LONG-TERM CHANGES IN NUMBERS OF CEREAL INVERTEBRATES ASSESSED BY MONITORING

N. J. AEBISCHER, G. R. POTTS

The Game Conservancy Trust, Fordingbridge, Hampshire SP6 1EF.

ABSTRACT

For the past twenty years, The Game Conservancy has monitored abundances of cereal invertebrates in over 100 fields in Sussex in late June. The total number of invertebrates (excluding Acari, Collembola and Thysanoptera) recorded per sample has dropped by almost half in the course of the study, corresponding to a quarter of what was present in pre-pesticide times. This overall change was the result of widespread declines in Araneae and Opiliones, Lepidoptera, Aphididae (Hemiptera), Parasitica and Symphyta (Hymenoptera), Staphylinidae, Cryptophagidae and Lathridiidae (all Coleoptera) and Lonchopteridae (Diptera); these groups constituted 72%, on average, of the total by number. Taking Staphylinidae as an example, the decline occurred equally across all farms, in *Tachyporus* and non-*Tachyporus* spp. alike and, within *Tachyporus*, across age classes and species. The staphylinid decline could not be attributed to weather, to hedgerow removal or to changes in proportions of spring and winter cereals. A possible cause was a drop in the availability of fungal food, as the level of mildew and rusts infecting crops dropped in line with the increasing use of foliar fungicides.

INTRODUCTION

Agricultural practices in Britain have changed dramatically over the past few decades. In many areas the traditional approach of rotational ley farming of small fields with mixed grazing has been largely abandoned in favour of a much more intensive approach involving the loss of grass and livestock, hedgerow removal, greater mechanisation, the use of more productive - and demanding - cereal varieties and a shift from spring to winter cereals (Jenkins, 1984). Equally dramatic has been the rise in inputs - pesticides, fertilisers, growth regulators - applied to the crops (Rands *et al.*, 1988). Intuitively, these major changes in arable farming are bound to have had some impact upon the animals and plants living in and around the crops - the questions are what kind and how much of an impact, and have they had any long-term effects upon the cereal ecosystem?

By their very nature, long-term effects require long-term studies in order to be detected. This paper summarises the results from a twenty-year monitoring study of invertebrates in cereal crops on 62 km^2 of the Sussex Downs. This period, 1970-1989, has seen major changes in farming practices in the area, in line with the rest of the country (Potts, 1986). It started too late to monitor the impact of the introduction of herbicides (mainly late 1950s), but it spans the introduction of foliar fungicides, the loss of ley farming, the increase in insecticides and the move towards monoculture (O'Connor & Shrubb, 1986; Potts, 1986).

METHODS

The study area covers 62 km² of the South Downs, Sussex. Each year from 1970 onwards, invertebrates in cereal crops were sampled by vacuum suction trapping (Dietrick 1961) in the third week of June. Approximately 100 fields were sampled annually, and each sample, comprising 5 subsamples, corresponded to an area of 0.46 m². At the same time as the invertebrates were sampled, crop type and levels of disease present in the crop (on an ordinal scale of 0=no disease to 6=entire crop infected) were noted. Further details of the area and methodology are given in Potts & Vickerman (1974), Potts (1986) and Aebischer (in press).

The results presented here derive from a 28 km² core area of five farms whose cereal fields were sampled systematically throughout the study period. Analysis was carried out using annual mean numbers of invertebrates from each farm, transformed to logarithms (base 10) and weighted by sample size (Aebischer, in press). Long-term increases or decreases were detected by linear regression of the logarithmically transformed means against time, after adjusting for between-farm differences (Kendall, 1976). The annual rate of change was obtained as 10^r-1, where r was the regression coefficient.

Continuous series of daily temperature and rainfall figures from 1969 to 1989 measured at Worthing Meteorological Station, about 5 km south of the centre of the study area, were used to calculate mean temperatures and total rainfall by calendar month and for the month before sampling, as well as sums of day-degrees above 0 °C, 1 °C, etc. to 10 °C from 1 January to the median sampling date.

RESULTS

Summary of trends

The overall trend in numbers of cereal invertebrates, excluding mites (Acari), springtails (Collembola) and thrips (Thysanoptera), which were not counted in all years of the study, was significantly downward (Fig. 1). The mean number of invertebrates recorded per sample during the first five years of the study (1078/m²) was almost twice as high as during the last five years (563/m²); the rate of the decline averaged 5.3% per annum.

These general figures cover a wide variety of invertebrate taxa, and the next step is to examine whether all declined in the same way, or whether the overall decline was the result of declines in particular taxa or trophic groups. The invertebrates were therefore split into five main groups of relevance to pest management and conservation: aphids (Aphididae), parasitoid wasps (Parasitica - predominantly aphid parasitoids), aphid-specific predators (Coccinellidae, Cantharidae, Neuroptera, Syrphidae), polyphagous predators (Araneae, Carabidae, Staphylinidae, Dermaptera, predatory Diptera) and chick-food items, i.e. taxa upon which partridge and pheasant chicks depend for survival during the first two weeks of life (Symphyta, Lepidoptera, non-aphid Hemiptera, Chrysomelidae, Curculionidae - Potts & Aebischer, 1989). These groups constituted 69% of the total by number. A sixth, miscellaneous, group included the remaining families which were numerically important in the

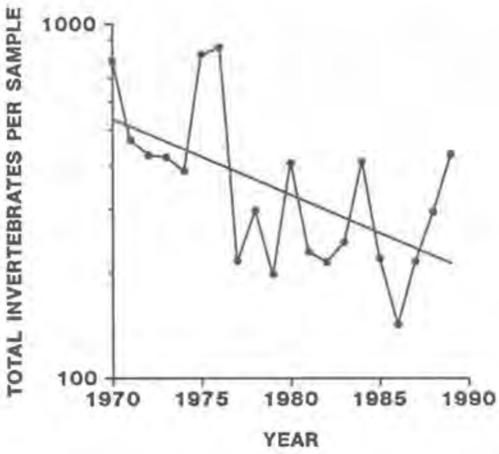

FIGURE 1. Mean numbers (logarithmic scale) of invertebrates, excluding Acari, Collembola and Thysanoptera, recorded per sample in the Sussex study in each of the years 1970 to 1989. Numbers declined significantly in the course of the study, at an average rate of 5.3% ($F_{1,18}$=11.0, P<0.01).

Sussex samples (arbitrarily defined as making up at least 2% by number of the captured invertebrates); it made up a further 21% of the total.

The numerical importance of the different groups and the long-term trends which they exhibit are summarised in Table 1. It is clear that the overall change in invertebrate abundance was caused by wide-ranging declines across the various taxa. Out of the six general groups defined above, declines occurred in the four numerically most important ones (aphids, parasitoids, polyphagous predators, miscellaneous). Among the heterogeneous group of polyphagous predators, the decline can be traced to decreases in numbers of spiders (Araneae) and of rove beetles (Staphylinidae); in the miscellaneous group, whose taxa were selected on the basis of their abundance, three out of five had declined: two families of small beetles (Cryptophagidae, Lathridiidae) and one of flies (Lonchopteridae). Finally, one of the most important component taxa in the group of chick-food items, sawflies (Symphyta) and Lepidoptera (Potts 1986), also showed a significant downward trend. Numerically, the taxa in decline accounted for 72%, on average, of the invertebrates recorded in cereal fields in Sussex. The annual rates of decline varied from 4.1% to 12.7%, with a mean of 6.8%. This corresponded approximately to a halving of abundance over ten years.

As yet, the causes of the declines are unclear in most cases. In the next section, we concentrate on one particular group, the rove beetles (Staphylinidae) to demonstrate some features of their decline which recur in other groups, to illustrate some of the difficulties in interpretation, and to investigate a possible role of pesticides as causative agents.

TABLE 1. Summary of long-term trends among a variety of invertebrate taxa present in the Sussex samples from 1970 to 1989. The taxa were chosen as belonging to five biologically relevant groups, plus a miscellaneous group of numerically important taxa which did not fit into the other groups.

Taxon	% in samples (by number)		Trend		Annual rate of change (%)	
Total (excluding Acari, Collembola, Thysanoptera)	100.0		Down		-5.3	
Aphididae	37.2		Down		-8.4	
Parasitoid wasps (Parasitica)	15.0		Down		-4.7	
Aphid-specific predators	0.5		None		-	
Coccinellidae		0.3		None		-
Others		0.2		None		-
Polyphagous predators	13.6		Down		-3.8	
Carabidae		0.5		None		-
Staphylinidae		6.5		Down		-7.7
Araneae, Opiliones		3.0		Down		-4.1
Dolichopod-,Empid-,Scathophagidae		3.6		None		-
Others		<0.1		None		-
Chick-food items	3.0		None		-	
Symphyta, Lepidoptera		0.5		Down		-4.5
Hemiptera (excl. Aphididae)		2.2		None		-
Chrysomelidae, Curculionidae		0.3		None		-
Miscellaneous	21.1		Down		-6.9	
Cryptophagidae		4.9		Down		-6.7
Lathridiidae		2.4		Down		-12.7
Cecidomyiidae		8.2		None		-
Lonchopteridae		2.4		Down		-5.4
Drosophilidae		3.2		None		-

Staphylinidae

The decline in rove beetles was replicated across all farms (Fig. 2): there was no significant difference between the slopes of the regression lines ($F_{4,90}=0.25$, n.s.), so that, on average, the rate of decline was the same on all farms. There were also similarities in year-to-year variation among the farms: for instance, common peaks occurred in 1972-1973 and 1984-1985, common troughs in 1975, 1983, 1986, 1989. Such features - similar long-term trends and similar patterns of year-to-year variation - were to be found in all the taxa examined in Table 1. Because of the similarities between farms, the data in subsequent analyses were pooled across farms.

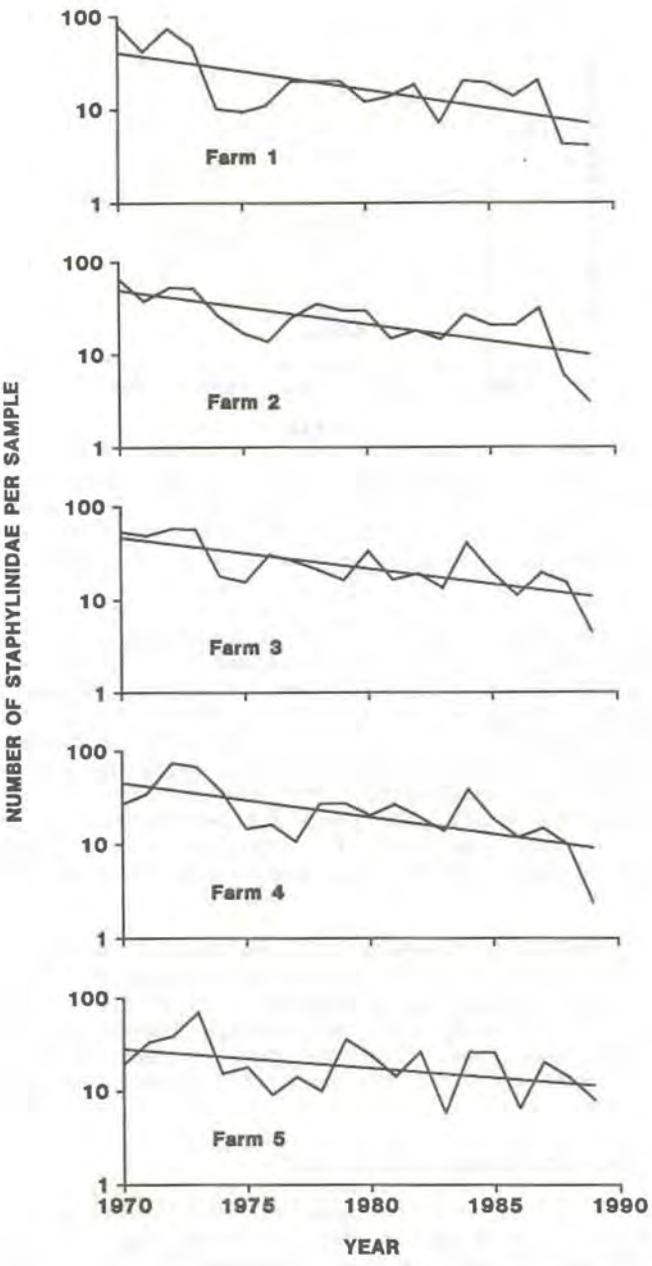

FIGURE 2. Annual mean numbers (logarithmic scale) of Staphylinidae recorded per sample on each of five farms in the Sussex study area from 1970 to 1989. The average rate of decline in the course of the study was 7.7% ($F_{1,94}$=72.9, $P<0.001$).

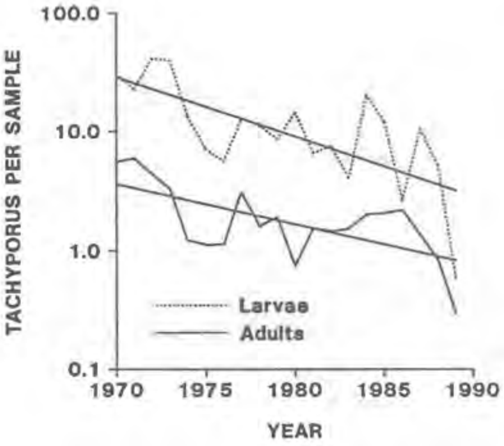

FIGURE 3. Mean numbers (logarithmic scale) of adult and immature *Tachyporus* recorded per sample in the Sussex study in each of the years 1970 to 1989. Abundances in both age classes declined significantly in the course of the study, at an average rate of 9.2% ($F_{1,37}$=32.5, P<0.001).

Within the rove-beetle complex, 65% of individuals belonged to the genus *Tachyporus*, and this genus was examined more closely. Figure 3 shows that the abundance of both adults and larvae was reduced during the period of the study. There was no significant difference in the slopes of the two regression lines ($F_{1,36}$=1.23, n.s.): the ratio of larvae to adults remained approximately constant at about 6:1, implying that changes in breeding rate were not responsible for the decline. According to identification based on adults, the genus was represented by four species in the samples: *T. chrysomelinus*, *T. hypnorum*, *T. nitidulus* and *T. obtusus*. Numbers of adults of all four species declined at similar rates (Fig. 4).

The overall decline in numbers of rove beetles was not, however, produced solely by the decrease in numbers of *Tachyporus*. The remaining, non-*Tachyporus*, rove beetles also showed a significant decrease in abundance ($F_{1,18}$=12.4, P<0.01), at an average annual rate of 5.8%. Although the latter was lower than the rate of decline of *Tachyporus* adults and larvae (9.3%), the two did not differ significantly ($F_{1,55}$=2.46, n.s.).

Possible causes of the staphylinid decline

Is it possible to discover the cause of the decline in rove beetles? The similarity in the effect across the five farms suggests that whatever the cause, it must have acted on a broad geographical scale rather than at the field or even the farm level. Therefore it is likely to be either a climatic effect or else a change in farming practice so widespread that it was effective throughout the study area.

The influence of climate was investigated using the daily weather records from Worthing Meteorological Station. None of the obvious relevant climatic variables, ranging from temperature and rainfall through

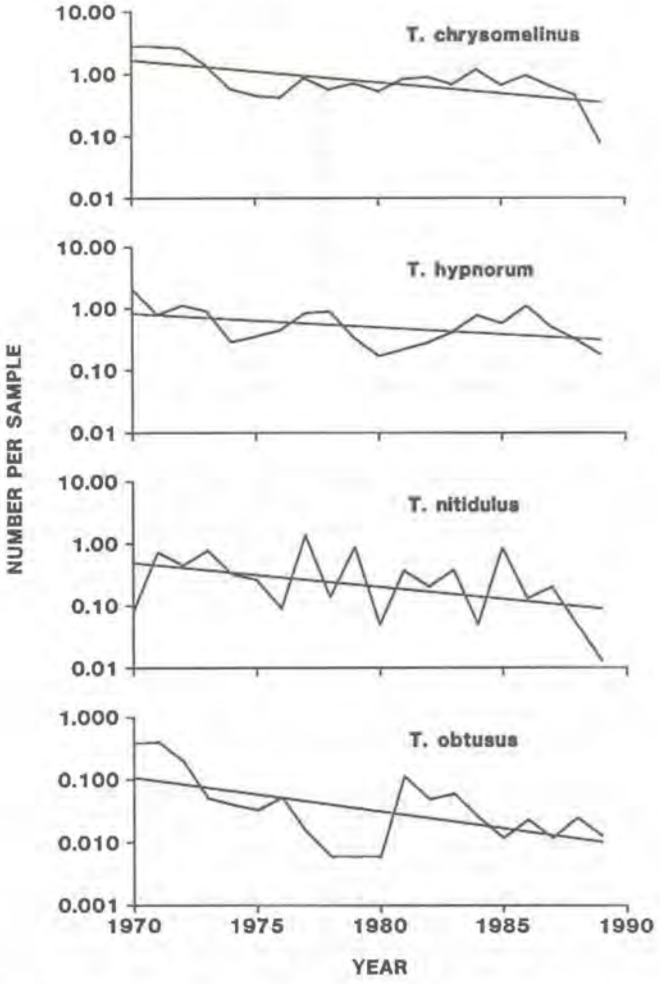

FIGURE 4. Annual mean numbers (logarithmic scale) of each of the four species of *Tachyporus* represented in the Sussex samples from 1970 to 1989. In each case numbers declined in the course of the study, at an average rate of 9.1% ($F_{1,75}$=26.3, P<0.001).

to day-degree sums, were able to account for the observed decline. This focused attention onto the farming methods.

One change which took place across the board on the study area was a gradual switch from spring cereals to winter cereals (Aebischer in press). However, the decline in numbers of rove beetles occurred at the same rate in winter wheat, winter barley and spring wheat, and there was no evidence that numbers were higher in spring barley than in either of the winter cereals. Therefore this change could be discounted as a reason for the decline. The destruction of overwintering habitat (Sotherton, 1984;

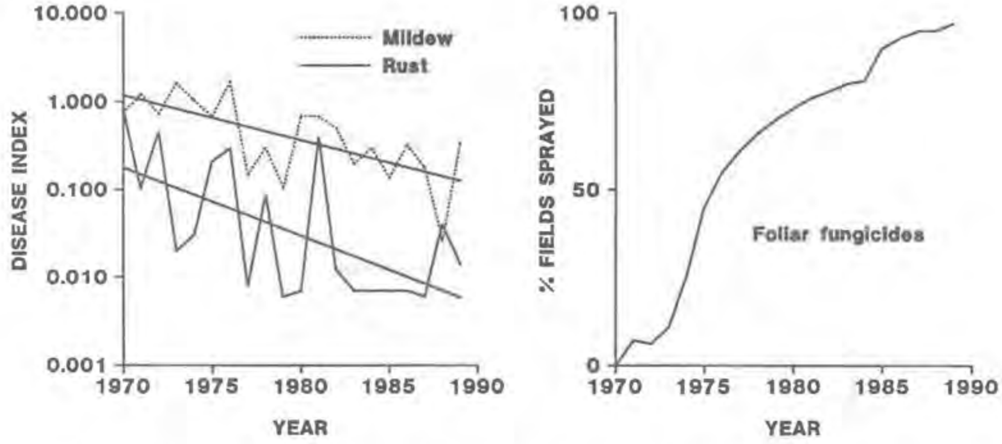

FIGURE 5. Mean index (logarithmic scale) of mildew *(Erysiphe graminis)* and of rusts *(Puccinia* spp.) in cereals on the Sussex study area for each of the years 1970 to 1989 (left), and corresponding increase in the proportion of fields in the study area treated with foliar fungicides (right). Both disease indices declined significantly in the course of the study (mildew: $F_{1,18}$=14.3, P<0.01; rusts: $F_{1,18}$=9.06, P<0.01).

1985) was also an unlikely cause, as the removal of hedgerows and ploughing up of grass banks occurred on only two of the five farms over the past 20 years (Potts, 1986; Aebischer, in press).

Another possibility was that changes on the farms wrought changes in the food supply of the beetles. As well as being predatory on aphids, the rove beetles, and *Tachyporus* spp. in particular, feed on fungal material, mainly mildews *(Erysiphe* spp.) and rusts *(Puccinia* spp.) (Sunderland, 1975; Dennis *et al*. in press). Figure 5 shows that the incidence of mildew *(E. graminis)* and of rusts has gone down significantly since the study began, while the proportion of fields treated with foliar fungicides increased. The latter were applied on less than 10% of cereal fields until 1974, when the proportion rose rapidly; in recent years, practically all cereal crops were treated as a matter of course. The disease indices suggest that the treatment was effective, as rusts have almost disappeared from the crops, and the level of mildew is much reduced.

Other explanations are possible, such as direct toxic effects of insecticides, increasingly used to control cereal aphids, or a rise in levels of parasitism by parasitoids or nematodes. However, the widespread use of insecticides did not take place until the 1980s on the study area, and we have no information on rates of parasitism (Potts, 1986).

DISCUSSION

Although the Sussex monitoring study did not start until after one of the first big changes in crop management, the use of herbicides, there have been considerable changes in the densities of the invertebrates recorded over the past twenty years. This paper shows that the changes give cause for concern: overall, the abundance of cereal invertebrates (excluding mites, springtails and thrips) dropped by approximately half in the course of the study, and the decrease is the result of declines across a wide range of taxa, from agricultural pests such as aphids, to beneficial arthropods such as spiders and rove beetles. As the effect of herbicide use has been estimated as causing a 50% reduction in invertebrate abundance in cereals (Southwood & Cross, 1969; Potts, 1986), this means that the number of invertebrates in crops now represents only about a quarter of the number present before the pesticide era.

The causes of the declines highlighted by this study are not easy to establish, and need not necessarily be the same for all taxa. Characteristically, the factors responsible for the declines were acting on a broad geographical scale, so that obvious candidates were climatic change on one hand, and widely adopted changes in agricultural practices on the other. Thus Aebischer (1990) found that the decline in sawflies shown in Table 1 was accounted for by changes in summer temperature and rainfall in conjunction with the disappearance of undersowing (cereals used as a nurse for grass). For rove beetles, the only explanation which, so far, seems plausible is that the rapidly increased use of fungicides from 1974 onwards reduced levels of the pathogenic fungi upon which the beetles feed. It is interesting that two other groups of mycophagous beetles, the Cryptophagidae and the Lathridiidae (Potts & Vickerman 1974), also showed sharp declines in abundance since the beginning of the study (Table 1).

The prime role of monitoring is to serve as a warning system. The main advantage of monitoring population densities, as described here, is that it is successful in detecting population change (cf. Table 1) for a relatively small outlay of time and resources. It is, however, a "black-box" approach, in that it records the outcome of internal processes that remain unknown, and that require much additional effort to assess effectively. Assuming that change is taking place, the time taken to detect it will vary from species to species. This depends upon the type of change (step or trend), the magnitude of the change, the accuracy of sampling, the range of natural between-year fluctuations and the confounding effects of different factors, in particular weather. The possible causes of change may be identified through a correlative or regression approach, although from the statistical viewpoint, potential problems of serial correlation between years require the use of time-series modelling, for which the 20-year span of the Sussex data is only just sufficient (Aebischer, 1990). Provided that the monitoring is extensive enough to encompass within-year as well as between-year variation, it should be possible to separate the effects of farming methods varying between farms from climatic effects. Once tentative causes have been identified though correlation, the demonstration of cause and effect must then lie with experimentation.

The Sussex study is currently sounding an alarm over the cereal ecosystem. Because of the vast area of Britain under cultivation (4 million ha), we cannot afford to ignore it. Many members of its invertebrate community are valuable tools for integrated pest management, and many form the basis of a complicated food chain upon which many birds and mammals rely. Amid the growing public concerns about the effects of pesticide and nitrate pollution, the Sussex study adds further cause for urgent research into the ecological implications of modern agriculture.

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