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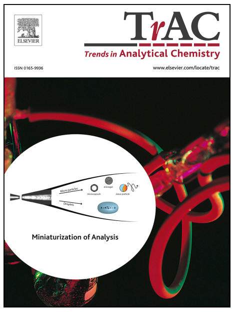


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# Are ecosystem services provided by insects "bugged" by micro(nano) plastics?

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## Abstract

Although the study of the effects of microplastics increased in the last years, terrestrial ecosystems remain less studied. In fact, the effects of microplastics in insects, the most abundant group of animals and major providers of key Ecosystem Services, are not well known despite the potential cascading negative effects on the ecosystems functioning in the habitats where they occur. In this paper, a revision on available studies on microplastics contamination is provided and potential consequences to major Ecosystem Services provided by insects are discussed, using the Common International Classification of Ecosystem Services (CICES) methodology.

The revision underpinned probable and potential impacts for all tree CICES divisions, i.e.: Provision, Regulation and Maintenance and Cultural Services. The available studies seem to show that different groups react differently to microplastics contamination, which clearly indicates that the effects in Ecosystem Services provided by insects need a more empirical and targeted approach.

**Keywords:** Insects; Microplastics; Ecosystem Services; Ecological Function; CICES

## 1. Introduction

Plastics are undoubtably an important pillar material in the current society due to their resistant, mouldable, and cost-effective nature. Plastic materials can be dispersed by wind, rivers and ocean currents across the globe. In the environment, plastics particles slowly break into smaller fragments (micro and nanoplastics) through physical degradation, photodegradation, and biodegradation. The term microplastics is frequently used to define plastic pieces smaller than 5 mm in size. Nanoplastics may be defined as particles smaller than 100 nm although some authors consider nanoplastics plastics smaller than 1000 nm [1, 2].

Microplastics found in the environment may be of a variety of sources like synthetic clothing fibres, industrial waste, or beauty products and they have been found in the digestive systems of different aquatic invertebrates [3], where they can remain for days or weeks before excretion [4]. This retention time may facilitate the transfer of microplastics through the food web, or to other ecosystems. However, the effects of microplastic exposure are not consistent across studies, with some organisms being resilient to the induced stresses [5], or able to egest them, which seems to indicate that potential cumulative impacts can be minimized. Nevertheless, several aquatic organisms exposed to microplastics seem to be negatively affected in their feeding and reproductive capabilities [6], growth [7], and survival [8].

In terrestrial environments the use of sewage sludge for agricultural fertilization [9] and plastic mulch to suppress weeds in crop production [10] can lead to micro(nano) plastics accumulation in soils. Although terrestrial systems have not been so exhaustively studied as aquatic systems, microplastic contamination may be 4-23-fold larger than in the ocean, according to estimations [11]. Insects are the most abundant and diverse group of organisms in the planet [12]. Found in almost all habitats on earth, insects are adapted to explore different food sources, making them able to persist in the most varied and environmental extreme niches. Due to their huge diversity, ecological function and ubiquitous nature, insects contribute to the structure and condition of ecosystems and are providers of several ecosystem services.

The pervasive nature of microplastics contamination, makes the contact between plastics and insects inevitable. However, there is a scarcity of information concerning on how this contact will affect major Ecosystem Services (ES) provided by insects.

A recent review by Ameixa et al. [13], underpinned several indicators of ES provided by insects using the Common International Classification of Ecosystem Services (CICES) methodology. Here we will try to identify relevant examples on the microplastics influence on these ES and try to highlight which ES can be negatively influenced by the presence of microplastics as well as existent knowledge gaps.

## 2. Methods

Following the work by Ameixa et al. [13], a search on existing evidences of microplastics effects on insects or their habitat was performed and the implications on the potential provided on ecosystem services by this group of animals discussed. In this work these services will be categorized according to the CICES, that considers three major categories: provisioning, regulating and maintenance, and cultural services [14]. The CICES latest full version can be downloaded at http://cices.eu/.

The literature search was performed in specific scientific libraries (i.e., Scopus and Web of Knowledge), using the following keywords (single and in combination): Microplastics, insects, ES, ecological function, pollination, seed predation, biological control, decomposition, seed dispersal, food, feed, materials, medicines, society and ecosystems.

## 3. Results

The results are structured and organized according with CICES hierarchical structure, on the major sections and on classes.

### 3.1. Provision services

This section includes all nutritional and material outputs (biomass) obtained from insects.

### Reared and wild animals and their outputs for direct consumption

A study by Liebezeit and Liebezeit [15] , analysed nineteen honey samples finding fibres and microplastics in all samples. In fact, fibre counts ranged from 40 up to 660 per kg of honey, and fragments ranged from 0 up to 38 per kg of honey. In a second study the authors presented data from 47 honey samples, with particle load ranging from 10 up to 336 fibres and 2 up to 82 fragments per kg of honey [16]. Introduction of particles during the honey processing and/or transferring from the flowering plants to the beehive by the worker bees during nectar collection were presented as potential sources of the particles. However, another study by Mühlschlegel et al. [17] found no evidence of honey samples being significantly contaminated with microplastic particles.

### Wild animals for indirect consumption

Insects are ingested by many different animal groups, including animals used in human nutrition. There are evidences that mandibulate insects are able to chew and eat plastic packages, including polyvinyl chloride (PVC), polyethylene (PE), and polypropylene (PP) packaging films [18-20]. A recent study found that *Culex pipiens* mosquitoes' larvae, that may be found across the world in many habitats, were able to consume 0.0002 cm microplastics which could be transferred ontogenically from the feeding (larva) all through the adult terrestrial life stage [21]. Microplastics were identified in approximately 50% of macroinvertebrate samples collected (Baetidae, Heptageniidae and Hydropsychidae) at concentrations up to 0.14 microplastics per mg of tissue [22]. These observations suggest a potential trophic transfer of microplastics along the food web since insects such as mosquitoes, are eaten by other animals which then are eaten by humans.

### Insects products for direct use or processing

There are potential impacts of microplastics on marine invertebrate physiology which may include decreased enzyme activity, diminished feeding, reduced growth rates, lowered steroid hormone levels, negative impacts on reproduction, and absorption of contaminants. In insects, although there is no evidence that the presence or ingestion of microplastics can interfere with the production of products such as honey, wax or silk, it is known that these processes are regulated by hormones. For instance, the application of juvenile hormones analogues to silkworms can increase their development and silk production [23]. Also, in social insects such as bees, pheromones play a key role in the regulation of group homoeostasis and the interference with these can indirectly impair honey production.

### 3.2. Regulation & Maintenance

This section covers all the ways in which insects can mediate or moderate the ambient environment (mediation by biota and mass flows) that affects human performance.

#### Bio-remediation by insects

Although it is known that some insects can eat plastics, until recently, little was known about whether the ingested plastic could be biodegraded in the gut of the plastic-eating insects. Yang et al. [24] study reported that waxworms (*Plodia interpunctella* larvae) were able to chew and eat polyethylene films, and later isolated, from the gut of the worms, two bacterial strains capable of degrading polyethylene (*Enterobacter asburiae* YT1 and *Bacillus* sp. YP1 [25]). In another study it was also demonstrated that the larvae of the mealworm beetle (*Tenebrio molitor*) was able to eat styrofoam, as their sole diet [26].

It was demonstrated that earthworms by producing biopores are able to transport microplastics down the soil profile [27]. Termites and ants, that are important ecosystem engineers, also move such particles in soil [28]. One of the possible implications of microplastics transport down the soil profile can be a slower turnover of these particles at greater depths, as microbial populations are much reduced [29].

Soil collembolans, formerly considered insects, are a key group of the soil fauna, playing crucial functions by feeding on soil detritus, litter and microbiota and by promoting organic decomposition and nutrient cycling in soil ecosystems [30]. A study by Zhu et al. [31] found that the exposure to microplastics altered gut microbiota, and inhibited growth and reproduction, which will have implications in the decomposition rates.

**Pollination by insects**

Pollination is a key driver in the maintenance of biodiversity and ecosystem functions. About 90% of flowering plant species directly depend on pollinators, as well as many agronomical important crops which require cross-pollination to produce seeds and fruits, with insects playing a central role in this process.

As already mentioned, microplastics may be found in flowers of several plant species [32]. In an early study, non-living particles (latex beads) were artificially introduced onto the transmitting tracts of styles of different plant species and were translocated to the ovary [33]. This suggest that microplastic beads of pollen size can interfere with plant pollination. The fall-out of microplastics can, for this reason, have huge implications on plant pollination, since these particles can mimic pollen grains.

**Seed dispersal by insects**

Plants and insects have developed several interactions (e.g., plants depending on insects for seed dispersion produce seeds with special coating which can be eaten by ants or other phytophagous insects without damaging their viability. In addition, seeds can be inadvertently dispersed by insects, gripping on to their hooks, teeth or viscous hairs [34].

Following the last section on pollination, if plants were to produce less seeds due to pollination interference by microplastics, then less seeds would be dispersed by insects. In addition, the consequences of pollination interference for wild plants and cash crops pollination can negatively affect the seed bank of wild flowers or commercial seed production in cash crops.

**Maintaining nursery populations and habitats**

Microplastics are ingested by several insect groups and are even able to pass through metamorphosis to life adult stages [21]. Wild insect species serve as food for other predators (e.g. fish, birds, spiders, lizards, bats) and, in this way, microplastics may be able to climb the food web. Furthermore, insects, which occasionally may be fed with contaminated by-products from agriculture or other industries, are being incorporated as feed into animal production systems (e.g. aquaculture).

In addition to the problems associated with microplastics themselves, due to their hydrophobic nature, microplastics may adsorb persistent organic pollutants (e.g. polychlorinated biphenyls, dichlorodiphenyltrichloroethane (DDT), polybrominated diphenyl ethers, polycyclic aromatic hydrocarbons) and metals, which can bioaccumulate in food-webs [35]. Furthermore, during plastic manufacture processes, additives are added to endow plastics with certain desired properties which may also affect biota. Plasticisers such as phthalates and bisphenol A, can induce acute toxicity in crustaceans and insects and can affect reproduction and hormone function [36]. Along the food-web, insects are eaten by other animals such as fish, for which these substances were linked with several adverse effects including endocrine disruption [37], decreased fish populations [38] and reduced species evenness and richness [39].

Insect behaviour, ecology and physiology strongly depend on hormones. If these chemicals can act as hormone analogues, they can interfere with processes such as growth and reproduction and could cascade to other trophic levels along the food web.

**Pest control by insects**

Pest insects have a large array of natural enemies, predators, parasitoids and pathogens which keep them under economic threshold levels. Entire orders of insects – such as Odonota and Neuroptera – are predators, and a large percentage of other orders (Hemiptera, Coleoptera, Diptera, and Hymenoptera) have a huge number of families which are predators. Also, insects can control noxious plants, for instance, snout beetles, successfully controlled water hyacinths in Lake Victoria [40]. This natural biocontrol provides an important ecosystem service, especially to agroecosystems. There are no studies dealing with microplastics biocontrol interference in insects, however if we consider that hormonal regulating processes are impaired, we can predict deleterious effects.

Prolonging larval instar duration in predators which are commonly used as biocontrol agents can enhance the predation of these as well. For instance, natural ladybird larval mortality has been estimated in 99% [41]. Susceptible instars of native ladybird's such as eggs, larvae and pupal instars can be more prone to predation by other predators, such as the invasive ladybird *Harmonia axyridis.* If due to hormonal deregulation, the duration of these vulnerable instars is increased, this may also increase the mortality during these instars.

Generation time ratio (GTR) in insect predator-prey systems is often large i.e., the developmental time of predators often spans several prey generations [42]. This is one of the reasons why some biocontrol agents seem to be less effective in controlling their prey. Thus, increasing GTR can influence the ability of predators to serve as effective biocontrol agents.

**Soil formation and composition**

Termites and ants provide rich substrates for the microbial degradation and mineralization of organic matter [43]. Due to their gut symbionts, termites probably are, among soil invertebrates, the biggest contributors to plant litter breakdown, including cellulose and lignin [43]. It is known that subterranean termites are able to damage plastic products [44]. Although gut bacteria of the beetle *Tenebrio molitor* have been shown able to degrade polystyrene [26], it is not known if and how microplastics can interfere with microbial activity in termite guts and consequently in the ability to degrade plant litter and wooden materials.

**Decomposition and fixing processes**

It has been already demonstrated for collembolans (formerly included in class Insecta), that the exposure to microplastics could, by altering gut microbiota, have potential implications in the decomposition rates and nutrient cycling [31]. Similarly, insects are major agents of waste biodegradation. Beetle larvae, flies, ants and termites break down organic matter until it is fit to be consumed by fungi and bacteria, making minerals and nutrients of dead organisms available for plant uptake. In fact, the decomposition of dead plant material can induce other services such as the decline in the frequency and severity of forest fires [45].

By altering insect feeding behaviour, microplastics may influence insect herbivory, and these changes can alter litter characteristics, such as carbon to nitrogen and lignin to nitrogen ratios, inducing changes in decomposition rates and subsequent nutrient transformations [46].

**3.3. Cultural**

This section covers all the non-material, and normally non-consumptive outputs of insects that affect physical and mental states of people.

**Experiential use of insects and insect dependent wildlife**

Several activities depend, even if indirectly, on insects. These activities include for instance, wildlife observation not only of insects but also of other insectivorous animals such as birds, amphibians, reptiles and small mammals. This also includes activities such as hunting and fishing of insect dependent wildlife.

It was already demonstrated that microplastics are ingested by numerous organisms, its intake and accumulation have been demonstrated for several animals ranging from filter organisms, invertebrates, fish, mammals, birds and even humans. Microplastics were found in several types of insects such as, mayflies, and caddisflies [22] and can be ingested by mosquito larvae [21]. These insects have an aquatic larval stage and provide important food sources for birds and other predators such as spiders, lizards, bats and even mammals.

In the case of terrestrial insects, these organisms are estimated to comprise up to 80% of some fish species diets [47], with indications that stream fish often prey selectively on terrestrial invertebrates that fall into streams [48]. For game birds, the high protein content of insects and other invertebrates, is essential for chick development [49]. It is clear that insects have a determinant roll in these trophic webs. Thus, any negative impact on these organisms may affect the development of several insect dependent wildlife and, consequently, human activities that depend on them.

**Scientific use of insects**

Since insects readily respond to environmental changes, including those from anthropogenic activities, they are good bioindicators of ecological condition. In fact, they have several characteristics such as small size, short life spans and high reproductive rates that make them more useful indicators of disturbance than larger or longer-lived organisms with slower responses.

It was demonstrated for collembolans that exposure to microplastics lead to growth and reproduction inhibition [49]. Thus, by changing the characteristics that make them good indicators, the bioindication service can be potentially compromised.

## 4. Conclusions

Due to their ubiquitous nature in the majority of ecosystems, insects, similarly to other wildlife animals, will be affected by microplastic contamination. Most studies so far have mainly looked at marine environment, however it is estimated that agricultural soils alone can store more microplastics than oceanic basins [50].

In the late years several reviews on the effects of microplastics in wild animals have been published. However, more studies on causal effects are necessary, since the available studies seem to show that different groups react differently to microplastics. For insects, for instance, some species are able to digest microplastics while others have their growth and reproduction impaired.

Other knowledge gaps are also of concern. For instance, it is known that termites are able to ingest plastics, but it is not known how these affect their gut microbes responsible for cellulose degradation. Also, the contradictory studies on honey contamination should be solved, since the potential presence of microplastics in honey samples can influence people's perceptions regarding honey as a natural product. Overall, due to the existence of all these knowledge gaps it is urgent to perform more studies on these major providers of Ecosystem Services.

## 5. Acknowledgements

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**Highlights:**

- Evidences seem to demonstrate that different insect groups react differently to microplastic contamination.
- Most impacted services are expected to belong to Provision and Regulation and Maintenance sections.
- The potential influence of microplastic contamination on some major services can cascade onto ecosystem functioning.
- A more empirical approach is necessary to understand how key Ecosystem Services provided by insects are affected by Microplastics contamination.