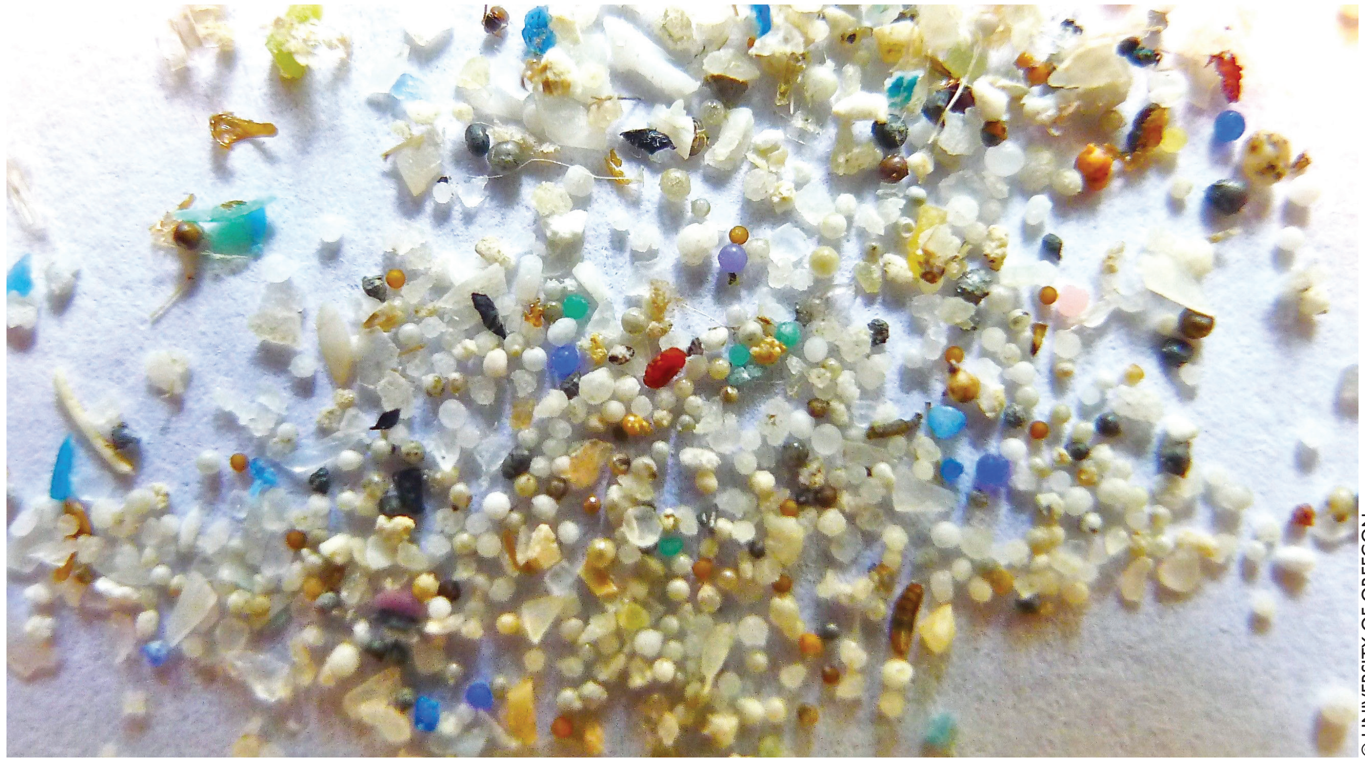
TIME TO TANGLE with plastic pollution

Steve Ormerod



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Amid the headlines, concern from environmental organisations and scrutiny from the UK's elected assemblies, public interest in river pollution has become intense. While the attention is often on combined sewer overflows (CSOs), intensive livestock farming and 'forever chemicals', plastic pollution also floats prominently among the contemporary issues. Yet, the presence of plastic in rivers is not a new problem. Already by the late 1980s, the National Rivers Authority - forerunner to Natural Resources Wales and the Environment Agency - had surveyed the contribution of plastics to the litter distributed along the rivers of South Wales[1] *(Davies & Boden 1991)*. Academic studies followed, confirming that CSOs, domestic waste and fly tipping were major sources of plastics and other litter reaching coastal waters via rivers[2] *(Williams & Simmons 1999)*. People described the 'Christmas Tree effect' where litter hung from riverside branches. In other words, we have known for over 30 years that plastic was a potential river pollution problem.

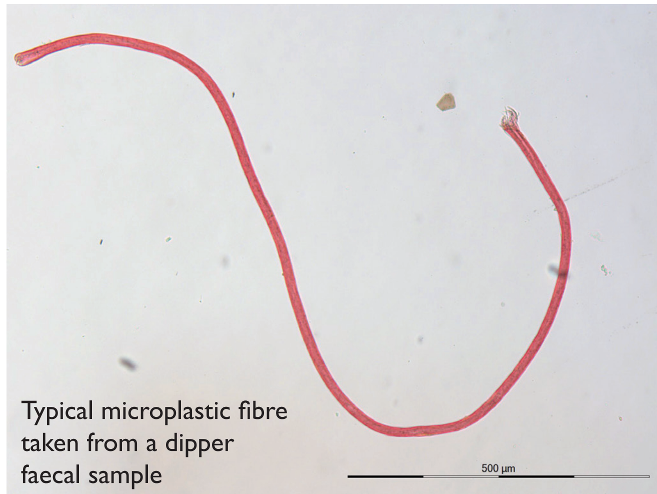
We were forewarned, but it took two more decades before several events converged to bring plastic pollution to the forefront of public attention. In 2004, Professor Richard Thompson and colleagues from Plymouth and Southampton published work in *Science*[3] illustrating how small plastic fragments had been increasing in ocean plankton samples since the 1960s - coining the term 'microplastic'. Legislators, too, began to act: in 2010 the Welsh Government, for example, initiated a charging scheme for single-use plastic carrier bags, recognising their growing contribution to long-term waste. Then, on 17 December 2017, Episode 7 of *Blue Planet II* aired. Seen by almost 12 million people in the UK and reaching almost a billion viewers worldwide, it brought viscerally moving scenes into our homes of albatrosses, cetaceans and turtles at lethal risk from plastic ingestion or entanglement. We learned that the world's oceans now contained trillions of microplastic particles small enough to be ingested by zooplankton, thus entering food webs. The plastic problem was now fully in the open and plaudits for *Blue Planet II* came thick and fast.

Plastic in rivers

By the 2010s, river scientists were also taking notice. Reviews of data - for example from the International Union for the Conservation of Nature in 2017[4] - revealed that up to 13 million tonnes of macroplastic and 1.5-2.5 million tonnes of 'primary' microplastics were probably entering the world's oceans annually. More recent estimates suggest that global plastic fluxes from land to water could exceed 20 million tonnes[5]. Estimated contributions vary among locations, with methods, and depending on how well the different pathways are measured, but synthetic textile fibres from clothes washing (~35%), tyre dust (~ 28%), 'city dust' (~24%) and road paint (~ 7%) have been identified as dominant microplastic sources. Rivers were not only likely to be a major transport route for this material - responsible for up to 80% of the ocean load - but their proximity to the major catchment sources meant even greater plastic concentrations than the oceans into which they emptied: wastewater treatment, combined sewer overflows, sewer misconnections, road runoff and resuspension from the terrestrial disposal of sewage sludge. Contrasting salt concentrations also meant that microplastics behaved differently in marine and freshwater systems: as many organic polymers have near-neutral buoyancy, materials that floated in the sea would sink into river sediments or bounce along the river bed, thus bringing microplastics into the spaces occupied by many river organisms. So it was in 2018 that Manchester University's Rachel Hurley, Jamie Woodward and James Rothwell showed how sediments in Stockport's River Tame had the largest microplastic concentration ever measured in any aquatic ecosystem - a staggering 517,000 particles per square metre[6]. Densities averaged around 16,000 m^{-2} across the wider Irwell system, while even the rural headwaters had up to 5,000 particles per kilogram of sediments. Further south, in the Thames system, Alice Horton and colleagues had already measured over 600 microplastic particles per kilogram of sediments[7]. Although this was lower than the Irwell, it illustrated that sediment contamination by plastic was not just a local problem.

Plastic in river organisms

At such high plastic densities in the river benthos, interactions with river organisms become inevitable. Our own work in 2016 showed how an astonishing 50% of insects in the Rivers Taff, Usk and Wye in South Wales contained microplastic fragments - typically fibres that are among the dominant classes of plastic in aquatic systems. The different organisms we examined - algal-grazing mayflies and net-spinning caddis - had contrasting feeding methods and showed that microplastic could enter food webs through different routes[8]. Using a combination of faecal analysis and energetic calculations of prey requirements, we also showed how dippers *Cinclus cinclus* - predatory river birds that feed on aquatic insects - were inadvertently ingesting hundreds of microplastic fragments daily[9]. They also fed thousands of microplastic particles ►



Typical microplastic fibre taken from a dipper faecal sample

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Sediments in Stockport's River Tame had the largest microplastic concentration ever measured in any aquatic ecosystem

to their nest-bound chicks between hatching and fledging. Hard-wired by evolution to take specific invertebrate prey, dippers have no means to avoid this intake: if their prey are contaminated, ingestion and inter-generational transfer is bound to follow. This work was the first to illustrate how microplastics were transferred through food webs in real river ecosystems. The phenomenon has now been confirmed elsewhere - including the transfer of microplastics from freshwater to aerially insectivorous tree swallows *Tachycineta bicolor* in shoreline locations[10].

Over a hundred studies of microplastics in freshwater organisms have now been published around the world showing that contamination is ubiquitous. Among assessments that also include amphibians, birds and piscivorous mammals such as otters and fishing cats, around a third of the studies have involved invertebrates. Just over half of the assessments in both standing and running freshwaters have been on fishes illustrating both direct plastic ingestion and indirect ingestion via prey. Trout *Salmo trutta* figure among the data in both their introduced and native ranges, and in both marine and freshwater phases. Most relevant to the British Isles, James O'Connor and colleagues found microplastics in the gastro-intestinal tracts or stomachs of 72% of 58 trout sampled in south east Ireland's Slaney River at just under two fragments per fish of which most were fibres[11]. In the world's more polluted river systems, concentrations in fishes are greater.


Dippers ingest microplastics via contaminated prey

Caveats and gaps in knowledge

There are still caveats about some of the published work as well as significant gaps in knowledge. Given the ubiquity of microplastic, for example in atmospheric dust, the risk of sample contamination must be carefully controlled at all investigative stages. Measurement protocols are still poorly standardised and care is needed in correctly identifying microplastic fibres alongside natural textile fibres such as cellulose which are also abundant in environmental samples. Even with extensive data, fully quantifying the sources, fluxes and fate of microplastic in freshwater ecosystems isn't straightforward given its diffuse distribution. In the UK, some data link sources strongly to wastewater, yet the occurrence of microplastics even upstream of such inputs means that this cannot be the whole story. At a global level, rivers from economically poorer countries appear to carry the greatest plastic loads, but there is debate about relative contributions from larger or smaller catchments. Then there is the issue of nanoplastics - beneath the size ranges of most field assessments to date and therefore poorly quantified in studies to date.

And perhaps the biggest question of all: what are the biological effects of microplastic? For macroplastic fragments, effects on individuals are clear - for example drowning entangled in plastic filaments or suffering through ingestion. For microplastics, adverse effects could arise through physical damage, through the direct toxicity of plasticizers, or through adsorbed co-pollutants. While a growing array of laboratory studies provide evidence for these effects, so far we have very little evidence that they have affected populations or communities in real ecosystems. Laboratory studies also illustrate potential effects on important processes in freshwater ecosystems such as primary production, decomposition or sediment oxygenation. There is much discussion, also, about interactions with other environmental stressors - for example where climate change is changing patterns of discharge and hence the movement of microplastics from land to water. Addressing these gaps and unknowns is urgent given the current trajectory and management challenges around plastic.


A silk feeding net spun by the caddis *Hydropsyche siltalai* has mesh dimensions (100 μm x 300 μm) of a size that make it likely to trap microplastic fibres

Are there solutions?

As a reflection of its low cost and utility, plastic production is burgeoning globally to the point that waste emissions to aquatic ecosystems are likely to reach 53 million tonnes annually by the end of this decade even if governments meet ambitious commitments. Releases could potentially reach 90 million tonnes[5] *(Borrelle et al. 2020)*. Broad management strategies focus on waste reduction, waste management, environmental recovery and product substitution – though other materials and so-called bioplastics come with their own problems. From the UN downwards through national governments and communities, initiatives such as international resolutions, environmental clean-up, zero-waste lifestyles, bans and taxes on single-use plastics, investment into waste management, circular economic solutions, and reduced plastic trade to countries with limited recycling capacity are all options. But, writes Stephanie Borelle and her team[5]:

"Plastic pollution is a burgeoning threat to the sustainability of our planet. The world is responding at an already impressive scale, with grassroots action, national-level product bans, public-private partnerships for investment in waste management infrastructure, innovative alternatives to leakage-prone plastic products, and greater transparency in the trade of plastic waste. Still, our results show that achieving substantial reductions in global plastic emissions to the environment requires an urgent transformative change...

Without this transformation, we risk continuing to invest large amounts of human capital and financial resources with little to no hope of reducing plastic pollution in the world's rivers, lakes, and oceans."

The worst, therefore, may yet be ahead. ☐

Steve Ormerod is Professor of Ecology at Cardiff University, where he has worked for over 40 years on the effects of global change on freshwater ecosystems. He is also Deputy Chairman of Natural Resources Wales, a member of the UK Joint Nature Conservation Committee and Vice-President of the RSPB. References can be found on the WTT website: www.wildtrout.org/content/salmo-trutta-article-references