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Microplastic ingestion by riverine macroinvertebrates

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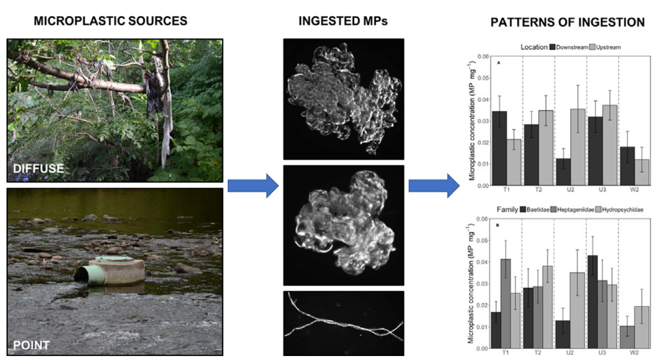
HIGHLIGHTS

- Microplastic ingestion by riverine macroinvertebrates was assessed over South Wales.
- Microplastics were identified in approximately 50% of macroinvertebrate samples.
- Ingestion of microplastics was observed in all taxa, across all sites.
- No difference in microplastic burden was observed downstream of sewage treatment works.

GRAPHICAL ABSTRACT



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ABSTRACT

Although microplastics are a recognised pollutant in marine environments, less attention has been directed towards freshwater ecosystems despite their greater proximity to possible plastic sources. Here, we quantify the presence of microplastic particles (MPs) in river organisms upstream and downstream of five UK Wastewater Treatment Works (WwTWs). MPs were identified in approximately 50% of macroinvertebrate samples collected (Baetidae, Heptageniidae and Hydropsychidae) at concentrations up to 0.14 MP mg tissue^{-1} and they occurred at all sites. MP abundance was associated with macroinvertebrate biomass and taxonomic family, but MPs occurred independently of feeding guild and biological traits such as habitat affinity and ecological niche. There was no increase in plastic ingestion downstream of WwTW discharges averaged across sites, but MP abundance in macroinvertebrates marginally increased where effluent discharges contributed more to total runoff and declined with increasing river discharge. The ubiquity of microplastics within macroinvertebrates in this case study reveals a potential risk from MPs entering riverine food webs through at least two pathways, involving detritivory and filter-feeding, and we recommend closer attention to freshwater ecosystems in future research.

1. Introduction

Microplastics (particles <5 mm) constitute a major potential threat to global aquatic ecosystems (Avio et al., 2017), with a widespread distribution (Barnes et al., 2009), and a wealth of literature demonstrating ecological effects (e.g. Wright et al., 2013a). Laboratory and field assessments show that the ingestion and translocation of microplastic particles (MPs) can affect aquatic organisms (Wright et al., 2013b) including zooplankton (Cole et al., 2013), invertebrates (von Moos et al., 2012), fish (Lusher et al., 2013) and birds (Provencher et al., 2014). Overwhelmingly, however, research has focused on marine ecosystems and organisms rather than on the freshwater ecosystems that are linked more closely to terrestrial microplastic sources (see Wagner et al., 2014; Eerkes-Medrano et al., 2015; Wagner and Lambert, 2017).

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Significant sources of MP pollution include plastic textile fibres (Browne et al., 2011) and degrading macroplastics whose origins are concentrated on land (Jambeck et al., 2015). From there, a major component of the flux of terrestrially derived plastic particles into marine environments is likely to arise from Wastewater Treatment Works (WwTWs) or associated storm overflow systems that discharge into rivers (Mani et al., 2015).

Studies assessing plastic contaminants in freshwater environments have focused on organisms occupying the higher trophic levels of food webs, such as fish (e.g. Foekema et al., 2013; Sanchez et al., 2014) but a few recent studies have identified the ingestion of microplastics by freshwater invertebrates, including Tubificid worms, *Gammarus pulex* and *Hyalella azteca* (Hurley et al., 2017; Weber et al., 2018; Redondo-Hasselerharm et al., 2018). Controlled exposures of freshwater invertebrates (*G. pulex*, *H. Azteca*, *Asellus aquaticus*, *Sphaerium corneum* and *Tubifex* spp.) to MPs have exhibited no overt toxicity for environmentally relevant concentrations (Redondo-Hasselerharm et al., 2018) and a meta-analysis of published studies indicates relatively few negative impacts of microplastic exposure in fish and invertebrates (Foley et al., 2018). Previous studies, however, have focused predominantly on broad scale or (e.g. growth, reproduction and feeding) lethal endpoints (survival and mortality) or have been conducted for short exposure durations (28 days). Thus, chronic effects across a range of more subtle biological endpoints may still present a health risk to invertebrates. A more comprehensive understanding on the ingestion of microplastics by riverine macroinvertebrates is needed given their frequent position as primary consumers supporting riverine food webs and their potential use for determining the origins and entry points of MPs in freshwater food webs.

Microplastic concentration and bioavailability in rivers is likely to be affected by factors that include upstream land-use, urban runoff, relative volumes of discharged effluent from point wastewater sources and local hydraulics that determine entrainment or deposition (Nizzetto et al., 2016; Besseling et al., 2017; Nel et al., 2018). Recent studies have indicated the existence of high concentrations of microplastics in river sediments (Hurley et al., 2018), but they have also shown the significant removal of MPs from river sediments in response to floods. These physical factors influencing the occurrence and abundance of microplastics within the environment will determine the likelihood of ingestion by aquatic organisms, particularly those whose feeding traits involve either ingesting organic particles from the benthos or by filtering material contained in the water column (e.g. Wright et al., 2013b). Other biotic factors such as organism size, mouthpart morphology and gut recharge rate may also influence both MP ingestion and retention. Thus, the presence of microplastics within the biotic components of freshwater food webs is likely to be related to a combination of biotic and abiotic factors.

Once ingested, microplastics can affect aquatic organisms in various ways (Wright et al., 2013a; Scherer et al., 2017). The presence of microplastics in the digestive tract, for example, has the potential to inhibit nutrient absorption and reduce; (i) consumption of resources, (ii) growth, (iii) reproduction and (iv) survival (Lee et al., 2013; Wright et al., 2013a; Au et al., 2015; Cole et al., 2015; Lei et al., 2018). These biological effects have been reported for marine polychaete worms and bivalves, but only for exposure concentrations far exceeding those found in natural environments (Lenz et al., 2016). MPs can also harbour polychlorinated biphenyls (PCBs) and other xenobiotic pollutants that adsorb onto their surface, thereby providing routes for secondary toxicity (Besseling et al., 2013; Ziccardi et al., 2016) and potentiating the effects of toxic chemicals (Syberg et al., 2017). All of these effects indicate both potential MP risks to individual organisms, and also potential emergent effects on ecosystem function that require investigation (Thompson et al., 2009).

This paper reports on microplastic ingestion by riverine macroinvertebrates around five Wastewater Treatment Works (WwTWs) along the Rivers Taff, Usk and Wye in South Wales (UK). In particular, we: (i) assessed the presence of microplastics within the bodies of macroinvertebrates from two contrasting feeding guilds (benthic grazers/detritivores vs filter feeders); (ii) determined whether microplastics are ingested and/or excreted; and (iii) explored the influences on microplastic ingestion across macroinvertebrate taxa.

2. Materials and methods

2.1. Sample sites

The South Wales valleys once held some of the most polluted watercourses in Europe, with over 70% of rivers classed as grossly polluted. Despite major recovery, there is continued contamination near to urban centres from both macronutrients and complex organic substances (Vaughan and Ormerod, 2012; Morrissey et al., 2013a, 2013b). The Taff catchment is representative of highly urbanised river systems within South Wales. The adjacent Usk and Wye systems drain more rural catchments that were never grossly polluted, but still maintain some urban drainage. Across these catchments five WwTWs were selected along a gradient of effluent input, river discharges and potential MP exposure (Fig. 1; Table S1). At each location, macroinvertebrates were collected (June–July 2016) from two 20 m reaches respectively within 200–1000 m upstream and downstream of WwTW outflows. Upstream sample locations were all a minimum of 5 km downstream of proximal upstream point-sources of pollution (e.g. WwTW discharges and industrial outflows).

2.2. Environmental characterisation

Stream chemistry at each site was assessed during the macroinvertebrate collection period through spot measurements of pH, electrical conductivity (EC), total dissolved solids (TDS) and water temperature (HI-9813-5; Hannah Instruments, UK). River discharge was calculated from gauging stations within 2 km of each sample site and collated as mean daily discharge (m^3 day^{-1}) using 5-yr data from Natural Resources Wales (NRW), the State regulatory organisation. Consented effluent discharges for WwTWs were derived from NRW secondary data (Licence No. ATI-10578a) and dry weather flow (m^3 day^{-1}) was collated. The ratio of daily WwTW effluent discharge to river discharge was calculated to assess the relative dilution of these effluent inputs and to understand the potential effects of point source effluent dilution on microplastic interactions with freshwater organisms.

Geographical Information Systems (GISs) were used to derive land use cover upstream of sites using ArcGIS software (version 10.2.2). Phase 1 JNCC habitat classification data for the UK (JNNC, 2010), coupled with flow network data from the NERC Centre for Ecology and Hydrology (CEH) (Licence no. 16122014), were processed using the Spatial Tools for the Analysis of River Systems (STARS) package (Peterson and Ver Hoef, 2014). This package allowed for calculation of cumulative area of land cover within contributing sub-catchments upstream of sample sites (see Peterson et al., 2006).

2.3. Macroinvertebrate sampling

We investigated three abundant macroinvertebrate families from two orders (Ephemeroptera and Trichoptera): Heptageniidae, Baetidae and Hydropsychidae. Heptageniidae and Baetidae mayflies feed predominantly upon benthic algae and fine amorphous particles within river systems, whereas hydropsychid caddisflies are generalist filter-feeders (Tachet et al., 2002). In each sample reach, 18 individuals of each taxon were collected using a validated method of intensive kick sampling and hand-searching (Bradley and Ormerod, 2002). The exceptions to this were for one sample site on the Wye (W2), and a site on the Usk (U2), where a limited abundance of Baetidae and Heptageniidae, respectively, precluded these taxa from microplastic analyses. Macroinvertebrate individuals were identified in the field and individuals of