

## CHAPTER 7

# Microplastic Microbiome Interactions: Emerging Threats and Bioremediation Potentials

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**Abstract:** Microplastics plastic particles smaller than 5 mm have become ubiquitous pollutants in marine, freshwater, and terrestrial ecosystems. Their durability, persistence, and ability to adsorb hazardous chemicals make them a growing ecological and health concern. A new dimension of this issue has emerged with the discovery of the *plastisphere*, a term used to describe microbial communities colonizing plastic surfaces. These communities influence the fate, degradation, and toxicity of microplastics while also acting as vectors for pathogens and antibiotic resistance genes.

This chapter explores the interdisciplinary field of microplastic microbiome interactions, detailing their ecological implications and biotechnological potential for bioremediation. It further discusses microbial succession on plastics, enzymatic degradation mechanisms, and the possibility

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of harnessing microbial consortia for sustainable management of microplastic pollution. Case insights from Indian freshwater systems, particularly the Godavari Basin, are presented to contextualize this emerging field within the framework of environmental sustainability.

**Keywords:** Microplastics, Plastisphere, Microbial biofilm, Biodegradation, Environmental sustainability, Bioremediation, Freshwater ecosystems

## 1. Introduction

Plastic pollution is one of the most pressing environmental challenges of the 21st century. Global plastic production exceeded 400 million tonnes in 2022, and an estimated 8 to 10 million tonnes enter aquatic systems annually (UNEP, 2023). Once in the environment, larger plastics fragment into smaller particles termed *microplastics* through photo degradation, mechanical abrasion, and oxidation.

These microplastics persist for decades, infiltrating marine, freshwater, and terrestrial food chains. Due to their hydrophobic surfaces, they adsorb toxic compounds such as heavy metals and persistent organic pollutants (Rochman et al., 2019). The ingestion of microplastics by aquatic fauna affects feeding behavior, reproduction, and physiological functions, making them a global ecological hazard.

Recently, attention has shifted from the physical impacts of microplastics to their biological interactions, especially with microbial communities. These interactions form the basis of a new research field: microplastic microbiome ecology.

## 2. The Plastisphere: A New Ecological Niche

The *plastisphere* a term coined by Zettler et al. (2013) refers to microbial biofilms that colonize plastic debris in aquatic environments. Unlike inert particles, plastics provide a stable and selective habitat that supports microbial adhesion and succession.

Biofilm formation typically occurs within hours after plastic exposure to water. Initial colonizers include opportunistic bacteria such as *Pseudomonas*, *Bacillus*, and *Vibrio*, followed by algae, fungi, and protozoa. These communities differ significantly from free-living or natural surface-attached microbiota (Amaral-Zettler et al., 2020).

The plastisphere influences not only the degradation potential of microplastics but also their transport and toxicity. Microbes can change the density and surface properties of plastics, causing them to sink or float and thus affecting ecosystem-level plastic distribution.

### 3. Microplastic–Microbiome Interactions

Microplastic microbiome interactions depend on several variables: polymer type, environmental conditions, surface roughness, and nutrient availability. For example, *polyethylene (PE)* and *polypropylene (PP)* tend to harbor distinct microbial assemblages compared to *polyethylene terephthalate (PET)* or *polystyrene (PS)*.

These biofilms serve dual roles. On one hand, they accelerate plastic degradation by secreting enzymes; on the other, they may harbor pathogenic species such as *Vibrio cholerae* or *Aeromonas hydrophila* (Keswani et al., 2021). Moreover, biofilms promote horizontal gene transfer, including the spread of antibiotic resistance genes (Zhao et al., 2022).

### 4. Microbial Degradation of Microplastics

Microbial degradation is a promising eco-friendly strategy for mitigating plastic pollution. Certain bacteria and fungi possess enzymes that can depolymerize synthetic polymers.

**Bacterial degraders:** *Pseudomonas putida*, *Ideonella sakaiensis*, *Rhodococcus ruber*

**Fungal degraders:** *Aspergillus flavus*, *Penicillium simplicissimum*, *Fusarium solani*

These microorganisms produce oxidases, hydrolases, and esterases that initiate polymer chain cleavage, eventually mineralizing plastics into CO<sub>2</sub> and H<sub>2</sub>O under aerobic conditions (Wei & Zimmermann, 2017).

However, degradation rates are influenced by temperature, polymer crystallinity, and microbial community dynamics. Laboratory studies have achieved partial degradation (10–30%) over several weeks, but full biodegradation in natural ecosystems remains limited.

**Table 1:** Representative microbes capable of degrading common plastic polymers

Polymer Type	Representative Bacteria	Representative Fungi	Key Enzymes
PET	<i>Ideonella sakaiensis</i>	<i>Fusarium solani</i>	PETase, MHETase
PE	<i>Pseudomonas aeruginosa</i>	<i>Aspergillus niger</i>	Laccase, Peroxidase
PS	<i>Rhodococcus ruber</i>	<i>Penicillium chrysogenum</i>	Monooxygenase
PVC	<i>Bacillus cereus</i>	<i>Phanerochaete chrysosporium</i>	Dehydrogenase

### 5. Biotechnological and Environmental Applications

Harnessing microbial degradation pathways has opened new avenues for sustainable bioremediation.

**Engineered microbial consortia:** Co-culturing bacteria and fungi enhances degradation rates through synergistic enzyme production.

**Algae–bacteria systems:** Microalgae remove dissolved nutrients while bacteria degrade plastics.

**Immobilized biofilms:** Biofilm reactors can treat wastewater containing microplastics efficiently (Kumar et al., 2023).

In aquaculture and wastewater contexts, integrating these systems could offer sustainable, low-cost solutions to mitigate plastic accumulation.

## 6. Challenges and Future Directions

Despite progress, key challenges remain:

1. **Standardization:** No universal protocols for detecting and quantifying microplastic degradation exist.
2. **Ecological risks:** Certain plastisphere microbes can be opportunistic pathogens.
3. **Efficiency limits:** Microbial degradation rates are too slow for large-scale remediation.
4. **Policy gaps:** Waste segregation and plastic-use reduction policies are inconsistently enforced.

Future research should prioritize *environmentally adapted native strains* and employ *metagenomic tools* to map biodegradation genes. Combining molecular biology, ecology, and environmental engineering can advance scalable solutions.

## 7. Case Insight: Microplastic and Microbial Dynamics in Indian Freshwaters

The Godavari River Basin exemplifies India’s freshwater microplastic problem. Studies from Nashik and Nanded regions report rising concentrations of fibers and fragments in surface waters (Deshmukh et al., 2022). Urban runoff, detergents, and agricultural plastics are key contributors.

Preliminary microbiological analyses indicate the dominance of *Pseudomonas*, *Cyanobacteria*, and *Bacillus* species on collected microplastic surfaces. These findings suggest that Indian freshwater microbiomes hold potential for indigenous bioremediation strategies.

Future collaborations between universities and state pollution boards could help develop microplastic monitoring protocols and biotechnological pilot programs for sustainable cleanup in the Godavari basin.

## 8. Conclusion

Microplastic microbiome interactions present both ecological threats and biotechnological opportunities. While the plastisphere poses potential risks, it also holds the key to sustainable plastic degradation. By integrating environmental microbiology, molecular biology, and sustainability science, we can transform microplastic pollution into a solvable challenge.

Harnessing native microbial communities for plastic bioremediation can contribute to India's commitments toward UN Sustainable Development Goals 12 (Responsible Consumption), 14 (Life Below Water), and 15 (Life on Land).

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