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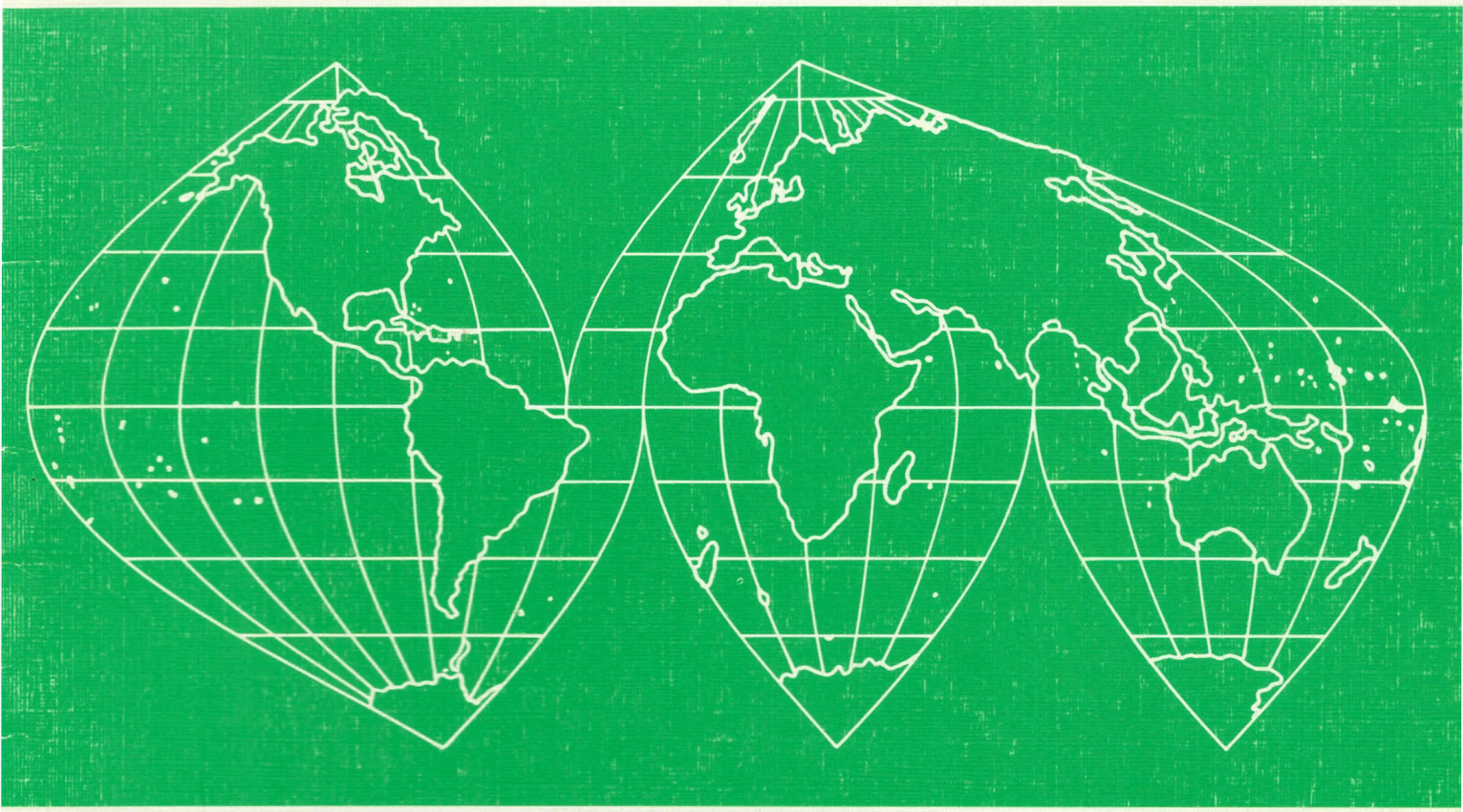

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THE LONG-TERM EFFECTS OF PESTICIDES ON BENEFICIAL INVERTEBRATES - LESSONS FROM THE BOXWORTH PROJECT

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One-third of the UK land area is used to grow arable crops.

BACKGROUND

Arable cropping includes a substantial proportion of ecologically important land and that sown to cereals alone is sixteen times greater than the combined area of all UK nature reserves (Potts, 1991). Despite the intensive use of this land, it has been estimated that most of the 25,000 species of terrestrial arthropod species in the UK inhabit farmland (Aldridge and Carter, 1992); in a Sussex study area alone, over 630 species were found, most of them beneficial or, in the case of butterflies, of conservation or amenity interest (Potts, 1991). Trends in agriculture over the last few decades have had effects on wildlife, including invertebrates: removal of hedgerows, adoption of monocultures, a decline in undersowing and intensive pesticide use have all taken their toll.

In the case of hedgerows, there had been a net loss of 24,600 kilometres in the short period between 1977/78 and 1984 (Anon, 1986) and this will have reduced invertebrates' habitats accordingly. Between 1984 and 1990, the removal rate was higher (Barr *et al*, 1991). For pesticides, establishing the direct toxicity of these to beneficial insects in the laboratory or field is easy, but the longer term ecological significance of this mortality is harder to judge. To investigate this The Game Conservancy in southern

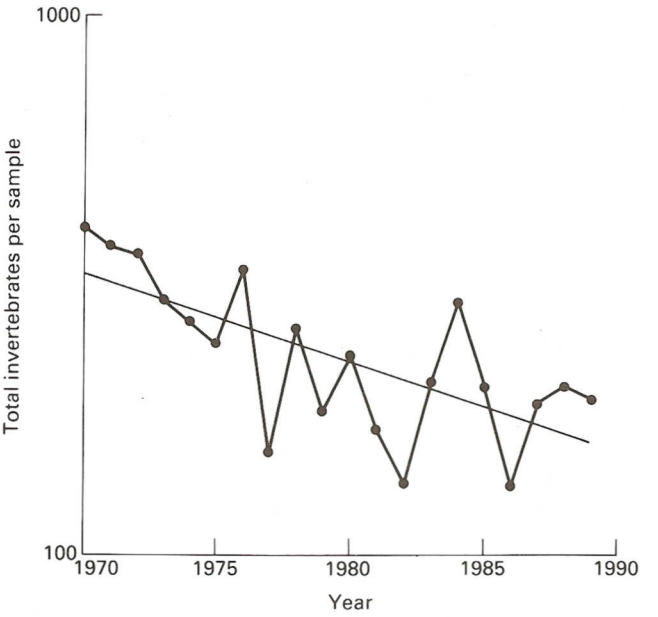

Figure 1. Decline in the mean number (logarithmic scale) of invertebrates (excluding mites, springtails, thrips and aphids) recorded per sample in The Game Conservancy's monitoring programme from 1970 to 1989. The decline was statistically significant, with a mean annual rate of 3.8%. (From Potts, 1991).

England began a long-term monitoring programme in the 1970s in which they recorded numbers of invertebrates and weeds over a large study area in southeast England. This revealed long-term declines in some of the fauna and flora which may have helped to explain a parallel decline in numbers of the grey partridge (*Perdix perdix*) (Aebischer, 1991; see Figure 1).

Although these declines may have been caused at least in part by pesticide use, The Game Conservancy's study was not experimental, so cause and effect could not be established. However, the implications of their work were so wide-ranging that they stimulated the setting up of a long-term experimental study by the UK Ministry of Agriculture, Fisheries & Food (MAFF). It ran on one farm in eastern England from 1981 to 1991. The results of this study, called

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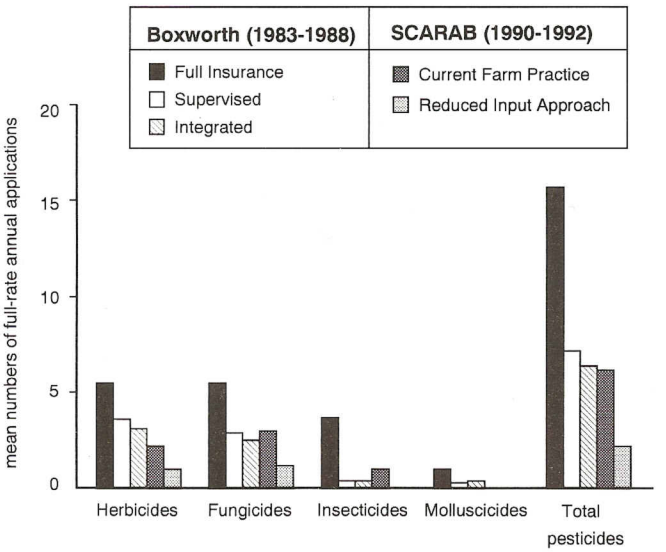

Figure 2. Mean numbers of annual pesticide applications per field in the three Boxworth and two SCARAB pesticide regimes.

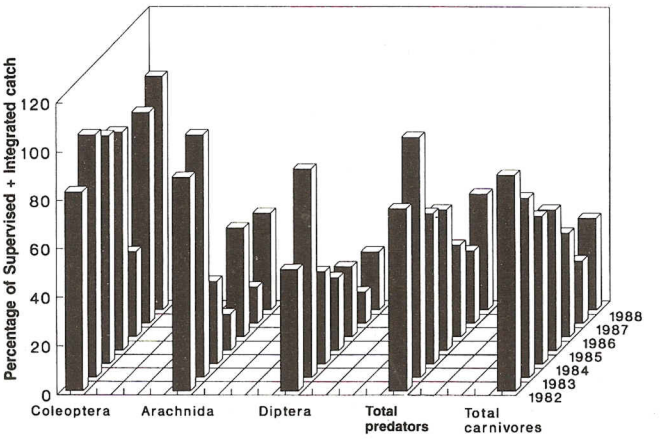

Figure 3. Numbers of beneficial arthropods trapped in the Full Insurance area of the Boxworth study as a percentage of numbers trapped in the lower-input before (1982 and 1983) and during the treatment period (1984-1988). (From Greig-Smith *et al.*, 1992).

the Boxworth Project, are reviewed below, along with those from related projects which have been set up subsequently in Britain and Europe.

THE BOXWORTH PROJECT

This was designed to investigate the possibility that the sustained prophylactic use of a wide range of pesticides was causing harmful environmental effects. Its main aim was to examine the overall effects of pesticides on birds, small mammals, soil fauna, crop invertebrates and plants in cereal fields at Boxworth Research Centre, starting in 1981. The project was an experimental comparison of matched blocks of fields subject to high or reduced inputs of pesticide. After two years of "baseline" data collection, three contrasting pesticide regimes were established (Figure 2). There were some criticisms of the project in the early stages and these were of two main types:

1. The studies were not strictly replicated because blocks of contiguous fields were used for each of the three treatments.
2. The prophylactic or full insurance regime had its pesticide applications fixed at the beginning of the programme so could not reflect changes in farmingpractice during the course of the project.

The first criticism can be countered to some extent because of the high mobility rates of many of the animals under study. Sometimes even whole fields may not be sufficient to detect effects on these groups other than in the very short term, as their rapid rates of movement allow them to recover quickly from depletions caused by pesticides. It was felt that only blocks of contiguous fields could solve this problem. The desire to have fixed and clear differences between the treatments led to the decision to fix the prophylactic regime from the outset. The main analyses therefore took the form of changes in numbers of organisms over time.

By 1988 the populations of some groups of invertebrates such as ground beetles (Carabidae) and springtails (Collembola) had decreased substantially and persistently under the high input (prophylactic) pesticides regime. Despite all the effort involved in the work on birds, small mammals and plants, there were no obvious long-term effects on these groups. There was little evidence that either herbicide or fungicide use had any substantial effects on the numbers of invertebrates compared with the effects of insecticides and molluscicides. The latter were divided into summer treatments (demeton-S methyl) and those applied in autumn and winter

Summer insecticide applications are commonly made to control aphids. (Photographed by Mike Mead-Briggs, Univ. of Southampton).

Some farmers spray many pesticides in a growing season.

(methiocarb, a pyrethroid (permethrin, cypermethrin or deltamethrin), chlorpyrifos and triazophos). The overall effect of the full insurance regime was to reduce the total numbers of herbivores by 50%. There were substantial reductions in the populations of caterpillars, butterflies and moths, thrips, flies and the lucerne-flea. For the predatory insects and spiders total numbers in the full insurance area were 53% lower on average than in the other two blocks (Figure 3). Beetles (Coleoptera) were less affected than were flies (Diptera) and spiders (Arachnida), which were on average around 70% lower in number in the full insurance area; in some years their numbers were up to 85% lower (Figure 3). In general, the species which were hardest hit by the full insurance regime were:

a) those which spent the whole year in the field rather than emigrating to the field boundary in autumn (i.e. exposed to all pesticide applications during their life cycles) and

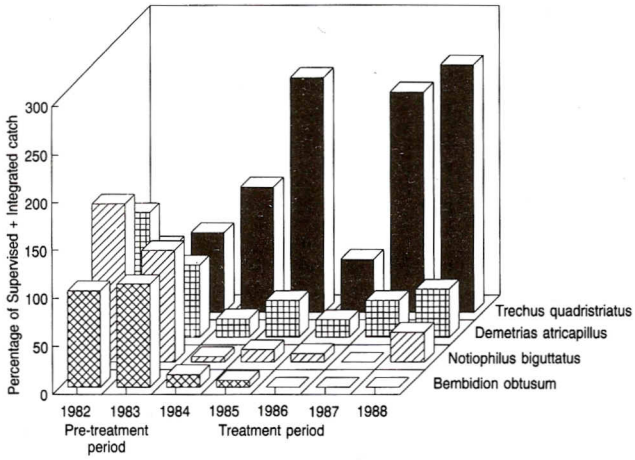

Figure 4. Numbers of some predatory ground beetles trapped in the Full Insurance area of the Boxworth study as a percentage of those trapped in the lower-input treatments during the pre-treatment and treatment periods. (From Greig-Smith *et al.*, 1992).

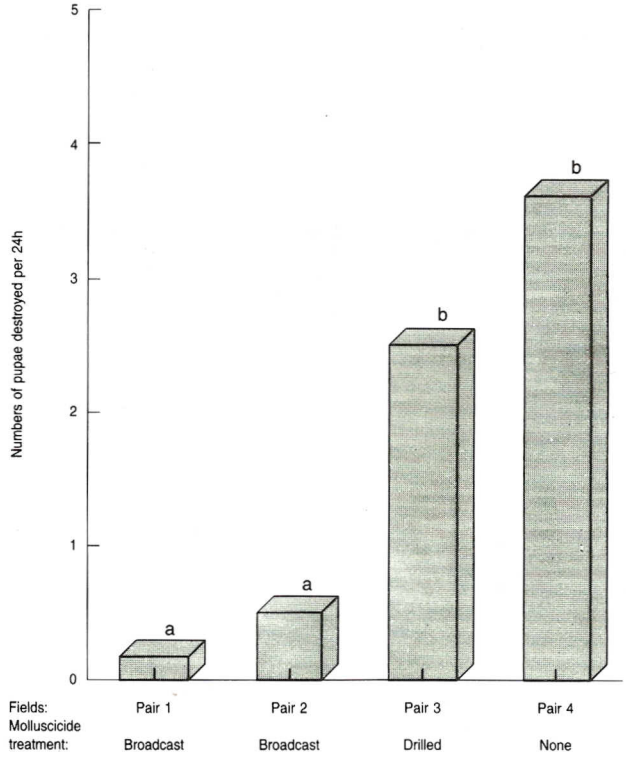

Figure 5. Average numbers of fruit-fly pupal baits eaten by predators in four pesticide treatments (pairs of fields) during winter at Boxworth. Pair 1 was two Full Insurance fields; Pair 2 was two Supervised fields; Pairs 3 and 4 were Integrated fields. (From Greig-Smith *et al.*, 1992).

b) those which inhabited the plant surface rather than on or under the soil as the latter are afforded some degree of protection by the plant canopy and are therefore exposed to lower levels of pesticides (Çilgi & Jepson, 1992).

In terms of population recovery some of the hardest-hit species remained virtually extinct for the duration of the experiment. The species which showed no or little recovery were those with the poorest dispersal ability; many of the predatory beetles for instance do not fly but disperse by walking (Figure 4). The project's results have been summarised in a recent book (Greig-Smith *et al.*, 1992).

Aphid numbers were highest under the full insurance regime in some years at Boxworth which may be attributed to the reduced numbers of natural enemies (Greig-Smith *et al.*, 1992). One way of finding out whether the reduction in predator numbers has any consequences for pest populations is to use living or dead insects as facsimiles of pests, as "baits" in the open field. This was done a few years ago in a separate study in southern England by Simon Duffield who showed that when large areas are sprayed with the broad-spectrum insecticide dimethoate the delayed recovery of many walking predators led to a lower rate of predation (bait removal) (Duffield and Aebischer, 1994). At Boxworth, the

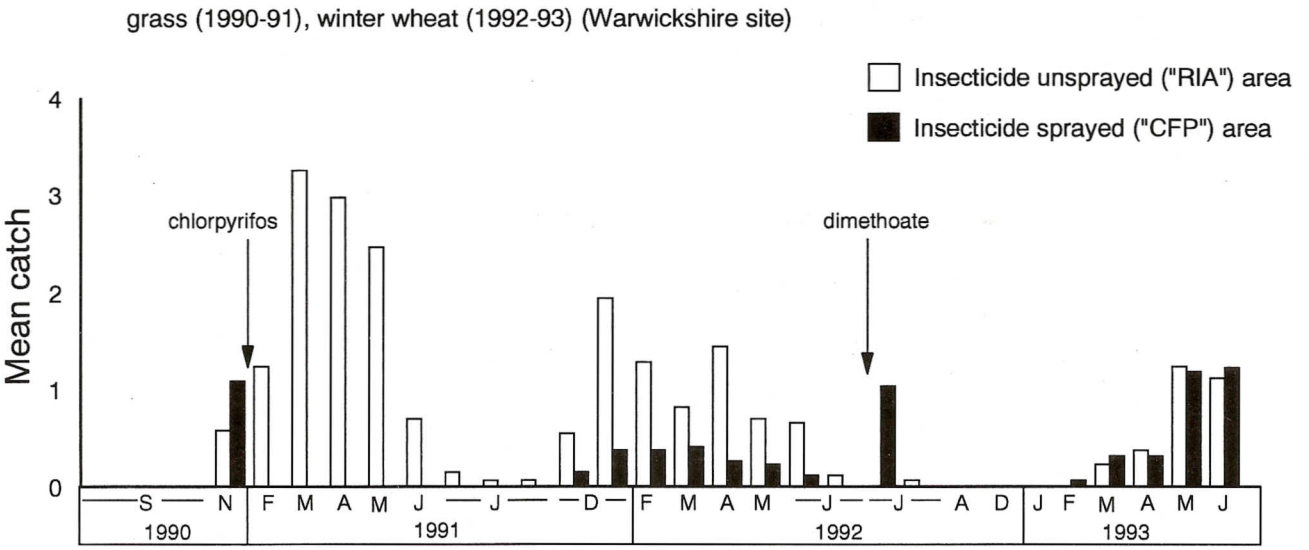

Figure 6. Pitfall trap catches of the carabid beetle *Bembidion obtusum* in the two pesticide treatments of the SCARAB project.

combination of the insurance treatment with insecticides and broadcast methiocarb slug baits severely reduced the rate of bait removal (Figure 5), indicating that rates of naturally occurring biological control of pests were also likely to have been lower.

After 1989 the experimental farm reverted to normal practices, the inputs of which were generally much lower than the earlier full insurance programme. It was therefore possible to investigate the recovery, if any, in the populations of the invertebrates which were most severely affected by the intensive regime. These data are being analysed now but preliminary results from the third year of the continuation study show that most of the severely affected species had still not fully recovered (G P Vickerman, pers. comm.), indicating that the effects of broad spectrum pesticides can persist for years after their final use. Rather than continue the study at one site after 1991, MAFF set up a follow-up study at three sites in the UK.

Ground beetles (Carabidae) include predators of aphids. (Photographed by Barry Lockyer, University of Southampton.

Springtails (Collembola) have shown adverse effects of pesticide use in the Boxworth and SCARAB projects. (Photographed by Barry Lockyer, University of Southampton).

This new long term project, called SCARAB (Seeking Confirmation About Results at Boxworth), is already beginning to show clear effects of broad spectrum pesticides on invertebrates and the groups most affected appear to be the same ones as in the Boxworth Project (Figure 4). As well as having more than one site and having split-field treatments, it also differs from Boxworth in that there are only two pesticide regimes. One is a conventional pesticide regime (Current Farm Practice; CFP), the other was a system managed in a less intensive way with respect to inputs of pesticides; this is called the Reduced Input Approach (RIA).

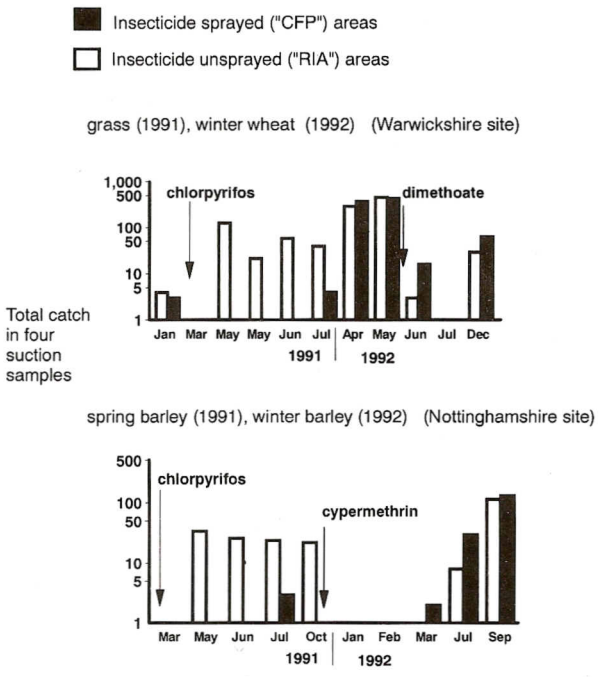

Figure 7. Suction sampling catches of a springtail *Sminthurinus elegans* in the two pesticide treatments of the SCARAB project.

Also, the protocol allows for treatments to evolve according to changes in farming practice. The preliminary results from the SCARAB project, mentioned above, have revealed substantial reductions in the numbers of the ground beetle (*Bemidion obtusum*; Figure 6) and of springtails (Figure 7). The results indicate that considerably lower pesticide inputs than those used in the Boxworth full insurance regime (Figure 2) can still have adverse effects on some beneficial arthropod populations. Such effects are primarily caused by one or two broad-spectrum compounds applied in a growing season.

EUROPEAN STUDIES

A number of major European long-term studies are currently examining the economic and environmental consequences of adopting Integrated Farming Systems (IFS). Two of these projects are the Lautenbach project in Germany and the Development of Farming Systems project at Nagele in the Netherlands. These projects began in 1977 and 1979, respectively, and are still continuing. Although different in their design and cropping plans, both were set up to compare the productivity, economics and environmental impacts of an integrated system with those of a conventional farming system (CFS).

In the IFS at Lautenbach the aim is to change husbandry practices to reduce the need for agrochemicals. These practices include non-inversion-tillage, reduced nitrogen, mechanical weeding, different row spacing and managed field margins to achieve minimum pesticide use and the total avoidance of insecticides. At Nagele, pesticides are not used at all in the IFS except as a last resort to maintain a viable crop. A third long-term study, INTEX (Developing an integrated farming system and investigating ecological effects of an extensification in arable production) has been investigating four different farming systems at two sites in Germany since 1990.

These three European projects differ from Boxworth and SCARAB in the UK in that they have an integrated farming approach, so that none of their treatments, (organic, IFS and CFS) focuses on pesticide input alone. However, they have all demonstrated higher numbers of beneficial invertebrates in "IFS" treatments compared with conventional ones. In contrast Boxworth and SCARAB were set up to investigate only the pesticide components of IFS. In fact these European projects share a rationale closer to four other UK programmes running now: these are called MAFF TALISMAN (Towards A Low Input System Minimising Agrochemicals and Nitrogen), MAFF/LINK Integrated Farming Systems, LA LIFE (Long Ashton Less-Intensive Farming and Environmental Research) and the Boarded Barns Farm Projects, the latter set up by the pesticide company, Rhone-Poulenc.

These studies do not concern only pesticides but are investigating alternative ways of growing crops with low inputs. Although they are producing data on invertebrate populations, it is too early to conclude much from these results as they have only been running since 1989. Further detailed comparisons of the UK and European long-term studies outlined here, are reviewed elsewhere (Holland *et al.*, 1994).

CONCLUSIONS

It is interesting that one of the criticisms of the Boxworth Project was that the full insurance regime was fixed and could not reflect changes in farmers' practices during the course of the project. In retrospect, this concern seems to have been partly justified as, driven by declines in the prices of grain over the past few years, many farmers have reduced their variable costs, including pesticides, to well below those of the Boxworth full insurance regime. However, Boxworth and SCARAB have both shown that it is the cheap broad spectrum insecticides which do most damage to the populations of beneficial arthropods, with the likely knock-on effects on prey populations. At present they

are still widely being used and misused in terms of irrational spray timing (Wratten *et al.*, 1990).

Detailed information about the harmful effects of broad spectrum pesticides on beneficial arthropods is rarely available to the grower, although a first step in this direction has been made by the UK MAFF entomologist Jon Oakley. He has compiled a table showing the relative toxicity of cereal aphicides to non-target invertebrate groups in order to assist farmers in making their product choice (Harris, 1993). Oakley points out that French farmers have had access to toxicity tables of this type since 1991. Ideally such information should be readily available to all farmers and updated annually.

Furthermore, those European countries that are in the process of implementing the plan to reduce up to 50% of their pesticide use before the year 2000 (Jansma *et al.*, 1993) could consider placing restrictions on the use of those broad spectrum pesticides found to be consistently harmful to beneficial invertebrates where alternative selective and/or less persistent compounds are available.

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Geoff K Frampton is employed by Southampton University to coordinate the invertebrate monitoring part of the MAFF SCARAB project. He studied the side-effects of fungicides on springtails for his PhD and co-edited a book about the Boxworth Project.

John M Holland is employed by The Game Conservancy Trust on the MAFF/LINK Integrated Farming Systems project. He has studied crop protection since 1984, obtaining a BSc (Reading University), MSc (Southampton University) and PhD (Lincoln University, New Zealand).