Abstract

[Project Information]

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[Abstract]

Microplastic (MP) pollution is a major global environmental concern that is increasingly considered threatening to both human and planetary health. MPs enter the ocean from various sources—including via urban dust, tire abrasion, textile washing, and fragmentation of marine plastic litter—yet few studies have quantitatively assessed the ecological risks of MPs derived from different sources to support effective deployment of control measures.

Here, we conducted a preliminary ecological risk assessment of MPs detected in Japanese surface waters (rivers: n = 28; oceans/lakes: n = 6) and sediments (beach: n = 25; surface: n = 36), using measured environmental concentrations and predicted no-effect concentration (PNEC) ratios. Median concentrations of small microplastics (SMPs; 0.02 to <0.3 mm) varied substantially (1.2×10^3–2.7×10^7 particles m^{-3}), with higher concentrations in sediments (beach: 2.7×10^7 particles m^{-3}; surface: 2.2×10^7 particles m^{-3}) than in surface waters (rivers: 2.9×10^3 particles m^{-3}; oceans/lakes: 1.2×10^3 particles m^{-3}). Across all media, median SMP concentrations were two to three orders of magnitude higher than those of large microplastics (LMPs; 0.3 to <5 mm), and SMPs in the 0.02 to <0.1 mm size range accounted for more than 65% of all detected MPs. Polypropylene (PP), polyethylene (PE), and polyethylene terephthalate (PET) were the dominant polymers in both SMPs and LMPs, with over 90% of LMPs identified as fragments

or fibers. Tire road-wear particles (TRWPs) were detected in surface sediments at 13–4300 μg g^{-1} dry weight (dw) (median: 180 μg g^{-1} dw). Plastic additives and their biological activities were assessed using gas chromatography–mass spectrometry and mammalian cell–based reporter gene assays. High concentrations of an antioxidant (oxidized Irgafos 168) and a plasticizer (DEHP, di-(2-ethylhexyl) phthalate) were detected in PP- and PE-MPs and showed strong pregnane X receptor agonist activity related to xenobiotic and endobiotic metabolism. Elevated concentrations of the flame retardant HBCD (hexabromocyclododecane)—a persistent organic pollutant restricted under the Stockholm Convention—were occasionally detected in expanded polystyrene MPs from ocean surface samples.

Simulated MPs, including tire wear particles, PP particles, and PET fibers, were prepared and exposed to ultraviolet (UV) irradiation to simulate environmental weathering. Leaching tests using cryo-milled tire tread identified 38 compounds, including antioxidants and vulcanization accelerators, which leached more readily at higher temperatures, while UV irradiation reduced their abundance. Biological impact tests with carp and amphipods showed that tire wear particles caused hematological toxicity and decreased survival and growth. PP particles also inhibited growth in both carp and amphipods, with virgin and smaller PP particles showing greater toxicity than weathered ones, whose effects were mitigated by UV exposure. PET fibers showed minimal toxicity, although UV-irradiated fibers suppressed carp growth.

Based on these results, the estimated PNECs for sediments were TRWPs: 500 μg g^{-1} dw, PP: 100 μg g^{-1} dw, and PET: 2500 μg g^{-1} dw. For water, the estimated PNEC for PP was 7.5 mg m^{-3}. Risk quotients derived from these PNECs indicate that TRWPs present substantial ecological risks, and that SMPs—particularly polyolefins such as PP and PE—may also pose potential risks to aquatic organisms in sedimentary environments.

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