Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 4, Issue 2, 2026

TERRESTRIAL GUT MICROPLASTICS AND INSECT GUT MICROBIOME: NEW HORIZONS OF FUNCTIONAL ECOLOGY

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DOI: https://doi.org/10.5281/zenodo.20175498

Keywords
Microplastics, Insect, Gut microbiome, Pollution, Biogeochemical circulation.

Article History
Received: 20 December 2025
Accepted: 27 January 2026
Published: 16 February 2026

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Abstract

Microplastic pollution is an extensive concern in the environment of both water and land ecology. Even though marine environment has been receiving a lot of attention. Consideration, it is increasingly becoming evident that the terrestrial ecosystems are also key sinks of Microplastics due to farming, atmospheric, plastic waste sludge, fragmentation and wastewater sludge. Soil dwelling insects also play a crucial role in soil bioturbation, nutrient cycling, and the decomposition of organic matter, which are also important parts of the ecosystem processes. According to a recent study, these organisms are able to consume. Microplastics in the soil matrices, posing a cause of concern as to the potential ecological impact. The consumption of Microplastic has been believed to have an impact on the functionality, diversity, and composition of insect gut microbiomes. The gut microbial community is crucial to the nutrition of the host, the digestion of complex organic matters, the detoxification, and the immunological control. Disruption of such microbial communities by Microplastics can in turn have ripple effects on the insect physiology and processes in the general ecosystem. Adsorption and transport of toxic, physical abrasion of gut tissues, changes in microbial metabolic pathway and microbial growth of plastic should be mentioned as the possible mechanisms. The latter review will consider the current trends in the body of knowledge of interactions between terrestrial. Microplastics and insect gut microbiomes, and its implications. This review discusses the sources of Microplastics and their places of appearance. Soil, routes of exposure of soil insects, alterations in microbiomes under the influence of taking in Microplastics, and the potential implications on the ecosystem. Besides, we highlight the relevance of environmental stressors such as climate change in forming them. Finally, we identify significant knowledge gaps and identify the future research areas. Focused on multi-omics methodology, multi-omics field-scale, and ecosystem-scale, long-term field studies. Monitoring to understand more about the effect of microplastic pollution on the ecology of terrestrial food webs.

1. INTRODUCTION

Microplastics (MPs) are one of them, being typically defined by its size smaller than 5mm of the most ubiquitous (Thompson, Olsen et al., 2004; Geyer, Jambeck et al., 2017; Ajith, Arumugam et al., 2020). Scientific interest in the marine Microplastic pollution has been dominant over the previous decade of time, yet a rising information shows that other terrestrial environments may also be significant sources of microplastic deposition particularly the agricultural soils (Nizzetto, Futter et al., 2016; Bläsing and Amelung 2018). These particles are due to a number of anthropogenic. These include plastic wraps, use of sewage sludge, compost supplements, wastewater irrigation, tire abrasion and deposition into the atmosphere (Zhang and Liu 2018). Hence, the volume of plastic remnants that continue to get into soils is now an issue of concern. In terms of the possible ecological impacts of Microplastics on soil organism and ecosystem in the long-term functioning. Soil ecosystems are one of the most intricate biologically amicable ecosystems on the planet and they harbor an enormous assortment of microorganisms and invertebrates that engage with each other to execute fundamental ecosystem roles such as nutrient cycle, organic matter breakdown as well as soil texture (Bardgett and Van Der Putten 2014; Rolsky, Kelkar et al., 2020).

One of the widely used and the most significant groups of organisms in the terrestrial food webs are insects. Soil insects are effective in litter littering, mineralizing of nutrients, and the control of microorganisms by feeding off of dead plants and animals. They also play significant roles as ecosystem processes (Lavelle, Decaens et al., 2006; Helmberger, Miesel et al., 2022). The soil particles, which are increasingly polluted with particles of the Microplastics, are inevitably ingested by insects due to the fact that a significant proportion of insects feed on the soil organic matter or detritus (Engel and Moran 2013; Huerta Lwanga, Gertsen et al., 2016). This close contact between insect species and polluted soil habitats opens a route where Microplastics may flow into the food webs of terrestrial biomes and react with biological systems at a variety of ecological levels.

The gut of the insect microbiome life is highly specialized and carries out significant physiological functions in its host. These colonies of micro-organisms are useful in the degradation of complex food substances, the synthesis of essential nutrients, the enhancement of immunity, and the detoxification process (Engel and Moran 2013; Li, Zhang et al., 2022). Insects consuming hard organic food such as lignocellulose, chitin, and plant secondary signorelli require symbiotic intestinal microorganisms to aid them in digesting it (Douglas 2015; Rondoni, Chierici et al., 2021). Homeostatic disturbance in these microbial communities can severely impact expert nutrition, metabolism and existence of the host. Recent studies have shown that environmental pollutants (including heavy metals, pesticides, and novel contaminants) have the potential to modify the types of bacteria and their functioning within the gut of invertebrates (Jin, Xia et al., 2018; Tamargo, Molinero et al., 2022). Host-microbe interactions based on physical, chemical, and biological mechanisms may share similar effects on Microplastics. Microplastics may have a number of possible impacts on the gut microbiomes of insects.

To begin with, eaten particles can lead to mechanical stresses or damage to the gut epithelium, which might alter the gut environment and the manner of microbial colonization (Wright and Kelly 2017; Zhang and Liu 2018; Wang, Guo et al., 2021; Zhang, Zheng et al., 2025). Second, they are usually made of Microplastics containing chemical additives such as plasticizers, preservatives, and flame retardants and so on, which when consumed pass on to the intestinal tract (Lithner, Larsson et al., 2011). Third, Microplastics may take environmental toxins, including heavy metals and pesticides and transport them to the living tissues (Rochman, Hoh et al., 2013). Finally, the plastic substances tend to be carrying various communities of microbes referred to as the plastisphere. These microbes may be absorbed in the digestive systems of insects when they consume them (Zettler, Mincer et al., 2013).

The most recent experimental results suggest that Microplastics intake may cause massive changes in the gut microbial composition and metabolic activity in various invertebrate species. The shift in the composition of the bacterial community, the reduction in the number of beneficial microbes, and increased opportunistic ones have been reported (Several studies on Microplastic exposure have reported opportunities with opportunistic pathogens (Lu, Wan et al., 2018). These alterations may have an impact on the way the insects feed, absorb nutrients, immune functionality, and reproduction.

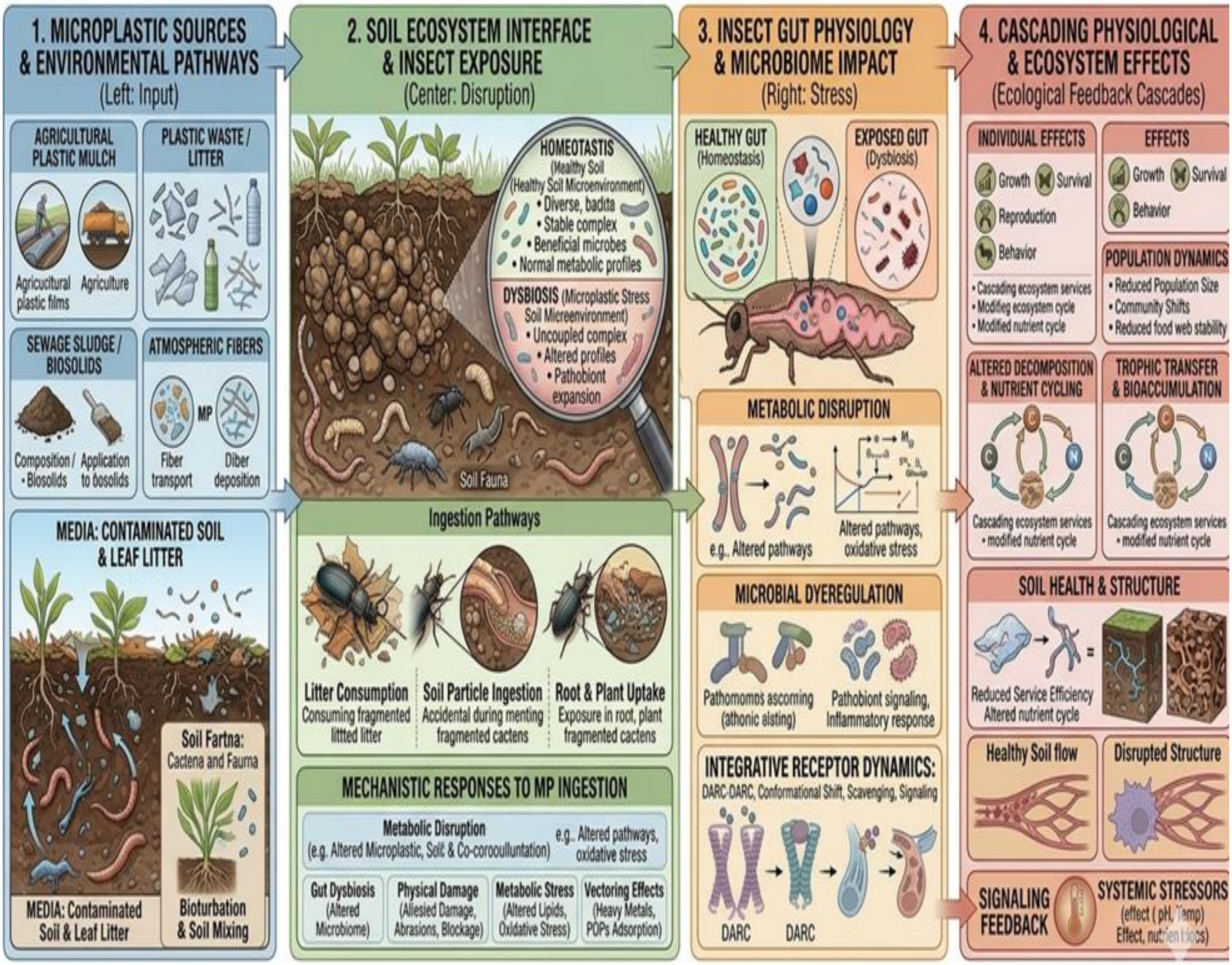

Figure 1: Roadmap of Bioaccumulation of Microplastic from soils to insects

Insects are related to vital functions of soil ecosystems, and issues in the interaction of insects with microorganisms may propagate via ecological networks and influence other ecosystem processes, such as the breakdown of things and movement of nutrients (de Souza Machado, Kloas et al., 2018). The same climate change can affect the interaction of insects and microorganisms within their digestive system at the same time by altering the way microbes and insects digest food. The combination of these stressors can result in an aggravating effect of either stressor, which will alter the stability of both the host and the microbial community and the functioning of the environment (Trojan et al., 2024). The mechanisms of these interconnected processes should also be known so that the manner in which land-based ecosystems will respond to new pollution loads in the future scenarios of environmental change can be predicted (Rillig, Lehmann et al., 2019).

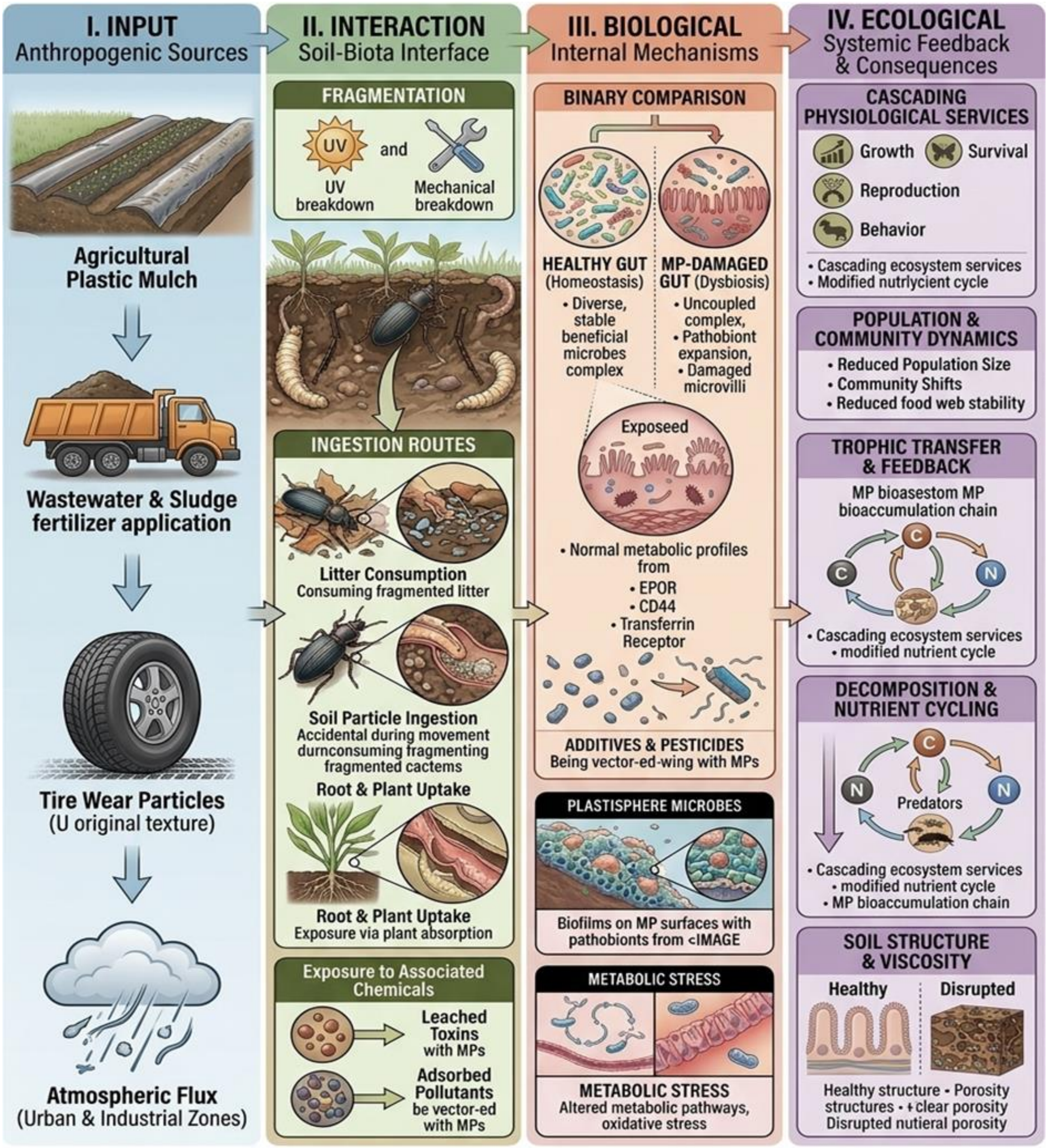

Figure 2: How Microplastics enter land habitats as well as land food webs.

The sources of Microplastics entry to the ground are the degradation of plastic waste, the use of agricultural mulching films, the release of sewage sludge, and their insertion out of the sky. With this accumulation, the earthworms, bugs and bacteria inhabiting the soil consume them.

2. Terrestrial Microplastics and Insect Gut Microbiomes

2.1 Microplastics in Terrestrial Ecosystems

The Microplastics (MPs) are prevalent on the ground, particularly in the agricultural soil whose products are usually made of plastic products. Some of such farming methods include plastic mulching, application of sewage sludge and watering crops with treated waste water. Contribute greatly to the accumulation of Microplastics in soils (Rillig 2012, Hurley and Nizzetto 2018). Recent studies have revealed that the soil ecosystems can form important locations where plastic garbage accumulates. Over time, the Microplastic residues tend to accumulate more in them as compared to their neighbors (Zhang and Liu 2018). Through mechanisms of fragmentation induced by ultraviolet radiations, mechanical weathering, and degradation of induced by microbes. The particles become further more integrated into the soil matrices and engage with soil biota (Rillig & Lehmann, 2020a).

2.2 Soil Biota Exposure to Microplastics

This is a continuous interaction with soil by burrowing soil organisms when they are fed particles. Because of this many soil invertebrates have to be exposed to Microplastics through the ingestion and physical contact. Most research findings have revealed that organisms like earthworms consume Microplastics with the soil processing and this resulted to low growth, physiological stress, and soil change structure (Huerta Lwanga et al., 2016). Such result indicates that Microplastics have the potential of poisoning has an effect on soil ecological processes as it interacts with soil organism.

2.3 Ecological Role of Insects in Soil Systems

The insects have been recognized to be the most diverse ecologically important group in the terrestrial environment. A number of soil-dwelling insects contribute to the decomposing processes and in the nutrient cycling, they are acting as detritivores, herbivores, or predators (Lavelle et al., 2006). The insects also aid in the degradation of different organic materials by feeding and burrowing activities as well as impacting on the abundance of the microbial communities in the soil niches. Because of their common interaction with the soil particles and organic debris, insects are extremely vulnerable to the consumption of Microplastic particles contained in the polluted soils.

2.4 Insects Gut Microbiome and Functional Ecology

The role of insect gut microbiome is significant in the metabolism, nutrition, and defense of the host. Communities of gut microbes aid in the degradation of complex diet items, including cellulose, lignin, or chitin, which allow insects to use a wide range of food sources (Brandon et al., 2018; Engel and Moran, 2013a). The symbiotic microbes also contribute to the detoxification mechanisms assisting insects to be tolerant to the environmental toxins and secondary metabolites of plants. The alteration of the microbial flora in the gut can cause adverse effects on insect ecological performance and physiology.

2.5 Microplastic - Microbiome in Insects Interactions

Most research studies indicate that the consumption of Microplastics might modify the gut microbial structure and metabolism in insects and other invertebrates. Experimental exposure studies indicated (Wright and Kelly, 2017a) that there was a change in the ratio of prominent bacterial taxa in response to ingestion of Microplastics. Microplastics affected guts microbiomes in a variety of ways such as physical contact with gut surfaces, the release of plastic additives, and the colonization of plastisphere-related microorganisms (Rochman et al., 2013; Zettler et al., 2013a).

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2.6 Implications for Soil Ecosystem Functioning

The modification of the gut microbiomes of insects may exert a significant impact on the environment since insects play an important role in re-distributing nutrients in the environment and releasing dead matter. In case the bacteria decompose organic material in soil differently, it would not work as effectively in ecosystem (Lu et al., 2018). Exposure to Microplastics can have implications on other macro sized activities within an ecosystem such as carbon cycling, soil fertility, and energy flow within food webs on the ground since it disaggregates the interactions of insects and bacteria (Bardgett & Van Der Putten, 2014a). Not much research on these challenging linkages is available in the real world despite the fact that more people are interested in this issue. This gives the importance of conducting research that combines any studies on environmental pollution, microbial ecology, and insect physiology (Lehmann et al., 2020; Wright et al., 2020).

Table 1: Types and Ecological Implications of Microplastics

Insect species	Microplastic Type	Method used	Key Findings	Significance	Reference
Meal worm (*Tenebrio molitor*)	Polystyrene	Labortatory exposure experiment	Microplastic altered gut microbial composition and digestive enzyme activity	Potential disruption of nutrient cycling	(Urbanek et al., 2020a)
Black soldier fly (*Hermetia illucens*)	Polyethylene	Controlled feedings trials	Microplastic ingestion influenced microbial diversity and metabolic pathways	Impacts on organic waste decomposition	(Xu et al., 2023)
Honey bee (*Apis mellifera*)	Microplastic fibers	Microbiome sequencing	Reduced beneficial gut bacteria and immune disruption	Pollinator health risk	(Wang et al., 2021)
Housefly larvae (*Musca domestica*)	Polypropylene	Growth and microbiome analysis	Altered microbial community structure and larval growth	Decomposition ecosystem impacts	(Ducarme et al., 2023)
Cricket (*Acheta domesticus*)	Mixed Microplastics	Feeding experiment	Gut dysbiosis and reduced survival rates	Food web disturbance	(Kuttiyawong et al., 2026)
Beetles (Coleoptera)	Polyethylene fragments	Soil exposure experiment	Microplastics accumulated in insect gut and affected microbiota	Soil ecosystem alteration	(Urbanek et al., 2020b)
Termites	Microplastic particles	Microbial diversity analysis	Significant shift in symbiotic gut microbes	Impaired cellulose digestion	(Przemieniecki et al., 2020a)
Ants	Microplastic fragments	Laboratory ingestion study	Microplastic ingestion modified gut microbial composition	Impact on soil engineering insects	(Ozturk-Ufuk et al., 2024)
Grasshoppers	Polyethylene	Feeding exposure	Gut microbiome diversity decreased after Microplastic ingestion	Herbivore ecological dynamics affected	(Ritchie et al., 2025)
Black soldier fly larvae	Mixed Microplastics	Microbial community analysis	Microplastic exposure promoted opportunistic microbes	Reduced waste bioconversion efficiency	(Fauzi et al., 2025)
Honey bees	Microplastic fibers	Gut microbiome sequencing	Dysbiosis observed in core microbial community	Pollination ecosystem services at risk	(Li et al., 2025)

3. Mechanistic Interactions between Microplastics and Gut Microbiomes

This figure gives us an idea of the impact of Microplastics ingested on the stomach and changes the gut microbial composition. Microplastics may disintegrate the intestinal barrier, transfer dangerous chemicals and pathogens, and cause oxidative stress and inflammation. These may cause dysbiosis, or the unbalance of the bacteria and gut operation issues, which may influence the entire body.

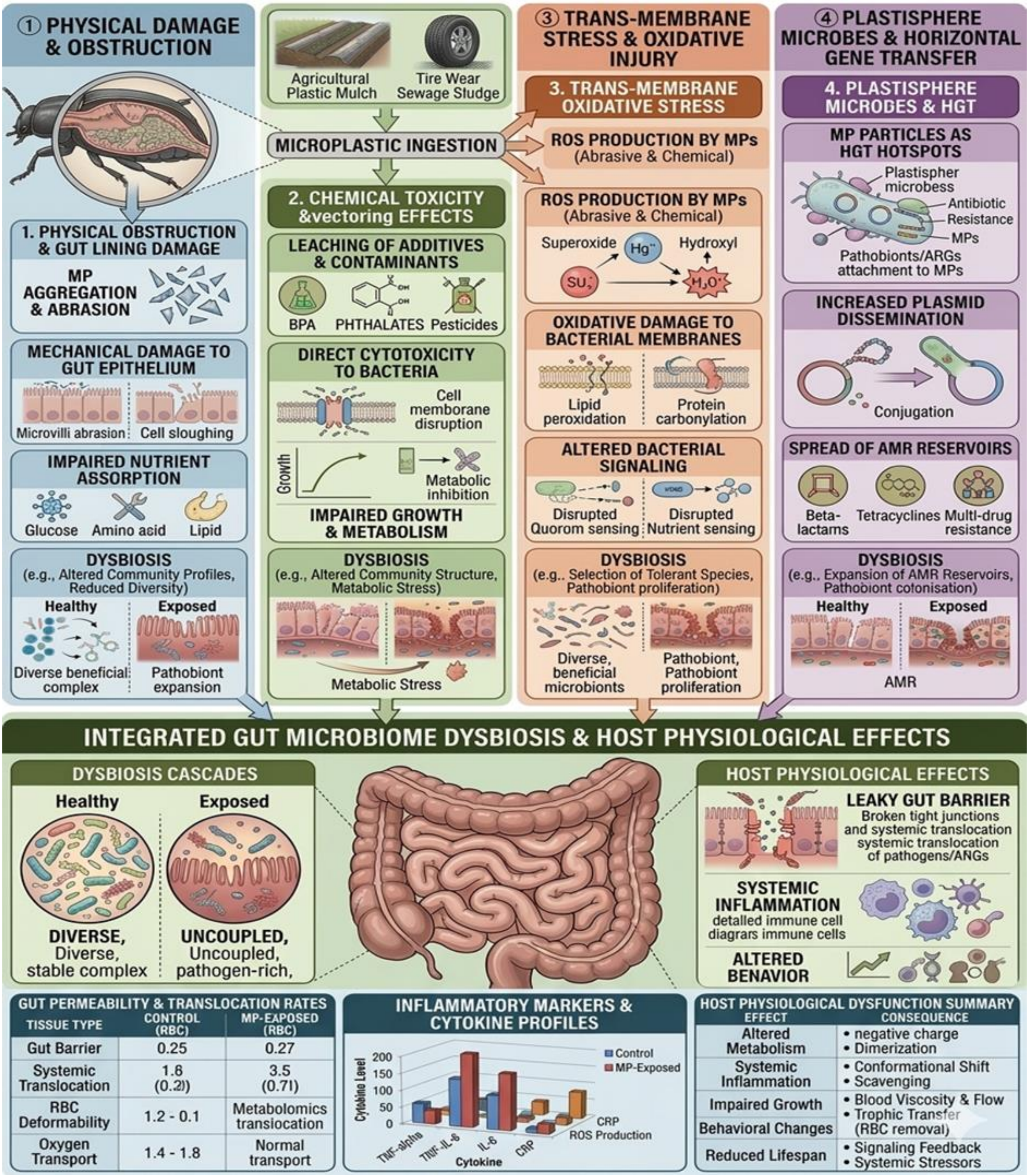

Figure 3: The way Microplastics can interfere with the good bacteria of the gut.

3.1 Physical Interactions and Gut Structural Disturbance

The development of Microplastics that attach themselves to the digestive tract is one of the primary mechanisms through which these microbiomes are altered by them. Eaten Microplastic particles may accumulate in the gut lumen, and this can create mechanical, obstructive, or irritative damage to the gut epithelial layers (Wright and Kelly, 2017b). Such physical alterations have the capacity of altering pH, oxygen and food supply in the gut. Microbial communities of the gut are highly sensitive to alterations in their environment and hence a small one can have a significant impact. The composition of the microbes may change because of a change in the structure or functioning of the gut (Jin et al., 2019). The gut is usually divided into three segments in insects; the foregut, the midgut and the hindgut. Every section contains its microbes, which dwell in it. The specifics of the compartment-specific microbial habitats may be disarranged by the remnants of Microplastics and other foreign substances that may, in turn, decrease the amount of microbes and increase opportunistic microorganisms (Engel & Moran, 2013b).

3.2 Leaching of Plastic Additives Chemically

It involves many other chemicals to plastic in order to make it stronger and more flexible as well as less prone to disintegration in environment. These include bisphenols, phthalates, stabilizers, flame retardants amongst many others. Others are known to be unhealthy or to have an effect on the endocrine system (Lithner et al., 2011). By consuming Microplastics, chemicals might enter your digestive tract in case it is acidic or contains enzymes. These substances can be produced, which can alter the process of microorganisms degrading food or prevent certain bacteria in the gut microbiome from flourishing (Hermabessiere et al., 2017). And when you ingest Microplastics, there is a chance that chemicals enter your digestive system either when it is acidic or when enzymes are involved. The synthesis of these compounds can alter the breakdown of food by microorganisms or stop the growth of certain species of gut microbiota.

3.3 Microplastics as Pollutant Vehicles in The Environment

Microplastics are able to take in numerous diverse pollutants within the surrounding because they possess a significant quantity of surface area relative to their volume and untidy surfaces that are not hospitable to water, pesticides, polycyclic, and heavy metals. Pollutants are of two types: aromatic hydrocarbons and persistent organic pollutants (de Souza Machado et al., 2019; Rochman, 2015). These contaminants will be transferred by the ecosystem and absorbed by living things when they consume them after the contaminants are deposited to the surfaces of Microplastics. In cases where insects ingest the Microplastics that have been contaminated with such pollutants, the digestive environment can increase chemical desorption, thereby increasing the bioavailability of the contaminants (Holmes et al., 2012). This process essentially facilitates the process where the Microplastics appear to serve an equivalent role of carrier of contaminants along with exposing the gut microbial communities to an increased number of chemical stressors that modify the microbial community structure and metabolic activity.

3.4 Introduction of Plastisphere Microbial Communities

The other process is movement of microbes in connection to the plastic surface. Microplastics are rapidly colonized by different microbial assemblages called the plastisphere in environment (Zettler et al., 2013b). Such biofilms of microbial microorganisms, which in some cases may harbor microorganisms capable of plastic breakdown, opportunistic pathogens or microorganisms resistant to pollutants, are often very different than the local ambient microbial communities. These microorganisms that can be related to the plastisphere can access the gut setting and interact with the native Microbiota in the event of insect feeding on Microplastic particles. Such interaction may cause microbial rivalry, the replacement of the native symbionts, or the microbial activity extrapolation in new microbial functions within the digestive system (Amaral-Zettler et al., 2020).

3.5 Microbial Metabolic and Functional Alterations

The form in which the bacteria in the gut breakdown food may vary when the types of bacteria change. According to metagenomics studies, the proximity to Microplastics might affect food breakdown genes, exogenous chemicals, and oxidative stress (Lu et al., 2019). Due to these alterations, microbes might be able to do useful things such as produce food, eliminate pollution and use enzymes to degrade complex organic compounds in different ways. When these microbial symbionts change plants find it more difficult to obtain the nutrients they need.

3.6 Host Physiologic Responses and Feedback

Alteration in the gut microbial communities have the potential to alter the functioning of the body of the insect host, including activation of immunity, oxidative stress, and metabolic distortion. There are also host mechanisms that can have an impact on the microbial composition of the gut. This has some feedback loops between the dynamics of the microbial population and the functioning of the body of the host (Lu et al., 2019). It is possible that these negative feedback loops are what can make or break the change of the digestive systems in insects in the short run or could be the long-term dysbiosis in insects having been exposed to Microplastics.

4. Climate Change and Microplastics-Microbiome Interactions in Terrestrial Ecosystems: A Multi-Stressor Perspective

Microplastic contamination does not exist in isolation; it interacts with other environmental pressures which are related to global climate change. The impacts of Microplastics on soil organisms and the environment could be influenced by several factors among them are the increase in temperature, changes in precipitation, and the increase in the frequency of extreme weather conditions, as well as changes in the physicochemical characteristics of soil.

We should understand the relationship between Microplastics pollution and climate change in order to predict the impact of climate change on the ecosystems in the future. Climate change by altering rainfall patterns can also impact on the movement of Microplastics through soil profiles and across landscapes. Droughts may lead to the accumulation of Microplastics in an elevated soil where the soil organisms might be most active. Conversely, massive rains and floods have the potential to deliver plastic particles on agricultural soils to the surrounding ecosystem. Such activities can increase the likelihood that insects and other invertebrates that live in soil will consume Microplastics.

4.1 Climate Effects on Microplastic Distribution and Degradation

Climate change may produce a significant impact on the movement of the plastic items, degradation, and their deterioration in the ecosystem. Macro and Nanoplastics can become degraded more rapidly in the soil at higher temperature and with the ultraviolet radiation (Douglas, 2015). When plastic wastes are stressed due to freeze-thaw cycles, soil erosion, and heavy rains they tend to disintegrate into smaller pieces.

Moreover, the alteration of the rainfall patterns due to changes in climate can also influence the vagrancy of Microplastics in soil profiles and across scenery. The agricultural soils don't release plastic particles into the surrounding ecosystems due to heavy rainfall and floods, however, drought conditions may result in Microplastic concentrations in the top layer of the soil, where soil organisms are most active (Rillig and Lehmann, 2020b). Such procedures have the potential to increase the risk of Microplastic insect and invertebrates' ingestion.

4.2 Microbial Metabolism Change Occurring Under the Influence of Temperature

Temperature in both soil and host-associated microbiomes play a vital role in regulating the metabolism of microbes and the composition of the community. Thus, an increase in global temperature can influence the microbial communities' response to the appearance of micro plastics. The high temperatures can also enhance the microbial reaction to the pollutants in the environment by escalating the rate of microbial metabolism (Allison and Martiny, 2008).

High temperatures will alter the behavior of the microbial visible in insect gut environments, turning on and off the symbiotic engagements saving hosts and high nutrient-providing microbes. The microbial disturbances triggered by Microplastic could be particularly apparent in these situations, in case temperature stress also reduces the microbial resilience or host immunological fidelity.

4.3 Climate Stress and Insect physiological informatics

Climate change affects the behavior, population dynamics and insect physiology. The change in temperature which influence the insect metabolism rate, feeding and gut transit time could have effect in the interaction between ingested Microplastics and the gut microbial communities (Ca, 2008). As an example, the insects might have to eat more given the increased metabolic activity in the warming conditions, and this would increase the chances of consuming Microplastics in the polluted environments. Host immunity may also be compromised by heat stress, which increases the likelihood of insects become ill due to the uncultured microbials using plastics around its Microplastics.

4.4 Synergistic Effects of Multiple Environmental Stressors

Microplastic pollution and climate change can exhibit both additive and potentially worse effects on the environment as compared to the stress of each. As an example, those chemicals associated with Microplastics can react to the physiological stress experienced by insects as the temperature varies to provide toxicological effects or alter the stability of the microbial communities (Crain et al., 2008a). Climate change has a possibility of altering the functioning of microbial ecosystems by altering the quantity of moisture and nourishment in the dirt. This would potentially alleviate the gut-associated bacteria response to plastic particles and other pollutants. Such discussions emphasize the importance of the need to look into rather than conceive Microplastic pollution as a single environmental issue, it must be considered to be a problem that impacts several things simultaneously (Zhang et al., 2023).

4.5 Potential Soil Ecology Stability Implications

The stability of the whole ecosystem may be impacted by Microplastics and climatic change as the insects and their intestinal microbiomes can be highly significant in the breakdown of objects and the reuse of nutrients. Alterations in the interaction between insects and the microbes can alter the rate at which organic matter decays, the activity of the enzymes of microorganisms and the amount of nutrients available in the soil (Bardgett and Van der Putten, 2014b). Such changes would ultimately have impacts on the fertility of the soil, plant growth, and the process of carbon transfer in terrestrial ecosystems. Consequently, it is highly significant to understand how the problem of Microplastic pollution influences the climate change in order to draw conclusions on the soil imperviousness of the Anthropocene ecosystems (Maqbool et al., 2025).

5. Ecological Implications of Microplastic-Microbiome Interactions in Terrestrial Insects

The pollution of Microplastics is capable of influencing not only individual beings but also the work of larger ecosystems. Alterations in the gut microbiomes of insects may also carry large impacts on land-based food webs and nutrient cycling and litter degradation of dead plants and animals. The impact of Microplastics can have a domino-like effect on the environment.

5.1 Effects on Nutrient Cycling and Decomposition

There is much-needed insects in the decomposition of organic matter within the soil. The detritivorous insects interrupt the litter of the plants and this assists the microbes to decompose the litter as they provide them with a better surface to proliferate. Digestive systems of the insects are assisted by the gut flora and thus, accelerate the process of converting organic material into nutrients that the body may utilize. Eating Microplastics may alter the bacteria in your stomach, which may impact the functioning of your digestive system and enzyme effectiveness. In case the microbial taxa breaking down lignocellulose perish, it is possible that insects will also be incapable of breaking down vegetal organic matter. The alteration could complicate the breakdown of litter and alter the quantity of nitrogen found in the soil ecosystem (Wall, 2012).

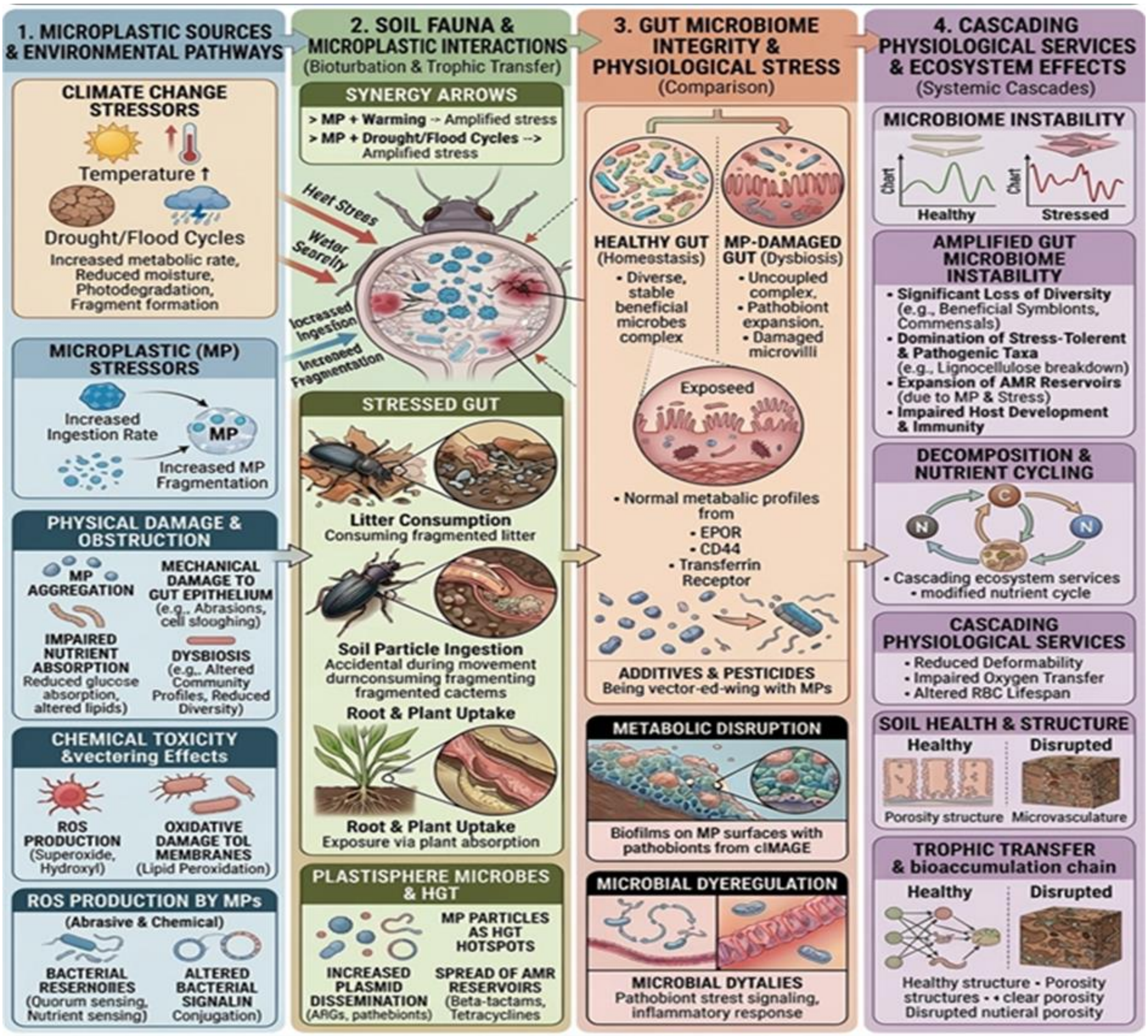

Figure 4: Climate change and Microplastic collision to alter the insects gut functioning

5.2 Soil Food Web Dynamics- Impact

A consumption of the Microplastics can also alter the interaction between various animals within the soil food chain. Some of the higher-order animals that feed on insects are birds, reptiles, amphibians and small mammals. When insects consume Microplastics, tiny fragments can be transferred to predators via trophic interaction, a process that can enhance the growth of Microplastics by land food networks (Provencher et al., 2019). Additionally, the modification in the gut microbiomes of insects can affect their host physiology, growth and reproductive success. The decrease in insect fitness can influence the population and ecological processes including pollination, predation and post mortgage.

5.3 Effect on Soil Microbial Community

The feeding and fecal deposition activities of insects impact the soil microbial communities of the soils through their fecal deposition and partially digested organic matter produced in the intestine microbiome which can affect microbial activity in adjacent soils. In the event that Microplastic exposure has effects on insect gut microbial communities, they may also have implications on microbial composition of a soil habitat through frass deposition. Such processes can also change the microbial diversity, enzymatic processes and nutrient cycling pathways in the soil ecosystem (Bardgett & Wardle, 2010).

5.4 Ecosystem Resilience implication

The concept of ecosystem resilience is described as the capacity of an ecological system to maintain the structure and functioning under environmental disturbances. Since there are a lot of crucial processes in the soil that are controlled by both insects and microorganisms, the perturbations affecting the insect-microbe interactions can potentially influence the resilience of the entire terrestrial ecosystem. Microplastic pollution is one of the more recent environmental stressors, and the ecological repercussions in the long run are familiar. Nevertheless, the fact that Microplastics interrupt microbial symbioses and influence the ecosystem processes contributes to the increased awareness being paid to ecological peculiarities of the plastic contamination of terrestrial ecosystems (Rillig et al., 2019).

6. Research Gaps

Although an increasing number of people know about Microplastic pollution in terrestrial ecosystems, the relationships between Microplastics and insect gut microbiomes along with ecosystem processes remain largely consistent. These gaps are highly essential to address in order to gain a full understanding of the ecological impact of plastic pollution in soil eco-systems.

6.1 Limited Research on Terrestrial Insect Systems

Most studies on the effects of Microplastics on microbiomes have been done on aquatic animals, including fish, marine invertebrates and zooplankton. Terrestrial insects on the other hand, have not been studied extensively although they are also important to soil ecosystems. A broader range of soil-dwelling insects such as beetles, termites, ants, and larvae feeding on dead things should also be considered in further studies (Potapov, 2022; Potapov et al., 2026).

6.2 Requirement of Integrated Microbiome and Ecotoxicology

Some of the existing publications investigate the toxicological implications of Microplastics or microbial community structure in the gut of insects in isolation. Nevertheless, the ecological implications of using Microplastic entail complex ecological effects that must involve a multidisciplinary approach that it unites insect physiology, ecotoxicology, and microbial ecology. Most of the advanced molecular methods are metagenomics, meta transcriptomics and metabolomics, which can help us understand how introducing Microplastic alters the mechanism of work of still microbes and how the metabolism of the host works (Knight et al., 2018).

6.3 Experiments of long duration and realistic conditions concerning the environment

Most studies being done nowadays are on short-term lab tests, which consume a large portion of micro plastics. Such studies prove handy to know the way things work although they may not be precise to reveal how things are in the actual ecosystem Long-term exposure tests and levels of Microplastics must be included in future research. The research should involve oil trials on a long-term basis, Microplastic levels on the ecology, and real-life conditions of soil. That field research should aid our comprehension of the manner in which Microplastics in the environment alter insects and microbes interact with another in extremely complex ecosystems (Lozano & Rillig, 2020).

6.4 How Different Environmental Stressors Affect Each Other

Microplastic pollution does not occur in a vacuum, but rather it typically occurs in combination with other environmental stressors such as heavy metals, herbicides and climate change. These may work in combination in various directions that might aggravate the impact on the environment. Future studies should use multi-stressor experimental designs in order to investigate the effects of different environmental stresses on insect gut microbiomes and ecosystem functions in parallel. This is because you need to know these relationships so that you can be able to predict how ecosystems of the world would respond to changes in the environment (Crain et al., 2008b).

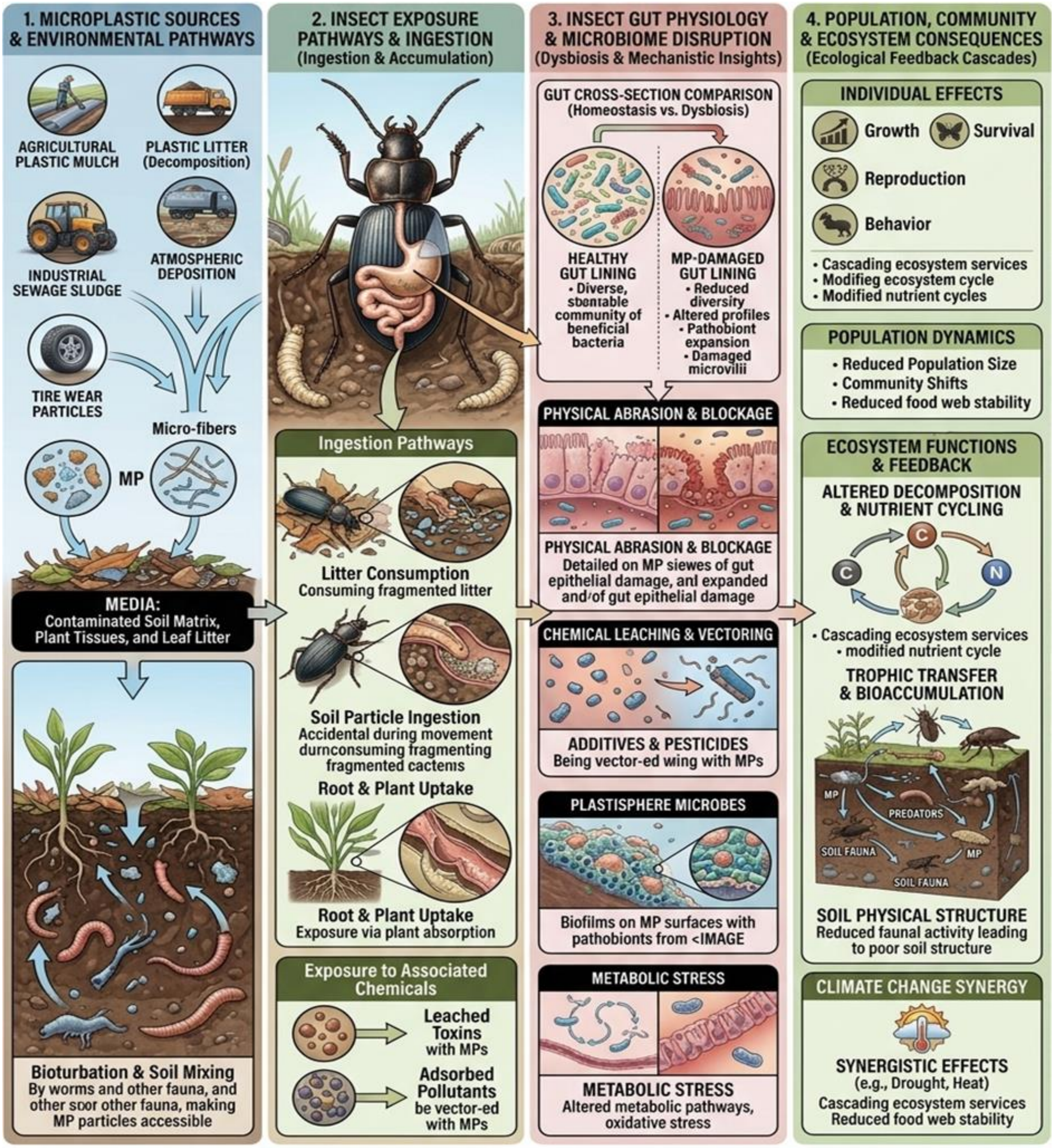

Figure 5: Impact of Microplastics on insect's habitats

6.5 Recommendations to the Soil Ecosystem Functioning

The issue of interactions between Microplastics and microorganisms on a larger scale is another significant research topic. Scientists are starting to research the influence of variations in the physiology of various species on such aspects as nutrient cycling, soil fertility, and carbon movement at the ecosystem level. More research needs to be carried out in future. Combine ecological investigation with biogeochemical tests to find out more about the impact of alterations in the dynamic of insects and microbes upon the condition and performance of soil ecosystems (Bardgett and Van Der Putten, 2014c).

7. Future Research Direction

The contamination of Microplastics is gaining an increasingly popular status as an international environmental issue, whereas the relationship between Microplastics and the microbiomes of insect guts remains at the preliminary level of investigation. The existing evidence suggests that such interactions can produce a tremendous effect on physiology of insects, structure of microbial communities, and ecosystem functions. Nevertheless, there exist a lot of significant questions to be answered. In order to fill these knowledge gaps, we shall have to apply an assortment of disciplines, such as soil ecology, microbiology, entomology, and environmental toxicity.

7.1 More Studies on Land Insects at the Species level

Much of the recent research on Microplastic consumption has been conducted on a limited number of relatively model species, and typically in highly controlled laboratory conditions. The insects are also of different types and each has different tastes. The Microplastics may produce rather a variety of effect on different animals, which depends on their location and type of microorganisms that live within their intestines. We ought to learn more of other kinds of insects which live in the soil and feed on dead plants and animals in the future. These are the beetles, the termites, the ants and the springtails as well as the larvae of the soil. Comparative study of the varieties of insects would inform us a lot regarding the response of various species to the presence of Microplastics.

7.2 Characterization of the Gut Microbiome Responses in Its Functions

Several studies have revealed that the alteration of the diversity of microbe following consumption of Microplastics varies. Limited information exists regarding the effects of the alterations in microbes in the body. Investigators ought to consider the impact that Microplastics have on how insects digest food in the future. The genes and metabolic pathways that are involved in the breakdown of food, elimination of toxins and potentially breaking down plastic can be identified using advanced molecular methods such as metagenomics, Meta transcriptomics and metabolomics. Such practical studies can enable us to get to know more about how Microplastics alter insects and microbes collaborative functioning.

7.3 Microorganism Gut Ecology of the Plastisphere Role in Insects

Microbiomes inside Microplastics have been termed and referred to as the plastisphere. Following feeding, such microorganisms associated with plastic can interact with intestines in insect microbiome, altering how microbial communities perform, and influencing the functioning of the body of the host. Future research must consider the settlement of plastisphere bacteria in the digestive system of insect and the influence on their microbial competitions, disease transmission or altered of the gut environment metabolic conditions. This knowledge of these interactions will enable us to determine whether Microplastics serve as vectors in the transmission of microbes in the terrestrial environment.

7.4 The Function of Microorganisms Present in Insects in the Degradation of Microplastics

According to the recent research findings, certain insect species can be involved in the breakdown of plastic polymers using the help of bacteria in their intestines. Still, it is not quite clear how it works. Few individuals are very familiar with how the operation works. Scientists are supposed to determine whether the insect-associated microorganisms possess enzymes capable of warranting polymer chain degradation or accelerating the plastic oxidation reaction. Daily, it is also necessary to know whether or not the polymers are fully broken down in these processes or not, only reduced to smaller Microplastic fragments, not nano plastic fragments. We could learn about these systems, then perhaps we will find additional biotechnological solutions to manage the plastic waste without harming the environment.

7.5 Long-Term Research of the Industry and the Environment.

Majority of the studies of the influence of Microplastics on insects and microbial communities have been conducted in artificially created conditions and over a limited time period. These are not the only things which research provides us with much information about the dynamics of the way things work, however, research may fail to capture enough of the complexity of the real situation in the ecosystem. Further studies are required to give full longitudinal field research on the effect of chronic exposure of Microplastics on insects, the microbial diversity and processes in the ecosystems in terms of time. Such studies should be done more often in order to gather additional knowledge about the impact of Microplastic pollution on the land.

7.6 The Capacity of the Climate Change and Microplastic Pollution

On land, Microplastic contamination to the atmosphere can have an increased impact on ecological processes due to climate change. Weather is increasing in temperature, rain is falling in various forms and quantity of extreme weather events could influence the spread of Microplastics within the ecosystem and response to it by the soil organisms. As an example, changes in temperature: increased temperatures might increase the rate of decomposition of plastic making smaller particles more accessible to flies to consume. Two examples of environmental stressors that can be researched as future studies are the impacts of combined climate change and Microplastic pollution on how insects work, how steady their microbiomes are, and how effectively ecosystems work.

7.7 The Impacts on the Trophic Transfer and Food Webs

Land dwelling insects are quite significant in food webs. They are fed on by a good number of animals such as birds, reptiles, amphibians and small mammals. There are chances that insects consume Microplastics when feeding. This will enhance free movement of the plastic particles across tropic levels. The study should be expanded on further to examine transport and distribution of micro plastics in the land food chains and how it can affect the health of predators, the food chemistry cycle, and the stability of the ecosystem. To see the bigger picture of micro plastics pollution to the environment, you have to be educated on how trophic transmission works.

7.8 Creation of Standardized Experimental Procedures

The alternative issue with existing studies on Microplastics is the fact that there are no apparent means to quantify the exposure and subsequent biological impact of Microplastic exposure on terrestrial organisms. Comparing the data known in various research is sometimes difficult due to the fact that the particles may be of different sizes, the polymers of different types, the dose of different types, and may be experimentally configured differently. Researchers should develop universally accepted methods of testing the impacts of Microplastics on insects and their microbiomes in the future. This will cover the way towards easier comparison of research and estimating ecological at-risk determinations.

7.9 Effects on the Health of Soil and Ecosystem Services

It is possible that changes in the interactions between insects and microorganisms would include an enormous impact on soil insects because they are crucial in the breakdown of organic substances, circulation of nitrogen, and strength of the soil ecosystem services. These insect intestinal microbiomes affect the operations of soil microbes, decomposition of organic matter and plant development. Combining soil science, microbial ecology, and entomology will be of very great importance understanding the impact of contamination of soil with Microplastic on the soil health over time and ecosystem health.

Microplastics are even making their way up onto the ground, and this is an astronomical and vast environmental challenge especially when it comes to how they affect species and microbiomes, which grow in the soil. A lot has been carried out to research the Microplastic pollution on water but not on land systems especially insects and bacteria on the gut.

There is still a lack of minimal research on systems found on land particularly insects or micro sensors found within the guts. The current information of this review is of the sources of Microplastics, their environmental consequence and effects on living organisms. It studies the gut microbiomes of insects dynamics on the species level induced by these particles and how it may change the overall ecosystem functioning.

One of the most valuable lessons that we have received during this part of study is that Microplastic is capable of settling in the land habitats. Plastic mulching, Farm particles, urban, applications, wastewater sludge. Because of rubbish dumping and air transportation, Microplastics are collected in the soil.

Plastic waste products can also travel a long way in the water, and land-based Microplastics prefer to stay in the soil framework, and hence have more possibilities of getting in contact with soil plants. Increasingly significant inoculators of soil-dwelling insects (which are vital in dead plant and animal decomposition, nutrient transfer and structural integrity of the soil) are being exposed to Microplastic particles through dietary, contact, and tropic exposures to Microplastic. One of such aspects in the ecology of terrestrial pollution is the interaction of Microplastics with microbiomes in insect gut, which is a phenomenon which is of a specific threat and little research.

The insect digestive pathways carry host of types of microorganisms that facilitate intake of nutrients, transformation of complex substances, secretion and production of toxins as well as modification of immune systems by the insects. Any devastation of these microbial communities as a result of microbial dysbiosis can be massive in terms of the manner in which insects exist, the means through which they survive as well as their functioning in the ecosystem.

A second important fact that was pointed out during this paper is that the bacteria that exist in the gut of insects could possibly have a capacity to change or digest plastic polymers. Two insects, which are found to eat and partially degrade various types of plastics, are known as mealworms and waxworms.

It has polystyrene and polyethylene. It is usually assumed by people that it is the power of the bacteria that are found in their guts and do their activities like digesting food. It is not known which mechanisms are involved in the degradation of plastic by microbes. That notwithstanding, likely there are certain types of bacteria that reside in the stomachs of insects capable of producing an enzyme that can either disassemble chain polymers, or speed up oxidative processes that will help degrade plastic. And not until, it has not yet been discovered whether it turns into actual mineralisation, or is merely the substance disintegrating into tiny minority Microplastic or nano-plastic particles.

Adverse effects on the functioning of insects that can be caused due to Microplastics are numerous, and one should also not disregard the effect it can have on the microbiota and potentially degenerate it. Plastic substances can be carriers of chemical pollutants such as heavy metals, chemuronic and permanent organic contamination, and plastic.

Bisphenols and phthalates once ingested they may enter the digestive tract where they may change the body food processing mechanisms that include the microorganism functioning and immune system functionality and coexist. Oxidative stress and inflammation, along with a change in nutrient intake, may be among the processes that may take place due to such interactions. All these can lead to injury to their health and fertility. On land, insects have a big part to play in the food webs hence these impacts might be extended to other stages of the food chain and harm the predators, parasites and other insect dependent animals.

Microplastics may disorganize the microbiota and begin the decomposition process. They may also influence the working of insects in a manner that is not good to them. Plastic debris may contain chemicals which are harmful to the environment such as heavy metals and organic wastes which cannot be decomposed. Phthalates and bisphenol are two of the compounds that are harmful to the environment but are incorporated as additives to plastics. When you consume these chemicals they may seep into your digestive system. This may alter the normal functioning of your body, the normal functioning of your immune system and the bacteria balance. These interactions also have the potential to result in oxidative stress, inflammation and changes in nutrient absorption. This may be unhealthy to insects and their ability to give birth. Insects form a significant component of the land food webs, thereby such consequences might have impacts on numerous levels of the food chain, negatively impacting predators, parasites and other insect-dependent creatures.

There was interaction between Microplastics and microbiome, and it was not only single organisms that were subject to the effects of this interaction. They also impact on the larger ecological processes. Ground dwelling insects are particularly exceptional when it comes to breaking up the organic debris, mixing it, and relocating nutrients. Alterations in bugs may result in alteration of the important ecological processes such as the soil fertility, carbon cycling and the growth of the plants. Microplastics may render cooperation between microorganisms more difficult in the insect digestive systems and inorganic waste may not be broken down faster. The contamination of Microplastic could alter the microbe-mixture interactions of insects and microbes, thereby altering the way the ecosystem functions. This would alter the process of the biochemical activities that occur in the soil and also by means of migration of bacteria.

Climate change is another important contributor that may alter the terrestrial ecology and may interact with Microplastic pollution. The alterations in temperature, precipitation distribution, and soil water content may alter in the migration of Microplastics and functioning of soil organisms. Rising temperatures can accelerate the degree of breaking and decomposing of plastic. This may produce smaller particles that can easily be absorbed by the soil organisms. Climate change stress might also affect insect working and stable microbiome as well. This may aggravate the impact of Microplastic. The impact of climate change and Microplastic pollution on the environment is significant so they need to be studied together.

The problem of Microplastic littering of land ecosystem is significantly better comprehended at present, yet there are also numerous gaps in huge knowledge. Firstly, most of the existing research done until now has been done on water living animals. The terrestrial insects have not been studied much. The types of bugs that may be damaged by Microplastics are quite numerous and it is highly important to pay a lot of attention to them. Second, the majority of the works are based on laboratory experiments that failed to portray how hard it is to deal with dirt in field. To see the implications in the real world, it is impossible to overestimate the significance of using field research in the analysis of the long-term impact of Microplastic pollution of the ecosystem. Third, we remain not clear about what the exact effects of Microplastics on intestinal microbiomes of insects are, both regarding the digestion of food by microorganisms, and how genes work. Closer scrutiny of the areas of metagenomics, metabolomics, and microbial ecology would inform us on the way these three entities relate to each other.

It should incorporate methods of soil science, microbiology, entomology and environmental toxicity in the research in future. Observations of the effect of Microplastic exposure on microbiomes through correlation between high-throughput sequencing and its hypotheses. Also, look into the development of bacterial living alongside insects as degradable plastic proximal agents can offer fresh uses of plastic waste within biotechnology. But it is to be questioned do these processes actually completely breakdown the material of plastic or merely make plastic particles that can be harmful in some other way to the environment.

Another of the concerns, which the future studies would focus on, is the food chain and ecosystems effects of Microplastics. The ingestion of Microplastics may be propagated across land-based food webs because certain insects serve as food to birds, reptiles, amphibians, and mammals. That is why it is of paramount importance to understand the way they affect the environment, and the ecology.

Lastly, the result analysis that was performed in this article suggests that Microplastics are becoming a significant threat in the terrestrial ecosystem and the extent of the interference with the insect gut microbiome and the associated ecology can be significant. Despite the presence of the current data, there is less research on this question, however, the available studies indicate that Microplastics might alter the physiology in insects, modify the composition of the microbial community, or influence another way of ecosystem operation. To solve these challenges, scientists will be demanded to cooperate with one another to define interactions between Microplastics and bacteria, long-term impact of plastic pollutions on an ecosystem, and the ways of reducing the usage of plastics on the soil. These things are to be understood more as researchers continue to conduct more research on them. We ought to know how these things interrelate to each other so that we can be capable of maintaining this biodiversity, so as to have the soil healthy, as well as be able to see that the terrestrial ecosystems can still exist in a world that is progressively becoming clouded with plastic waste.

The accumulating number of Microplastics in land environments is an emerging global environmental issue with extended environmental impact on that environment. Majority of the earlier studies about Microplastic pollution centered on the marine ecosystems, but as per more recent studies it can also be observed that disclose that these long-term pollutants may also accumulate in the terrestrial and soils. All the time farming, plastic mulching, deposits of wastewater sludge, litter presented in urban areas, as well as air movement, and introduce Microplastics into terrestrial ecosystems. Consequently, living organisms settle on soil by chewing, physical contacts and troglo-parasitism. The review has juxtaposed what we have already known of the origin of Microplastics, their entry routes, as well as the impact that they have on the environment with particular attention to their interaction with the gut microbiomes of insects. The insects are being host to complex and highly specialized.

Their digestive systems have microbial communities that assist them in acquiring nutrients, digesting complex materials, eliminating harmful chemicals and supporting their immunological systems. Insects require these symbioses of microbes to remain alive and healthy. This is critical in the ecological services that are delivered by insects within the soil ecosystem. This is a review of evidence that could make being in the proximity of Microplastics affect these things. The interactions among microbes are low, and this is capable of altering the kinds of microorganisms, their digestion of food and even causing microbial dysbiosis in insect stomachs. Microplastics seem to affect the insect gut microbiomes in a number of ways. The visually experienced processes of plastic particles with intestinal mucosa can damage the normal digestion, and chemical substances related to plastics can sneak into the environment when in the intestines and germ that functions. The groups of microorganisms called the plastisphere microbiota may also exist in Microplastics after ingestion. This might adapt the construction of these groups and their performance. The consequences of these interactions might be eventually on the functioning of insects as concerns their work, their ability to digest food, their immune systems functioning, and their reproduction.

Another thing that is also discussed in this examination is the importance of other microorganisms found in the intestines of insects, when it comes to slipping down plastic. There exist numerous kinds of bugs which can consume and decompose certain kinds of plastic polymers. This ability appears very closely connected with the metabolism of bacteria in their intestinal systems. Those findings indicate that insect-related bacteria might contribute to the degradation of plastics but the ecological consequences are still not sufficiently clear. Otherwise, in most cases, as opposed to total mineralization.

The exposure of Microplastic is not only a harmful practice to the insects but to bigger ecosystems as well. Earth living insects aid in decomposing organic food, distributing nutrients, and maintaining the soil structure. Intestines of insects are twisting. Microbiomes have the ability to affect the way in which bacteria decompose things, the fitness of fertile soil, and the ease with which plants can absorb the nutrients they need. The Microplastics pollution may alter the interaction between insects, microorganisms and soil processes. This may indirectly impact positively on the health and the development of the ecosystems.

With global change and Microplastic contamination, things become a lot more difficult. Climate change can cause changes in the weather, the level of rainfall, and the content of the moisture in the soil. Such changes would possibly change the regions of Microplastics in nature and the bioreactions of living organisms in the terrestrial environment. Any alterations in the weather conditions and the increase in temperatures may alter the functionality of insects and microorganisms, and this might exacerbate the effects of Microplastic exposure. Owing to the ability to be able to predict what will occur in the future in the areas where land turns over rapidly, it will be significant to comprehend the related stresses.

A larger number of people are aware of the existence of Microplastic pollution in soils, but we have not answered all the questions we should know. Majority of research being conducted today has been conducted in limited laboratory studies or has mainly been studying animals that dwell in water. Long term ecological studies examining the ecological effects on exposure to Microplastic in terrestrial ecologies are poorly known. In addition, functionally important connections between Microplastics and microbiomes of the insect gut are also poorly characterized, especially in terms of metabolic pathways by microbes, gene expression levels, and host-microbe interactions. High-tech molecular techniques, such as metagenomics, transcriptomics, and metabolomics, provide us with the excellent opportunity to analyze complicated interactions better.

The forthcoming study should focus on an interdisciplinary approach that should include soil exchange, microbiology, entomology and environmental toxicity. There will be wide research on different species of insects in different ecological conditions that would be essential.

Conclusion

Microplastics are a symptom of a valuable and increasing component of land eco systems that is the result of the interaction between the eco system and the gut microbiomes of insects and other such activities. Existing studies provide us with a multitude of effective information about these interactions, yet, we are still unaware of the long-term impact of the exposure of Microplastic in soil on the environment and how it transforms the soil. In addition, the investigations of trophic transfer pathways and food-web interactions will be useful to understand better how Microplastics interact with terrestrial ecosystems and how they can influence the high trophic levels. We should fill these gaps of our knowledge so that we can learn more on how pollution impacts land and to come up with ways in which we can address the environmental impact of the plastic pollution in future. Such research will be of great use in identifying the best measures to conserve the environment as well as policies that will help reduce pollution of earth ecosystems.

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