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# The potential of Collembola as indicators of pesticide usage: evidence and methods from the UK arable ecosystem

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**Summary.** Results of seven years' monitoring epigeic Collembola abundances under conventional and reduced pesticide input regimes in the MAFF SCARAB project are presented. Substantial negative changes in abundance occurred after some pesticide applications, particularly where organophosphorus insecticides were used in consecutive seasons. The duration of such changes varied spatially and between species, being most protracted for *Lepidocyrtus* spp. and least so for *Sminthurinus elegans*. Reasons for the observed spatial and interspecific variation in pesticide effects are considered in relation to using epigeic Collembola as indicators of pesticide side-effects in field studies.

**Key words:** Collembola, pesticides, side-effects, indicator species, arable rotations

## Introduction

Arthropods have been used widely as bioindicators of anthropogenic disturbance (Paoletti & Bressan 1996) but in recent decades research on the side effects of pesticides in arable systems using single-season replicated plot trials has tended to focus on predatory macroarthropods. In the UK, Carabidae, Staphylinidae and Linyphiidae were monitored in approximately 96 %, 88 % and 76 % of published one-season replicated plot pesticide studies whilst relatively few studies (28 %) monitored Collembola (Çilgi 1997). Though Collembola are known to be sensitive to a range of pesticides currently used in Europe (Frampton 1994), studies have rarely been adequate in temporal scale to allow detection of long-term population effects. Where long-term monitoring has been carried out, persistent effects (positive and negative) have occurred for several years as a result of single chemical applications (e.g. Krogh 1991) or repeated applications associated with permanent cropping systems such as wheat (Vickerman, 1992) and hops (Filser et al. 1995). The Ministry of Agriculture, Fisheries and Food (MAFF) Boxworth project (1981–88) demonstrated 5-year declines in populations of *Sminthurus viridis* L. (Vickerman 1992) and *Folsomia quadrioculata* (Tullb.) (Frampton et al. 1992) under the pesticide inputs of commercial wheat production during the 1980s. To establish whether such effects would occur in other arable rotations, with 1990s pesticide inputs, MAFF initiated the SCARAB (Seeking Confirmation About Results At Boxworth) project in 1990 (Cooper 1990). This paper presents data from seven years' monitoring of Collembola under conventional and reduced pesticide inputs in three arable rotations of SCARAB to illustrate the impact of current UK pesticide usage on epigeic species.

## Materials and Methods

The MAFF SCARAB project comprised seven fields sited on three farms in central and northern England (Cooper 1990). Data from one field at each farm are presented here. Each field contained an arable rotation typical of its locality (Table 1), and was divided into two halves to which conventional and reduced-input pesticide regimes were applied from autumn 1990 to autumn 1996 in a split-field comparison (Hancock et al. 1995). The two pesticide regimes differed only in their pesticide content; other aspects of husbandry (drilling, fertilising, harvesting, cultivating) were performed on a whole-field basis. The conventional regime reflected current farm practice for each crop as indicated by MAFF surveys (e.g. Garthwaite et al. 1995) whereas the reduced regime employed lower fungicide and herbicide inputs where possible and avoided use of insecticides in all of the project fields (Table 1). Further details on the background, design and rationale of SCARAB were given in Cooper (1990) and Hancock et al. (1995).

**Table 1.** Site details for three fields in the MAFF SCARAB project

| *Farm name:* | | **Drayton** | **Gleadthorpe** | **High Mowthorpe** |
|---|---|---|---|---|
| Location: | | 52.2° N 1.8° W | 53.2° N 1.1° W | 54.1° N 0.6° W |
| *Mean precipitation year$^{-1}$ (mm) (1990–96):* | | 604 | 593 | 641 |
| Field name: | | Field 5 (F5) | Near Kingston (NK) | Bugdale (BU) |
| *Area (ha):* | | 8 | 8 | 19 |
| Soil type: | | calcareous clay | stony sand | calcareous loam |
| *pH (1995):* | conv. | 7.5 | 7.2 | 8.1 |
| | reduced | 7.5 | 7.1 | 7.9 |
| % OM | conv. | 5.8 | 3.1 | 5.3 |
| (1995) | reduced | 6.0 | 2.8 | 5.1 |
| *Cropping:* | 1990–91 | grass | spring barley | winter rape |
| | 1991–92 | winter wheat | winter barley | winter wheat |
| | 1992–93 | winter wheat | spring beans | spring barley |
| | 1993–94 | grass | winter wheat | spring beans |
| | 1994–95 | grass | winter barley | winter wheat |
| | 1995–96 | grass | sugar beet | winter barley |
| *Number (conventional, reduced-input) of label-recommended-rate pesticide applications, 1991–1996 (excluding seed treatments):* | | | | |
| insecticides | | 5, 0 | 6, 0 | 7, 0 |
| herbicides | | 8, 4 | 14, 7 | 9, 5 |
| fungicides | | 8, 3 | 10, 5 | 10, 3.5 |
| total pesticide applications | | 21, 7 | 30, 12 | 26, 8.5 |

Collembola were monitored using a D-vac suction sampler (Dietrick, 1961) along a central transect in each pesticide regime, perpendicular to a field margin that was shared by both regimes. In each regime, twenty 10-s suction sub-samples, each of area 0.092 m$^{-2}$, were taken at 5 m-intervals 25 m to 125 m from the field margin. Groups of five sub-samples were pooled to give four 0.46 m$^{-2}$ samples representing the distances 25–50, 50–75, 75–100 and 100–125 m from the margin. Data from the four samples in each regime were normalized by the transformation $\log_{10}(x+1)$. Detransformed means and their standard errors are presented in Fig. 1. Collembola were identified according to Gisin (1960).

## Results

For brevity, results are presented for three taxa, *Sminthurinus elegans* (Fitch), *Entomobrya multifasciata* (Tullb.) and *Lepidocyrtus* spp. (*cyaneus* Tullb. and *violaceus* Lubb. combined). Long-term differences in collembolan abundance between the conventional and reduced-input regimes were most prominent in the wheat – grass rotation of field F5, where differences in *Lepidocyrtus* spp., first evident after a chlorpyrifos spray in 1991, persisted to 1996 (Fig. 1c), though with evidence of recovery (parity in conventional and reduced input catches) at low densities in June and July 1993. In this field following a negative effect of chlorpyrifos there was relatively rapid recovery in the abundance of *S. elegans* (Fig 1a) whilst that of *E. multifasciata* did not quite fully recover in summer 1993 before a further decline followed a dimethoate aphicide spray (Fig. 1b). Transient negative effects of pesticides on the abundance of *S. elegans* were also evident in the cereal – break crop rotations of fields NK and BU following chlorpyrifos in 1991 and dimethoate in 1992 respectively (Fig. 1a). A long-term tendency for *Lepidocyrtus* spp. to be more numerous in reduced-input than conventional catches in field BU (Fig. 1c) was not obviously related to any one pesticide application. During the seven years of monitoring, *E. multifasciata* was not trapped in field BU whilst *Lepidocyrtus* spp. were not encountered in field NK.

## Discussion and Conclusions

The SCARAB project was initiated primarily to investigate the overall relative impact of conventional and reduced-input pesticide regimes, rather than the effects of individual applications. The design is amenable to multivariate methods of analysing the full data set (e.g. using CANOCO as in Siepel & Van de Bund 1988) and does not include replication of the regimes within each rotation, so statistical tests are not valid for comparisons of the data shown in Fig. 1. In the absence of such tests, confidence that negative changes in collembolan abundance reflect pesticide effects is based on (1) coincident timing of changes in abundance with pesticide applications; (2) magnitude of the changes; and (3) persistence of the changes relative to reduced-input (no insecticide) abundance. Using benomyl and isofenphos, Krogh (1991) classed Collembola as sensitive if they exhibited both an immediate depression of abundance, and an effect persisting for 1 to 4 years. Other studies which, like SCARAB, lacked orthodox statistical replication, have also used the temporal coincidence of pesticide application and changes in collembolan abundance to infer a negative (Vreeken-Buijs et al. 1994) or positive (Stinner et al. 1986) pesticide effect. Conversely, lack of any change in abundance at the time of a pesticide application has been used to infer that no direct effect occurred (e.g. with herbicides in a no-till agroecosystem; House et al. 1987).
The SCARAB project utilised differential inputs of fungicides and herbicides as well as insecticides (Table 1) but for clarity only insecticides are shown in Fig. 1. The abundance patterns shown in Fig. 1 may not be due entirely to insecticides alone, but adverse effects of the broad-spectrum organophosporus insecticides chlorpyrifos and dimethoate reported in the literature (Çilgi 1997) broadly agree with the changes in collembolan abundance seen in the SCARAB fields (Fig. 1). Using the criteria described above, the data given in Fig. 1 provide no evidence for negative effects of pirimicarb or cypermethrin, which are among the most widely-used insecticides in arable crops (Garthwaite et al. 1995). Effects of these chemicals on Collembola have not been studied in detail; summer use of cypermethrin increased abundance of epigeic species in winter wheat (Frampton 1997) but effects of pirimicarb were equivocal in microcosms (Petersen & Gjelstrup 1995), bioassays (Wiles & Frampton 1996) and winter wheat fields (Frampton 1997). A consistently higher abundance of *Lepidocyrtus* spp. in the reduced-input regime of BU field (Fig. 1c) cannot definitely be attributed to the pesticide regime as the species were not present in the pre-treatment year (1990). Indirect effects of fungicide and/or herbicide use on microflora, microfauna and weed populations (unpublished SCARAB Annual Reports, 1993–1996, ADAS High Mowthorpe), or subtle variation

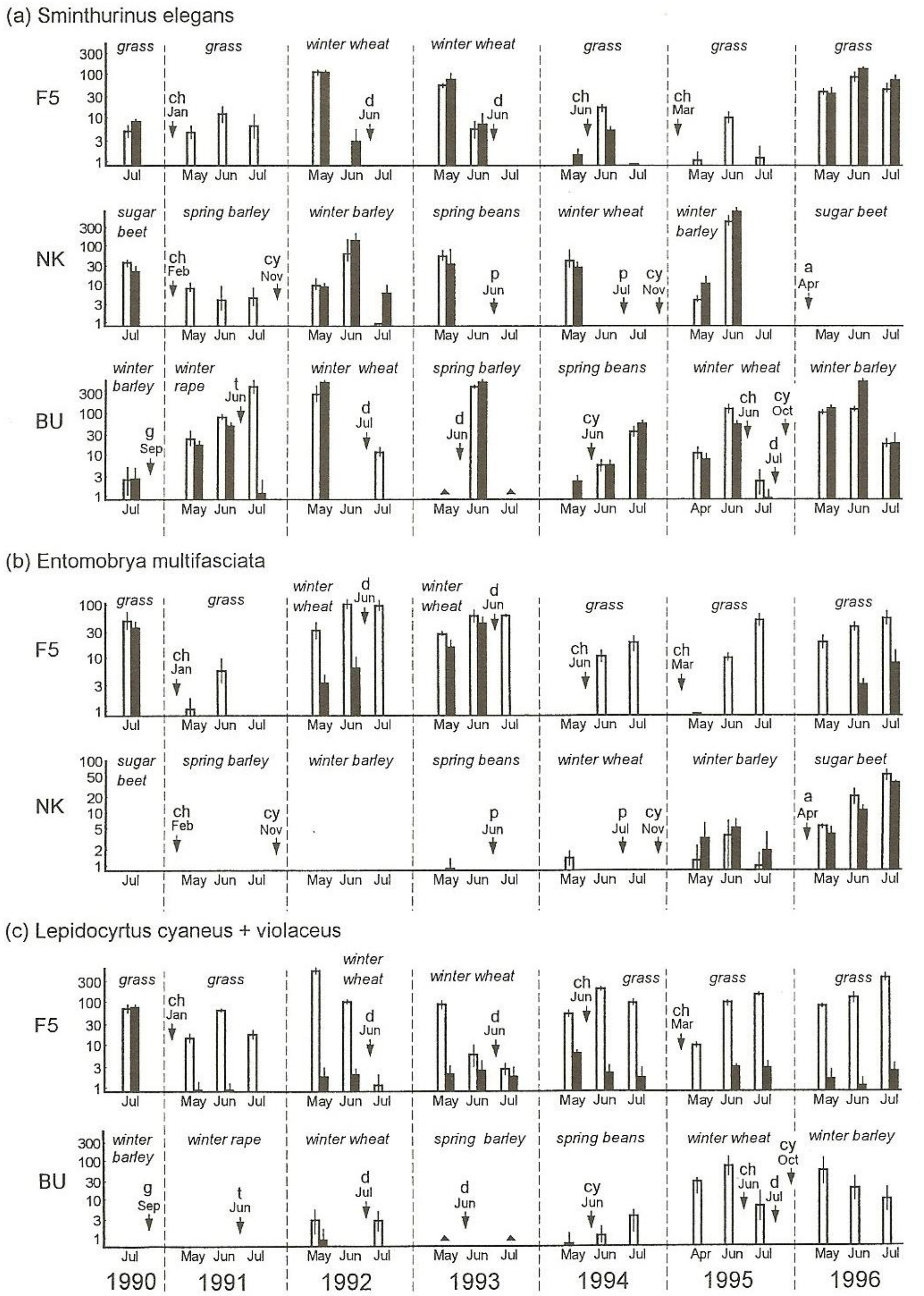


**Fig. 1.** Detransformed $\log_{10}(x+1)$ mean ± S.E. (N = 4) summer suction sample catches of Collembola in conventional (black bars) and reduced (white bars) pesticide regimes in three fields, F5, BU, NK (Table 1). Arrows indicate applications (sprayed unless indicated otherwise) of insecticides made only under the conventional regime: a: aldicarb (drilled); ch: chlorpyrifos, cy: cypermethrin, d: dimethoate, g: gamma-HCH (seed coating), p: pirimicarb, t: triazophos. Triangles (BU, 1993) denote data unavailable

in soil properties (Table 1) could be responsible. Spatial reversal of the two pesticide regimes will be used (1996–99) to explore the role of the pesticide regimes in determining such patterns of collembolan distribution.
The data presented here are a small sub-set of the results from the SCARAB project but nevertheless illustrate points of importance concerning epigeic Collembola as bioindicators of negative pesticide effects: (1) sensitive species (*E. multifasciata, Lepidocyrtus* spp.) may be local in distribution and absent from some experimental sites; (2) variation between species and sites in responses to pesticides precludes extrapolation of data from any one species or location; (3) life histories influence exposure; e.g. *S. elegans* had usually declined in abundance before summer use of dimethoate occurred (Fig. 1a); (4) Collembola may be unsuitable for detecting negative effects of carbamate (e.g. pirimicarb) and synthetic pyrethroid (e.g. cypermethrin) insecticides. These limitations do, however, also apply to other arthropods. For instance, *Poecilus cupreus* (L.) (Carabidae) is recommended as a test species in field pesticide studies (Barrett et al. 1994) but during 1990–96 it occurred in only one of seven SCARAB project fields. Carabidae have also exhibited between-species differences in responses to pesticides in the field (Vickerman, 1992). The merits of Collembola as bioindicators must therefore be judged in relation to those of other non-target arthropod taxa.
To conclude, results from the SCARAB project and other studies suggest (1) that effective detection of off-target pesticide effects requires observations to be made on groups of species (Frampton, 1994) or communities (Filser et al. 1995; Paoletti & Bressan 1996) rather than on single species. (2) Multiple geographical sites are needed to ensure that a representative range of sensitive species and habitat conditions are included. (3) Collembola may be suitable bioindicators of negative effects of some pesticide types (e.g. being more sensitive to organophosphorus insecticides than many predatory species; Vickerman 1992; Hancock et al. 1995), but in studies of overall pesticide systems a wider taxonomic range of bioindicators will be required for detecting effects of other chemical types. Interactions between Collembola and macroarthropods must also be considered when determining the value of bioindicator taxa to allow the separation of direct and indirect effects. A full analysis of the results from the SCARAB project, in which over 200 arthropod taxa were monitored, should allow these considerations to be investigated in more detail.


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