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CHAPTER 4

The Impact of Microplastics in Food Chain

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Abstract

In recent years, environmental pollution has become an increasingly pressing concern. Plastic pollution has played a significant role in disrupting the ecological system. The ecological system forms the food chain and food web, which includes every living organism. Any reflection in the food chain can have an impact on every living creature on Earth. At this point in time, plastics are quite widespread, and it is very simple to transport the goods from one location to another. Humans use a variety of plastic-based goods on a daily basis, including infant feeding bottles, water cans, food containers, cosmetics, and cars. Biodegradation techniques recycle and biodegrade numerous plastic materials in an appropriate manner. On the other hand, the build-up of microplastics (MP) in the environment is becoming a growing problem. The accumulation of microplastics in soil and aquatic ecosystems influences the primary consumer in the food chain and contributes to its recycling. As a result, MP pollution impacts every single ecological

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system, including people, plants, and animals. In this chapter, our primary attention is on the influence that MP has on the natural environment, namely the soil and the water.

Keywords: Ecological system, Food chain, Environmental pollution, Plastic pollution, Microplastics

Introduction

Environmental pollution refers to the presence of an agent in the environment that can potentially harm the environment or human health. Factors such as an increasing human population, a more prosperous economy, and new technologies all contribute to environmental degradation. Increased human population, poverty, and lack of development can lead to pollution of the natural world. Fast economic expansion leads to an increase in both natural resource demand and supply. Planned obsolescence is a result of technological progress that causes waste and environmental damage.

Major environmental pollution risk factors, such as pollutants, pesticides, and industrial waste, contain chemicals that have a significant impact on the food chain. The potential adverse effects of environmental contaminants classified as endocrine disrupters or hormone-active agents have been a growing concern in recent years. Emerging contaminants (ECs) are chemicals that are widely present in the environment due to common human activities, including farming, manufacturing, and household chores. These compounds have recently faced increased scrutiny as a result of the development of more sensitive testing technologies, which have revealed their prevalence in the air, soil, and water. The ECs assign a classification to about three thousand distinct compounds and byproducts. Fertilisers, pesticides, heavy metals, MP, polycyclic aromatic compounds (PHAs), polyphosphates, and hormones (both synthetic and natural) are all part of this category (Naeem et al., 2023).

Plastics are artificial synthetic compounds utilized in a variety of products. A network of molecular monomers bonds together to form polymers of plastics, which have countless applications in human society. It has a lower economic cost and is easy to handle when compared with metal and glassware. Plastics are lightweight, biocompatible, cheap, and energy-efficient. These materials are suitable for single-use disposable healthcare products, including soft, translucent, flexible, or biodegradable synthetic tissues, absorbable sutures, and prostheses, which make up 85% of surgical instruments. Plastic pollution is a global issue that affects both people and the environment, significantly impacting areas such as biodiversity, climate change, and human health. Plastics expose humans through everyday products, plastic-based medical supplies, the food chain, and airborne plastic pollution. In plastic pollution, MP materials play a crucial and significant role in disrupting the environmental system (Rizan et al., 2020).

1. Microplastics (MPs)

MP, a prevalent pollutant, pose considerable health concerns to humans through oral consumption, inhalation, and skin contact. These three modes of exposure are all possible. Damage to DNA, oxidative stress, organ failure, metabolic diseases, immunological reactions, neurotoxicity, toxicity to reproduction and development, and chronic illnesses are all possible outcomes. According to epidemiological research, these exposures have the potential to cause a range of chronic diseases. In order to better comprehend the exposure risk and possible health effects of MP (Li et al., 2023).

Physical and chemical characteristics of MPs

1. Size

Plastics are categorized into macroplastics (25 mm are macroplastics), mesoplastics (between 5 mm to 25 mm), MP (less than 5 mm), and nanoplastics (1 to 1000 nm) based on final degradation plastic materials size. The international standard (SI) classifies MP as having a size between 1 and 5 µm, and they range in size from 100 to 5.5 mm. Since air MP tend to be smaller than their aquatic counterparts, size plays a vital role in their analysis. MPs in the atmosphere are usually a lot smaller than MPs in water. The number of MP in the atmosphere is inversely related to their concentration.

2. Shape

Particles of MPs can vary in size and shape according to variables such as plastic durability, decomposition mechanisms, and starting shape. The textile, carpet, sofa, and chair production industries frequently encounter chip-shaped MPs due to tension, wear, and UV radiation. MP texture, characterized by cracks, shells, grooves, and dimples, indicates physical degradation and chemical erosion. There are physical and chemical variables that make it difficult to differentiate between chip-shaped MPs and fibrous MPs, which can range in width and thickness from 1-500 µm. The ability of film-shaped MPs to absorb and transmit contaminants is higher than that of other shapes. Some MPs have the potential to physically harm creatures and can travel from land to sea.

3. Colour

Multicoloured MPs are able to identify pollution in the environment through chemical and spectroscopic research. White low-density polyethylene (LDPE), propylene, and polyethylene microparticles typically connect with crystal microparticles. Polar ice with darker MPs increases the likelihood of climate change. The presence of blue MPs in fish intestines demonstrates their high absorption capacity.

4. Composition

The chemical make-up is the most important factor in identifying plastic contamination. Many different types of polymers, both commonplace in everyday life and in manufacturing, come together to form MP. The structure of these polymers determines their physical and chemical properties, which impact their decomposition. There are two main types of polymers: thermoplastics and thermosets. For the former, production and demand for Polypropylene (PP), LDPE, High-density polyethylene (HDPE), Polyvinyl chloride (PVC), Polyurethane (PUR), Polyethylene terephthalate (PET), and Polystyrene (PS) are at an all-time high. In saltwater, polyethylene (PE) is present in higher concentrations than polypropylene (PP) or PS. Polymer compounds in the air vary by city or region. Based on the region and distance explored, additional research is required to identify the main polymers and their composition.

5. Sources

Cosmetics, personal care items, and drilling fluids for the oil and gas industries are just a few of the many products that include minute particles known as MP. Plastic particles and other primary MPs are used in both domestic and commercial environments. Secondary MPs such as acrylic, polyester, and melamine cleansers are used in machines and engines to remove rust and paint. Microfibers are also used as medication carriers in medicine. Unfortunately, the current methods of discarding and processing industrial and domestic trash cannot adequately remove these MPs. Natural processes like heat, waves, wind, and UV radiation break down macroplastics into smaller pieces, creating new particles known as secondary MP. Exposure to UV radiation and physical erosion by waves, oxygen, and turbulence can physically break polymer bonds through optical breakdown. Another factor that contributes to MPs is the regular presence of plastic debris, such as road markings and worn tires. The plastics manufacturing and waste management sectors release MP that are harmful to people and the planet. Other sources of MP pollution include sludge from commercial and residential sewage systems, as well as ineffective waste management (Saeedi et al., 2024).

Food chain and Food web

In ecology, Photosynthetic creatures, including plants and phytoplankton, get their energy from the sun and inorganic nutrients. The food chains are the flow of mass and energy from one living thing to another, with plants being the main source of food. They are at the base of the food chain. Bands of predators, parasites, and plants that consume other plants form a food web that connects them all. The food chain shows the interdependence of all living things is by showing how they feed on one another. Herbivores and other primary consumers tend to be small and numerous, whereas carnivores and other secondary consumers tend to be larger and less frequent. A food chain's trophic level is the series of steps from producers at the base to primary, secondary, and tertiary consumers. Each tier of an ecological food web is known as a trophic level. Like a pyramid, the energy transfer between trophic levels is broader at the base and narrower at the summit. Since there are fewer consumers than producers due to this inefficiency, there is an abundance of food for herbivores, but just enough for a small number of top-level consumers.

A food web, a larger form of interconnected food chains, demonstrates energy flow through interactions between organisms, unlike a food chain, which may not accurately represent energy flow due to interconnected trophic levels. Grazing and detrital food chains are the two categories that make up the food chain. In a grazing chain, energy and nutrients are transferred from plants to herbivores and predators. Bacteria and fungi are responsible for the breakdown of dead organic matter in a detrital chain, which then passes on to carnivores and detritivores. Food-chain length, the number of feeding linkages from a basal species to a top predator, regulates many ecological processes, including trophic cascades and toxin biomagnification. Ecosystem management and biodiversity conservation hinge on our ability to comprehend the factors that influence food-chain length, since this length plays a pivotal role in both processes. Environmental pollution causes problems for ecosystems, such as contaminated air, water, and soil. Also, pollution alters ecosystems and food chains. To lower pollution levels in order to re-establish the food chain, as well as the complexities of pollution's effects, strategies for a healthy ecosystem must prioritise wastewater treatment, industry pollution prevention, and pollution removal from both homes and businesses (Steffan et al., 2019).

Fig. 1. MP affect the pyramid level food chain

MPs contamination in environment

MP fragments negatively impact a wide range of ecological domains, making them a major environmental concern. Less than 20% come from water, while over 80% come from land. Marine animals, birds, fish, and reptiles are all victims of MP, which kill or injure them. Environmental concerns are critical for land, water, and public health. Plasticization produces MP, which are harmful to terrestrial ecosystems. Studies increasingly concentrate on terrestrial ecosystems, where the interaction of MP with biota leads to geochemical reactions and toxicity. MPs change soil characteristics like structure, performance, and microbial diversity; they drastically lower air, water, and soil quality. The additional organic carbon they produce affects the carbon cycle, soil microbes, plant development, and garbage breakdown. PE micropollutants correlate with soil organic matter levels and have a significant negative effect on soil total phosphorus, nitrogen, and potassium. Larger particles, such as HDPE and Polylactic acid (PLA), affect water stability, which in turn affects soil quality. MP and similar substances enhance the transport of water, which speeds up the drying process. However, polyester particles can reduce bulk density and increase soil water capacity. Exposing HDPE particles to light and heat can decrease the pH and acidity of the soil. This chapter further explores the pressures associated with global change for MP (Ziani et al., 2023).

1. MP contamination in soil ecosystem

All around the world, especially in agricultural soils, researchers have found MP like biodegradable PLA, HDPE, and MP textile fibres in the dirt. Aquatic runoff, sewage sludge, littering, and air deposition are some of the ways they end up in the soil. Factors such as soil biota and properties control the movement of MP inside the soil. Poor lighting and oxygen conditions have an impact on soil fauna and fitness. Plants can absorb some MP, which they then pass on to subsequent stages of the food web. Lumbricus terrestris seeds, soil microbes like earthworms, and microarthropods and worms are all susceptible to their effects on germination, development, and death. Maximum concentrations of MP have a major effect on terrestrial ecosystems (Sajjad et al., 2022).

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Environmental conditions influence landfill waste, fragmenting plastics into MP. Diffusion, hydrolysis, and decomposition processes can release hazardous organic substances like bisphenol A (BPA) from landfill leachate. Van Praagh et al. (2018) monitored 11 landfills in Finland, Ireland, and Norway to collect data on MP in leachate. Researchers are focusing on potential MP emission sources and determining how different treatment strategies affect removal efficiency. Kilponen (2016) found harmful substances in all collected samples, including polycyclic aromatic hydrocarbons, Polychlorinated biphenyls (PCBs), and phthalates. The presence of developing organic compounds, such as caffeine, N,N-diethyl-meta-toluamide (DEET), carbamazepine, and ibuprofen, in landfill leachate poses a threat to groundwater quality.

2. MP contamination in aquatic ecosystem

MP contaminants in aquatic habitats can be degraded or broken down, releasing new contaminants such as additives, plasticisers, and co-polymers. These chemicals, known as endocrine disruptors, have a devastating effect on water quality when they combine with other contaminants. BPA, a plasticiser found in many common household and commercial items, is mass-produced all across the globe. The release of BPA into water bodies is caused by landfill leaks or wastewater discharge. Due to insufficient source separation and plastic waste disposal policies, landfills comprise Serbia's and Bosnia and Herzegovina's waste management systems, with more than 90% of the garbage ultimately ending up in these locations (Li et al., 2023).

The Galapagos Islands, Cocos Island, and Coiba National Park in Panama are among the most famous marine reserves in the world, but recent studies have shown that they are also home to MP pollution in the eastern tropical Pacific Ocean. A recent study by the International Atomic Energy Agency (IAEA) found that MP, which are plastic particles less than 5 mm in length, can enter the food chain when digested by marine creatures. Without intervention, the expected increases in MP in the area are 3.9 times by 2030, 6.4 times by 2050, and more than 10 times by 2100 (khan et al., 2022).

MP pose a significant threat to aquatic and terrestrial ecosystems. A study on aquatic herbivorous larvae of the moth Cataclysta lemnata found that larvae fed contaminated Lemna minuta fronds ingested the contaminant, leading to high mortality and an inability to complete the life cycle after 21 days. The study also found that MP transfer from producers to primary consumers along a freshwater food chain, negatively impacting the larvae's life cycle. The findings highlight the transfer of MP from producers to primary consumers (Mariani et al., 2023).

Bioaccumulation of MP in plants

The extensive usage of MP and nanoplastics (NPs) in agriculture has made them a major environmental problem. Plants physiologically respond to them, as they can absorb them from the soil. Farming methods, shifting weather patterns, and soil organisms all have an impact on their movement. When compared to MPs, NPs have a much higher likelihood of penetrating plant cell walls. Depending on the level of exposure and how they interact with other pollutants, the harmful effects of MPs and NPs in territorial habitats can vary. These substances can alter the properties of agroecosystems and plastic surfaces. Assessments of the effects on agroecosystems must prioritize research into the interconnections between contaminants. Common compounds used to modify plastic quality, such as phthalates, polybrominated diphenyl ethers (PBDE), and BPA, are still degrading (Seo et al., 2024).

Modern farming practices have significantly increased the problem of plastic contamination in agroecosystems. MPs and nanoparticles (NPs) affect soil biota, especially plants. Recent research has shown that NPs have an effect on plant development and biomass output; some studies have even looked at the potential toxicity of NPs to lettuce and maize plants. Because of their enormous size, MPs are unable to penetrate plant tissues directly; in contrast, nanoparticles overcome cell barriers with ease. Cells outside the root cap mucilage caught 0.2-micrometre PS microbeads, whereas tobacco plants absorbed 20- to 40-nanometre beads. Root cap mucilage particles help wheat and lettuce roots sense cell walls and allow them to diffuse into apical meristem tissue. Because casparian is still immature, PS beads can only reach the apical meristem via the epidermis. They seem restricted to vascular tissues in lettuce plants. PS beads were able to reach the cortical layer via epidermal cell gaps, but they were unable to enter the endoepidermis. Major sites into the root xylem of wheat and lettuce were small PS bead crack entrances (Azeem et al., 2021).

Bioaccumulation of MP in animals

MP are emerging environmental pollutants in aquatic environments, threatening aquatic life and health. They are biologically transferable and can accumulate in organisms at high trophic levels. MPs enter organisms through various pathways, with animal digestion and body accumulation being the most common. Research reveals that PE excreted MPs expose sea urchin larvae within hours of ingestion, whereas sea scallops and purple mussels tend to retain less dense MP particles. The intestinal or digestive tract of mussels can also transfer MPs to their circulatory systems. Large marine mammals, particularly filter-feeding ones, are more susceptible to MPs. Organisms at higher trophic levels can biologically transport and enrich MPs as they pass through the food chain, thereby affecting human health. Nutrient transfer may be an indirect pathway for MP ingestion. Studies have also demonstrated that zooplankton can transfer MPs from lower to higher trophic levels. Various freshwater organisms, such as goldfish, zooplankton, bivalves, benthic macroinvertebrates, and tadpoles, can ingest and accumulate MPs. These organisms can damage their digestive tract and have varying retention times, as reported in field surveys (Jeong et al., 2024).

Various organisms in the aquatic environment can ingest MPs, a type of metal, and accumulate them in the aquatic food web. Factors influencing MP bioaccumulation include exposure concentration, particle size and shape, polymer type, and biological characteristics. Increased exposure concentrations improve the effectiveness of MP bioaccumulation. The particle size of MPs also affects their accumulation; decreasing size increases organisms' MP accumulation capacity. Different shapes of MPs affect their bioaccumulation at different trophic levels and habitats. The type of polymer determines MP particle density, which affects their trajectory, sedimentation rate, and distribution area. Different organisms' feeding patterns also influence the number and type of MPs ingested (Li et al., 2023).

Among all taxonomic groupings, non-fish vertebrates bioaccumulated the highest levels of MPs, whereas zooplankton had the lowest body load. Fish, crustaceans, and bivalve molluscs did not differ significantly in MP body burden when compared pairwise. We expected fish to be more polluted than invertebrates due to their elevated status in the food chain and propensity for longevity. Regardless of the fish's trophic level, MP consumption, gut concentration, and occurrence rate were all unaffected. The danger of MP consumption is higher, nevertheless, for marine species lower on the food chain. Due to their unique biological characteristics, small, planktonic feeders like clupeids may be most at risk of ingesting MPs and may collect the highest quantities in their digestive systems (Feniova et al., 2019).

The study suggests that feeding tactics rather than trophic status are the main factors determining MP intake and accumulation in fish. Previous research did not show significant changes in MP concentration in fish intestines based on trophic level. Variation in size and age also contributes to the observed variation in MP body burden. Larger fish consume more MPs, but this doesn't necessarily mean higher MP retention rates. Vertebrates larger than fish have the highest MP body burden, highlighting the importance of body size in MP ingestion and accumulation.

Focussing on taxonomy and geographical origin, the bioaccumulation of MP in marine creatures. It shows that different taxonomic groupings have different amounts of accumulated MPs; for example, zooplankton has the lowest levels and vertebrates have the highest levels. The wide variation among taxonomic groups, however, makes it difficult to comprehend patterns of contamination on a worldwide scale. Variability in MP characterisation is mostly due to variations in sampling and isolation techniques. To guarantee strong inter-comparability among researchers, the review recommends standardising and harmonising sample, isolation, and identification methodologies for MPs analysis. It is necessary to standardize MP isolation procedures and develop more detailed sampling strategies. Future investigations should investigate uptake efficiency, retention period, and MP abundance in saltwater and sediments from the same locations. Standardised approaches for monitoring MP levels are essential to improve our understanding of the mechanisms of uptake and accumulation in biomonitoring studies (Parolini et al., 2023).

Bio magnification of MP in plants and animals

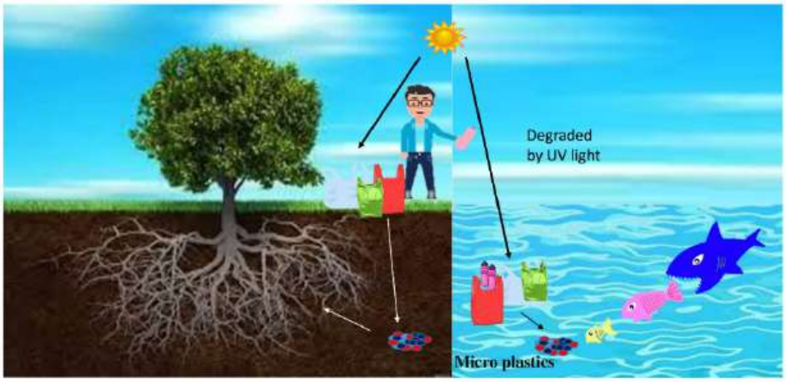
Biomagnification refers to the accumulation of dangerous compounds by creatures at different levels of the food chain. Bottom feeders ingest wastes found in the oceans, such as industrial, agricultural, and human wastes, which generally generate these harmful substances. Humans are exposed to higher concentrations of harmful compounds as they eat higher-ranked fish, as these components are found in progressively more concentrated forms in the food chain. This phenomenon, known as biomagnification, occurs when an organism's contaminant concentration exceeds its diet concentration as a result of food exposure. Food web biomagnification refers to the increase in contaminant concentration that happens with increasing trophic status. Mercury, heavy metals, and biogenic chemicals are among the pollutants that have been subject to biomagnification, a term first used to describe the bioaccumulation of chlorinated pesticides in aquatic food webs. The term originally referred to the concentration of (1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane) DDT residues in earthworms. The biomagnification of persistent organic compounds is an intricate process that requires growth-conversion efficiency and lipid co-assimilation. The first DDT model outlined lipid co-assimilation, the efficient assimilation of both lipids and pollutants from the diet. Age inversely relates to both the growth rate and the elimination rate coefficient, resulting in an increase in biomagnification with age (Miller et al., 2020).

Top predators can make food webs larger because they are good at moving chemicals around, but they are not very adept at moving energy through their lipid co-assimilation mechanism. The model suggests that trophic levels and transfer efficiency determine the maximum contamination, while individual organism growth and elimination attenuate it. Biological energy and trophodynamics both agree that lipid co-assimilation is a way for living things to grow, but chemical bioaccumulation through passive partitioning processes is not. Transporting chemicals from low concentrations (digesta and consumed food) to high concentrations (animal tissues) is essential to the suggested biomagnification model. The alternative GI magnification model considers both biomagnification and chemical diffusion. At first, sceptics thought that, because lower-trophic animals had a different lipid composition than upper-trophic ones, equilibrium partitioning was the primary biomagnification mechanism. On the other hand, features unrelated to food consumption have been considered in alternate pathways.

When levels of hydrophobic organic contaminants in an organism exceed those of its food, a process known as biomagnification occurs, and the contaminants travel up the food chain. Dietary intake can increase an animal's chemical potential, as explained by the GI magnification model and its recent revisions. It is challenging to assess other pollutants, such as mercury, in the thermodynamic setting of biomagnification. The processes of absorption, assimilation, and excretion require more research (Bilal et al., 2023).

Impact of MP on the food chain

MP are significantly affect the food chain. Researchers have discovered that the presence of MP decreases the bulk density of the soil. This could potentially reduce plant roots' resistance to root penetration and improve soil aeration, ultimately leading to greater root growth. On the other hand, the addition of plastic films of varying sizes might result in the formation of water channels, which in turn leads to an increase in water evaporation. This has the potential to cause the soil to dry out and reduce plant performance.



Plastic particles, due to their high carbon content, decompose slowly, which results in microbial immobilisation. This effect is more pronounced for MP materials, such as biodegradable plastics. A study discovered that plant performance parameters decreased in the presence of biodegradable plastic residues, possibly due to microbial immobilisation. Researchers should consider these temporary effects when conducting experiments on plant growth. MP have the ability to coat soil with hydrophobic surfaces, which prolongs the stability of contaminants and enhances their enrichment. These particles carry pollutants that have the potential to harm plants by interfering with their root systems and overall development. MP surfaces have the potential to influence pollutant effects by reducing their availability for soil biota and plants. A wide range of creatures, including those in the human diet, can absorb and consume PS nanoparticles (Cverenkárová et al., 2021).

There are more than 250,000 metric tonnes of floating plastic trash among the 5 trillion tonnes of trash already in the ocean. Aquaculture is a lifeline for underdeveloped nations' food security, yet these particles pose a hazard to plankton in the water. The survival of these species is in jeopardy because of the contamination of the food chain with MPs. A study examining the transfer of PS nanoparticles from moss to fish revealed significant impacts, including a twofold increase in zooplankton consumption time and a change in cholesterol distribution. As they go up the food chain, aquatic organisms like shrimp, paropa, polychaetes, and ciliates can absorb 10 µm PS MP, which are subsequently passed on to shrimp. MP biomagnification in marine ecosystems is evidenced by their presence in otoliths, lantern fish, and sea lion excrement. MPs can carry toxic substances like hexachlorobenzene and DDT, putting both plants and animals at risk due to their genetic makeup (Alengebawy et al., 2021; Al Mamun et al., 2023).

MPs, found in living things, can hinder development, growth, and chromosome mutation. They can also alter bacterial populations, posing risks to both living things and humans. MPs used in plastic production can affect marine species' endocrine function. They can enter the body through inhalation, eating polluted food, and drinking contaminated water. Consuming MPs whole can cause cell damage, energy disturbance, oxidative stress, and oedema. Air pollution, including MP, disrupts human respiratory and cardiovascular systems. Ingestion of MPs can lead to cancer. Plastic processing workers are at risk for respiratory illnesses. Phthalates, a main ingredient in MPs, can interfere with endocrine gland function, delay puberty, and reduce birth weight (Saeedi et al., 2024).

Mitigate the effect of MP on the food chain

Removing even a single link in the food chain can cause a drastic drop in population size, or even the extinction of an entire species. The loss of keystone species can throw the whole food web out of kilter, increasing the risk of extinction or drastically reducing the chances of survival for other species. Air, water, and soil pollution all have a major influence on food webs because they alter species' ability to survive, reproduce, and disperse. The extinction of primary producers could have an impact on carnivores. As they move up food chains, the concentration of pollutants in higher organisms can increase as a result of bioaccumulation and biomagnification. Toxic compounds in bigger fish may accumulate in smaller fish in polluted rivers, which could lead to high levels of poisons in humans and other top predators. In addition to lowering populations and upsetting food web equilibrium, pollutants can interfere with reproduction by acting as endocrine disruptors. As a result of pollution's effects on species distribution, further alterations to the food chain may occur, causing certain species to relocate to less contaminated regions or invade vacant niches. When it comes to food webs, biodiversity, and ecosystem services, pollution is a major player (Wu et al., 2017).

Governments and consumers can reduce MP in food by replacing synthetic fibers with natural ones, installing water filters, promoting the elimination of microbeads and single-use plastics, and promoting producer responsibility rules.

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