The effects of the insecticide chlorpyrifos on spider and Collembola communities

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Ceratophysella denticulata; Chlorpyrifos; Collembola; Ecotoxicology; Spiders; Springtails

**Summary**
The effects of chlorpyrifos on aquatic systems are well documented. However, the consequences of the pesticide on soil food webs are poorly understood. In this field study, we hypothesised that the addition of a soil insecticide to an area of upland grassland would impact spider and Collembola communities by decreasing numbers of spiders, consequently, causing an increase in detritivore numbers and diversity. Chlorpyrifos was added to plots on an upland grassland in a randomised block design. Populations of Collembola and spiders were sampled by means of pitfall traps (activity density) and identified to species.

Twelve species of Collembola were identified from the insecticide-treated and control plots. Species diversity, richness and evenness were all reduced in the chlorpyrifos plots, although the total number of Collembola increased ten-fold despite the abundance of some spider species being reduced. The dominant collembolan in the insecticide-treated plots was *Ceratophysella denticulata*, accounting for over 95% of the population.

Forty-three species of spider were identified. There were a reduced number of spiders in insecticide-treated plots due mainly to a lower number of the linyphiid, *Tiso vagans*. However, there was no significant difference in spider diversity between the control and insecticide treatments.

We discuss possible explanations for the increase in abundance of one collembolan species in response to chlorpyrifos and the consequences of this. The study emphasises the importance of understanding the effects of soil management practices on soil biodiversity, which is under increasing pressure from land...
Introduction

Populations of litter-dwelling Collembola and spiders are subjected to many anthropogenic disturbances including agriculture, pollution and other land management practices, which expose them to physical and chemical stresses (Wardle et al., 1995). The consequence is often a change in species assemblage. The outcome of such change can mean a reduction in taxonomic and functional diversity which, it is hypothesised, may reduce the resistance and resilience of an ecosystem (Wardle et al., 2000).

The organophosphate insecticide, chlorpyrifos (Durban, Dow AgroSciences) is a broad-spectrum compound that also has acaricidal and nematicidal properties. It is used for controlling agricultural, horticultural and forest pests and is approved for use against some soil insects such as leatherjackets (Tipula spp.). The pesticide is an acetylcholinesterase inhibitor, which results in an accumulation of the neurotransmitter acetylcholine at the nerve ending, eventually resulting in the death of organisms, particularly arthropods. Soil surface half-lives are approximately 3–14 days (Barron and Woodburn, 1995).

Recent research has investigated the effects of chlorpyrifos on non-target organisms in aquatic ecosystems (Leeuwangh et al., 1994; Van Wijngaarden et al., 1995; Beauvais et al., 1999; Galloway and Handy, 2003; Bellas et al., 2005). Few studies have examined the effects on more than one trophic level in non-target soil communities, although some studies have targeted root herbivores with chlorpyrifos to examine the effects on plant growth and germination (Ganade and Brown, 1997; Hector et al., 2004). In terrestrial systems, the acetylcholine esterase activity of the wolf spider, Lycosa hiliaris, was reduced by 61% when males were exposed to chlorpyrifos spiked soil (Van Erp et al., 2002). When earthworms, Aporrectodea caliginosa, were exposed to 28 μg g⁻¹ of the insecticide in soil, they showed a 70–80% inhibition of acetylcholine esterase (Booth et al., 2000). However, there were no effects on the enzyme efficiency when exposed to recommended doses in the field (O’Halloran et al., 1999). Chlorpyrifos added to soil was toxic to six species of earthworms with 14-day no observed effect concentrations for survival of 46–875 μg g⁻¹ (Ma and Bodt, 1993). The pesticide is also reported to be toxic to soil dwelling insects at concentrations of 0.5–5 μg g⁻¹ (Harris and Hitchon, 1970). Gels et al. (2002) demonstrated that the bumble bee, Bombus impatiens, was unable to detect chlorpyrifos in the environment and consequently colony vitality was reduced.

The significance of predators, such as spiders, controlling pests in agricultural ecosystems (Marc et al., 1999) and as an important food source for farmland birds has been recognised (Wilson et al., 1999). In addition, the importance of Collembola for increasing fungal decomposition (Cragg and Bardgett, 2001) and maintaining spider numbers when pest populations are low (Marcussen et al., 1999; Bilde et al., 2000; Harwood et al., 2001, 2003, 2004; Agusti et al., 2003) has highlighted the need for more studies investigating mechanisms for soil invertebrate population regulation.

The application of a soil insecticide to plots at the Sourhope field site, to reduce numbers of root pests, gave us an ideal opportunity to investigate the effects of chlorpyrifos on predators (spiders) and their potential prey (Collembola) in the litter layer. We hypothesised that the addition of a soil insecticide to plots on an upland grassland would decrease predators (spiders) causing an increase in detritivore (Collembola) numbers and diversity.

Materials and methods

Field site

The Sourhope Research Station site (NT855196) is located in the Bowmont valley, south of Kelso in the Scottish Borders, UK. The site lies between 300 and 350 m in altitude, with an annual rainfall of 950 mm (10 year mean). Historically, the area was used for cereal and oat production, but more recently (the last 50 years) the area has been permanent grassland for sheep and cattle grazing (Davidson et al., 2002). The study was part of the Soil Biodiversity Programme (Natural Environmental Research Council), and was conducted on the programme’s experimental field site which was established in April 1998. Since that time, grazing animals have been excluded.
The soil is a brown podzol, of the Sourhope series (SH74711), and has been described in detail by Davidson et al. (2002). The site is dominated by Agrostis and Festuca grasses and is a National Vegetation Classification U4d (Rodwell, 1992).

The plot experiment was a randomised complete block design consisting of five replicate blocks (Fig. 1). The treatments were allocated at random to the main plots, which measured 20 × 12 m², with each treatment (insecticide-treated and control) represented in each block. Within each main plot were four smaller sub-plots (5 × 5.5 m²).

The treatments at the site began in 1999. The insecticide chlorpyrifos (Dursban 4 EC (44.65% w/w), Dow AgroScience, molecular formula C₉H₁₁Cl₃NO₃PS) was applied to the appropriate plots (Fig. 1) each month between May and September, with five applications each year at a rate of 1.5 l ha⁻¹. This was the maximum dose recommended by the manufacturer for leatherjackets which were common on the site (Murray et al., 2006). The site, including control plots, was mown monthly between May and September each year and the cut material removed. The control plots received no other treatments.

Invertebrate sampling and identification

Invertebrate sampling took place in July and October 2002, and April and June 2003. The activity density of spiders and epigeic Collembola were sampled by pitfall traps (11 cm deep and 8 cm diameter), which were quarter filled with 25% ethylene glycol. Four traps were placed in each main plot (one in each sub-plot) 6 m apart in a quadrat (total of 40 traps on each sampling occasion). The traps were removed after 1 week and the fauna stored in 70% alcohol.

Spiders from all four sampling occasions were identified to species. Due to the time and difficulty of identifying large numbers of Collembola (Hopkin, 2000), only individuals from the July 2002 sampling were identified to species, though abundance data are available for all samples. The keys by Hopkin (2000) and Fjellberg (1998) were used for collembolan identification and Roberts (1987) for spiders.

Statistical analyses

The effect of the treatment on the spider and Collembola assemblages was examined using the Canoco for Windows package (version 4.51). The community data were log-transformed (Log₁₀ (x+1)) to stabilise variances and examined using redundancy analyses (RDA). This analysis is a canonical form of principal components analysis and was used to detect unimodal relationships between species and the treatments, allowing a distinction to be made between the communities where present.
Table 1. One-way (Collembola species data, d.f. = 4) and repeated measures ANOVAs (spider and total number data), showing significant differences in spider and Collembola numbers between the control (C) and chlorpyrifos (Chlo) plots in an upland grassland.

<table>
<thead>
<tr>
<th>Actual means</th>
<th>Analyses of Log₁₀ (n + 1) data</th>
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<tbody>
<tr>
<td></td>
<td>Treatment</td>
</tr>
<tr>
<td></td>
<td>F prob</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Collembola</td>
<td></td>
</tr>
<tr>
<td>73.6</td>
<td>808.0</td>
</tr>
<tr>
<td>Ceratophysella denticulata</td>
<td>1.6</td>
</tr>
<tr>
<td>Dicyrtomina ornata</td>
<td>3.2</td>
</tr>
<tr>
<td>Isotoma anglicana</td>
<td>2.0</td>
</tr>
<tr>
<td>Parisotoma notabilis</td>
<td>2.8</td>
</tr>
<tr>
<td>Isotoma viridis</td>
<td>8.8</td>
</tr>
<tr>
<td>Isotomurus palustris</td>
<td>25.6</td>
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<tr>
<td>Sphaeridia pumilis</td>
<td>21.2</td>
</tr>
<tr>
<td>Juvenile Isotomidae</td>
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</tr>
<tr>
<td>Total spiders</td>
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</tr>
<tr>
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<tr>
<td>Allomengea scopigera</td>
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<tr>
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<tr>
<td>Centromerita bicolor</td>
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<tr>
<td>Erigone dentipalpis</td>
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<tr>
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</tr>
<tr>
<td>Leptyphantes tenuis</td>
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<tr>
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<td>Oedothorax retusus</td>
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<td>Pachygnatha degerei</td>
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<tr>
<td>Pardosa pullata</td>
<td>0.4</td>
</tr>
<tr>
<td>Tiso vagans</td>
<td>5.0</td>
</tr>
<tr>
<td>Trochosa rugulosa</td>
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</tr>
<tr>
<td>Walckenaeria vigilax</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Differences are shown for the effects of sampling date and treatment, and the interaction between these variables (d.f. treatment = 1,4, time & time*treatment = 3,3,24). Data were analysed using log₁₀(n + 1) transformed data, means are actual means per plot (n = 5). Species data where there were no significant differences (NS) for any of the variables are omitted for clarity. nd indicates ‘no data’. 

The significant differences are highlighted for each variable.
Differences between communities in the RDA analysis were examined using Monte Carlo tests with unrestricted permutations (blocks not used as co-variables).

For closer examination of the invertebrate assemblages, means for individual species were compared using one-way (Collembola data) and repeated measures (spider species and total numbers data) ANOVAs (data were log-transformed \((\log_{10}(x+1))\) before analyses using Genstat 7th Edition, 7.1.0.198. Diversity indices (Shannon Wiener, Richness and Evenness) were calculated using the ‘Species Diversity and Richness II Package’ (Pisces Conservation Ltd., England) and then compared using one-way ANOVAs.

## Results

### Collembola

Twelve epigeic Collembola species from four families were identified from the July 2002 pitfall traps. Communities showed a significant change in total numbers and species diversity in response to the insecticide treatment (Tables 1 and 2 and Fig. 3). The total number of Collembola caught in the pitfall traps was higher in the insecticide-treated plots (July 2002 and June 2003, Table 1). These plots were dominated by one species, Ceratophysella denticulata, whilst other species, Isotomurus palustris, Isotoma anglicana, Parisotoma notabilis, Isotoma viridis, Dicyrtoma ornata and Sphaeridia pumilis, were significantly reduced (Fig. 2). Additionally, juvenile Collembola were not found in the insecticide-treated plots (Table 1). Consequently, species richness, evenness and diversity were lower in the insecticide treatment compared to the untreated control plots (Table 2).

### Spiders

The number of spider species identified totalled 43 from only four families (Table 2). More than 80% of the species were Linyphiidae. The abundance of many spider species was subject to significant seasonal variation (Table 1 and Fig. 3). There were significantly fewer spiders in the insecticide-treated compared to the control plots, mainly attributable to lower numbers of Tiso vagans and Pardosa palustris. Although not significant, juvenile Linyphiidae were also less numerous in plots treated with the insecticide in July 2002 and June 2003.

### Table 2. Shannon Wiener, species richness and evenness indices for the epigenic Collembola and spider populations on the insecticide-treated and control plots (one-way ANOVA, \(n = 5\), d.f. = 4, means \(\pm \) S.E.D)

<table>
<thead>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Collembola</td>
<td></td>
<td>Spiders</td>
<td></td>
<td>Spiders</td>
<td></td>
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<td></td>
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<tr>
<td>Shannon Wiener</td>
<td>0.59</td>
<td>0.04</td>
<td>1.34</td>
<td>0.90</td>
<td>1.01</td>
<td>0.64</td>
<td>2.14</td>
<td>1.89</td>
<td>1.95</td>
</tr>
<tr>
<td>F-prob</td>
<td>&lt;0.001</td>
<td>0.142</td>
<td>0.162</td>
<td>0.071</td>
<td>0.398</td>
<td>0.083</td>
<td>0.166</td>
<td>0.126</td>
<td>0.166</td>
</tr>
<tr>
<td>SED</td>
<td>0.117</td>
<td>0.239</td>
<td>0.216</td>
<td>0.103</td>
<td>0.126</td>
<td>0.166</td>
<td>0.126</td>
<td>0.166</td>
<td>0.166</td>
</tr>
<tr>
<td>Species richness</td>
<td>8.0</td>
<td>2.6</td>
<td>8.4</td>
<td>5.8</td>
<td>3.4</td>
<td>2.2</td>
<td>11.8</td>
<td>7.8</td>
<td>12.4</td>
</tr>
<tr>
<td>F-prob</td>
<td>0.003</td>
<td>0.152</td>
<td>0.070</td>
<td>0.054</td>
<td>0.553</td>
<td>0.166</td>
<td>0.283</td>
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</tr>
<tr>
<td>SED</td>
<td>0.812</td>
<td>1.470</td>
<td>0.490</td>
<td>1.483</td>
<td>0.927</td>
<td>2.370</td>
<td>2.370</td>
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</tr>
<tr>
<td>Evenness</td>
<td>0.560</td>
<td>0.013</td>
<td>0.434</td>
<td>0.293</td>
<td>0.374</td>
<td>0.237</td>
<td>0.664</td>
<td>0.586</td>
<td>0.569</td>
</tr>
<tr>
<td>F-prob</td>
<td>&lt;0.001</td>
<td>0.142</td>
<td>0.162</td>
<td>0.071</td>
<td>0.398</td>
<td>0.283</td>
<td>0.283</td>
<td></td>
<td>0.283</td>
</tr>
<tr>
<td>SED</td>
<td>0.041</td>
<td>0.078</td>
<td>0.080</td>
<td>0.032</td>
<td>0.037</td>
<td>0.044</td>
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</tbody>
</table>

Significant differences existed for the Collembola between all of the indices with the insecticide-treated plots (Chlo) scoring lower than the control (C) plots. There were no significant differences between the control and insecticide-treated plots when diversity indices were calculated for spiders. See Fig. 2 for Collembola species.

Spider species: Lycosidae; Pardosa pullata, Pardosa palustris, Pardosa nigriceps, Xerolycosa miniata, Trochosa ruvicola, Trochosa terricola, Alopecosa pulverulenta, Tetragnathidae; Pachynatha degeeri, Thomisidae; Xysticus cristatus, Linyphiidae; Ceratinella brevipes, Walckenaeria vigilax, Walckenaeria atrocellula, Walckenaeria acuminate, Dicycymbium tibiale, Parisotia juncea, Hypomma bluberculumatum, Oedothorax retusus, Oedothorax gibbosus, Tiso vagans, Silometopus elegans, Tapinocyba praecox, Agyneta decora, Monochelopus fusiceps, Gongylidiellum vivum, Micrargus herbigradus, Erigone dentipalpis, Erigone atra, Savignya frontata, Scotinotylus evansi, Leptohypna robusta, Centromerita bicolor, Centromerita concinna, Bathypantes gracilis, Bathypantes parvulus, Bolyphantus luteolus, Leptyphantus tenuis, Leptyphantus zimmermanni, Leptyphantus mengesi, Leptyphantus flavipes, Leptyphantus tenebricola, Leptyphantus ericaeus, Microlinyphia pusilla, Allomerina scopigera.
Time treatment interactions were apparent for the species *Agyneta decora*, *Bathyphantes gracilis*, *Lepthyphantes ericaeus* and *Trochosa ruricola*. The number of individuals caught in pitfall traps in October 2002 and April 2003 was very low (Table 1), and consequently, communities (Fig. 3) and diversity indices (Table 2) did not differ on these sampling occasions.

**Discussion**

The addition of the soil insecticide, chlorpyrifos, decreased numbers of spiders, and diversity, species richness and evenness of Collembola as hypothesised. However, collembolan abundance was increased (Tables 1 and 2, Figs. 2 and 3). The spider species *T. vagans* was sensitive to chlorpyrifos, whereas the collembolan *C. denticulata* increased in abundance with the pesticide application. Clearly, non-target soil community structure can be strongly affected by the application of an insecticide such a chlorpyrifos. Some spider species showed a time treatment interaction (*A. decora*, *B. gracilis*, *L. ericaeus* and *T. ruricola*); therefore, lower numbers of these species in the treated plots could not be attributed to the application of chlorpyrifos alone.

This study highlights the importance of identification to an appropriate taxonomic level for biodiversity estimates. Effects on the litter community could have been misinterpreted if Collembola were identified to family or order level. Here, for example, our data may have led to the simplistic conclusion that chlorpyrifos was beneficial to Collembola by increasing abundance. Although the identification of Collembola can be time consuming, identifying the species from only one sampling occasion at the Sourhope site demonstrated a dramatic change in species composition as a consequence of the application of chlorpyrifos to the experimental plots.

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**Figure 2.** (A) Redundancy analyses (RDAs) comparing Collembola communities on chlorpyrifos (Chlor) and control (NoChlor) plots. Species are denoted with the first two letters of genus and first three letters of the species (*Is. juv* = Isotomid juveniles). (B) Mean number of Collembola species per pitfall trap in the control and insecticide plots from the July 2002 sampling (y-axis on log scale, *n* = 5, ± SE). * denotes significant differences between the insecticide and the control (Isotomid juv = Isotomid juveniles).
Figure 3. Redundancy analyses (RDAs) comparing communities of spiders on the four sampling dates in the chlorpyrifos (Chlor) and control (NoChlor) plots. Species are denoted by the first two letters of genus and first three letters of the species name (Juvenile followed by first letters of spider family). See Fig. 2 for a full list of spider species.
Collembola

The insecticide-treated collembolan communities were dominated by *C. denticulata*, a very common and widespread species found in damp habitats (see http://www.stevehopkin.co.uk/collembolamaps/), resulting in a dramatic reduction in species equitability (Table 2). By contrast, Chernova et al. (1995) showed *C. denticulata* to be a sensitive species when fed herbicide-contaminated fungi. The results of our study agree with findings by Endlweber et al. (2006). Their field experiment (soil core samples divided into litter and soil layers) showed a significant increase in one taxon (*Protaphorura*, a soil collembolan not sampled in our study) in response to chlorpyrifos. In contrast to our study, the overall abundance of Collembola in the chlorpyrifos plots was reduced, including members of the genera *Ceratophysella* (Endlweber et al., 2006). The dissimilarity between the two studies could be due to different sampling techniques or variation in habitat type (upland grassland versus set-aside arable).

*C. denticulata* is a member of the Hypogastruridae family, known to form swarms (Hägvar, 1995) and often associated with freshly disturbed or burned ground (Hutson, 1980; Parsons and Parkinson, 1986; Shaw, 2003; Shaw and Usher, 1996; Dunger et al., 2001). Theories for swarming behaviour include response to food source (Christiansen, 1970; Dromph, 2003), humidity, temperature, reduced competition or the synchronisation of reproduction (Baweja, 1939; Hopkin, 1997). Reduced predation may also be important; there were fewer spiders in the insecticide-treated plots (Table 1). It is also possible that *C. denticulata* is able to repel predators by producing phenolic acids in its integument (Bitzer et al., 2004). When treated topically with these acids, *Stenus comma* (Staphylinidae), spent longer periods cleaning their mouthparts than control beetles (Bitzer et al., 2004).

Other members of the Hypogastruridae (*Xenylla grisea*) also have a low sensitivity to chlorpyrifos (200 µg g⁻¹ added to food) compared to other Collembola families (e.g. Isotomidae) (Sims and Martin, 1997). Abel and Larink (1994) demonstrated that chlorpyrifos (Dursban, sprayed at 2 l ha⁻¹) affected Collembola species composition. Indeed, as with this study, most species declined, with only a species Neelidae increasing in abundance (Abel and Larink, 1994). Chlorpyrifos residues were more toxic than cypermethrin and pirimicarb residues to Collembola (Wiles and Frampton, 1996; Frampton, 1999) with effects of chlorpyrifos (480 g l⁻¹ *Spannit*® Zeneca) evident up to 8 weeks after application (Frampton, 1999).

In some studies, Sminthuridae have been shown to be sensitive to chlorpyrifos (Stark, 1992; Michereff et al., 2004); the insecticide was used to control the lucerne flea, *S. viridis*, in Australia (Bishop et al., 2001). In contrast, Wang et al. (2001) found an increased abundance (by 3 times) of Sminthuridae in chlorpyrifos-treated plots. The pesticide dissipates rapidly with increased crop cover, decreasing the toxicity of the insecticide (Al Hussein et al., 1991). In our study, the vegetation height was maintained across the plots by regular mowing throughout the growing season, thereby reducing the effects of vegetation cover.

Spiders

The majority of spider species trapped at Sourhope consisted of Linyphiidae (34 sp.). There were seven Lycosidae species and only one Thomidae and Tetragnathidae (Table 2). This is typical of upland grassland spider pitfall trap catches (Coulson and Butterfield, 1986; Rushton et al., 1987) and many species at Sourhope were aeronauts (e.g. *Erigone dentipalpis*, *Leptophantes tenuis* and *T. vagans*). In addition, several of the species were associated with wet habitats (e.g. *Allomenega scopigera*, *Gongylidiellum vivum* and *Leptophantes ericaeus*). *Silometopus elegans*, *A. scopigera*, *Bolyphantes luteolus*, *Dicymbium tibiale*, *Agyneta decora* and *Scotinotylus evansi* are more typical northerly British Isles species (Harvey et al., 2002).

Site management has major influencing effects on spider communities, including disturbance, vegetation structure and moisture (Rushton et al., 1987). The abundance of *T. vagans* and *P. palustris* trapped in the insecticide plots was low compared to the control plots. Chlorpyrifos is toxic to spiders (Amalin et al., 2000; Pekár, 2002) and also reduces other beneficial predators (Staphylinidae, Easterbrook, 1997; Frampton, 1999; Wang et al., 2001 and Carabidae, Asteraki et al., 1992; Bale et al., 1992; Reed et al., 1992; Curtis and Horne, 1995). In a study by Stark (1992), chlorpyrifos applied at 112 g a.i. ha⁻¹ had a negative effect on non-target invertebrates inhabiting turf grass; 1.5 times more spiders were found in control compared to chlorpyrifos-treated plots and populations remained reduced up to 5 weeks post-treatment application.
The effect of the chlorpyrifos on the spider populations at Sourhope could be due to direct toxicity; however, indirect effects (lack of edible prey) cannot be ruled out. Molecular methods of analysing predation have shown strong Collembola species prey choice by spiders (Agusti et al., 2003); indeed, spiders require a varied diet for survival and successful reproduction (Greenstone, 1979; Otto and Svensson, 1982; Oelbermann and Scheu, 2002).

**Juveniles**

Immature Collembola and spiders were either absent or in low numbers on the insecticide plots, respectively. Juveniles are often more sensitive to xenobiotics than adults (Fountain and Hopkin, 2001) and it is possible that adults are better at detecting and avoiding insecticides (Fábián and Petersen, 1994).

**Other considerations**

The influence of vegetation structure in this study was kept to a minimum with regular mowing of the plots during the growing season. Hence, microclimate and refugia for predatory arthropods would have been relatively uniform across the field site. This study highlights that the use of chlorpyrifos in ecological studies, to exclude root herbivores from plant communities, are difficult to interpret because of a lack of understanding of the pesticide effects on non-target soil invertebrates and the soil taxon interactions that take place.

Although many of the arthropod species present on the site were capable of dispersing, differences in species composition and abundance remained between the insecticide-treated and untreated control plots. An explanation for the increased densities of *C. denticulata* in the insecticide-treated plots remains unclear and more research is needed to tease apart the underlying mechanisms; unpalatability to predators, resistance to xenobiotics (e.g. Fountain and Hopkin, 2004) and reduced competition are all possibilities. The link between species diversity and ecosystem function is an important mechanism to understand (Mikola and Setälä, 1998) considering the decline in species diversity worldwide. Effects of fauna on ecosystem processes were determined to be due to differences in the composition of the collembolan community, rather than the number of species present in a study by Cragg and Bardgett (2001). It is unclear whether *C. denticulata* is performing similar ecological functions to the mixed Collembola assemblages in the control plots. However, this seems unlikely given the specificity of Collembola feeding preferences (Walsh and Bolger, 1990).

Future studies are needed to clarify the ecology and feeding preferences of *C. denticulata* and to determine whether this species fulfils the same ecological functions as a mixed community of Collembola species. It would be valuable to determine whether spiders, like staphylinids (Bitzer et al., 2004), are deterred from feeding on this species.

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**References**


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