MICRO-PLASTICS IN THE OCEAN: SOURCES, EFFECTS AND MITIGATION STRATEGIES

Tharani G, School of Excellence in Law, Ambedkar University

ABSTRACT

Microplastics, defined as plastic particles less than 5 mm in diameter, have emerged as a pervasive environmental pollutant in marine ecosystems. These synthetic particles originate from both primary sources—such as microbeads in personal care products and industrial abrasives—and secondary sources, where larger plastic debris undergoes degradation due to environmental factors like UV radiation and wave action. Once introduced into the ocean, microplastics pose significant ecological and health risks, affecting marine biodiversity, disrupting food chains, and potentially threatening human health through bioaccumulation and trophic transfer. The effects of microplastic pollution are profound. Marine organisms, including plankton, fish, seabirds, and larger marine mammals, ingest microplastics, mistaking them for food, leading to gastrointestinal blockages, reduced energy intake, and exposure to harmful chemical additives and adsorbed contaminants. Additionally, microplastics serve as vectors for persistent organic pollutants (POPs), heavy metals, and pathogenic microorganisms, further exacerbating marine pollution. The impact extends to commercial fisheries and aquaculture, with potential economic losses and food safety concerns. Mitigation strategies require a multifaceted approach, encompassing policy interventions, technological advancements, and behavioral changes. Regulatory frameworks, such as bans on microbeads and restrictions on single-use plastics, play a crucial role in curbing primary microplastic pollution. Innovations in biodegradable plastics, wastewater treatment upgrades, and filtration technologies aim to reduce microplastic leakage into aquatic environments. Moreover, public awareness campaigns and corporate responsibility initiatives encourage sustainable consumer choices and industry practices. This research critically examines the sources, environmental and biological effects, and existing mitigation strategies for microplastics in the ocean. By evaluating policy measures, technological innovations, and global responses, the study aims to propose integrated solutions for addressing this pressing environmental issue. A collaborative effort between governments, industries, and civil society is imperative to mitigate the longterm ecological and human health risks associated with microplastic pollution.

Keywords: Microplastics, Marine pollution, Marine Bio-diversity, Marine organisms, Regulatory frameworks.

CHAPTER - 1 INTRODUCTION

1.1 INTRODUCTION:

The rapid increase in plastic production and consumption over the past several decades has led to severe environmental consequences, particularly in marine ecosystems. Among the most concerning issues is the presence of **microplastics**—tiny plastic particles less than **5 millimeters in size**—which have infiltrated marine environments at an alarming rate. Microplastics originate from a variety of sources, including **industrial waste, domestic plastic usage, and the breakdown of larger plastic debris**. Due to their small size and persistence in the environment, microplastics have been detected in **oceans, rivers, and even the most remote polar regions**. Their prevalence has raised significant concerns regarding their **impact on marine biodiversity, food security, and potential risks to human health**.

Microplastic pollution is now recognized as a **global environmental crisis**. These particles are not only ingested by marine organisms, leading to potential **bioaccumulation and biomagnification**, but they also act as carriers for toxic pollutants, further exacerbating their harmful effects. Studies have found microplastics in a wide range of seafood species, drinking water, and even human organs, indicating the urgency of addressing this issue. The persistence of microplastics in the ocean, combined with their ability to **adsorb harmful chemicals**, makes them a long-term ecological and public health threat.

Despite growing awareness, effective **mitigation strategies remain limited**, and research on the long-term effects of microplastics is still in its early stages. While governments and environmental organizations have taken steps to regulate plastic waste, **comprehensive global policies and innovative solutions are necessary to curb microplastic pollution**. This research paper aims to **examine the sources of microplastics, analyze their environmental and health effects, and evaluate potential mitigation strategies**. By understanding these aspects, we can contribute to the development of more effective policies and sustainable practices to protect marine ecosystems and human health.

1.2. SIGNIFICANCE OF THE STUDY:

The pervasive presence of microplastics in marine environments poses significant ecological and human health risks. Understanding the sources, effects, and potential mitigation strategies is crucial for developing effective policies and interventions. This study aims to provide a comprehensive analysis of micro-plastic pollution, contributing valuable insights to the scientific community and informing policymakers, environmentalists, and the public about the urgency of addressing this issue.

1.3 SCOPE AND LIMITATIONS

This research will focus on examining the major sources of microplastic pollution in the ocean, assessing its effects on marine life and human health, and evaluating current mitigation strategies. The study will analyze existing literature, case studies, and policy frameworks to provide a global perspective on the issue. Special attention will be given to the effectiveness of national and international policies in tackling microplastic contamination. The study will primarily rely on secondary data sources, including published research papers, reports, and policy documents, which may limit the ability to present novel empirical findings. Additionally, microplastic pollution is a rapidly evolving field, and new data may emerge after the completion of this research, potentially influencing future interpretations of the findings. Lastly, while the study will discuss various mitigation strategies, the feasibility of implementing specific recommendations will vary across different geographical and socioeconomic contexts.

1.4 OBJECTIVES OF THE STUDY

- ➢ To identify and categorize the sources of microplastics in marine ecosystems.
- ➢ To assess the environmental impacts of microplastics on marine biodiversity.
- ➢ To evaluate existing mitigation strategies aimed at reducing microplastic pollution in marine environments.
- ➢ To explore future directions and innovative approaches for addressing microplastic pollution.

1.5 RESEARCH GAP:

Despite growing awareness, there remain substantial gaps in our understanding of microplastic pollution. Current research often lacks comprehensive data on the long-term ecological impacts and the effectiveness of various mitigation strategies. This study seeks to fill these gaps by examining not only the sources and effects of microplastics but also evaluating existing and potential mitigation measures, thereby providing a more holistic understanding of the issue.

1.6 RESEARCH QUESTIONS:

1. What are the primary sources and pathways through which microplastics enter the ocean?
2. How do microplastics affect marine ecosystems, biodiversity, and human health?
3. What are the existing policies and mitigation strategies for controlling microplastic pollution in the ocean?
4. How effective are current mitigation measures, and what improvements can be made to enhance their impact?
5. What role can technological advancements, regulatory frameworks, and public participation play in reducing microplastic pollution?

1.7 HYPOTHESIS:

It is hypothesized that the Micro-plastics have a significant adverse impact on marine biodiversity and pose potential risks to human health through bioaccumulation and food chain contamination. Existing mitigation strategies are insufficient to effectively address microplastic pollution, and innovative interventions are required to enhance their effectiveness.

1.8 RESEARCH METHODOLOGY:

The research method adopted for this study is a multidisciplinary approach, combining qualitative and quantitative research techniques. This method is particularly suitable for the nature of this research as it allows for an in-depth exploration of the sources, environmental impacts, and mitigation strategies for microplastics in the ocean. The approach focuses on studying the current scientific understanding of microplastic contamination, assessing environmental and health risks, and evaluating the effectiveness of technological and policy interventions. Through a combination of literature review, case study analysis, environmental sampling, and policy evaluation, this methodology provides a comprehensive analysis of microplastic pollution in marine ecosystems.

CHAPTER-2

OVERVIEW OF MICROPLASTICS

2.1 OVERVIEW OF MICROPLASTICS:

Plastics are synthetic polymers which are supple or malleable (flexible) in nature and can be transformed in different shapes. Plastic is composed of long chains of polymers which are composed of carbon, oxygen, hydrogen, silicon and chloride and are acquired from natural gas, oil and coal. The most prominent synthetic plastics are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephtalate (PET), polyvinyl chloride (PVC), low density polyethylene (LDPE) and high-density polyethylene (HDPE) and constitute 90% of the worldwide plastic production. The properties of plastics such as flexibility, durability, low cost, easy to handle (lightweight) and resistant to corrosion makes it a widely acceptable compound. Plastic can withstand high rate of electrical and thermal insulation and thus have tremendous industrial and commercial usage. There has been an exponential increase in plastic production from 1950 (1.5 million tons) to 2015 (322 million tons).

The disposal of plastic materials is an issue of concern these days because of its durability and corrosion resistance. Plastic compounds take up to years to get degraded in smaller fragments. Larger plastic debris slowly degrades into small fragments with various size ranges extending from meter to micrometer due to changing environmental conditions. This fragmented plastic with size smaller than 5 mm are known as microplastics and are highly persistent in the ecosystem. Based on shapes, sizes and chemical composition, microplastics can be differentiated as follows. [1]

2.2 PRODUCTION OF PLASTIC AND MICROPLASTICS:

The production of plastic has been a significant driver of industrial growth and consumer convenience, making plastics an integral part of modern life. Derived primarily from petrochemical feedstocks, such as crude oil and natural gas, plastic production involves the

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[1] Subhankar Chatterjee & Shivika Sharma, *Microplastics in Our Oceans and Marine Health*, *Field Actions Science Reports*, Special Issue 19, 54-61 (2019)

polymerization process, where small molecules called monomers are chemically bonded to create long chains known as polymers.

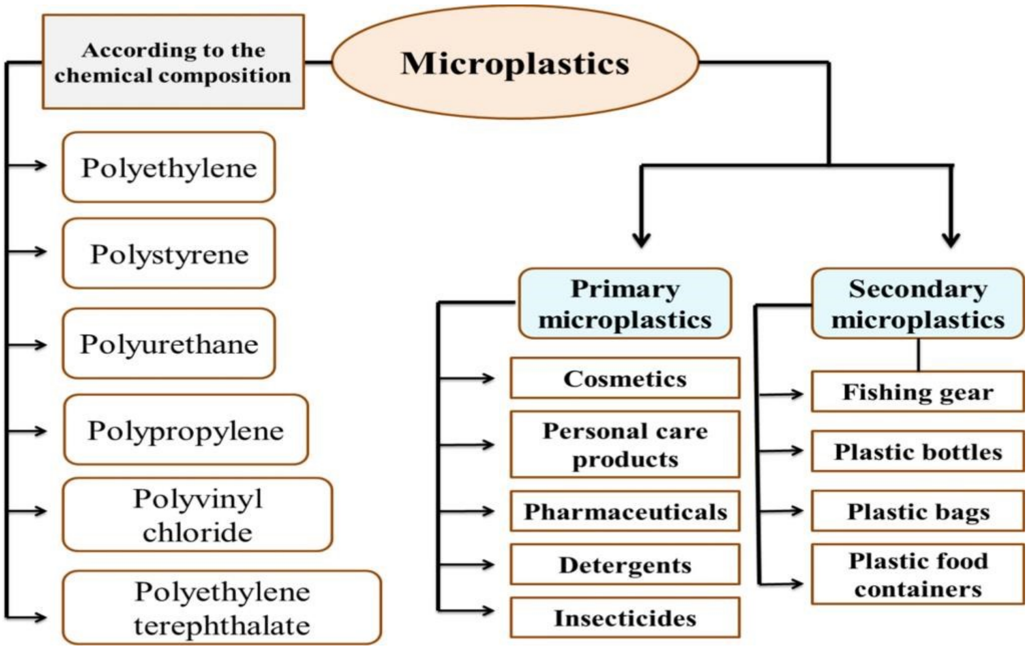
These polymers are then formed into various products, including packaging, textiles, construction materials, and medical devices. The widespread use of plastics, particularly in disposable items, has led to a significant rise in plastic waste. In 2019, global plastic production reached approximately 368 million tons, with much of it eventually entering the environment.[2] As plastic waste accumulates, it degrades into smaller particles, known as **microplastics**, which are typically defined as plastic fragments less than 5 millimeters in size.

Microplastics are categorized into two main types: **primary microplastics** and **secondary microplastics**. Primary microplastics are deliberately manufactured small particles, typically found in personal care products like exfoliating facial scrubs, toothpaste, and cleaning agents. They also include plastic pellets, used as raw materials in plastic manufacturing. These tiny particles enter the marine environment through wastewater discharges, where they are not always captured by treatment plants and are carried into rivers and oceans. Secondary microplastics, on the other hand, are the result of the breakdown of larger plastic debris, such as plastic bags, bottles, fishing nets, and packaging, due to physical, chemical, and biological factors. Over time, exposure to sunlight (UV radiation), mechanical forces from wave action, and oxidation break down larger plastic items into microplastics, which are then dispersed by ocean currents. This process can take years or even decades, with plastic items slowly fragmenting into smaller pieces that are difficult to detect and clean up. The proliferation of microplastics in the oceans is further exacerbated by the durability of plastic, which does not biodegrade easily and can persist in the environment for hundreds of years. Microplastics can be found in all oceanic environments, from the surface to the deep sea, and in some of the most remote areas of the planet, posing significant environmental challenges. As they accumulate in marine ecosystems, microplastics are ingested by marine organisms, from plankton to large whales, often mistaken for food. This ingestion can lead to physical harm, such as digestive blockages, malnutrition, and even death.[3]

Consequently, microplastics enter the food chain of aquatic organisms and undergo

[2] Andrady AL, *The Plastic in Microplastics: A Review*, 119 *Mar. Pollut. Bull.* 12, 22 (2017), https://doi.org/10.1016/j.marpolbul.2017.01.082.
[3] Andrady AL, *The Plastic in Microplastics: A Review*, 119 *Mar. Pollut. Bull.* 12, 22 (2017), https://doi.org/10.1016/j.marpolbul.2017.01.082.

bioaccumulation in their tissues, gradually working their way up the trophic levels as zooplankton, small fish, larger fish, and other organisms consume them. Swallowing these pollutants has been shown to have toxic effects on aquatic life, including fish, oysters, mussels, and sea turtles, such as compromising their immune and digestive systems and potentially leading to their demise.Microplastics have the potential to directly affect human health, as they can enter the human food chain through the consumption of contaminated fish or other aquatic organisms. Studies have shown that microplastics can have cytotoxic effects on human brain cells. In addition to carrying toxic chemicals, microplastics can adsorb various ,contaminants, including antibiotics, due to their large surface area, further exacerbating the problem of microplastic pollution. Furthermore, the cycle of microplastics in the environment continues as they may be excreted by humans or discharged as plastic waste materials.[4]



Microplastics have been recently monitored in drinking water in many countries and in bottles of mineral. Hence, it is imperative to develop new methods and innovative techniques for removing plastics from water sources, as conventional methods are ineffective in eliminating microplastics due to their small size. This has led to an increase in the prevalence and persistence of microplastics in the environment. The review thoroughly investigates several innovative treatment strategies, including the removal of plastic microbeads from cosmetics and personal care products, the utilisation of bioplastics like polyhydroxyalkanoates that can

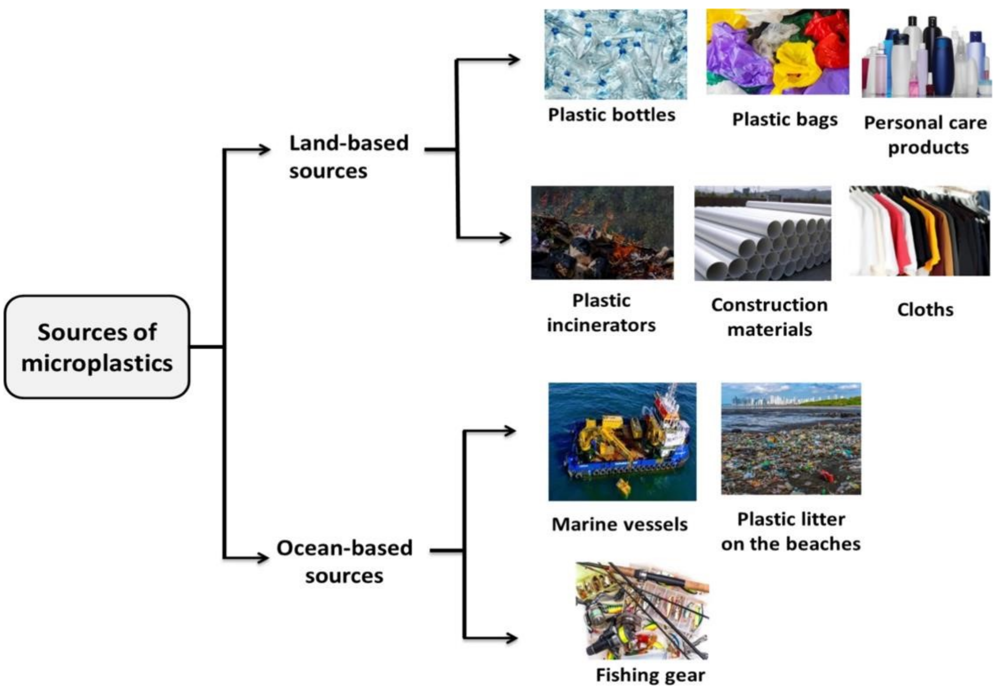
[4] Li C et al., *Assessment of Microplastics in Freshwater Systems: A Review*, 707 *Sci. Total Environ.* 135578 (2020), https://doi.org/10.1016/j.scitotenv.2019.135578.

be biologically degraded in the environment, the enhanced reuse and recycling of plastics, the development of efficient waste separation strategies in waste treatment facilities, and the use of bioremediation treatments.

It is worth noting that research into removing microplastics is relatively new, having only started in 2014. The number of publications related to microplastic removal was very low in the first two years, with only one publication each in 2014 and 2015. However, this number has significantly increased recently, reaching 145 in 2020. This increase in research could be attributed to a combination of factors, including the free time researchers had due to coronavirus disease 2019 (COVID-19) lockdowns and a growing scientific interest in addressing the microplastics issue and finding effective solutions in line with global initiatives to minimise plastic waste.[5]

2.3 SOURCES OF MICROPLASTICS:

There is ample evidence that watercourses contain microplastics with various shapes, sizes, densities, structures, and chemical compositions. Generally, there are many sources of microplastics, but they are mainly classified into land- and ocean-based sources.



[5] Li Z et al., *Polystyrene Microplastics Cause Cardiac Fibrosis by Activating Wnt/β-Catenin Signaling Pathway and Promoting Cardiomyocyte Apoptosis in Rats*, 265 *Environ. Pollut.* 115025 (2020), https://doi.org/10.1016/j.envpol.2020.115025.

➢ **Land-based sources of microplastics:**

Land-based sources are responsible for 80–90% of microplastics in water bodies. These sources include plastic bags, bottles, personal care products, construction materials, and clothing. Plastic incinerators, which generate bottom ash that contains microplastics, are also a landbased source of these particles. Construction materials, household products, packaging items, food and drink packaging waste, and waste generated from shipbuilding are some of the most significant sources of larger plastic objects on land. Sewage sludge and industrial activities, particularly those using granules and small resin pellets, are other probable sources of microplastic discharge into the aquatic environment.[6] In addition to medicines and construction materials, certain cosmetics and personal care products are also considered potential sources of plastic pollution, as they may contain microplastics used as drug carriers or as ingredients. Face washes, hand soaps, hand gels, laundry detergents, washing powder, toothpaste, facial creams, mascaras, lipsticks, sunblock, and shower gels are some of the common examples of such products. [7] Many synthetic fibres, such as polyester, nylon, and acrylics, have been found to shed off clothing and discharge with the stream wastewater into water bodies. Tire wear and tear of cars greatly release microplastics into the environment. Therefore, It is clear that numerous sources of microplastics must be effectively controlled and minimised to the greatest extent possible.

Single-use products made of polymeric plastics, such as drinking bottles, straws, cutlery, coffee cups, and bags, have been identified as a significant source of plastic pollution in the environment. Furthermore, the excessive use of single-use face masks made of plastic polymers, such as polyesters and polypropylenes, during the coronavirus disease 2019 (COVID-19) has significantly increased microplastic waste. Replacement of conventional plastic materials used in face masks and other products with sustainable, eco-friendly materials that can be easily degraded is necessary should future waves of COVID-19 occur.[8]

➢ **Ocean-based sources of microplastics:**

Approximately 10–20% of microplastics discharged into the aquatic environment come from

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[6] Rochman CM, *Microplastics Research—From Sink to Source*, 360 *Science* 28, 29 (2018), https://doi.org/10.1126/science.aar7734.
[7] Carney Almroth BM et al., *Quantifying Shedding of Synthetic Fibers from Textiles: A Source of Microplastics Released into the Environment*, 25 *Environ. Sci. Pollut. Res.* 1191, 1199 (2018), https://doi.org/10.1007/s11356-017-0528-7.
[8] Fadare OO & Okoffo ED, *COVID-19 Face Masks: A Potential Source of Microplastic Fibers in the Environment*, 737 *Sci. Total Environ.* 140279 (2020), https://doi.org/10.1016/j.scitotenv.2020.140279.

ocean-based sources, including seaside tourism, commercial fishing, marine vessels, and offshore industries. Discarded or lost fishing gear, such as plastic monofilament lines and nylon nets, are a significant source of microplastics that can float at different depths in the ocean. Over 600,000 tonnes of fishing gear are thrown away in the ocean each year, contributing to the problem. [9] Shipping microplastic waste, commonly released from shipping and naval vessels, also adds to the problem. Moreover, a massive quantity of plastic waste from offshore industries, such as petrochemicals, is being released into marine ecosystems. While the contribution of ocean-based sources to microplastic pollution is not as high as land-based sources, it is still significant. Control strategies are needed to reduce this contribution.[10]

CHAPTER-3

IMPACTS OF MICROPLASTICS

3.1 EFFECTS OF MICROPLASTICS ON MARINE BIOTA

These tiny plastic fragments are persistent in the marine ecosystem and due to their micron sized particle nature, these fragments are mistaken as food and ingested by a range of marine biota which includes corals, phytoplanktons, zooplanktons, sea urchins, lobsters, fish etc. and ultimately get transferred to higher tropic level. The impact of microplastic on marine biota is an issue of concern as it leads to the entanglement and ingestion which can be lethal to marine life.[11] Due to their widespread presence in oceans, microplastics pose a severe threat to marine organisms through ingestion, toxicity, bioaccumulation, behavioral changes, and damage to coral reef ecosystems. This section explores the five major impacts of microplastics on marine life in detail.

1. Ingestion

One of the most prevalent ways microplastics affect marine life is through ingestion. Many marine organisms, including plankton, fish, seabirds, and larger marine mammals, mistake microplastic particles for food due to their small size and resemblance to natural prey. Once

[9] Karbalaei S et al., *Abundance and Characteristics of Microplastics in Commercial Marine Fish from Malaysia*, 148 *Mar. Pollut. Bull.* 5, 15 (2019), https://doi.org/10.1016/j.marpolbul.2019.07.072.
[10] Naji A et al., *Plastic Debris and Microplastics Along the Beaches of the Strait of Hormuz, Persian Gulf*, 114 *Mar. Pollut. Bull.* 1057, 1062 (2017), https://doi.org/10.1016/j.marpolbul.2016.11.032.
[11] Jessica Reichert et al., Responses of Reef Building Corals to Microplastic Exposure, 237 Envtl. Pollution 955 (2018), https://doi.org/10.1016/j.envpol.2017.11.006.

ingested, microplastics can cause a range of harmful effects, from physical injury to malnutrition and even death. At the microscopic level, zooplankton—the base of the marine food web—consume microplastics, reducing their ability to feed on nutritious phytoplankton. This, in turn, disrupts the entire food chain, as fish and other marine species rely on zooplankton as a primary food source. In fish and seabirds, microplastics accumulate in the digestive tract, leading to blockages, internal injuries, and reduced energy intake. Studies have found that species such as anchovies and sea turtles often ingest microplastics floating on the ocean surface, mistaking them for plankton or jellyfish.

Ingested microplastics do not provide any nutritional value, and as they accumulate in an organism's stomach, they create a false sense of fullness, leading to malnutrition and starvation. Additionally, some microplastics have sharp edges that can damage internal tissues, leading to infections and impaired digestion. For larger marine animals, such as whales and seals, the ingestion of large quantities of microplastics can result in severe health complications, including gastrointestinal blockages.

2. Toxicity

Microplastics act as carriers of toxic chemicals that pose significant risks to marine life. These pollutants include **persistent organic pollutants (POPs)**, **heavy metals**, and **endocrine-disrupting chemicals**, which leach into the surrounding environment or enter organisms upon ingestion. Many of these chemicals are linked to immune system suppression, reproductive issues, and developmental abnormalities in marine species.[12]

One of the most concerning aspects of microplastic toxicity is the ability of plastics to absorb and concentrate hazardous substances from seawater. Microplastics often bind with contaminants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and pesticides, making them even more harmful when ingested. Once inside an organism, these toxins can disrupt cellular functions, cause oxidative stress, and lead to tissue damage. Toxic microplastic exposure has also been linked to endocrine disruption in marine species, which affects hormone regulation and reproductive health. In fish, for instance, chemicals leached from microplastics have been found to impair reproductive development, reduce fertility, and cause deformities in offspring. Similarly, shellfish, such as mussels and

[12] "Unravelling the Impact of Microplastics in Our Oceans and Bodies," SkootEco Blog (Nov. 28, 2024), https://skoot.eco/articles/theimpact-of-microplastics-in-our-oceans-and-bodies.

oysters, absorb microplastic toxins through filter-feeding, leading to bioaccumulation that ultimately affects human seafood consumption.

3. Bioaccumulation

Bioaccumulation refers to the gradual build-up of microplastics and their associated toxins in an organism's tissues over time. This process is particularly concerning because it allows toxic substances to persist in marine food webs, ultimately affecting predators at higher trophic levels. Microplastics first enter the marine ecosystem through smaller organisms such as plankton, which consume them unintentionally. As these contaminated plankton are eaten by larger fish, the concentration of microplastics and toxic chemicals increases. This accumulation continues up the food chain, affecting top predators such as sharks, dolphins, and even humans who consume seafood.

A related concept is **biomagnification**, where the concentration of toxins increases as they move up the food chain. For example, microplastics containing PCBs and heavy metals accumulate in small fish, which are then eaten by larger predators. Since top predators consume multiple prey items, they end up with a higher concentration of these harmful substances. This poses serious risks to marine ecosystems and human health, as seafood is a primary source of nutrition for millions of people worldwide. Bioaccumulation not only affects marine biodiversity but also leads to economic consequences for fisheries and aquaculture industries. Contaminated seafood can result in health hazards, leading to strict regulations and reduced consumer demand.[13]

4. Behavioural Changes

Emerging research indicates that microplastic pollution can alter the behavior of marine organisms, affecting their feeding habits, predator-prey interactions, and social behaviors. These changes have the potential to disrupt marine ecosystems by altering natural population dynamics and species survival rates.

In fish and invertebrates, exposure to microplastics has been linked to **reduced foraging efficiency**. Many species mistakenly consume microplastics instead of their natural food

[13] "Unravelling the Impact of Microplastics in Our Oceans and Bodies," SkootEco Blog (Nov. 28, 2024), https://skoot.eco/articles/theimpact-of-microplastics-in-our-oceans-and-bodies.

sources, leading to lower energy intake and impaired growth. Additionally, studies have shown that microplastics can interfere with **olfactory cues**, making it harder for fish to detect predators or locate food.

Some marine organisms exhibit increased stress responses when exposed to microplastics. For example, crustaceans and mollusks exposed to high concentrations of microplastics have been observed to exhibit erratic swimming patterns, reduced reproductive output, and altered shell formation. Behavioral changes in marine larvae and juveniles are particularly concerning, as they can affect survival rates and long-term population stability. Furthermore, microplastics have been shown to impact cognitive functions in fish, affecting their ability to learn and adapt to environmental changes. Disruptions in predator-prey dynamics can lead to cascading effects throughout the ecosystem, potentially altering species compositions and food web structures.

5. Impacts on Coral Reefs

Coral reefs, which support nearly 25% of marine biodiversity, are highly vulnerable to microplastic pollution. Corals rely on filter-feeding to obtain nutrients, and during this process, they often trap microplastic particles that can cause significant harm. One of the primary concerns is coral tissue damage caused by microplastic ingestion. When corals consume microplastics, their digestive systems become clogged, leading to reduced energy intake and lower growth rates. Additionally, the physical presence of microplastics on coral surfaces can smother coral polyps, restricting their ability to photosynthesize and produce energy.

Microplastics also act as carriers for pathogens and harmful bacteria, which can contribute to coral diseases such as white syndrome and black band disease. Studies have shown that corals exposed to microplastics have higher incidences of disease due to the attachment of pathogenic microbes to plastic surfaces. This accelerates coral degradation, leading to widespread coral bleaching and ecosystem collapse.[14] Furthermore, microplastics interfere with coral reproduction by reducing larval settlement rates. Coral larvae, which rely on chemical signals to attach to suitable reef surfaces, can become disoriented by microplastic pollution, leading to lower recruitment rates and impaired reef regeneration. Given the essential role of coral reefs in marine biodiversity and coastal protection, their decline due to microplastic pollution poses

[14] "Unravelling the Impact of Microplastics in Our Oceans and Bodies," SkootEco Blog (Nov. 28, 2024), https://skoot.eco/articles/theimpact-of-microplastics-in-our-oceans-and-bodies.

a significant ecological and economic threat.

3.2 IMPACTS OF MICROPLASTICS ON FISHES AND SEA BIRDS

Impact on fishes: Certain features of microplastics such as microscopic size, attractive colors and their high buoyancy makes these tiny fragments easily available for fish. Fish ingest microplastics by mistaking these fragments as planktons or other natural prey. In a study, the microplastic ingestion was found in the planktivorous fish Acanthochromis polyacanthus where microplastics of the dimensions < 300μm was present in the gut cavity of individual fish[15].

In one of the experiments, ingestion of microplastics by fish showed that exposure of these plastic fragments causes histopathological modifications in the intestine, resulting in the detachment of mucosa epithelial lining from the lamino propia and causing its widening, reduction and puffing of villi, increase in number of globet cells and certain alterations in the normal structure of serosa of fish. The effect of polystyrene on a European fish (Perca fluviatilis) was studied in which eggs and larvae of Perca fluviatilis were exposed to different concentration levels of microplastics found in the Swedish coast, namely 10,000 particles per m^3 and 80,000 particles per m^3.

It was found that eggs which were exposed to high concentration of microplastics had a comparative slower hatching rate when compared to control. Also the larvae exposed to microplastics were smaller and slower in comparison to normal larvae. The responsive ability of microplastics exposed Perca fluviatilis larvae to the chemical alarm (existence of predator) was found to be very low and thus it has a deleterious effect on the survival rate of fish. Other study also showed that microplastic ingestion in fishes cause metabolic alterations which include up-regulation and down-regulation of fatty acids and amino acids respectively. The ingestion of micro and nano plastics causes alteration in the ratio of triglycerides and cholesterol in the blood serum level of fish and also causes variation in the delivery of cholesterol between muscle and liver of fish.[16]

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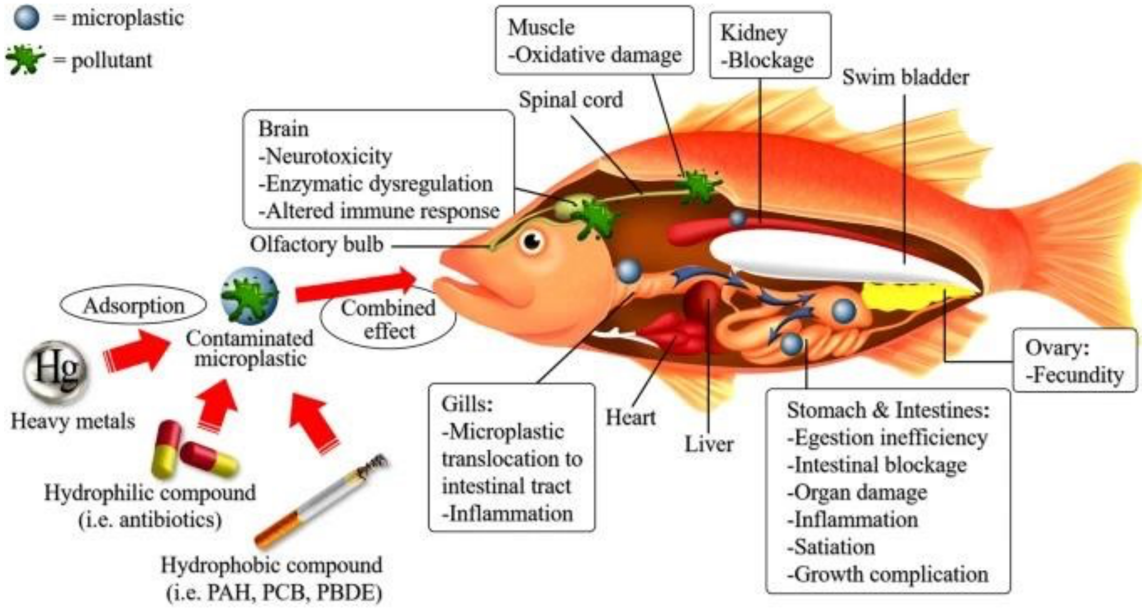
[15] Kay Critchell & Mia O. Hoogenboom, Effects of Microplastic Exposure on the Body Condition and Behaviour of Planktivorous Reef Fish (Acanthochromis polyacanthus), *PLoS One*, e0193308 (2018), https://doi.org/10.1371/journal.pone.0193308.

[16] Tommy Cedervall et al., Food Chain Transport of Nanoparticles Affects Behaviour and Fat Metabolism in Fish, *PLoS One*, e0032254 (2012), https://doi.org/10.1371/journal.pone.0032254.



Impact on Sea-Birds: The harmful effects of microplastic ingestion is an issue of concern specially in case of sea birds as half of the species are endangered and the toxic effect of plastic fragments has negative effects on their body which could cause alteration in the feeding behavior, reproduction and mortality. It was found that six species of sea birds, Phalacrocorax bougainvillii, Pelecanoides garnotii, Pelecanoides urinatrix, Pelecanus thagus, Spheniscus humboldti and Larus dominicanus have the plastic fragments in their stomach region and maximum ingestion capacity was detected in case of Larus dominicanus which commonly feds upon fishing nets, waste disposal products and plastic containers.[17]

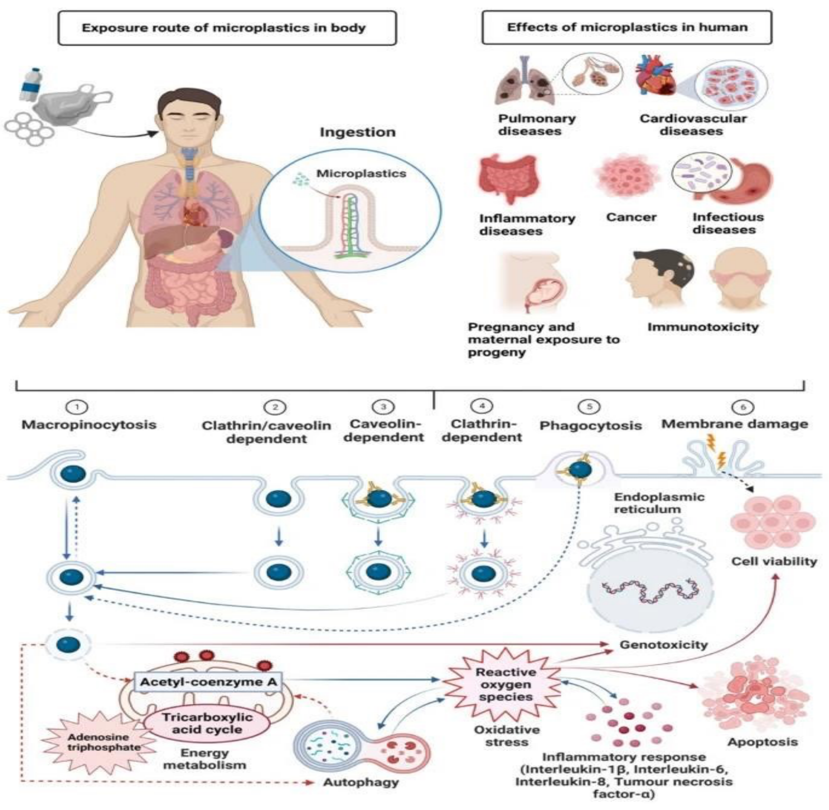
The ingestion of plastic debris by these species mainly depends on certain factors such as size, weight and habitat of the sea birds; e.g. the species of sea birds Spheniscus penguins and Thalassarche albatross have small body size and thus ingestion rates were lower in comparison to large sea birds. The species such as Fulmarus fulmars, Cyclorhynchus auklets, Oceanodroma, Pachyptila prions and Pelagodroma have higher ingestion rate of plastic debris due to their large body size and weight. The large creatures of marine biota which includes sharks, whales, seals, sea turtles and polar bears are also vulnerable to microplastics ingestion in the oceans throughout the world; e.g. the presence of microplastics was detected in the stomach and intestine of harbor seal, Phoca vitulina. This class of marine mammals is filter feeders and thus ingests substantial amounts of microplastics either directly swallowing from

[17] Chris Wilcox, Erik Van Sebille & Britta Denise Hardesty, Threat of Plastic Pollution to Seabirds Is Global, Pervasive, and Increasing, *Proc. Nat'l Acad. Sci. U.S.A.*, 112, 11899 (2015), https://doi.org/10.1073/pnas.1502108112.

ocean water or indirectly by consuming prey containing microplastics in their body cavity. The presence of the microplastics in the stomach of sharks of Sea of Cortez and whales of Mediterranean Sea proved that most of the littered plastic waste worldwide ultimately ends up at sea and imposed a great threat to marine animals. In a study done on Mediterranean fin whale (Balaenoptera physalus), high concentrations of phthalates were detected in these baleen whales, which indicates the severity of microplastic pollution in the world's oceans.[18]

3.3 IMPACTS OF MICROPLASTICS ON HUMAN HEALTH

Microplastics pose a growing threat to human health, as they infiltrate our bodies through various pathways. Scientific research is beginning to uncover the potential risks these tiny plastic particles present, and the findings are cause for concern.



1. Ingestion through Food and Water

Consumption of microplastics occurs predominantly through dietary sources. Seafood, particularly filter-feeding organisms like mussels and oysters, has been identified as a

[18] U.N. Environment, Ocean Experts Call for Greater Local Government Role in Fight Against Marine Waste (2014), https://europa.eu/capacity4dev/unep/blog/ocean-experts-call-greater-local-government-role-fight-against-marine-waste

significant contributor to microplastic ingestion. A study highlighted that 99% of tested seafood samples contained microplastic contamination, with fibers from clothing and textiles comprising over 80% of the detected particles[19]. This contamination poses health risks, as these pollutants have been associated with various health issues, including cancer and hormone disruption. Beyond seafood, microplastics have been detected in other food items and beverages. For instance, studies have found microplastics in tap water, bottled water, beer, and even salt. One study estimated that the average adult consumes approximately 2,000 microplastic particles per year through salt alone. The ingestion of these particles raises concerns about potential health implications, as they may carry harmful chemicals or pathogens into the human body.

2. Inhalation of Airborne Particles

Airborne microplastics represent another significant exposure route. These particles can become airborne through the degradation of larger plastic debris, abrasion of synthetic textiles, and industrial processes. Once suspended in the air, microplastics can be inhaled and potentially reach the respiratory system. Research has indicated that inhaled microplastics can lead to respiratory issues, including inflammation and oxidative stress. The small size of these particles allows them to penetrate deep into the lung tissue, potentially causing adverse health effects. Indoor environments may also contribute to microplastic inhalation, especially in areas with high concentrations of synthetic fibers from carpets, upholstery, and clothing. Activities such as vacuuming or dusting can resuspend these particles into the air, increasing the likelihood of inhalation. While the full extent of health impacts from inhaled microplastics is still under investigation, the potential for respiratory harm underscores the need for further research and preventive measures.[20]

3. Chemical Contaminants and Toxicity

Microplastics can act as vectors for chemical contaminants, including additives used during plastic production and pollutants adsorbed from the environment. These chemicals may leach from microplastics upon ingestion or inhalation, leading to potential toxic effects. For example, certain additives in plastics, such as phthalates and bisphenol A (BPA), are known endocrine

[19] "Study finds microplastic contamination in 99% of seafood samples," The Guardian (Feb. 3, 2025), https://www.theguardian.com/usnews/2025/feb/03/seafood-microplastic-contamination-study.
[20] World Health Organization, Microplastics in Drinking Water: Human Health Risk Assessment, WHO Publ'n (2024), https://www.who.int/publications/i/item/9789240054608.

disruptors, which can interfere with hormone function and have been linked to reproductive and developmental issues.[21] Additionally, microplastics can adsorb environmental pollutants like heavy metals and persistent organic pollutants (POPs) onto their surfaces. When these contaminated particles enter the human body, they may release these harmful substances, contributing to toxicity. Studies have suggested that exposure to such contaminants through microplastics could lead to oxidative stress, inflammation, and even genotoxic effects, potentially increasing the risk of chronic diseases.[22]

CHAPTER-4 MITIGATION STRATEGIES

4.1 LEGISLATIVE SOLUTIONS TO MICROPLASTIC POLLUTION

Addressing the issue of microplastic pollution requires robust legislative solutions. Governments, organisations, and individuals must collaborate to reduce plastic waste, enhance recycling efforts, and prevent microplastics from entering the environment. Several potential legislative measures can help achieve these goals

Extended Producer Responsibility (EPR) is a critical legislative tool designed to hold manufacturers accountable for the entire lifecycle of their products, particularly regarding postconsumer waste. EPR shifts the responsibility of disposal, recycling, and waste management from the public sector to producers, incentivizing companies to reduce the environmental impact of their products. Under EPR systems, producers are required to take responsibility for their products' disposal, which encourages them to design products that are easier to recycle or that have less environmental impact overall. For microplastic pollution, EPR encourages manufacturers to reconsider the materials they use in their products. For instance, producers of plastic packaging are incentivized to create packaging that can be more efficiently recycled or replaced with biodegradable alternatives, preventing plastic waste from breaking down into microplastics in the environment. EPR also promotes better waste management systems by ensuring that producers, rather than local governments or taxpayers, bear the cost of recycling or disposal. In countries like Sweden and France, EPR schemes for plastic packaging have been implemented, with notable success in increasing recycling rates

[21] M. Prata, Airborne Microplastics: Consequences to Human Health?, 234 Envtl. Pollution 11519 (2020), https://pmc.ncbi.nlm.nih.gov/articles/PMC7068600.
[22] J. Smith et al., Microplastics and Human Health: Assessing Toxicity and Exposure Risks, 58 Envtl. Sci. & Tech. 12345 (2023), https://pubs.acs.org/doi/10.1021/envhealth.3c00053.

and reducing plastic waste.

Deposit-Refund Systems (DRS) are another significant legislative measure that incentivizes the recycling of plastic products by requiring consumers to pay a deposit when purchasing certain items, such as plastic bottles and containers. This deposit is refunded when the empty bottle or container is returned to a collection point. The goal of DRS is to reduce littering and increase recycling rates by providing a financial incentive for consumers to return empty containers for proper disposal or reuse. For microplastic pollution, DRS can be highly effective in preventing plastic waste, particularly plastic bottles, from entering the environment and breaking down into microplastics. By encouraging the return of bottles and containers, DRS directly prevents littering, which is a major contributor to plastic pollution in oceans. In countries like Norway, the DRS has proven successful, with high return rates of beverage containers. Germany has also implemented an effective deposit-refund system, resulting in reduced plastic waste and promoting the reuse of bottles. The success of DRS systems in reducing plastic littering and increasing recycling rates shows promise for tackling microplastic pollution, especially in marine environments.[23]

Bans on Single-Use Plastics have become one of the most widely discussed and implemented legislative responses to plastic pollution. Single-use plastics, such as straws, bags, and utensils, are typically used once and then discarded, contributing significantly to plastic waste and, over time, breaking down into microplastics. By banning or restricting the use of these products, governments aim to reduce the amount of plastic waste that ends up in landfills and oceans. These bans target plastic items that are often non-recyclable and easily contribute to litter. When plastic items such as straws and bags are banned, it not only reduces the overall amount of plastic waste in the environment but also prevents these plastics from fragmenting into microplastics that can accumulate in marine ecosystems. For example, the European Union implemented a ban on several single-use plastic items in 2021, including plastic cutlery, plates, and straws, with the objective of curbing plastic pollution in oceans and waterways. Similarly, countries like Kenya and Rwanda have imposed stringent bans on plastic bags, which has resulted in significant reductions in plastic waste and microplastic pollution. Banning singleuse plastics can also encourage the adoption of more sustainable alternatives, such as reusable bags and biodegradable products, further reducing the environmental footprint of consumer

[23] "Unravelling the Impact of Microplastics in Our Oceans and Bodies," SkootEco Blog (Nov. 28, 2024), https://skoot.eco/articles/theimpact-of-microplastics-in-our-oceans-and-bodies.

products.

Funding for Research and Development (R&D) plays a crucial role in understanding the extent of microplastic pollution and developing effective technologies and solutions to address it. Legislative bodies and governments must prioritize research into the sources, impacts, and mitigation strategies for microplastics. Research funding supports the development of new technologies for detecting, removing, and recycling microplastics in the environment. For instance, various filtration systems are being developed to remove microplastics from wastewater before it reaches marine environments, which would help prevent the further spread of microplastic pollution. Additionally, R&D investments are critical for exploring biodegradable plastic alternatives that could replace conventional plastics, thus reducing the potential for microplastics to form in the first place. Research also aids in understanding the environmental impacts of microplastics on marine ecosystems, human health, and biodiversity. Through funding for R&D, governments can facilitate the development of comprehensive solutions to combat microplastic pollution. The European Union's Horizon 2020 research program, for example, has funded numerous projects focused on understanding the sources and impacts of microplastics in marine environments. Similarly, the U.S. National Oceanic and Atmospheric Administration (NOAA) funds research into marine debris, including microplastics, to develop more effective policies and technologies for pollution reduction.

Regulations on Microplastics are essential in addressing the specific issue of microplastic contamination at its source. These regulations target the intentional use of microplastics in products such as cosmetics, cleaning agents, and paints, which are directly released into the environment. For example, many personal care products such as exfoliating scrubs, toothpaste, and facial cleansers contain microbeads, which are small plastic particles that can easily wash down the drain and enter the marine environment. To address this, governments have introduced regulations that limit or ban the use of microplastics in consumer products. The U.S. Microbead-Free Waters Act, for example, banned the use of microbeads in personal care products in 2015, significantly reducing the amount of plastic waste entering marine ecosystems. Similarly, the European Chemicals Agency (ECHA) has recommended restrictions on the use of microplastics in products such as cosmetics and detergents. Regulations also cover the discharge of microplastics from industrial processes, requiring companies to adopt safer alternatives or implement better filtration systems to prevent the release of microplastics into waterways. In addition to reducing plastic waste, these regulations also help to raise awareness among consumers about the environmental harm caused by microplastics and encourage more responsible consumption.[24]

4.2 EXISTING MITIGATION STRATEGIES AND SOLUTIONS

Understanding the impacts of microplastics on ecosystems and human health, it is crucial to develop effective mitigation strategies. Inadequate waste management infrastructure is projected to exacerbate marine plastic pollution by 2025, leading to increased volumes of plastic waste entering oceans. Without improved collection, recycling, and disposal systems, higher plastic leakage from urban areas is likely, particularly in developing regions. This could result in greater harm to marine ecosystems, biodiversity loss, and negative impacts on human health through the food chain. Moreover, failing to address these challenges may hinder efforts to achieve sustainability and circular economy goals. Key criteria for assessing the effectiveness of technologies for reducing microplastics and macroplastics include removal efficiency, particle size range effectiveness and operational feasibility. Removal efficiency, often measured as a percentage of particles captured, is critical for evaluating technology performance. Additionally, the ability to target a wide range of particle sizes, including nanoscale microplastics, is essential. Also, operational feasibility including cost, scalability, and energy consumption, plays a significant role in determining the practical applicability of these technologies.[25] Traditional waste management approaches often fall short in addressing microplastic pollution due to the difficulty in capturing these tiny particles and the variety of their sources. In response, a range of innovative technologies and methods have emerged to capture and eliminate microplastics from the environment, including filtration systems and biodegradation techniques. However, implementing these strategies present challenges such as cost-effectiveness, scalability, and the risk of unintended harm to non-target organisms.

Additionally, removing microplastics from marine and terrestrial environments is complicated by their widespread distribution and the inaccessibility of some areas. Instead of solely focusing on removal, researchers are increasingly investigating ways to repurpose microplastics, which could mitigate their environmental impact while addressing waste management challenges. This innovative approach spans various fields, including materials science, engineering and art.

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[24] "Unravelling the Impact of Microplastics in Our Oceans and Bodies," SkootEco Blog (Nov. 28, 2024), https://skoot.eco/articles/theimpact-of-microplastics-in-our-oceans-and-bodies.
[25] Bhat M. A. (2024). "Indoor Microplastics and Microfibers Sources and Impacts on Human Health," in Microfibre Pollution from Textiles Research Advances and Mitigation Strategies, 1st Edition. Eds. Rathinamoorthy R., Balasaraswathi S. R. (CRC Press), 285–307. doi: 10.1201/9781003331995-16

A recent study has developed a new type of polyethylene made from renewable oils. This innovative material enhances recyclability, allowing for the recovery of most of the original polymers and creating a closed-loop system. This advancement represents a significant step toward achieving the long-sought goal of sustainable plastics. The growing interest in sustainable plastics has enhanced the search of petroleum-based biodegradable plastics, which on the contrary, has led to consumer confusion, as many mistakenly refer these products as bioplastics, resulting in widespread uncertainty about proper waste disposal.[26]

Several current and future approaches to mitigate plastic and microplastic pollutions include extended producer responsibility programs, initiatives aimed at reducing single-use plastic consumption, and the Plastics Treaty, which will address the entire plastics life cycle.[27] This treaty aims to curb production, promote a circular economy, establish environmental reporting standards, raise consumer awareness, and enhance performance measures has recommended ten crucial ways for reducing plastic pollution such as regulating production and consumption, implementing eco-design principles, boosting demand for recycled plastics, minimizing plastic usage, utilizing renewable energy in recycling processes, establishing extended producer responsibility for waste management, enhancing waste collection systems, prioritizing recycling initiatives, promoting the use of bio-based and biodegradable plastics and improving the recyclability of electronic waste.

In addition to conventional treatment methods, advanced techniques such as membrane bioreactors, rapid sand filtration, electrocoagulation, and photocatalytic degradation have also been explored for the removal of microplastics, which has been proven effective, achieving removal efficiencies exceeding 99%. Bioremediation strategies have shown that species like seagrasses, lugworms, and blue mussels can act as natural traps for microplastic pollutants, making them potential candidates for integration into wastewater treatment plants. Furthermore, it is crucial to implement effective laws and regulations to control the use and unregulated release of microplastics into the environment. Innovative technologies for capturing and eliminating microplastics include advanced filtration systems, such as membrane filtration, which effectively remove microplastics from wastewater. Magnetic nanoparticles are being explored for their ability to bind to microplastics, enabling easy removal with magnets.

[26] Charlebois S., Walker T. R., Music J. (2022). Comment on the food industry's pandemic packaging dilemma. Front. Sustain. 3, 812608.
[27] Diggle A., Walker T. R. (2020). Implementation of harmonized Extended Producer Responsibility strategies to incentivize recovery of single-use plastic packaging waste in Canada. Waste Manage. 110, 20–23.

Emerging strategies to address microplastics include micro- and nanomotors such as tiny, selfpropelled devices powered by chemical fuels or light.[28] These motors are designed to autonomously recognize, capture, and break down pollutants. Previously, various micromotors were developed to efficiently remove and degrade soluble organic contaminants. Current research focuses on the rational design and surface functionalization of these devices to enable them to capture, transport, and release microplastics of diverse shapes and chemical compositions. Catalytic micromotors utilizing photocatalysis and photo-Fenton chemistry show particular promise for degrading common plastic materials. These technologies represent significant advancements in addressing microplastic pollution.[29]

CHAPTER-5 RECOMMENDATIONS AND CONCLUSION

5.1 RECOMMENDATIONS:

Addressing the issue of microplastic pollution in the ocean requires a multi-faceted approach that includes policy reforms, technological advancements, public awareness, and international cooperation. First, stronger regulatory frameworks must be implemented to control the production and disposal of plastic materials. Governments should enforce stricter regulations on plastic manufacturing industries, limit the production of single-use plastics, and mandate the use of biodegradable alternatives. Additionally, industries should be encouraged to adopt sustainable production practices, such as reducing plastic packaging and incorporating eco-friendly materials. Policies like the banning of plastic microbeads in personal care products should be expanded globally, ensuring that such harmful materials do not enter marine ecosystems.

Technological interventions also play a crucial role in mitigating microplastic pollution. Advancements in wastewater treatment facilities should be prioritized to improve filtration systems capable of capturing microplastics before they enter rivers and oceans. Researchers should continue to explore innovative solutions, such as nanotechnology-based filtration systems and biodegradable plastic substitutes, to minimize the long-term impact of plastic

[28] Hermanová S., Pumera M. (2022). Micromachines for microplastics treatment. ACS Nanosci. Au 2, 225–232. doi: 10.1021/acsnanoscienceau.1c00058

[29] Krishnan R. Y., Manikandan S., Subbaiya R., Karmegam N., Kim W., Govarthanan M. (2023). Recent approaches and advanced wastewater treatment technologies for mitigating emerging microplastics contamination – A critical review. Sci. Total Environment 858, 159681. doi: 10.1016/j.scitotenv.2022.159681

waste. Moreover, industries should invest in the development of closed-loop recycling systems that effectively recover and reuse plastics, reducing their entry into marine environments.

Public awareness and participation are equally important in tackling microplastic pollution. Educational campaigns should be launched to inform the public about the dangers of microplastics and promote eco-friendly consumption habits. Encouraging people to reduce plastic usage, switch to reusable alternatives, and properly dispose of plastic waste can significantly contribute to reducing marine pollution. Schools, universities, and social organizations should integrate environmental literacy programs to instill responsible waste management practices from an early age. Additionally, supporting citizen science initiatives, such as beach cleanups and microplastic monitoring programs, can enhance community involvement in environmental conservation efforts.

International cooperation is essential, as microplastic pollution is a transboundary issue that affects global marine ecosystems. Governments, research institutions, and environmental organizations should collaborate on global treaties and policies aimed at reducing plastic waste production and improving waste management infrastructure. Agreements such as the United Nations Environment Programme (UNEP) plastic pollution initiatives should be expanded to include stringent international policies that hold plastic producers accountable for environmental damage. Moreover, funding for scientific research on microplastic pollution should be increased to improve our understanding of its long-term ecological and health effects and to develop effective mitigation strategies.

Finally, corporate responsibility and industry accountability must be reinforced through extended producer responsibility (EPR) policies that require companies to manage the end-of-life disposal of their plastic products. Industries should be incentivized to develop sustainable packaging solutions, use eco-friendly materials, and adopt circular economy models that minimize plastic waste generation. Additionally, stricter penalties and incentives should be introduced to encourage industries to comply with environmental standards.

5.2 CONCLUSION:

The problem of plastic pollution in the marine ecosystem is an issue of concern nowadays because of its deleterious effects on marine biota. Due to the size of microplastics, their bioaccumulation potential is very high. They are ingested by an array of marine habitants like corals, planktons, fish, seabirds and marine mammals and are transferred along the food chain. Also plastic polymers have different chemical additives and stabilizers due to which it absorbs various toxic contaminants and pollutants from the surrounding environment. Thus these harmful contaminants adhere to the microplastics which act as a vector. The problem of microplastics has been ignored for a long time and this threat has been recognized only recently. At present, drinking water, table salt and other daily used food items are contaminated with microplastics. There are various social active platforms such as *Plastic Pollution Coalitions, Plastics for change, Plastic Oceans, Surfers Against Sewage, Greenpeace, By the Ocean We Unite, One More Generation, One Green Planet, Surf Rider Foundation, Earth Guardians* who are working on the issue of microplastic pollution and contributing substantially. The adverse effects of microplastics pollution in the marine environment spans from molecular level of organism to its physiological actions and include poor health of organisms and poor economic services. Thus immediate actions are urgently required against the unnecessary use of plastics and its products. Strict measures must be enforced at national and international levels against the use of plastics. New scientific studies are required to elucidate various factors which influence the presence of microplastics in marine ecosystem and its biological impacts on marine biota. New research methodologies must be developed for conservation management and supporting different educational programmes for the protection of ecosystem against these harmful polymers. The very urgent call in this field is to spread awareness among the general public regarding the nocuous effects of microplastics. This would stimulate various innovations to reduce the utilization and consumption of plastic and its products. To minimize the plastic input into the ecosystem the most important approach is to collect and reuse of plastic fragments. To avoid future threat, the best solution is to stop producing it further and find out the alternative of plastic products.

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16) European Union (2023). Marine plastic: new method for choosing the best clean-up technologies. Available online at: https://environment.ec.europa.eu/news/marine-plastic-new-method-choosing-best-clean-technologies-2023-11-08_en