THE EFFECTS OF PESTICIDE REGIMES ON NON–TARGET ARTHROPODS

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Introduction

Farmland is a substantial geographical feature throughout Europe and provides habitats for many species of wildlife. One fifth of the land area of Great Britain is sown to arable crops (Thomas *et al.*, 1997) and cereal farming (which occupies about one sixth of the land area) covers sixteen times as great an area as all UK nature reserves combined (Potts, 1991). Arable farmland may appear barren if crop monocultures extend over large areas but cereal crops have a diverse invertebrate fauna of dynamically interacting herbivores, fungus-feeders, predators and parasitoids (Potts & Vickerman, 1974; Jones, 1976a). At least 180 species of spider live in arable ecosystems (26% of all the UK species) and the figure for insects has been estimated to exceed 1,800 species (Potts, 1991). Most inhabitants of farmland are not themselves pests. However, they may encounter harmful residues of chemicals applied to combat crop pests, diseases and weeds, or they may experience indirect effects of pesticide use on their habitat or food supply. These 'non-target' species include predators and parasitoids that are beneficial as natural antagonists of pests such as cereal aphids (Wratten & Powell, 1991). They also include pollinators, species of aesthetic or conservation value (e.g. butterflies), those involved in nutrient cycling and maintaining soil fertility (earthworms, springtails) and species which may serve as indicators of ecosystem health. The beneficial value of the non-target arthropod fauna of farmland is now widely accepted, with the protection and enhancement of predatory species important ingredients in programmes of Integrated Crop Management (ICM). There is concern, however, that current farming practices, including pesticide use, may be to blame for long-term declines in the abundance of a variety of farmland wildlife species (Sotherton, 1998; Ewald & Aebischer, 1999).

The Boxworth Project

During the 1970s, monitoring by the Game Conservancy Trust in cereals in southern England revealed long-term declines in the abundance of some arthropods, particularly rove beetles and spiders (Aebischer, 1991). These changes occurred at a time of considerable growth in pesticide usage on arable crops. The number of fields treated with foliar fungicides had increased steadily during that decade and the first widespread use of summer aphicides in Britain occurred in 1975 (Potts, 1991). The number of available chemicals, the proportion of fields treated with pesticides, the frequency of applications within a season and the incidence of spraying several pesticide products together as mixtures all increased during the 1970s, raising concerns that pesticide use could have contributed to the observed declines in arthropod populations. Orthodox field trials, which usually lasted no longer than one season and involved single applications of individual pesticides within one or few fields, could not detect large-scale or long-term effects and so a new experimental approach was needed. Following a period of consultation and planning to develop the most appropriate experimental design (Greig-Smith, 1992) the Boxworth Project was initiated in 1981, at the then Boxworth Experimental Husbandry Farm in eastern England. The aim of the Boxworth Project was to investigate the effects on wildlife of the high pesticide inputs then associated with commercial wheat production, using an experimental scale large enough to detect long-term effects.

Reducing Agrochemical use on the Arable Farm: The TALISMAN and SCARAB Projects.

Young J E B, Griffin M J, Alford D V, Ogilvy S E. [*eds*] 2001. London: DEFRA.

The Boxworth Project comprised a 67 ha block of four 'Full Insurance' fields and a 68 ha block of six lower-input fields, three of which received 'Supervised' pesticide inputs and the remaining three 'Integrated' inputs. Fields were cropped with winter wheat. The pros and cons of the Boxworth experimental design were considered by Greig-Smith (1992). The Full Insurance regime involved prophylactic use of pesticides designed to eliminate any pest, disease or weed problems, whereas the Supervised and Integrated regimes, which had similar pesticide inputs, were managed such that chemicals were applied only in response to a threat of crop yield loss or unacceptable damage. During the 'baseline' (pre-treatment) phase of the Project (1981–1983) all fields received Supervised pesticide inputs; then, in autumn 1983, the Full Insurance treatment was initiated and operated until autumn 1988 (Greig-Smith *et al.*, 1992). The responses of a wide range of wildlife (including plants, birds, small mammals and arthropods) to the pesticide regimes were monitored throughout the Project by specialist scientists using a variety of methods. At the end of the Project, it was apparent that some sub-lethal and short-term effects of insecticide and molluscicide use had occurred among birds and mammals, but it was only arthropods that had exhibited long-term responses to the pesticide regimes. Some species of ground beetles and surface-dwelling springtails were immediately reduced in abundance by the implementation of the Full Insurance regime in 1983, and failed to recover while Full Insurance pesticide use continued (Burn, 1992; Vickerman, 1992). More subtle long-term changes occurred among soil-dwelling springtails, with some species showing a gradual decline and others a gradual increase in density under the Full Insurance regime (Frampton *et al.*, 1992). At the end of the Project, reversion of some Full Insurance fields to Supervised inputs (Greig-Smith & Griffin, 1992) did not immediately reverse effects of the Full Insurance regime on the most vulnerable arthropod species.

SCARAB arthropod monitoring

Results from the Boxworth Project implied that intensive, prophylactic use of pesticides in commercial wheat production could be damaging to arthropod populations. However, it was not known whether similar results would have been obtained under different crops or on farms sited elsewhere. The SCARAB Project, which included several crops on different farms, was initiated in 1990 to clarify the situation (Cooper, 1990; see also Chapter 1.1). SCARAB focused on arthropods, the group of wildlife most vulnerable to Boxworth's Full Insurance regime. To permit studies of invertebrate species without the need for the large experimental areas employed at Boxworth, a split-field design was adopted for SCARAB, employing paired comparisons of conventional and reduced-input pesticide regimes within each of seven fields (Chapter 3.1). As at Boxworth (Greig-Smith, 1992), the trade-off between statistical replication and realism of the study meant that orthodox statistical designs were inappropriate for studying the long-term impact of overall pesticide regimes where effects of many variables are not readily separable. Nevertheless, the long time-scale of the study and its coverage of three UK farms provided a substantial amount of data from which effects of the pesticide regimes could reasonably be inferred with confidence. This chapter presents results from arthropod monitoring in the SCARAB Project during 1990 (the 'baseline' or pre-treatment year) and 1991–1996 (the phase of pesticide regime contrasts). An extension to the original SCARAB Project was initiated in 1996 to further explore long-term changes in arthropod distributions that had developed during the treatment phase of the Project in two of the study fields. Some results from this follow-up study are also presented here as they lend support to inferences drawn from the original SCARAB Project.

Methods and materials

Farms and fields

The design of the Project involved seven arable fields sited at three ADAS Research Centres (**Table 3.2.1**). The largest field, 'Old Type', was divided into two 15 ha units which are treated here as separate fields ('Old Type North' and 'Old Type South') but which had identical cropping, pesticide regimes and soil types. These contiguous fields were included in the Project to provide information on variation in effects of the CFP and RIA regimes between similarly-managed fields with different field margins. Cropping in each field varied from year to year, in accordance with the typical rotation for the locality (Chapter 3.1).

Pesticide regimes

Two regimes of pesticide use were compared in the SCARAB Project: 'Current Farm Practice' (CFP) and a 'Reduced Input Approach' (RIA) (Chapter 3.1). The pesticide regimes were flexible to accommodate the pesticide needs of different crops and year-to-year changes in farming practice. CFP mimicked conventional farming practice for the crop according to survey data (e.g. Thomas *et al.*, 1997), with the proviso that at least one insecticide was applied to each arable crop (except grass) to ensure that arthropods were exposed to a representative range of pesticides (Chapter 3.1). In comparison with CFP, lower pesticide inputs in the RIA regime reflected the omission of some applications, or the use of reduced application rates (Chapter 3.1). The major difference between the pesticide regimes was that no insecticides or nematicides were applied under the RIA regime and so all insecticide use documented below refers to the CFP regime. Over the Project as a whole, the RIA regime had 44% fewer label-recommended-rate herbicide applications and 52% fewer label-recommended-rate fungicide applications than CFP. Molluscicides were not included in either pesticide regime because the three SCARAB Project farms had not historically experienced problems of slug damage to crops. The CFP regime would have permitted molluscicide use in the event that slug damage unexpectedly threatened crop yields but such a scenario did not occur during the SCARAB Project.

Layout of the Project

To compare the effects of the pesticide regimes on the invertebrate fauna, each field was divided in half at the start of the 1990–1991 crop season, then, Current Farm Practice was applied to one half of the field whilst the other received the Reduced Input Approach. These contrasting regimes were operated until harvest 1996. As cropping and fertilisation were carried out on a whole-field basis, pesticide inputs were the only agronomic variables that differed between the RIA and CFP halves of each field. During summer and autumn in 1990, pre-treatment monitoring of arthropods was done to establish 'baseline' densities before the pesticide contrasts were applied.

Arthropod monitoring

'D-vac' suction sampling and pitfall trapping were the methods used to collect invertebrates. All species captured and identified during this work belong to the phylum Arthropoda, principally insects and spiders. Earthworms were monitored separately within the SCARAB Project, using different sampling procedures (Chapter 3.4). Arthropod monitoring was done at matched locations in the CFP and RIA areas of each field, following standard protocols for D-vac and pitfall sampling. The protocol for the former adopted a suction sampler nozzle that gave an area per sample of 0.46 m^2; that for the latter involved beakers (9 cm in diameter) open for periods of seven days (Chapter 3.1).

The follow-up study

Arthropod captures made during the treatment phase (1991–1996) revealed long-term differences in abundance between the pesticide regimes in two of the fields ('Bugdale' and 'Field 5') which persisted to the end of the monitoring period in autumn 1996. A follow-up study (1997–1999) involving these two fields was initiated to further explore these results. This study involved spatially reversing the CFP and RIA regimes in 1997, to permit monitoring of arthropod recovery (following a change from CFP to RIA pesticide inputs). Some initial results from this work in 'Field 5' are given to aid interpretation of effects of the CFP and RIA pesticide regimes.

Data interpretation

The SCARAB Project was designed to explore the overall effects of complete pesticide regimes rather than the effects of individual chemicals; however, the effects of some broad-spectrum insecticides were sometimes readily apparent where substantial changes in arthropod abundance concurred with insecticide applications. Replication of the pesticide regimes was incompatible with the long duration and large spatial scale of monitoring needed to detect large-scale effects, so standard statistical tests could not be invoked to detect pesticide effects. Instead, evidence that the pesticide regimes had influenced arthropod density or activity was based upon changes in arthropod abundance or distribution which:

- coincided with pesticide applications;
- differed between the pre-treatment year (1990) and treatment phase (1991–1996).

Confidence was increased if such changes also:

- were relatively large or persistent compared with 'background' fluctuations;
- were consistent, following pesticide applications in different fields or years;
- resulted in long-term differences in species composition between the two regimes.

The above criteria were applied to densities of individual species, species richness, species diversity and a measure of the similarity of the faunas under the two pesticide regimes. Arthropod species were grouped functionally to determine whether effects of the pesticide regimes on trophic structure could be detected. The multivariate ordination method Redundancy Analysis was also used to investigate changes in the species compositions of the two pesticide regimes over time in 'Field 5', where the largest differences in arthropod catches between the pesticide regimes were seen.

Multivariate analysis

Multivariate ordination techniques allow information from a complex data set, in this case containing more than 100 taxonomic groups (**Tables 3.2.2 & 3.2.3**), to be concisely summarised in a two-dimensional diagram. The axes of the diagram are drawn so as to represent the major sources of variation in the data. Various statistical methods are available to plot sample points or species points in an ordination diagram, such that the position of each data point relative to the ordination axes shows how strongly the point (representing a species or sample) is influenced by different environmental variables. Redundancy Analysis (RDA) is a particularly useful ordination technique in ecotoxicology because the environmental variables can be specified so that the ordination diagram displays only the part of the total variation which is explained by variables of interest, e.g. pesticide treatment and time (Van den Brink & Ter Braak, 1997; 1999). Redundancy analysis was used to investigate the responses of arthropods to the Current Farm Practice and Reduced Input Approach pesticide regimes in all SCARAB Project fields. For brevity, the focus here is on suction captures of arthropods in 'Field 5', where differences in arthropod abundance between the regimes were most pronounced (e.g. **Figs 3.2.1–3.2.5**). The analysis was performed using the computer program CANOCO 4 (Ter Braak & Šmilauer, 1998), using the same procedure as that described by Van den Brink & Ter Braak (1999). In this case, all levels of the factors 'pesticide regime' and 'sampling date' were introduced as dummy variables into the RDA to permit the analysis to focus on the variance in the data set attributed to time, pesticide regime, and their interaction.

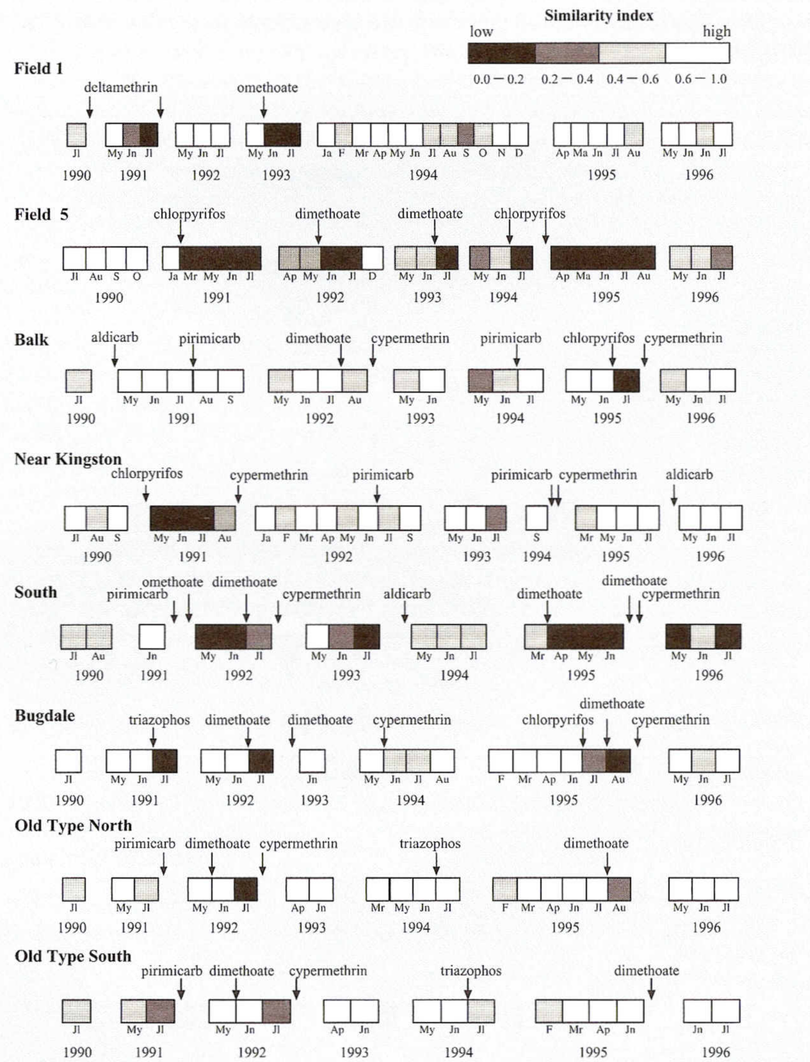

Figure 3.2.1. Monthly mean similarity of RIA and CFP springtail communities (Sorenson quantitative similarity index) in eight SCARAB Project fields, 1990–96. Low captures (fewer than 10 springtails/sample) are excluded. Insecticides (arrows) were applied under the CFP regime only.

Results

Overall composition of the arthropod fauna in SCARAB

The compositions of the fauna differed between pitfall trapping and D-vac suction sampling (**Tables 3.2.2 & 3.2.3**). It was not practical to sample the entire fauna trapped by these methods, the principal arthropod omissions being the exclusion of mites (Acari) from all samples and springtails (Collembola) from pitfall samples. Given these constraints, pitfall trapping captured predominantly carnivorous taxa (**Table 3.2.2**), whereas D-vac samples were dominated by detritivores (springtails) and herbivores (bugs: Hemiptera; and thrips: Thysanoptera) (**Table 3.2.3**). Pitfall catches included nocturnally active species, and some diurnally active beetles (Coleoptera) too large to be captured by the D-vac (e.g. large *Pterostichus* spp. ground beetles), whereas D-vac samples contained mainly diurnally active species. Both sampling techniques captured surface-active (epigeic) or litter-dwelling (hemiedaphic) arthropods; however, only rarely were soil-inhabiting (edaphic) species, e.g. of springtails, trapped. 'Kill' pitfall trapping (i.e. traps in which captured invertebrates are killed), as was used here, tends to record more specimens than 'live' trapping (Weeks & McIntyre, 1997), as predation within traps and escape are minimised.

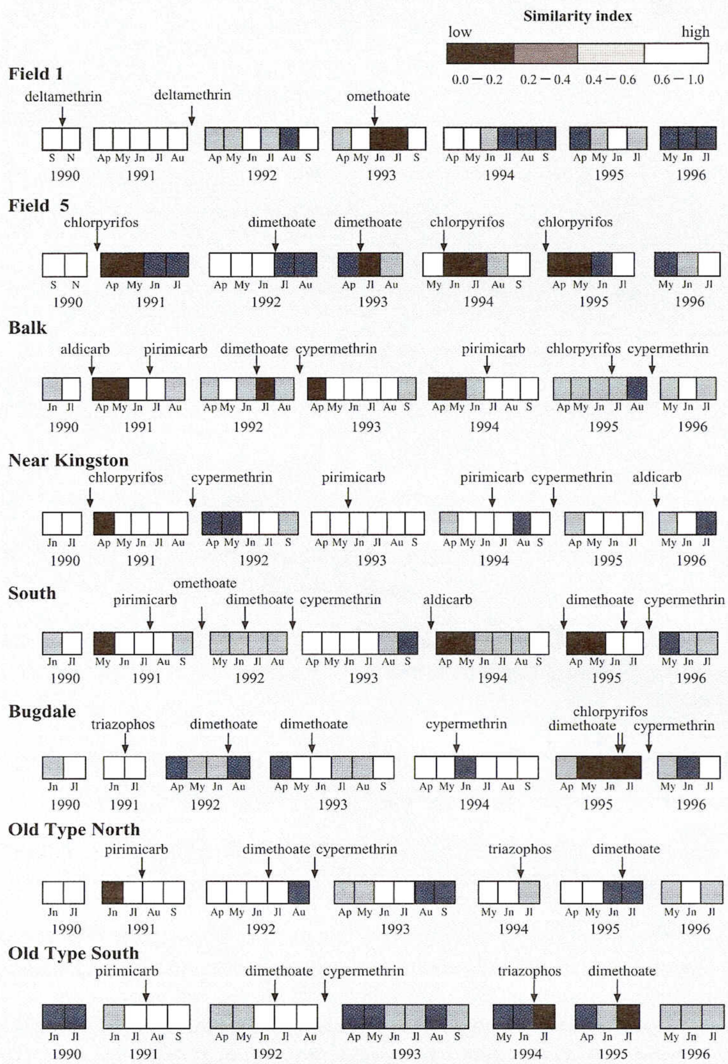

Figure 3.2.2. Monthly mean similarity of RIA and CFP ground beetle communities (Sorenson quantitative similarity index) in eight SCARAB Project fields, 1990–96. Low captures (fewer than 5 beetles/trap/7-day trapping period) are excluded. Insecticides (arrows) were applied under the CFP regime only.

The most numerous and widespread of the arthropods encountered during the SCARAB Project can be considered typical inhabitants of arable farmland in northern Europe. The ground beetle *Pterostichus melanarius* and the money spider *Erigone atra* were the predatory species most frequently encountered (i.e. in all fields and years) during the Project. Over the Project as a whole, *P. melanarius* and *Trechus quadristriatus* together comprised 57% of the total ground beetle catch. The dominance of these species, both of which are apparently favoured by conventional farming systems (Kromp, 1999), is consistent with other studies of

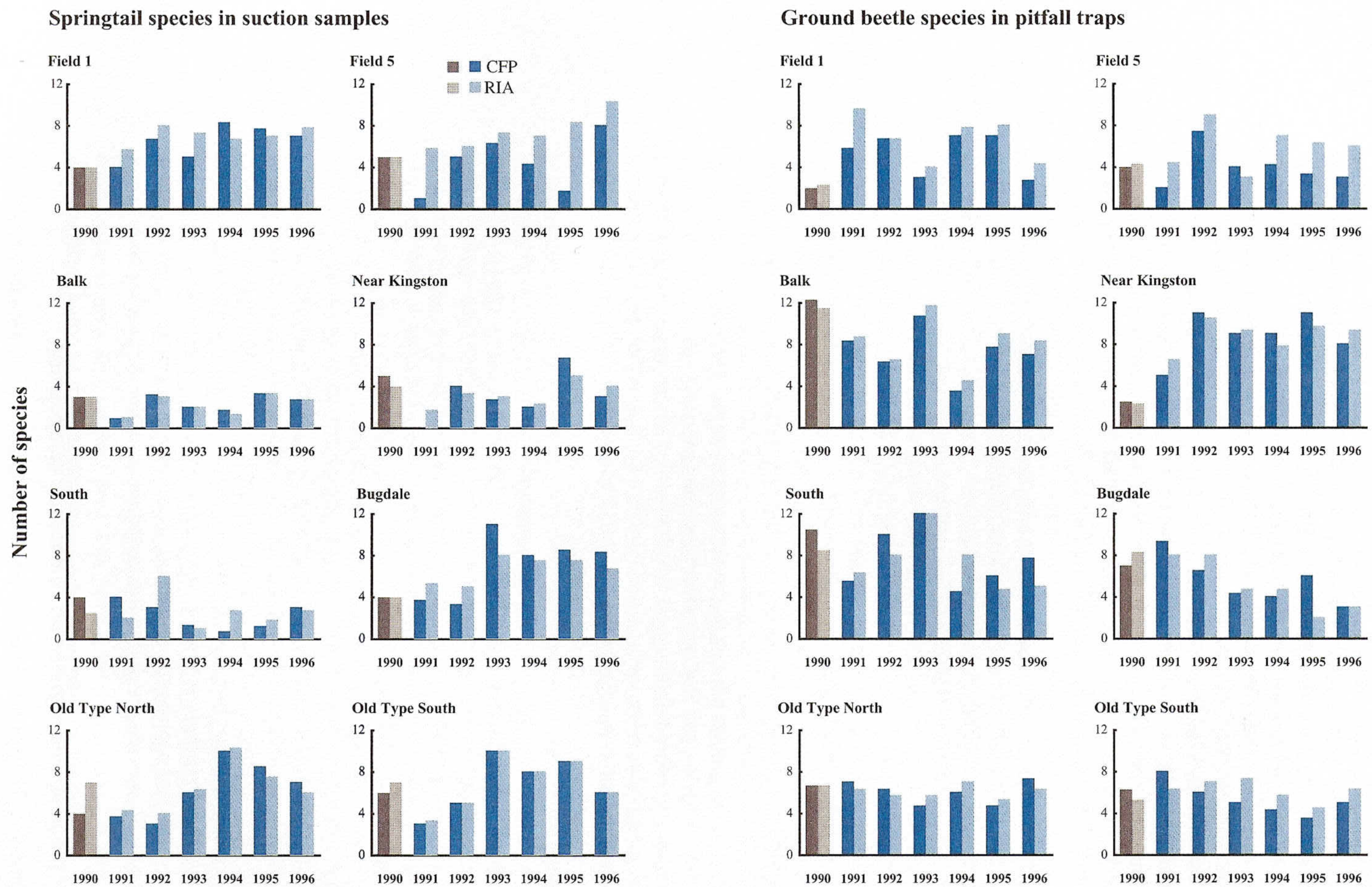

Figure 3.2.3. Number of springtail and ground beetle species captured in summer 1990–1996 in the eight SCARAB Project fields. Data are means from all sampling occasions in May, June and July in each year (except 'Field 1' and 'Field 5' 1990 data, which are from September). Grey bars denote pre-treatment year (1990).

ground beetles on farmland in northern Europe (Jones, 1976b; Thiele, 1977; Jones, 1979; Luff, 1987; Wallin, 1989; Hance, 1990; Luff, 1990; Lovei & Sárospataki, 1990; Thomas & Marshall, 1999), including the Boxworth Project (Vickerman, 1992). The dominant money spiders encountered in the SCARAB Project are representative of the most frequently occurring spiders of arable land in northern Europe. For example, five widespread species (*Bathyphantes gracilis*, *E. atra*, *E. dentipalpis*, *Meioneta rurestris* and *Oedothorax apicatus*), which Everts *et al.* (1989) recommended as a 'guild' of bioindicators for the detection of pesticide effects, together formed 62% of the overall SCARAB Project money spider catch. The species composition of rove beetles in the Project, which was dominated by Aleocharinae and *Tachyporus* spp., is also broadly consistent with that reported in the Boxworth Project (Vickerman, 1992) and other farmland studies (e.g. Jones, 1976b; Good & Giller, 1991; Krooss & Schaefer, 1998).

Although the overall species composition and abundance of arthropods in the SCARAB Project are typical of European farmland, the abundance and distribution of individual species varied considerably between fields and years. Differences in faunal composition between the SCARAB farms were the most obvious. Gleadthorpe had a smaller number of springtail species than Drayton or High Mowthorpe and a different composition of ground beetles. For example, *Calathus melanocephalus* and *Bembidion tetracolum* were found almost exclusively at Gleadthorpe whereas *Bembidion obtusum* was found only at Drayton and High Mowthorpe. It is possible that the sandy soil at Gleadthorpe played a part in these differences, as *C. melanocephalus* is characteristic of dry and sandy habitats (Lindroth, 1975; Eyre & Luff, 1990). Other notable spatial patterns in species' distributions within the SCARAB Project concern the ground beetles *Pterostichus cupreus* and *P. madidus* which were present only at Drayton and High Mowthorpe respectively. In England, *P. cupreus* has a predominantly southern distribution, which explains its presence only at Drayton, whereas *P. madidus* is more widespread (Luff, 1998); the reason for the restricted distribution of the latter species in the SCARAB Project is not clear.

Factors which could explain some of the temporal and spatial patterns in arthropod abundance include crop type and vegetation density (e.g. Thiele, 1977; Jensen *et al.*, 1989; Booij & Noorlander, 1992; Luff, 1987; Varchola & Dunn, 1999), field size (Wallin, 1985), intensity and timing of cultivation (Krooss & Schafer, 1998; Kromp, 1999), the proximity of source habitats for field colonisation (e.g. den Boer, 1977; Alvarez *et al.*, 2000), and weather such as patterns of spring rainfall (Alvarez *et al.*, 1999; Frampton *et al.*, 2000a; 2000b).

The spatial and temporal patterns of arthropod distribution as observed in the SCARAB Project must also be taken into consideration when comparing community-level effects of pesticides in different studies. For instance, *B. obtusum* was one of the ground beetles most seriously affected by pesticide use during the Boxworth Project (Vickerman, 1992) but was not always present during the SCARAB Project. In 'Field 5', the frequent usage of organophosphorus insecticides would be expected to have had a long-term impact on abundance of *B. obtusum*, but transient occurrence of the species precluded the possibility of detecting such effects.

Effects of the pesticide regimes on community composition

Similarity

The Sorenson quantitative index (Magurran, 1988) was used to investigate the similarity of RIA and CFP communities of springtails (**Fig. 3.2.1**) and ground beetles (**Fig. 3.2.2**), using data on species abundance. Low captures were excluded from the analysis, to reduce bias in the index. Applications of the broad-spectrum organophosphorus insecticide chlorpyrifos were consistently followed by a decrease in the similarity of RIA and CFP communities, both for springtails (**Fig. 3.2.1**) and for ground beetles (**Fig. 3.2.2**). Most other broad-spectrum insecticides (aldicarb, dimethoate, omethoate and triazophos) were also associated with declines in the similarity of RIA and CFP communities after application, but not following all applications. In contrast, applications of the synthetic pyrethroids cypermethrin and deltamethrin, and the selective aphicide pirimicarb, were not obviously associated with changes in the similarity of RIA and CFP communities (**Figs 3.2.1 & 3.2.2**). Some of the fluctuations in similarity that did not coincide with insecticide applications could reflect influences of other types of pesticide (see Discussion).

The longest periods of low similarity between RIA and CFP occurred after chlorpyrifos sprays (**Figs 3.2.1 & 3.2.2**), but only among springtails did very low similarity of RIA and CFP communities persist beyond one season (**Fig. 3.2.1**). In 'Field 5', following the use of chlorpyrifos in 1991, the similarity index for springtails remained below the pre-treatment (1990) values for most of the duration of the Project (**Fig. 3.2.1**).

Diversity

All measures of diversity have their limitations, so use of several complementary indices has been recommended (Magurran, 1988). The diversity of SCARAB springtail and ground beetle assemblages under the RIA and CFP pesticide regimes was, accordingly, investigated by calculating three widely accepted indices of diversity: species richness, the Shannon-Wiener index, and the Berger-Parker index. These indices give different views of arthropod diversity: species richness indicates the number of species (or other nominated taxonomic groups) present; Shannon-Wiener is a combined measure of species richness and abundance which is sensitive to species number (and most affected by rare species); Berger-Parker is a combined measure of species richness and abundance which is most sensitive to species dominance (and influenced most by the abundance of the commonest species). The latter two indices can condense information on the abundance of many taxa into a single value and are thus useful in summarising arthropod community data.

The average number of species of ground beetles and springtails trapped varied from year to year, and species richness of springtails was generally lowest on the sandy Gleadthorpe soil (in 'Balk', 'Near Kingston' and 'South' fields). Where a difference between the pesticide regimes persisted over several years, species richness was usually greater under the RIA regime than CFP, with the largest differences between the regimes being in 'Field 5' (**Fig. 3.2.3**). For springtails, differences between the regimes were most pronounced in years when there had been either winter or spring applications of chlorpyrifos ('Field 5' in 1991 and 1995, and 'Near Kingston' in 1991), omethoate ('South' in 1992) or aldicarb ('South' in 1994).

Over the SCARAB Project as a whole, the Shannon-Wiener and Berger-Parker indices gave similar results in 67% of RIA–CFP comparisons (135 of 201 sampling occasions examined). However, only after one insecticide application did a substantial RIA–CFP difference in ground beetle diversity persist for several months, following the 1991 use of chlorpyrifos in 'Field 5' (**Fig. 3.2.4**). On this occasion, only a small effect on springtail diversity could be discerned, even though chlorpyrifos has high toxicity both to ground beetles (Luff *et al.*, 1990; Asteraki *et al.*, 1992) and springtails (Van Straalen & Van Rijn, 1998; Frampton, 1999). These results are consistent with the idea that some measures of diversity (such as Shannon-Wiener) may be insensitive to the effects of pesticides (Siepel & Van de Bund, 1988), as other evidence (see below) indicated that springtails were in fact strongly affected by the use of chlorpyrifos in 'Field 5'. For ground beetles in 'Field 5', the lack of effects of other chlorpyrifos sprays (in 1994 and 1995) on diversity could reflect species turnover, as some vulnerable species (such as *Bembidion obtusum*) were present in the field in 1991 but rare or absent in subsequent years.

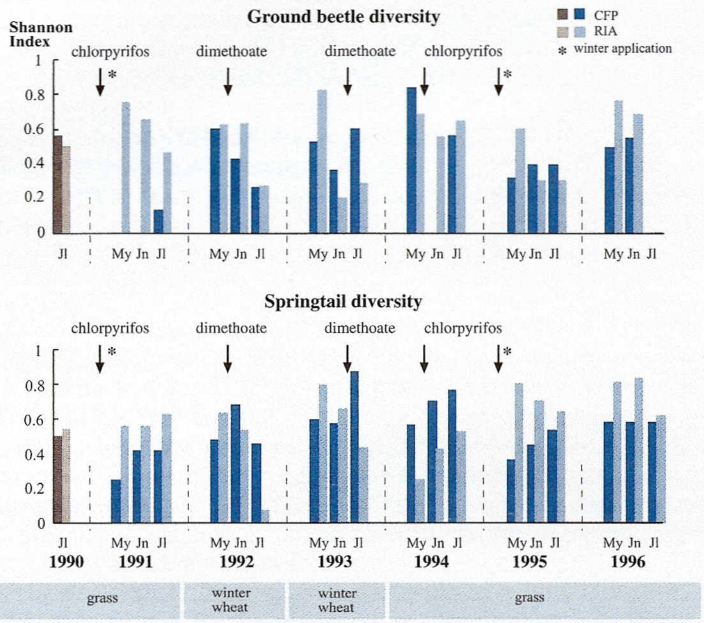

Figure 3.2.4. Shannon diversity index for 'Field 5' for ground beetles in pitfall traps and springtails in suction samples. Low captures (fewer than 10 springtails/sample or 5 beetles/trap/7-day trapping period) are excluded. Grey bars denote pre-treatment year (1990).

Distribution between the pesticide regimes

The average summer distribution between the two pesticide regimes (**Fig. 3.2.5**) was more even for ground beetles than for springtails. There were year-to-year fluctuations, which were particularly large for springtails in 'South' field where, in some years, numbers caught were considerably higher under the CFP regime. There were also differences in distribution between 'Old Type North' and 'Old Type South', two fields which had received identical pesticide inputs. However, with the exception of springtails in 'Field 5', no long-term trends in distribution were evident. In this field, catches of springtails declined under the CFP regime relative to catches under RIA when the treatment phase of the Project was initiated, and subsequently did not recover (**Fig. 3.2.5**).

Functional groups

Arthropods were assigned to functional groups (**Table 3.2.4**), to permit examination of effects of the pesticide regimes on trophic structure of the arthropod community. It is important to recognise that the functional groups used here relate to the surface-dwelling cohort of the fauna as sampled using pitfall trapping and D-vac sampling, hence omitting some important burrowing species. This limitation is not serious, because the aim was to make comparisons between the two pesticide regimes.

Allocation of some species to functional groups was not straightforward, because the degree of taxonomic resolution employed did not always discriminate between different feeding guilds. For instance, many rove beetles regarded as beneficial predators (e.g. Coombes & Sotherton, 1986) also eat fungi (Dennis *et al.*, 1991). Thus, for present purposes, all rove beetles, cecid midges (Diptera: Cecidomyiidae) and *Helophorus* spp. (mud beetles) (Coleoptera: Hydrophilidae) were classified as omnivores, because the carnivorous, fungus-feeding and herbivorous guilds among them could not be readily separated. Facultative insectivory occurs among the ground beetles *Amara* spp. (Jørgensen & Toft, 1997) and thrips (Milne & Walter, 1997), but these arthropods are mostly herbivores. Conversely, springtails include among them herbivorous and carnivorous species, but the majority are detritivorous.

Captures of total carnivores did not show any long-term declines under the CFP regime (**Fig. 3.2.6**). This is in contrast to the situation observed during the Boxworth Project, where the 'Full Insurance' regime had an overall negative impact on predators (Vickerman, 1992).

Total herbivore catches in SCARAB deviated strongly between the RIA and CFP regimes in some years, but only in 'Balk' field was a consistent decline in the CFP herbivore captures seen at the end of the treatment phase, both for suction samples and pitfall catches (**Fig. 3.2.7**). A possible explanation is that RIA herbicide use in 'Balk' failed to adequately control weeds, which increased in abundance in the RIA area of the field during the latter part of the treatment phase (Ogilvy *et al.*, 1996). Higher RIA densities of weeds would have favoured some groups of herbivores by providing food plants and refuges.

Detritivores (**Fig. 3.2.8**) generally did not exhibit any long-term patterns in distribution between the RIA and CFP pesticide regimes. This situation was true for all fields when springtails were not included in the detritivore class (**Fig. 3.2.8**). However, when springtails were included as detritivores, a long-term difference between the pesticide regimes emerged in 'Field 5' after the onset of the treatment phase, with lower CFP than RIA captures persisting over the remaining six years (**Fig. 3.2.8**). These results illustrate the importance of carefully assigning arthropods to functional groups. Vickerman (1992) omitted springtails from the detritivore class, which probably explains why he did not detect effects of the Boxworth pesticide regimes on detritivores.

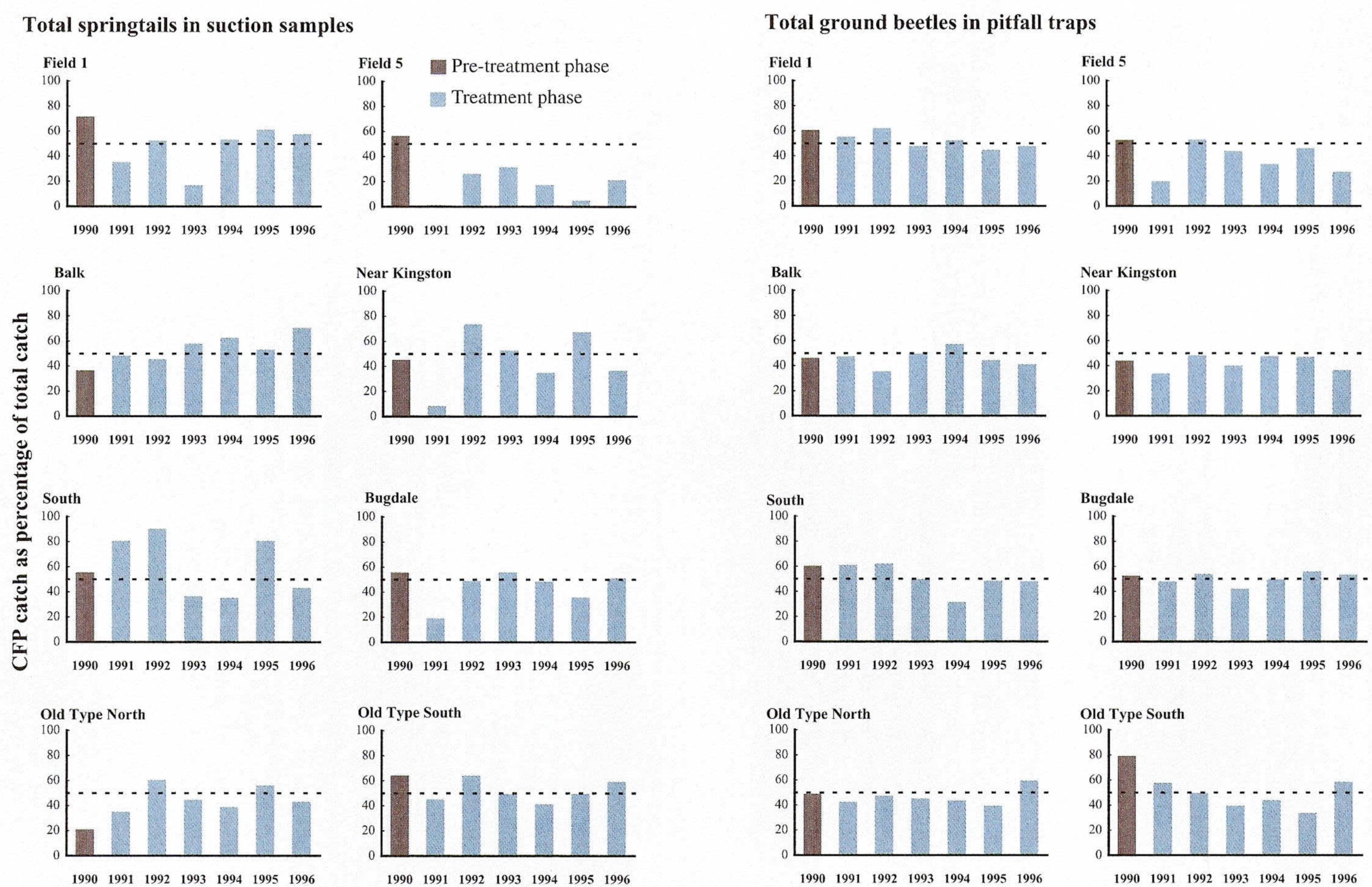

Figure 3.2.5. Distribution of springtails and ground beetles between RIA and CFP pesticide regimes. Based on total summer (May–July inclusive) catches (except 'Field 1' and ' Field 5' 1990 pitfall trap data, which are from September). Bars below 50% line indicate CFP catches lower than RIA catches. Grey bars denote pre-treatment year (1990).

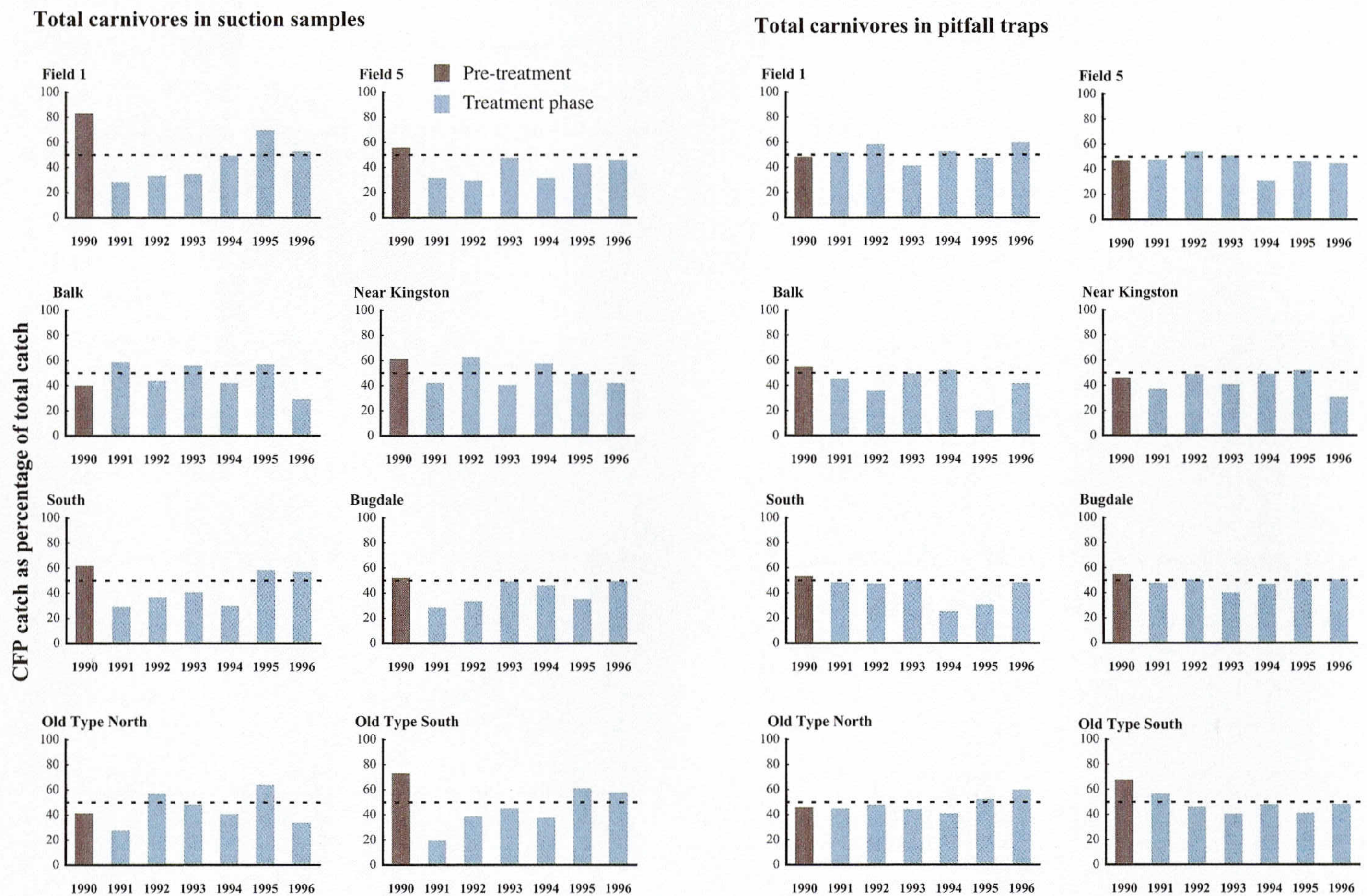

Figure 3.2.6. Distribution of total carnivores between RIA and CFP pesticide regimes. Based on total summer (May–July inclusive) catches (except 'Field 1' and ' Field 5' 1990 pitfall trap data, which are from September). Bars below 50% line show where CFP catches are lower than RIA catches. Grey bars denote pre-treatment year (1990).

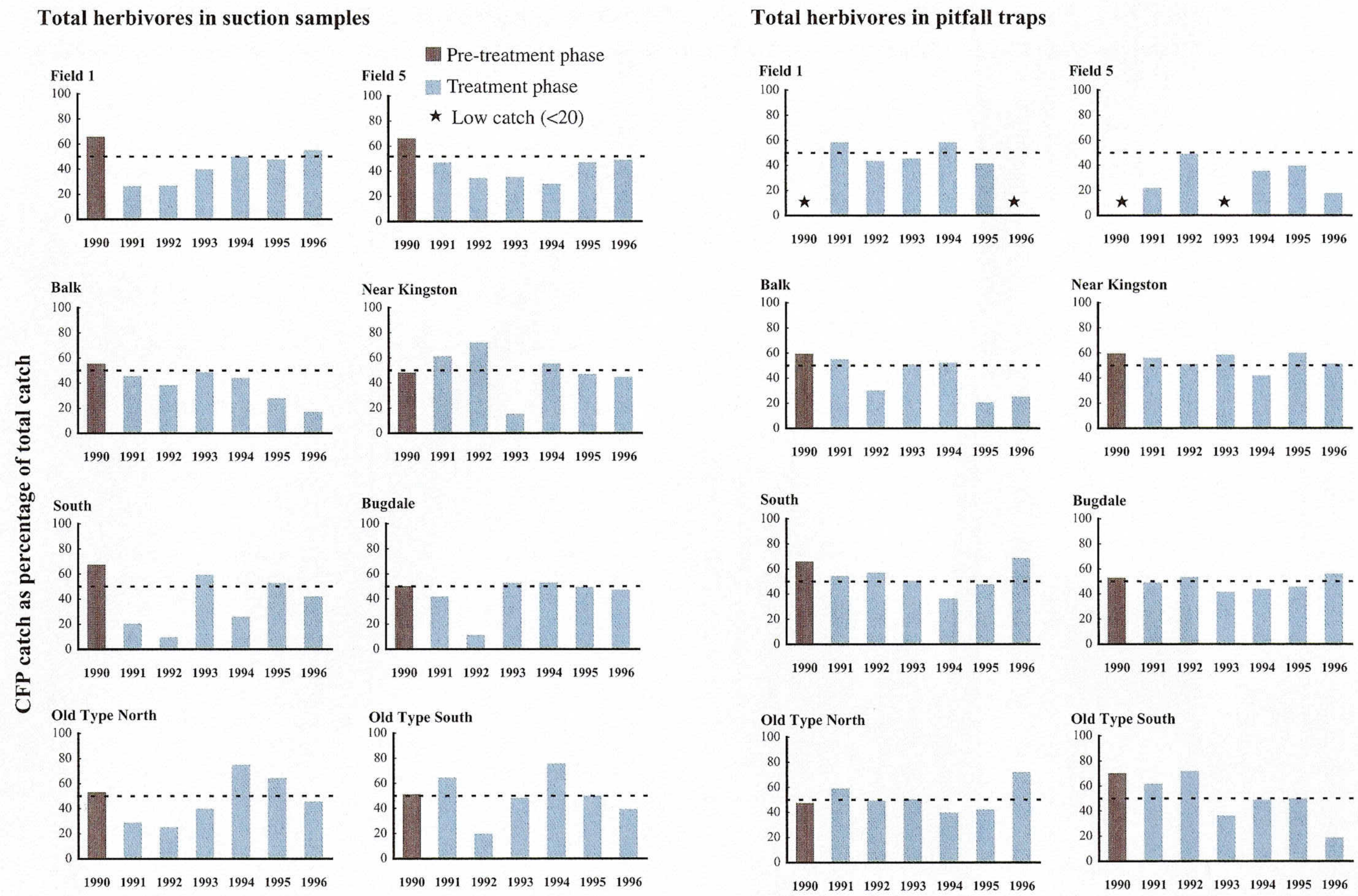

Figure 3.2.7. Distribution of total herbivores between RIA and CFP pesticide regimes. Based on total summer (May–July inclusive) catches (except 'Field 1' and ' Field 5' 1990 pitfall trap data, which are from September). Bars below 50% line show where CFP catches are lower than RIA catches. Grey bars denote pre-treatment year (1990).

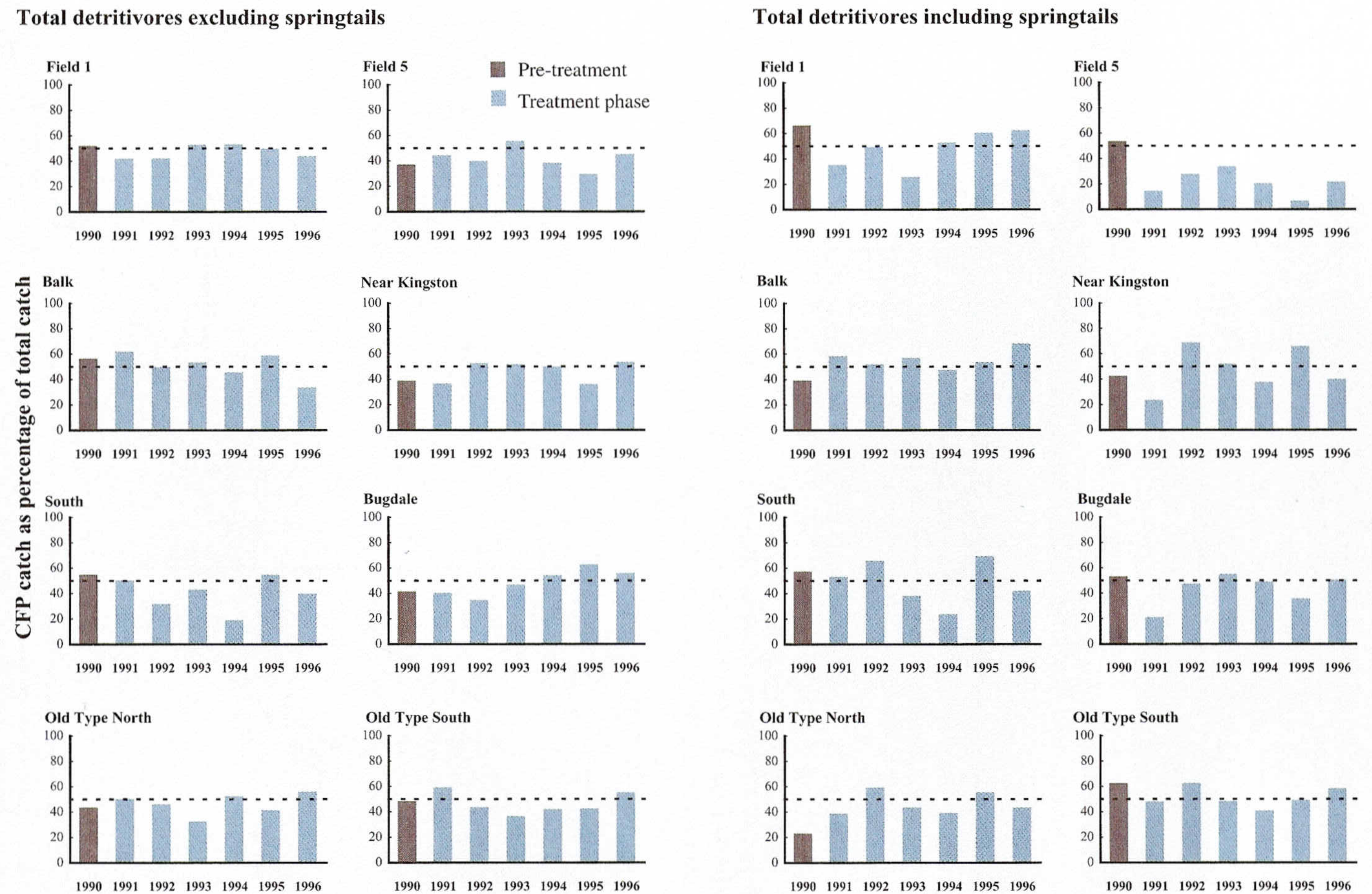

Figure 3.2.8. Distribution of total detritivores between RIA and CFP pesticide regimes. Based on total summer (May–July inclusive) suction trap catches. Bars below 50% line show where CFP catches are lower than RIA catches.

Redundancy analysis

Sample points and species points may be plotted together in a single ordination diagram but for clarity the samples and species data from 'Field 5' are plotted separately (**Figs 3.2.9 & 3.2.10**). Sample points (**Fig. 3.2.9**) represent the species composition in a given pesticide regime and year, based on the combined abundance of all species present. The closer points are together in the ordination diagram, the more similar their species composition. Species' points (**Fig. 3.2.10**) indicate the contribution of individual species or groups to the overall variation exhibited by the data, with points further from the origin of the ordination diagram indicating a greater contribution. The sample and species points are based on summer captures, with each point representing the pooled catch from three sampling dates (one each in May, June and July). An exception is the 1997 data, which are based on a single sampling date in January.

The separation of sample points in the ordination shows that the first (horizontal) axis mainly reflects the effect of time whilst the second axis reflects effects of treatment (**Fig. 3.2.9**). Of the total variance, 66% was accounted for by time and 17% by treatment regime. RIA and CFP treatments were initially similar in species composition (1990) but diverged over time (**Fig. 3.2.9**). The majority of species points were positive in value in relation to axis 2 (**Fig. 3.2.10**) which is also true of the distribution of sample points for the RIA regime, but not the CFP regime (**Fig. 3.2.9**). This indicates that overall abundance of many taxonomic groups was higher under RIA than CFP. Of all the arthropods included in the analysis (**Table 3.2.3**), springtails showed the strongest relationship with the second (treatment effect) axis, whilst species points for many other arthropods lie close to the origin (**Fig. 3.2.10**), indicating little contribution to the observed differences in species composition between the pesticide regimes.

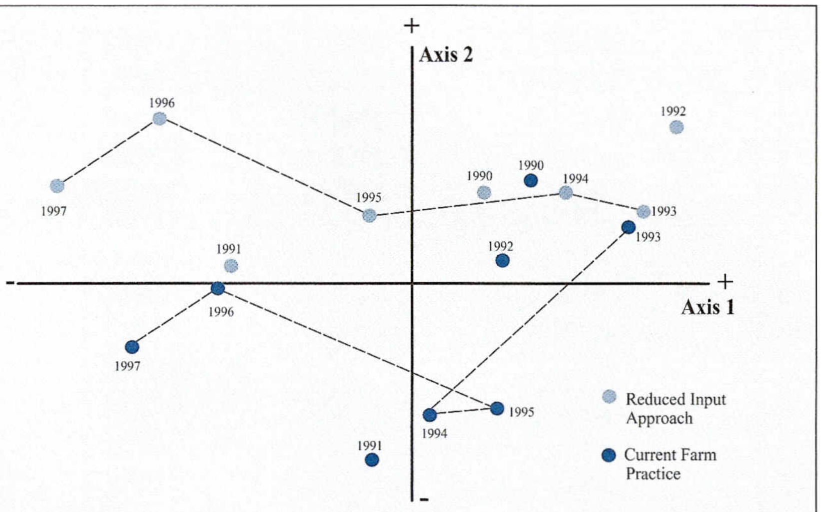

Figure 3.2.9. Arthropod suction captures in Field 5 displayed as sample points in an ordination diagram (redundancy analysis) to show relative differences in species composition between pesticide regimes and years. Distance from the origin indicates deviation (+ or -) in arthropod abundance from the overall mean abundance for the field. Sample points closer together in the diagram are more similar in species composition. Horizontal and vertical axes reflect effects of time (Axis 1) and pesticide regime (Axis 2). Dashed lines show separation of Current Farm Practice and Reduced Input Approach samples after 1993.

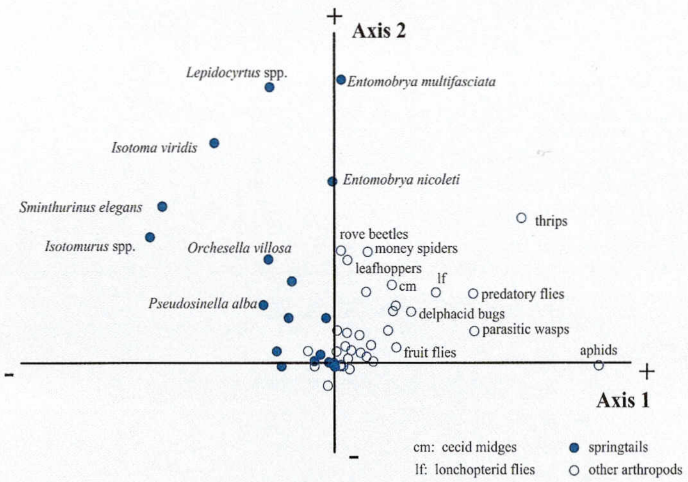

Figure 3.2.10. Arthropod suction captures in Field 5 displayed as species points in an ordination diagram (redundancy analysis), with the same axes as Figure 3.2.9. Points further from the origin indicate stronger species responses to effect of time (horizontal direction) or pesticide regime (vertical direction). Some species points close to the origin omitted for clarity.

The overall impact of Current Farm Practice

The foregoing results show that long-term effects of the CFP pesticide regime were mainly restricted to the wheat and grass rotation of 'Field 5'. Short-term effects of insecticide use did, however, occur more widely. One way of gauging the overall impact of the CFP regime is to compare the effects of the CFP regime in each treatment-phase year, relative to the corresponding pre-treatment data. For each field, the contribution that the CFP catch made to the total (CFP + RIA) catch in each of the six treatment-phase years (1991–1996) was compared with the CFP contribution in the pre-treatment year (1990). Over the Project as a whole, this gave up to 48 pre- to post-treatment contrasts (eight fields and six years). Overall, in the treatment phase of the Project, the CFP share of the catch decreased relative to the pre-treatment share on more occasions than it increased (**Table 3.2.5**). These results indicate that the overall impact of the CFP regime on arthropod abundance was a negative one.

Recovery responses: the follow-up study

Of all the arthropods monitored (**Tables 3.2.2 & 3.2.3**), only springtails exhibited long-term responses to the pesticide regimes. In 'Field 5', some species showed a clear response which coincided with the onset of the contrasting regimes, with *Entomobrya nicoleti* and *Lepidocyrtus* spp. (**Fig. 3.2.11**) being among the species which almost disappeared from CFP catches during the treatment phase of the Project (1991–1996). The only other field in which long-term patterns in springtail catches were seen was 'Bugdale'. Here, *Lepidocyrtus* spp. and *Pseudosinella octopunctata* (**Fig. 3.2.12**) occupied mutually exclusive distributions, the former being trapped only in the RIA half of the field and the latter only in the CFP half. Unlike the situation in 'Field 5', neither of these species in 'Bugdale' was trapped in the pre-treatment year (1990), so the possibility that factors other than the pesticide regimes were responsible for their patterns of distribution could not be ruled out. The species *P. octopunctata* recorded in the CFP regime of 'Bugdale' was not trapped anywhere else within the SCARAB Project, so opportunities for investigating its response to the pesticide regimes were limited.

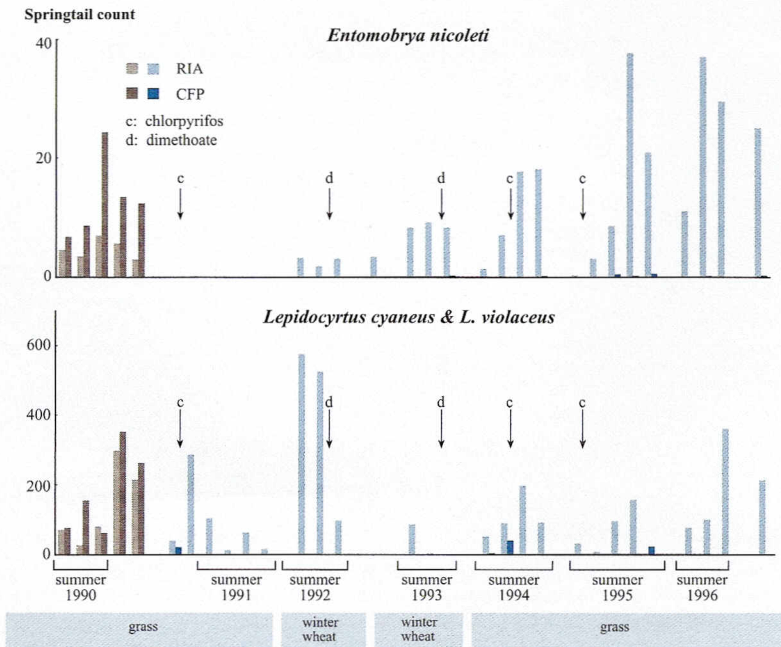

Figure 3.2.11. Mean catches per suction sample of the springtails *Entomobrya nicoleti*, *Lepidocyrtus cyaneus* and *L. violaceus* in 'Field 5', 1990–97. Grey bars denote numbers in pre-treatment year (1990).

Spatial reversal of the RIA and CFP pesticide regimes was the method used to investigate recovery in 'Field 5' and the spatial distributions of the species in 'Bugdale'. This follow-up study was conducted only in these two fields, and entailed changing the CFP regime to RIA and *vice versa*, in April 1997. Both regimes of pesticide use were administered in accordance with the protocol used for the SCARAB Project itself (Chapter 3.1). Although not part of the original SCARAB Project, some initial results from the follow-up study in 'Field 5' are presented here, to illustrate the value of the experimental approach. In 'Bugdale', the restricted spatial distributions of *Lepidocyrtus* spp. and *P. octopunctata* in the RIA and CFP halves of the field (**Fig. 3.2.12**) did not change when the pesticide regimes were reversed in 1997, and further monitoring provided no evidence that the manipulation of pesticide inputs had affected these species up to summer 1998 (Frampton, 2000b). The distribution patterns of Collembola in 'Bugdale' thus appear to be independent of the RIA and CFP pesticide regimes. In 'Field 5' however, reversal of the pesticide regimes had an immediate effect on the spatial distribution of Collembola and other arthropods.

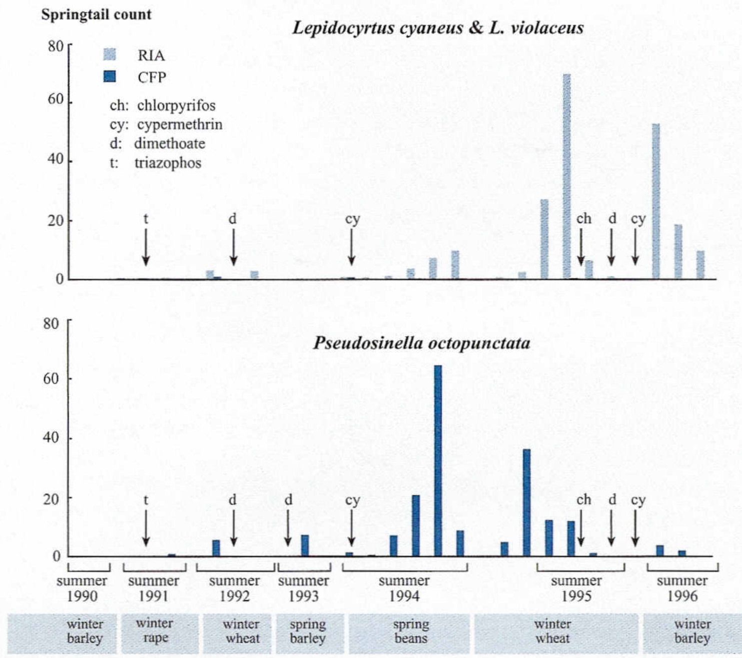

Figure 3.2.12. Mean catches per suction sample of the springtails *Lepidocyrtus cyaneus, L. violaceus* and *Pseudosinella octopunctata* in 'Bugdale' field, 1990–96.

Reversing the pesticide regimes in 'Field 5' provided unequivocal evidence that pesticides had long-term effects on springtails. For example, a reversal of the abundance patterns of *Isotoma viridis* and *Lepidocyrtus* spp. in the east and west areas of the field (**Fig. 3.2.13**) occurred when the RIA regime was switched to CFP and the CFP regime to RIA. There was an indication that springtails as a group and total arthropods (**Fig. 3.2.14**) may have been capable of rapid recovery once the CFP regime was removed (i.e. replaced by RIA inputs), but certain individual species of springtails exhibited little or no evidence for recovery at least within two years after removal of the CFP regime (Frampton, 2000; 2001).

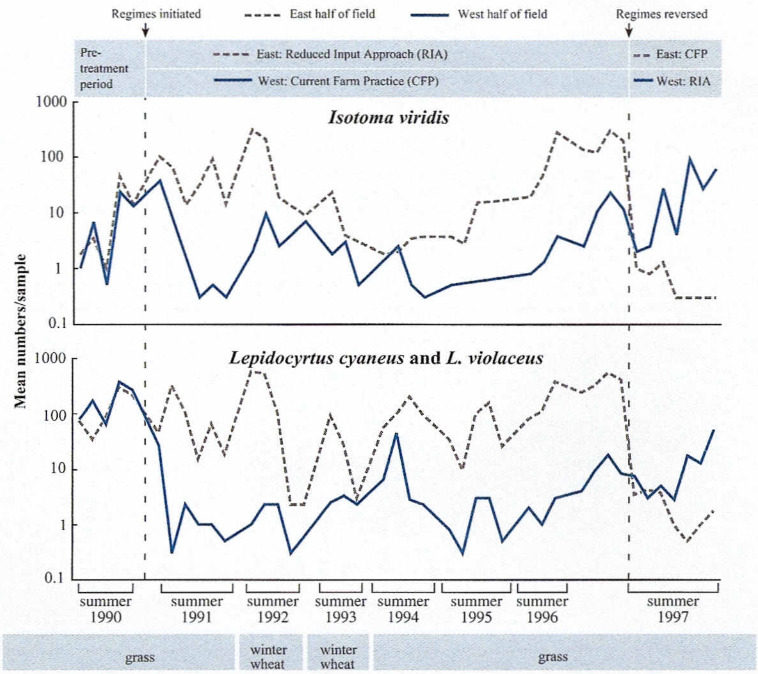

Figure 3.2.13. Mean catches per suction sample of the springtails *Isotoma viridis*, *Lepidocyrtus cyaneus* and *L. violaceus* under RIA and CFP pesticide regimes in 'Field 5', 1990–97.

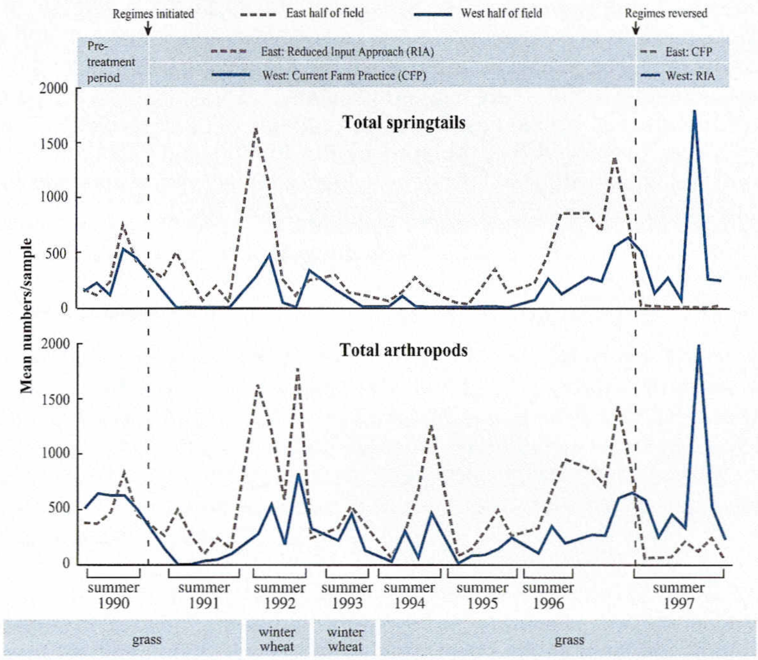

Figure 3.2.14. Mean catches per suction sample of total springtails and total arthropods under RIA and CFP pesticide regimes in 'Field 5', 1990–97.

Predictability of species in space and time

The large scale of the SCARAB Project provided a sizeable set of data that can be used to explore species' distributions in space and time. One of the findings of the Project was that relatively few species were common to all fields, or occurred in all years. This can be illustrated by ranking species according to the number of field-by-year occasions on which they were trapped. If rankings are based simply on the presence or absence of species in summer (May–July inclusive) in each year, a range of ranks from 1 (present in all fields in all summers) to 70 (present in only one field in only one summer) is obtained. On this scale, only the following captured by pitfall trapping were ubiquitous in summer distribution (rank 1): the ground beetle *Pterostichus melanarius*, rove beetles of the subfamily Aleocharinae, and the money spiders *Erigone atra* and *Lepthyphantes tenuis*. The ground beetle *Bembidion obtusum*, a species vulnerable to effects of broad-spectrum insecticides (Vickerman, 1992), was sporadic in occurrence (rank 39), whereas another ground beetle, *Pterostichus* (= *Poecilus*) *cupreus* (which is used as an indicator species in regulatory testing procedures with pesticides) (Barrett *et al.*, 1994) also had a limited distribution (rank 57). The beetle *Helophorus aequalis* was trapped only in 'Field 5' in 1991 (rank 70) but RIA catches were much larger than CFP, suggesting that the species may have been affected adversely by the use of chlorpyrifos. The 'low' occurrence ranking of this species shows that its presence in the field was actually a rare event and that, although effects of chlorpyrifos might have been severe, it would not usually be exposed to the chemical.

Discussion

Potential influence on arthropods of pre-SCARAB farm management

Crop rotations in the SCARAB Project fields prior to the Project (1987–1989) were similar to those employed during the Project itself (1990–1996, **Table 3.1.1**). However, pesticide inputs before the Project began were not the same for all fields, meaning that the impact of the CFP regime relative to previous farming practice differed between fields (**Appendix Tables 3.1.1 – 3.1.8**). At Drayton, no pesticides had been used in either 'Field 1' or 'Field 5' for at least five years prior to the SCARAB Project (Chapter 3.1), so the CFP pesticide regime represented a substantial increase in pesticide inputs. The RIA regime on the other hand represented no change in insecticide use but an increase in fungicide and herbicide use. In contrast, pesticide inputs in 'Bugdale' and 'Old Type' fields at High Mowthorpe, and 'Balk' and 'South' fields at Gleadthorpe were similar prior to the SCARAB Project (1987–1989) to the CFP inputs used during the Project itself (Chapter 3.1). In these fields, the CFP regime thus gave little change on previous pesticide inputs whereas RIA effectively represented a decrease in pesticide use from former conventional management; the change was most pronounced for insecticides (**Appendix Tables 3.1.3–3.1.8**), which were avoided altogether during the Project. In 'Near Kingston' field at Gleadthorpe, the CFP and RIA regimes both represented a general decrease in average annual inputs of fungicides, herbicides and insecticides relative to previous farming practice, with the decrease greater under RIA than CFP (**Appendix Table 3.1.5**). The type of insecticides used in 'Near Kingston' also changed, with a greater frequency of use of cypermethrin and pirimicarb under the SCARAB CFP regime (1990-1996) than previously (1987-1990); these insecticides are, respectively, less persistent and more selective than the organophosphates and aldicarb which dominated prior to the Project.

It is clear that only at Drayton ('Field 1' and 'Field 5') did the CFP pesticide regime result in an increase in pesticide inputs relative to previous practice. At Gleadthorpe and High Mowthorpe (i.e. in all other Project fields) the most obvious change from previous practice was a reduction in pesticide usage under the RIA regime. The situation at Drayton mirrors the increase in pesticide inputs which occurred at the start of the Boxworth Project (Greig-Smith *et al.*, 1992), except that overall intensity of CFP pesticide use in SCARAB was lower than in the Full Insurance regime at Boxworth (Chapter 3.1). As the fields at Gleadthorpe and High Mowthorpe received lower pesticide inputs under the RIA regime than those used prior to the Project, the RIA regime could be viewed as providing an opportunity for recovery of any arthropods whose populations had been adversely affected by previous conventional pesticide use. In fact, arthropod monitoring provided no indication of long-term increases in arthropod abundance under the RIA regime, with the exception of the springtails *Lepidocyrtus* spp. in 'Bugdale' (**Fig. 3.2.12**) and *Entomobrya multifasciata* in 'Near Kingston' (Frampton, 1997a), but it is not possible to say conclusively whether these changes were related directly to changes in pesticide use.

Comparisons with the Boxworth Project and other studies

The SCARAB Project was initiated to extend the information obtained from the Boxworth Project which focused on winter wheat (Cooper, 1990; Greig-Smith *et al.*, 1992). SCARAB set out specifically to investigate whether long-term effects of pesticides observed during the Boxworth Project (Burn, 1992; Frampton *et al.*, 1992; Vickerman, 1992) could occur in other cropping systems and at other geographical locations. One of the findings from SCARAB was that some of the species vulnerable to pesticide use at Boxworth, such as the ground beetle *Bembidion obtusum* or the springtail *Sminthurus viridis*, did not occur in all years or in all fields. The implication of these findings is that the same results might not have been obtained from the Boxworth Project had it been conducted in different years or at another site. However, a consistent result both from Boxworth and SCARAB is that a rotation which involves repeated use of organophosphorus insecticides in consecutive seasons is likely to be detrimental to arthropods, especially springtails, in the long term.

Short-term effects of synthetic pyrethroid insecticides such as cypermethrin and deltamethrin were also clearly evident but were generally short-lived. A possible explanation for the lack of long-term effects of pyrethroid insecticides is that the arthropods most sensitive to them (e.g. money spiders, aphids and flies) are capable of rapid recolonisation of fields. Conversely, arthropods which seem to have poorer recovery ability such as springtails (Frampton, 1997b) appear not to be sensitive to these insecticides (Frampton, 1999). The lack of long-term effects of pyrethroid use in SCARAB contrasts with recent findings from an analysis of the Game Conservancy Trust's long-term monitoring (1970–1995) of cereal fields in Sussex, which revealed that effects on arthropods of synthetic pyrethroid insecticides persisted over more than one season (Ewald & Aebischer, 1999). Effects of pyrethroid insecticides are spatially and temporally variable, as the persistence of residues is highly dependent upon the weather conditions after application. It is not surprising therefore that long-term effects of these insecticides were not readily detected within the relatively short duration of the SCARAB Project. The possibility that increases in the abundance of springtails could be a sensitive indicator of adverse effects of pyrethroid insecticides on their natural enemies (Frampton, 1999) warrants more detailed investigation, as springtail catches in one field ('Near Kingston') were considerably higher under the CFP regime than the RIA regime when cypermethrin had been used as a CFP treatment in the previous autumn.

Relevance of SCARAB data to risk assessments with pesticides

Knowledge of the spatial and temporal distribution of species is important for risk assessment. Species that occur rarely are less likely to be exposed to a pesticide than those that are widespread and abundant; however, if exposed, the former may have a poorer ability to recover. Pesticide applications in SCARAB often gave different effects in different fields and years, partly because vulnerable species such as *Bembidion obtusum* or *Pterostichus cupreus* were not present in all fields and in all years. Long-term data on species' distributions are therefore needed to put the results of single-field, single-season field trials into context (Eijsackers, 1997). The large data set obtained during the SCARAB Project includes information on spatial, temporal and taxonomic variability in arthropod occurrences between sites and years; this may be used in a probabilistic manner to improve estimates of exposure likelihood and persistence of effects in the field.

Prediction of recovery rates

Recovery among predatory arthropods has been investigated in a series of field experiments with broad-spectrum insecticides (Jepson & Thacker, 1990; Thomas *et al.*, 1990; Duffield & Aebischer, 1994; Duffield *et al.*, 1996), and factors affecting recovery at a landscape scale have been investigated using modelling approaches (e.g. Sherratt & Jepson, 1993; Halley *et al.*, 1996). The large empirical data set obtained from the SCARAB Project should be valuable for the refinement and validation of such models. Despite this work on predator recovery, most of the studies set up specifically to investigate pesticide side-effects on arthropods have focused on initial responses rather than on recovery (Van Straalen & Van Rijn, 1998), even though recovery is as critical to assess as is the initial response (Kelly & Harwell, 1990).

Using ecotoxicological data on pesticide toxicity and residue persistence, Van Straalen & Van Rijn (1998) predicted that arthropod recovery following the use of chlorpyrifos in 1991 in SCARAB 'Field 5' would take 0.82 years. In fact, the SCARAB data for springtails (Çilgi & Frampton, 1994) and also the Boxworth arthropod data (Çilgi *et al.*, 1993) 'provide evidence for ecological recovery lagging considerably behind expectation' (Van Straalen & Van Rijn, 1998). A plausible explanation for the discrepancy between the observed (ecological) recovery rates and predicted (ecotoxicological) rates is that arthropods in Boxworth and SCARAB were influenced by more than one pesticide, whereas Van Straalen & Van Rijn based their predictions upon single applications. Another possible explanation is that poor dispersal ability of springtails precluded the immediate recolonisation of the CFP regime after the chlorpyrifos residue had decayed. The importance of ecological processes such as dispersal has been underestimated in risk assessment (Jepson, 1997). Even among ground beetles, which have been studied extensively by ecologists, there is a need to acquire further information on biology and population dynamics (Luff, 1996). The ecology of springtails in temperate agriculture is less well known than that of beetles, despite springtails' vulnerability to pesticide use.

Side-effects of the different pesticide types

The pesticide effects observed in the SCARAB Project varied between chemical types, arthropod species, fields and years. Variation between chemical types was broadly as would be expected from previous work. A wide spectrum of non-target species is known to be affected by the organophosphates chlorpyrifos (e.g. Luff *et al.*, 1990; Asteraki *et al.*, 1992; Van Straalen & Van Rijn, 1998; Frampton, 1999) and dimethoate (Vickerman & Sunderland, 1977; Løkke, 1994); however, compared with those of dimethoate, residues of chlorpyrifos are up to 10 times more persistent, the half-life of chlorpyrifos being 16–210 days (Van Straalen & Van Rijn, 1998). Synthetic pyrethroids have broad-spectrum effects, but the range of affected species may be smaller than for dimethoate (Cole *et al.*, 1986), as residues have short persistence and are readily diluted by rainfall (e.g. Everts *et al.*, 1991). Results from the SCARAB Project agree with other recent studies which suggest that synthetic pyrethroid insecticides are not in general harmful to springtails (Wiles & Frampton, 1996; Frampton, 1999). Synthetic pyrethroids are, however, particularly toxic to spiders. For example, the non-target money spider *E. atra* is more susceptible to deltamethrin than the grain aphid (*Sitobion avenae*) target pest (Wiles & Jepson, 1992).

Previous field studies have yielded mixed effects of pirimicarb on non-target arthropods. In some studies in wheat, pirimicarb had no adverse effect on ground beetles and rove beetles (DeClercq & Pietraszko, 1984; Powell *et al.*, 1985) or on springtails (Wiles & Frampton, 1996; Frampton, 1999). In others, however (compared with controls), it reduced catches of rove beetles by 27% and catches of ground beetles by 26% (Vickerman *et al.*, 1987a) and, apparently, also caused slight reductions in the numbers of rove beetle and hoverfly larvae (Poehling, 1987). Declines in the numbers of parasitoid wasps and ladybird larvae after pirimicarb treatment were thought by Vickerman *et al.* (1987b) to be a result of starvation rather than of direct toxicity, whereas Powell *et al.* (1985) attributed effects of pirimicarb on parasitoid wasps to both direct toxicity and host removal.

In addition to the effects of insecticides, it is possible that fungicides could have influenced arthropod catches in SCARAB. Carbendazim, which was used on a number of occasions in the Project, is toxic to at least one springtail species (Frampton, 1988) and is highly persistent; indeed, effects of benomyl, which degrades immediately to carbendazim after application, may persist for 2–3 years (Krogh, 1991; Van Straalen & Van Rijn, 1998). Other fungicides used in the SCARAB Project, such as propiconazole and triadimenol have been found to be harmful to several springtail species (Frampton & Wratten, 2000). Fungicides may also indirectly affect carnivorous arthropod species, either by reducing the availability of fungi for facultative fungus-feeding predator species or by reducing the abundance of fungus-feeding prey (Sunderland, 1992).

It seems unlikely that direct side-effects of herbicides on arthropods would have occurred in SCARAB, as few (none of which was used during the Project) have exhibited direct effects in other studies (Edwards & Stafford, 1979). However, indirect effects of herbicide use could explain the higher RIA than CFP catches of herbivores in 'Balk' field during 1995 and 1996, where RIA weed densities tended to increase during the Project as a result of low herbicide inputs (Ogilvy *et al.*, 1996).

Aspects of the SCARAB Project design

The large scale of the SCARAB Project precluded the use of routine statistical tests for investigating effects of the pesticide regimes, because the experimental areas could not be properly replicated. Lack of replication in farming systems' studies is not uncommon, and the coincidence of changes in faunal abundance with pesticide applications is often used as a yardstick to judge whether pesticide side-effects have (e.g. Stinner *et al.*, 1986; Vreeken-Buijs *et al.*, 1994) or have not (e.g. House *et al.*, 1987) taken place.

The sporadic occurrence of many arthropod species poses problems for the assessment of pesticide effects. In SCARAB, several species were trapped during the phase of treatment contrasts, but were absent in the pre-treatment year. Some species were so restricted in their spatial distribution (e.g. *Pseudosinella octopunctata* – found only in part of 'Bugdale' field) that replication of the experimental areas, even if it had been feasible, would have made no improvement. Results from the original SCARAB Project and the follow-up study in which the spatial orientation of the pesticide regimes was reversed show that the SCARAB split-field design could be a valuable experimental approach where space is limited; the need for replication may be eliminated altogether if adequate pre-treatment monitoring and later spatial reversal of treatments are incorporated.

Wider relevance of the results

Of the arthropods monitored (which excluded mites), only springtails were adversely affected in the long term by Current Farm Practice pesticide use. The affected species constituted a small proportion of all species monitored (< 3%) so it could be argued that arthropods in general would be unlikely to be affected adversely in the long term by regimes of pesticide use similar to Current Farm Practice. In terms of abundance, however, vulnerable species of springtail were important components of the overall arthropod fauna. *Lepidocyrtus* spp., for instance (**Fig. 3.2.11**), made up on average 26% of the total suction-sampled arthropod catch under the reduced input regime of 'Field 5' (up to 83% of the total arthropod catch on some sampling occasions). Unfortunately, it is difficult to predict the wider ecological significance of these observations without knowing the ecological importance of the species concerned. As springtails are important in the arthropod food web, and not all their predators were monitored during the

SCARAB Project, a cautious interpretation would be to assume that effects of the Current Farm Practice regime in 'Field 5' could be potentially serious if allowed to occur more widely in farmland. It is important therefore to consider the realism of the pesticide regime which led to the long-term effects in 'Field 5'.

In the SCARAB Project, long-term adverse effects of Current Farm Practice occurred under a grass and wheat rotation but not under rotations of cereals and break crops. However, such effects of pesticide use were manifest only in one of two fields under the grass and wheat rotation, largely because insecticide inputs differed between fields; long-term adverse effects of the CFP regime in 'Field 5' resulted from the repeated use of organophosphorus insecticides in consecutive seasons, especially of chlorpyrifos in grass. The grass and wheat rotation of SCARAB roughly approximates the crop survey category 'grassland less than 5 years old' (e.g. Thomas & Garthwaite, 1994). In Great Britain, such short-term grassland occupies an area *c.* 28% of that sown to arable crops, but the figure varies regionally, from only *c.* 4% in eastern England to *c.* 57% in the south west (cf. Thomas & Garthwaite, 1994; Thomas *et al.*, 1997). Besides being less widespread than arable rotations, most short-term grassland is not treated with insecticides (Thomas & Garthwaite, 1994), so the Current Farm Practice use of insecticides in 'Field 5' would appear representative only of a minority of agricultural situations. A reasonable conclusion would be that although ecological consequences of Current Farm Practice in 'Field 5' are difficult to determine, such long-term effects would be unlikely to occur in UK arable agriculture except in a minority of cropping scenarios where pest outbreaks and usage of organophosphorus insecticides occur in consecutive seasons.

Conclusions

Results from SCARAB confirm one of the findings at Boxworth, that repeated use of organophosphorus insecticides in successive seasons can lead to long-term declines in abundance of certain arthropods. However, geographic variation in the occurrence of vulnerable species suggests that some effects of pesticides seen in the Boxworth Project might not have occurred had the experiment been conducted at other sites or in different years.

Springtails were the only group of arthropods to exhibit long-term adverse responses to the SCARAB pesticide regimes, though many other arthropod groups were temporarily affected by insecticide applications and subsequently recovered. Detection of long-term effects at functional group or community level depended wholly upon the inclusion of springtail data. The information currently available shows that, among springtails, long-term effects persisted at least two years after the conventional pesticide inputs ended.

Long-term effects of Current Farm Practice pesticide use on springtails in the SCARAB Project were confined to a grass and wheat rotation which employed frequent use of organophosphorus insecticides. Such a pest management situation, though legally permissible, is relatively uncommon in UK agriculture.

Restricted spatial and temporal distributions of some arthropods means that pre-treatment monitoring in one year may not be sufficient to provide a baseline against which to contrast post-treatment data. Monitoring arthropods before and after spatial reversal of experimental regimes is an alternative approach that may be substituted for orthodox replication where site availability is limited.

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Table 3.2.1. SCARAB Project fields and cropping.

Farm:	Drayton		Gleadthorpe			High Mowthorpe	
Location:	52.2°N 1.8°W		53.2°N 1.1°W			54.1°N 0.6°W	
Soil:	Heavy clay		Loamy sand/sandy loam			Silty clay loam	
Field name:	Field 1	Field 5	Balk	Near Kingston	South	Bugdale	Old Type
Area (ha):	11	8	12	8	12	15	30
Cropping:							
1989–90	Grass	Grass	W. barley	Sugar beet	W. barley	W. barley	W. barley
1990–91	W. wheat	Grass	Sugar beet	S. barley	Potatoes	W. rape	S. beans
1991–92	W. wheat	W. wheat	S. wheat	W. barley	S. wheat	W. wheat	W. wheat
1992–93	Grass	W. wheat	W. barley	S. beans	W. barley	S. barley	W. barley
1993–94	Grass	Grass	Potatoes	W. wheat	Sugar beet	S. beans	W. rape
1994–95	Grass	Grass	S. wheat	W. barley	S. wheat	W. wheat	W. wheat
1995–96	Grass	Grass	W. barley	Sugar beet	W. barley	W. barley	S. barley

W = Winter; S = Spring.

Table 3.2.2. Rounded mean catch of arthropods per pitfall trap per 7-day trapping period in samples taken from the RIA area of SCARAB fields during summer (May to July). Within each site, data are averaged across all fields and years (1990–1996).

Arthropod group	Life stage	No. taxa monitored	Mean catch per trap per 7 days (% of total catch per trap) Drayton		Gleadthorpe		High Mowthorpe	
Carabidae (ground beetles)	adults	33	21	(27.2)	19	(23.7)	12	(36.4)
Staphylinidae (rove beetles)	adults	24	13	(16.9)	13	(16.2)	4	(12.1)
	larvae	3	2	(2.6)	6	(7.5)	1	(3.0)
Lathridiidae (fungus beetles)	adults	4	1	(1.3)	3	(3.8)	1	(3.0)
Leiodidae (scavenger beetles)	adults	1	4	(5.2)	1	(1.3)	1	(3.0)
Cryptophagidae (fungus beetles)	adults	1	1	(1.3)	2	(2.5)	1	(3.0)
Other beetles	adults	16	3	(3.9)	2	(2.5)	1	(3.0)
	larvae	9	1	(1.3)	7	(8.7)	1	(3.0)
Total beetles		**91**	**46**	**(59.7)**	**53**	**(66.2)**	**22**	**(66.5)**
Linyphiidae (money spiders)	all*	12	18	(23.4)	26	(32.5)	11	(33.3)
Lycosidae (wolf spiders)	all*	1	12	(15.6)	1	(1.3)	<1	(0.1)
Other spiders	all*	1	1	(1.3)	0	(0)	<1	(0.1)
Total spiders		**14**	**31**	**(40.3)**	**27**	**(33.8)**	**11**	**(33.5)**
Total monitored arthropods		**105**	**77**	**(100)**	**80**	**(100)**	**33**	**(100)**

*Excluding eggs.

Table 3.2.3. Rounded mean catch of arthropods per square metre in suction samples taken from the RIA area of SCARAB fields during summer (May to July). Within each site, data are averaged across all fields and years (1990–1996).

Arthropod group	Life stage	No. taxa monitored	Mean catch per square metre (% of total catch per square metre)					
			Drayton		Gleadthorpe		High Mowthorpe	
Carabidae (ground beetles)	adults	16	1	(0.1)	<1	(<0.1)	1	(0.1)
Staphylinidae (rove beetles)	adults	14	8	(0.6)	6	(0.9)	7	(0.4)
	larvae	1	8	(0.6)	6	(0.9)	11	(0.7)
Lathridiidae (fungus beetles)	adults	4	5	(0.3)	15	(2.2)	13	(0.8)
	larvae	1	5	(0.3)	4	(0.6)	15	(0.9)
Curculionidae (weevils)	adults	3	<1	(<0.1)	<1	(<0.1)	9	(0.5)
Cryptophagidae (fungus beetles)	adults	2	1	(0.1)	2	(0.3)	6	(0.4)
Nitidulidae (pollen beetles)	adults	1	2	(0.2)	<1	(<0.1)	2	(0.1)
Other beetles	adults	14	1	(0.1)	1	(0.1)	1	(0.1)
	larvae	3	2	(0.2)	1	(0.1)	1	(0.1)
Total beetles		**59**	**33**	**(2.5)**	**35**	**(5.1)**	**66**	**(4.1)**
Hemiptera (bugs, inc.aphids)	all*	11	199	(15.3)	241	(34.8)	213	(13.1)
Diptera (flies)	adults	22	147	(11.3)	53	(7.7)	106	(6.5)
Thysanoptera (thrips)	all*	1	93	(7.1)	197	(28.5)	113	(6.9)
Hymenoptera (parasitic wasps)	adults	5	36	(2.8)	16	(2.3)	43	(2.6)
Araneae (spiders)	all*	3	20	(1.5)	7	(1.0)	18	(1.1)
Collembola (springtails)	all*	33	774	(59.5)	143	(20.6)	1069	(65.7)
Total monitored arthropods		**134**	**1302**	**(100)**	**692**	**(100)**	**1628**	**(100)**

*Excluding eggs.

Table 3.2.4. Functional grouping of arthropods captured by (a) D-vac suction sampling and (b) pitfall trapping.

(a)	Coleoptera (beetles)	Diptera (flies)	Other arthropods
Predators	Carabidae (excl. *Amara* spp.) Cantharidae some Coccinellidae	Dolichopodidae Empididae	Nabidae Araneae
Herbivores	*Amara* spp. (Carabidae) Chrysomelidae some Cryptophagidae Curculionidae Elateridae Nitidulidae	Agromyzidae some Chloropidae Opomyzidae Tipulidae	Aphididae Cicadellidae Delphacidae Miridae Thysanoptera
Detritivores	some Cryptophagidae Lathridiidae Phalacridae	Bibionidae Chironomidae Drosophilidae Lonchopteridae Mycetophilidae Phoridae Sciaridae Sepsidae Sphaeroceridae	Collembola
Omnivores	Staphylinidae	Cecidomyiidae	

(b)	Coleoptera (beetles)	Other arthropods
Predators	Carabidae (excluding *Amara* spp.), Cantharidae, some Coccinellidae	Araneae, Opiliones Syrphidae (larvae)
Herbivores	*Amara* spp. (Carabidae), Chrysomelidae, some Cryptophagidae, Curculionidae, Nitidulidae, Elateridae	Tipulidae (larvae)
Detritivores	some Cryptophagidae Lathridiidae Leiodidae Silphidae	
Omnivores	*Helophorus* spp. (Hydrophilidae) Staphylinidae	