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Pesticides in agricultural headwater streams in southwestern Germany and effects on macroinvertebrate populations

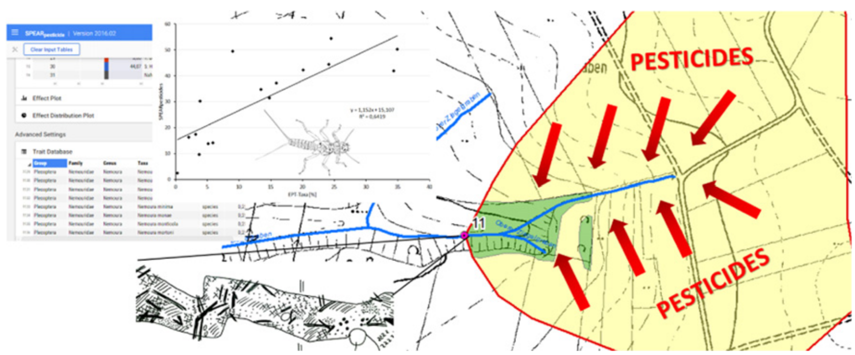
Gero Weber [a,*], Nicole Christmann [a], Ann-Cathrin Thiery [a], Dieter Martens [b], Jochen Kubiniok [a]

[a] Saarland University, Physical Geography and Environmental Research, Am Markt Zeile 2, D-66125 Saarbrücken, Germany
[b] LUFA Speyer, Obere Langgasse 40, 67346 Speyer, Germany

HIGHLIGHTS

- A considerable pesticide pollution was detected in agricultural headwater streams.
- Biotic metrics like SPEAR did not clearly correlate with pesticide toxicity.
- Habitat factors overlay toxic effects on macroinvertebrates in small water bodies.
- Combined approach including toxicity parameters and ecological indicators is needed.

GRAPHICAL ABSTRACT



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ABSTRACT

Pesticides are a major burden for stream ecosystems in the central European cultivated landscape. The objective of the present study was to investigate the applicability of ecological indicator methods in relation to toxicity of pesticides under the specific hydro-morphological conditions in small water bodies. Thus, an association of toxicity evaluating methods with different ecological indicators was to be attempted. Based on three random samples taken within the 2016 vegetation period, 23 headwater areas in the Saarland were investigated to test for pesticides and their metabolites. The macroinvertebrate population was also surveyed in 16 of these streams. Evidence was found of 41 substances in total. Most dominant substances include atrazine, isoproturone, quinmerac and tebuconazol as well as metabolites of dimethenamid, chloridazon and metazachlor. At 9 of the 23 sampling points, over 10 plant protection products and metabolites were found. Only 17% of the water bodies investigated contained fewer than 5 substances. Around half of the bodies of water investigated show noticeably high concentrations of metabolites of plant protection products. Maximum concentrations exceeding environmental quality standards or the Health-oriented Guideline Values were measured for 13 substances at individual sampling points.

Analysis of the biological data for only 4 of the water bodies investigated resulted in the Ecological Status Class (ESC) "good". All others fell short of the quality target, although they were classified as "good" or "very good" according to the Saprobic index. $SPEAR_{pesticides}$ as a measurement of the sensitivity of the biocoenosis to pesticides shows their influence in a few water bodies. Likewise, high toxic unit values have also been calculated, indicating

* Corresponding author at: Universität des Saarlandes, Physische Geographie und Umweltforschung, Am Markt Zeile 2, D-66125 Saarbrücken, Germany.
E-mail address: gero.weber@geo.uni-saarland.de (G. Weber).

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the presence of toxic substances at relevant concentrations. However, an actual correlation between $SPEAR_{pesticides}$ and toxic unit could not be derived. Clearly in these very headwater streams other habitat-determining hydromorphological factors overlay the toxic impact of pesticides.

1. Introduction

Streams in the central European cultivated landscape are exposed to a large number of stress factors. Structurally morphological effects due to hydraulic engineering measures such as expansion of the channel bed, straightening and damming due to transverse structures are further complicated by changes to the water chemistry due to the discharge of chemical substances (Damalas and Eleftherohorinos, 2011; Schriever et al., 2007). This impacts aquatic life in a variety of ways and consequently, can lead to degradation of the biocoenosis, which manifests in a negative classification of the ecological status according to the provisions of the EU Water Framework Directive (WFD) and the German Surface Waters Ordinance (EU WFD, 2000; OGewV, 2016).

It is a well-established fact that pesticides constitute a major stressor for macroinvertebrate populations in stream ecosystems in agricultural catchment areas (Liess and von der Ohe, 2005; Schäfer et al., 2007; Liess et al., 2008). Pesticides can enter these ecosystems from point sources such as waste water treatment plants, and from non-point sources via land used for agricultural purposes (Neumann et al., 2002; Damalas and Eleftherohorinos, 2011). For these point sources, in addition to direct discharge from wastewater/sewage treatment plants, stormwater overflows and other relief structures of combined sewer drainage systems are also very common, leading to peak discharges of substances in the event of heavier rainfall and storms. The additional contaminants that pool together with substances from non-point sources have a heightened effect on macroinvertebrate populations at these types of discharge point. On the one hand, they cause multiple stress on already weakened aquatic organisms and lead to increased total concentrations of particular pollutants on the other (Berenzen et al., 2003; Wittmer et al., 2010; Kosmala et al., 1999; Gücker et al., 2006). This effect can often be observed several miles below the point of discharge (Bunzel et al., 2013). However, it is no longer possible to clarify the significance of the respective discharge sources in these particular sections. In bodies of water of an average size above a catchment area measuring >10 km^2, both contamination routes usually overlap, rendering it impossible to differentiate the origin of the contamination by substance. This is also the case for official monitoring points, which, due to their location at reportable water bodies, are generally found both within the reach of the diffuse discharges from the catchment area and of the one-off discharges from urban water treatment facilities.

To record the effect of pesticide discharges from agriculture, sections of water must be investigated for which one-off discharges, e.g. due to sewage treatment plants, rain water overflows or drainage systems of larger traffic infrastructures can be excluded. In an initial study using random samples taken at source brooks in the catchment area of Theel in central Saarland, we were able to find signs of a correlation between the cumulative evidence of pesticides in the water body and the degradation of the biocoenosis (Thiery et al., 2016). The study has also shown that it is in small water bodies in particular that structural-morphological and hydrological factors can overlap with contamination by the substances and can even be dominant. Thus at headstreams which periodically dry out or in small channels with homogeneous substrate, there are often diminished macroinvertebrate populations with low individual density and reduced taxa numbers. In such cases, the use of the standard metrics that have established themselves in the field of water monitoring must be seen as critical (Meier et al., 2006). More recent investigations have shown that the habitat structure and its depletion overlap with the stress caused by pesticides (Rasmussen et al., 2012; Bunzel et al., 2014). $SPEAR_{pesticides}$ (Species at Risk), which was introduced as a bioindicator for the burden on aquatic populations caused by pesticides (Liess and von der Ohe, 2005; Liess et al., 2008; Beketov and Liess, 2008) should therefore be interpreted in conjunction with other information.

Apart from the aforementioned studies, there is very little data available on pesticides or their metabolites in the water bodies of the low mountainous region of the Saarland. Analyses based on random sampling have been used only as a part of official water monitoring under the requirements of water legislation. However, these were then limited to the so-called river-basin specific pollutants and priority substances in accordance with the German Ordinance on the Protection of Surface Waters (OGewV, 2016).

Consequently one first objective of this study was to obtain an initial overview of agricultural pesticide contamination of streams in the agrarian areas of the Saarland. In addition, the methodological aim was to investigate the applicability of standardised ecological indicator methods in relation to toxicity of pesticides under the specific hydromorphological conditions in small water bodies. Thus, the association of the toxicity evaluating system with different ecological indicators was to be attempted.

The prime focus was high reaches, because firstly, these can serve as areas of refuge outside the influences on colonisation and secondly, are directly exposed to the substance discharges from the surrounding catchment area due to interflow and surface run-off. As these sections usually have highly fluctuating water levels and extremely heterogeneous bed structures, the suitability of standardised procedures to evaluate the ecological quality of streams should continue to be tested according to the WFD and the German Ordinance on the Protection of Surface Water.

To do so, watercourses were selected outside the area of influence of one-off discharges by urban drainage or larger traffic systems further to extensive preliminary probing. Sampling took place in 2016 during the main vegetation period in April and May, and in October after pesticide application for the winter crop. To evaluate the toxicity of the pesticides found, the toxic units approach was employed (Bundschuh et al., 2014; Beketov et al., 2013). The biological data were interpreted using the Perlodes evaluation software (Meier et al., 2006). The SPEAR method was used to perform an integrative assessment of the impact of the pesticides on aquatic populations (Liess and von der Ohe, 2005).

2. Methodology

2.1. Study design and selection of water bodies

The study was performed on 23 high reaches of the stream system in the low mountainous region of the Saarland (south-west Germany). These are water bodies of the first and second order according to Strahler's classification system (Strahler, 1952), which drain into the Rhine via the Saar and the Mosel. The following criteria were paramount in the selection of the water bodies and determining the sampling locations:

- Predominantly agricultural use of the catchment area (mainly arable use)
- No direct or indirect discharges (drainage systems, sewage treatment plants, etc.)
- No urban settlements or larger traffic infrastructures within the catchment area