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Bioremediation: A natural solution to mitigate the environmental impact of plastic waste

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Abstract
The increase in the consumption of plastics and their use in the day to day life makes them to the most leading industry in the world. The plastic waste in the municipal waste in 2017 is 14 million out of which only 12% waste is burned and remained waste is still present in the environment. In the all aspects of emerging environmental issues the plastic waste is the rapidly growing sector and its use excessive use creating dangerous problems to all lives present on the earth. Due to which impact on climate change and on tourism which is the source of income to the country in many ways, But the plastic waste is vector for microbes in the aquatic life and it leads to the emergence of newly modified organisms, the organisms (superbugs) produced from plastic waste is more hazardous to the human health occurs and also it also affects the human lives. According to WHO if plastic waste is not controlled then till 2030 the plastic waste will double in oceans than aquatic animals.

Keywords: Bacteria, plastic environment biodegradation

Introduction
The plastic industry is one of the fastest-growing industries worldwide, driven by the heavy dependence of human beings on plastic products. Plastic waste has become a global problem, with one of the significant contributors to air pollution being the burning of plastic waste in open fields. Marine environments are also disturbed by plastic waste, leading to air pollution. Plastics have become a major component of municipal solid waste (MSW), with containers and packaging being the highest tonnage of plastic waste, totaling over 14 million tons in 2017. Plastic items like bags and covers play a crucial role in our daily lives, particularly in transporting food and other goods. However, the issue of plastic consumption is not adequately addressed, leading to an increase in plastic production and subsequent environmental degradation. The worldwide demand for plastic has surged significantly, escalating from 1.5 million tons during the 1950s to approximately 335 million tons by 2016. Almost 50% of these plastic items are intended for single-use purposes. Unfortunately, inadequate disposal practices or accidental releases during manufacturing and transportation can lead to the introduction of plastics into the marine ecosystem, where they endure as pollutants. Research suggests that an estimated 4.8 to 12.7 million tons of plastic find their way into the oceans each year (1).
Plastics are synthetic organic polymers that came into mass production in the 1930s and 1940s (2). The dominant market shares are held by economical and common thermoplastic polymers often known as "plastics." This group comprises of polyethylene terephthalate (PET), various forms of polyethylene like high-density (HDPE), low-density (LDPE), and linear-low density (LLDPE), along with polyvinyl chloride (PVC), polypropylene (PP), and polystyrene (PS) (3). Plastic materials offer unique properties, contributing significantly to the quality of our daily lives. The mentioned materials are cost-effective, lightweight, robust, long-lasting, resistant to corrosion, and exhibit excellent thermal and electrical insulation characteristics. The extensive use of plastics and their waste disposal may lead to assembly of superbugs; if superbugs produced then no one can save us from the upcoming pandemics. Alexander flaming already warn us about the rising problems with the superbugs. The aim of present study is to focus on the hazardous problems produced from the plastic bottles, plastic bags which will produce the superbugs which are resistant to antibiotics, the superbugs may produced from the plastics which arise due to the presence of waste food material, antibiotics and many waste material in the waste plastics which lead to production of superbugs.

In the research conducted on the influence of ocean microplastics (MP) on distinct microbial communities under varying environmental circumstances, the investigation revealed that a majority of potentially pathogenic groups did not show an increase in abundance on MP. Nevertheless, the identification of specific bacteria linked to antibiotic resistance on microplastics within a wastewater treatment plant (WWTP) highlights that tiny plastic particles serve as significant hubs for horizontal gene transfer mechanisms (4).

Table 1: The information available spans from 1960 to 2017 and covers the total tonnage of plastics produced, recycled, composted, used for energy recovery, and sent to landfills

Data spanning from 1996 to 2017 regarding the weight of plastics in municipal solid waste (MSW) is presented in thousands of U.S. tons.										
Management Pathway	1960	1970	1980	1999	2000	2005	2010	2015	2016	2017
Generation	390	2,900	6,830	17,130	25,550	29,380	31,400	31,480	34,870	35370
Recycled	-	-	20	370	1,480	1,780	2,500	3,120	3,240	2,960
Composted	-	-	-	-	-	-	-	-	-	-
Combustion with Energy Recovery	-	-	140	2,980	4,120	4,330	4,530	5,330	5,340	5,590
Landfilled	390	2900	6670	13,780	19,950	23,270	24,370	26,030	26,290	26,820

***Source*:** United States Environmental Protection Agency (EPA)

Plastic Waste Generation

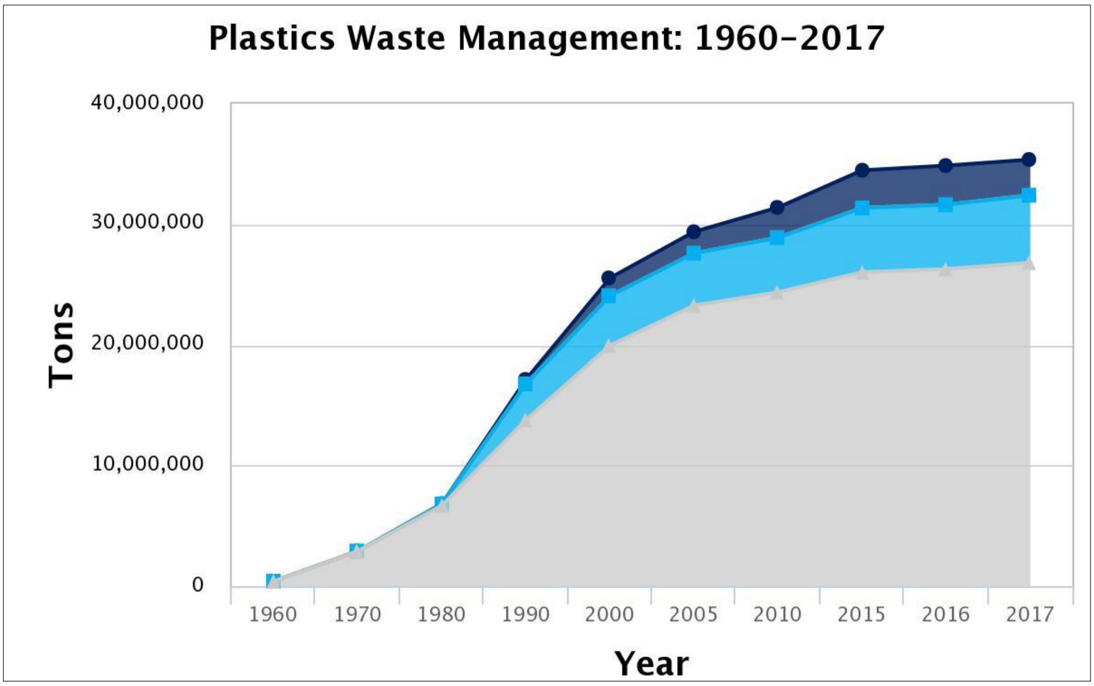
Over the 57-year period from 1960 to 2017, plastic waste generation in municipal solid waste (MSW) has experienced substantial growth. Starting at 390 thousand U.S. tons in 1960, it increased to a remarkable 35,370 thousand U.S. tons in 2017. This significant rise indicates a concerning trend of increasing plastic consumption and disposal, highlighting the need for better waste management strategies (Table. 1).

Recycling

The data reveals an encouraging trend in plastic waste recycling over the years. While there was no recorded data for recycling in 1960 and 1970, recycling started to emerge as a management pathway in 1980, with 20 thousand U.S. tons being recycled. The recycling rates steadily increased, reaching 2,960 thousand U.S. tons in 2017. Though the recycling efforts have grown, there is still significant room for improvement to manage plastic waste more sustainably.

Composting: Throughout the entire period from 1960 to 2017, there is no recorded data for composting of plastic waste. This absence of data suggests that composting is not a prevalent method for managing plastics in MSW during this timeframe. Composting plastics is known to be challenging due to their non-biodegradable nature, and alternative management methods are required.

Overall, the comparative results indicate a concerning increase in plastic waste generation over the years, with recycling showing some progress as a management pathway. However, the lack of data for composting highlights the need for exploring innovative and sustainable waste management solutions to address the growing plastic waste problem effectively. To mitigate the environmental impact of plastic waste, continued efforts are essential to enhance recycling rates and implement alternative disposal methods that align with the principles of circular economy and environmental sustainability.



Graph 1: The information detailing plastic statistics between 1960 and 2017 includes the total volume of plastic produced, recycled, composted, utilized for energy recovery through combustion, and deposited in landfills.

Types of Plastics

The plastics are made from synthetic organic substances which are soft and can be molded into solid objects of different shapes (Varma). There are different types of plastics are used for different uses for making bags and bottles and there uses are as follows:

Table 2: Types of plastic general properties and common household uses.

Plastic Type	General Properties	Common Household Uses
1 PETE Polyethylene Terepthalate	Good gas & moisture barrier properties High heat resistance Clear Hard Tough Microwave transparency Solvent resistant	Mineral Water, fizzy drink and beer bottles Pre-prepared food trays and roasting bags Boil in the bag food pouches Soft drink and water bottles Fibre for clothing and carpets Strapping Some shampoo and mouthwash bottles
2 HDPE High Density Polyethylene	Excellent moisture barrier properties Excellent chemical resistance Hard to semi-flexible and strong Soft waxy surface Permeable to gas HDPE films crinkle to the touch Pigmented bottles stress resistant	Detergent, bleach and fabric conditioner bottles Snack food boxes and cereal box liners Milk and non-carbonated drinks bottles Toys, buckets, rigid pipes, crates, plant pots Plastic wood, garden furniture Wheeled refuse bins, compost containers
3 V Polyvinyl Chloride	Excellent transparency Hard, rigid (flexible when plasticised) Good chemical resistance Long term stability Good weathering ability Stable electrical properties Low gas permeability	Credit cards Carpet backing and other floor covering Window and door frames, guttering Pipes and fittings, wire and cable sheathing Synthetic leather products
4 LDPE Low Density Polyethylene	Tough and flexible Waxy surface Soft – scratches easily Good transparency Low melting point Stable electrical properties Good moisture barrier properties	Films, fertiliser bags, refuse sacks Packaging films, bubble wrap Flexible bottles Irrigation pipes Thick shopping bags (clothes and produce) Wire and cable applications Some bottle tops
5 PP Polypropylene	Excellent chemical resistance High melting point Hard, but flexible Waxy surface Translucent Strong	Most bottle tops Ketchup and syrup bottles Yoghurt and some margarine containers Potato crisp bags, biscuit wrappers Crates, plant pots, drinking straws Hinged lunch boxes, refrigerated containers Fabric/ carpet fibres, heavy duty bags/tarpaulins
6 PS Polystyrene	Clear to opaque Glassy surface Rigid or foamed Hard Brittle High clarity Affected by fats and solvents	Yoghurt containers, egg boxes Fast food trays Video cases Vending cups and disposable cutlery Seed trays Coat hangers Low cost brittle toys
7 OTHER	There are other polymers that have a wide range of uses, particularly in engineering sectors. They are identified with the number 7 and OTHER (or a triangle with numbers from 7 to 19).	Nylon (PA) Acrylonitrile butadiene styrene (ABS) Polycarbonate (PC) Layered or multi-material mixed polymers

***Source*:** Ryedale District Council UK

Toxicity of plastic waste

Incinerating plastic waste in the environment is a significant contributor to air pollution. In many instances, the combustion of plastic materials leads to the emission of harmful gases such as Furans, Dioxins, Mercury, and polychlorinated compounds. Notably, approximately 12% of municipal waste is disposed of through burning (5). To address this issue, it's crucial to formulate comprehensive policies that tackle chemical exposure arising from plastics. Concurrently, promoting research in this field is essential for informed decision-making.

Plastic waste may increase superbugs and antibiotic resistant bacteria

Plastic waste can act as carriers for the dissemination of multiple antibiotic resistances in Antarctic marine environments (6). Normally, bacteria wouldn't survive in such harsh conditions, but when microplastics are present, they can be transported from one location to another. The World Health Organization (WHO) now acknowledges Antibiotic Resistance (AR) as a substantial peril to worldwide health, food security, and progress. AR occurs when bacteria progressively develop the ability to withstand the effects of antibiotics, a natural process that has been greatly accelerated by the misuse and overuse of these drugs. This jeopardizes the tremendous progress made in combating infectious diseases since the discovery of penicillin in the early 20th century. To curb the spread of this problem, WHO advocates for intensive monitoring to identify and monitor critical hotspots. Numerous research projects have investigated the routes of antibiotic-resistant bacteria and have found that microplastics and macroplastics are among the major contributing factors (6).

Rising problems in marine environment due to plastics

Plastic waste presents a significant and widespread challenge for marine ecosystems. It not only jeopardizes the well-being of oceans but also affects food safety, quality, and human health, while also impacting coastal tourism and contributing to climate change. Non-biodegradable plastics disrupt aquatic life, leading to severe environmental damage and harm to marine organisms. According to the United Nations, plastic makes up about 80 percent of marine litter, affecting around 800 species worldwide. Fish, marine birds, sea turtles, and aquatic mammals frequently become ensnared in or ingest plastic waste, leading to instances of suffocation, malnutrition, and drowning. Prolonged exposure to seawater causes toxic contaminants to accumulate on the surface of plastic materials, introducing additional risks. As marine organisms ingest plastic debris, these contaminants enter their digestive systems, gradually building up in the food web. This poses health hazards as the contaminants transfer between marine species and eventually reach humans through the consumption of seafood. Moreover, since plastic is derived from petroleum, it contributes to global warming. When plastic waste is incinerated, it releases carbon dioxide into the atmosphere, contributing to increased carbon emissions. Given these factors, it is crucial to address the issue of plastic waste urgently to mitigate its adverse effects on the environment and human health.

Impact on climate change

The plastic waste after burning produces dangerous gases like carbon dioxide which is the most responsible for climate change.

According to IUCN of marine plastic

- Approximately 300 million tons of plastic are produced each year to serve diverse purposes.
- Annually, no less than 8 million tons of plastic enter the oceans, accounting for 80% of the total marine debris discovered in surface waters and deep-sea sediments.
- Marine organisms consume or become ensnared in plastic waste, leading to significant harm and even loss of life.
- Plastic pollution poses risks to food safety and quality, human health, coastal tourism, and plays a role in contributing to climate change.
- It is imperative to consider utilizing existing legally binding international agreements to combat marine plastic pollution effectively.
- Implementing recycling and reusing of plastic products and promoting research and innovation to create alternatives to single-use plastics are crucial steps in preventing and reducing plastic pollution.

Pandemic responsible for Plastic waste and pollution?

The widespread use of plastic materials, gloves, masks, and various other items made of plastic has significantly contributed to pollution during this pandemic. Since December 2019, the world has been grappling with a pandemic caused by a novel coronavirus (SARS-CoV-2) responsible for the severe respiratory syndrome known as COVID-19 (WHO). During this pandemic, the focus has been primarily on human health, often overshadowing concerns about environmental care. Medical waste and household waste have increased during the pandemic, posing a higher risk to both human health and the environment. The WHO has warned that plastic waste by 2030 is projected to be double that of aquatic animals, a concerning issue that cannot be neglected.

Role of plastics on human health

Plastic, due to its low cost and easy availability, has become an integral part of the modern economy. However, its usage exposes human health to various direct and indirect risks (8). Researchers are actively exploring alternatives to plastic, as some types of plastic have been linked to certain cancers. Almost 99% of plastic originates from fossil fuel sources. The extraction of oil and gas, which includes processes like hydraulic fracturing for natural gas, leads to the emission of various harmful substances into the atmosphere and water, frequently in substantial amounts. Over 170 chemicals utilized in the production of the primary material for plastics possess established detrimental effects on human health, encompassing conditions like cancer, neurological disorders, reproductive and developmental toxicity, compromised immune systems, and other health concerns. These toxins have documented effects on various body systems, including the skin, eyes, respiratory system, nervous system, gastrointestinal system, liver, and brain. The conversion of fossil fuels into plastic resins and additives also releases carcinogenic and highly hazardous elements into the atmosphere. Contact with these elements has been associated with neurological impairment, issues with reproduction and development, instances of cancer and leukemia, as well as genetic effects including low birth weight. Those at the highest risk of exposure include industry workers and communities residing near refining facilities, who may face both chronic and acute exposures during uncontrolled releases and emergencies (CIEL).

The role of microbes in plastic degradation

Microbes, particularly microorganisms like bacteria, have evolved strategies to survive and degrade plastics. These specialized microbial communities have the ability to break down the chemical structure of plastics, converting them into harmless substances such as carbon dioxide, water, and biomass. The discovery of plastic-degrading bacteria in industrial waste water has opened up new possibilities for using these microorganisms to tackle the plastic waste crisis. Researchers have identified specific bacterial genera, such as Pseudomonas and Acidovorax, that possess the enzymes necessary for breaking down the components of plastics like polyethylene terephthalate (PET).To harness the potential of plastic-degrading microorganisms, scientists are engaged in bio-prospecting efforts. These efforts involve isolating and studying microbial strains that have the ability to efficiently decompose and assimilate various types of plastic. High-throughput gene sequencing and bioinformatics analysis techniques are used to evaluate the diversity of bacteria on the surface of plastic samples exposed to different environments, such as industrial waste water and natural fresh water. By understanding the metabolic pathways and enzymes involved in plastic degradation, researchers can develop strategies to enhance the efficiency of plastic degradation processes. Some of the microbes reported having capacity to degrade plastics are listed below.

Table 3: Some of the reported Plastic degrading bacteria.

Sr. No.	Organism	Plastic type	Degradation time (Days)	Biodegradation efficiency (%)	Reference
1	*Pseudomonas fluorescens* PE	270	18.0	Thomas *et al*. (2015) [19]	
2	*Bacillus vallismortis* bt-dsce01	LDPE	120	75.0	Skariyachan *et al*. (2017) [17]
3	*Klebsiella pneumoniae* CH001	HDPE	60	18.4	Awasthi *et al*. (2017) [2]
4	*Aspergillus oryzae* strain A5	LDPE	112	36.4	Muhonja *et al*. (2018) [8]
5	*Bacillus cereus* strain A5	LDPE	112	35.72	Muhonja *et al*. (2018) [8]
6	*Trichoderma viride* RH03	LDPE	45	5.13	Munir *et al*. (2018) [10]
7	*Aspergillus nomius* RH06	LDPE	45	6.63	Munir *et al*. (2018) [10]
8	*Bacillus* sp. & *Paenibacillus* sp.	PE	60	14.7	Park and Kim (2019) [14]
9	*Aspergillus flavus*	HDPE	100	5.5	Taghavi *et al*. (2021) [18]
10	*Bacillus siamensis*	LDPE	90	8.46	Maroof *et al*. (2021) [7]

Biodegradation of Plastics

Biodegradation of plastics refers to the process in which microorganisms, such as bacteria, actinomycetes, and fungi, cause physical and chemical changes in the material (Alshehrei, 2017) [1]. This phenomenon occurs in both natural and synthetic plastics.

Aerobic biodegradation (aerobic respiration)

In this degradation process, microorganisms aid in breaking down substantial organic compounds into smaller forms by utilizing oxygen as an electron acceptor. The outcomes of this process involve the production of carbon dioxide and water (Müller, 2005) [9].

Carbon plastic + Oxygen ! carbon dioxide + water + Carbon residual

Anaerobic biodegradation

Anaerobic biodegradation encompasses the decomposition of substances by microorganisms in the absence of oxygen. Nonetheless, oxygen remains essential for the natural reduction of pollutants at sites with hazardous waste. Anaerobic bacteria utilize substitute electron acceptors such as nitrate, iron, sulfate, manganese, and CO2 in lieu of oxygen to disintegrate substantial organic compounds into smaller forms.

When it comes to carbon (plastic) degradation, it is converted into methane, carbon dioxide, water, and carbon residual. Since most polymers are too large and insoluble to enter microorganism cells directly, microorganisms utilize these polymers as an energy source by secreting extracellular enzymes. These enzymes facilitate depolymerization outside the bacterial cells, contributing to biodegradation both inside and outside the cells. In the biological degradation of plastic polymers, two main processes are involved: depolymerization and mineralization.

Exoenzymes, enzymes secreted externally by cells, are responsible for breaking down extensive polymers into smaller, soluble molecules. These molecules can traverse the semi-permeable bacterial membrane and function as a source of energy. The procedure of breaking down significant polymers is termed depolymerization, while the transformation of resultant substances into inorganic forms such as H_2O, CH_4, and CO_2 is referred to as mineralization (Gu, 2003) [4]. When conditions are aerobic, the resulting products encompass H_2O, CO_2, and microbial biomass. Under anaerobic/methanogenic and sulfidogenic conditions, alongside these three elements, the degradation of polyethylene also yields CH_4 and H_2S.

The literature reports the degradation potential of various plastic polymers, including Polyethylene (PE), low-density polyethylene (LDPE), and high-density polyethylene (HDPE), by different organisms.

Mechanism of biodegradation

The biodegradation process of polymers comprises three primary stages: (a) initial attachment of microorganisms to the polymer's surface, (b) utilization of the polymer as a carbon source, and (c) the actual degradation of the polymer. Microorganisms adhere to the surface of the polymer and initiate degradation by secreting enzymes, which serve as an energy source for their growth. Large polymers are broken down into smaller units, such as monomers and oligomers, which are molecules with low molecular weight. Some of these oligomers can diffuse into the interior of microorganisms and be assimilated within their internal environment.

Enzymatic degradation of plastics

The degradation of plastic using microbial enzymes is a challenging process due to the lack of hydrolysable groups in the carbon-carbon backbone. The initial step involves reducing the molecular weight, which is achieved through a combination of biotic and abiotic factors. Microbial enzymes are facilitated by UV light exposure, which enables them to attack the carbonyl group of the polymer (Novotný *et al*., 2018) [11]. Several enzymes are employed for polymer degradation, including laccase, manganese-dependent enzymes (lignin degrading enzymes), urease, lipase, and protease. For example, thermos table laccase has demonstrated the ability to degrade polyethylene (PE) within 48 hours of incubation at 37 °C.

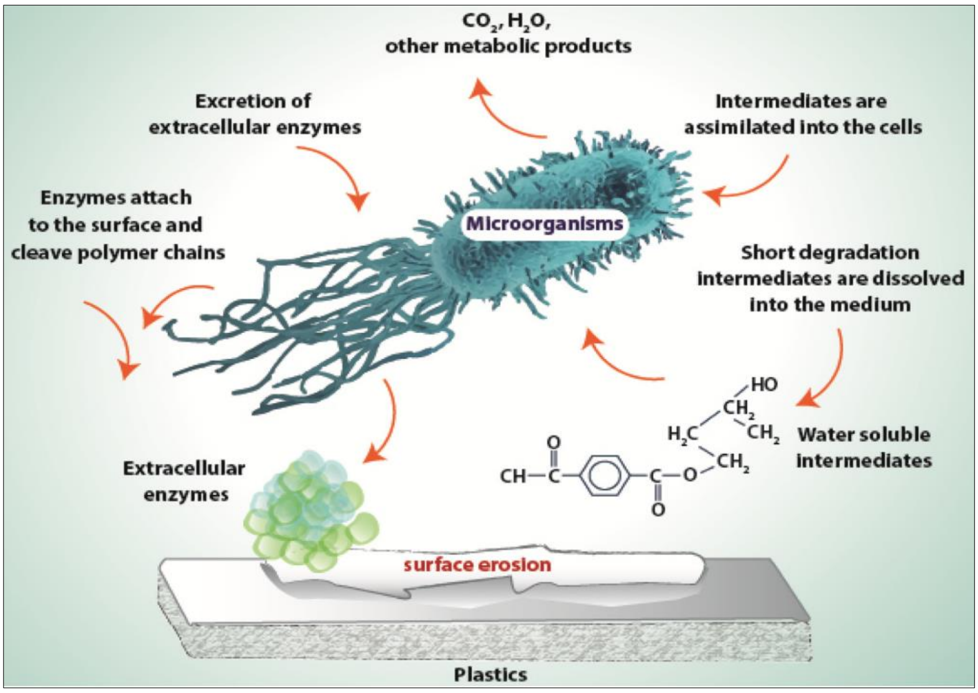


Fig 1: General mechanism of plastic degradation under aerobic conditions (Müller, 2005) [9].

Conclusion

The increasing generation of plastic waste and its environmental impact have become pressing global concerns. The rapid growth of the plastic industry and the prevalence of disposable plastic products contribute to the escalating problem of plastic pollution. Improper disposal and burning of plastic waste release hazardous pollutants, threatening marine life and human health, and contributing to climate change. Recycling efforts have shown progress, but composting remains a less prevalent method for plastic waste management. Bioremediation offers a promising natural solution, with microorganisms capable of degrading plastics. However, challenges remain in optimizing degradation efficiency and understanding the impact on ecosystems. A comprehensive approach is needed, including reducing plastic consumption, promoting alternatives to single-use plastics, and fostering responsible consumer behavior through awareness and education. Collaboration from governments, industries, researchers, and the public is essential to mitigate the environmental impact of plastic waste and create a cleaner and more resilient world.

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