33 Pesticide Effects on Stream Ecosystems

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Which ecosystem services are addressed? Water quality.

What is the research question addressed? What is the risk of pesticides for stream communities and how is it expected to develop under global climate change?

Which method has been applied? Literature review.

What is the main result? Streams in more than 40 % of the global land area can be affected by insecticide runoff. Pesticides have negative effects on biodiversity and the ecosystem function leaf litter degradation. Finally, the ecological risk due to insecticides is expected to increase under climate change.

What is concluded, recommended? Despite existing regulations, pesticides present a major stressor for stream ecosystems. More realistic effect predictions are necessary and effective mitigation measures can be implemented at the landscape level or reduce the use of pesticides.

33.1 Pesticides in Freshwater Ecosystems

Pesticides are currently applied on a large scale in agricultural crops, but also in urban areas, private gardens, and households. Pesticides enter freshwater ecosystems for example via surface runoff, spray drift, or wastewater treatment plants. The study from Ippolito et al. shows that more than 40% of the global land area is at risk to insecticide, as displayed in Fig. 33.1. The authors modelled insecticide exposure using the runoff potential model [7]. Up to 18% of the global land area is predicted to cause a high to very high insecticide runoff into draining freshwaters. Parameters that contribute to a high runoff potential are predominantly pesticide use, proportion of cropland, precipitation, slope and soil characteristics. For validation of exposure, the authors compared the predicted runoff potential with measured pesticide concentrations in streams from field studies in Europe and Australia.

While the runoff potential model mainly represents a risk potential of certain regions towards pesticide exposure, high pesticide concentrations in freshwater systems have also been reported in several studies. Examples are included in a recent study by Stehle and Schulz [8] that detected insecticide concentrations exceeding regulatory thresholds in 50% of the investigated concentrations at a global scale. Also, Malaj et al. [9] reviewed the available exposure monitoring studies of organic pollutants in European freshwater systems and identified pesticides as one of the major contributors to toxicant exposure of freshwater ecosystems.

33.2 Impacts on Invertebrate Communities, Biodiversity, and Ecosystem Functions

Effects on aquatic invertebrate communities could be linked in several field studies to measured pesticide concentrations. These field observations in streams show a decline of the trait-based indicator $SPEAR_{pesticides}$ in Germany [12], but also across different biogeographical zones in Europe, Russia, and Australia [10].

The trait-based indicator $SPEAR_{pesticides}$ represents the ratio of pesticide vulnerable against invulnerable taxa and gives a measure for the freshwater ecosystem effects of pesticides [1]. In addition to structural changes in the invertebrate communities, the study by Beketov et al. [3] observed a strong decline in biodiversity due to pesticide exposure for different biogeographical regions in Europe and Australia (Fig. 33.2). The authors highlight that species diversity significantly decreased to 58% at sites with high pesticide exposure compared to sites with low pesticide exposure.

Relevant ecosystem functions in headwater streams comprise especially leaf litter degradation and primary production as basic energy sources. A reduction of these ecosystem functions can, in turn, affect ecosystem services such as water purification. In contrast to primary production, leaf lit-

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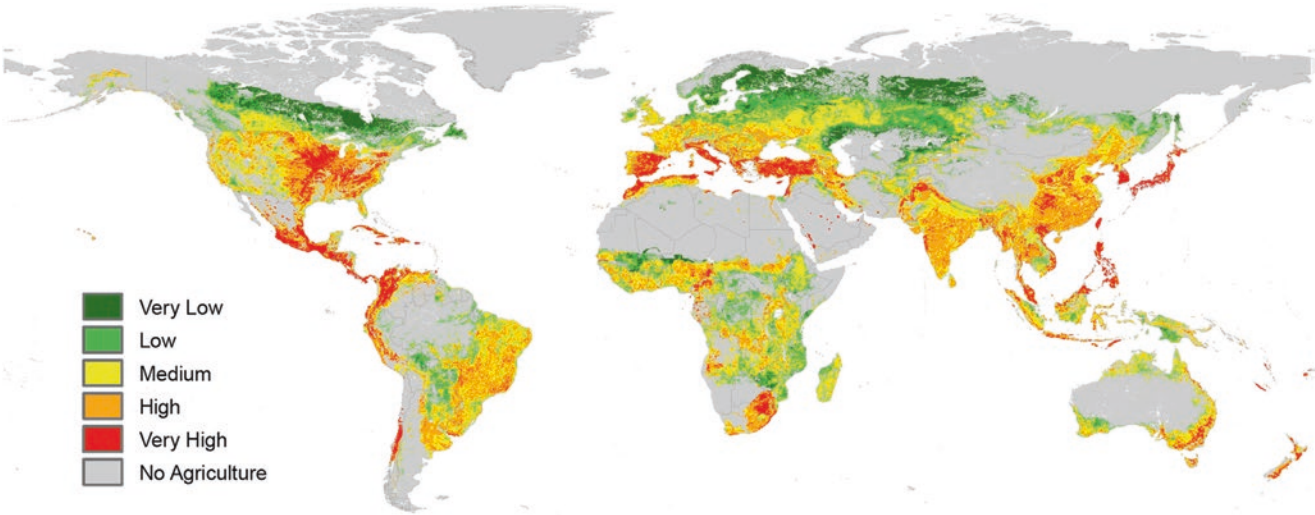

Fig. 33.1 Global insecticide runoff potential map. The map shows the spatial distribution of potential insecticide runoff to stream ecosystems considering agricultural activities, geomorphological and climatic conditions. The class boundaries of the runoff potential (−3; −2; −1; 0) follow the same definition as in [6]. (*Reprinted from* Ippolito et al. [2]; *with permission*)

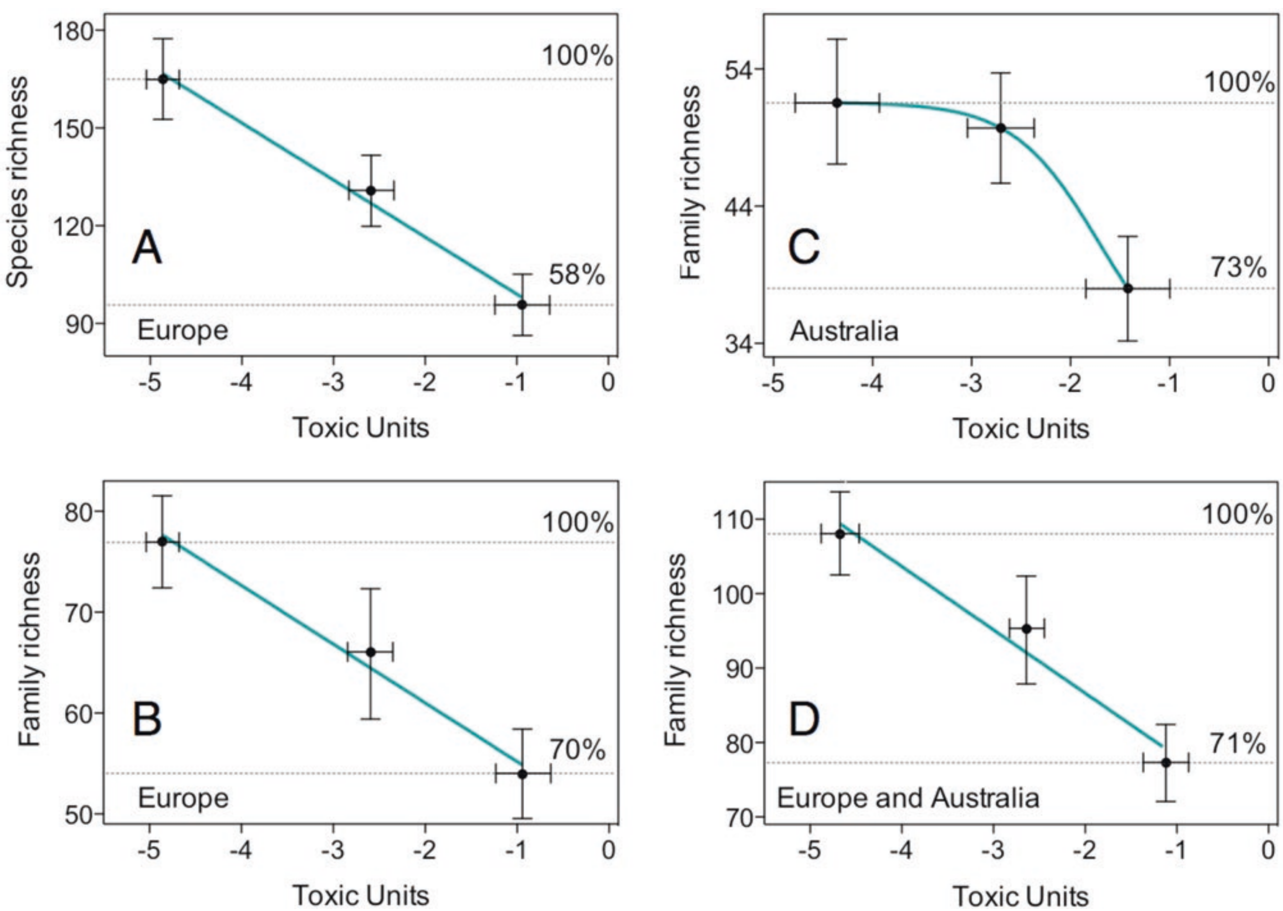

Fig. 33.2 Concentration–response relationships between the pesticide concentration (Toxic Unit) and mean overall taxa richness of stream invertebrates. The relationships are given for species and family richness in the investigated regions Europe (**a**, **b**), Australia (**c**) and the combined data set (**d**). Pesticide data have been classified in three groups according to the level of pesticide concentrations. Maximum and minimum taxa richness is displayed with dashed horizontal lines. (*Reprinted from* Beketov et al. [3]; *with permission*)

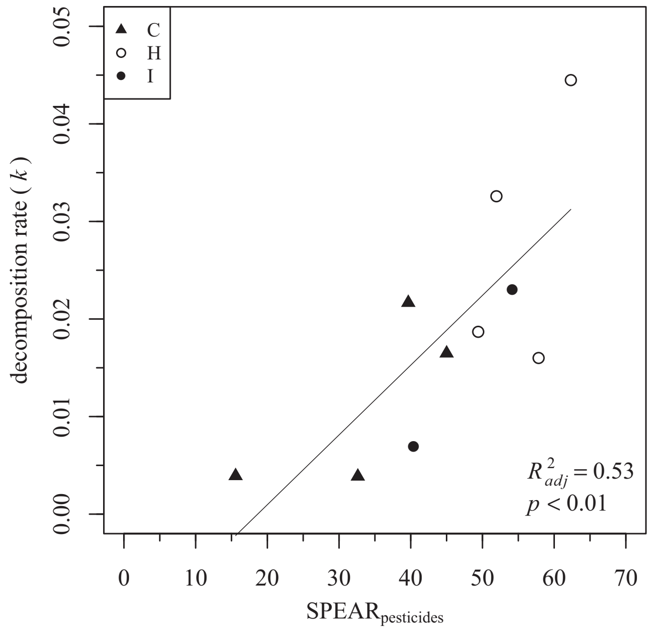

Fig. 33.3 Relationship between the leaf litter decomposition rate k and trait-based indicator $SPEAR_{pesticides}$. The relationship is based on ten stream sites in Germany. Regression line, R_2 and p-values describe the significant linear regression. *C* carbofuran, *H* herbicide, *I* insecticide other than Carbofuran. (*Reprinted from* Münze et al. [5]; *with permission*)

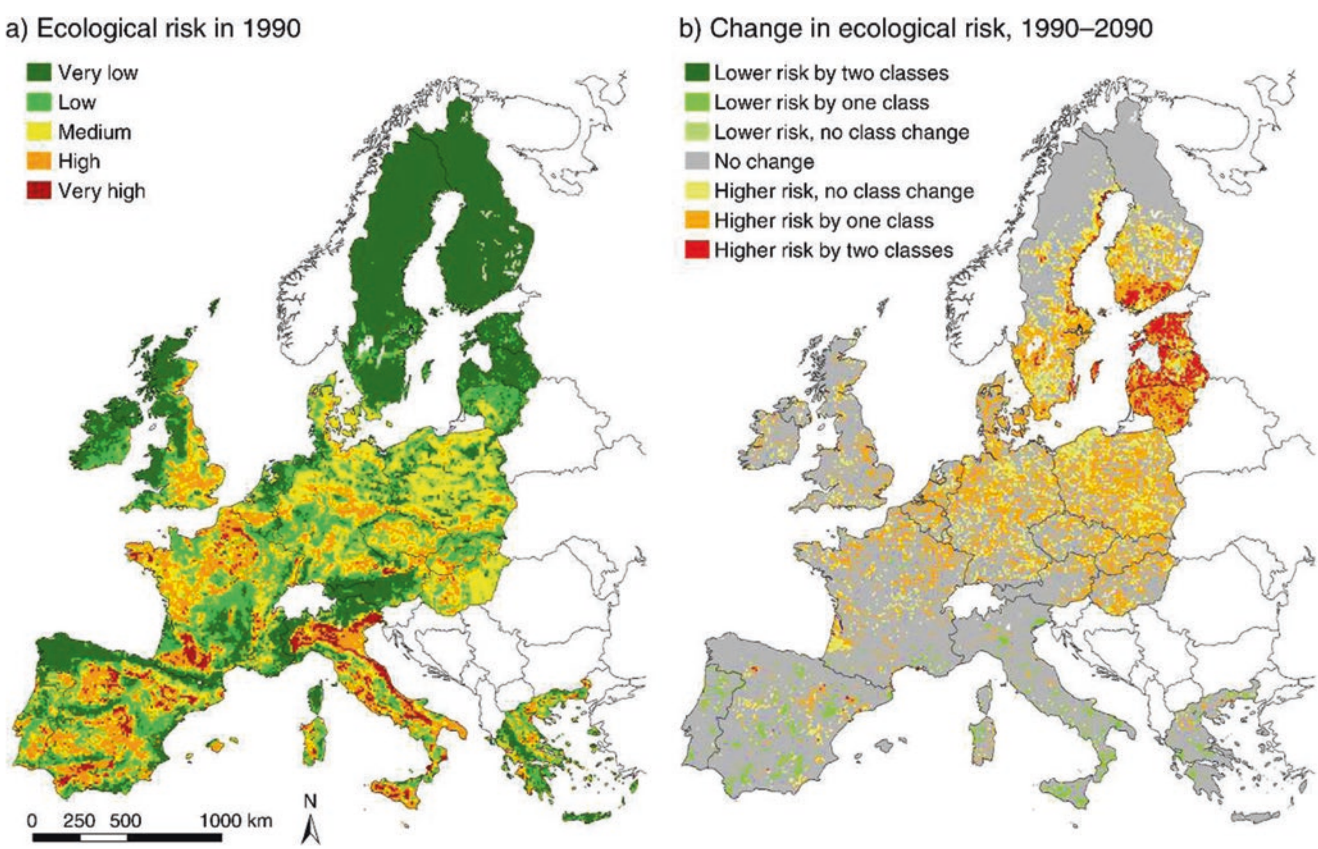

Fig. 33.4 (**a**) Ecological risk in 1990 and (**b**) change in ecological risk from 1990 to 2090 based on the A1B scenario. The ecological risk is based on the empirical relationship between runoff potential, recovery parameters, and changes in the invertebrate communities. The ecological risk has been classified to "very high," 75–100% of all stream sites within a cell were predicted to have an ecological status worse than "good"; for the class "high," 50–75%; for the class "medium," 25–50%; for the class "low," 10–25%; and for the class "very low," 0–10%. The change in the ecological risk represents the deviation from 1990 to 2090. (*Reprinted from* Kattwinkel et al. [6]; *with permission*)

ter degradation has been observed to decrease due to pesticide exposure in Australian streams [4]. Münze et al. [5] also observed a decrease in leaf litter degradation in German agricultural streams that was significantly correlated with the detected pesticide concentrations, but even stronger with a decreasing $SPEAR_{pesticides}$ as shown in Fig. 33.3.

33.3 Pesticide Effects Under Climate Change

Agriculture includes, in large part, the use of pesticides that depend to a significant extent on climate conditions and, hence, are predicted to change under global climate change. The analysis by Kattwinkel et al. [6] identified a positive relation between the mean annual temperature and the rate of applied insecticides across different European states. Applying space-for-time analyses, the authors used this link to predict a runoff potential under future climate and land-use scenarios for freshwater communities. Kattwinkel et al. [6] determined the ecological risk of stream ecosystems based on an empirical exposure-response relationship between the runoff potential, the presence of recovery areas, and the indicator $SPEAR_{pesticides}$. The authors concluded from the analyses that the ecological risk is especially increasing in Central and Northern Europe until 2090 due to increasing insecticide applications and land-use change (Fig. 33.4). Similar shifts in agricultural activities and increased pesticide exposure due to climate change is not only expected for Europe, but in general for higher latitudes and altitudes [11].

33.4 Conclusions and Recommendations

Despite strict regulations and registration procedures as, for example, implemented in the European Union and North America, pesticides in freshwater streams present a major stressor for stream invertebrates, including relevant ecosystem functions and services. Hence, we need to better understand pesticide effects under different environmental conditions. The underlying mechanistic knowledge of realistic effects is necessary to extrapolate from laboratory studies to the field using protective safety factors and effect models that predict current and future pesticide impacts. Regarding mitigation measures at the landscape level, riparian buffer strips and uncontaminated stream sections (refuge areas) have been proven to, respectively, reduce the pesticide exposure and impact on freshwater invertebrates. Other measures, like pesticide taxes, non-chemical alternatives, and the substitution of critical pesticides in terms of environmental effects and human health, focus on the use of pesticides. These measures present important tools to reduce pesticide use in general and the risk of pesticides for humans and non-target organisms.

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