PERSPECTIVES

Plastic fragments, including microplastics, are now ubiquitous on land, in freshwaters, and in the ocean.

POLLUTION

Microplastics research—from sink to source

Microplastics are ubiquitous not just in the ocean but also on land and in freshwater systems

By **Chelsea M. Rochman**

Research on microplastic pollution (small particles of plastic <5 mm in size) has long focused on their largest sink: the ocean. More recently, however, researchers have expanded their focus to include freshwater and terrestrial environments. This is a welcome development, given that an estimated 80% of microplastic pollution in the ocean comes from land (*1*) and that rivers are one of the dominant pathways for microplastics to reach the oceans (*2*). Like other persistent pollutants, such as polychlorinated biphenyls (PCBs), microplastics are now recognized as being distributed across the globe. Detailed understanding of the fate and impacts of this ubiquitous environmental contaminant will thus require a concerted effort among scientists with expertise beyond the marine sciences.

Scientists sporadically reported the presence of small plastic particles in the ocean as early as the 1970s, but research into their distribution and impacts effectively began in 2004 with a pioneering study led by marine ecologist Richard Thompson (*3*). To describe small plastic particles and differentiate them from large plastic debris such as fishing nets, bottles, and bags, the authors dubbed them "microplastics." Recognizing that microplastics were both widespread and potentially unique in their impact on the environment, they encouraged scientists to include the fate, contamination, and effects of microplastics on Earth's natural cycles, ecosystems, and organisms in their studies of plastic pollution.

What resulted was a scientific explosion. Over the past 14 years, researchers have documented and studied microplastics across the globe, resulting in tremendous advances regarding the sources, fate, and effects of microplastics and their associated chemicals. Several hundred scientific publications now show that microplastics contaminate the world's oceans, including marine species at every level of the food chain, from pole to pole and from the surface to the seafloor. Yet, scientists have only just begun to document and study microplastics in freshwater and terrestrial systems.

Microplastics were first reported in freshwater lakes in 2013 (*4*). Since then, microplastics have been reported on freshwater beaches, in lakes, or in rivers in Africa, Europe, Asia, North America, and South America (*5*). Just like in the marine realm, microplastics are common in freshwater systems at a global scale. Although contamination tends to be greater near large population centers, microplastics—often in the form of microfibers—have also been found in remote locations (*6*), perhaps as a result of atmospheric deposition (*7*). Microplastic concentrations in freshwater ecosystems are highly variable, and even though these systems are less dilute than oceans, concentrations reported thus far appear to be in a range similar to those in the marine environment (*5*). Microplastic contamination, as seen in marine animals, has also been reported in freshwater animals, including insects, worms, clams, fish, and birds.

Researchers generally seem to expect the effects of microplastics on freshwater organisms to be similar to those on marine organisms. In fact, scientists have been testing impacts of microplastics on freshwater animals for many years because several of them—such as Japanese medaka, zebrafish, *Daphnia*, and *Ceriodaphnia*—are standard toxicity test species. As a result, impacts from exposure to microplastics have been demonstrated in freshwater plants, invertebrates, and several species of fish (*5*). Still, the research remains young, and most studies of freshwater systems and organisms aim to better understand the sources of microplastics to the environment and their effects on animals in general. Given that freshwater ecosystems are highly diverse, with roughly as many fish species as in the oceans, researchers must also ask questions about the unique fate and effects of microplastics in

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these vulnerable ecosystems themselves.

Research on microplastics is even more limited for terrestrial environments. Despite a call for more research in terrestrial systems in 2012 (*8*), only a handful of studies have since sought to quantify microplastics in terrestrial birds (*9*), soils (*10, 11*), dust (including tire dust) (*12*), and atmospheric fallout (*7*). The discovery that microplastics can undergo atmospheric transport contributed appreciably to the current understanding of their global transport (*7*). To predict effects on wildlife, a few researchers have exposed insects, nematodes, and earthworms to microplastics in a laboratory setting. These studies have shown how microplastics may be transported through soils (*13*) and incorporated into habitats (*10*), as well as how they affect the feeding behavior and health of various terrestrial invertebrates (*14*).

Soils may act as an important long-term sink for microplastics (*8*). This has been demonstrated via the presence of plastic microfibers and fragments in sewage sludge that is widely applied on vast expanses of agricultural land (*11*). Other large-scale sources of microplastics in soils are the weathering and disintegration of protective plastic sheeting (plasticulture) over agricultural fields and the fragmentation of plastic litter and plastic items in landfills. To better understand microplastics as an emerging global contaminant, further field sampling should aim to measure the extent of the contamination on land. Models and laboratory and field experiments should aim to better understand the sources, fate, and effects of microplastics in terrestrial biomes.

Studies of terrestrial and freshwater ecosystems will continue to be particularly helpful for elucidating sources of microplastic pollution to the environment. This is because freshwater and terrestrial ecosystems are direct receivers of treated and untreated urban, industrial, and agricultural waste. The plastics in these environments therefore more readily reveal their original source than in the open ocean, where particles tend to be weathered, fouled, and highly fragmented.

For example, plastic microbeads from personal care products were first reported in the freshwater Laurentian Great Lakes (*4*), leading to legislation aimed at eliminating this source of microplastics in several regions (including the United States, Canada, and Taiwan). Moreover, a study from 2005 demonstrated that synthetic fibers are spread on soils when sewage sludge is applied (*11*). This study proposed synthetic fibers as an indicator of the land application of sludge, but also led researchers to conclude that laundry effluent is an important source of microfibers to the environment (*15*).

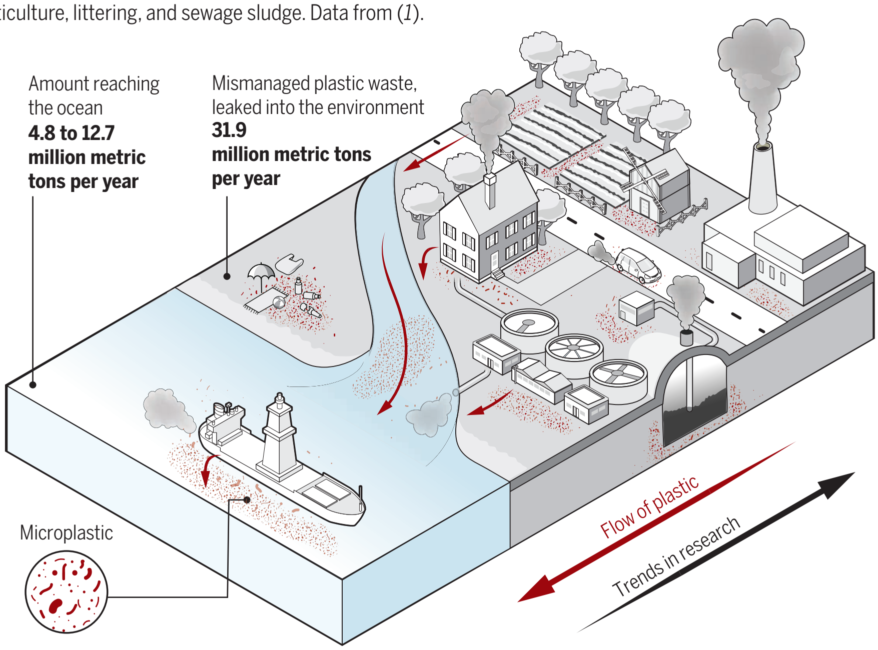
In general, freshwater and terrestrial studies have helped increase understanding of microplastic sources to the environment. Moreover, the current evidence suggests that microplastic contamination is as ubiquitous on land and in freshwater as in the marine environment (see the figure). But little is known about its fate and effects in freshwater and terrestrial ecosystems, which are governed by physical, chemical, and biological processes that differ from those in the marine realm. Progress in these systems can be accelerated by building on more than a decade of focused research on microplastics in marine ecosystems. For example, well-developed methods for sampling, extracting, and quantifying microplastics can be applied. Moreover, the same chemicals used to detect microplastics in marine environments can be applied in all environments.

Microplastic fate and impacts may vary across these systems, however. For example, there may be differences in how microplastics are transported in freshwater bodies because of differences in salinity, temperature, and current patterns. In terrestrial systems, atmospheric circulation may be responsible for long-range atmospheric transport of microplastics, similar to other persistent chemical contaminants. Exposure of and effects on organisms may also vary owing to differences in physiology. For example, marine fish drink water to maintain osmotic balance, whereas freshwater fish absorb water through their skin and gills; this should lead to different amounts of microplastic ingestion for identical concentrations of microplastics. Thus, these systems bring new challenges that must be considered, even as scientists apply knowledge of microplastics in the oceans to fast-track understanding of microplastics in fresh water and on land.

Even though the oceans cover more than 70% of our planet, the biodiversity in freshwater and terrestrial systems combined is more than five times greater than in the ocean. Researchers often ask questions about impacts to human health as a result of microplastics in seafood, yet microplastics in dust, groundwater, and agricultural soils may also be of great importance. As such, microplastic research must be global and include a greater understanding of the scale, fate, and effects of microplastic pollution at all stages, from its sources via freshwater and terrestrial ecosystems to its ocean sink. ■

Microplastics everywhere

High amounts of microplastics have been found not just in the sea and on beaches, but also in rivers and soils around the world, demonstrating how pervasive this modern pollution is. Sources include leakage from landfills, plasticulture, littering, and sewage sludge. Data from (*1*).



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