Science of the Total Environment 642 (2018) 937–945

Contents lists available at ScienceDirect

Science of the Total Environment

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

Effects of urban wastewater on hyporheic habitat and invertebrates in Mediterranean streams

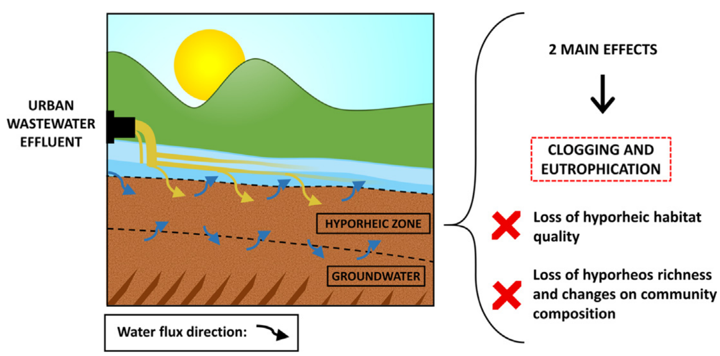
Marc Sánchez-Morales [a,b,*], Francesc Sabater [a], Isabel Muñoz [a]

[a] Department of Evolutionary Biology, Ecology and Environmental Sciences, Universitat de Barcelona, Av. Diagonal, 643, 08028 Barcelona, Spain
[b] Department of Geography, Universitat Autònoma de Barcelona, 08193 Cerdanyola del Vallès, Spain

HIGHLIGHTS

- Wastewater effluents cause nutrient and fine particulate accumulation in the hyporheic zone.
- Clogging causes more ecological effects on hyporheic fauna than does eutrophication.
- Most invertebrates with worm-like bodies increase their populations downstream of wastewater inputs.
- Macrocrustaceans, Hydrachnidia and several species of insect larvae suffer sharp population declines.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 April 2018
Received in revised form 24 May 2018
Accepted 11 June 2018
Available online xxxx

Keywords:
Wastewater
Hyporheic zone
Hyporheic invertebrates
Clogging
Eutrophication

ABSTRACT

Wastewater discharges into fluvial ecosystems represent a significant and continuous source of fine particles and nutrients that can severely modify stream community composition and functionality. Depending on both wastewater and stream features (e.g., nutrient removal treatments and stream dilution capacity), the ecological effects can be more or less severe. To determine how hyporheic habitat and hyporheos are affected, we analysed eight Mediterranean streams both upstream and downstream of a wastewater effluent. The results demonstrated that environmental factors associated with clogging, such as the quantity of fine particulate and organic matter in sediment, were magnified downstream of the wastewater inputs. Likewise, dissolved nutrients also increased but depended to a greater extent on the presence of a wastewater treatment plant and on the nitrogen and phosphorus removal treatments. The hyporheic invertebrates were more affected by clogging than by eutrophication. Both richness and diversity parameters were negatively correlated with clogging features but were not correlated with eutrophication. The most affected taxa were Macrocrustaceans, Hydrachnidia and several insect species, which decreased or were not detected downstream of the effluents. On the contrary, other taxa such as Naididae (Oligochaeta), Orthocladiinae (Chironomidae) and *Potamopyrgus antipodarum* (Gastropoda) benefited from the wastewater inputs.

1. Introduction

In recent years, urban areas have rapidly developed, and it is projected that 66% of the world's population will reside in cities by 2050 (UN DESAPD, 2014). This event will generate more water demand

* Corresponding author.
E-mail addresses: marc.sanchez.morales@uab.cat (M. Sánchez-Morales), fsabater@ub.edu (F. Sabater), imunoz@ub.edu (I. Muñoz).

https://doi.org/10.1016/j.scitotenv.2018.06.132
0048-9697/

(Postel, 2000), and larger volumes of wastewater will require treatment. Wastewater treatment plants (WTPs) treat urban sewage by improving water quality before returning the effluent back to streams. However, WTPs do not completely purify wastewater, and furthermore, not all wastewater effluents are treated by WTPs. Several ecological perturbations are associated with wastewater discharge into fluvial ecosystems, such as the introduction of micropollutants to stream flow or the loss of invertebrate biodiversity (e.g., Ziajahromi et al., 2016; Luo et al., 2014; Iepure et al., 2013).

One of the most important physicochemical effects is eutrophication, due to the considerable amount of nutrients contained in wastewater effluent (Carey and Migliaccio, 2009; Martí et al., 2009). It is well known that in nutrient-enriched fluvial systems, macroinvertebrate communities are affected in terms of richness and density (Trigal et al., 2009). The growth of benthic and filamentous algae is stimulated by nutrients (Carey and Migliaccio, 2009; Smith, 2003), and when algae die, detritus accumulates on the streambed, likely limiting dissolved oxygen (DO) diffusion into the sediment and reducing the hydraulic conductivity and interstitial spaces of the hyporheic zone (Wu, 2002). Additionally, these clogging features increase with the discharge of fine particulate organic matter from WTPs (Ruggiero et al., 2006). The effects from both eutrophication and clogging have been reported with regard to benthic and hyporheic invertebrates in field studies (e.g., Astiz and Sabater, 2015; Descloux et al., 2014; Ortiz et al., 2008) and in mesocosms (Jones et al., 2015). In Mediterranean streams, which suffer from natural seasonal decreases in discharge (Lake, 2003), wastewater effects can be more severe due to a lower dilution capacity. According to Stocker et al. (2013), over the next several decades, precipitation rates will probably decrease in dry regions, and streams with intermittent flow regimes will extend their non-flow periods. One example of stream flow depletion has been observed in the Ebro River, where stream discharge decreased by almost 40% in 50 years due to both climate change and land use changes (MIMAM, 2000). In other Mediterranean areas, stream discharges also decreased up to 79% within similar periods of time (Skoulidikis et al., 2009).

One stream compartment directly exposed to wastewater effects is the hyporheic zone (HZ). This ecohydrological interface represents a dynamic transition area between surface water and ground water (Krause et al., 2017). Considering that it receives both downwelling and upwelling fluxes, the HZ is characterized by a sharp gradient of physicochemical conditions that provide distinct ecological niche functions (Krause et al., 2017) and regulate the biogeochemical turnover of chemicals (Williams et al., 2010). Therefore, perturbations such as wastewater emissions from WTPs can modify the functionality of the HZ, causing changes in water chemistry and in the resident hyporheic invertebrate community (Pacioglu and Moldovan, 2016; Astiz and Sabater, 2015).

Different organisms can be found in the HZ depending on their affinity towards hyporheic features. Stygobitic invertebrates are those that present specific adaptations for living in groundwater and remain therein for their whole life cycle, while stygophiles only inhabit the HZ during part of their life cycle. As invertebrates with no subterranean affinities, stygoxenes can also be found inadvertently (Gibert et al., 1994). For all these organisms, the HZ functions as a refuge during extreme events such as floods and droughts (Gaudes et al., 2010; Boulton et al., 1998). However, as a result of the invertebrate diversification, different responses can be expected from each taxa when environmental conditions change. For example, Chironomidae, Oligochaeta and Nematoda can increase in density following the accumulation of fine particles on the streambed (Leitner et al., 2015; Jones et al., 2012; Herbst and Kane, 2006). These taxa take advantage of their worm-like bodies to excavate into the sediment, hence having the aptitude to survive under clogging conditions (Dole-Olivier et al., 1997; Townsend, 1989). Furthermore, some species are also adapted to live under conditions of low DO as they have a high concentration of haemoglobin analogues (Cranston, 1988; Vinogradov, 1985). Conversely, species from other groups such as Ephemeroptera, Plecoptera, and Trichoptera, whose early larval instars can be found in the HZ as temporary meiofauna, respond differently to clogging features, but in general, their richness and abundance values are negatively affected (e.g., Leitner et al., 2015; Bryce et al., 2010; Larsen et al., 2009; Angradi, 1999). Hydrachnidia are also sensitive to environmental changes (Goldschmidt, 2016; Cicolani and Di Sabatino, 1985), and some macrocrustaceans cannot survive under high nitrate levels (Camargo et al., 2005). Iepure et al. (2013) observed that macrocrustaceans were dominant in pristine hyporheic waters, while microcrustaceans proliferated under moderate levels of disturbance. Neither macrocrustaceans nor microcrustaceans were observed in excessively polluted sites. Therefore, in consideration of the whole hyporheic community, the study of hyporheic fauna can provide qualitative information not only about chemical water quality but also regarding hydromorphological changes.

In this study, we aimed to analyse how wastewater effluent modifies hyporheic habitat characteristics and how hyporheic faunal communities are affected. Eight Mediterranean headwater streams were sampled, which shared similar temperature and precipitation regimes and type of substrata. All the streams were geomorphologically similar, as their hydrological flow structure consisted of riffle-pool sequences. However, they differed in stream order (from 2 to 6), suggesting different stream dilution capacities for wastewater effluent. The streams were affected by urban wastewater effluents that varied from 216 to 3047 population equivalents. Despite these differences, we hypothesized that wastewater inputs cause nutrients and fine particles increments in the HZ in all streams. Therefore, we predicted that these increments would lead to higher organic content in sediment and cause the loss of hydraulic conductivity and DO depletion in the HZ downstream of the wastewater effluents. Consequently, we also hypothesized that the hyporheic faunal communities would be affected in terms of density, diversity and composition, depending to a greater extent on the magnitude of fine particle accumulation and clogging than on the increments of nutrients in the HZ.

2. Methodology

2.1. Study sites and sampling procedure

The discharge regime of Mediterranean streams depends on the rainfall patterns and exhibit seasonal and annual variability (Davies et al., 1994). In particular, this work is focused on the study of wastewater effects on the HZ during the dry period. The sampling campaigns were conducted during the summer months (2016), when the stream discharge decreases and the dilution capacity is lower. Consequently, the effects of wastewater inputs are more accentuated and can be better studied. The eight sampled streams, located in the headwaters of the Ebro, Llobregat, Ter and Muga basins, received an urban wastewater effluent. Two of the effluents did not received treatments for improving water quality whilst the remaining six were treated in a WTP. Some of the treated effluents also received additional nitrogen and/or phosphorus removal treatments (Table 1). At each stream, two reaches measuring 100 m long were selected: one upstream and one downstream of the effluent. From each reach, 3 replicate samples were obtained from the HZ (40 cm depth) using the Bou and Rouch (1967) technique, and the minimum distance between sample replicates was 15 m. Since the hyporheic exchange flow can vary between riffles and pools (Käser et al., 2009), we only sampled in riffle zones to minimize differences. For each sample, 20 L of interstitial water was pumped and filtered (with 100 μm mesh) for taxa identification. An additional 40 mL was filtered with Whatman GF/F filters (0.7 μm) for physicochemical analysis. Taxa identification was performed on fresh samples without fixation in order to facilitate identification to the lowest possible taxonomic level, using a binocular stereoscope or microscope. All samples were maintained in a cooler prior to arriving at the laboratory.

At each sampling site, the vertical hydraulic gradient (VHG) and vertical hydraulic conductivity (K) were measured using a clear piezometer