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What we know and what we think we know about microplastic effects – A critical perspective

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Abstract

Microplastic pollution is currently perceived as an environmental hazard, and adverse effects have been reported at various levels of biological organization. However, the experimental design of most studies does not allow distinguishing plastic-specific effects from those caused by any other particles, such as clay and cellulose, which are ubiquitously present in the environment. We suggest that microplastic effects reported in recent ecotoxicological studies are similar to those induced by the natural particles. To provide a basis for risk assessment, experimental designs must allow disentangling food limitation and particle toxicity effects and demonstrate whether microplastics cause impacts that differ from those induced by natural particles.

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Introduction to the problem

As a result of plastic degradation, the accumulation of microscopic plastic particles, commonly termed microplastics (<1 mm), is increasing in the environment. Today, microplastic pollution is perceived as an environmental threat, mainly because ingestion of larger plastic debris has been observed to cause gastrointestinal blockage in, e.g., mammals, fish, and birds [1]. By analogy, similar effects are anticipated in organisms at lower trophic levels [2]. Such parallelism or "guilt by association" should, however, be handled with caution. One should keep in mind that non-food-particles in the microplastic size range, such as mineral (clay, sand, etc.) and organic particles (cellulose, chitin, amber, etc.), are naturally abundant and ubiquitous in the environment, where they by far exceed ecologically plausible microplastic concentrations [3,4]. Moreover, filter-feeders, the animals that encounter microplastics at the base of the food webs, have successfully evolved to handle mixtures of edible and non-edible particles [5] and would, therefore, be well-equipped to handle exposure to a variety of inert particles. These aspects have been largely ignored in the microplastic research. Furthermore, the current lack of proper particle characterization [6,7] and the inappropriate treatment of plastic as a single substance have hampered the identification of relevant modes of action, understanding of interactions between microplastics and biota, and, consequently, the advancement towards a meaningful risk assessment. Although similar challenges have been recognized in the field of nanomaterial research [8–10], the studies on microplastics are rather ignorant about the similarity of the problems. As a consequence, many experimental studies have been ridden with misconceptions regarding exposure conditions and uninformative from a risk assessment perspective. Due to such misinterpretations, the perception of the hazardous nature of microplastics continues to rise.

Here, we review recently published studies and discuss observed effects from an ecological perspective and relevance for risk assessment. Particular attention is paid to the experimental settings of the microplastic exposure and effects on feeding and growth. The effects involving persistent organic pollutants, leachates and biofilms associated with microplastics are discussed elsewhere e.g. [11,12], although the main points outlined here are fully applicable to the contaminant- or biofilm-mediated impacts of microplastics.

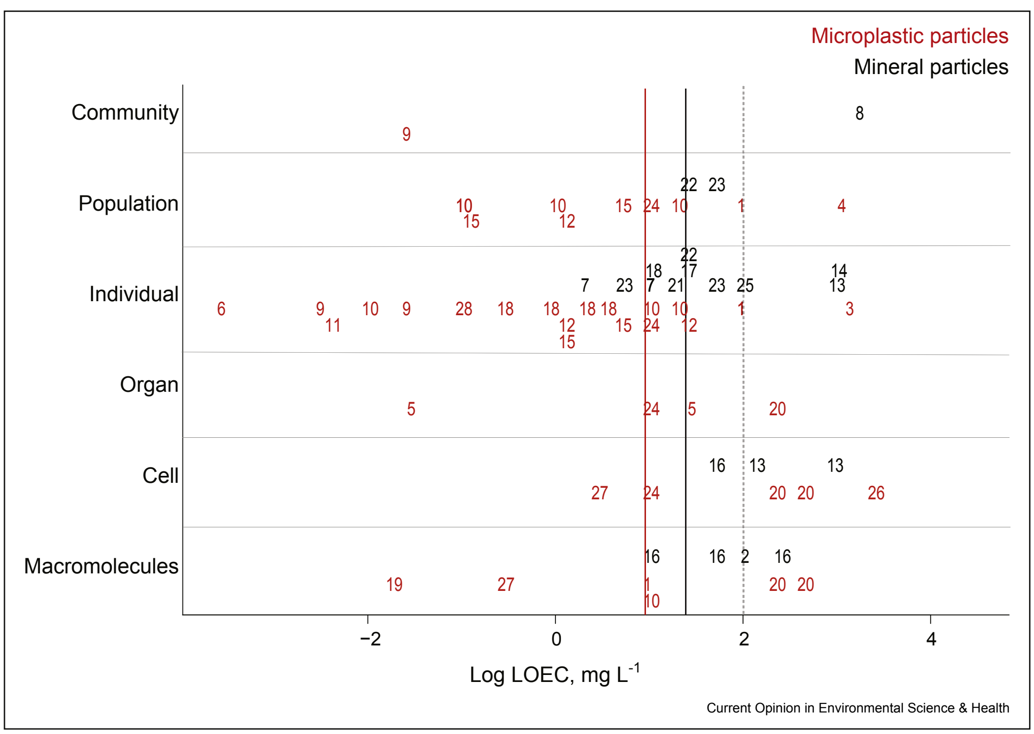
Effects of particle exposure are not unique to microplastic particles

Most aquatic organisms can ingest microplastics. Effect studies have primarily focused on organisms at lower trophic levels, i.e. zooplankton [13–15], benthic invertebrates [16–19], and fish larvae [20–22], because they have been identified as particularly susceptible to ingesting microplastics. These are also the animals frequently encountering turbid environments. Indeed, terrestrial runoff, tidal flushing and resuspension of bottom sediment by currents often lead to highly elevated concentrations (in the order of g L^{-1}) of non-palatable particles in the water column. Organismal responses to turbid conditions in suspended sediments and fine particulates have, therefore, been studied in ecology and aquaculture. It is, therefore, relevant to compare responses to particle exposure between the microplastics and other suspended solids present at ecologically relevant concentrations.

The comparison of the reported effects of microplastics and suspended sediments in various test organisms and across the different levels of biological organization suggests that effect concentrations are often comparable (Fig. 1). Still, the LOEC values reported in the experiments with microplastics are significantly lower compared to the values for suspended mineral particles (Table S2, Fig. S1), albeit only for the higher-level responses (Supporting Information Table S3 and Fig. S2). The comparison may be affected by the difference in specific gravity between the microplastics (close to 1 g cm^3) and mineral particles (2–3 g cm^3) leading to both slightly lower LOEC values and faster removal of the sediment particles from the water during the exposure, and hence overestimated LOEC values. Also, microplastics used in such experiments have smaller and more uniform particles compared to the size spectra of natural sediment [c.f. 4,23]. The latter implies that on a particle count basis, the experimental microplastic concentrations would be higher than those of sediment particles. As clearance rate in most non-selective feeders is a function of particle abundance [24], the number of particles in a searchable volume is more important than mass-based concentrations. Consequently, controlled experiments are needed to conclude whether microplastics have indeed lower LOEC values and thus higher toxicity compared to the naturally occurring particles.

The effect mechanisms of microplastics vary across biological scales. Particles that are too large (>5 µm) to translocate to systemic organs, can mostly cause sublethal effects, e.g., compromised feeding, impaired condition and fecundity [14,18,20,25]. However, in the micron/nano range (<5 µm), the particles are easily phagocytized and transported into tissues [26,27], where they may cause inflammatory responses [16,28,29]. At the macromolecular/cellular level, microplastic exposure

Fig. 1



LOEC values reported for plastic and mineral microparticles. Log10-transformed lowest observed effect concentration (LOEC, mg L^{-1}) in various species exposed to a suspension of microplastics or mineral particles; the values are summarized using 28 experimental studies. The responses were measured at different levels of biological organisation (macromolecules, cell, organ, individuals, population and community) at varying exposure conditions. The reported values are plotted as a reference number of the study (Supporting Information, Table S1). As the LOEC concentration, we used the lowest test concentration that resulted in a significantly different response (in any direction) compared to a particle-free control. Solid vertical lines show median values for each group. Observe that most values, irrespective of the particle type, are below the acceptable daily discharge limit for total suspended solids (TSS; 100 mg L^{-1}) in stormwater shown as the vertical, dashed line [50].