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Long-term stream invertebrate community alterations induced by the insecticide thiacloprid: Effect concentrations and recovery dynamics

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ABSTRACT

In pesticide risk assessment, effect concentrations and dynamics of long-term community-level effects caused by pulse exposures remain to be investigated. This is because long-term experiments are exceptionally rare, and most of the previously investigated communities had low proportions of sensitive long-living species. The aim of the present study was to investigate the effect of a single pulse contamination with the insecticide thiacloprid on invertebrates. We employed mesocosms designed to realistically mimic communities in small streams within the agricultural landscape. Specifically, the objectives were to (i) compare the community Lowest-Observed-Effect Concentration (LOEC) with organism-level median lethal concentrations (LC50), and (ii) to assess recovery dynamics with special focus on short- and long-living taxa. The contamination resulted in long-term alteration of the overall invertebrate community structure (7 months, until the end of the experiment). Long-term community LOEC was 3.2 μg/L (Redundancy Analysis), slightly below the acute LC50s known for sensitive invertebrates relevant to the mesocosm community. However, one species (stonefly *Nemoura cinerea*) was affected at the lowest tested concentration, 70 times below the lowest known LC50. Concerning time to recovery from the effect, we found that the duration depends on the life-cycle characteristics of species, but not on the toxicant concentration: short-living (mulivoltine) species recovered after 10 weeks following contamination, whereas long-living (uni- and semivoltine) species did not recover until the end of the experiment (7 months). The present example shows that concentrations of pesticides at which majority of the species is affected can be predicted by acute organism-level toxicity tests with sensitive species. However, tests with longer observation periods, as well as consideration of environmental factors and inter-taxon variability in sensitivity are required to predict effects on all species comprising a community. Realistic prediction of community recovery dynamics requires consideration of the species' life-cycle traits.

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1. Introduction

One of the crucial aims of ecotoxicology is to assess and define the concentration levels at which contaminants cause effects on communities and ecosystems, and to investigate and predict recovery of these systems following toxicant stress (e.g. Campbell et al., 1999; Giddings et al., 2002). Among the contaminants in current use, modern non-persistent insecticides as well as other pesticides are relevant stressors for many aquatic and terrestrial organisms (Liess et al., 2005), and a great number and variety of studies have been conducted to derive and predict the effect concentrations for these toxicants and to understand the processes of recovery from the effects of these contaminants.

Concentration levels for ecological effects of pesticides and many other toxicants are typically derived from laboratory single-species tests. Results of such tests are used for predicting potential effects of toxicants on ecosystems either by applying safety factors (e.g. EEC, 1991) or using species-sensitivity distribution (SSD) methods (e.g. Posthuma et al., 2002). In addition to these predictive methods based on laboratory single-species tests, a wide array of more complex experimental systems is used for validation of the laboratory tests in semi-natural conditions. These model ecosystems, referred to as micro- and mesocosms, are used for risk assessment of pesticides and are known as higher-tier risk assessment testing systems (Campbell et al., 1999).

For pesticides, a recent review focused on comparison of the result from laboratory and mesocosm test systems revealed that effects of these toxicants on biological communities in mesocosms have rarely been observed at concentrations >10 times lower than the acute Median Effective Concentrations (EC50) obtained for the species known to be sensitive in laboratory conditions (*Daphnia magna*), and in most cases have been observed at much higher concentrations (Van Wijngaarden et al., 2005). On the other hand, several microcosm studies focused on chronic post-exposure effects of insecticides have shown that these toxicants can have a long-term influence on most sensitive endpoints even at concentrations up to 1000 times lower than the laboratory-generated acute EC50s (for *D. magna* or sensitive insect species) (Lozano et al., 1992; Liess and Schulz, 1996; Liess, 2002; Beketov and Liess, 2005). In addition, existing field monitoring studies indicate that pesticides may have adverse effects on freshwater invertebrates at concentrations more than 100 times below the laboratory-generated acute EC50s derived for *D. magna* (Liess and von der Ohe 2005; Schäfer et al., 2007).

Recovery of ecological systems after chemical stress caused by pesticides and other environmental toxicants currently receives increasing attention from scientists and regulators (Giddings et al., 2002; Barnthouse 2004; Caquet et al., 2007). Investigations of the recovery processes usually employ micro- and mesocosms. For pesticides, community recovery in mesocosms is frequently observed within a relatively short period after contamination. Thus, for non-persistent insecticides the majority of previously published studies have shown that recovery is already completed within two months after contamination (reviewed by Van Wijngaarden et al., 2005). However, a few long-term mesocosm experiments have revealed that even a single short-term exposure to pesticides may result in long-term and permanent elimination of long-living species if external recolonisation is hampered (Van den Brink et al., 1996; Caquet et al., 2007). Hence, the rapid recovery observed in many mesocosm systems that are predominantly inhabited by short-living organisms (e.g. plankton and short-living benthic insects) and open for external recolonisation (e.g. aerial entry of insects from neighbouring controls) may easily underestimate the recovery duration for communities that include long-living species and are relatively isolated from unimpaired ecosystems (Caquet et al., 2007; Hanson et al., 2007).

Thus for pesticides uncertainty remains regarding both effect concentrations and recovery patterns. In the authors' opinion one main reason for this uncertainty is the paucity of long-term mesocosm experiments employing ecologically realistic communities with a large proportion of long-living taxa and extensive field monitoring studies. Long-term experimental studies are particularly important for understanding effects on long-living species, as experimental observation periods covering significant part of species life-spans are needed to understand duration of effects and recovery patterns (e.g. for univoltine taxa desirable observation period is from >0.5 year to ≤1 year).

Long-term mesocosm experiments are rare. To the authors' knowledge only 5 out of 62 community-level studies on non-persistent insecticides published so far (70 papers) include post-contamination observation periods longer than half a year. These are studies by Brock et al. (1992), Fairchild and Eidt (1993), Van den Brink et al. (1996), Woin (1998), and Hanson et al. (2007) (for the studies reported as paper series, only the first papers are cited). All these investigations were performed with standing-water systems.

Although these long-term studies were not focused on understanding the importance of species' life-cycle traits for post-exposure recovery, two of them have shown that recovery of long-living (univoltine) species after pronounced toxic effect can take long time periods comparable to the species' lifespans (≥1 year) (Van den Brink et al., 1996; Woin 1998). However, the numerical proportion of the long-living species (with generation time ≥1 year) in the communities analysed in these two studies was low (about 10 and 24% of the analysed communities respectively; own calculations based on reported information). Besides, long-term effects on the entire community structure were either not found under ecologically realistic conditions (as stated by the authors) because relatively few long-living taxa were affected (Van den Brink et al., 1996) or this aspect was not analysed (Woin, 1998). Importantly, invertebrate communities in natural streams uncontaminated with pesticides usually include much greater proportions of long-living taxa. For example in Europe, the percentage of the taxa having generation time ≥1 year in uncontaminated streams in France and Finland varies from 60 to 80% and from 40 to 70% of the overall taxa richness respectively (own calculations with data from Schäfer et al., 2007). However, significance and patterns of the long-term effects caused by single pulse contamination with an insecticide remain to be investigated.

The aim of the present study was to investigate long-term effects of a single pulse contamination with the neonicotinoid insecticide thiacloprid on invertebrate communities of stream mesocosms, which were allowed to establish a community