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The use of meiofauna in freshwater sediment assessments: Structural and functional responses of meiobenthic communities to metal and organics contamination

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ABSTRACT

Because soft sediments are often hotspots of chemical contamination, their assessment can aid in identifying the causes of environmental stress and the implementation of measures to improve the health of the respective ecosystems. Achieving a “good ecological status” of surface waters, as required by the European Water Framework Directive, strongly depends on recognition of the chemical status of sediments. Meiobenthic organisms are important, but widely neglected components of the ecologically relevant fauna of a wide variety of ecosystems. In the present study, microcosms containing freshwater sediments were used to investigate the effects of eight different metals and polycyclic aromatic hydrocarbons (PAHs), in single and mixed applications, on natural meiofaunal assemblages. Structural (abundance and biomass) and functional (secondary production) parameters of the investigated assemblages were measured as ecologically relevant endpoints. Their sensitivity in revealing both the differential effects and the responses of meiofaunal taxa was evaluated to assess the general suitability of meiofauna and, in particular, of individual tested taxa, as bioindicators of soft sediment contamination. Structural parameters were found to be more valuable indicators than functional measurements, with more pronounced effects observed on the taxon level than on total meiofauna. Among the meiofaunal taxa considered in this study, nematodes were of particular utility as early indicators of chemical stress in freshwater soft sediments. Overall, this study provides new insights into the impact of toxicants on soft freshwater sediments and demonstrates the suitability of meiofaunal communities, especially nematodes, in assessing contamination of this ecosystem.

1. Introduction

Toxic chemicals are discharged into freshwater ecosystems from industrial and agricultural sources, runoff processes, and other anthropogenic origins. Following their binding to settling particles, they accumulate in the sediment, posing a threat not only to benthic fauna but also to the entire aquatic ecosystem through remobilisation processes such as flood events (Hollert et al., 2000) and trophic transfer by bioaccumulation (European Commission, 2010). Achieving the “good ecological status” of surface waters required by the European Water Framework Directive (WFD, 2000/60/EC) strongly depends on knowledge of the chemical status of sediments, such as achieved in highly recommended surveys of their fauna (Long and Chapman, 1985). Most determinations of the ecological quality of sediments are based on the use of macroinvertebrates (Hering et al., 2004), although these organisms represent only a fraction of the benthic community. Benthic meiofauna (metazoans that pass through a 1000 μm-sieve but are retained by a 42 μm-sieve); (Giere, 2009) have been largely ignored, despite their well-examined advantages in ecotoxicological studies (Giere, 2009; Höss et al., 2006). The majority of meiobenthic taxa are restricted to an interstitial or a burrowing lifestyle in aerobic sediment horizons (Coull and Bell, 1979); accordingly, compared to macrozoobenthos their abundance and species-richness are much higher (Wolfram et al., 2010), especially in soft (fine and sandy) sediments. More-

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over, they are exposed to polluted sediments over their entire life cycle (Coull and Bell, 1979; Traunspurger and Drews, 1996).

In freshwater ecosystems, meiofauna play a key role in the benthic food web. With their high abundance and diversity and numerous feeding-types, they serve as a link between basal resources (bacteria, microalgae, protozoans and fungi) and organisms of higher trophic levels, including larger invertebrates and fishes (Majdi and Traunspurger, 2015; Schmid and Schmid-Araya, 2002; Weber and Traunspurger, 2015). The very high densities achieved by meiofaunal organisms are also a major contribution to benthic energy flow (Bergtold and Traunspurger, 2005; Reiss and Schmid-Araya, 2010). Consequently, changes in meiofaunal communities in response to pollution are likely to have immediate and important impacts on the whole freshwater ecosystem. In the case of noxious bioavailable compounds in the sediments, their accumulation as ingested particles by meiofauna provides a route for their remobilisation via sediment-based food webs (Coull and Chandler, 1992). Additionally, because of the shorter generation cycles of meiofauna compared to macroinvertebrates, their response to pollutants is faster (Balsamo et al., 2010). These characteristics of meiofauna have been exploited in ecotoxicological studies, including field studies (Beier and Traunspurger, 2001; Burton et al., 2001; Heininger et al., 2007) and experimental studies in model ecosystems (Brinke et al., 2010, 2011; Faupel et al., 2011; Faupel and Traunspurger, 2012; Haegerbaeumer et al., 2016), but the use of meiofauna as a biomonitoring tool remains largely unexplored (e.g. Höss et al., 2017). However, a prerequisite to their use in assessing the (quality) status of freshwaters (Reiss and Schmid-Araya, 2010) and in fully gauging the implications of anthropogenic impacts (Burton et al., 2001) is an understanding of the effects of contaminants on these organisms.

A consideration of taxa of all sizes and trophic levels (bacteria, algae, and metazoans) concurrently enables analyses of the direct and indirect (competition, predator–prey relationships) effects of chemicals on whole benthic communities and on the benthic food web (Faupel et al., 2011). Most investigations of the impact of contaminants on freshwater ecosystems have focused on community structure, considering parameters as abundance and biomass. Among the studies that used biomass, the majority consisted of standardised laboratory assays for single-species toxicity tests (Organisation for Economic Co-operation and Development, 2006, 2007) and field studies using one or a few selected representative macrobenthic (Iwasaki et al., 2009) or microbenthic (Fernandez-Leborans and Novillo, 1996) communities; thus, comprehensive studies are scarce (e.g. Faupel et al., 2011). However, while changes in community structure, as assessed by structural measures such as abundance and biomass, are widely accepted indicators of ecological responses to anthropogenic stressors, they are not necessarily related to changes in ecological functioning (Frost et al., 1995; Grime, 1997; Lawton, 1994). Nevertheless, determinations of meiofaunal abundances and biomass provide the basis for estimating energy transfer and productivity (Heip et al., 1990), two key parameters required for the assessment of ecosystems.

Simultaneous examinations of structural and functional parameters allow the disentanglement of energy flows and thus assessments of a system's trophic status (Beaver and Crisman, 1982). Secondary production is one of the major pathways of energy flow in ecosystems (Stead et al., 2005; Strayer and Likens, 1986) and is thus a meaningful functional measure, as it provides insights into population, food web, community and ecosystem dynamics (Benke, 1996; Hall et al., 2000; Majdi et al., 2016), during disturbances and subsequent recoveries (Benke and Huryn, 2010). Yet, only a few ecotoxicological assessments have included evaluations of secondary production (Newman and Clements, 2008). Generally, pollution is viewed as either a resource subsidy that leads to increased production or a physiological stressor that ultimately decreases production (Benke and Huryn, 2010), although recent studies have shown that secondary production by freshwater communities decreases under toxic stress (Carlisle and Clements, 2003; Faupel and Traunspurger, 2012).

Microcosms provide model ecosystems to investigate the impacts of pollutants on entire natural meiofaunal communities and to study the interactions among community members and at different community levels in response to contamination (Haegerbaeumer et al., 2015). Since the toxicity of contaminants depends on several other relevant physical and chemical parameters and on interactions within the investigated assemblages, microcosms provide a relatively realistic picture and are an effective compromise between laboratory toxicity tests and field studies. In the present study, ecotoxicological impacts on whole benthic communities were comprehensively assessed in a long-term (180 days) microcosm-based investigation of natural meiofaunal assemblages. Pristine freshwater sediments were spiked with metals and polycyclic aromatic hydrocarbons (PAH), either in single or mixture applications. Samples from the sediments and the overlying water phase of the microcosms were analysed in terms of chemical concentrations and toxicity in standardized toxicity tests with *Caenorhabditis elegans* (ISO 10872) in course of the study to estimate bioavailability and the tested compounds.

The objectives of the study were: 1) to evaluate structural (abundance, biomass) and functional (secondary production) endpoints in terms of their response to the tested compounds and 2) to determine the sensitivity of the various meiofaunal taxa to assess their suitability as bioindicators for the assessment of soft sediments.

2. Material & methods

2.1. Collecting site

Sediment used in the microcosm experiments was collected from the Örtze (53°00′58.4″N, 10°05′00.5″E), a sandy stream located in the Lunenburg Heath in Lower Saxony, Germany (18% water content; 2.1% gravel, 96.1% sand, 1.5% silt and clay, 0.3% total organic carbon). The high abundances and diversity of meiobenthic organisms at this site and its low levels of anthropogenic contamination were described in a previous study (Haegerbaeumer et al., 2016). The upper 5 cm of the surface sediment, including the indigenous benthic community, was collected with clean stainless scoops, transferred to the laboratory in high-density polyethylene containers and stored until the start of the experiment following standardised guidelines (International Organization for Standardization, 2009). Water collected from the sampling site was used as overlying water for the microcosms.

2.2. Experimental design and spiking

The impact of the tested contaminants on whole meiobenthic communities was monitored in two separate experiments (described below) using 307 indoor microcosms (glass jars; volume = 1700 ml, diameter = 12 cm) that were monitored over a period of 180 days, with sampling on days 30, 90 and 180 (Fig. S1). The initial meiobenthic communities were assessed before the compounds were added in additional microcosms (Day 0; first experiment n = 7, second experiment n = 12; Table S1). In each experiment, the collected sediment was homogenised with a stainless steel scoop and transferred in equal portions to the microcosms to obtain a 5-cm layer of sediment. Water from the sampling site was added until a 10-cm water column on top of the sediments was achieved.