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Quick guide

Micropollutants

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What are micropollutants?
Micropollutants are organic and inorganic contaminants that have become widespread in ecosystems around the globe. By definition, micropollutants are of anthropogenic origin and occur in the environment at trace concentrations — that is, in the range of micrograms, nanograms, or picograms per litre or kilogram. These contaminants include a wide array of natural and synthetic organic compounds, such as pharmaceuticals and personal care products (PPCPs), perfluoroalkyl and polyfluoroalkyl substances (PFASs), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), nanomaterials, steroid hormones, pesticides, and plasticisers. Likewise, metals present in the environment at greater than (potential) background levels fall into the category of micropollutants and include heavy metals, trace metals, and metalloids. Notably, while chemical pollution has historically been attributed to a defined group of industrial chemicals, many micropollutants are instead considered to be emerging contaminants, which were traditionally unmonitored and unregulated but are potentially hazardous to wildlife and human health.

Where are micropollutants found?
Thousands of micropollutants are released due to anthropogenic activities and their resulting contamination of natural systems is among the leading environmental challenges of our time. Pathways by which micropollutants enter ecosystems are highly diverse, including both point sources (localised and stationary sources) such as domestic and industrial wastewater, and non-point sources (without a specific point of discharge) like agricultural runoff, road and roof runoff, and unintentional spreading of pesticides, herbicides, and fungicides. Given these varied

Figure 1. Micropollutants have been detected in ecosystems globally, as well as in the tissues of a wide array of species.
(A) Pharmaceutical residues have been found in osprey (*Pandion haliaetus*) nestlings feeding on tainted fish from the Delaware River. (B) Polychlorinated biphenyls (PCBs) have been sampled in Greenland killer whales (*Orcinus orca*). (C) Approximately one-fifth of roach (*Rutilus rutilus*) sampled in UK rivers were intersex (i.e. possessing both female and male characteristics) due to exposure to 17α-ethinylestradiol (EE2) and other endocrine-disrupting hormones. (D) PCBs are bioaccumulated by amphipod species inhabiting the deepest reaches of the ocean, including the Mariana Trench at a depth of over 10 kilometres. Photo credits: (A) iStock.com/MikeLane45; (B) iStock.com/Rasmus-Raahauge; (C) iStock.com/crisod; and (D) ©Alan Jamieson.

pathways, it is unsurprising that micropollutants are commonly found in a range of different environmental matrices, from runoff and sludges to freshwater and marine ecosystems, sediment, groundwater, soil, and dust. Concentrations of micropollutants also vary spatially and temporally. For instance, the composition and concentrations of micropollutant mixtures in effluent released from wastewater treatment plants fluctuate depending on the size and makeup of the community served by each plant, the time of year (for example, with changing weather and consumer behaviour), as well as the hydrology of the receiving system.

How are wildlife exposed to micropollutants? Micropollutants are commonly detected in the tissues of aquatic and terrestrial biota (Figure 1). Routes of uptake are, again, highly varied. For example, fish and other aquatic animals take up micropollutants from the water through their skin and respiratory organs (uptake solely from water is termed bioconcentration), as well as by food ingestion and contact with sediments (combined uptake via water, food, and sediment is termed bioaccumulation). Micropollutants can also accumulate in plants via foliage, stems, and roots. This has received particular research attention in agricultural systems, given the potential for commercial crops irrigated with reclaimed effluent to accumulate contaminants. Many micropollutants can also be magnified across trophic levels (termed biomagnification), whereby increasing contaminant concentrations are seen at successively higher levels in a food chain. An alarming example of this is the failure of many killer whale (*Orcinus orca*) populations to breed due to the biomagnification of PCBs. Exacerbating this issue, PCBs — and various other micropollutants — can be passed from mother to offspring (in this case, via placental and lactational transfer).

What effects can micropollutant exposure have on wildlife? Micropollutant exposure can have a range of adverse effects on wildlife. Well-documented examples include mass mortalities of Oriental white-backed vultures (*Gyps bengalensis*) scavenging on livestock carcasses contaminated with the anti-inflammatory drug diclofenac, and widespread endocrine disruption and intersex in fish exposed to the contraceptive pill estrogen 17α-ethinylestradiol (EE2) in sewage effluents. While population crashes and sex reversal are a relatively obvious sign of contamination, exposure to micropollutants can also have subtler but nevertheless important effects on wildlife. In fact, micropollutants have been shown to alter the development, physiology, anatomy, morphology, reproduction, and behaviour of numerous species. In support of this, dilute concentrations of a common anti-anxiety medication (oxazepam) led to increased activity and feeding rates and to reduced sociality in wild-caught European perch (*Perca fluviatilis*). Such trait changes are likely to increase predation risk, with implications for population persistence.

What is the future for research on the impacts of micropollutants? As the global population continues to grow, the already increasing rates of production, use, and release of chemicals are only predicted to escalate further. As such, research aiming to understand and mitigate the environmental impacts of micropollutants will likely continue to intensify. In understanding how these chemicals affect wildlife, a key recent departure from more conventional ecotoxicological approaches has been a shift towards assessing the impacts of micropollutants under environmentally realistic conditions. This involves the investigation of effects at field-realistic exposure levels, in complex mixtures, and on sublethal endpoints with ecological and evolutionary significance (such as behaviour). A crucial next step will be to expand this research to cover the large number of micropollutants for which scientific knowledge is lacking, and to establish whether and how sublethal trait changes produce population-level effects in the real world. In this regard, a targeted approach is clearly necessary, given that testing all micropollutants would be logistically and ethically prohibitive. For example, large-scale programs are using high-throughput screening methods and computational toxicology approaches (for example, the United States Environmental Protection Agency's Toxicity Forecaster, ToxCast) to identify hazardous chemicals. In addition, many ecosystems are affected by multiple forms of human-induced environmental change concurrently, including other kinds of pollution (such as noise, heat and light), invasive species, and climate change. Therefore, a formidable challenge that has received relatively little research attention to date is how micropollutant exposure might interact with other stressors and what implications this may have for exposed individuals and populations.

How can we limit the environmental impacts of micropollutants? Given the tremendous diversity of micropollutant sources, pathways into ecosystems, mechanisms of action, and effects on wildlife, a multipronged strategy is necessary to reduce the environmental impacts of micropollutants. Available approaches are diverse but many can be broadly categorised into either source controls (controlling chemical production, distribution, and use before potential release) or end-of-pipe controls (systems used to remove already-formed contaminants at the last stage before entering the environment). Source controls encompass green chemistry, a field dedicated to the design of compounds that minimise or eliminate the generation of hazardous substances — a highly promising but long-term approach. For substances of particular concern, targeted restrictions on production, marketing, and use are likely necessary to prevent environmental damage. However, this approach is not always viable because placing restrictions on certain chemicals may be ethically problematic (for example, if these chemicals are effective pharmaceutical drugs). There is also the risk that replacement products may themselves pose a potential hazard (for instance, the ‘regrettable substitution’ of bisphenol A with bisphenol S). Information campaigns aimed at changing consumer behaviour can also be effective in optimising usage, storage, and disposal of chemicals. However, compound-specific regulations and information campaigns are unlikely to ease the overall burden of micropollutants, given the many thousands of chemicals in commerce. For this reason, source controls should be accompanied by other measures, including end-of-pipe controls, such as wastewater treatment.

Where can I find out more?

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