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EDITORIAL

Focus on plastics from land to aquatic ecosystems

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Abstract

Plastic pollution in oceans and rivers is of growing concern. Aquatic ecosystems play an important role in transport and storage of plastic waste from land-based storage to riverine and marine environments. This focus issue brings together new insights on the sources, transport dynamics, fate, and impact of plastic pollution through aquatic environments. The work collected in this focus issue shows that urban areas, transportation infrastructure, and wastewater treatment plants are consistently identified as sources for micro-, meso-, and macroplastics. Transport dynamics of plastics over land and through rivers were found to be driven by human factors, flood and storm events, and hydrodynamics, and combinations thereof. Most plastics were found not to make it to the open sea, but rather beach, float in coastal waters, or accumulate on land and within river systems. When exposed to the environment, both conventional and biodegradable plastics degrade into smaller pieces. Yet, the degradation and fragmentation of plastics in the environment remain unresolved. Future work should focus on transferability of new river and region specific insights, collection and exploration of large-scale and novel datasets, source and entry point identification, and understanding fundamental transport mechanisms. This focus issue provides new insights on sources, transport, fate, and impact of plastics, but also emphasizes that need for further work on plastics in aquatic ecosystems.

1. Introduction

Release, dispersal, and accumulation of plastic in the environment are widely acknowledged to contribute to the emerging global pollution crisis (March *et al* 2022). Plastic pollution has negative effects on species, biodiversity and human livelihoods (Hardesty *et al* 2017, van Emmerik and Schwarz 2020). A growing body of evidence shows the key role that aquatic ecosystems play in the transport and storage of global plastic pollution. Rivers are major conduits of land-based plastic waste into the ocean, but also retain plastics for long periods of time (van Emmerik *et al* 2022). Recent work suggests that most mismanaged plastic waste will never make it to the open sea (Harris *et al* 2021, Meijer *et al* 2021). However, the sources, transport dynamics, fate, and impact of plastic across environmental compartments remain poorly understood. Reliable monitoring and an improved fundamental understanding of plastic pathways from land into aquatic ecosystems are crucial to design prevention, reduction and assessment strategies (Borrelle *et al* 2020, March *et al* 2022). In this focus issue (FI) we bring together contributions that investigate plastic pollution and its pathways through the environment, ranging from identifying sources and transport mechanisms, to quantifying accumulation, exploring impacts and assessing fate of marine plastics.

2. Main outcomes of this FI

2.1. Sources

Several papers in this FI explored the potential sources of plastics found in the environment, covering a broad range of environmental compartments. Schuyler *et al* (2022) used a long-term and large-scale dataset of litter surveys conducted across Australian cities. They found increased litter amounts close to assumed litter sources, including areas with transitory use (e.g. roads, car parking, highways) and waterways. The latter was explained by known practice of illegal dumping around such areas. Furthermore it was found that higher levels of litter were found in economically and socially disadvantaged neighborhoods. At the local scale, population density and litter are strongly positively correlated. However, at regional levels the correlation was negative. This was explained by the economies of scale, suggesting that waste management is more effective in larger communities.

Arturo and Corcoran (2022) investigated the abundance and origin of large micro-, meso-, and macroplastics at 66 sites across the Laurentian Great Lakes. At only three of the sampled shores no plastics were found. Most sampled items were pre-production pellets (58.3%). Of the non-pellets, the majority was associated with urban areas (41.8%) or shoreline recreation (39.1%) as sources. Further identification and source attribution was difficult, as most items were weathered.

Margenat *et al* (2021) studied the role of wastewater treatment plants (WWTP) as point sources for microplastic pollution to freshwater systems. They found that the abundance of large microplastic in the sediment decreased with distance from the WWTP, but the abundance of small microplastics increased. The differences in transport and accumulation patterns were explained by the combination of preferential filtration in the sediment, and fragmentation of larger particles. The bypass upstream of the WWTP, which becomes active when the flow exceeds the WWTP capacity, was identified as a major pathway for microplastics into the river. This was the main route by which large microplastics, which are otherwise removed by the WWTP, find their way into the river.

Urban areas were also identified as a source of aquatic plastic pollution by Haberstroh *et al* (2021). From field measurements in the Mekong-Tonlé Sap-Bassac river system around Cambodia's capital city Phnom Penh, it was estimated that 42% of the plastic waste generated in the city entered the river. For increased river discharge, the plastic concentration at the location upstream of Phnom Penh decreased, suggesting a diluting effect. Downstream of Phnom Penh plastic concentrations increased, suggesting additional input from the city with stormwater runoff.

2.2. Transport mechanisms

Several contributions studied the fundamental transport mechanisms of plastics on land, through rivers, and in the ocean. Cowger *et al* (2022) investigated how litter arrives at roadsides, addressing one of the key open questions in plastic research. By focusing on receipts with visible timestamps and location of origin, factors such as wind, surface runoff, and human travel were explored as potential transport mechanisms. Only 9% of the analyzed items could have experienced runoff, and no correlation was found between wind direction and the travel path of the items. Human travel, deduced from smartphone tracking, and receipt transport were similar in magnitude and distribution, suggesting this as the main transport agent.

Both Roebroek *et al* (2021) and Margenat *et al* (2021) identified floods and storm events as major drivers of plastic mobilization. At a more local level, Margenat *et al* (2021) demonstrated how during storm events the WWTP is bypassed when its capacity is exceeded. Roebroek *et al* (2021) used global datasets of mismanaged plastic waste and flood extent for different return periods to estimate the potential flood-driven plastic mobilization. For a 10 year return period, global plastic mobilization was found to be ten times higher compared to non-flood conditions. The increase in mobilization from floods varies greatly between countries and river basins. The most affected areas showed increases of over five orders of magnitude, and were mainly located in coastal regions with large populations in river deltas, such as the Mekong, Nile, Gambia, and Ganges. Note that mobilization is not equal to emissions into the ocean, and it may be that most of the mobilized plastic is not transported far downstream.

Haberstroh *et al* (2021) investigated in-stream transport dynamics. They showed that most plastic was transported at the surface, but also revealed downward movement and accumulation in the lower water column in slowly flowing sections. As one of the first studies to quantify plastic concentration across the water column, they demonstrated that the submerged plastics should not be neglected. At times, the subsurface concentrations were equal to or higher than those observed at the surface.

2.3. Accumulation and impact

Almost all contributions explicitly or implicitly addressed the accumulation and impact of plastic in aquatic environments. Arturo and Corcoran (2022) reiterated that the Great Lakes serve as major sinks of plastic across size ranges. Cowger *et al* (2022) and Schuyler *et al* (2022) both linked litter accumulation to roads. If indeed surface runoff and wind are not major driving forces of plastic transport (Cowger *et al* 2022), roadside litter may accumulate over long time periods. Roebroek *et al* (2021) emphasized that their assessment only estimated the potential mobilization by floods, and not the actual transport and emission into the ocean. Plastics mobilized by floods are not likely to be transported over great distances, but are deposited on the floodplains and in riparian vegetation instead. Here, they can be retained and remobilized during the next flood event. Once exposed to the environment, plastics degrade into smaller particles. Ribba *et al* (2022) specifically reviewed the effects of biodegradable plastics. They found that although biodegradable plastics can have advantages, the effects can be similar or worse compared to conventional microplastics. Degradation and fragmentation of plastics in the environment remain underexamined, especially for biodegradable plastics.

2.4. Fate of marine plastic

The paper by Onink *et al* (2021) focused on the fate of plastics in the marine environment. Observations indicate that coastlines contain significant amounts of plastic debris, but the amount, distribution, and origin remain unknown. Using a Lagrangian model, Onink *et al* (2021) show that within the first 5 years of release into the ocean, 77% of the land-based plastic is either beached or floats in coastal waters. The origin of beached plastics varied greatly. In some regions only local plastics are beached, whereas in others they mainly originate from remote sources. The discrepancy between the marine plastic input estimates and the floating plastic in the open ocean may partially be explained by the large amounts of plastic beached and retained in the coastal waters, matching with global results developed on marine macro-litter distribution by Morales-Caselles *et al* (2021).

3. Remaining challenges and future opportunities

Based on the contributions, we identified several open challenges and opportunities for future research. First, as most studies are still focused on specific rivers or regions, the transferability of results should be further tested. If the findings that most litter is transported through humans, rather than wind or surface runoff (Cowger *et al* 2022) are transferable to other regions, this may have large implications on the current global assessments that are based on hydrometeorological drivers. At a global scale, the finding of Cowger *et al* (2022) could persuade other authors to address the topic of 'plastic waste shipments overseas' (another type of human transport). Also, the finding that most plastic is transported at the surface (Haberstroh *et al* 2021) should be tested in other regions. Especially for efforts to quantify the total mass balance, or for clean-up efforts focused at the surface, a better understanding of the distribution of plastic throughout the water column is crucial. Second, several studies demonstrated the value of large-scale and novel datasets. Schuyler *et al* (2022) used a dataset that is unique in its spatial and temporal coverage. Similar efforts to quantify litter at the national scale exist globally, yet the full potential of such datasets have not been fully explored yet. Such datasets would also allow for more comparative studies to also address the challenge of transferability of results. Third, the source identifications of litter sampled in the environment remains challenging. Arturo and Corcoran (2022) mentioned that most items were difficult to identify due to weathering. Cowger *et al* (2022) presented a novel approach to make use of the identifiable timestamp and location of receipts, but such information remains largely unknown for the vast majority of litter items found in the environment. Finally, the fundamental transport mechanisms of plastic through the environment require further attention. Several papers in this FI shed new light on the governing mobilization, transport, and retention dynamics, but all together they show that such dynamics are highly variable over space and time, and may depend strongly on the particle or item characteristics.

4. Concluding remarks

This FI provides several novel insights on the sources, transport, fate, and impact of plastic pollution on land, in freshwater systems, and in the ocean. The contributions span across environmental compartments, plastic size ranges, and spatiotemporal scales. Urban areas were found to be the main sources of plastic on land, rivers, and lakeshores. Floods, storm events, and human travel were identified as major drivers of plastic transport. Large portions of plastics accumulate along roadsides, on riverbanks, and in the sediment. Here they degrade and fragment, but the extent and effects remain unresolved. The discrepancy between marine plastic input and plastic at the ocean surface can partially be explained by beaching and plastics floating in the coastal zone. Finally, we identified several open challenges and opportunities that can be addressed in follow-up studies.

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