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Effects of organic pollutants from wastewater treatment plants on aquatic invertebrate communities

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ABSTRACT

Pesticides are a major stressor for stream ecosystem health. They enter surface waters from diffuse agricultural sources but also from point sources such as municipal wastewater treatment plants (WWTPs). However, to date, no studies have focused on the ecological effects of pesticide-contaminated WWTP effluent on macroinvertebrate communities. On the basis of governmental monitoring data of 328 sites in Hesse, Germany, we identified insecticidal long-term effects on the structure of the macroinvertebrate community up to 3 km downstream of WWTPs. The effects were quantified using the trait-based $SPEAR_{pesticides}$ index, which has been shown to be an effective tool for identifying community effects of pesticide contamination. In addition, based on the German Saprobic Index, we revealed that WWTPs are still an important source of oxygen-depleting organic pollution, despite the extensive technological improvements in wastewater management over several centuries. In general, our findings emphasize the need to take municipal WWTPs into consideration in the management of river basins under the EU Water Framework Directive to achieve good ecological and chemical status for European streams and rivers.

1. Introduction

The adoption of the EU Water Framework Directive (WFD; Directive 2000/60/EC) in 2000 marked the beginning of a new era of European water policy, with aquatic ecosystems becoming the central focus for water management (European Parliament, 2000). The aim of the WFD is not only to achieve good chemical status but also good ecological status for all water bodies by 2015.

However, only few years before this deadline, in Germany, for example, about 90% of rivers and streams are still at risk of failing to meet this objective (UBA, 2010). To date, hydromorphological degradation and lack of river continuity have been considered as the most common features that result in classification into an inferior status class (BMU, 2005). However, Kattwinkel et al. (2011) estimated recently that pollution with insecticides probably prevents invertebrate communities in one-third of small European streams

Abbreviations: C, Celsius; EPT, Ephemeroptera; Plecoptera, and Trichoptera; EU, European Union; m, metre; mm, millimetre; km, kilometre; PE, Population Equivalent; RP, Runoff Potential; SPEAR, SPEcies At Risk; WFD, Water Framework Directive; WWTP, Wastewater Treatment Plant.

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(<0.25 m^3/s) from meeting the requirements for a good ecological status.

To develop an effective strategy to reduce pesticide contamination, it is important to evaluate the various sources of pesticide input into surface waters. A considerable number of investigations have been published on pesticide input from diffuse agricultural sources and the subsequent negative effects on aquatic communities (Liess and von der Ohe, 2005; Schäfer et al., 2007; Schriever et al., 2007a).

In addition to this, over the last decade, an increasing number of studies have emphasized the importance of WWTPs as point sources of pesticides by their detection of not only significant amounts of herbicides but also insecticides and fungicides (Berenzen et al., 2003; Gerecke et al., 2002; Müller et al., 2002; Neumann et al., 2002; Wittmer et al., 2010). However, most of these previous studies investigated only a small number of WWTPs (one to five) and all of them focused exclusively on the detection and quantitative evaluation of pesticides. To date, no study has linked the pesticide input from WWTP effluent to benthic macroinvertebrate communities in the receiving streams.

According to the WFD, benthic macroinvertebrates are one of the elements that reflect biological quality and should be used to assess ecological status; they are also a widely acknowledged indicator of the health of stream ecosystems. Macroinvertebrate species are often stressed by a multitude of natural and anthropogenic factors, which makes it difficult to assess the effects of one specific stressor. A promising approach to solve this problem is the use of species traits (ecological, physiological and behavioural traits) (Statzner and Beche, 2010). Recently, the trait-based bioindicator system SPEAR (SPEcies At Risk) was developed which calculates the fraction of species sensitive to a specific type of contaminant (e.g. pesticides, general organic toxicants) in the macroinvertebrate community (Liess and von der Ohe, 2005). In the case of pesticides, the $SPEAR_{pesticides}$ index has been shown to be an effective tool for the evaluation of effects of pesticides (insecticidal toxicity) on macroinvertebrates in streams (Liess et al., 2008).

Against this background, the aim of the study reported herein was to evaluate the long-term insecticidal effects of WWTP effluent on the downstream macroinvertebrate community using governmental monitoring data from 328 sites in the Federal State of Hesse, Germany. In addition, we investigated the on-site quality of the physical habitat as a confounding factor that potentially alters the effects of pesticides on the macroinvertebrate community. Furthermore, we investigated the effect of organic pollution to verify the statement of German water authorities that nowadays organic pollution from WWTPs only rarely poses a problem due to the extensive technical improvements in wastewater management over several centuries (UBA, 2010).

2. Material and methods

2.1. Study area

The sampling sites are situated in the German Federal State of Hesse, which is located in the centre of Germany (Fig. 1). Hesse is characterized by low mountain ranges with an elevation up to 950 m and consists mainly of richly wooded uplands. Besides forest (approximately 40% of the total area), agriculture is the most common land use (approximately 43% of the total area, consisting of 27% arable land and 16% permanent grassland).

The Hessian River Basin Analysis 2004 identified hydromorphological degradation, high nutrients level, and pesticide contamination as the main stressors in Hessian streams (HLUG, 2004). In Hesse, approximately 90% of the farms are connected to the municipal wastewater treatment system, which includes approximately 740 WWTPs. The majority of the sewer network consists of a combined sewer system that collects stormwater and domestic wastewater in a single pipe system and then directs it to the next WWTP. During intensive rainfall, these combined sewer systems discharge excess untreated water, via overflows, directly into streams (HMUELV, 2007).

2.2. Macroinvertebrate data and biological indices

In 2005, the Hessian State Office for Environment and Geology (HLUG) commissioned independent consultants to undertake an extensive operational WFD monitoring to verify the results of the Hessian River Basin Analysis and to support the development of the river basin management plan by 2009.

For the present study, we selected a total of 328 sampling sites from this dataset on macroinvertebrates provided by HLUG. We applied the following criteria to obtain a relatively harmonized dataset. First, the sites were situated at siliceous streams in the lower mountain range, by far the most common stream type in Hesse (two-third of the WFD-relevant watercourse length of Hesse). Second, the stream sites were characterized by stream width smaller than 10 m (1–5 m: 88% of sites; 5–10 m: 12% of sites). Third, the sampling of the community took place before the main period of application of insecticides and fungicides in Germany (which occurs from May to July) to reflect possible long-term effects from the previous year. The majority of the sites were sampled in March or April 2005, and were supplemented by 24 sites sampled in March or April 2006. Finally, the sites were at a minimum of 1500 m from the stream source.

Some of the sampling sites were located at 100–500 m intervals from each other at the same stream which could potentially produce a pseudoreplication effect, due to the spatial correlation in structural and biological conditions. To minimize the potential for pseudoreplication, while also retaining as much information as possible, we decided on a compromise. We chose one of the sites at random if the following criteria were met: structural quality class differs to a maximum of one class, similar land uses in the vicinity of the sampling site, and no tributary joins the stream between these sites. Otherwise, we kept both sides in the dataset.

We used the index $SPEAR_{pesticides}$ to detect and quantify the effects of agricultural pesticides (insecticide toxicity) on the macroinvertebrate community. In this study, we considered the insecticidal effects of insecticides and fungicides. Herbicides were not taken into account due to their generally low toxicity on macroinvertebrates. Insecticides and fungicides are in general applied on a seasonal basis. Thus, $SPEAR_{pesticides}$