Science of the Total Environment 612 (2018) 950–956

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Sinks and sources: Assessing microplastic abundance in river sediment and deposit feeders in an Austral temperate urban river system

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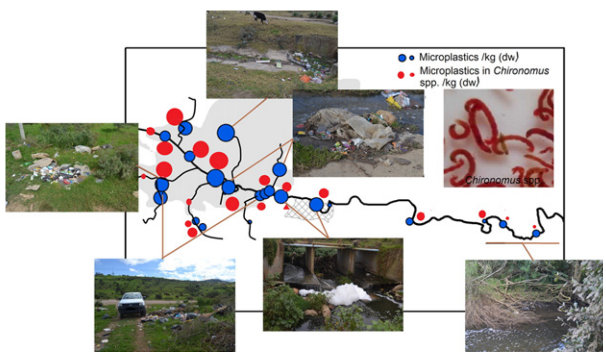
HIGHLIGHTS

- Microplastics abundance in sediment and chironomid larvae varied from wet to dry periods.
- There was a relationship between sediment and chironomid microplastic levels.
- Water flow, substrate and sediment organic matter may determine microplastic distribution.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 June 2017
Received in revised form 29 August 2017
Accepted 29 August 2017
Available online 5 September 2017

Editor: D. Barcelo

Keywords:
Chironomids
Bloukrans River
Freshwater ecosystem
Microplastics
Hydrodynamics
Biotic sink
Ingestion

ABSTRACT

Microplastics are important novel pollutants in freshwaters but their behaviour in river sediments is poorly understood due to the large amounts of coloured dissolved organic matter that impede sample processing. The present study aimed to 1.) estimate the microplastic pollution dynamics in an urban river system experiencing temporal differences in river flow, and 2.) investigate the potential use of chironomids as indicators of microplastic pollution levels in degraded freshwater environments. Microplastic levels were estimated from sediment and *Chironomus* spp. larvae collected from various sites along the Bloukrans River system, in the Eastern Cape South Africa during the summer and winter season. River flow, water depth, channel width, substrate embeddedness and sediment organic matter were simultaneously collected from each site. The winter season was characterised by elevated microplastic abundances, likely as a result of lower energy and increased sediment deposition associated with reduced river flow. In addition, results showed that particle distribution may be governed by various other external factors, such as substrate type and sediment organic matter. The study further highlighted that deposit feeders associated with the benthic river habitats, namely *Chironomus* spp. ingest microplastics and that the seasonal differences in sediment microplastic dynamics were reflected in chironomid microplastic abundance. There was a positive, though weakly significant relationship between deposit feeders and sediment suggesting that deposit feeders such as *Chironomus* spp. larvae could serve as an important indicator of microplastic loads within freshwater ecosystems.

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http://dx.doi.org/10.1016/j.scitotenv.2017.08.298

1. Introduction

Plastic, a synthetic polymer used in a multitude of applications may end up littering aquatic environments due to improper waste management, poor human practise and accidental loss (Derraik, 2004). The durability of this material results in the accumulation of plastic waste throughout global ecosystems and the slow breakdown often produces successively smaller pieces; so-called microplastics (Andrady, 2011; Cole et al., 2011; Hidalgo-Ruz et al., 2012; Cesa et al., 2017; Horton et al., 2017). Microplastics act as points of accumulation for many dissolved chemicals, concentrating harmful persistent organic pollutants onto their surface (Ryan et al., 2012; Avio et al., 2017). Harmful additives, to improve flexibility are added during the manufacture of plastic items. These additives are suspected to leach out into the environment or organism and may be endocrine disrupters (Teuten et al., 2009). While the implications of microplastic pollutants in aquatic ecosystems have yet to be fully realised, they have been associated with detrimental effects for certain biota as a result of lab induced ingestion (Teuten et al., 2009; Ivar do Sul and Costa, 2014; Halden, 2015; GESAMP, 2015; Avio et al., 2017).

There has been a recent surge in the documentation and quantification of microplastics in aquatic ecosystems (Gregory, 1996; Fendall and Sewell, 2009; Andrady, 2011; Browne et al., 2011; Murphy et al., 2016). The multitude of potential sources for these pollutants makes it difficult to determine their exact origin. However, published research highlights that their occurrence in aquatic environments is often associated with areas of high industrial activity, such as harbours (Mathalon and Hill, 2014; Naidoo et al., 2015; Nel et al., 2017; Wang et al., 2017) and urban centres (Dris et al., 2015a, b). The occurrence of microplastics is well documented in marine ecosystems; however data on estuarine and freshwater environments is lacking (Wagner et al., 2014; Eerkes-Medrano et al., 2015; Anderson et al., 2016; Chen et al., 2017; Waller et al., 2017).

Freshwater ecosystems such as lakes and reservoirs may serve as sinks for microplastic contaminants, given the high residence times of these environments (Anderson et al., 2016). For example, Free et al. (2014) microplastic pollution study in Lake Hovsgol, Mongolia highlighted an extremely high microplastic load (mean 20,264 particles km^{-1}) which was attributed to the long residence time estimated between 500 and 600 years. However, residency time varies among lentic water bodies. The Laurentian Great Lakes, for instance, are considered a potential source of microplastics for the North Atlantic Ocean (Eriksen et al., 2013) and this has been attributed to their lower residence time: Lake Erie (2 years), Lake Michigan (38 years) and Lake Ontario (<20 years; Quinn, 1992). Lotic environments (i.e. streams, rivers and estuaries) have a lower residency time than lentic aquatic habitats (Soballe and Kimmel, 1987), thus their roles as sources of microplastic pollutants need to be considered.

Streams, rivers and estuaries are considered a major source of inland microplastic pollution to marine environments, although substantial evidence is still scarce (Eerkes-Medrano et al., 2015). Sediment samples along the St Lawrence River, which connects the Great Lakes to the Atlantic, showed extremely high microbead concentrations at an overall mean of 13,759 ± 13,685 (SE) particles m^{-2} (Castañeda et al., 2014). Klein et al. (2015) showed that German rivers are already highly contaminated with microplastics (range: 228–3763 particles kg^{-1}). There has been relatively little work on microplastic pollutants within lotic environments. The little work that has been done to date highlights their potential importance as transporters of plastic inputs into marine environments. For example, during high rainfall events, the Pearl River Estuary was considered a major source of macro- and microplastics to beaches along the west coast of Hong Kong (Cheung et al., 2016).

Given that a large quantity of marine pollution is transported with freshwater inputs, understanding pollution dynamics in lotic freshwater environments is relevant within the context of cross-ecosystem subsidies. Freshwater ecosystems may be subject to a number of various sources of microplastic pollution, for example urban runoff, sewage effluent and sludge applied to agricultural areas (Eriksen et al., 2013; McCormick et al., 2014). McCormick et al. (2014) illustrated that the microplastic contamination was lower upstream from the waste water treatment plant effluent pipe, while downstream concentration increased. By contrast, Klein et al. (2015) found no correlation between population density, industrial activities and sewage treatment plant locations and microplastic abundance.

A major consideration in stream ecology is the disproportionately high sediment to water column ratio when compared to large lakes, reservoirs and marine aquatic ecosystems. Most studies have focused on investigating microplastic contamination in the water column, with only three studies sampling river bed sediments (see Dris et al., 2015b and references therein; Klein et al., 2015). Furthermore, most investigations on microplastics in lotic ecosystems have been conducted in systems where freshwater is not limiting and environments are characterised by year-long river flow. However, in many arid regions river flow dynamics are highly temporally variable. This variability will likely have implications for the settling rate and residence time of microplastics that may be locked in sediments. In addition, given that many benthic organisms feed on particulate matter settling on sediment, microplastic densities and river flow dynamics could have implications for the incorporation of microplastics into benthic food webs.

The present study aimed to contribute to the understanding of microplastic pollution dynamics in an urban river system experiencing temporal differences in river flow. More specifically, the study assessed microplastic sediment pollution within ~230 km^2 urbanised catchment of an Austral temperate river system in the semi-arid region of South Africa during high (summer season) and low (winter season) river flow periods. In addition, microplastic concentrations in deposit-feeding chironomid larvae, *Chironomus* spp. the dominant benthic fauna, from these environments were simultaneously assessed (Dalu et al., 2017a). *Chironomus* spp. were assessed in sites where they were found in abundances large enough for feasible microplastic extraction. We hypothesized: (i) that there would be a seasonal difference in sediment microplastic densities, and (ii) that the deposit-feeder, *Chironomus* spp. would contain microplastics that would depict these temporal differences. Given the known difficulty in detecting microplastics in polluted river sediments, as a result of a high percentage of coloured dissolved organic matter in these systems, the potential for the use of chironomids as indicators of microplastic pollution in degraded freshwater environments is discussed.

2. Materials and methods

2.1. Study area

The Bloukrans River drains the town of Grahamstown (i.e. population ~70,000) and Belmont Valley farms, flowing in a south-east direction before joining the Kowie River. The Kowie River feeds into the Indian Ocean through an estuary at Port Alfred along the south coast of South Africa (Fig. 1). The Bloukrans River catchment area is approximately ~230 km^2, with a total river length of ~40 km. The Bloukrans River is located on the eastern periphery of the Mediterranean rainfall area i.e. the warm temperate climatic zone, which covers the southern Cape. The mean annual catchment rainfall is between 600 and 800 mm, which is evenly distributed, with summer (September–March: ~470 mm) rainfall being higher than winter (~210 mm) rainfall (Sinchembe and Ellery, 2010). Minimum and maximum air temperatures are 1.5 °C and 43 °C, respectively (South Africa Weather Services (http://www.weathersa.co.za) database; Heydorn and Grindley, 1982).

The river is subjected to various sources of pollution, such as overflowing sewage drains and litter from the largest town i.e. Grahamstown in the Makana Local Municipality, Eastern Cape province of South Africa. As the river leaves the town, effluent from the Grahamstown Wastewater Treatment Works is released into the river, before the