Environmental Pollution 241 (2018) 272–278

Contents lists available at ScienceDirect

Environmental Pollution

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

Comparing macroinvertebrate assemblages at organic-contaminated river sites with different zinc concentrations: Metal-sensitive taxa may already be absent☆

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ARTICLE INFO

Article history:
Received 16 February 2018
Received in revised form
10 May 2018
Accepted 13 May 2018

Keywords:
Metal bioavailability
Urban river
Aquatic insect
Organic pollution
BOD

ABSTRACT

We investigated responses of macroinvertebrates to different zinc concentrations in urban rivers contaminated with organic matter in a regional-scale monitoring survey and a smaller-scale field study. The present study was designed to test our prediction that total zinc concentrations of ~60 μg/L (twice the Japanese environmental quality standard) do not lead to significant reductions in richness or abundance of macroinvertebrates in organic-contaminated rivers (biochemical oxygen demand of >3 mg/L). At the organic-contaminated sites in both surveys, very few species were present, and metal-sensitive heptageniid and ephemerellid mayflies were generally absent. In the regional-scale study, total zinc concentrations of up to 70 μg/L resulted in little reduction in macroinvertebrate richness. In the local-scale study, macroinvertebrate richness and abundance were not greatly reduced at the polluted downstream site with a total zinc concentration of 48 μg/L. Results from both surveys support our prediction. Therefore, an important implication of this study is that macroinvertebrate taxa that are susceptible to metal pollution should be sparse or absent in organic-contaminated rivers, so the impacts of metals such as zinc may be limited owing to the species-poor communities. Further research is required to evaluate the importance of reduced zinc bioavailability associated with increased organic matter and water hardness to the species-poor communities in organic-contaminated rivers.

1. Introduction

Ecological impacts of metal pollution are a worldwide concern (Iwasaki and Ormerod, 2012; Luoma and Rainbow, 2008). Accordingly, much attention has been paid to general management needs such as the establishment of environmental quality standards (EQSs) and prioritization under European Union (EU) Regulation EEC/793/93 in 1995. Adequate evaluation of ecological risks in the real environment is thus vital to aid effective management. Bioavailability is an important factor affecting metal toxicity in water, depending on water quality parameters such as pH, concentrations of major ions such as calcium and magnesium, and organic matter (OM) (Niyogi and Wood, 2004).

Zinc is one of the metals that have provoked increased environmental concern worldwide (Bodar et al., 2005; Iwasaki et al., 2011; Naito et al., 2010; Van Sprang et al., 2009). In Japan, the EQS for total zinc in freshwaters was established in 2003 as 30 μg/L, and the EU Risk Assessment Report for zinc was published in 2008 (EU, 2008). Zinc is a ubiquitous metal, and contaminated freshwater sites are distributed not only in mountainous or upland areas affected by mining activity or natural sources of metals (Iwasaki and Ormerod, 2012; Schmidt et al., 2012), but also in urban rivers receiving industrial and municipal wastewater (Bodar et al., 2005; Naito et al., 2010). In Japan, major reasons for contamination were identified as industrial and municipal effluents at ~60% of freshwater monitoring sites with elevated zinc concentrations (Naito et al., 2010; Tsushima et al., 2010). Further, ~60% of river sites with zinc concentrations greater than the Japanese EQS were also contaminated with OM (biological oxygen demand [BOD] of >3 mg/L; Iwasaki and Oikawa, 2009).

☆ This paper has been recommended for acceptance by Wen-Xiong Wang.
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https://doi.org/10.1016/j.envpol.2018.05.041
0269-7491/

Field surveys have an important complementary role in ecological risk assessments (ERAs; Crane et al., 2007; Iwasaki and Ormerod, 2012) by providing realistic descriptions of biotic populations and communities in the environment and thus by testing ecological risk predictions of laboratory toxicity results. Benthic macroinvertebrates are relatively sedentary and have a wide range of sensitivity to stressors, and are thus frequently used to investigate the effects of metals (Clements et al., 2000; Iwasaki et al., 2009, 2012; Schmidt et al., 2011). Field surveys in metal-contaminated rivers often show high sensitivity (reduced abundance and richness) of mayflies, particularly heptageniid species, and moderate to high tolerance of caddisfly and chironomid species (Clements, 1991; Clements et al., 2000; Iwasaki et al., 2018). Many field studies aimed at investigating the impacts of metals on lotic macroinvertebrates, however, have been performed in mountainous or upland streams with little contamination by OM (but see e.g., De Jonge et al. (2008) and Van Ael et al. (2015)).

Our field studies suggest that zinc concentrations 2 to 3 times the Japanese EQS do not affect the richness or abundance of macroinvertebrate assemblages and thus the EQS is likely overprotective in this regard (Iwasaki et al., 2012; Iwasaki et al., 2011). Since these studies were conducted mainly in mountainous or upland streams contaminated predominantly by metals, it is uncertain whether the results can be applied to urban rivers or streams contaminated with both metals and OM. Organic pollution may lead to lower metal bioavailability and thereby lower the toxicity of zinc in such rivers. More importantly, as some metal-sensitive macroinvertebrates such as heptageniid species are also intolerant of organic pollution (Armitage et al., 1983; Hilsenhoff, 1988), they may be less abundant or even not occur in organic-contaminated rivers. This line of thinking leads to the hypothesis that metals have minimal impact on species-poor communities in such rivers.

We investigated responses of macroinvertebrates to different zinc concentrations in urban rivers contaminated with OM. Here, we tested our prediction that in such rivers, total zinc concentrations of approximately twice the Japanese EQS do not lead to significant reductions in the richness or abundance of macroinvertebrates. This "safe" level (ca. 50–70 μg/L) was based on the results of our previous studies (Iwasaki et al., 2012; Iwasaki et al., 2011). We used the results from a regional-scale monitoring survey and a smaller-scale field study at two sites with different concentrations of zinc. The former was designed to test our prediction at a relatively large spatial scale, but cannot fully control confounding factors. The latter is a complementary study that minimized the influences of such factors. BOD was used as an indicator of organic pollution.

2. Methods

2.1. Regional-scale monitoring dataset

We obtained data from macroinvertebrate surveys conducted at 32 river sites in Kanagawa Prefecture (Fig. 1), central Japan (Kanagawa Environmental Research Center, 2005; Table S1). All sites had a similar riffle–pool structure (i.e., one riffle–pool pair present in one meandering reach), although the channel width (2–100 m, mean = 15 m) and annual mean discharge (0.12–25 m^3/s, mean = 5.2 m^3/s) varied (Kanagawa Environmental Research Center, 2005; Kanagawa prefecture, 2003). Macroinvertebrates were sampled in both winter (November 2002 to January 2003) and spring (April to June 2003) at each site. Because zinc and organic pollution levels were not measured, we used data on total zinc concentration ([Zn]) and 5-day BOD from a water quality monitoring program in the same rivers (Kanagawa prefecture, 2003). Data were available for 60% of the survey sites; otherwise we used data from the closest monitoring sites to individual survey sites (<1.5 km apart). No major tributaries or sewage plants lay between the two sites on each river. We used average values from multiple samplings from April 2002 to March 2003. Zinc concentration (<10–70 μg/L, mean = 10 μg/L) and BOD (0.8–8.6 mg/L, mean = 2.9 mg/L) varied by site.

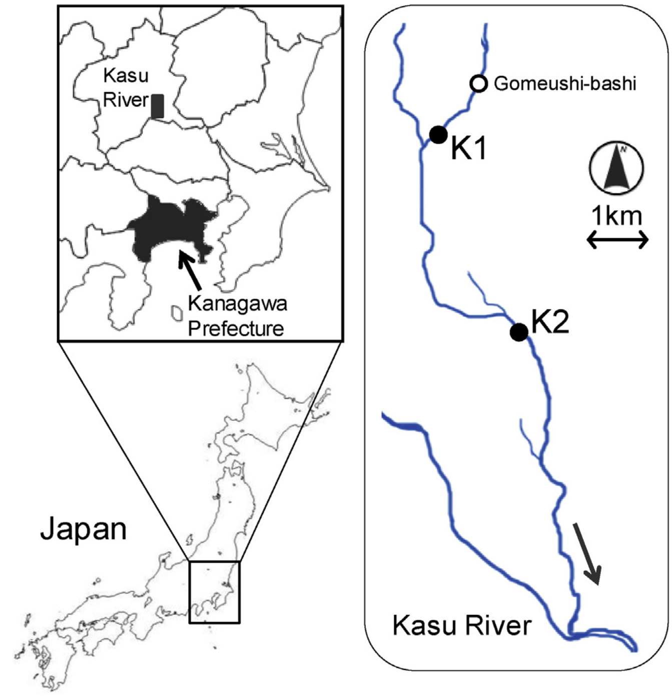

Fig. 1. Locations of Kanagawa Prefecture (the region where the regional-scale monitoring survey was conducted) and field study sites in the Kasu River.

Macroinvertebrates were collected from four 0.25-m × 0.25-m quadrats in riffles at each site using a Surber sampler (mesh size of 0.5 mm), and most were identified to species or genus (Kanagawa Environmental Research Center, 2005). We used six diversity metrics: total taxon richness of all invertebrates, EPT (Ephemeroptera, Plecoptera and Trichoptera), and four dominant insect orders (Ephemeroptera, Plecoptera, Trichoptera, and Diptera). These diversity metrics were calculated as the total number of taxa in either the winter or the spring sample. We did not use abundance metrics, which would have varied dramatically owing to the seasonal timing of life cycle events such as recruitment, high mortality of young larvae, and emergence.

In evaluating the effects of zinc on invertebrates at sites contaminated with OM, we *a priori* defined the organic-contaminated sites as those with BOD >3 mg/L. This cutoff was based on the Japanese system of river water classification, in which β-mesosaprobic zones are demarcated from oligosaprobic zones at this value (MoE: http://www.env.go.jp/kijun/wt2-1-1.html; see, e.g., Kolkwitz and Marsson (1909) for the Saprobien system). Because mayflies, stoneflies, and caddisflies include many indicator species of oligosaprobity (Cairns and Pratt, 1993; Hilsenhoff, 1988), sites with BOD > 3 mg/L are likely to have lower EPT richness, which is widely used for measuring biological integrity in stream bio-assessment (Barbour et al., 1999). To verify this expected distinction, we modeled the relationship between BOD and EPT richness by using a piecewise regression model (Toms and Lesperance, 2003) and investigated whether the breakpoint of the model approximated 3 mg/L. We also tested the differences in