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Nematode species at risk — A metric to assess pollution in soft sediments of freshwaters

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ABSTRACT

Soft sediments are often highly polluted as many of the toxic chemicals introduced into surface waters bind to settling particles. The resulting accumulation of pollutants in the sediments poses a risk for benthic communities. However, pollution induced changes in benthic communities have been difficult to determine when using macro-invertebrates as bioindicators, as these organisms are often absent in soft sediment. The present study therefore examined the ability of meiofaunal organisms, specifically, nematodes, to assess the ecological status of soft sediments. Over a 9-year period, nematode communities present in sediments collected from large rivers and lake Constance in Germany were studied. These sediments showed a large range of physico-chemical properties and anthropogenic contamination. After the degree of metal and organic contamination was translated into ecotoxicologically more relevant toxic units (TUs), multivariate methods were used to classify nematode taxa in species at risk (NemaSPEAR) or not at risk ($NemaSPE_{not}AR$). This approach clearly distinguished the influence of sediment texture from that of the toxic potential of the samples and thus allowed classification of the nematode species according to their sensitivity to or tolerance of toxic stress. Two indices, expressing the proportion of species at risk within a sample ($NemaSPEAR[\%]_{metal}$, $NemaSPEAR[\%]_{organic}$), were calculated from independent data sets obtained in field and experimental studies and showed good correlations with the toxic potential (field data) or chemical concentrations (microcosm data). NemaSPEAR[%] indices for metal and organic pollution were therefore judged to be suitable for assessing the impact of chemical contamination of freshwater soft sediments.

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1. Introduction

The pollution of aquatic ecosystems with anthropogenic chemicals poses a serious risk to the inhabiting biota. The direct and indirect effects of toxic chemicals lead to alterations in community structure at all trophic levels and thereby disturb the functioning of the entire ecosystem. Addressing this risk, the aim of the EU water framework directive (EU WFD) is to achieve a good chemical and ecological status of European water bodies by the year of 2015 (European Community, 2000). However, to assess the impact of anthropogenic pollution on ecological status and thereby monitor compliance with the EU WFD, suitable tools are required that are able to discriminate pollution-induced changes in aquatic communities from changes arising from other types of stress, such as hydro-morphological alterations. Here, the analysis of resident, exposed benthic communities can be part of weight-of-evidence studies (Chapman, 2007). Currently, macro-invertebrates are most often used for bioindication (Hering et al., 2004; Rosenberg and Resh, 1993), with the SPEAR (SPEcies At Risk) index as a promising tool for determining the effects of anthropogenic pollution by organic toxicants, such as pesticides (Liess and Von der Ohe, 2005; Schäfer et al., 2007; Von der Ohe et al., 2007; Von der Ohe et al., 2009). However, in soft sediments, which are of particular ecotoxicological interest due to their ability to accumulate chemicals, macro-benthic communities are often of low diversity and their suitability for bio-indication is therefore limited (Van den Brink and Van der Velde, 1991; Wolfram et al., 2010).

Meiobenthic invertebrates are frequently the most abundant metazoan organisms in soft sediments. They comprise organisms able to pass through 1000-μm-sieve but which are retained by a 42-μm-sieve (Higgins and Thiel, 1988). Representatives of this size class include nematodes, harpacticoid copepods, rotifers, tardigrades, ostracodes and benthic phyllopods, but also small oligochaetes and chironomids, which are usually not considered as macro-fauna.

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Despite their important role in benthic habitats and thus their ecological relevance (Giere, 2009; Traunspurger et al., 2006), meiofaunal organisms have been largely neglected in environmental studies. However, they have several advantages over macro-invertebrates in biomonitoring studies: (1) Meiobenthic taxa are usually more abundant and richer in species than macro-benthic taxa. (2) Meiobenthic species are strictly benthic in their development (without a pelagic or aerial stage), and are thus subjected over their entire life cycle to the impacts of noxious material present in their sediment habitat. (3) Meiobenthic communities respond faster to disturbances, such as pollution, because of the relatively short generation cycles of their component species.

In many lakes and rivers, nematodes are the dominant organismal group within meiofaunal communities (Anderson, 1992; Beier and Traunspurger, 2003; Michiels and Traunspurger, 2004; Prejs, 1977; Traunspurger, 1996, 2000; Witthöft-Mühlmann et al., 2007). They comprise both interstitial dwellers and burrowers and represent different trophic levels with species feeding on detritus, bacteria, algae, fungi, and higher plants, besides omnivorous and predatory species (Yeates et al., 1993; Traunspurger, 1997). Moreover, nematode species have evolved various life strategies, ranging from relatively tolerant species with short generation times enabling them to easily adapt to new environmental conditions, to more sensitive species with long generation times (Bongers, 1990). Nematodes have already widely been used as bioindicators (Höss et al., 2006; Sochova et al., 2006; Wilson and Kakouli-Duarte, 2009), with nematode community analysis shown to be a suitable tool to assess aquatic pollution (Danovaro et al., 2009). Of particular interest is the Maturity Index (MI), which categorizes nematode taxa along a continuum from tolerant colonizers to sensitive persisters. However, while the MI has been frequently applied to assess the quality of soils (Chen et al., 2009; Korthals et al., 1996, 1998; Nagy et al., 2004), for freshwater sediments it may not be suitable to detect anthropogenic pollution, as suggested by field (Heininger et al., 2007) and experimental studies (Brinke et al., 2010, 2011).

The aim of this study was to develop an index able to detect pollution-induced alterations in freshwater nematode communities. Based on a large data set of nematode communities from lentic and lotic freshwater sediments contaminated with varying quantities and qualities of anthropogenic pollution, nematode species were categorized as either species at risk or not at risk of being affected by organic and metal toxicants, according to the concept of the SPEAR index (Liess and Von der Ohe, 2005). Accordingly, sediment samples were ranked in terms of their potential toxicity expressed as toxic units (TUs). These were calculated based on the chemical concentrations of metals and organic pollutants in the sediment and then scaled by their acute toxicity (LC50-values) towards *Daphnia magna*. Using canonical correspondence analysis, nematode species composition was related to the TUs of the sediments, thus revealing species that predominantly occur in sediments with low toxic potential (species at risk) as well as ubiquitous species or species that predominantly occur in sediments with high toxic potential (species not at risk). A similar strategy was previously used for categorizing soil nematodes in terms of their sensitivity towards chemical and physical disturbance in agro-ecosystems (Fiscus and Neher, 2002). The reasoning behind our approach was that the percentage of nematode species at risk (NemaSPEAR) should constitute two nematode indices for assessing the impact of organic and metal pollution of freshwater sediments ($\text{NemaSPEAR[\%]}_{\text{metal}}$ and $\text{NEmaSPEAR[\%]}_{\text{organic}}$).

2. Methods

2.1. Sampling sites and sediment characteristics

From 103 sites, 203 sediments were sampled in lentic and lotic freshwater systems of six different river basins in Germany (Fig. 1).

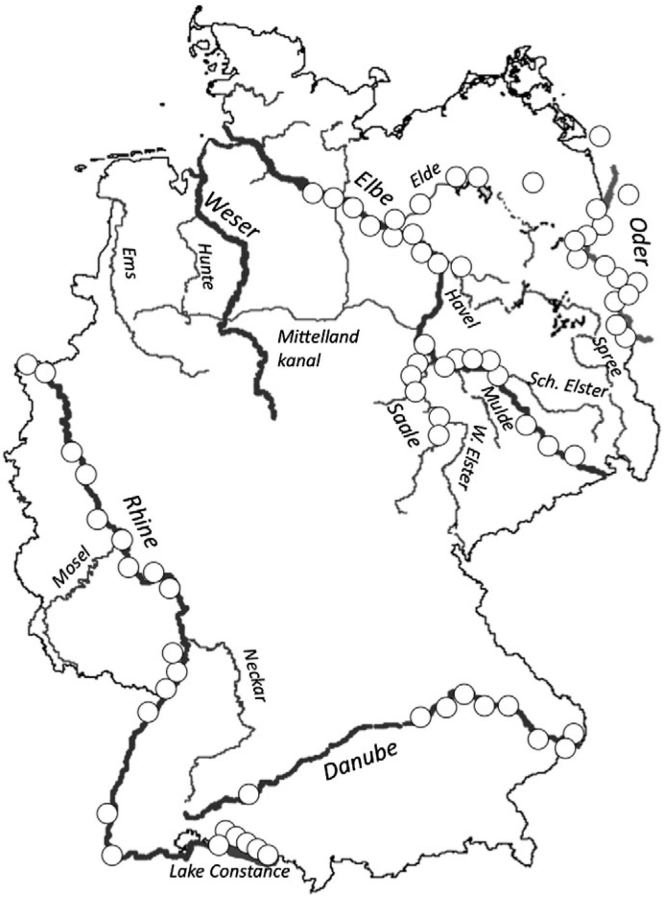

Fig. 1. Sampling sites at rivers and at Lake Constance in Germany.

Among the river systems, 165 samples were taken from 65 sites, with 40 sites sampled on only one sampling date and 25 sites sampled repeatedly (2–13 samples) within the period 2000 to 2008. For nematode analysis from the river sites, samples were collected by means of piston drill with Plexiglas tubes with 52 mm diameter, according to Heininger et al., 2007. The uppermost 2–3 cm of three subsamples were combined for each sample. The sites differed in terms of their hydro-morphological type (back water, barrage, branche, channel, groyne field, harbor, lake, and sheet pile) and were representative of a broad gradient of physico-chemical properties and chemical contamination. Sampling and subsequent analysis of the sediment's properties and contamination (heavy metals and organic chemicals) were carried out according to Heininger et al. (2007). The bulk material (top layer of 0–10 cm) was collected by a stainless steel Van-Veen-type grab sampler. At Lake Constance, 38 samples were taken in 2004 from 38 sites all over the lake, including its littoral and profundal zones, using a multi-corer-sampler (IKGB, 2009). The samples and sites were assigned to seven regions or transects with five and three subsamples combined for each sample, for nematode and chemical analysis, respectively.

Metals (Cd, Cr, Cu, Hg, Ni, Pb, and Zn), As, organic chemicals (7 PCBs: 28, 52, 101, 118, 138, 153, 180; 16 PAH: according to the US EPA; α-, β-, γ-HCH; DDTs: pp′-DDT, pp′-DDD, pp′-DDE; HCB; nonylphenols, tributyltin, mineral oils), fine (<63 μm) and coarse (> 63 μm) particles and total organic carbon (TOC) were analyzed in the entire data set of 203 samples. Other elements, such as P, Ca, and Mg were analyzed in 133 samples, and N, Fe and Al only in 94 samples. A more detailed analysis of grain size distribution (>2000, 630–2000, 200–630, 63–200, 20–63, and <20 μm) was carried out only for the river samples (n = 165).

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