagrass.[36]

MPs can adsorb and transport contaminants, potentially leading to toxic effects on seagrass and associated organisms. In a recent study Thalassia hemperichii leaves have been found to have MPs adhered to their surface, increasing the likelihood that herbivores will ingest the tiny particles and allow them to make their way into the food chain.[37] According to a recent study, exposure to MPs made of polyethylene (PE) and polypropylene (PP) affects the respiration and photosynthesis of the seagrass species *Zostera marina* L. and the epiphytes that are associated with it. Additionally, at extremely high MP concentrations, certain photosynthetic variables, including the highest net photosynthesis and the dark respiration rate, are negatively impacted in exposed seagrass leaves.[38]

MPs enter the marine food web when consumed by herbivores or detritivores, posing risks to higher trophic levels, including humans. According to a recent study, *Chelonia mydas* are likely consuming large amounts of MP indirectly through the food web. This is consistent with a global study on the ingestion of macroplastics which discovered that more than 40% of marine green turtles consumed degraded remains.[39] Since they unconsciously eat the MP hoarded in the seagrass when they consume food on seagrass beds in reef lagoons, exposes them to microplastic contamination rather than macro-plastics.[40] Fish and shellfish associated with seagrass were the major supply of animal protein for the locals. By ingestion of fish from MP-contaminated seagrass beds biomagnification occurs and this silent killer can reach the human food chain. This trophic transfer can ultimately jeopardize higher trophic levels, including humans who consume seafood, leading to possible health risks related to the ingestion of MPs and the contaminants they carry. Based on a recent study due to symbiotic epibionts on their surface, seagrass leaves can accumulate MPs particles and since E. acoroides has longer leaves than other species, this capacity is especially strong in them. It was necessary to focus on the abundance of MPs on seagrass leaves because these MPs can enter the food webs in seagrass ecosystems, which ultimately lead to humans.[41]

Seagrasses were also used as folk medicine and agricultural inputs. Additionally, it aids in the biomagnification of MPs. According to recent studies, MPs have entered the human body (human blood,[26] human feces,[27] human placentae,[28] and even in human breast milk),[29] which may also happened as a consequence of marine MP effluence, and the above statement is substantiated by recent researches. According to a recent study,[37] MPs were discovered on the outer layer of leaves in *Thalassia hemperichii,* increasing the risk of MP ingestion by plant eaters and thereby entering the food web. Another study discovered the chances of getting MPs in fish and shellfish in the Mediterranean is 47.2% and 46.3%, with an average of 2 parts/individual.[42] MPs composition in market bivalve in China can reach 4.3-57.2 items/individual.[43] As a result, MPs in the marine realm can cause far more problems than the anticipated boundary at the global margin.

The biological and chemical impact of MP pollution on the seagrass ecosystem has been found in very only a few studies. More research should be done to better understand how plastics affect the chemical and physical characteristics of seagrasses as well as the potential for plastics to release toxic chemicals that are harmful to marine life.[44] Another investigation also found that, on a relatively small scale, MP pollution may vary depending on location.[45] This variation may be caused by not only the human-induced parameters but also the tidal features (which frequently generate stormy conditions that cause MPs to resuscitate and redistribute) of the sampling site. This also highlights the necessity of a standardized sampling protocol and guidelines for optimal sampling which represents a significant research gap in the investigation of the effects of MP pollution. According to a recent study, between nineteen and twenty three million metric tons, or eleven percentage of the plastic remaining produced worldwide in 2016 found its path into the aquatic ecosystems.[46] The existence and dispersion of micro-plastics in the marine environment posssess a serious danger to global ecosystems.[47] Thus, the matter of controlling microplastic pollution in the ocean ecosystem is a serious threat that wants immediate attention on a global scale. According to the current assessment of the literature, a few seagrass ecosystems around the globe have been studied. In the studied area MPs are widely found in sediments, seagrass canopies, and seagrass-associated marine organisms. There is insufficient evidence to support the idea that MPs cause contamination and have an effect on seagrass growth and decline. The specific impacts of microplastics on organisms, waterlogged flora, and the larger seagrass biota are still unknown. Though, the continued build-up of microplastics, it is critical to investigate the potential environmental risks which they could trigger shortly. In conclusion, the ecological consequences of MP pollution are multifaceted, encompassing physical, chemical, and trophic impacts, making it imperative to address this issue for the health and sustainability of marine ecosystems and human populations alike.

Conclusion

With overwhelming evidence of MPs' deleterious effects on marine ecosystems, the influence of MP pollution on seagrasses demands critical intervention. Many herbivores, fish, turtles, dugongs, and gastropods, graze in seagrass beds, and MP biomagnification in these taxa could have ramifications further up the food chain. Therefore, there should be an imperative demand to specify the depth of actual consequences and evaluate the long-term consequences of rising MP levels in the seagrass ecosystem. Strategies to alleviate the impact of MP contamination in seagrass ecosystems include the reduction of plastic input through improved waste management and regulation, restoration and conservation of seagrass habitats to enhance their resilience, and the advancement of innovative skills to eliminate MPs from the marine environment. In conclusion, even with the increasing recognition of MP pollution in seagrass ecosystems, several noteworthy research gaps demand attention for a comprehensive understanding of this complex issue. These gaps include:

(a) The need for sustained, long-term monitoring efforts to quantify MP levels and elucidate their sustained effects on seagrass health.
(b) Further investigations into the intricate interactions between MPs and seagrass-associated microorganisms are essential for comprehending the full scope of ecological degradation. Since many microorganisms have the innate potential to degrade plastics and MPs, they can be used as a potential candidate for mitigating MP pollution by microbial degradation of MPs. This area of research must be given adequate attention as a sustainable management of MP pollution.
(c) The integration of modeling approaches to predict the cumulative impacts of multiple stressors on seagrass ecosystems represents an essential avenue for future research, facilitating a more holistic and predictive understanding of the ecological dynamics involved.

Addressing these research gaps is imperative to guide effective management and administration strategies for seagrass biota in the face of ongoing MP pollution.

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Not applicable

Ethics approval statement
Not applicable

Authors' contributions
Hazeena M. Ameen conducted the literature review and had a crucial role in the drafting of the manuscript. Rohini P helped in the literature review collection and drafting of the manuscript. Maha Madhu prepared maps for Indian seagrass distribution. Rajani V conducted the first correction of the manuscript. Ayona Jayadev performed critical revision of the article and final approval of the version to be published. The final manuscript was read and approved by all authors.

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