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MICROPLASTICS IN AQUATIC AND TERRESTRIAL INSECTS: A GROWING ENVIRONMENTAL CONCERN

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ABSTRACT

Microplastic pollution is an escalating global concern, infiltrating both aquatic and terrestrial ecosystems and significantly affecting insect populations. These pollutants originate from industrial waste, synthetic textiles, packaging materials, and degraded plastic products, dispersing through water, air, and soil. Their pervasive presence enables interactions with diverse insect species across multiple habitats, raising concerns about their long-term ecological consequences. Aquatic insect larvae, such as those of mayflies and chironomids, ingest microplastics directly from contaminated water or indirectly through prey, leading to severe physiological disruptions. These include developmental abnormalities, increased mortality rates, and bioaccumulation, which can transfer up the food chain. Additionally, microplastics act as carriers of toxic pollutants, such as heavy metals, persistent organic pollutants (POPs), and endocrine disruptors, exacerbating their harmful effects on insect physiology and survival. Similarly, terrestrial insects, including honeybees, fruit flies, and silkworms, encounter microplastics via atmospheric deposition and contaminated food. Ingesting these particles can cause physiological stress, gut microbiota imbalance, reduced reproductive success, and immune suppression. Wood-feeding beetles and soil-dwelling insects, such as springtails, ingest plastic fibres, disrupting nutrient cycling. Ground-dwelling species, including ants, may experience behavioural modifications due to microplastic entanglement, impairing foraging and nest-building activities. This review highlights the ingestion, bioaccumulation, and toxicity of microplastics in insects, emphasizing their ecological risks. Despite growing evidence, research gaps persist regarding their long-term consequences. Addressing these challenges requires urgent research and policies on sustainable waste management and pollution control. Mitigating microplastic pollution is crucial for preserving insect biodiversity and maintaining ecosystem functions.

INTRODUCTION

Plastic pollution has become a widespread environmental concern, significantly affecting both freshwater and terrestrial ecosystems (Ritchie and Roser, 2018). In 2018, global plastic production reached approximately 359 million tons, and projections estimate this figure could surge to nearly 34,000 million tons by 2050 (Du and Wang, 2021). Plastics are primarily synthetic or semi-synthetic organic polymers with high molecular weight, with polyethylene (PE), polypropylene (PP), and polystyrene (PS) being among the most widely used microplastics (Fig.1) (Erni-Cassola *et al.*, 2019). Microplastics (MPs), defined as plastic particles measuring less than 5 mm in size (ranging from 1 micrometer to 1 millimeter), are now recognized as persistent environmental pollutants found across the globe. Due to their durability, MPs remain in ecosystems for extended periods, and water serves as a primary medium for their transportation between different environments (Jaikumar *et al.*, 2019; Xia *et al.*, 2021). Based on their origin, MPs can be categorized into two types: primary MPs, which are intentionally manufactured for specific commercial applications, and secondary MPs, which result from the breakdown of larger plastic debris. Notably, secondary MPs contribute to nearly 80% of global plastic pollution (Andrady, 2017) (Table.1).

Primary MPs are manufactured in various forms, including microbeads, and are incorporated into products such as cosmetics and personal care items for exfoliation (Fendall and Sewell, 2009; Darling *et al.*, 2015; Leslie, 2015). Additionally, they are used in industrial applications like sandblasting (Sundt *et al.*, 2014) and as plastic pellets in manufacturing processes (Browne *et al.*, 2011). These MPs often enter the environment due to accidental spillage during production, transportation, or usage. Meanwhile, secondary MPs originate from sources like synthetic textile fibers shed during washing (Fendall and Sewell, 2009; Browne *et al.*, 2011) and agricultural plastic residues left in fields (Kyrikou and Briassoulis, 2007). However, one of the most significant contributors to secondary MPs is the degradation of plastic waste in coastal areas due to environmental exposure (Andrady, 2017), as highlighted by Hidalgo-Ruz *et al.* (2012) (Fig.1).

In recent years, the widespread distribution of MPs has garnered increasing global attention due to their potential threats to ecosystems and human health (Du and Wang, 2021). The persistence of these pollutants in diverse habitats necessitates further research to understand their long-term ecological consequences and mitigate their environmental impact.

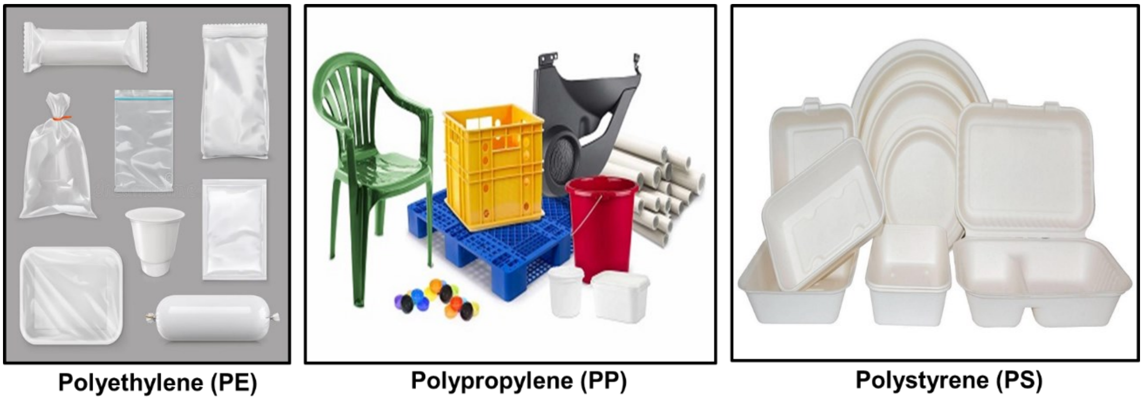
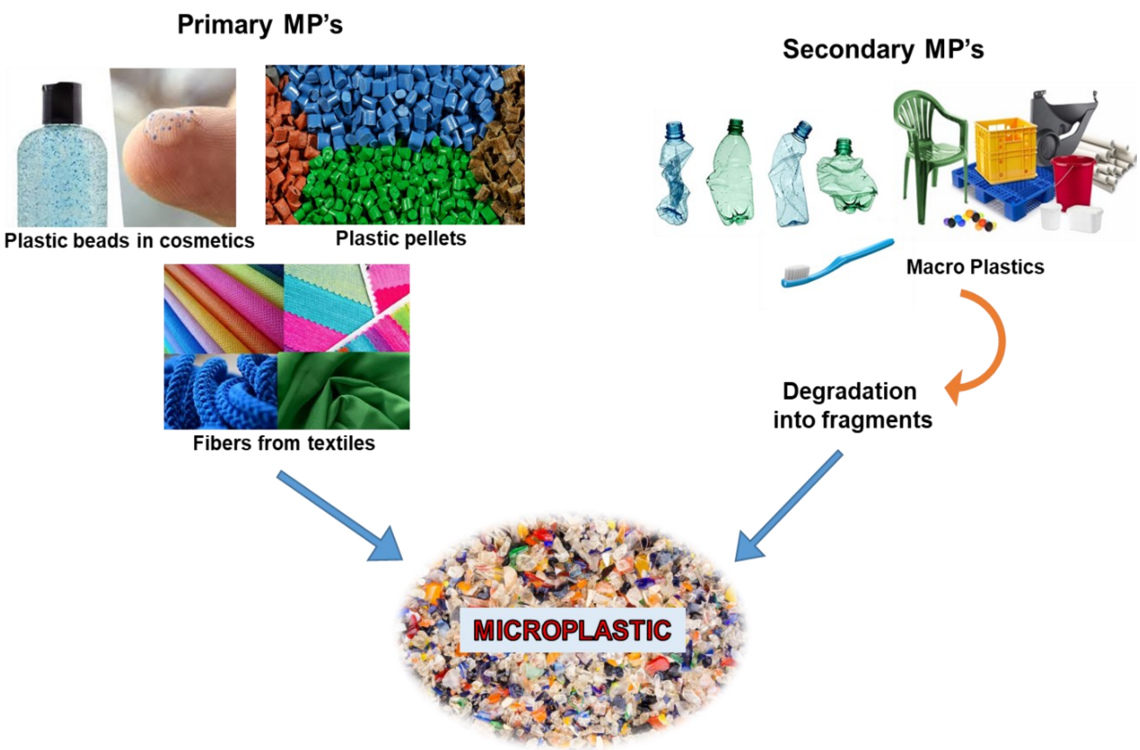


Fig.1 Various types of plastics and their contribution to microplastic pollution



Type of Microplastic	Description	Examples
Primary Microplastics	Manufactured microplastics, often used directly in products or as raw materials.	Microbeads in cosmetics and plastic pellets (Waldman and Rillig, 2020).
Secondary Microplastics	Result from the degradation of larger plastic items due to environmental factors.	Fragments from plastic bags, bottles, and other debris breaking down in the environment (Jaikumar *et al.*, 2019; Xia *et al.*, 2021).

Table1. Classification of microplastics with examples

2. Microplastics in Aquatic Insects

2.1 Microplastic ingestion in larval stages

Microplastics, recognized as a widespread environmental contaminant, significantly impact the early developmental stages of aquatic insects, influencing their growth, feeding patterns, and overall survival. These minuscule plastic particles infiltrate freshwater environments through sources such as wastewater effluent, surface runoff, and atmospheric deposition. Once in aquatic habitats, they are ingested by insect larvae either directly or indirectly via contaminated prey.

Research findings suggest that microplastic ingestion adversely affects larval development, leading to inhibited growth, disrupted moulting processes, and increased mortality rates (Bellinger *et al.*, 2021). For instance, exposure to microplastics has been linked to diminished feeding efficiency and delayed emergence in *Cloeon dipterum* (mayfly) larvae, which could have repercussions on adult population structures (Nelms *et al.*, 2020). Furthermore, the ingestion of microplastics alters energy allocation in larvae, as they expend considerable metabolic resources expelling non-nutritive particles rather than utilizing them for growth and metamorphosis. This energy misallocation may ultimately reduce reproductive success and population stability in these species (Eckert *et al.*, 2022).

2.2 Microplastic Bioaccumulation and Toxicity

Beyond direct ingestion, microplastics serve as carriers of hydrophobic pollutants, heavy metals, and microbial biofilms, intensifying toxicity levels in aquatic larvae. Studies indicate that *Chironomus riparius* larvae, after absorbing microplastics, experience oxidative stress and enzymatic disturbances due to their role as vectors for persistent organic pollutants (Scherer *et al.*, 2018). Additionally, microplastic ingestion may alter larval buoyancy, affecting dispersal patterns and habitat selection. These changes increase susceptibility to predation and environmental stressors, further jeopardizing survival rates (Windsor *et al.*, 2019). Given the essential role of aquatic insects in freshwater food webs, their decline due to microplastic contamination could lead to significant ecological imbalances, disrupting nutrient cycling and energy transfer to higher trophic levels, including fish and amphibians. As microplastic pollution escalates, assessing its long-term ecological implications is crucial for conservation and risk management efforts. A study by Corami *et al.* (2022) examined microplastic ingestion in two *Simuliidae* (Diptera) larval species from Italian rivers, reporting a mean microplastic abundance ranging between 144 and 1101 items per individual. Similarly, research by Ehlers *et al.* (2019) found that microplastic films and fragments were predominant in the larval cases of the freshwater caddisfly *Lepidostoma basale*.

2.3 Microplastics in Edible Aquatic Insects

Microplastic contamination in aquatic ecosystems is well-documented, yet its presence in edible aquatic insects raises concerns about potential human exposure through dietary consumption. A recent investigation into *Pantala* sp., a dragonfly larva found in rice fields, confirmed the presence of microplastics within various anatomical compartments, including the whole body, gastrointestinal tract, and body excluding the gastrointestinal tract. The study reported an average microplastic abundance of 1.34 ± 1.11 particles per individual, with plastic fragments being the most frequently detected type, followed by fibres and rods. Fourier-transform infrared spectroscopy (FT-IR) analysis identified the presence of polymethyl methacrylate (PMMA), polyethylene terephthalate (PET), and polypropylene (PP) in the examined larvae (Maneechan and Prommi, 2022).

Similar contamination patterns have been observed in other freshwater insects. For instance, *Pantala* sp. (Odonata: Libellulidae) from Thailand exhibited a dominance of microplastic fragments and fibres, mirroring findings in *Siphlonurus* sp. and *Chironomus* sp. from Nigeria (Akindele *et al.*, 2020). The occurrence of microplastics in edible aquatic insects highlights the potential risk of human exposure through food chains, underscoring the need for further research on the implications of microplastic accumulation in insect-based diets. As microplastic pollution continues to rise globally, its impact on aquatic insects—both in terms of ecological disruption and food safety—necessitates urgent attention. Future studies should focus on evaluating the bioaccumulation potential of microplastics across insect developmental stages and their subsequent transfer to higher trophic levels, including human consumers.

3. Microplastics in Terrestrial Insects

3.1 Microplastic Contamination in Foraging and Beneficial Insects

Microplastics have been found to affect various terrestrial insects, including honeybees (*Apis mellifera*), fruit flies (*Drosophila melanogaster*), and silkworms (*Bombyx mori*) (Wang *et al.*, 2022). While short-term exposure generally does not significantly impact insect mortality, prolonged ingestion of microplastics leads to alterations in growth, motility, gene expression, feeding behaviour, oviposition, gut microbiota, and immune response (Wang *et al.*, 2022; Liang *et al.*, 2022). Honeybees, being active foragers, frequently encounter microplastics in their environment, with studies identifying various polymer types attached to their bodies and within their hives (Edo *et al.*, 2021; Deng *et al.*, 2021). Long-term ingestion of polystyrene (PS) microplastics in honeybees results in their accumulation in the midgut, immune suppression, increased susceptibility to pathogens, and potential colony health risks (Wang *et al.*, 2022; Deng *et al.*, 2021). Similarly, silkworm larvae ingest PS nanoparticles (PS-NPs), which penetrate tissues and haemolymph, affecting locomotion and immune function (Parenti *et al.*, 2020). These findings highlight the complexity of microplastic toxicity, emphasizing the need for further studies on different insect species, microplastic types, and exposure concentrations to fully understand their ecological consequences.

3.2 Microplastics in Wood-Feeding and Soil-Dwelling Insects (e.g., Long-Horned Beetles)

Long-horned beetles (Coleoptera: Cerambycidae) play vital roles in terrestrial ecosystems, particularly in forest environments, where they contribute to pollination and serve as a food source for various vertebrates (Grünwald *et al.*, 2010; Haddad *et al.*, 2018; Hoang and Mitten, 2022). Their diet primarily consists of solid plant tissues and decaying wood (Mohammed *et al.*, 2018), making them likely to ingest microplastics present in their environment. More than ten types of polymer composition were identified in long-horned beetle samples, with fibres being the predominant shape of microplastics. These fibres likely originate from indoor textiles, fabric furniture, and carpets (De-Falco *et al.*, 2018; Dris *et al.*, 2017; Tiffin *et al.*, 2022). Fragmented microplastics mainly result from the degradation of larger plastic debris (Liu *et al.*, 2023; Xu *et al.*, 2020). However, further studies are needed to confirm microplastic ingestion in wild long-horned beetles and assess its ecological consequences.

3.3 Microplastic Entanglement in Insects (e.g., Ants and Ground-Dwelling Species)

Microplastic pollution poses emerging environmental risks, potentially impacting numerous insect species. One example is ants becoming entangled in synthetic fibres collected from natural habitats. A total of 113 ants were analyzed for the presence of microplastics in their bodies (Luna, 2023). Specifically, *Lasius grandis* and *Monomorium* sp. (Hymenoptera: Formicidae) were found entangled in plastic fibres within the summit broom shrubland and Canary pine forest of La Palma, Spain. While no immediate physical harm was observed, the mechanisms behind this interaction remain unclear. Ants may be redistributing microplastics within soils, influencing ecological interactions (Vazquez and Rahman, 2021; Liu *et al.*, 2023).

4. Strategies to reduce microplastic pollution

4.1. Improving waste management and recycling efficiency

- Enhancing plastic waste collection, sorting, and recycling processes can significantly reduce microplastic generation (Geyer *et al.*, 2017).
- Implementing advanced recycling technologies, such as chemical recycling, can help convert plastic waste into reusable materials (Ragaert *et al.*, 2017).

4.2. Reducing primary microplastic emissions

- Banning or restricting microplastics in personal care products and cosmetics (Fendall and Sewell, 2009).
- Encouraging the use of natural alternatives, such as biodegradable exfoliants in skincare products (Leslie, 2015).

4.3. Controlling microplastic release from textiles

- Developing and adopting microfiber filters in washing machines can prevent synthetic fibres from entering wastewater systems (Hartline *et al.*, 2016).
- Promoting sustainable textile production by using natural fibres and modifying synthetic fibre structures to minimize shedding (De-Falco *et al.*, 2018).

4.4. Biodegradable and eco-friendly plastic alternatives

- Encouraging research and development of biodegradable plastics derived from renewable resources such as starch, cellulose, and polylactic acid (PLA) (Karan *et al*., 2019).

- Supporting policies that incentivize businesses to adopt sustainable packaging solutions (Song *et al*., 2009).

4.5. Microplastic removal from water systems

- Advancing filtration and wastewater treatment technologies, such as membrane bioreactors and nanotechnology-based filters, to effectively capture microplastics before they enter aquatic ecosystems (Ziajahromi *et al*., 2017).
- Developing bio-based solutions, such as microplastic-degrading microbes and biofilms, for environmental remediation (Shen *et al*., 2020).

4.6. Public awareness and policy interventions

- Implementing educational campaigns to inform consumers about microplastic pollution sources and prevention strategies (Napper *et al*., 2020).
- Strengthening policies to regulate plastic production, improve labelling of microplastic-containing products, and enforce restrictions on single-use plastics (Andrady, 2017).

4.7. Monitoring and research for better solutions

- Expanding research on microplastic behaviour in different environments to develop effective mitigation strategies (Horton *et al*., 2017).
- Establishing long-term monitoring programs to track microplastic pollution levels and assess the effectiveness of intervention measures (Koelmans *et al*., 2019).

CONCLUSION

Microplastic pollution is an emerging environmental threat with profound implications for insect populations in both aquatic and terrestrial ecosystems. The ingestion of microplastics by aquatic larvae disrupts their development, increases mortality, and contributes to bioaccumulation, potentially affecting entire food chains. Similarly, terrestrial insects, including pollinators, decomposers, and soil-dwelling species, suffer physiological stress, immune suppression, and behavioural alterations due to microplastic exposure. The presence of microplastics in edible insects also raises concerns about their transfer to higher trophic levels, including humans. Despite growing awareness, many aspects of microplastic-insect interactions remain poorly understood. Further research is needed to assess long-term ecological consequences, the bioaccumulation potential across insect life stages, and the cascading effects on biodiversity and ecosystem stability. Addressing microplastic contamination requires interdisciplinary efforts, including improved waste management strategies, stricter regulations on plastic production and disposal, and the development of biodegradable alternatives. By mitigating microplastic pollution, we can safeguard insect diversity and preserve the essential ecological services they provide.

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