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REVIEW ARTICLE

A review of Plastics global dread in mangrove ecosystems

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ABSTRACT
Mangroves function as a massive filter for environmental plastics between land and sea, collecting plastics from terrestrial, marine, and atmospheric sources. Microplastics (MPs) are widely trapped in a variety of ways while flowing through mangroves due to the high primary production and complex hydrodynamic conditions in these ecosystems, resulting in a long-standing but rapidly growing MPs accumulation. However, contemporary studies have largely ignored the function of mangrove forests in the interception of MPs, focusing instead on the occurrence, source, and fate of MPs pollution in mangroves. MP Pollution has lately been recognized as a significant threat to ecosystem health. MPs are usually smaller than 5 mm in size and come in a variety of shapes, including pellets, fibres, fragments, films, and granules. marine & mangroves are delicate, constrained ecosystems that offer a variety of free ecological services, including coastal protection, the maintenance of natural cycles, the preservation of biodiversity hotspots, and the production of products with high economic value. However, even these protected environments are now becoming contaminated by urbanisation and industrial activity. In this article, we examine the trophic levels of the mangrove ecosystem's microplastics sources, frequency, and toxicity.
Keywords: *Microplastics, Mangrove, Marine litters, Plastic degradation, Marine microbes, Microbial degradation.*

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INTRODUCTION

The accumulation of plastic in the marine ecosystem has serious harmful effects on the environment. Over the past three decades, the use of plastic materials in the food & clothing shelters, transportation, medical & leisure sectors has increased [1]. According to the research, the production of plastics is thought to have grown nearly 200 fold, around 30% of plastics are used as packaging materials globally [2]. By 2050, According to projections, the worldwide plastic production will reach a staggering 33 billion tonnes [3] with 10% of that amount ending up in the oceans. When plastic is released into the environment, its residence period is thought to be between tens and hundreds of years [4]. The widespread persistence of Microplastics is a result of high resistance because it results in exceptionally low degradation and extended half-lives of plastics under environmental conditions [5]. Because aquatic organisms can easily consume plastic waste, it threatens biodiversity and degrades the aesthetic value of water environments [6]. Plastic litter is also a serious environmental and economic issue. Living things can be exposed to chemicals through plastic, whether they are water contaminants or additives [7]. Plastic pellets can, in fact, adsorb hydrophobic pollutants and then desorb them into habitats or creatures to release them. Polymers have some advantages because they are sturdy, lightweight, and long-lasting. Though, they pose a greater threat because they are resistant to biodegradation, continue to pollute, and are detrimental to both living things and inanimate objects. However, Beach litter has lately been reported that there are items made of bioplastics. Bioplastics were developed and recently released on the market to decrease plastic pollution, but questions have been raised about their ability to decompose and they offer any ecological advantages over traditional plastics. In actuality, biodegradation is a complicated process that may be dependent on polymer characteristics and is greatly affected by the biotic and abiotic environments to which they are exposed. Some biodegradable plastics could withstand in coastal habitats for at least 9 to 12 months before fully degrading. Mangrove ecosystems have already developed into massive sinks for plastic garbage that enters from either marine or terrestrial sources. The objective of this review is to briefly discuss the possessions of plastic waste on marine environment, especially in mangroves and to identify the crucial areas for research on the degradation of plastics by marine microorganisms, with a particular emphasis on plastic degrading enzymes and potential applications.

Oceanic habitat with plastics

The plastic materials are able to accumulate over time at the core of significant ocean vortices, creating enormous masses of continuously growing floating debris fields known as garbage patches across the oceans. An estimated 11 million tonnes of plastic are expected to be reached in World Ocean each year [8], according to a recent study by the United Nations Environment Programme (UNEP). Megacities, particularly those along the shore, are at risk from these solid waste-related issues. Historically, solid refuse has been dumped in preference at the coastal mangroves [9]. One of the main routes for stores of plastic is river to the ocean [**Figure. 1**] [10]. 90% of the plastic waste that enters the ocean each year originates in eight rivers in Asia (the Yangtze, Yellow, Indus, Hai He, Ganges, Mekong, Amur, and Pearl) and two rivers in Africa (the Nile and the Niger) [11]. 1.15 to 2.41 million tonnes of plastic garbage is dumped into the ocean each year by river-fed estuaries [12]. 5 million tonnes of plastic debris were released into the Pacific Ocean by the Japan Tsunami in 2011, which is roughly equal to the quantity of plastic waste that enters the ocean annually [13]. Trash, dumping, and plastic pollution ultimately reach estuaries and coastal seas by shifting ocean currents, waves, wind speed, rainfall, and wind direction. The most prevalent form of non-biodegradable solid waste that has recently been identified as posing a serious danger to marine life is polythene. Fish, birds, and marine animals' intestines could occasionally become blocked by polythene [14] [15]. Besides by-products of manufacturing industries and being smaller than 5 mm, including nanoplastics (NPs) (0.1 mm) formed breakdown of plastics fragments by UV photodegradation, mechanical action, hydrolysis and biological degradation, these Microplastics (MPs) are then transported to coastal regions. The coastal vegetation over and above the marine flora and fauna has been discovered to be increasingly threatened by them. MPs build up in plant tissues and obstruct the absorption of nutrients [16]. MPs transport and absorb organic pollutants and heavy metals, finally increasing their toxicity. Animals and vegetation may be more at risk from MPs enriched with organic pollutants when ingested or absorbed than from MPs alone [17]. The first study on MPs occurring in aquatic systems was released at the start of the 1970s [18]. MPs are primarily introduced into freshwater and marine environments by naturally and anthropogenic activities (aquaculture, tourism, industrial and residential wastewaters) [19] [20].

In general MP/NPs are also transferred to marine environments by agricultural runoff, land destruction, and atmospheric deposits. Field research on the Ciwalengke River's banks in Indonesia revealed that [21] the existence of microparicles of plastics as primary fibres, with concentrations varying from 5.85 particles per litre in surface water to 3.03 particles per 100 g of sediment, with sizes ranging from 50 to 2000 m. In the shoreline sediments of Lake Chiusi in central Italy, the abundance of MPs varied from 112 to 234 particles kg^{-1} dry weight [22]. According to the research microalgae can also inhabit MP/NPs and raise their specific density through biofouling and hetero-aggregation [23].

Plastic dumping & Impacts on Global mangroves

Increased anthropogenic activity in nearby and coastal mangrove areas may result in inefficient waste management techniques that cause a variety of toxins to enter these ecosystems, posing a threat to the sustainability of the mangroves. As deposit-feeders, many benthic species, including crustaceans, mussels, and bivalves, live on the coastal side of these mangroves, increasing their likelihood of consuming MPs found in sediments of mangroves. Industrial effluents, water treatment plant discharges, and other land-based sources can all introduce MPs into this environment, whereas tourism, fishing supplies, and other ocean-based sources can do so as well. According to the investigation, the Muara Angke Wildlife Reserve in Indonesia had an average concentration of MPs of 28.09 $\pm$ 10.28 particles/kg of sediments, with the outer portions of mangroves being more vulnerable to higher concentrations than the inner parts due to tidal patterns [24]. Researchers examined the spatial distribution of MPs in sediment samples from Southern Brazil's mangroves and found that less preserved sites in basin areas that were subject to human activity were more vulnerable and had higher MPs concentrations than fringe areas due to stagnant, low flow, or weak tides [25]. The action is a component of a broader international initiative to halt the tide of plastic pollution. Due to the intricate aerial root systems that give mangrove forests a high structural complexity [**Figure. 2**] and a high capacity for collecting marine debris, the majority of which is made up of plastics [26]. According to United Nation [27], over 800 marine species are impacted by plastics, which can happen through ingesting it, becoming entangled and suffering severe physical injuries, starving to death after ingesting it, or having less obvious effects on behaviour and ecological interactions, like the ability to flee from predators or migrate, reducing feeding and depleting energy reserves, or having an impact on fertility and growth [28]. Plastics have the ability to change fishery stocks and wildlife populations through affecting genetic expression, tissues, reproduction, population size, and social structure [29]. Alarmingly, fish and coral species in the Gulf of Bengal and nearby areas were found to contain MPs [30]. The livelihoods of around 200,000 subsistence fishermen could be threatened by plastic garbage, which is thought to have an adverse effect on 291 varied fisheries species supported by 177 tidal creeks and channels in this forest [31]. Since 2014, multiple efforts have been made to evaluate the various polymer kinds and forms of these trapped MPs within the mangrove sediments. The initial reports on the distribution of mangrove MPs among them were from mangrove wetlands in Malaysia [32], Indonesia [33], and Singapore [34]. The characteristics of MPs pollution are extensively researched in mangrove ecosystems covering Chinese coastal regions in comparison to other places of the world. This included seven mangrove ecosystems at Qinzhou Bay, where the very first study was undertaken [35]. Following that, it was discovered that a total of 55 mangrove habitats in China, including the Jinjiang Estuarine region, Beibu Gulf, Pearl River Estuarine, Futian, and Maowei Sea, were contaminated with MPs [36[[37] [38] [39] [40]. Although the beaches of Singapore are among the earliest study areas for MPs pollution, there have been no other noteworthy publications from Singapore. Similarly, one report each is available from [41], Colombia [42], and Panama [43]. The second and most recent MPs reports from the other two original research polluted sites, Malaysia [44] and Indonesia [45], was just released after a protracted hiatus. Five separate researches [46] [47] [48] examined the distribution of MPs in a total of 11 mangrove habitats in the Persian Gulf of Iran. The greater trapping ability was confirmed by the findings that mangroves and tidal marshes had larger plastic abundances [**Figure. 3**] than tidal flats and seagrass meadows and that debris density was positively correlated with tree density [26]. Similar assessment of the process of MP entrapment by three specimens—sea meadows, macroalgae, and corals—that are predominate in nearshore habitats [49]. When researchers collected samples of reeds from the wetlands surrounding East Dongting Lake in China to test for the presence of MPs; they discovered an average of 511.2 ± 295.0 items/kg. This result supported the theory that the abundance of MPs could have come from lakes and other fishing activities [50]. Interesting factor contributing to these high pollution levels is that 54% of mangrove habitats are located within 20 km of a river mouth, many of which are among the most polluted in the world, and a large portion of this plastic pollution initially stays close to the river mouth and nearby coastline [51]. As a result, mangroves are where some of the largest levels of plastic pollution have ever been documented [52]. The growth of seedlings and the establishment of seeds are hampered by plastic on the mudflats and in the mangroves. Suffocation prevents physiological functions from continuing, including photosynthesis and respiration. Plastic pollution also limits the habitats that are available to various faunal species, including molluscs, crabs, birds, mudskippers, etc. For instance, the prevalence of crab holes is adversely connected with the amount of plastic waste found in the Panamanian mangroves [53]. The presence of MP particles found in sediments and fish samples of *Periophthalmus waltoni* in mangrove forests of Southern Iran, and they came to the conclusion that polystyrene and polycarbonates were the most (26%) and least (3%) detected polymers in both samples. Some more attempted to investigate the prevalence of MPs in 14 different species of commercial fish that were bought from markets of the northern Persian Gulf coast [54]. Recent research conducted an investigation into the prevalence of MPs in the stomach region of fish in the Ulhas River estuary in India. They found an average range of 3.75 to 6.11 particles per fish [55]. The highest MP concentrations were found in the gills of the *Thunnus tonnggol* fish species and the gut region of the *Sphyraena putnamiae* species, respectively, with 5.71 and 5.67 particles per individual and fibres being the most prevalent form. These fishes were also identified as being from the pelagic region (Maghsodian et al. 2021). Studying the colonisation of rhizosphere microbes on MP surfaces was observed, intriguingly they discovered that in addition to rhizosphere microbes that showed biodegradation towards MPs, a small number of pathogenic organisms, including *Vibrio parahaemolyticus* and *Escherichia shigella*, were also persistent along with MPs and soil [56]. The prevalence of polystyrene, polypropylene, and polyethylene-based polymers in mangrove sediments may be caused by the breakup of food packaging and textiles discarded during maritime transit, as well as from the fishing gear used during fishing activities [24]. On interesting study conducted, the sampled specimens, which were found in three separate mangroves across Hong Kong and belonged to four dominant species, all showed evidence of microparticle ingestion. We've shown that the types and abundances of MPs in crab stomachs are related to the role of the crab in the food web and its feeding habits, with generalist feeding techniques being used by crabs that consume a larger abundance and more varied range of types of MPs [57]. An important bird area (IBA) in India is the mangrove mudflats of Sewri-Mahul and Thane Creek in

Mumbai, which are home to nearly 205 species of migratory and non-migratory birds, including several rare, threatened, and near-threatened species like the Indian Skimmer, Red-headed Bunting, Eurasian Collared Dove, White Stork, Painted Stork, Lesser Flamingo, and Black-Mumbai's urban beaches have been found to contain MPs that are smaller than 5 millimetres. Their appearance is most likely a result of marine plastic trash degrading and gathering in the mangroves [34]. Birds' feeding and foraging habits are to blame for ingesting MPs, which pose a serious hazard to the food chain since they go up the trophic chain [58]. Smaller in size than natural sediments, MPs are better at adsorbing pollutants like polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and other pesticides. The migrating flamingo birds that visit Sewri-Mahul and Thane creek to feed in the polluted waters and sediments face a possible risk [59]. The Mangalavanam bird sanctuary, a protected mangrove forest in the Indian city of Cochin, underwent an investigation [60] to determine the abundance and characteristics of MPs in three different environmental compartments: soil (933 ± 564 particles/kg), sediment (1275 ± 532 particles/kg d.w.), and water (101.6 ± 24 particles/liter). The MPs may contain chemical substances like diethylhexylphtalate (DEHP), which is bad for aquatic life [61]. Moreover, several metals and chemicals that are linked to MPs may continue to negatively affect aquatic life [62]. In earlier research, where acetylcholinesterase activity was assessed in a laboratory setting, the neurotoxic effects of MPs were also found [63]. Moreover, MPs can produce oxidative stress, which results in the lipid peroxidation of cellular membranes [64]. The discovery of MPs in several commercially significant edible fish raises the possibility that it will spread to higher organisms, including people [65]. Studies on the impact of MPs exposure in a range of test organisms, including fish, molluscs, crustaceans, etc., interpret the induction of physical and chemical toxicity, genotoxicity, and strong transgenerational impacts on populations [66]. Another study [67] discovered that polystyrene MPs had a negative impact on oyster reproductive and nutrition, affecting egg count and sperm count. MPs also have a significant negative impact on the zooplankton ecosystem. Two economically significant zooplankton species, *Neocalanuscristatus* (a calanoid copepod) and *Euphasia pacific* (an euphausiid) have been tested for the presence of MPs in the North Atlantic using the acid digestion method [68].

Microplastics degradation by mangrove dwelling microbes

Recent times have seen a preference for using microorganisms for MP bioremediation instead of alternative remediation methods [**Table. 1**]. The remediation or destruction of MPs in this method uses microbes that produce enzymes that break down MPs, such as PETase, hydroxylases, peroxidases, etc. Some significant variables that may impact how much MPs are degraded by microorganisms include the type of polymer used, its characteristics, its molecular weight, and any chemical additives included during the manufacturing process. Around the MP structure, the microorganisms first create biofilms and produce the enzymes needed to break down polymers into monomers. Later, after being digested, these monomers are totally metabolised or decomposed within their body to produce simpler chemicals like carbon dioxide, water, etc. It was discovered that the combination of *Vibrio alginolyticus* and *Vibrio parahaemolyticus* can degrade PVA-LLDPE [69]. Plastics are submerged in the marine environment and take a very long time to decompose. Following the adhesion of the microorganisms to the polymer, the microbial enzymes are secreted, and these enzymes cause the hydrolysis—or breakdown—of the polymeric structure. According to some theories, hydrolases like ureases, proteases, and esterases function enzymatically to break down polymers through the process of biodegradation. Abiotic hydrolysis is the first step in the environmental breakdown of synthetic polymers. The research of degradation involved the isolation of unique bacteria that break down synthetic polymers in marine environments as well as creative ideas that entail the cloning of particular enzymes. Microorganisms that are engaged in plastic degradation and how they break down synthetic polymers including nylon, polyvinyl alcohol (PVA), polycaprolactone (PCL), low density polyethylene (LLDPE), HDPE, and LDPE. The structural orientation of polymers is altered as a result of microorganisms using nutrients. PCL, biodegradable polyester, has the potential to be broken down by marine organisms like *Pseudomonas, Alcanivorax,* and *Tenacibaculum,* which are isolated from deep sea sediments. Many abiotic parameters, including UV light, oxygen and water content, temperature, and others, affect how different polymers degrade in marsh soil and sediment. For instance, after 10 years, low-density polyethylene macro-films exposed to extend UV light before being buried in organic soil lost up to 5.5% more mass than those exposed to no radiation. In light of the likelihood that plastics in the environment may be exposed to UV light before being buried in a wetland, the first requirement is particularly pertinent. According to the observation, some of the most common plastics found in sediments, such as polyethylene, polypropylene, and polystyrene, is so persistent because of their chemical structures, which include having carbon as the only atom in the molecular backbone. When exposed to temperature and moisture variations in the intertidal zone and abrasion by sediments, the polymer's relative density [70] and crystallinity [71] will also impact the degree of fragmentation. Although rhizosphere-dwelling bacteria are primarily in charge of maintaining the subsoil system and other nutrient cycles in mangroves, the effects of microplastics on such species are also currently being researched. A few pathogenic organisms, including *Vibrio parahaemolyticus* and *Escherichia shigella*, were also persistent along with microplastics, soil, and also associate with heavy metals [89], lubricating oil [90], crude oil [91], benzo[a]pyrene [92], and polycyclic aromatic hydrocarbons (PAH) [93]. Because they can adapt to practically any environment, microorganisms are opportunistic. A range of substances, including plastic polymers, can be transformed by microorganisms. With the help of this adaptive trait, bacteria can metabolise considerably in the presence of contaminants, and in some situations, it can even accelerate degradation and biotransformation. *Ideonella sakaiensis 201-F6*, a bacterium capable of using PET as its sole source of carbon and energy, was the subject of an investigation into the degradation of PET [94]. Pseudomonas and Bacillus species can degrade brominated high-impact PS [95]. Using different PE pellet incubation times, [96] assessed how the fungus *Zalerion maritimum* responded. The fungus was found to be able to use PE in the tested conditions, which led to a reduction in pellet mass and size. These results suggested the possibility of microplastic degradation by naturally occurring fungi. A sustainable solution to the effects of lethal MP pollution in the world's mangrove wetlands is microbial degradation. To better understand the interactions between plastic and microbes, it is crucial to characterise the microbiome of the mangrove plastisphere. Understanding it is crucial because MPs provide distinct surfaces for bacteria to colonise, which changes the composition and functioning of the microbial population. Enzymatic processes are mostly used to establish the interactions between MPs and microbes [**Table. 2**]; however the majority of these interactions are still poorly understood. Interesting examination conducted in the biodegradation of a copolyester blend (PBAT-based blend flm, PF) by a microbial consortium from maritime samples from three distinct nations, namely Germany, Greece, and Italy. This study identified additional significant genes for PF-degrading enzymes including PETase-like enzymes (Ples) and MHETase-like enzymes (Mles), which are essential for the degradation of PF, using multi-omics methods like meta-transcriptomics, metaproteomics, and metagenomics [107]. After key candidate genes with MP degradation potential have been characterised, biotechnological techniques like gene editing and genetic engineering can be used to build over-expressed, genetically altered, or genetically edited microorganisms with increased biodegradability potential. Mangrove microbes are the least used microbiota for their potential in bioremediation of MPs, as evidenced by the paucity of information on both the enzymes that break down MPs and mangrove microbes. Developing and using highly effective microorganisms for the bioremediation of the MPs would benefit from genetic dissection of the enzymes and identification of other regulators, such as miRNAs and lncRNAs, that mediate the functioning of the enzymes [108]. The precise enzymes and genes that encode them can also be found and located using the multi-omics tools, making it easier to manipulate them utilising methods for gene modification and editing [109]. Through the use of multi-omics techniques, it is simple to identify the candidate genes encoding the most significant enzymes [110]. Also, it is possible to clarify the microbial interactions inside a biofilm that may be influencing the pace of MP breakdown.

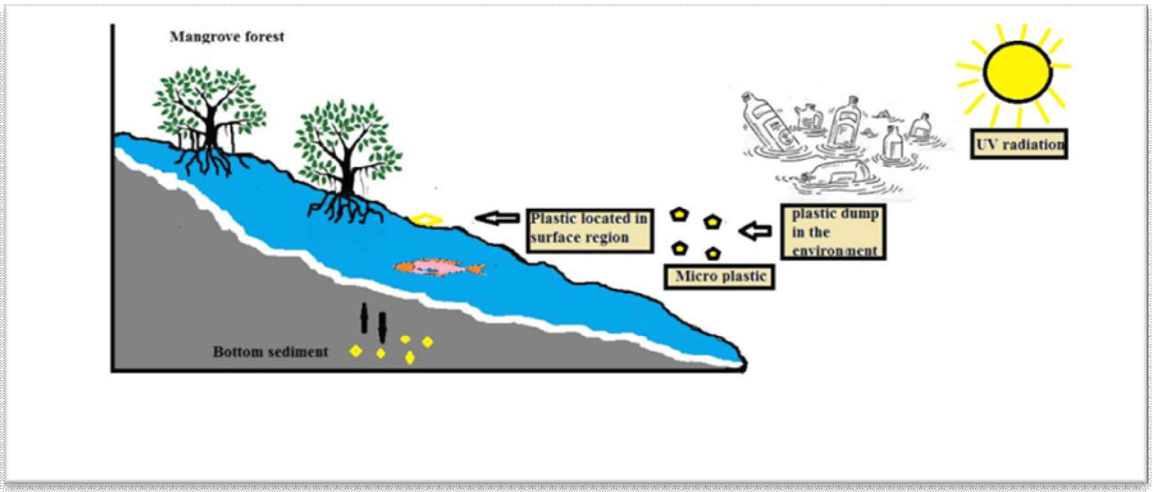

Figure 1. Illustration shows accumulation of plastics debris in mangrove region.

Figure. 2. Images show the structural complexity of mangrove trees, *Rhizophora* and *Avicennia* root systems, Chinnapalam mangrove, Gulf of Mannar, Southeast coast of India.

Figure. 3. A). Shows plastics reached the mangrove system by naturally * anthrophogically. B). shows collection of soil samples form plastics accumulated region, Pichavaram Mangrove, Tamil Nadu

Table. 1. Summary of studies on microbial degradation of plastics from mangrove

S.NO	Plastic material	Microorganism	sources	Reference
1	PP, PE, PPT, PS	*Bacillus, Bacillus gottheilii, Rhodococcus*,	Mangrove sediments	72
2	PP	*Bacillus cereus, Sporosarcina globispora*	Mangrove sediments in Peninsular Malaysia	73
3	PE, PP, PET	*Zalerion maritimum, Aspergillus niger, Cladosporium, Penicillium simplicissimum*	Marine coastal habitats	74, 75,76

4	HDPE, PAHs	Klebsiella pneumonia Brevibacillus ***borstelensis***	marine soil sediments, marine water and oil spilled marine water)	77
5	PE	*Pseudomonas sp.*	Mangrove soil	78
6	HDPE	*Pseudomonas sp., Arthrobacter sp.,*	Marine ecosystem	79
7.	PE	*Lysinibacillus sp. Salinibacterium sp.*	Marine	80
8.	PVC, LDPE. HDPE	*Bacillus sp.*	Coastal water	81
9	PS	*Bacillus paralicheniformis G1*	Depth sediments	82
10.	PE/PET	*Streptomyces sp.*	Marine Sponge	83
11	PE/PET	*Anabaena spiroides*	Marine environment	84
12	PVC	*Pseudomonas putida*	Marine environment	85
13	Gamma irradiated polypropylene and biomass	*Bjerkandera adusta*	Marine water	86
14	PET	*Alcanivorax, Hyphomonas, Cycloclasticus species*	Marine ecosystem	87
15	PVA-LLDPE	*Oceanimonas sp., Vibrio sp., Paenibacillus sp., Shewanella sp., Rheinheimera sp., Bacillus sp.*	Coastal area	88

*PP-polypropylene, PE-polyethylene, PPT-polypropylene terephthalate, PS-Polystyrene, HDPE-high density polyethylene, PVC-polyvinyl chloride, LDPE-low density polyethylene, PET-polyethylene terephthalate, LLDPE-Linear low-density polyethylene, PVA-Polyvinyl alcohol, PAHs-olycyclic Aromatic Hydrocarbons.

Table. 2. Summary of studies involved enzyme based plastic degradation

S.No	Plastic	Enzymes	Microorganism	Reference
1	HDPE, LDPE	Peroxidase	*Pseudomonas Bacillus*	[97]
2	PUR	Lipase B	*Candida rugosa and Candida antarctica*	[98]
3	PBS	PHB depolymerase	*Aspergillus fumigatus Penicillium funiculosum*	[99]
4	PET	MHETase, PETase	*Ideonella sakaiensis*	[100]
5	Styrene	Styrene monooxygenases	*Paraglaciecola agarilytica*	[101]
6	PUR	Polyurethanases	*Pseudomonas sp.*	[102]
7	PUR	Urethane	*Geomyces pannorum*	[103]
8	PE	Peroxidase	*Aspergillus terrus*	[104]
9	PBS	Proteinase	*Tritirachium album*	[105]
10	PVA	Oxidase, hydrolase and dehydrogenases	*Penicillium sp.*	[106]

*PUR-polyurethane, PBS- Poly butylene succinate

CONCLUSION

Mangrove forests are capable of trapping large amounts of plastic garbage, which can be found in the sediment as well as on the forest floor. As plants invest in root growth to overcome the anoxic circumstances, layers of plastic that are deposited on top of the aerial roots of mangroves might immediately produce a local response. Mangrove plants partially suffocated by plastic exhibit a root-growth response, appear stressed, and seem to be able to withstand the partial suffocation. Mangrove trees will eventually perish if their entire root zones are covered in plastic. Moreover plastic deposition also affects the entire mangrove associated communities, like birds, fishes, oyster, molluscus and etc. Our review indicates that mangrove ecosystem, particularly those that are close to sources of improperly managed plastic, are under stress due to the current levels of plastic pollution.

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