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Field data reveal low critical chemical concentrations for river benthic invertebrates

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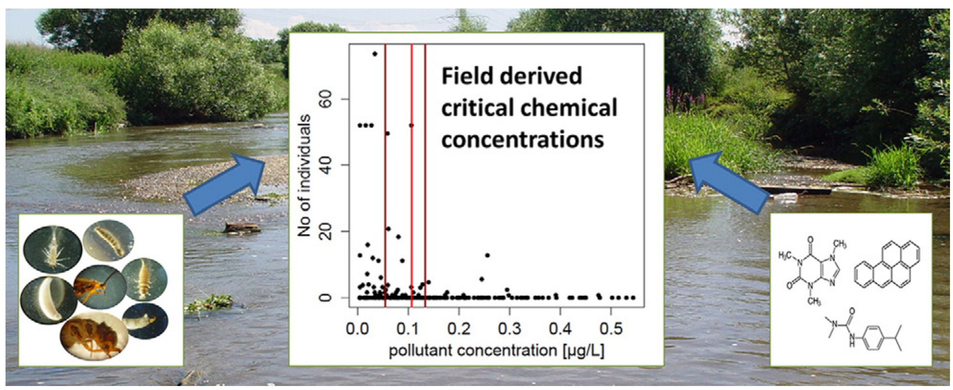
HIGHLIGHTS

- Invertebrates are affected by common organic pollutants at current exposure levels.
- Critical chemical concentrations are calculated for benthic invertebrate taxa.
- Taxa are lost at concentrations lower than is expected from laboratory tests.
- Taxa shown to be sensitive in the field are not used in regulatory ecotoxicology.

GRAPHICAL ABSTRACT



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ABSTRACT

River ecosystems are of immense ecological and social importance. Despite the introduction of wastewater treatment plants and advanced chemical authorization procedures in Europe, chemical pollution is still a major threat to freshwater ecosystems.

Here, large-scale monitoring data was exploited to identify taxon-specific chemical concentrations beyond which benthic invertebrate taxa are unlikely to occur using Threshold Indicator Taxa Analysis (TITAN). 365 invertebrate taxa and 25 organic chemicals including pesticides, pharmaceuticals, plasticisers, flame retardants, complexing agents, a surfactant and poly- and monocyclic aromatic hydrocarbons from a total of 399 sites were analysed. The number of taxa that responded to each of these chemicals varied between 0% and 21%. These sensitive taxa belonged predominantly to the groups Plecoptera, Coleoptera, Trichoptera, Ephemeroptera, Turbellaria, Megaloptera, Crustacea, and Diptera. Strong effects were observed in response to wastewater-associated compounds, confirming that wastewater is an important cause of biological degradation. The majority of change points identified for each compound were well below predicted no-effect concentrations derived from laboratory toxicity studies. Thus, the results show that chemicals are likely to induce effects in the environment at concentrations much lower than expected based on laboratory experiments.

Overall, it is confirmed that chemical pollution is still an important factor shaping the distribution of invertebrate taxa, suggesting the need for continued efforts to reduce chemical loads in rivers.

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1. Introduction

River ecosystems are of immense ecological and social significance. They are biodiversity hotspots, nursing grounds and food sources for many organisms, sources of drinking water, as well as recreational areas for human well-being. Unfortunately, with increasing industrialisation, urbanisation, and agricultural intensification, rivers have suffered severe degradation worldwide (Carpenter et al., 2011).

To protect and restore the biological integrity of European rivers, a unique environmental law – the EU water framework directive (WFD) – was implemented in 2000. A primary aim of the WFD is to achieve a good chemical and ecological status of surface waters. This legislation introduced new standards, criteria, institutions and processes for managing Europe's waters under an integrated, ecosystem-based approach using state-of-the-art knowledge (Kallis and Butler, 2001) and continues to create strong incentives for further research. Thus, intensive chemical and biological monitoring programmes have been developed and implemented by water authorities. Ecological status is determined through measures of composition and the abundance of flora and fauna. The chemical status of a river is defined as either good or not good based on a list of 45 priority substances that are not allowed to exceed defined environmental quality standards (EQS, European Parliament and Council, 2013). The list of priority pollutants is under continuous scrutiny, and environmental agencies measure chemicals of emerging concern that may become controlled under the WFD in the future (Leverett, 2014). Additionally, 162 river-specific pollutants with national EQS are measured in Germany. However, to date, there is no commonly accepted tool for linking chemical and ecological status assessments (Wernersson et al., 2015).

Ecotoxicology as a relatively new branch of science is dedicated to the study of effects of chemical compounds on ecosystems. However, most studies focus on elucidating the mechanisms of toxicity and the development of laboratory or mesocosm tests for predicting the effects of chemicals in the environment. Laboratory tests come with the benefit of controlled conditions, where the species response can be clearly assigned to the chemical tested. However, laboratory tests also come with some drawbacks, such as a) the short duration of the vast majority of tests, b) the limited number of tested taxa, and c) the limited transferability of results from a single stressor study to a multiple stressor environment. The duration of most laboratory tests is much shorter than the life span of many benthic invertebrate taxa. Thus, vulnerable life-stages, such as embryonic development or the pupal phase of holometabolous insects, may not be tested. In such cases, concentrations that induce no effect in the laboratory may not harm the tested stadium (e.g., the larval stage), but may affect another lifecycle stage (e.g., the egg or the pupal stadium), leading to the effective loss of the species in the field. Moreover, the number of river benthic invertebrate taxa that are established as test organisms is low compared to the number of taxa occurring in the field. Thus, we may miss the most sensitive organisms. Specifically, only three freshwater invertebrate taxa are currently considered as test organisms in the laboratory by standardised OECD technical guidelines for the testing of chemicals (*Daphnia* sp., *Chironomus* sp. and *Lumbriculus variegatus*) compared to 1050 taxa that are distinguished in the German river monitoring programmes. Finally, transferring results from single stressor studies carried out in the laboratory to situations in the field is difficult, considering that multiple stressors in the field can operate additive/synergistically or antagonistically (Matthaei et al., 2010; Piggott et al., 2015; Piggott et al., 2012). Assuming an additive or slightly synergistic effect, a mixture of several chemicals is more harmful than an individual chemical alone — commonly known as the “cocktail effect” (Silva et al., 2002). Due to these limitations and a simultaneous focus on laboratory studies, it can be argued that the core questions of ecotoxicology, such as “What are the effects of toxicants on biodiversity”, remain unanswered (Beketov and Liess, 2012). A meta-analysis showed that out of 1307 studies investigating the effect of pesticides on invertebrates, only 0.6% used field data (Beketov and Liess, 2012). There is a lack of research investigating large-scale patterns between chemical exposure and changes in species distribution in the field. There may be legitimate reasons as to why ecotoxicology has adopted more traditional toxicological approaches rather than macroecological approaches. For example, data from large spatial scales, whose collection demands much time and money, are required for such analyses. Chemicals often cannot be measured in the field, because analytical methods must first be developed. However, there have been great advancements in environmental chemistry and, thanks to the WFD, data from extensive chemical and biological monitoring programmes are now available. Thus, it is now possible to look for relationships between chemical exposure and species distribution in the field and to adopt new approaches for ecotoxicology.

The lack of field research is addressed in the present study, and the wealth of data sampled in the context of the WFD is exploited. Changes in the occurrence and abundance of 365 individual invertebrate taxa in response to 25 different organic chemicals are investigated and change point concentrations beyond which these taxa decrease rapidly are calculated using Threshold Indicator Taxa Analysis (TITAN, Baker and King, 2010). TITAN is based on change point analysis and was designed to identify abrupt changes in the occurrence and abundance of taxa over a relatively small concentration range. In ecological theory, such response patterns are expected to occur more often than gradual decreases along an environmental gradient (Tett et al., 2007), which can be better identified using regression analysis. Moreover, TITAN can be viewed as a filtering method to identify sensitive taxa that show a very clear and reliable response to the chemical gradients. These change point concentrations are then compared to current EQS and predicted no effect concentrations (PNECs). Taxa identified as sensitive are compared to taxa commonly used in laboratory studies. Thus, two main questions are addressed: “Are river benthic invertebrates sufficiently protected by current EQS?” and “Are we using appropriate model organisms in the laboratory to protect invertebrate taxa in the field?” Regarding the first question, it is hypothesised that changes in species abundance in the field can be observed at concentrations much lower than EQS or PNECs because EQS and PNECs are mainly derived from single species — single chemical laboratory tests with the limitations described above. Regarding the second question, it is hypothesised that less sensitive taxa are used as model organisms in the laboratory because they must be sufficiently robust to survive in these unnatural conditions. It is thus predicted that the taxa that will be identified as sensitive here will differ from the taxa commonly used in the laboratory.

2. Methods

2.1. Monitoring sites

A total of 399 sites in Germany, where information on both chemical concentrations and benthic invertebrate abundance was available, were used for the analysis. The sites covered a diverse range of stream types, and the land use cover in the catchment area varied from natural vegetation to agricultural areas to a completely urbanised land cover (Table 1). To calculate upstream catchment land use, Corine Land Cover classes (CLC2000, www.eea.europa.eu; Keil et al., 2005) were grouped into the following categories: urban (CLC class 1), arable (CLC classes 2.1 and 2.2), pastures (CLC classes 2.3 and 2.4) and natural (CLC classes 3–5).

2.2. Chemical variables

Chemical monitoring data were obtained from nine state water authorities in Germany and compiled into one dataset based on the CAS (Chemical abstract service) number and/or name of the substance. The dataset comprised approximately 350 organic chemicals that were measured in water samples at the same sites (within 2 km) and in the same and/or previous year of the invertebrate sample. To determine the chemical exposure at a site, a mean concentration was