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Long-term impacts of an organophosphate-based regime of pesticides on field and field-edge Collembola communities

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Abstract: During a 6-year study, effects of two contrasting regimes of pesticide use on pitfall and suction catches of Collembola were monitored in an arable field under a rotation of grass and winter wheat. Current farm practice (CFP) represented conventional fungicide and herbicide use plus applications of organophosphorus (OP) insecticides, whereas reduced input approach (RIA) utilised minimum inputs of fungicides and herbicides and excluded any use of insecticides. Compared with RIA, the CFP regime caused a substantial decline in the abundance and diversity of Collembola in the field, including the local disappearance of one species, without recovery during the study. At the field edge, which was protected during OP applications by a 6-m unsprayed buffer zone, effects of the CFP regime were less severe, and were not persistent in the long term. Some Collembola species occurred only in field-edge samples. Pitfall and suction sampling yielded remarkably similar patterns of catches, indicating that pitfall trapping may be appropriate for detecting long-term changes in collembolan abundance caused by intensive agricultural management practices.

Keywords: organophosphate insecticides; unsprayed headland; buffer zone; field margin; principal response curves; SCARAB Project

1 INTRODUCTION

1.1 Collembola in temperate agroecosystems

Collembola (springtails) are among the most numerous arthropods in temperate agroecosystems[1,2] where they are consumed by a wide variety of predatory arthropods and also by some insectivorous vertebrates.[3] The distribution and abundance of Collembola in arable fields can influence the spatial disposition and abundance of their predators.[4] Collembola also influence nutrient cycling and plant productivity by grazing upon fungi and micro-organisms.[5–7] In temperate agroecosystems, Collembola seldom present problems as crop pests and are thus not targeted directly with pesticides. While their ecological and economic value in temperate agriculture are difficult to establish, Collembola appear, on balance, to be beneficial in view of their trophic relationships.[2,3]

1.2 Responses of Collembola to pesticides

Exposure of farmland Collembola to pesticides is inevitable and large declines in abundance can be caused by the routine use of broad-spectrum organophosphate (OP) or carbamate insecticides,[8] although the widely used synthetic pyrethroids and the selective carbamate insecticide pirimicarb appear not to be harmful to Collembola.[9,10] When applied in consecutive years, OP insecticides may cause long-term declines in the abundance of some collembolan species, whereas other species are able to recolonise treated fields within the same year.[8,11] Mechanisms of collembolan recovery are not well understood whereas, for macro-arthropods, recovery is known to be strongly influenced by their dispersal ability and the proximity of the treated area to potential source populations.[12–14] There is evidence that rapid recovery of Collembola at the centre of fields can occur as a result of the delayed arrival of predators recolonising from field edges or other off-crop refuges,[15] but that mechanism does not explain the poor recovery ability observed for some individual collembolan species.[8,11] The possibility that some Collembola might be dependent on field margins or other unsprayed refuges as sources of recovery has so far not been investigated, and very little published information exists on the species composition of Collembola at arable field edges. Accordingly, the aim of the present work was to investigate the response of a field-edge collembolan

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community to long-term use of pesticides that had negatively affected collembolan abundance and diversity in the field. During the study, five annually repeated OP insecticide applications were made to the field, but were withheld from the field headland.

1.3 Study background

From 1990 to 1996, the SCARAB Project investigated the effects on arthropods of the long-term (6-year) use of two contrasting regimes of pesticide use.[16] The regimes were compared in eight study fields, which differed in their crop rotations.[17] Suction catches of arthropods revealed a long-term negative effect of pesticide use in one of the study fields under a rotation of grass and wheat. At that site ('Field 5'), a regime that included OP insecticides caused a long-term decline in arthropod abundance, with Collembola particularly severely affected; *Entomobrya nicoleti* (Lubbock) and *Lepidocyrtus* spp respectively exhibited no recovery and limited recovery within the duration of the study.[8,11,18] Because little is known about the collembolan community composition of arable field edges, this work sought to determine whether the field-edge collembolan community was affected by the Field 5 pesticide regimes. In particular, the distributions of *E nicoleti* and *Lepidocyrtus* spp are of interest because a lack of potential recolonists at the field edge (eg as a consequence of pesticide effects) could be a plausible explanation for the apparent poor recovery ability of these taxa. Suction samples were not taken at field edges during the SCARAB Project,[17] so it was necessary to obtain field-edge Collembola data from pitfall traps instead. As a check that pitfall trapping was suitable for detecting the effects of the CFP regime on Collembola, long-term comparisons were made between catches from field-sited suction samples and pitfall traps. This paper presents hitherto unpublished Collembola data from the pitfall traps.

2 METHODS

2.1 Study site

The study site, 'Field 5' was an 8.3-ha field under a rotation of grass and winter wheat located on a heavy clay soil with good drainage (soil series Haselor/Drayton; pH 7.7; 4.7% OM) in the South Midlands of England (52.2°N, 1.8°W). The field was administered during 1990 to 1996 as part of the SCARAB Project, the principal objective of which was to compare the effects of conventional and reduced-input pesticide use on non-target arthropods in a range of crop rotations at different sites.[16] Cropping at the study site was grass (silage and mixed livestock) from 1987 to 1996, with the exception of autumn 1991 to autumn 1993 when two consecutive crops of winter wheat were grown. During 1987–1990, the whole field was managed as a single unit and received no pesticide applications. Commencing in January 1991, the field was divided in half (but without a physical barrier) and each of the 4.15-ha areas received contrasting pesticide regimes until autumn 1996. Pesticide applications were the only managed variables that differed between the field halves, with all other husbandry activities performed on a whole-field basis. A novel spatial manipulation of the study design was later included to ensure that effects on arthropods of the two unreplicated pesticide regimes were not confounded spatially with other variables (Section 2.4 below).

2.2 Pesticide regimes

The pesticide regimes were a 'reduced input approach' (RIA) and 'current farm practice' (CFP). The RIA regime avoided the use of any insecticides, and permitted applications of herbicides and fungicides only if they were deemed necessary to avert a specified loss of yield or crop quality.[17] The CFP regime aimed to mimic conventional practice for each crop with the proviso that at least one label-recommended-rate insecticide application per crop could be applied to ensure that arthropods were exposed to appropriate insecticides.[17] In practice, during the 6-year phase of contrasting regimes, the CFP regime comprised five applications of organophosphorus insecticides, together with a greater quantity of fungicide and herbicide applications than the RIA regime (Table 1). This represents a relatively high intensity of broad-spectrum insecticide use which, although not typical of the majority of grass-and-wheat rotations in the UK,[18] provided a clear impact on Collembola in the field. In keeping with the product label guidance, all insecticide applications were excluded from the outermost 6 m of the crop headland, but other pesticides were applied to the full crop area (Table 1).

2.3 Arthropod sampling and identification

Arthropods were monitored at matched locations in the CFP and RIA areas of the field using suction samples and pitfall traps. On each sampling occasion, four suction samples per field half were taken between 25 and 125 m from a common hedgerow using a 'D-vac'.[17] Each sample comprised five randomly-placed sub-samples of area 0.092 m^2 that were pooled to give an area per sample of 0.46 m^2. Groups of four pitfall traps, consisting of white plastic beakers (9 cm diameter, 15 cm deep), were located in each field half at a distance of 75 m from a common hedgerow and at the field edge adjacent to a ditch beside the hedgerow (0 m); within each group the traps were aligned parallel to the hedgerow with 12 m spacing between them. Traps each contained water with a drop of detergent to ensure that captured arthropods sank, and were operated for 7-day periods. The minimum distance between the sampling areas within each pesticide regime and the interface of the two regimes was 60 m for suction samples and 42 m for pitfall traps.[17] The number of samples employed per treatment was a compromise between the number required to achieve adequate precision of estimating Collembola abundance and the number that could feasibly be processed. Historical data from Collembola sampling in cereal crops indicated that four samples per treatment would give reasonable precision of abundance estimates (SE < 20% of the mean) for the dominant species.[19] Samples were usually collected on at least three occasions in each year, including a 'pre-treatment' monitoring year (1990) and the phase of contrasting RIA and CFP regimes (1991–1996). After collection, samples were preserved in 70% ethanol, and Collembola were subsequently identified using several taxonomic keys.[20–22] Due to the large number of samples processed, individuals of *Isotoma viridis* Bourlet and *I anglicana* Lubbock were not separated and are here reported as *Isotoma viridis* 'group'.

2.4 Confirmation of pesticide regime effects

The split-field comparison of pesticide regimes used in the SCARAB Project aimed to provide an ecologically realistic spatial scale of pesticide treatment, but this precluded formal replication of the regimes.[23,24] Instead, spatial manipulation of the regimes was conducted to determine whether the pesticide regimes were responsible for observed differences in Collembola abundance and community composition between the two halves of the field. From autumn 1996 to autumn 1999, the former RIA (east) half of the field received CFP pesticide inputs whereas the former CFP (west) half received RIA inputs. The outcome of this manipulation has been reported previously[8,18] (see also Results; Section 3.3).

2.5 Community analysis

A null hypothesis directly concerning the effects of pesticide regime was not tested because pesticide regime would be confounded spatially with other (unknown) factors that differed between the two halves of the study field. Instead, the null hypothesis tested was that collembolan community composition did not differ between the east and west halves of Field 5. Evidence that differences in collembolan abundance and community composition between the field halves were caused by pesticide use, rather than by effects of other variables, was obtained separately by comparing pre- and post-treatment arthropod catches and also catches made before and after the pesticide regimes were reversed spatially.

The long-term changes in the collembolan communities in the east and west halves of Field 5 were compared graphically for field and field-edge samples using principal response curves (PRC) analysis. PRC is a multivariate technique derived from redundancy analysis (RDA) that focuses on the proportion of the variance explained by specified environmental vari-

Table 1. Insecticide (I), fungicide (F) and herbicide (H) applications made under the current farm practice (CFP) and reduced-input approach (RIA) pesticide regimes in Field 5 during 1990–1997

			Application rate ($g\ AI\ ha^{-1}$)	
Crop	*Date*	*Active ingredient*	*CFP*	*RIA*
Grass 1990–1991	28 Jan 91	Chlorpyrifos (I)[a]	720	0
Winter wheat 1991–1992	26 Nov 91	Diflufenican (H)	100	50
		Isoproturon (H)	1000	500
	29 Apr 92	Propiconazole (F)	125	62.5
		Fluoroxypyr (H)	200	100
		Metsulfuron-methyl (H)	6	3
	09 Jun 92	Propiconazole (F)	125	62.5
	23 Jun 92	Dimethoate (I)[a]	340	0
Winter wheat 1992–1993	04 Nov 92	Paraquat (H)	800	400
	05 Feb 93	Diflufenican (H)	100	50
		Isoproturon (H)	1000	500
	25 Mar 93	Fenoxaprop-P-ethyl (H)	69	34
	22 Apr 93	Cyproconazole (F)	60	30
		Prochloraz (F)	400	200
		Metsulfuron-methyl (H)	6	3
		Mecoprop-P	1380	690
	02 Jun 93	Fenpropimorph (F)	375	187
		Propiconazole (F)	125	62.5
	23 Jun 93	Dimethoate (I)[a]	340	0
		Propiconazole (F)	125	62.5
Grass 1993–1994	14 Jun 94	Chlorpyrifos (I)[a]	720	0
Grass 1995	22 Mar 95	Chlorpyrifos (I)[a]	720	0
	03 Apr 95	Propiconazole (F)	125	0
Grass 1996	09 Apr 96	Propiconazole (F)	125	0
Grass 1997	02 Apr 97[b]	Chlorpyrifos (I)[a]	720	0
	09 Apr 97[b]	Propiconazole (F)	125	0

[a] Pesticide application excluded a 6-m buffer strip at the field edge.
[b] Pesticide regimes were spatially reversed.

ables of interest, in this case field half and sampling date. PRC models the response pattern of each species, T_{dtk}, as a multiple (b_k) of one basic response pattern (c_{dt}), ie $T_{dtk} = b_k \times c_{dt}$. A detailed explanation of the method is given by van den Brink *et al.*[25–27] By plotting values of c_{dt} for each treatment, *d*, and sampling time, *t*, a PRC diagram is obtained that shows the temporal change in community composition (the principal response of the community) under one treatment level (ie, field half) relative to the other. By definition, $c_{dt} = 0$ for the reference treatment level, so the response curve for the reference treatment (here, the east field half) is a straight horizontal line against which values of c_{dt} for the other treatment level (ie, the west field half) can be compared to clearly display temporal changes in treatment effects.[25–27] The species weight b_k indicates the affinity each individual taxon, *k*, has with the overall community response as displayed in the PRC diagram. Species weights can be interpreted quantitatively to give the fitted relative abundance of a taxon relative to the reference treatment.[25–30] In the current work, values of c_{dt} and b_k were obtained for the comparison of the two field halves by performing PRC analyses with the software program CANOCO 4,[31] using $\ln(x+1)$-transformed suction or pitfall counts, *x*, ($n = 4$ per field half) for up to 24 sampling dates (Table 2). Three PRC analyses were performed: (1) field suction-captured Collembola (16 taxa); (2) field pitfall-captured Collembola (23 taxa); and (3) field-edge pitfall-captured Collembola (23 taxa). In the case of suction-sampled Collembola, sampling dates from the first year following spatial reversal of the pesticide regimes (Section 2.4 above) were included to permit the PRC diagram to display the effect of the spatial manipulation. For pitfall catches, which were not collected after 1996, data are limited to the period before spatial reversal of the pesticide regimes (Table 2). For each analysis, the null hypothesis that the PRC diagram does not display the treatment variance (ie $T_{dtk} = 0$ for all *t*, *d* and *k*) was tested using an *F*-type statistic obtained by permuting whole time series in the partial RDA from which that PRC was obtained.[31] Permutation tests were also performed among samples within each sampling date as described previously[25–30] to test the null hypothesis that on each date the principal response c_{dt} did not differ significantly between the treatments (here, east and west halves of the field).

3 RESULTS

3.1 Collembola composition of field and field-edge samples

In suction samples, the overall catch (all samples pooled) comprised *Lepidocyrtus* spp (17.9%), *Sminthurinus elegans* (Fitch) (16.0%), *Entomobrya multifasciata* (Tullberg) (15.6%), *Isotoma viridis* 'group' (12.8%), *Isotomurus* spp (11.7%), *Pseudosinella alba* (Packard) (6.6%), *Orchesella villosa* (Geoffroy) (6.4%), *E nicoleti* (5.1%) and eight other taxa (together 7.9%). Pitfall samples in the field and at the field edge respectively comprised *Lepidocyrtus* spp (18.0 and 17.9%), *Isotomurus* spp (15.7 and 11.8%), *I viridis* 'group' (14.3 and 9.2%), *Sminthurinus* spp (12.1 and 8.1%), Sminthuridinae (11.3 and 5.7%), Poduroidea (8.2 and 10.3%), *E multifasciata* (7.4 and 7.3%), *E nicoleti* (5.3 and 9.4%), *O villosa* (3.6 and 5.3%) and 14 other taxa (together 4.1 and 15%). Notable differences between field and field-edge catches were that, in all years, *Orchesella cincta* (L) and *Tomocerus* spp were found only in field-edge samples.

3.2 Distributions of *Entomobrya nicoleti* and *Lepidocyrtus* spp

Field-sited suction and pitfall catches clearly show the disappearance of *E nicoleti* from the west half of Field 5 when the CFP pesticide regime was first applied there in January 1991 (Fig 1(a), (b)). However, this species was abundant at both the east and west field edges during the latter part of the study, with no evidence for an effect of the CFP regime on the field-edge populations (Fig 1(c)). A similar pattern of catches is evident for *Lepidocyrtus* spp, with effects of the CFP regime apparent in the field (Fig 2(a), (b)) but not at the field edge (Fig 2(c)).

3.3 Field and field-edge collembolan community patterns

Of the total variance in the suction sample catches, 46.9% is explained by sampling date and 37.3% by

Table 2. Suction and pitfall sampling dates

	1990	1991	1992	1993	1994	1995	1996	1997[a]
Suction samples	17 Jul[b] 31 Jul[b]	29 May 12 Jun 10 Jul	14 May 24 Jun 16 Jul	5 May 15 Jun 6 Jul	11 May 22 Jun 7 Jul	24 May 7 Jun 19 Jul	8 May 3 Jun 5 Jul	29 May 23 Jun 10 Jul
Pitfall samples (7-day catch ending)	18 Sep[b] 23 Oct[b] 13 Nov[b] 31 Dec[b]	15 Jan[b] 21 Jan 5 Mar 25 Jun 10 Dec	18 Feb 12 May 7 Jul	27 Apr 20 Jul 17 Aug	10 May 26 Jul 27 Sep	30 May 8 Aug 17 Oct	5 Mar 14 May 9 Jul	No pitfall samples

[a] After spatial reversal of the pesticide regimes.
[b] Before CFP and RIA pesticide regimes were applied.

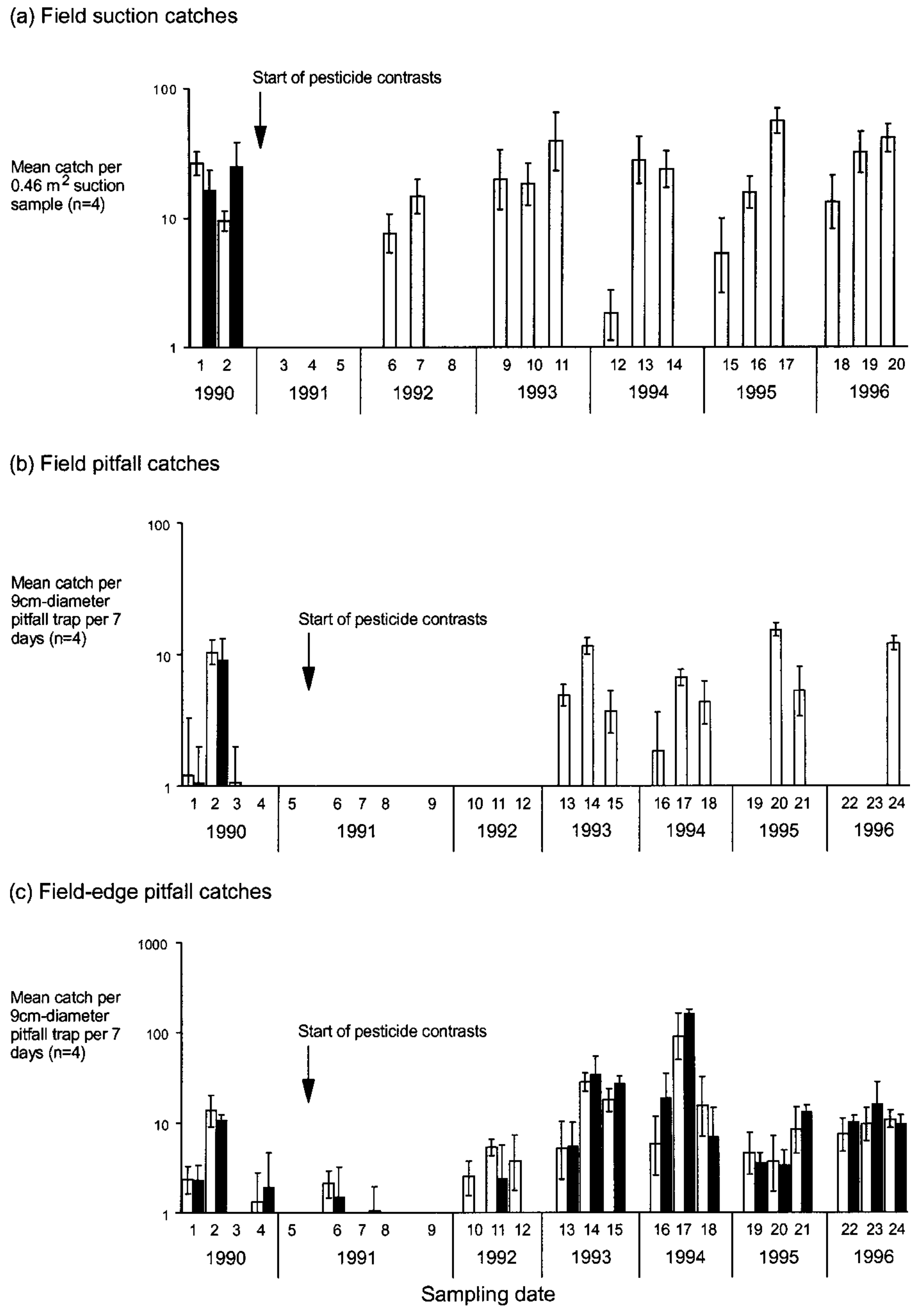

Figure 1. (a) Field suction, (b) field pitfall and (c) field-edge pitfall catches of *Entomobrya nicoleti* in the (white bars) east and (black bars) west of Field 5. On sampling dates 3–24 the west half of the field received current farm practice pesticides and the east half received a reduced-input regime. Means ($\pm$SE) are derived from $\ln(x+1)$-transformed counts, x. Details of sampling dates are given in Table 2.

differences between the field halves. A significant proportion of this variance (68.6%; $F=14.6$; $P<0.05$) is displayed on the vertical axis of the PRC diagram (Fig 3). The diagram clearly shows the effect of spatially reversing the pesticide regimes in spring 1997, after which relative abundance in the east half of the field (CFP, formerly RIA) was consistently lower than in the west half (RIA, formerly CFP). The principal response of the collembolan community did not differ significantly between the two field halves before the contrasting pesticide regimes were applied, but thereafter differed significantly ($P<0.05$) on nearly all sampling dates (Fig 3). Species weights indicate that *Lepidocyrtus* spp was the taxon most strongly associated with the overall community response displayed by the PRC diagram.

For field pitfall catches, 61.4% of the total variance is explained by sampling date and 27.3% by differences between the field halves, with a significant proportion of this variance (61.2%; $F=14.4$; $P<0.05$) displayed by the PRC diagram (Fig 4). PRC analysis of field pitfall catches for 1990–1996 yielded a similar response pattern to that seen with suction catches (Fig 4). Collembolan community composition did not differ significantly in the two field halves during pre-treatment monitoring, but differences were significant ($P<0.05$) on nearly all sampling dates after the contrasting regimes were applied, with relative abundance consistently lowest in the west half of the field, which received CFP pesticide inputs (Fig 4). Again, *Lepidocyrtus* spp was the taxon most closely associated with this overall community response pattern.

For field-edge pitfall catches, 77.5 and 6.0% of the total variance, respectively, were explained by sampling date and field half, with a significant proportion of the field-half variance (41.7%; $F=18.6$; $P<0.05$) displayed by the PRC diagram (Fig 5). The field-edge PRC diagram differs in two key respects compared with the previous analyses of the field collembolan community responses. First, although the effect of applying the CFP regime in 1991 is clearly evident in the PRC diagram (Fig 5), after 1991 the difference in principal response between the east and west halves of the field is less marked, with differences significant on fewer sampling dates. Relative abundance, however, was still nearly always lowest in the CFP-treated west half of the field. Second, species weights indicate that different taxa (principally Poduroidea and *I viridis* 'group') were associated with this pattern of community response at the field edge (Fig 5); *Lepidocyrtus* spp and *E nicoleti* in contrast have relatively low weights, consistent with the lack of any clear differences in their relative abundance between the east and west field edges (cf Figs 1 and 2).

4 DISCUSSION

4.1 Implications for Collembola recolonisation dynamics

It is clear that substantial in-field effects of CFP pesticide use on *E nicoleti* and *Lepidocyrtus* spp did not extend to populations of these species at the field edge. The hypothesis that poor recovery ability of these species in the field could be caused by lack of potential

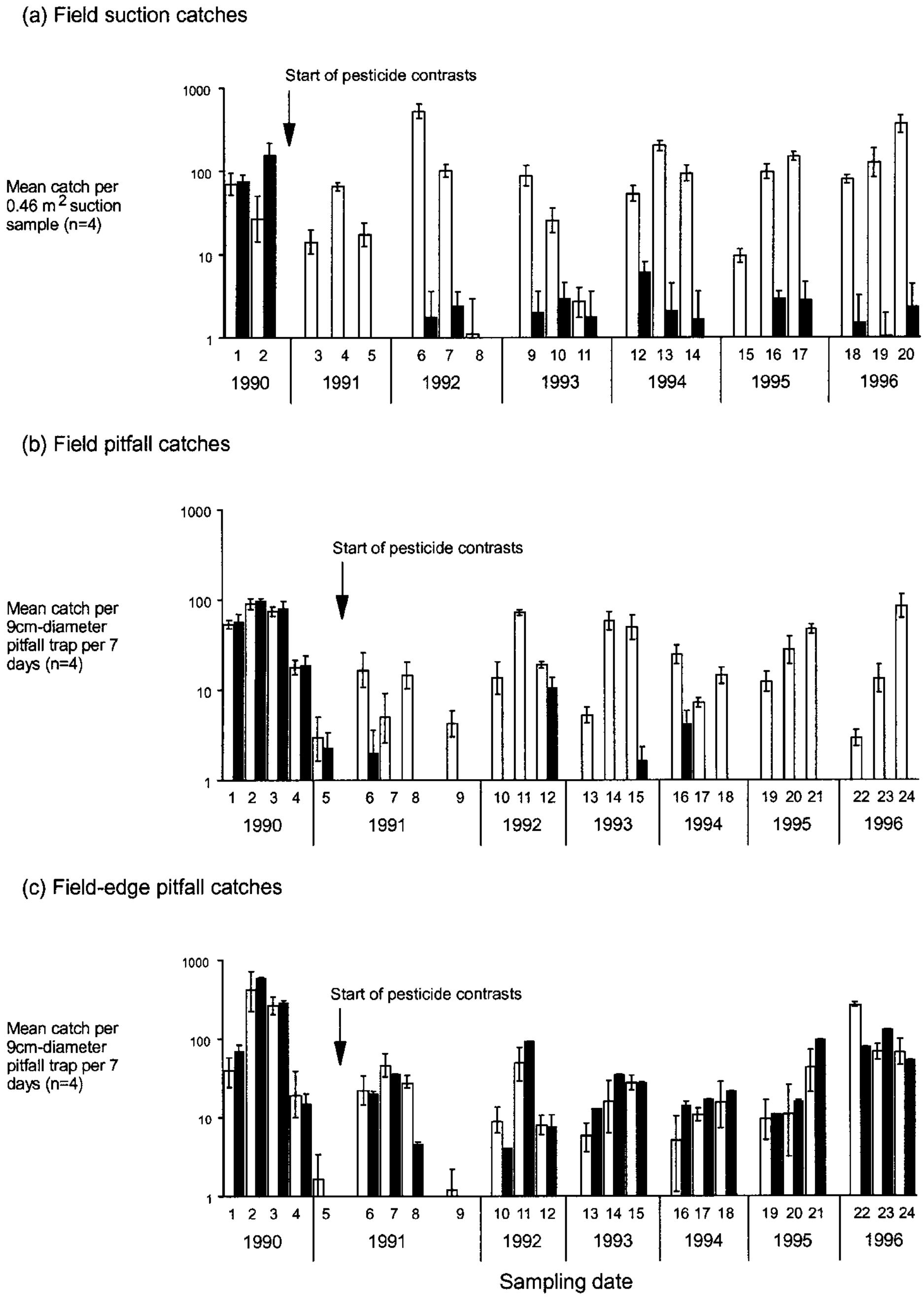

Figure 2. (a) Field suction, (b) field pitfall and (c) field-edge pitfall catches of *Lepidocyrtus* spp in the (white bars) east and (black bars) west of Field 5. On sampling dates 3–24 the west half of the field received current farm practice pesticides and the east half received a reduced-input regime. Means (±SE) are derived from $\ln(x+1)$-transformed counts, x. Details of sampling dates are given in Table 2.

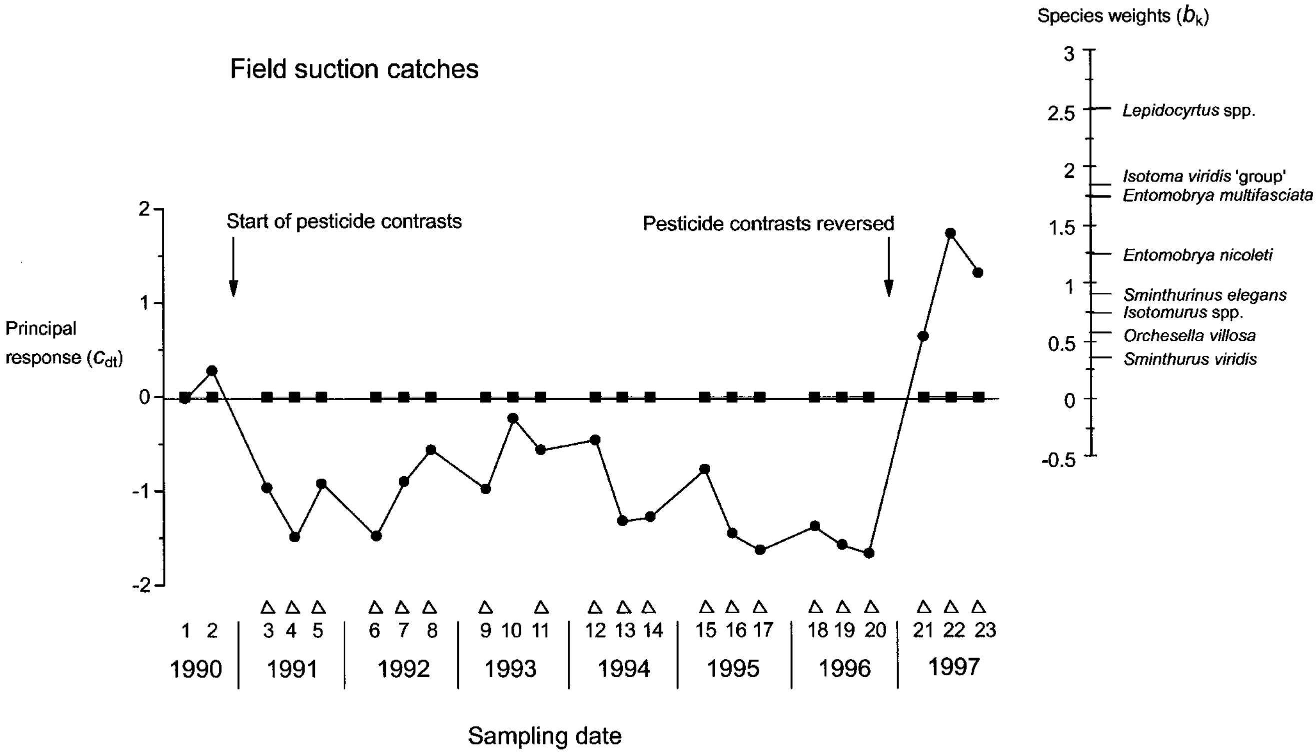

Figure 3. PRC diagram and species weights showing the temporal change (principal response) of the field suction-sampled collembolan community in (●) the west half of Field 5 relative to (■) a reference community in the east half. On sampling dates 3–20 the west half received current farm practice pesticides and the east half received a reduced-input regime; thereafter, the regimes were spatially reversed. (△) denotes significant within-date departures of the principal response (c_{dt}) from zero ($P < 0.05$). Details of the sampling dates are given in Table 2.

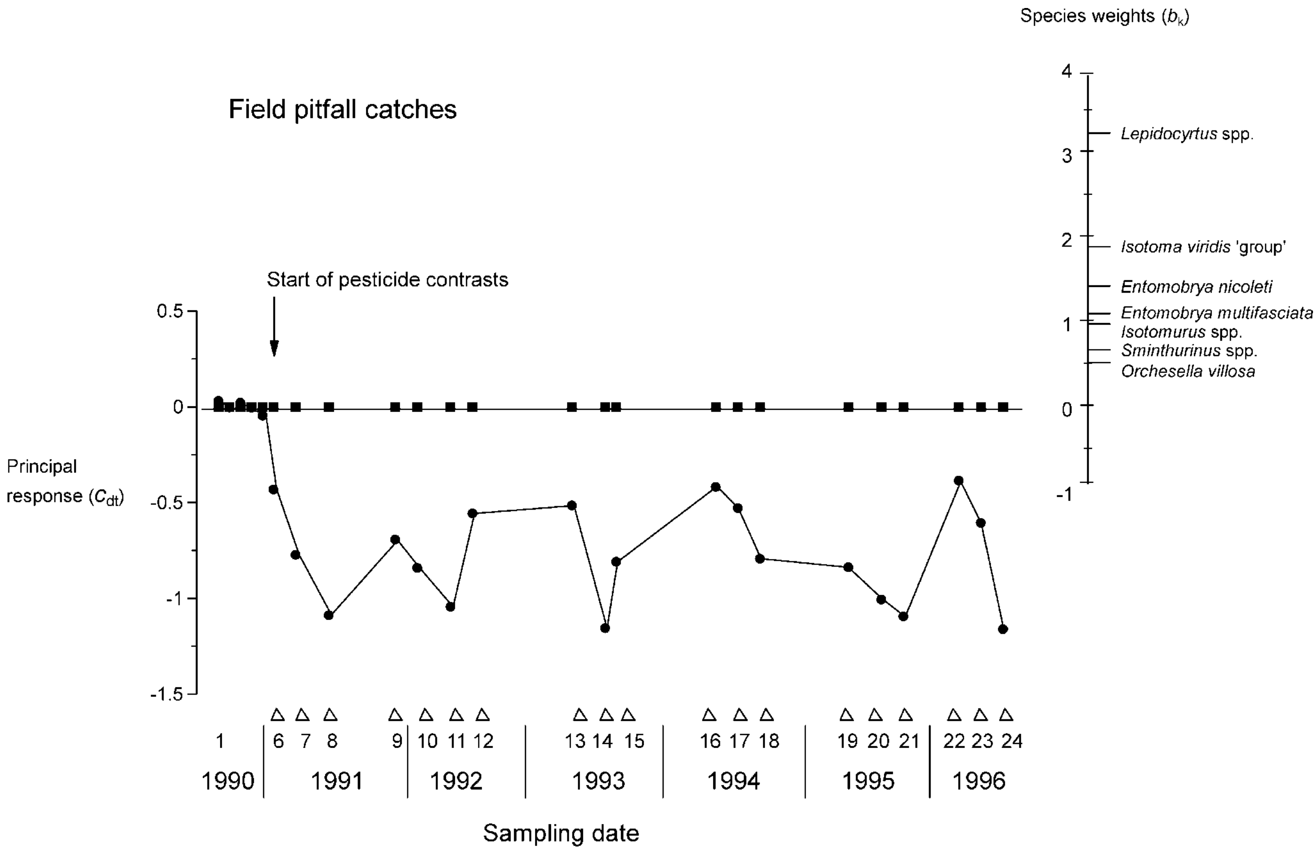

Figure 4. PRC diagram and species weights showing the temporal change (principal response) of the field pitfall-sampled collembolan community in (●) the west half of Field 5 relative to (■) a reference community in the east half. On sampling dates 3–20 the west half received current farm practice pesticides and the east half received a reduced-input regime. (△) denotes significant within-date departures of the principal response (c_{dt}) from zero ($P < 0.05$). Details of the sampling dates are given in Table 2.

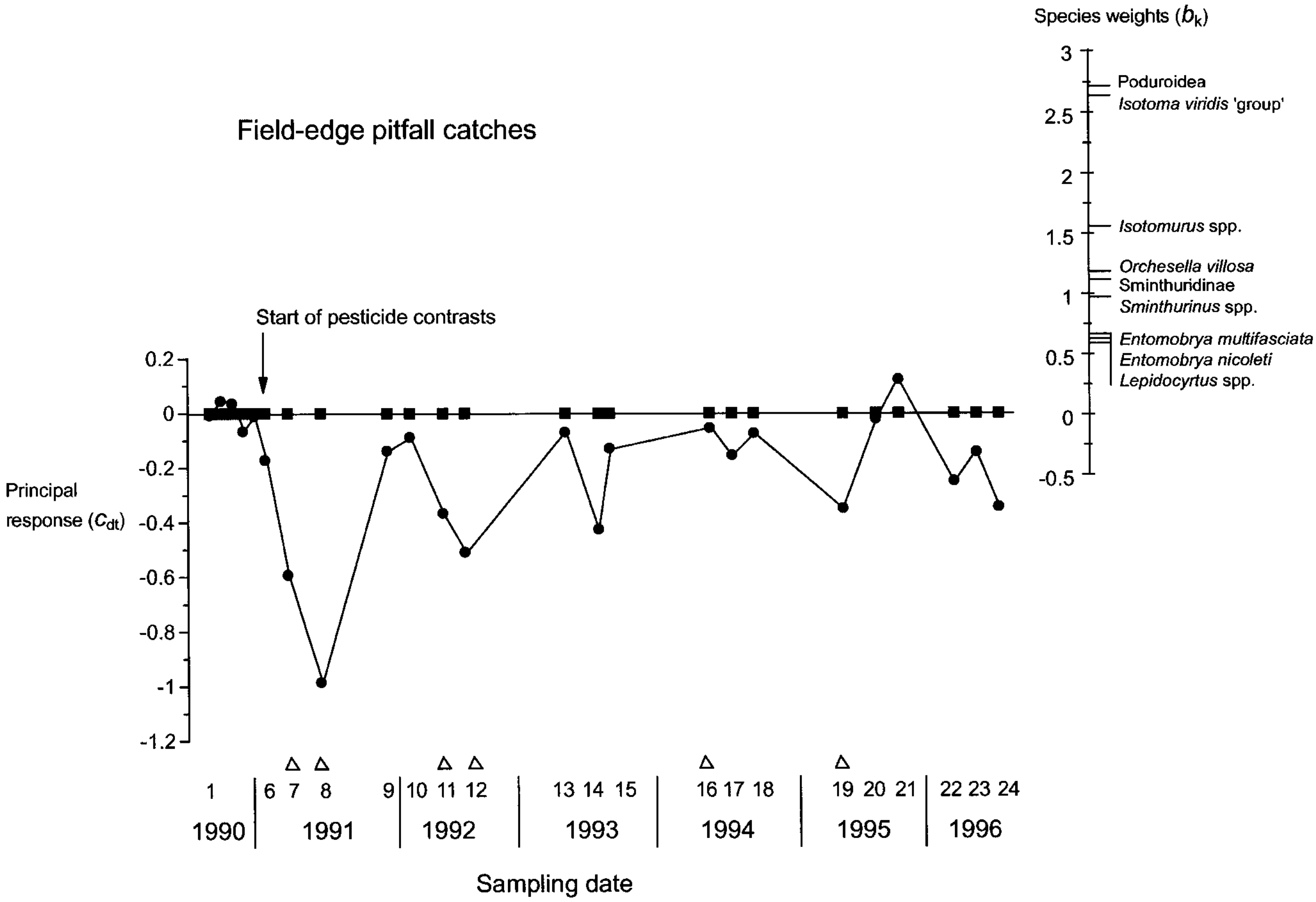

Figure 5. PRC diagram and species weights showing the temporal change (principal response) of the field-edge pitfall-sampled collembolan community in (●) the west half of Field 5 relative to (■) a reference field-edge community in the east half of the field. On sampling dates 3–20 the west half received current farm practice pesticides and the east half received a reduced-input regime. (△) denotes significant within-date departures of the principal response (c_{dt}) from zero ($P<0.05$). Details of the sampling dates are given in Table 2.

recolonists in the vicinity therefore has to be rejected; low catches of these Collembola in the west (CFP-treated) half of the field did not increase after the last OP insecticide application in 1995 despite the nearby presence of populations both in the east and west field edges and also in the east (RIA-treated) half of the field. Accordingly, it seems likely that the poor recovery ability of *E nicoleti* and *Lepidocyrtus* spp may be related either to low mobility or to an (as yet unknown) environmental change brought about by pesticide use that has rendered the former CFP area temporarily unsuitable for recolonisation (eg by influencing interactions with other organisms or the availability of food).

4.2 Implications for unsprayed headlands

The edge of Field 5 comprised a ditch and hedgerow, typical of arable field margins.[32] All pesticide applications to Field 5 were made in accordance with statutory label restrictions, which prevented application of OP insecticides, but not fungicides or herbicides, to the outermost 6m of crop headland adjacent to the ditch. The lack of obvious effects of the CFP pesticide regime on field-edge populations of *E nicoleti* and *Lepidocyrtus* in any of the study years, despite the relatively high intensity of insecticide use (Section 4.3 below), suggests that for these species the label guidance for applying fungicides, herbicides and insecticides gave adequate protection of field-edge populations. At the level of the overall collembolan community, however, differences between the east and west field edges were consistent with some negative effects of the CFP regime penetrating to the field edge. The largest impact of the CFP regime at the field edge occurred when the regime was first applied to the field in 1991, possibly indicating perturbation of a relatively vulnerable arthropod community that had built up during a period of no pesticide use prior to the study (Section 4.3 below). Thereafter, the community response pattern at the field edge fluctuated through time, consistent with transient effects of the individual insecticide applications in each year, interspersed with periods of community recovery. Current (but limited) regulatory guidance on the off-crop acceptability of pesticide impacts to non-target arthropods is that risk mitigation should be employed if effects outside the cropped area are severe and persistent.[33] Bearing in mind that Field 5 received a relatively high frequency of OP insecticide applications, the PRC analysis does not provide strong evidence for severe and persistent effects at the field edge. However, the observed response of the field-edge community represents the impact of pesticide use with a risk mitigation strategy (6-m insecticide-free headland) already operating.

4.3 Relevance of the pesticide regimes and crop rotation

The CFP pesticide regime applied to Field 5 comprised five consecutive applications of OP insecticides. Such frequent use of OP insecticides in the UK is legally permissible but unlikely to be practised routinely.[8] The results do not preclude the possibility that fewer than five of the applied OP chemicals were responsible for the long-term declines in collembolan abundance; however, it was not an objective of the SCARAB Project to investigate effects of individual chemicals.[16] In other SCARAB Project fields, isolated OP insecticide applications did not lead to long-term declines in collembolan abundance, but in such cases the collembolan species composition was different, notably lacking *E nicoleti* (which was found only in Field 5).[8] Despite possible arguments that the CFP regime is not representative of UK agricultural practice, it nevertheless provides a relatively high-intensity scenario of pesticide use that can be used to explore the relative vulnerability of field and field-edge arthropod communities; this might otherwise be difficult to discriminate against stochastic variability if less intensive regimes of pesticide use were applied. It is notable in this respect that regimes of pesticides based on synthetic pyrethroids, which are the most widely used insecticides in Britain,[34] would not be expected to have had such a clear impact on the collembolan communities, as these insecticides appear not to be generally harmful to Collembola.[9,10]

The CFP regime comprised fungicide and herbicide inputs as well as the OP insecticides but, except in the wheat crops, fungicide and herbicide use was relatively infrequent (Table 1). The major changes in the collembolan community composition between the two field halves coincided with OP insecticide applications, and these pesticides are likely to have been largely responsible for the overall negative effect of the CFP regime.[8] However, the possibility cannot be excluded that negative effects of, for instance, propiconazole (Table 1) on collembolan abundance[35] might also have occurred.

The cropping scenario of Field 5 could have influenced the vulnerability of the arthropod communities resident there. Prior to the application of the CFP regime in 1991, there had been no pesticide applications nor major cultivations for at least four years.[16] The CFP regime was thus applied to an arthropod community that would have developed without conventional agricultural management pressure and might, as the disappearance of *E nicoleti* suggests, have been relatively vulnerable to pesticide use. In this respect it is notable that the strongest impact of the CFP pesticide regime on the collembolan community at the field edge occurred when the regime was first applied in 1991. However, the field-edge Collembola data provide no obvious evidence of species turnover, which would be expected to have occurred if the CFP regime, once applied, caused a shift in community composition towards less vulnerable species. Information on spray drift in Field 5 is not available but it is unlikely that the relatively large initial impact of the CFP regime at the field edge in 1991 would have been caused by drift of the first OP (chlorpyrifos) application (Table 1), as weather conditions during that winter application (calm; mean air temperature during spraying 1.5 °C) would not have been conducive to volatilisation or drift.

4.4 Experiment design and statistical interpretation

Despite the lack of formal replication of the SCARAB Project pesticide regimes, the PRC diagram for suction-sampled Collembola clearly demonstrates that the differences in the collembolan communities between the two halves of the study field resulted directly from the manipulation of pesticide use. The statistical tests of differences in the principal response at each sampling date provide supporting information to aid interpretation of the overall community response, but, as with any field study, should not be taken in isolation as an exact indication of treatment effects.[36] Up to 24 such statistical tests were performed for each PRC diagram, meaning that, with an experiment-wise error rate (α) of 5%, approximately one of the indicated significant differences between the field halves in each PRC diagram might have occurred by chance. This would have little bearing on the overall interpretation of the community response pattern and, as $\alpha = 0.05$ gives a conservative indication of Type I error in field studies,[37] adjustment of the experiment-wise error rate was considered inappropriate.

4.5 Collembola sampling

Pitfall traps provide a combined measure of activity and abundance, hence their catches can be influenced by micro-climatic conditions and, at least over short time periods, the catches do not accurately reflect abundance of Collembola in the field.[30] The remarkable similarity of pitfall and suction catches of Collembola in this study suggests that pitfall trapping may in fact be a reliable means of estimating changes in collembolan abundance at longer time scales, at least where effects of intensive agricultural management practices are concerned.

5 CONCLUSIONS

A regime of pesticide use with a relatively high frequency of OP insecticide applications did not substantially affect field-edge Collembola, even though effects on field-inhabiting populations were severe and included the local disappearance of one species. Although the evidence is circumstantial, the relative lack of field-edge pesticide effects could reflect the use of a 6-m insecticide-free headland as a risk-mitigation strategy for protecting off-crop arthropods. Results from this study clearly refute the hypothesis that lack of recovery of *Entomobrya nicoleti* and *Lepidocyrtus* spp in the field was caused by adverse effects of the pesticides on potential recolonists at the field edge.

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