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Spray drift of pesticides and stream macroinvertebrates: Experimental evidence of impacts and effectiveness of mitigation measures

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Pulsed pesticide exposures via spray drift adversely affected stream invertebrates but did not cause population or community-level effects and were mitigated by no-spray buffer zones.

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ABSTRACT

Impoverished stream communities in agricultural landscapes have been associated with pesticide contamination, but conclusive evidence of causality is rare. We address this deficiency by adopting an experimental approach to investigate the effects of the insecticides cypermethrin and chlorpyrifos on benthic macroinvertebrates. Three treatments were established and a combination of biomarker, bioassay and biomonitoring approaches was employed to investigate, individual, population and community-level effects. Animals deployed during pesticide application had altered enzyme activity, depressed feeding rate and reduced survival, but these effects were only observed where pesticide was sprayed to the stream edge. There were no clear pesticide-related effects on macroinvertebrate community structure or on the population densities of individual species. Hence, short-term pesticide exposure did cause individual-level effects in stream macroinvertebrates, but these were not translated to effects at the population or community-level and were effectively mitigated by the adoption of a no-spray buffer zone.

1. Introduction

Pesticides play an important role in modern agriculture, but their use is not without risks to non-target organisms and habitats. In order to protect against undesirable impacts, many countries require pesticides to undergo a detailed ecological risk assessment and identification of mitigation methods prior to their registration for use (EC, 1991). These risk assessments have a primary focus on freshwater ecosystems, due to their distribution in agricultural landscapes and high conservation value (Williams et al., 2004). Pesticides may enter fresh waters directly via spray drift or indirectly via surface runoff or drainflow, and an important risk mitigation method is to reduce pesticide exposure by imposing 'no-spray' buffer zones (Reichenberger et al., 2007). Despite these measures, pesticides do enter freshwater environments (Schultz, 2004), but what evidence is there that pesticides, when used in accordance with good agricultural practice, are having an adverse effect on freshwater ecosystems?

Comparisons of freshwater communities in different landscapes (i.e. arable and non-arable; organic and non-organic) provide some field-based evidence of adverse effects (Liess et al., 2005), but the difficulty with these types of studies is demonstrating that the impacts observed are due to pesticides and not a consequence of either other differences in land management (e.g. ploughing regime, fertilizer use and riparian vegetation) or due to co-occurring stressors (Schultz, 2004). Runoff and drainflow, for instance, are induced by rainfall or irrigation and hence pesticide inputs are associated with changes in other environmental factors that may themselves have ecological impacts (e.g. increased flow and sediment transport). A few studies have attempted to separate the effects of pesticides from those of hydraulic stress (Liess and Schultz, 1999) or suspended solids (Anderson et al., 2006) using field or laboratory manipulations, but isolating pesticide effects from a background of co-occurring stressors is still a major challenge (Schriever et al., 2007). Direct pesticide inputs via spray drift are not associated with the same event-related co-stressors; here the challenge is to separate effects due to short-term pesticide exposure from other aspects of land management.

Here we adopt an experimental approach to characterise the effects of pesticides in spray drift on stream benthic macroinvertebrates and to assess the effectiveness of 'no-spray' buffer zones. The focus is on a dominant crop in Great Britain (i.e. wheat) and on insecticides, which pose the greatest risk to stream invertebrates. The insecticides are chlorpyrifos and cypermethrin, which are both subject to a statutory 'no-spray' buffer zone when used with a ground crop sprayer in the UK. We use a combination of

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in situ bioassays and benthic surveys to investigate whether pesticides applied during normal agricultural practice have adverse effects on individuals, populations or communities of stream benthic macroinvertebrates. Pesticide exposure is manipulated by applying it to within 6 m of the stream bank (i.e. 'no-spray' buffer zone) or right up to the stream bank. One of the major difficulties in field studies with pesticides is obtaining accurate exposure information (Capri et al., 2005), particularly when exposure is via spray drift. Here we complement the EU regulatory modelling approach for predicting pesticide exposure concentrations (FOCUS, 2001) with information from molecular biomarkers. Organophosphorus pesticides, such as chlorpyrifos, inhibit cholinesterase activity (Streit and Kuhn, 1994) whereas pyrethroid pesticides such as cypermethrin are known to induce glutathione S-transferase activity (Gowland et al., 2002). Hence, in this study, GST and ChE activities were used as biomarkers of exposure to cypermethrin and chlorpyrifos, respectively.

2. Methods

2.1. Study site

The study was conducted in a tributary of the River Arrow at Titley Court Farm, Herefordshire, UK (NGR SO336589), hereafter referred to as Titley Court stream. The source of the stream was a small lake approximately 500 m upstream from the study area and it passed through mixed woodland and then rough pasture before flowing south–southeast between arable fields and draining into the River Arrow. The study area consisted of three 25-m long stream sections, each approximately 1.5 m wide and 25 cm deep with a pebble and gravel substrate. A small weir at the boundary between the pasture and arable land prevented upstream movement of organisms beyond this point. The upper section was 100 m upstream of the weir and the other two sections were downstream of it, adjacent to arable fields and separated from each other by 10 m. The field margins were planted with winter wheat for at least 30 m from the stream boundary and all pesticide applications within this area were strictly controlled. The upper stream section was designated a no-application control, a 6-m no-spray buffer zone was applied to the middle section (i.e. buffer), but pesticide was applied to the stream edge at the lower section (i.e. no-buffer).

2.2. Pesticide applications

Winter wheat received three pesticide applications over two crop cycles; an autumn/winter combined application of insecticide (cypermethrin) and herbicide (isoproturon and simazine) in year 1 and an autumn and spring application of insecticide (chlorpyrifos) in year 2. Pesticides were applied by spray boom at normal farm application rates when a 2.7–3.6 m/s west to west–northwest wind was blowing, which carried pesticide spray across the stream in a downstream direction.

Table 1
Aqueous pesticide concentrations (μg/L) in the 'buffer' and 'no-buffer' sections of Titley Court stream resulting from spray drift determined using the FOCUS drift calculator (FOCUS, 2001)

	Buffer	No-buffer
Distance from sprayed crop to water's edge (m)	6	1
% Application rate entering stream via spray drift	0.44	1.93
Cypermethrin	0.04	0.19
Isoproturon	0.23	1.00
Simazine	0.27	1.16
Chlorpyrifos (Sept)	0.85	3.70
Chlorpyrifos (Mar)	1.28	5.55

A mixture of Ambush (25 g cypermethrin/ha) and Harlequin (130 g isoproturon/ha and 150 g simazine/ha) was applied in December 1997. Durban-4 was applied in September 1998 at a rate of 480 g chlorpyrifos/ha and then again in March 1999 at an application rate of 720 g chlorpyrifos/ha. In-stream pesticide concentrations resulting from spray drift were calculated using a standardised modelling approach for surface waters in Europe (FOCUS, 2001). The 90th percentile mean drift loading of pesticide over the width of the stream (mg/m^2) was calculated using regression equations derived from German drift studies and application-specific information (i.e. application rate and number, crop and water body type, distance between crop and water body). Loading was converted to aqueous pesticide concentration assuming thorough mixing and correcting for water depth.

2.3. Environmental variables

Environmental variables were measured at each of the three stream sections every 4 weeks, as well as on the day of pesticide application, giving a total of 30 sets of measurements per section. Stream water pH, temperature, conductivity, dissolved oxygen and flow rates were measured using hand-held meters and 250-ml water samples were collected and analysed for alkalinity by titration with HCl (Mackereth et al., 1978).

2.4. Benthic macroinvertebrates

The benthic macroinvertebrate community at each section was sampled at four-weekly intervals between October 1997 and June 1999, as well as 6 days after each pesticide application. On each of the 26 sampling occasions, ten 0.09-m^2 Surber samples were taken from each section and preserved in 70% industrial methylated spirits with 1% glycerol. Macroinvertebrates were identified to species level where possible and enumerated.

Principal response curve (PRC) analysis was used to explore how the macroinvertebrate assemblage at the 'buffer' and 'no-buffer' sections responded during pesticide application relative to the assemblage in the 'no-application' section. PRC analysis is a multivariate method for analysing repeated measured designs and for

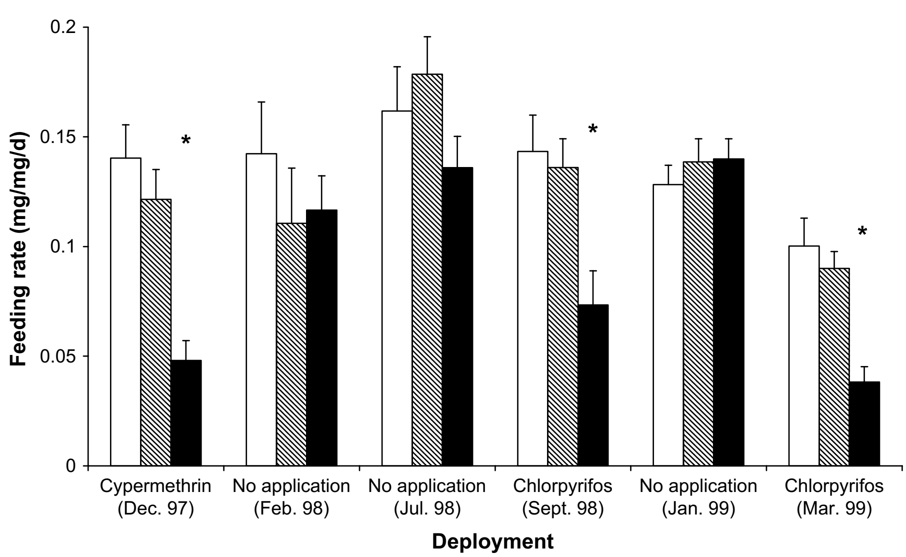

Fig. 1. Mean (±SE) feeding rate of *Gammarus pulex* deployed in Titley Court stream either during application of pesticide or during periods when no pesticide was being applied. On each occasion animals were deployed in the 'no-application' (white bars), '6-m buffer' (hatched bars) and 'no-buffer' (black bar) sections and asterisks denote deployments where there was statistically significant between-section differences in feeding rates.