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# Long-term changes in the abundance of flying insects

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**Abstract.** 1. For the first time, long-term changes in total aerial insect biomass have been estimated for a wide area of Southern Britain.

2. Various indices of biomass were created for standardised samples from four of the Rothamsted Insect Survey 12.2 m tall suction traps for the 30 years from 1973 to 2002.

3. There was a significant decline in total biomass at Hereford but not at three other sites: Rothamsted, Starcross and Wye.

4. For the Hereford samples, many insects were identified at least to order level, some to family or species level. These samples were then used to investigate the taxa involved in the decline in biomass at Hereford.

5. The Hereford samples were dominated by large Diptera, particularly *Dilophus febrilis*, which showed a significant decline in abundance.

6. Changes in agricultural practice that could have contributed to the observed declines are discussed, as are potential implications for farmland birds, with suggestions for further work to investigate both cause and effect.

**Key words.** Biodiversity, biomass, Diptera, long-term monitoring, suction trap.

## Introduction

There is widespread concern over biodiversity extinction rates and their impact on the human species (Pimm *et al*., 1995). More than half of all known species are insects (May, 1988) and, if the known global extinction rates of vertebrate and plant species are found to be paralleled in the insects and other invertebrates, the suggestion that the world is experiencing its sixth major extinction event would be greatly strengthened (Thomas *et al*., 2004). There are very few standardised, long-term datasets on insect populations available to confirm or refute this. Exceptions in the UK include butterflies and moths, many species of which have, indeed, been shown to be declining at alarming rates (Warren *et al*., 2001; Conrad *et al*., 2004, 2006; Thomas *et al*., 2004). In contrast the abundance of many pest insects is thought to be increasing (Cannon, 1998). For the vast majority of insects throughout the world, solid evidence one way or the other is largely lacking.

Even insects that are pests of crops may be beneficial in supporting higher trophic levels such as birds, many of which have undergone well-documented declines in recent years. These declines coincided with a period of agricultural intensification (Buckwell & Armstrong-Brown, 2004; Buckingham *et al*., 2006), one effect of which was almost certainly to reduce populations of certain insect groups (Aebischer, 1991; Woiwod, 1991) and birds (Chamberlain *et al*., 2000) in farmland. The declines in bird and insect populations may be mechanistically linked, at least in some species. In support of this suggestion, Benton *et al*. (2002) found temporal correlative links between numbers of farmland birds, numbers of invertebrates, and agricultural practice near Stirling in Scotland. In that study, invertebrates were monitored using a 12.2 m tall suction trap (Macaulay *et al*., 1988) of the type used by the Rothamsted Insect Survey (RIS) (Harrington & Woiwod, 2007). The Stirling study demonstrated the potential value of these traps in monitoring the availability of insects to farmland birds over a large area and recommended examination of data from other traps in the RIS national network.

This study uses the historical samples from four RIS suction traps to compile indices of total aerial invertebrate biomass at those sites and then investigates temporal trends, using subsets of these samples to elucidate the taxa mainly responsible.

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## Methods

Rothamsted Insect Survey suction traps (Macaulay *et al.*, 1988) have been used to monitor aphids in the UK since 1965 (Harrington & Woiwod, 2007). The trap inlet is 12.2 m above ground level and the traps are standardised to sample 50 $m^3$ air per minute. Traps are emptied daily. Aphidoidea (aphids) are removed, identified, counted and stored. Neuroptera, Syrphidae, Coccinellidae, Lepidoptera, Apoidea and Vespoidea are also removed from samples, identified, counted and, until recently, destroyed. The rest of the sample (referred to hereafter as 'other insects', but including a few arachnids) is stored in a mixture of ethanol and glycerol. Several of these samples have become dehydrated at various times, but the presence of glycerol has meant that they have rarely dried out completely and can be rehydrated with little damage. Samples from 1973 onward are available for most sites, although the trap at Rothamsted has three missing years from 1976 to 1978. At various times, for various reasons, certain 'other insects' have been removed. In most cases, adequate records of such removals are available, but for some years records for certain species have been lost. However, such losses have very little impact on the current study. Data from the RIS traps at Rothamsted, Hereford, Wye and Starcross (Figure 1) are analysed in this paper.


**Fig. 1.** Location of RIS suction traps in the UK. Filled stars indicate sites used in this study.

### *Total biomass*

An index of total biomass was created for each of the four RIS traps as follows. Samples of 'other insects' trapped on every fourth day from 1st April to 30th September between 1973 and 2002 were emptied onto a piece of muslin over a beaker and the alcohol drained off. The insects from each sample were then transferred to filter paper and weighed. A 'wet weight' of insects was obtained by re-weighing the filter paper after the insects had been replaced in their bottles and subtracting this weight from the combined weight of insects and filter paper. Tests showed that the effect of liquid evaporation between weighings was negligible. Some other material, including seeds, was present in the samples but, compared to the 'other insects', this did not constitute a significant mass. Wet weights of the insect taxa which had been removed from the samples were estimated and recorded separately for each taxon. In these cases, samples from every day (not every fourth day) were assessed. Weights of these removed taxa were estimated by weighing known numbers of individuals and regressing total weight on number of individuals present, the slope being the mean weight. Mean weights were multiplied by the number of removed insects in each sample for inclusion in the sample's total annual biomass index. As long-term count data were already available for aphids, moths and social wasps, these were also converted into biomass estimates. All biomass measurements for each year were converted into mean wet weight per sample, logged (to base 10), and were then regressed on year (Harrington *et al.*, 2003).

### *The Hereford data*

Analysis of data from all the four sites showed a decline in biomass with year at the Hereford trap, but not at the other three (see 'Results'). Further work was therefore carried out on the Hereford trap samples to identify declines in individual taxa. Time constraints meant that only larger insects (those that did not pass through a 2 mm × 2 mm sieve) could be included in this analysis, but numbers of smaller insects were found not to decline significantly with year (Moore *et al.*, 2004) and so it is unlikely that individual taxa within this fraction would show significant decline.

*Biomass*. Samples were combined to produce an annual index of biomass using 26 sample dates from each of the years 1973–2004 as follows. Samples were taken from the day with the highest maximum temperature in each sample week starting on the 2nd April and ending on 30th September, using Hereford (Rosemaund) meteorological data from BBSRC ARCMET database (© Crown copyright 2008, the Met. Office). Samples of 'other insects' were first passed through a 2 × 2 mm sieve to remove the smaller insects and then the biomass ('wet weight' in alcohol) of the insects retained on the sieve (i.e. the larger insects) was recorded. An approximate wet weight for previously removed Neuroptera, Syrphidae, Coccinellidae and Lepidoptera was calculated (see above) and added to the observed wet weight. Measurements for each year were converted into mean wet weight per sample. The mean weights were logged [$\log_{10}(n + 0.05)$], and these indices of biomass were regressed on year.

*Counts*. The larger insects from the 12 weeks of highest biomass, 23rd April to 3rd June (spring) and 20th August to 30th September (autumn), were identified as follows and counted. The Bibionidae, which dominated many of the samples in terms of mass, were identified to species, counted and weighed. In the case of males of the genus *Dilophus*, the first one hundred individuals were identified to species [invariably *D. febrilis* (L.), the fever fly] and the rest were assumed to be the same species. Other taxa identified and counted were: Coleoptera (to family, occasionally genus or species); Diptera (to family); Hemiptera (Auchenorrhyncha to family, Heteroptera to sub-order); Neuroptera (to family); Dermaptera (to species); Hymenoptera (to super-family, family, genus, or species as feasible); Trichoptera (to order); Ephemeroptera (to order) and Araneae (to division). A combined weight for these other taxa was recorded. Microlepidoptera from the last 3 years of study were not available, but owing to the small numbers recorded in other years they were not expected to contribute significantly to the overall biomass.

The data from biomass and counts were analysed using GenStat (Payne *et al*., 2005). Linear regressions on year were carried out for all data and bootstrap estimates made from 1000 resamples.

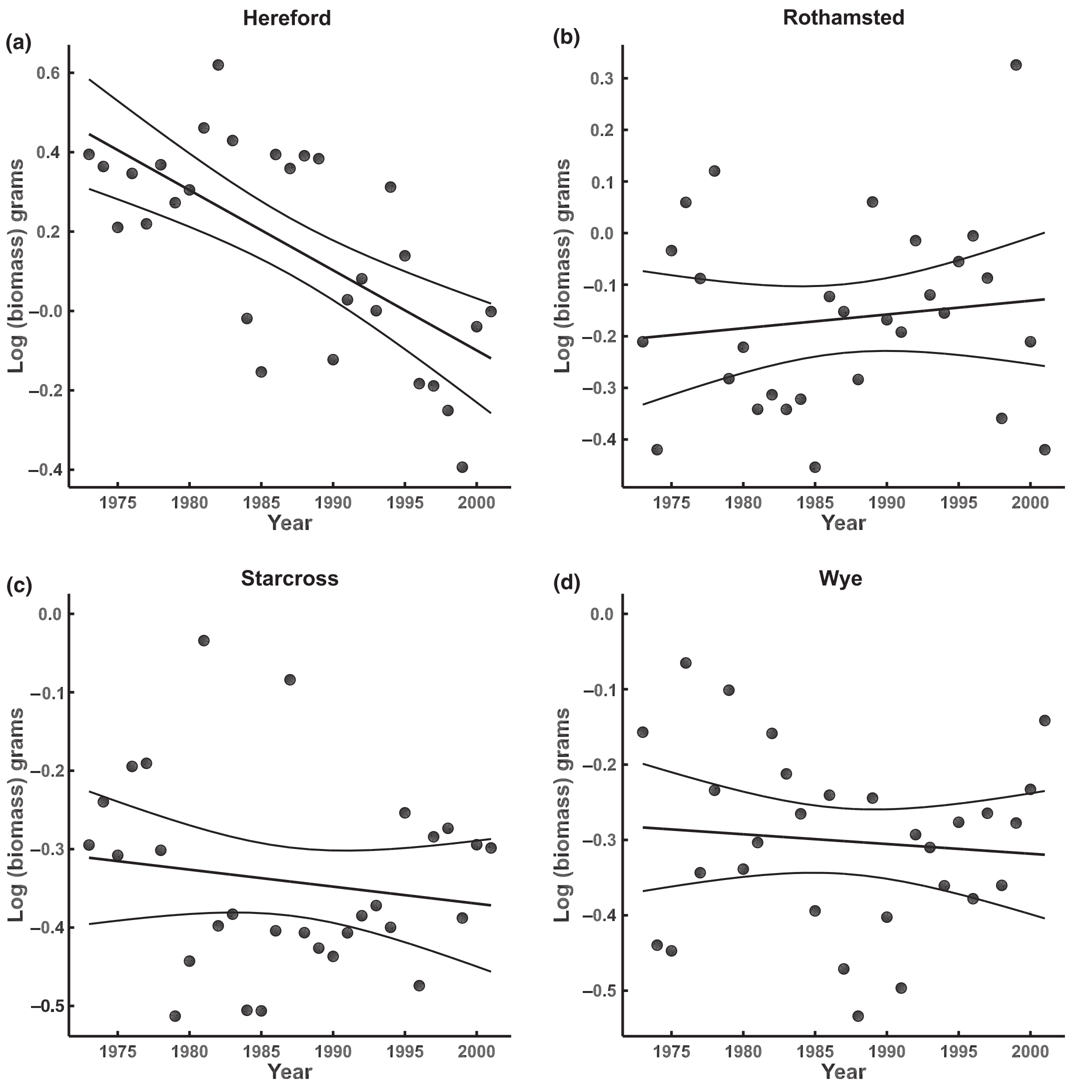


**Fig. 2.** Trends in total insect biomass ($\log_{10}$ mean weight in grams of insects per sample) plotted against year with 95% confidence intervals.

**Table 1.** Summary statistics, all data regressed against year.

| | Slope | SE of slope | Intercept | SE of intercept | % Variance accounted for | *P*-value | Bootstrap slope | Bootstrap SE | Bootstrap 95% confidence intervals | |
|---|---|---|---|---|---|---|---|---|---|---|
| Biomass Hereford | −0.01885 | 0.00410 | 37.63 | 8.16 | 40.9 | < 0.001 | −0.01894 | 0.00335 | −0.02659 | −0.01228 |
| Biomass Rothamsted | 0.00557 | 0.00409 | −11.22 | 8.13 | 3.2 | 0.186 | 0.00554 | 0.00462 | −0.00378 | 0.01503 |
| Biomass Starcross | −0.00217 | 0.00265 | 3.97 | 5.26 | – | 0.420 | −0.00219 | 0.00212 | −0.00626 | 0.00197 |
| Biomass Wye | −0.00129 | 0.00265 | 2.27 | 5.26 | – | 0.629 | −0.00135 | 0.00275 | −0.00685 | 0.00370 |
| Aphid biomass Hereford | −0.00377 | 0.00357 | 6.35 | 7.10 | 0.4 | 0.300 | −0.00355 | 0.00371 | −0.01102 | 0.00368 |
| Aphid biomass Rothamsted | 0.00119 | 0.00516 | −3.6 | 10.3 | – | 0.819 | 0.00108 | 0.00566 | −0.01078 | 0.01174 |
| Aphid biomass Starcross | 0.00335 | 0.00390 | −7.98 | 7.75 | – | 0.399 | 0.00341 | 0.00415 | −0.00506 | 0.01161 |
| Aphid biomass Wye | −0.00115 | 0.00375 | 1.10 | 7.46 | – | 0.762 | −0.00091 | 0.00442 | −0.00983 | 0.00809 |
| Moth biomass Hereford | −0.02351 | 0.00415 | 45.05 | 8.25 | 52.6 | < 0.001 | −0.02359 | 0.00347 | −0.03069 | −0.01717 |
| Moth biomass Rothamsted | −0.00754 | 0.00534 | 13.4 | 10.6 | 3.8 | 0.171 | −0.00775 | 0.00498 | −0.01671 | 0.00282 |
| Moth biomass Starcross | −0.02420 | 0.00396 | 46.35 | 7.88 | 56.4 | < 0.001 | −0.02407 | 0.00364 | −0.03185 | −0.01756 |
| Moth biomass Wye | −0.01386 | 0.00559 | 25.9 | 11.1 | 15.5 | 0.020 | −0.01390 | 0.00488 | −0.02308 | −0.00399 |
| Wasp biomass Hereford | −0.0275 | 0.0122 | 52.8 | 24.2 | 14.5 | 0.034 | −0.0133 | 0.0176 | −0.0492 | 0.0188 |
| Wasp biomass Rothamsted | 0.0111 | 0.0146 | −23.6 | 29.0 | – | 0.455 | 0.0120 | 0.0132 | −0.0130 | 0.0404 |
| Large insect biomass Hereford | −0.04094 | 0.00855 | 81.4 | 17.0 | 41.4 | < 0.001 | −0.04108 | 0.00884 | −0.5917 | −0.2585 |
| Bibionid biomass Hereford | −0.0454 | 0.0119 | 90.0 | 23.6 | 30.5 | < 0.001 | −0.0453 | 0.0121 | −0.0691 | −0.0222 |
| Other large insect biomass Hereford | −0.01660 | 0.00671 | 32.4 | 13.3 | 14.2 | 0.019 | −0.01683 | 0.00669 | −0.03248 | −0.00346 |
| Bibionid count Hereford (spring) | −0.0446 | 0.0140 | 90.5 | 27.9 | 23.2 | 0.004 | −0.0440 | 0.0139 | −0.0699 | −0.0162 |
| Large Diptera count Hereford (spring) | −0.01886 | 0.00950 | 38.2 | 18.9 | 9.5 | 0.048 | −0.01835 | 0.00977 | −0.03825 | 0.00083 |
| Bibionid count Hereford (autumn) | −0.0421 | 0.0201 | 84.8 | 39.9 | 11.6 | 0.046 | −0.0429 | 0.0182 | −0.0811 | −0.0082 |
| Large Diptera count Hereford (autumn) | −0.01679 | 0.00718 | 33.9 | 14.3 | 12.6 | 0.026 | −0.01687 | 0.00740 | −0.03174 | −0.00361 |

## Results

There was a significant decline ($P < 0.001$) in total biomass with year at Hereford, but no significant trend at Rothamsted ($P = 0.52$), Starcross ($P = 0.42$) or Wye ($P = 0.63$) (Fig. 2) (see Table 1 for a summary of all statistics).

Total aphid biomass did not show a significant trend with year at any site (P > 0.05). There was a significant decline in moth biomass at Hereford ($P < 0.001$), Starcross ($P < 0.001$) and Wye ($P < 0.05$) but not at Rothamsted (P > 0.05). There was no significant trend ($P > 0.05$) in biomass of social wasps at Rothamsted, but a significant decline at Hereford ($P < 0.05$). These three groups (aphids, moths and social wasps) each form only a small proportion of the total aerial biomass.

### *The Hereford samples*

There was a strong decline in biomass of larger insects at Hereford ($P < 0.001$; Fig. 3) along similar lines to that recorded in the total biomass index, which included insects of all sizes. When the data were converted into a weekly mean across years, the majority of the biomass was concentrated in two peaks, a large spring peak around May (weeks 18–22) and a smaller autumn peak in September (weeks 36–39) (Fig. 4).

In terms of numbers, the Bibionidae (Diptera) made up the greater part of the samples of larger insects in most years, especially in spring (Table 2). The major orders in the samples of larger insects were Diptera and Coleoptera, with Hymenoptera and Lepidoptera also having large percentages in some years. The total bibionid catch was 60,308 individuals. The families with the highest counts of larger insects other than Bibionidae were: Chironomidae (Diptera) 914, Empididae (Diptera) 327, Anthomyiidae (Diptera) 317, Anisopodidae (Diptera) 133, Calliphoridae (Diptera) 122, Tipulidae (Diptera) 112, Curculionidae (Coleoptera) 341, Staphylinidae (Coleoptera) 246 and Carabidae (Coleoptera) 108. Of these the Tipulidae, Calliphoridae and some Carabidae (e.g. *Amara* sp.), being large insects, will have had a greater effect on the total wet weight.

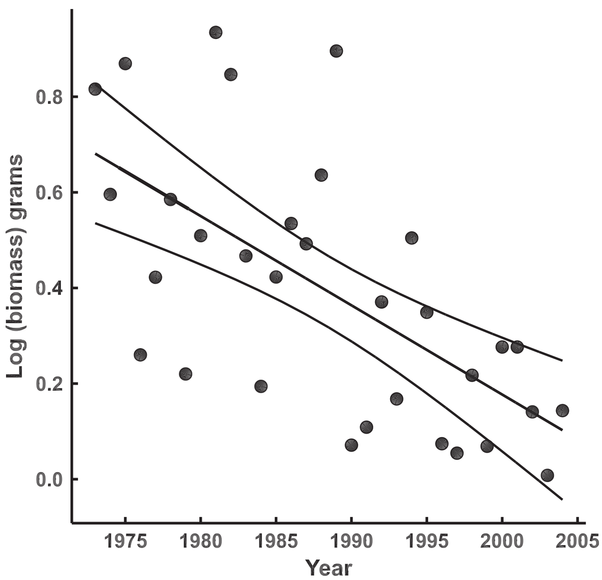


**Fig. 3.** Total annual biomass index of larger insects in stored samples from Hereford suction trap plotted against year with 95% confidence intervals.

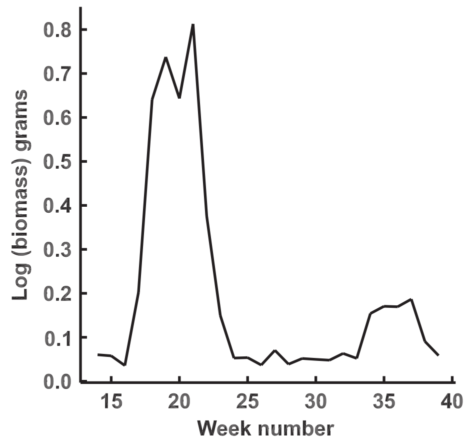


**Fig. 4.** Mean weekly biomass index (1973–2004) of larger insects from Hereford suction trap.

The wet weight of bibionids declined significantly ($P < 0.001$) during the period (Figure 5), as did the wet weight of the remaining large Diptera combined with other taxa ($P < 0.05$) (Figure 6). Tests of parallelism showed that the bibionid wet weight did not decline at a significantly different rate to that of the remaining large Diptera combined with other taxa ($P > 0.05$).

The majority of all samples of larger insects were Diptera and the majority of these Diptera were Bibionidae. In the logged count data the decline of bibionids was particularly evident during the spring ($P < 0.01$) (Fig. 7), and was significantly greater ($P < 0.001$) than for each of the other taxa examined, amongst which only the combined other large Diptera declined significantly ($P < 0.05$). In the autumn the pattern was similar, bibionids declining ($P < 0.05$) and other large Diptera declining ($P < 0.05$) (Fig. 8). The small numbers of individuals of other taxa recorded may have reduced the statistical power of the analyses and may be the reason for the lack of significance in some cases. The trend for summer has not been determined, because of the relatively small number of large insects sampled.

## Discussion

Linear regression analyses have been used to describe the overall trends in biomass and abundance of a range of insect taxa. Cyclical patterns of temporal variation may occur but these require more data to elucidate with confidence and will be investigated in future studies.

The decline in total invertebrate biomass in the Hereford suction trap with time was clear but was not repeated at the other

**Table 2.** Percentage of catch of selected taxa by year and season (count data).

| Date | | *n* | Bibionidae | Other Diptera | Hemiptera | Coleoptera | Lepidoptera | Hymenoptera | Others | | *n* | Bibionidae | Other Diptera | Hemiptera | Coleoptera | Lepidoptera | Hymenoptera | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | Spring | 6 | 97.94 | 2.00 | 0.00 | 0.01 | 0.01 | 0.03 | 0.00 | Autumn | 5 | 20.00 | 55.00 | 0.00 | 5.00 | 20.00 | 0.00 | 0.00 |
| 1974 | Spring | 6 | 98.99 | 0.87 | 0.03 | 0.07 | 0.03 | 0.00 | 0.00 | Autumn | 5 | 70.52 | 23.88 | 0.00 | 1.87 | 3.73 | 0.00 | 0.00 |
| 1975 | Spring | 6 | 97.49 | 2.35 | 0.02 | 0.11 | 0.02 | 0.02 | 0.00 | Autumn | 6 | 37.84 | 29.73 | 0.00 | 13.51 | 17.57 | 1.35 | 0.00 |
| 1976 | Spring | 6 | 92.58 | 4.64 | 0.00 | 2.32 | 0.23 | 0.23 | 0.00 | Autumn | 5 | 48.98 | 34.69 | 0.00 | 14.29 | 0.00 | 0.00 | 2.04 |
| 1977 | Spring | 5 | 58.62 | 24.14 | 0.00 | 13.79 | 0.00 | 0.00 | 3.45 | Autumn | 6 | 38.05 | 53.98 | 0.00 | 1.77 | 5.75 | 0.00 | 0.44 |
| 1978 | Spring | 6 | 92.89 | 5.73 | 0.11 | 1.21 | 0.06 | 0.00 | 0.00 | Autumn | 6 | 94.90 | 2.75 | 0.14 | 1.10 | 0.83 | 0.00 | 0.28 |
| 1979 | Spring | 3 | 56.00 | 16.00 | 0.00 | 24.00 | 0.00 | 4.00 | 0.00 | Autumn | 6 | 92.35 | 4.59 | 0.17 | 2.21 | 0.17 | 0.17 | 0.34 |
| 1980 | Spring | 6 | 95.68 | 2.82 | 0.23 | 0.75 | 0.23 | 0.23 | 0.06 | Autumn | 6 | 88.61 | 6.33 | 0.25 | 0.76 | 2.53 | 0.51 | 1.01 |
| 1981 | Spring | 6 | 99.46 | 0.26 | 0.03 | 0.23 | 0.00 | 0.01 | 0.00 | Autumn | 6 | 88.68 | 7.76 | 0.00 | 2.10 | 0.84 | 0.21 | 0.42 |
| 1982 | Spring | 6 | 97.00 | 2.37 | 0.08 | 0.30 | 0.08 | 0.10 | 0.07 | Autumn | 5 | 72.87 | 23.26 | 0.00 | 0.78 | 3.10 | 0.00 | 0.00 |
| 1983 | Spring | 3 | 96.54 | 2.48 | 0.00 | 0.71 | 0.09 | 0.18 | 0.00 | Autumn | 5 | 6.67 | 43.33 | 6.67 | 21.67 | 0.00 | 10.00 | 11.67 |
| 1984 | Spring | 6 | 93.64 | 0.85 | 0.00 | 5.08 | 0.42 | 0.00 | 0.00 | Autumn | 5 | 5.26 | 26.32 | 10.53 | 26.32 | 0.00 | 5.26 | 26.32 |
| 1985 | Spring | 6 | 86.23 | 9.58 | 0.00 | 3.29 | 0.30 | 0.30 | 0.30 | Autumn | 4 | 66.86 | 17.44 | 1.16 | 6.40 | 2.33 | 4.07 | 1.74 |
| 1986 | Spring | 6 | 96.71 | 1.86 | 0.19 | 1.24 | 0.00 | 0.00 | 0.00 | Autumn | 6 | 96.32 | 2.20 | 0.00 | 1.29 | 0.05 | 0.00 | 0.14 |
| 1987 | Spring | 5 | 96.54 | 2.94 | 0.00 | 0.46 | 0.00 | 0.00 | 0.06 | Autumn | 6 | 95.24 | 1.88 | 0.00 | 2.01 | 0.25 | 0.13 | 0.50 |
| 1988 | Spring | 6 | 91.98 | 7.31 | 0.00 | 0.65 | 0.00 | 0.06 | 0.00 | Autumn | 5 | 98.23 | 0.86 | 0.10 | 0.67 | 0.14 | 0.00 | 0.00 |
| 1989 | Spring | 6 | 96.82 | 2.35 | 0.03 | 0.67 | 0.11 | 0.04 | 0.00 | Autumn | 6 | 77.99 | 4.31 | 1.91 | 13.40 | 0.00 | 0.96 | 1.44 |
| 1990 | Spring | 5 | 72.66 | 16.55 | 0.00 | 7.19 | 0.00 | 3.60 | 0.00 | Autumn | 6 | 4.88 | 56.10 | 0.00 | 19.51 | 0.00 | 14.63 | 4.88 |
| 1991 | Spring | 5 | 87.70 | 7.54 | 0.40 | 3.57 | 0.00 | 0.40 | 0.40 | Autumn | 6 | 56.16 | 10.96 | 0.00 | 21.92 | 0.00 | 2.74 | 8.22 |
| 1992 | Spring | 5 | 87.84 | 4.28 | 1.03 | 6.68 | 0.00 | 0.00 | 0.17 | Autumn | 5 | 16.28 | 48.84 | 4.65 | 20.93 | 0.00 | 9.30 | 0.00 |
| 1993 | Spring | 6 | 57.94 | 9.35 | 2.80 | 21.50 | 0.00 | 7.48 | 0.93 | Autumn | 4 | 49.15 | 44.92 | 0.00 | 4.24 | 0.00 | 0.85 | 0.85 |
| 1994 | Spring | 6 | 97.68 | 0.82 | 0.00 | 1.24 | 0.04 | 0.21 | 0.00 | Autumn | 6 | 86.41 | 5.43 | 0.54 | 3.80 | 0.00 | 1.63 | 2.17 |
| 1995 | Spring | 6 | 90.50 | 7.50 | 0.35 | 1.13 | 0.09 | 0.35 | 0.09 | Autumn | 6 | 51.28 | 15.38 | 0.00 | 25.64 | 0.00 | 2.56 | 5.13 |
| 1996 | Spring | 5 | 88.89 | 4.44 | 2.22 | 4.44 | 0.00 | 0.00 | 0.00 | Autumn | 6 | 5.41 | 20.27 | 2.70 | 45.95 | 0.00 | 20.27 | 5.41 |
| 1997 | Spring | 6 | 59.04 | 22.89 | 0.00 | 8.43 | 1.20 | 7.23 | 1.20 | Autumn | 5 | 8.70 | 30.43 | 4.35 | 30.43 | 0.00 | 17.39 | 8.70 |
| 1998 | Spring | 6 | 92.50 | 3.65 | 0.58 | 2.69 | 0.00 | 0.19 | 0.38 | Autumn | 6 | 4.71 | 30.59 | 1.18 | 41.18 | 0.00 | 11.76 | 10.59 |
| 1999 | Spring | 6 | 49.90 | 16.70 | 2.44 | 24.03 | 0.20 | 5.70 | 1.02 | Autumn | 5 | 34.78 | 39.13 | 0.00 | 13.04 | 0.00 | 4.35 | 8.70 |
| 2000 | Spring | 6 | 12.59 | 41.48 | 0.74 | 17.04 | 0.00 | 28.15 | 0.00 | Autumn | 6 | 76.32 | 12.87 | 0.58 | 6.14 | 0.00 | 3.22 | 0.88 |
| 2001 | Spring | 6 | 82.57 | 10.09 | 0.00 | 6.42 | 0.00 | 0.00 | 0.92 | Autumn | 6 | 94.15 | 2.46 | 0.12 | 1.99 | 0.47 | 0.70 | 0.12 |
| 2002 | Spring | 6 | 78.88 | 11.80 | 1.24 | 6.83 | 0.62 | 0.00 | 0.62 | Autumn | 6 | 58.14 | 28.12 | 0.21 | 6.77 | 2.33 | 2.33 | 2.11 |
| 2003 | Spring | 6 | 0.00 | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Autumn | 1 | 0.00 | 66.67 | 0.00 | 0.00 | 0.00 | 0.00 | 33.33 |
| 2004 | Spring | 6 | 72.99 | 19.43 | 0.47 | 5.21 | 0.00 | 1.42 | 0.47 | Autumn | 5 | 0.00 | 11.43 | 0.00 | 14.29 | 14.29 | 31.43 | 28.57 |

*n*, number of samples.

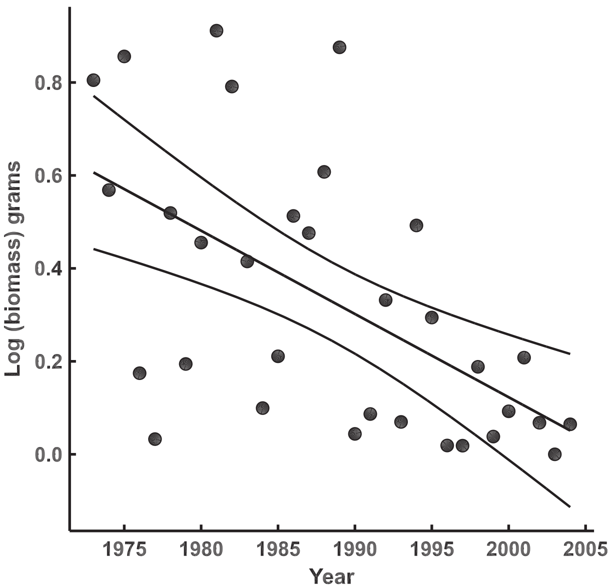


**Fig. 5.** Total annual biomass of Bibionidae in samples from Hereford suction trap plotted against year with 95% confidence intervals.

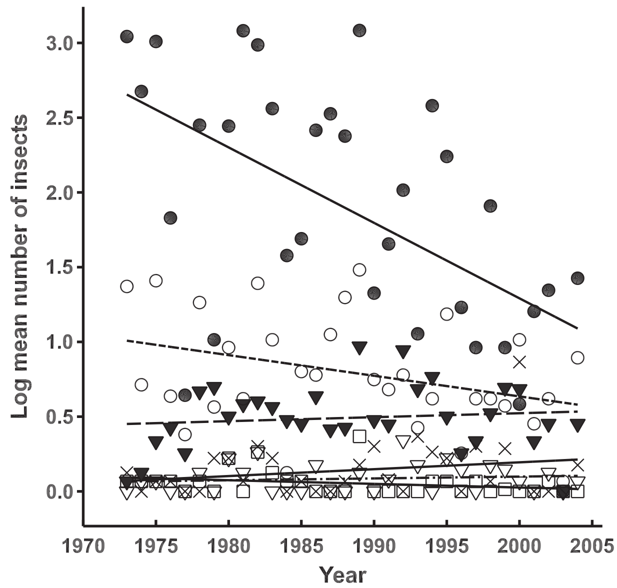


**Fig. 7.** Total number of larger insects in spring samples from the Hereford suction trap plotted against year. —●— Bibionidae ···▼··· Coleoptera —⊖- Other Diptera ····×···· Hymenoptera -·⊟·- Lepidoptera — ▽ — Hemiptera

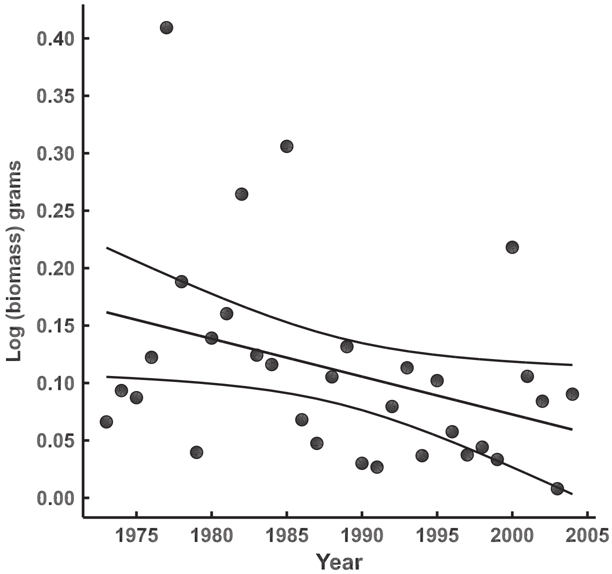


**Fig. 6.** Total annual biomass of other large insects in samples from Hereford suction trap plotted against year with 95% confidence intervals.

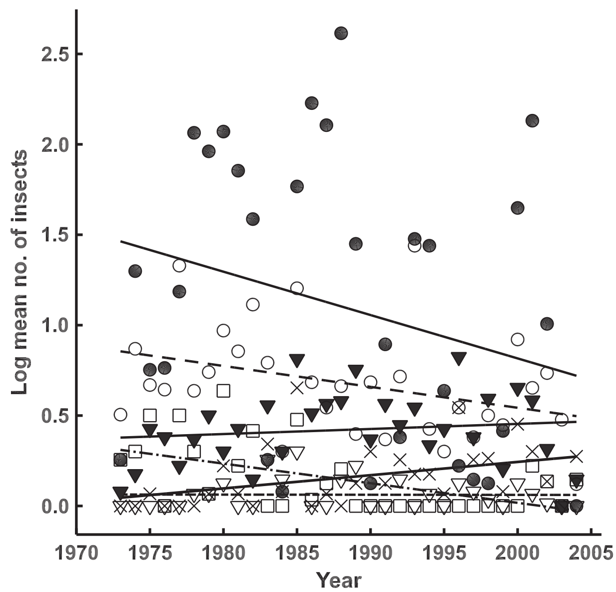


**Fig. 8.** Total number of larger insects in autumn samples from the Hereford suction trap plotted against year (for legend, see Fig. 7).

three sites examined. However, the total biomass in the Hereford trap was much greater than at the other sites, especially in the earlier years, so it is possible that any overall declines at the other sites had already taken place before 1973. Indeed the little evidence available does suggest that such declines, at least for the Lepidoptera in arable areas, took place as a result of the first phase of agricultural intensification in the 1950s (Woiwod, 1991).

In the case of aphids the traps are representative of the aerial population over at least an 80 km radius (Taylor, 1974; Benton *et al*., 2002; Cocu *et al*., 2005). Whether this is the case for all taxa has not been investigated, so the spatial extent of the decline in the Hereford area is not certain, although insects flying at 12.2 m are likely to be affected by wind, and therefore randomised, over a considerable area (Taylor, 1974).

 

The fraction in the trap samples that did not pass through a $2 \times 2$ mm sieve made up only 16% of the total number of individuals sampled (Moore *et al*., 2004), although its contribution to the total biomass was much greater. There was much annual variability in the data so that whilst the decline in biomass and number of bibionids and other Diptera was highly significant, the year term only accounted for a relatively small percentage of the variance.

*Dilophus febrilis* adults first appear in late April and early May, with warm dry weather favouring early emergence. Unlike other *Dilophus* and *Bibio* species, *D. febrilis* appears throughout the year with peaks in spring and autumn (Freeman & Lane, 1985). They are active in bright sunshine, visiting flowers of cultivated and wild plants (Edwards, 1941) and are possibly important supplementary pollinators of fruit trees (Free, 1970; D'Arcy-Burt & Blackshaw, 1991). The species is known to swarm in mass aggregations on low vegetation (Freeman & Lane, 1985). After mating the females burrow into the soil, where 200–300 eggs are laid in an egg sac at a depth of 3 cm or more. After this the female flies die, usually just outside the egg sac. The males do not survive long after mating (Freeman & Lane, 1985). The larvae have been reported to damage various crops and grass lawns, but it is generally believed that they are harmless, feeding mainly on decaying organic matter with more damage caused by birds searching for the larvae, than by the larvae themselves (Edwards, 1941; D'Arcy-Burt & Blackshaw, 1991). D'Arcy-Burt and Blackshaw (1991) reported high abundance of bibionids in the UK in1976/77 and 1984/85. These are not reflected in the current study; in fact 1984/1985 showed a relatively low abundance in the Hereford dataset.

The factors that have affected populations of insects at Hereford are unknown. Benton *et al*. (2002) suggested that changes in aerial arthropod abundances, as reflected in suction trap samples, are related to regional changes in farmland practice. One factor could be a reduction in the use of organic fertiliser, although Edwards (1941) claimed that the incidence of attacks by bibionid larvae on sports fields and private lawns is not necessarily related to high amounts of humus and organic manure input. Increased management of grassland and the associated reduction of rough grassland has been cited as a reason for reduced insect numbers (Newton, 2004), and this could affect bibionid numbers. It is also possible that the decrease in biomass is related to a general increase in the use of pesticides (Avery *et al*., 2004; Boatman *et al*., 2004), although these declines were not reflected in the biomass index at the other three sites. It is known that many changes in agriculture occurred earlier in the east of Britain than the west (Newton, 2004) and this may explain the higher biomass at Hereford early in the series in comparison with the other sites, although the other western site, Starcross, does not show the same pattern. The use of insecticides to control the similar and closely related leatherjackets (Tipulidae larvae) (McCracken & Tallowin, 2004) may have had an effect on *D. febrilis* numbers and other studies have linked declines of other taxa to the use of pesticides (Campbell *et al*., 1997; Sotherton & Self, 1999). Another possible factor is the use of avermectins to treat cattle for parasites as this has been shown to have a detrimental effect on dung insects (McCracken, 1993; Hutton & Giller, 2003) and may also affect insects such as *D. febrilis* that feed on decaying organic matter. Although this species dominates the samples in spring, other large insects are also declining at a rate that is not significantly different from the rate of decline of bibionids. It is likely that the decline is due to factors that are not taxon specific, although there are signs in this dataset that the Diptera are being more affected than other taxa sampled.

There is increasing evidence of an indirect effect of insecticides on birds (Donald *et al*., 2001; Boatman *et al*., 2004). Insects, particularly larger ones, are an important component of the diet of many birds (Davies, 1977; Moreby, 2004). Diptera have been identified as important in the diet of adults and chicks across a range of species (Barker, 2004; Moreby, 2004; Buchanan *et al*., 2006; Holland *et al*., 2006). Declining numbers of insects can remove an important source of food for chicks and have a knock-on effect on population sizes of a wide range of bird species (Southwood & Cross, 1969; Wilson *et al*., 1999). The Bibionidae have been shown to make up a significant part of the dipteran diet of partridges, *Perdix perdix* (L.) (Evans, 1912), dunnocks, *Prunella modularis* L. (Moreby, 2004), swifts, *Apus apus* L. (Parmenter & Owen, 1954) and other species (Buchanan *et al*., 2006). In addition, larvae of bibionids may form an important component of the diet of ground feeding birds and mammals, although the soft bodies of the larvae mean that faecal and pellet analysis will not reveal their presence (Moreby, 2004). Several studies have highlighted the importance of tipulid larvae to birds (Holland *et al*., 2006), but it is unclear what measures were taken to distinguish them from the very similar bibionid larvae. The declines shown at Hereford are thus likely to have had some effect on the bird populations of the surrounding area. That bird populations are in decline is not in doubt, for example between 1970 and 1990 the distribution of 86% and the abundance of 83% of UK farmland bird species declined (Fuller *et al*., 1995). Over a longer period (1966–1999) significant declines were also recorded in 10 of 32 species of woodland bird (Fuller *et al*., 2005).

It is likely that species using tall landscape features as aggregation markers will be over-represented in suction trap samples in relation to other species, although comparisons within species should be sound. Observation of *D. febrilis* by one of the authors (CRS) at the Hereford suction trap indicated that it does not have such aggregation behaviour and that the large numbers caught were indicative of a high aerial density. Freeman and Lane (1985) stated that *Dilophus* species typically form mass accumulations on low vegetation and this is consistent with observations at Hereford.

Long-term trends in the abundance of social wasps from RIS suction traps and other data series have been examined previously (Archer, 2001). The abundance of *Vespula germanica* (Fabricius), but not *V. vulgaris* (L.) was shown to decline during the late 1970s and early 1980s. Other long-term studies (Luff, 1990; Aebischer, 1991; Conrad *et al*., 2004) have identified declines in numbers or species richness in other invertebrate groups such as carabid beetles and Lepidoptera. It is interesting, then, that significant declines in total annual insect biomass were not found at three out of the four sites analysed here. It would be worthwhile to look more closely at the data series from these sites, together with other traps in the RIS network, to establish the status of the larger Diptera in other areas for comparison with the Hereford results.

Further work is necessary to quantify any changes to the land-use in the area of the Hereford trap and determine whether these are correlated with the observed declines. It would also be interesting to examine bird census data from the Hereford area to quantify any parallel declines. Stored RIS suction trap samples are available from other sites providing scope for studying whether the trends reported here are applicable more widely. There is also the suggestion of a multi-annual cycle in the wet weight of Bibionidae (Fig. 5) that warrants further study.

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