11

Changes in the soil fauna at Boxworth

Geoffrey K Frampton, Stephen D Langton, Peter W Greig-Smith and **Anthony R Hardy**
(MAFF Central Science Laboratory)

Introduction

Many of the invertebrates inhabiting cereal fields live in the soil, at least for part of their life cycle. The soil fauna includes earthworms (Lumbricidae), proturans (Protura), symphylids (Symphyla), and many species of mites (Acari) and springtails (Collembola), which are well-adapted to a subterranean lifestyle. Some beetles and flies spend their larval life in the soil.

Springtails are among the most abundant of the soil fauna, and they formed the focus of this study. They are prey for a variety of predatory arthropods including ants, bugs, earwigs, flies, mites, centipedes, beetles and spiders, many of which occur in the diet of farmland birds (Chapter 15). Some ground beetles, rove beetles and money spiders are natural enemies of cereal aphids and other crop pests, and springtails may be an important alternative prey for these predators when numbers of cereal aphids are low (Chapter 10).

The aim of this study was to determine whether the soil fauna at Boxworth was affected by the pesticide regimes used in the Project. Springtails are known to be influenced by a variety of insecticides (eg Edwards & Thompson, 1973) and fungicides (Frampton, 1988). However, there have been no long-term studies of the effects on these insects of repeated applications of different pesticides. If pesticides cause perturbations of populations of springtails or other invertebrates, there could be knock-on effects on beneficial invertebrates, through changes in their food supply.

Other groups of invertebrates found in soil samples (such as mites) were also examined in case they were affected by pesticides. In addition, sampling for soil nematodes was carried out in June 1988 to assess the numbers of pest species (Hancock, 1989).

Sampling was carried out both on a field-scale and in the replicated plots. Field-scale comparisons between treatments are realistic in scale because pesticides are usually applied to whole fields, but they lack the replication necessary for orthodox statistical analysis. For soil animals with very limited powers of dispersal, the replicated plots should provide a good indication of effects likely to occur at a field-scale. Accordingly, statistical analysis of any treatment differences observed in the replicated plots may help to indicate whether differences between the field-scale treatments were real rather than due to chance variation.

Methods

The soil fauna was sampled by taking soil cores from fields and plots using an auger. The cores were 5 cm in diameter and were taken to a depth of 10 cm. Each core was transferred to the laboratory in a 6 cm-diameter sealed aluminium canister, groups of which were kept in chilled storage boxes.

Extraction of the fauna from cores commenced within 48 hours of sampling, using a modified version of the high gradient extractor described by Macfadyen (1961). An extractor at Brooms Barn Experimental Station was used initially but identical extractors were constructed at the Central Science Laboratory, Tolworth, and became available for use in August 1984. An assessment of the relative efficiencies of the two sets of apparatus was made in August and September 1984. Thereafter the soil fauna was extracted from cores using only the extractors at Tolworth.

The extraction apparatus

Each extractor consisted of an array of Tullgren funnels set in a vertical temperature gradient, created by 15-watt light bulbs above the funnels and cold water piped around their bases. This arrangement relies on avoidance of unfavourable stimuli by soil animals to expel them from soil cores. The cores were located in sieves above the funnels, and dried slowly in the temperature gradient, causing many animals to move downwards to more favourable conditions (of lower temperature and higher humidity). If the drying period is sufficiently long (seven days in this study), some of the soil animals eventually fall out of the cores and can be collected in vials below the funnels. Although this method does not extract all the animals in a soil core, it provides a consistent method whereby differences between soil cores may be identified, if the cores are subjected to the same drying conditions.

Invertebrates were preserved in 99% ethanol, then identified and counted under a binocular microscope. Most were identified to order or family, but where possible springtails were identified to species. Table 11.1 lists the invertebrate taxa extracted from soil cores using this method.

Table 11.1 The variety of invertebrates in soil cores taken from Boxworth Project fields from 1983 to 1988. The 14 species or groups of springtails are indicated by asterisks. Their classification follows Kloet & Hincks (1964).

Species or group	*Average number extracted from each soil core (based on c. 2000 cores)*
Mites (order Acari)	42.57
**Isotoma* spp. (family Isotomidae)	7.12
*White blind springtails (family Onychiuridae)	6.19
**Folsomia quadrioculata* (family Isotomidae)	6.15
**Isotomiella minor* (family Isotomidae)	2.67
*Hypogastruridae (springtail family)	2.20
Symphylids (order Symphyla)	0.95
Pot worms (family Enchytraeidae)	0.79
*Neelidae (springtail family)	0.69
Fly larvae (order Diptera)	0.61
**Lepidocyrtus* spp. (family Entomobryidae)	0.54
**Pseudosinella alba* (family Entomobryidae)	0.52
Beetle larvae (order Coleoptera)	0.45
*Sminthuridae (springtail family)	0.37
Booklice or psocids (order Psocoptera)	0.33
Thrips (order Thysanoptera)	0.29
Pauropods (order Pauropoda)	0.29
Millipedes (class Diplopoda)	0.28
Bugs (order Hemiptera)	0.25
Spiders (order Araneae)	0.22
Bristletails (order Diplura)	0.18
Adult flies (order Diptera)	0.16
**Isotomodes productus* (family Isotomidae)	0.14
Adult beetles (order Coleoptera)	0.14
Woodlice (order Isopoda)	0.12
Centipedes (class Chilopoda)	0.12
**Pseudosinella decipiens* (family Entomobryidae)	0.10
Proturans (order Protura)	0.08
Earthworms (family Lumbricidae)	0.07
**Entomobrya* spp. (family Entomobryidae)	0.03
**Isotomurus palustris* (family Isotomidae)	0.02
*Moss springtails, *Heteromurus nitidus* (Entomobryidae)	0.01

Relative efficiency of extracting the soil fauna

There were changes in the efficiency of extracting springtails and mites from soil cores on two occasions: with the change from the use of the extractor at Brooms Barn to those at Tolworth, between September 1984 and March 1985; and with the installation of a 'flow cooler' to increase the temperature gradient of the Tolworth extractors, between August 1986 and March 1987. The efficiency of the extractors at Tolworth relative to the one at Brooms Barn was assessed in August and September 1984 by extracting springtails and mites from duplicate pairs of soil cores. For springtails this was initially c. 70%, and increased to 117% after the flow cooler was installed; for mites it varied considerably between dates (48%–68% in August and September 1984) and was not increased by the installation of the flow cooler (45% in March 1987). Analysis of the results takes account of these changes by comparing the proportions rather than the numbers of each species or group extracted from soil cores from each of the treatment areas.

Field-scale sampling

Sampling commenced in the spring of 1983, the second of the 'baseline' years. Soil cores were taken on three occasions in each year, in March or April, May or June and July or August. On each occasion, soil cores were taken from three fields in the same 'triplet group' (see Chapter 2).

In each of these fields two transects were marked out parallel to a hedgerow; one at 75 m from the hedgerow, the other at 150 m. The location of the transects was the same on each sampling occasion. In 1983 five soil cores, and in subsequent years ten, were taken along each transect at 10-m intervals.

Sampling in the replicated plots

The 24 rectangular plots comprising this experiment were located in Shackles Aden (a field in the Full Insurance area), and are described in Chapter 2. The layout, which was randomized, gave eight plots each of the Full Insurance, Supervised and a 'Minimum Input' treatment, which consisted only of the minimum number of herbicide applications deemed necessary to keep the plots weed-free; this replaced the field-scale Integrated treatment, which could not be recreated in the plots.

Sampling commenced in March 1984, the first of the treatment years. Except in June 1984, when only one soil core per plot was taken (because the soil was very sticky), two cores, 2 m apart in the centre of each plot, were taken on each sampling occasion. In most years, soil cores were taken on three occasions in the spring and summer, between March and September.

Although soil cores contain mostly subterranean fauna, some surface-dwelling species may also be trapped. Conversely, suction samples contain mostly surface-dwelling invertebrates but some species in the uppermost layers of the soil may be collected with a powerful suction sampler, especially if the soil is very dry. These two methods, which can provide an insight into invertebrates' vertical distribution, were compared by taking matched soil cores and suction samples from the same plots on 3 September 1987. The suction samples were taken using a Dietrick vacuum insect sampler (D-vac) (see Chapter 9).

Two suction samples, each comprising five randomly-placed 10-second sub-samples, were taken from each of the plots in two of the four blocks (ie from 12 of the 24 plots). Each sample was sealed in a polythene bag then transferred in a chilled storage box to the laboratory at Tolworth where it was frozen for storage. Inorganic material was removed from thawed samples by mixing them with a saturated salt solution; floating organic material was separated by sieving and then was preserved in 99% ethanol. Invertebrates were sorted from the organic material under a binocular microscope and were identified and counted in the manner described for those extracted from soil cores.

Results

Of 32 species or groups of fauna examined (Table 11.1) only the springtails and mites were sufficiently numerous to show clear differences in their populations between the field-scale or replicated plot treatments.

Trends in the proportions of springtails or mites in the fauna of each treatment area might indicate long-term effects of pesticides. These were examined at a field-scale by plotting, for each of 40 sampling occasions, the number in Full Insurance soil cores relative to the Supervised and Integrated samples, and the number of Supervised relative to Integrated soil cores (Figure 11.1). Trends in the replicated plots over 13 sampling occasions were also examined for comparison with the field-scale results. For each of the 13 sampling occasions, statistically significant differences between the plot treatments were identified using Analysis of Variance with a square root transformation (Figure 11.2). For the field-scale, trends were identified using regression analysis, while in the replicated plots a more rigorous test involving analysis of contrasts over time was used.

Figure 11.1 Trends in the relative proportion of springtails and mites in different field-scale treatments. (a)–(e) show the numbers in Full Insurance soil cores as a percentage of the numbers in all soil cores; (f) shows the numbers in Supervised soil cores as a percentage of the combined numbers in Supervised and Integrated soil cores. Lines indicate statistically significant regression equations. The total springtails and mites showed no statistically significant trends.

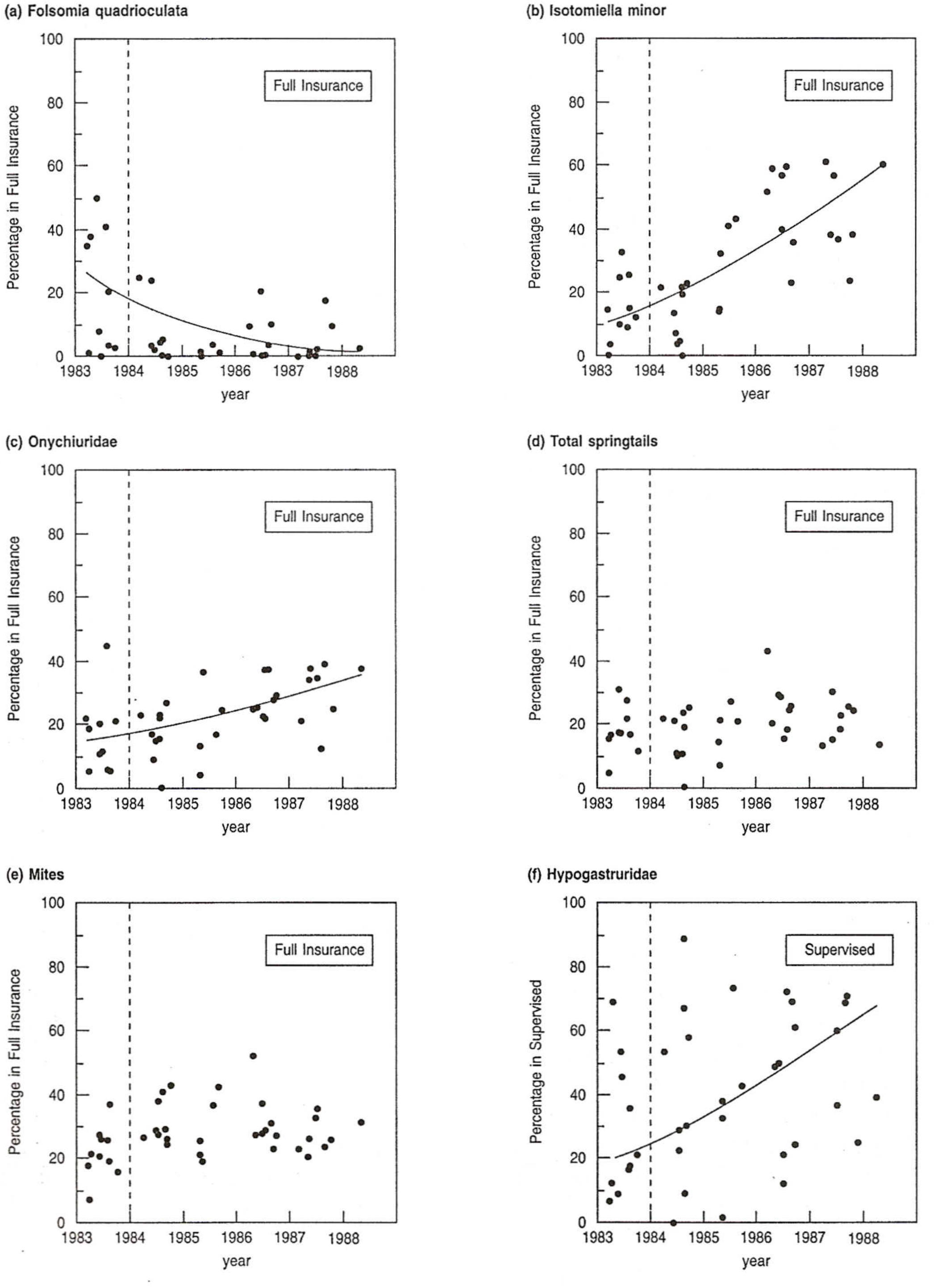


Figure 11.2 Relative proportions of springtails and mites extracted from the three replicated plot treatments on each of 13 sampling occasions. Asterisks indicate dates on which differences between the Full Insurance and the other regimes were statistically significant (*P<0.05, **P<0.01, ***P<0.001). Comparisons are omitted when there were too few insects for analysis.

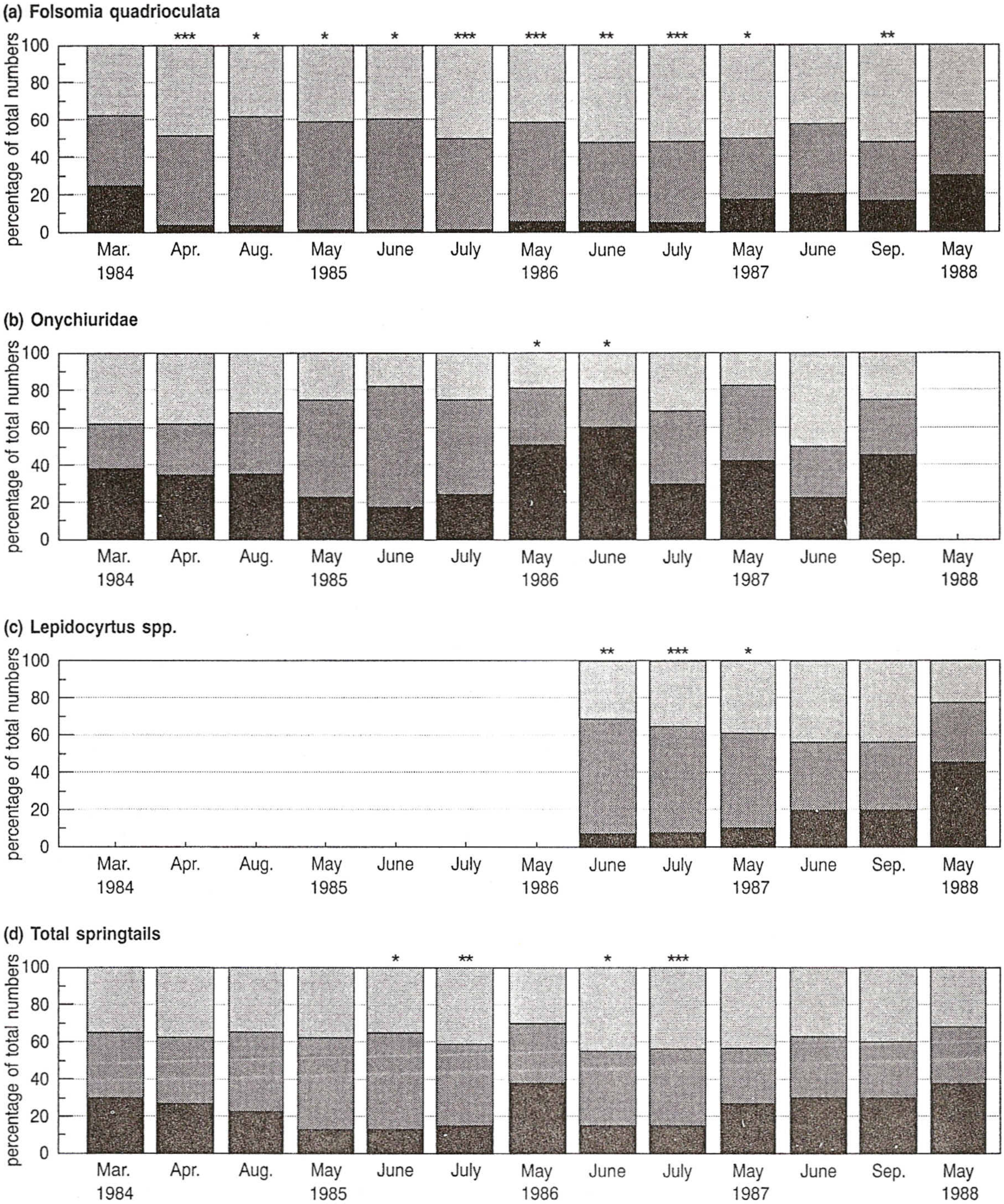
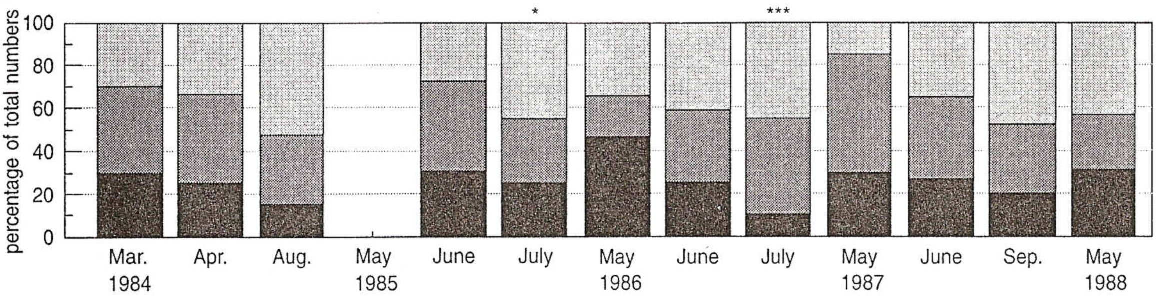
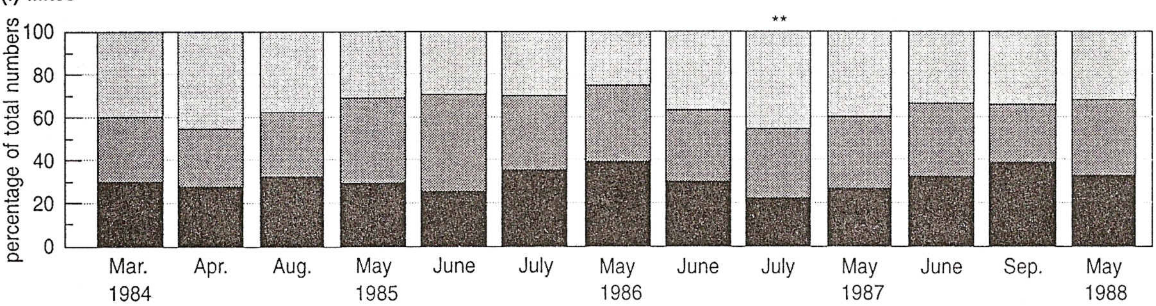


Figure 11.2–*continued*

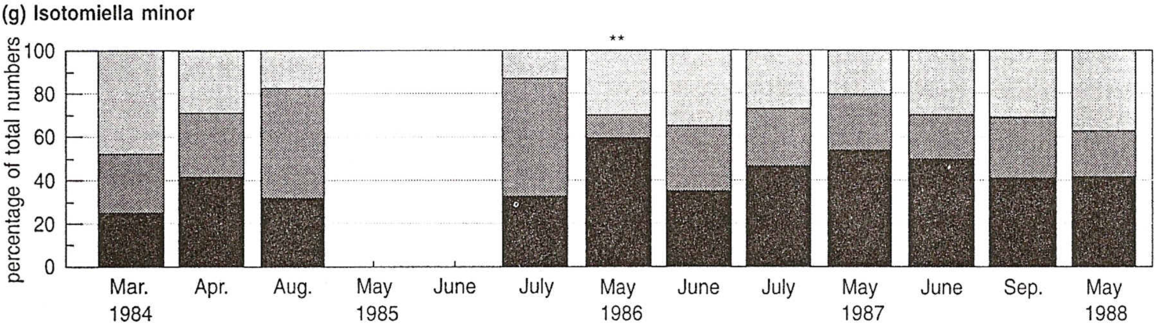
(e) Hypogastruridae



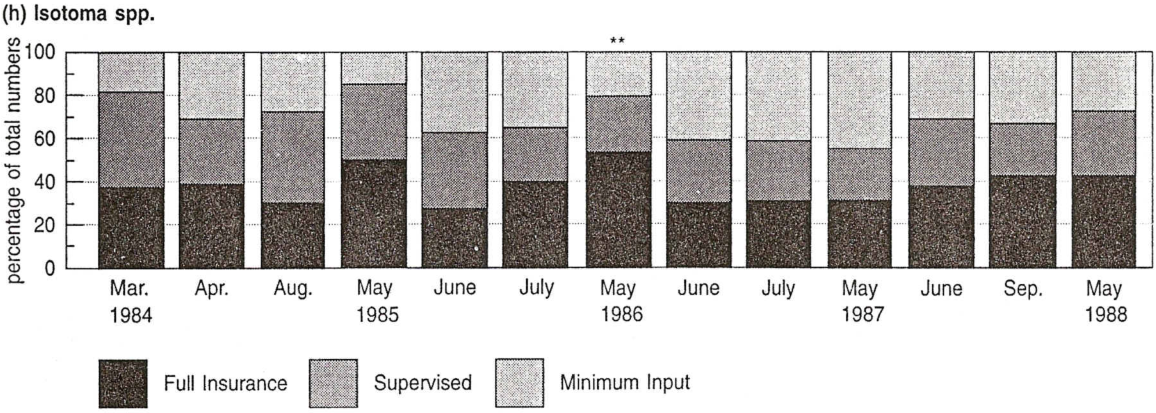
(f) Mites



(g) Isotomiella minor



(h) Isotoma spp.



Field-scale trends

On the field-scale, *Folsomia quadrioculata, Isotomiella minor* and the springtail family Onychiuridae showed changes during the course of the Project (Figure 11.1). The proportion of *F. quadrioculata* from the Full Insurance area decreased from 1983 onwards and remained low throughout the remainder of the Project, with no evidence of a recovery, although it is not possible to identify precisely when the decline started (Figure 11.1a). In contrast, *I. minor* and the Onychiuridae (Figure 11.1b and 11.1c) showed an increase from 1983 onwards, this being particularly pronounced for *I. minor*. There was evidence for a significant, though less pronounced, decline in the Sminthuridae in Full Insurance fields. This might reflect adverse effects of the Full Insurance regime on the lucerne-flea *Sminthurus viridis* (Chapter 9), although this is primarily a surface-dwelling species and relatively few occurred in soil cores (Table 11.1). None of the other species or groups examined showed any clear trends in the Full Insurance fields and this was also true for the total springtails (which comprised the 14 species or groups listed in Table 11.1) and mites (Figure 11.1d and 11.1e). Only for the springtail family Hypogastruridae was there evidence of a statistically significant trend indicating a difference between the Supervised and Integrated areas, with a relative increase in the proportion of individuals from the Supervised area during the treatment phase of the Project (Figure 11.1f). However, as the figure shows, there was great variation between samples.

Springtails and mites in the replicated plots

In the replicated plots nine species or groups of springtails and mites showed statistically significant differences between treatment regimes. Most of these were between the Full Insurance area and the other treatments (Figure 11.2). Excluded from Figure 11.2 are the Sminthuridae, whose numbers were sufficient for analysis only on one of the 13 sampling occasions (June 1986), when significantly fewer of these springtails were extracted from Full Insurance soil cores than from Supervised or Minimum Input cores.

Numbers of *F. quadrioculata* were lower in soil cores from Full Insurance plots on all 13 sampling occasions, the difference being statistically significant for 10 of these (Figure 11.2a). *Lepidocyrtus* spp., the Hypogastruridae, the total springtails, and mites, were also less numerous in Full Insurance soil cores on several sampling occasions but relatively few of these differences were significant (Figure 11.2 c–f). In contrast, *I. minor* was often more numerous in Full Insurance than in Supervised or Minimum Input soil cores (Figure 11.2g). For *Isotoma* spp. and the Onychiuridae, the proportions of individuals which were from Full Insurance plots varied between sampling occasions, with no consistent pattern (Figure 11.2b and h), though an overall trend in the Onychiuridae was significant (see below).

Significant differences between Supervised and Minimum Input plots are given in Table 11.2. *F. quadrioculata* and mites were less numerous in Supervised plot soil cores whereas the reverse was true for the Onychiuridae, *Lepidocyrtus* spp. and *I. minor*, though no group showed significant differences on more than one sampling occasion.

Four groups of springtails, *F. quadrioculata, Lepidocyrtus* spp., the Onychiuridae, and the total springtails, showed progressive changes during

Table 11.2 Differences in the relative numbers of springtails and mites extracted from Supervised and Minimum Input plots.

Species or group	*Sampling occasion*	*Treatment from which most were extracted*	*Significance of difference*
Folsomia quadrioculata	Sept. 1987	Minimum Input	$P<0.05$
Mites	July 1984	Minimum Input	$P<0.05$
Onychiuridae	June 1985	Supervised	$P<0.01$
Lepidocyrtus spp.	June 1986	Supervised	$P<0.05$
Isotomiella minor	July 1985	Supervised	$P<0.05$

the Project, identified using an analysis of contrasts over time.

As on the field-scale (Figure 11.1a), the proportion of *F. quadrioculata* extracted from Full Insurance plots decreased initially in 1984. Hardly any individuals of this species were found in Full Insurance soil cores in 1985, but from 1986 onwards, in contrast to the field-scale results, the proportion increased; by 1988 it was similar to that recorded in 1984 (Figure 11.2a).

The Onychiuridae showed considerable variation between sampling occasions, with some suggestion of a complicated pattern; this appears to obscure a significant trend indicating an overall increase from 1984 to 1988 in the proportion from Full Insurance plots (Figure 11.2b).

Numbers of *Lepidocyrtus* spp. were very low until June 1986 but thereafter there was an increase in the proportion extracted from Full Insurance plots, which exceeded the proportion from Supervised or Minimum Input plots in 1988 (Figure 11.2c). *Lepidocyrtus* spp. were the only springtails showing a significant trend in the relative proportion extracted from Supervised and Minimum Input plots. There was a decrease in the proportion of these species extracted from Supervised plots from 1986 onwards (Figure 11.2c).

The trend for the total springtails in the Full Insurance plots was similar to that for the most abundant species, *F. quadrioculata*; there was an initial decrease followed by a recovery. The trend also reflects high proportions of the Hypogastruridae, *I. minor* and *Isotoma* spp. in Full Insurance plots in May 1986 (Figure 11.2d).

Springtails and mites in soil cores and suction samples

The different sampling biases of soil cores and suction samples provide information on the vertical distribution of springtails and mites. Knowledge of this may give an insight into the mechanisms of any observed pesticide effects on the soil fauna.

Information from the matched samples collected on 3 September 1987, together with data from c. 2000 soil cores collected during the course of the Project (Table 11.1) was compared with results obtained from three years' sampling of cereal fields in southern England (using 884 suction samples and 1330 pitfall traps; Frampton, 1989) to group the springtails according to their vertical distribution (Table 11.3).

Springtails' morphological characteristics (such as the size of the antennae, eyes and springing organ) may also reflect their vertical distribution (eg Gisin, 1943). The morphological characteristics of *F. quadrioculata* suggest that it is shallower-living than the Onychiuridae or *I. minor*, but sampling indicated that it was rarely found above ground (Table 11.3).

Both subterranean and surface-dwelling springtails showed trends suggesting pesticide effects (Table 11.3). Mites, which were extracted in large numbers both from soil cores and suction samples, are excluded from Table 11.3 because the total represents many different species which may differ in their vertical distribution. As a group,

Table 11.3 Vertical distribution of springtails in cereal crops and the effects of the Boxworth pesticide regimes. '√' indicates a trend suggesting a pesticide effect.

	Fields	*Plots*
Surface-dwelling		
Sminthuridae	√	
Lucerne-flea (Chapter 9)*	√	
Lepidocyrtus spp.*		√
Entomobrya spp.		
Surface-dwelling & subterranean		
Hypogastruridae	√	
Isotoma spp.		
Pseudosinella alba		
Pseudosinella decipiens		
Mostly subterranean		
Folsomia quadrioculata	√	√
Wholly subterranean		
Onychiuridae	√	√
Neelidae		
Isotomiella minor	√	

*also found on cereal plants

mites did not show any trends which might be indicative of pesticide effects.

Large numbers of Sminthuridae were found in suction samples, and the identification of individual species was thought to be worthwhile. Numbers of the lucerne-flea (*Sminthurus viridis*), *Sminthurinus elegans* and the garden springtail (*Bourletiella hortensis*) were noticeably lower in samples taken from Full Insurance plots than from Supervised or Minimum Input plots; these differences were statistically significant for the lucerne-flea and *S. elegans*. Too few Sminthuridae were extracted from soil cores to permit analysis. None of the other species or groups of springtails in suction samples showed significant differences between the treatments.

Discussion

Identification of treatment effects

On each sampling occasion, all samples were handled identically. Therefore, the differences described above in the proportions of springtails or mites extracted from different treatment regimes should reflect real population differences. However, it cannot be assumed that they necessarily reflect effects of pesticides.

The decrease of *F. quadrioculata* under the Full Insurance regime was clearly evident in both fields and plots. The field-scale pattern seems to represent a long-term effect of the Full Insurance regime, rather than a response to a specific pesticide event, as there was no evidence of recovery at any time during the treatment phase of the Project. The reason for the apparent recovery in the Full Insurance plots after 1986 is unclear; if it represents a response to a specific pesticide application, a similar pattern might have been expected on the field-scale.

In contrast to *F. quadrioculata*, the proportion of *I. minor* and the Onychiuridae in the Full Insurance fields increased during the treatment phase of the Project. There was a statistically significant trend in the proportion of Onychiuridae in Full Insurance plots which mirrored the even greater field-scale increase. However, the marked field-scale increase in the proportion of *I. minor* in the Full Insurance fields was not seen in the replicated plots. For both these groups, on the few occasions when the differences between plot treatments were statistically significant (May and June 1986 for Onychiuridae; May 1986 for *I. minor*), numbers were highest in the Full Insurance plots.

The increase in the proportion of Onychiuridae in the Full Insurance plots could be explained by the effects of pesticides on predation or competition. For example, the numbers of some predatory ground beetles, such as *Bembidion obtusum* and *Pterostichus* spp. (whose larvae are largely subterranean) were considerably lower in Full Insurance than Supervised and Integrated fields (Chapters 9 and 10). Predatory mites might also have been affected by the Full Insurance regime; increases in populations of *I. minor* in an arable field were seen in an earlier study after populations of predatory mites were reduced by DDT (Edwards, Dennis & Empson, 1967).

Populations of two abundant springtail species, the lucerne-flea (Chapter 9) and *F. quadrioculata*, were adversely affected by the Full Insurance regime, but it is not known if these species compete with the Onychiuridae for food or space; this seems unlikely in the case of the lucerne-flea, which feeds on plants and lives above ground.

For *I. minor*, the disparity between the field-scale and replicated plot results suggest that the increase in the occurrence of this species in Full Insurance fields was not caused by the pesticide regime. Indeed, there was no marked change at the start of the treatment phase of the Project to suggest otherwise. However, it is possible that if there was an effect of pesticides on predation of springtails, this might have been obscured in the replicated plots (but not on the field-scale) by rapid dispersal of mobile predators, overcoming any differences in predation due to the treatments.

Some pesticides might have had favourable indirect effects on some species. In other studies, increases in numbers of springtails have been observed after herbicide applications, caused, it seems, by an increased rate of litter input to the soil (eg Conrady, 1986). However, some herbicides may also have direct adverse effects on springtails (eg Edwards & Stafford, 1979). There was no evidence to suggest that applications of herbicides used in the Project caused such favourable or adverse effects, though it is conceivable that cumulative effects of successive applications may have contributed to the overall effect of the Full Insurance regime.

Also, the location of the replicated plots in the Full Insurance area, where populations of some predators were lower than in the other treatment areas (see Chapters 9 and 10), would have made any effects of pesticides on predation more difficult to detect. Therefore, the possibility that the increase in the proportion of *I. minor* in Full Insurance fields was caused by indirect effects of the pesticide regime on predation cannot be ruled out.

For *Lepidocyrtus* spp. there was no obvious pattern in the proportion in Full Insurance fields, though a reliable trend indicated an increase in the Full Insurance plots. Numbers of *Lepidocyrtus* spp. were very low in all fields until 1986, after which they increased, but there was much variation between fields and this could explain the lack of any obvious effects of the treatment regimes on the field-scale.

There were sporadic significant differences in the proportions of *Isotoma* spp., the Hypogastruridae and mites in different plot treatments (Figures 11.2 f–h). There were also significantly fewer of the surface-dwelling lucerne-flea and *Sminthurinus elegans* in suction samples taken from Full Insurance plots. These differences, which might represent the transient effects of specific pesticide applications, or increased susceptibility on particular occasions, indicate that a wider range of species was affected by the Full Insurance regime than the long-term trends alone suggest. Only the most abundant of the groups sampled (Table 11.1) showed obvious responses to pesticides and it seems likely that more effects would have been detected if some of the rarer animals had been sampled more efficiently. For example, the lucerne-flea, which was not efficiently sampled by soil cores, was abundant in suction samples, and showed major effects of the Full Insurance regime (Chapter 9).

Variation in the susceptibility of springtails and mites to pesticides might occur if sparse crop cover allowed greater than usual penetration of pesticides on some occasions, or if pesticide residues were washed into the soil by rainfall. It is notable that for most species, the majority of significant differences between plot treatments was in 1986 (Figure 11.2), a year in which crop cover was exceptionally thin.

Only the Hypogastruridae showed a reliable difference between the two reduced-input regimes, suggesting that there was a transient increase in occurrence in Supervised fields between 1985 and 1987. It is not known if this increase was caused by pesticides. In the replicated plots, the only consistent difference between Supervised and Minimum Input plots was shown by *Lepidocyrtus* spp.; this indicated a decrease in the proportion of these springtails in Supervised plots. In very few comparisons were differences between numbers in Supervised and Minimum Input plots statistically significant (Table 11.2).

Life cycles and vertical distribution

The springtails and mites described above spend their entire life cycle in arable crops, so it seems reasonable that surface-dwelling species such as the lucerne-flea are likely to be exposed to most of the pesticides applied to the Project fields, whereas subterranean springtails such as the Onychiuridae might be afforded some protection. However, the results of this study show that both surface-dwelling and subterranean springtails may be sensitive to the effects of the Full Insurance pesticides.

Potential effects of the pesticides used at Boxworth

Other studies have shown that springtails may be susceptible to some of the pesticides used at

Boxworth. Dimethoate has been shown to reduce numbers of surface-dwelling springtails, including the lucerne-flea, in winter barley (Frampton, 1988). This broad-spectrum organophosphorus insecticide was used at Boxworth only in May 1986. Most of the sporadic significant effects of the Full Insurance regime were seen in May–June 1986 (Figure 11.2). However, there is no direct proof of a connection. Organophosphorus insecticides tend to be detrimental to springtails (eg Madge, 1981), and the routine applications of triazophos and demeton-S-methyl to Full Insurance fields could well have contributed to the overall effects of the Full Insurance regime.

Many species of springtails eat various kinds of fungi, so fungicides could affect them indirectly via their food supply. Three of the fungicides used in the Boxworth Project, propiconazole, triadimenol and carbendazim, have shown adverse effects on some surface-dwelling springtails (including the lucerne-flea) in wheat plots, though these effects were brief and sporadic (Frampton, 1989).

It is clear that at least some of the pesticides used at Boxworth were potentially harmful to springtails and mites. However, none of the observed effects of the Full Insurance regime, or differences between the Supervised and Integrated regimes, could be traced definitely to individual pesticide applications.

Conclusions

The Full Insurance regime had long-term effects on populations of some springtails, whilst for others the effects were transient. Overall, the changes were varied: *F. quadrioculata* were adversely affected whereas the Onychiuridae and *Lepidocyrtus* spp. appeared to benefit in the long-term. The mechanisms for these effects are not known, though the beneficial effect on the Onychiuridae might reflect a lower predation pressure in the Full Insurance regime. *I. minor* seemed also to be favoured in the long-term by the Full Insurance regime, but the evidence for this was circumstantial.

Discrete guilds of mites were not studied separately, but there was no evidence that mites as a group experienced any long-term effects of the Full Insurance regime. Other groups of soil fauna were too rare in samples to allow analysis.

A number of springtail groups, and mites, exhibited short-term responses to the pesticide regimes. Most of these were in 1986, perhaps influenced by exceptionally poor crop cover in that year. These transient effects, like the field-scale effects, were varied: some groups were adversely affected by the Full Insurance regime whilst a few appeared to benefit. Although seemingly unimportant in comparison with long-term effects, brief within-season reductions in numbers of springtails could be important if they occur at times when other prey for beneficial predatory arthropods are scarce.

Relatively few significant differences in springtail populations were observed between the Supervised and Integrated areas, reflecting the broad similarity in the pesticide applications which these areas received. The only long-term effect seen in the lower-input regimes was an increase in *Lepidocyrtus* spp. in Supervised relative to Minimum Input plots. The underlying reason for this is not clear.

The markedly different responses of different species or groups to the Full Insurance regime at Boxworth make it difficult to determine the importance of the overall effect on the fauna in cereal fields. Surface-dwelling springtails are usually regarded as beneficial insects because they are known to be important in the diet of beneficial predators, such as money spiders and ground beetles which are antagonists of pests (eg Sunderland, 1975, 1986). A reduction in numbers of surface-dwelling springtails could, therefore, have undesirable effects on their predators (Chapter 10). Predators which specialize in eating springtails, such as some ground beetles (Bauer, 1982), are particularly at risk. On the other hand, some subterranean springtails, notably the Onychiuridae, are pests of a variety of crops because they may attack plant roots (eg Getzin, 1985). An increase in these springtails, like that caused by the Full Insurance regime at Boxworth, is likely to be undesirable, particularly if the use of fungicides increases the springtails' propensity to attack plant roots by reducing the amount of fungal material available as alternative food.

It is unwise to extrapolate the consequences of the Full Insurance regime at Boxworth to other farming situations but it is clear that some components of the soil fauna may be adversely affected in the long-term by the continued use of a prophylactic pesticide programme.

Summary

The soil fauna at Boxworth was examined using soil cores. Springtails and mites were the only groups sufficiently numerous to show effects of the pesticide regimes, but there was no evidence for long-term effects on mites as a group.

Effects of the Full Insurance regime on springtails were mixed, and affected both surface-dwelling and subterranean insects. *Folsomia quadrioculata* was adversely affected in the long-term whereas the family Onychiuridae and *Lepidocyrtus* spp. appeared to benefit from the Full Insurance regime.

The implications of these effects are unclear but they could be undesirable if, as was the case at Boxworth, they favour pest springtails such as the Onychiuridae and lower populations of beneficial species such as *Lepidocyrtus*.

Acknowledgements

We thank the following Hatfield Polytechnic students, each of which contributed a year's research to the study of the soil fauna at Boxworth: Jem Smith (1982–1983), Les Reeves (1983–1984), Helen Shortridge (1984–1985), Dawn Harratt (1985–1986), Helen Dickens (1986–1987), Philip Williamson (1987–1988) and Frank Wimpress (1988–1989). L Allen-Williams kindly agreed to supervise the students, A Dewar and J Cooper provided help with the use of the Brooms Barn extractor and H Gough assisted with advice on the identification of springtails.

References

Bauer, T (1982). 'Predation by a carabid beetle specialised for catching Collembola.' *Pedobiologia* **24**, 169–179.

Conrady, D (1986). 'Okologische Untersuchungen uber die Wirkung von Umweltchemikalien auf die Tiergemeinschaft eines Grunlandes.' *Pedobiologia* **29**, 273–284.

Edwards, C A, Dennis, E B & Empson, D W (1967). 'Pesticides and the soil fauna: effects of aldrin and DDT in an arable field.' *Annals of Applied Biology* **60**, 11–22.

Edwards, C A & Thompson, A R (1973). 'Pesticides and the soil fauna.' *Residue Reviews* **45**, 1–79.

Edwards, C A & Stafford, C J (1979). 'Interactions between herbicides and the soil fauna.' *Annals of Applied Biology* **91**, 125–146.

Frampton, G K (1988). 'The effects of some commonly-used foliar fungicides on Collembola in winter barley: laboratory and field studies.' *Annals of Applied Biology* **13**, 1–14.

Frampton, G K (1989). 'Effects of some commonly-used foliar fungicides on springtails (Collembola) in winter cereals.' Unpublished PhD. Thesis. University of Southampton.

Getzin, L W (1985). 'Chemical control of the springtail *Onychiurus pseudarmatus* (Collembola: Onychiuridae).' *Journal of Economic Entomology* **78**, 1337–1340.

Hancock, M (1989). 'Soil Nematodes.' In: *The Boxworth Project 1988 Annual Report*. Ministry of Agriculture, Fisheries and Food. p. 79.

Kloet, G S & Hincks, W D (1964). *A check-list of British insects, 2nd ed. Part 1: Small orders and Hemiptera.* Royal Entomological Society, London. pp. 1–11.

Macfadyen, A (1961). 'Improved funnel-type extractor for soil arthropods.' *Journal of Animal Ecology* **22**, 65–77.

Madge, D S (1981). 'Influence of agricultural practice on soil invertebrate animals.' In: Stonehouse, B. (Ed.) *Biological husbandry. A scientific approach to organic farming.* Butterworths, London. pp. 79–98.

Sunderland, K D (1975). 'The diet of some predatory arthropods in cereal crops.' *Journal of Applied Ecology* **12**, 507–515.

Sunderland, K D (1986). 'Spiders and cereal aphids in Europe.' *International Organisation for Biological Control WPRS Bulletin* **1987/X/1**, 82–102.