environments

Editorial

Microplastics Pollution in Aquatic Ecosystems: Challenges and Perspectives

Farhan R. Khan [1,*], Charles Rolsky [2], Ana I. Catarino [3] and Varun Kelkar [4]

1 Norwegian Research Centre (NORCE), Department of Climate & Environment, Nygårdsgt 112, 5008 Bergen, Norway
2 Shaw Institute, Blue Hill Research Center, 55 Main Street, Blue Hill, ME 04614, USA; crolsky@shawinstitute.org
3 Flemish Marine Institute (VLIZ), Wandelaarkaai 7, 8400 Oostende, Belgium; ana.catarino@vliz.be
4 Alta Southwest, Tucson, AZ 85705, USA; vpkelkar93@gmail.com
* Correspondence: fakh@norceresearch.no or farhan.khan@gmx.com

Over the last 20 years, microplastics have emerged as a grave environmental concern owing to their ubiquitous presence and demonstrable toxic effects [1]. They have been found in all compartments of the aquatic environment, in both marine waters and freshwaters—water, sediment, and biota [2–4]. Over 1300 species, from invertebrates to apex predators, show evidence of exposure and impacts at cellular to ecosystem levels [1,5]. Adverse effects can result from the physical particle or the microplastic's chemical burden of plastic-associated chemicals and sorbed environmental pollutants [6–8]. The aim of the Special Issue "Microplastics Pollution in Aquatic Ecosystems: Challenges and Perspectives" was to expand knowledge on microplastics in aquatic environments and to improve understanding of how human pressures and environmental conditions shape their abundances and morphologies across diverse locations. We also encouraged contributions exploring novel exposure scenarios, including long-term and transgenerational effects, as well as studies addressing emerging plastic pollutants such as nanoplastics and e-waste.

Microplastics (330 µm–5 mm) were sampled from surface waters at six sites along Italy's Calabrian coast (Contribution 1: Brunetti et al., 2025). The average abundance was 0.06 particles/m^2, with higher concentrations near the commercial ports in Gioia Tauro and Cetraro. The most common microplastics were white or transparent polyethylene fragments (1–2 mm), with polymer type, size, shape, and color varying by location and season. Heavy metals, including lead, chromium, and zinc, were measured from the microplastics, indicating they are a vector of adsorbed environmental pollutants, as has been suggested elsewhere [9,10].

Microplastic concentrations were assessed in two headwater basins in the Southern Appalachians of North Carolina (the United States) and measured in atmospheric depositions (Contribution 2: Miller et al., 2025). Microplastic concentrations were among the highest globally, reaching up to 65.1 MPs/L, with fibers comprising ~90% and polystyrene, polyamides, and PET being dominant polymers. Concentrations varied widely by location, being higher near developed areas yet also significant in remote forested tributaries, indicating atmospheric fallout as a key source. These patterns reflect the complex interplay of land use, hydrology, atmospheric deposition, and transport dynamics.

Staying in the American waters, microplastics were measured at seven sites across the Mississippi River System during both flash drought and non-drought periods (Contribution 3: Wontor et al., 2025). Concentrations ranged from 16 to 381 MPs/L, with no significant difference between drought and non-drought conditions. The most abundant

check for updates

Received: 28 August 2025
Revised: 1 September 2025
Accepted: 2 September 2025
Published: 5 September 2025

Citation: Khan, F.R.; Rolsky, C.; Catarino, A.I.; Kelkar, V. Microplastics Pollution in Aquatic Ecosystems: Challenges and Perspectives. *Environments* **2025**, *12*, 315. https://doi.org/10.3390/environments12090315

polymers were PET (22%), resin (17%), and PE (10%). Microplastics were predominantly small (30–100 µm). While concentrations remained stable, drought significantly affected polymer composition. Flash drought conditions were associated with higher proportions of fluoropolymers ($p < 0.001$), revealing shifts in microplastic characteristics under rapid water-level decline.

Although Antarctica lacks permanent human settlements, it is not spared from microplastic contamination. The review by Pellegrino et al. (2025) (Contribution 4) documents the pervasive presence of microplastics in diverse Antarctic environments, including marine waters, sediments, freshwater veins, snow, glaciers, and atmospheric deposition, as well as biota (krill, benthic organisms, and fish). Evidence of microplastics has been found in terrestrial food webs, such as in collembolan species, and in tissues of Adélie penguins and seabirds. The review highlights the far-reaching spread of plastic pollution into one of the most remote locations on earth.

A study on *Biomphalaria glabrata* (freshwater snail) embryos examined the effects of polystyrene nanoplastics across three generations (Contribution 5: Martin et al., 2025). Results showed size- and concentration-dependent toxicity, with smaller nanoplastics (30 nm) causing higher mortality and reduced hatching rates. Gene analyses revealed upregulation of detoxification (CYP450), stress–response (HSP70), and developmental (MATN1) markers, particularly in F2 embryos, highlighting transgenerational impacts. Notably, F2 embryos exhibited lower survival and developmental success, indicating inherited vulnerability. The findings demonstrate that nanoplastics not only disrupt early development but also exert lasting effects across generations, underscoring their ecological risk and the urgent need for pollution mitigation strategies.

New waste streams are also being increasingly recognized. The study by Prata (2025) (Contribution 6) reviewed 24 studies on microplastics derived from electronic waste (e-waste), using a DPSIR (Driver–Pressure–State–Impact–Response) framework. Drivers include rising electronics use and inadequate recycling; pressures stem from plastic fragmentation and poor waste management. E-waste microplastics accumulate in soils near disposal and recycling sites and pose risks to ecosystems, organisms, and possibly human health. The co-occurrence of metals and flame retardants is also noted with microplastics. Responses emphasize sustainable product design, stronger waste handling, cleanup efforts, and policy reform. Critical knowledge gaps remain in environmental concentrations, toxicity mechanisms, and effective mitigation strategies.

The studies presented in this Special Issue add to the weight of evidence that recognizes microplastics as a significant environmental and toxicological problem that requires, and is receiving, immediate attention on a global scale [11].

Conflicts of Interest: The authors declare no conflict of interest.

List of Contributions:

1. Brunetti, L.S.; Piersante, C.; La Russa, M.F.; Cellini, E.; Bolea, E.; Laborda, F.; Ruffolo, S.A. Examining Micro-plastics Along the Calabrian Coastline: Analysis of Key Characteristics and Metal Contamination. *Environments* **2025**, *12*, 4. https://doi.org/10.3390/environments12010004.
2. Miller, J.; Barrett, N.; Love, J.; Gray, A.; Youker, R.; Hall, C.; Meiri, N.; Gaesser, M.; Randall, G.; Jarrett, R.; et al. Temporal and Spatial Variations in Microplastic Concentrations in Small Headwater Basins in the Southern Blue Ridge Mountains, North Carolina, USA. *Environments* **2024**, *11*, 240. https://doi.org/10.3390/environments11110240.
3. Wontor, K.; Olubusoye, B.S.; Cizdziel, J.V. Microplastics in the Mississippi River System during Flash Drought Conditions. *Environments* **2024**, *11*, 141. https://doi.org/10.3390/environments11070141.
4. Pellegrino, D.; La Russa, D.; Barberio, L. Pollution Has No Borders: Microplastics in Antarctica. *Environments* **2025**, *12*, 77.

5. Martin, L.; Armendarez, C.; Merrill, M.; Huang, C.; Xu, W. Accumulation of Nanoplastics in Biomphalaria Glabrata Embryos and Transgenerational Developmental Effects. *Environments* **2025**, *12*, 28. https://doi.org/10.3390/environments12010028.
6. Prata, J.C. The Environmental Impact of E-Waste Microplastics: A Systematic Review and Analysis Based on the Driver–Pressure–State–Impact–Response (DPSIR) Framework. *Environments* **2024**, *11*, 30.

References

1. Thompson, R.C.; Courtene-Jones, W.; Boucher, J.; Pahl, S.; Raubenheimer, K.; Koelmans, A.A. Twenty Years of Microplastic Pollution Research—What Have We Learned? *Science* **2025**, *386*, eadl2746. [CrossRef]
2. Courtene-Jones, W.; Clark, N.J.; Fischer, A.C.; Smith, N.S.; Thompson, R.C. Ingestion of Microplastics by Marine Animals. In *Plastics and the Ocean*; Andrady, A.L., Ed.; Wiley: Hoboken, NJ, USA, 2022; pp. 349–366.
3. Hossain, M.A.R.; Olden, J.D. Global Meta-Analysis Reveals Diverse Effects of Microplastics on Freshwater and Marine Fishes. *Fish Fish.* **2022**, *23*, 1439–1454. [CrossRef]
4. Cera, A.; Cesarini, G.; Scalici, M. Microplastics in Freshwater: What Is the News from the World? *Diversity* **2020**, *12*, 276. [CrossRef]
5. Kühn, S.; van Franeker, J.A. Quantitative Overview of Marine Debris Ingested by Marine Megafauna. *Mar. Pollut. Bull.* **2020**, *151*, 110858. [CrossRef] [PubMed]
6. Khan, F.R.; Catarino, A.I.; Clark, N.J. The Ecotoxicological Consequences of Microplastics and Co-Contaminants in Aquatic Organisms: A Mini-Review. *Emerg. Top. Life Sci.* **2022**, *6*, 339–348. [CrossRef] [PubMed]
7. Alijagic, A.; Suljević, D.; Fočak, M.; Sulejmanović, J.; Šehović, E.; Särndahl, E.; Engwall, M. The Triple Exposure Nexus of Microplastic Particles, Plastic-Associated Chemicals, and Environmental Pollutants from a Human Health Perspective. *Environ. Int.* **2024**, *188*, 108736. [CrossRef] [PubMed]
8. Wagner, M.; Monclús, L.; Arp, H.P.H.; Groh, K.J.; Løseth, M.E.; Mucke, J.; Wang, Z.; Wolf, R.; Zimmerman, L. *State of the Science on Plastic Chemicals—Identifying and Addressing Chemicals and Polymers of Concern*; Zenodo: Geneva, Switzerland, 2024.
9. Tanaka, K.; Watanuki, Y.; Takada, H.; Ishizuka, M.; Yamashita, R.; Kazama, M.; Hiki, N.; Kashiwada, F.; Mizukawa, K.; Mizukawa, H.; et al. In Vivo Accumulation of Plastic-Derived Chemicals into Seabird Tissues. *Curr. Biol.* **2020**, *30*, 723–728.e3. [CrossRef] [PubMed]
10. Hahladakis, J.N.; Velis, C.A.; Weber, R.; Iacovidou, E.; Purnell, P. An Overview of Chemical Additives Present in Plastics: Migration, Release, Fate and Environmental Impact during Their Use, Disposal and Recycling. *J. Hazard. Mater.* **2018**, *344*, 179–199. [CrossRef] [PubMed]
11. Landrigan, P.; Symeonides, C.; Raps, H.; Dunlop, S. The Global Plastics Treaty: Why Is It Needed? *Lancet* **2023**, *402*, 2274–2276. [CrossRef] [PubMed]