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Gardens as a Winter Feeding Refuge for Declining Farmland Birds

A Report to the Leverhulme Trust
Grant number F/01503/A

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Gardens as a Winter Feeding Refuge for Declining Farmland Birds

Report Summary

(a) Aims and Objectives

Declines in granivorous farmland birds are likely to have been influenced by decreases in over-winter survival rates. Loss of food resources, particularly cereal stubbles, are thought to have caused decreases in survival. Provision of bird food in gardens is a common activity which may provide an alternative food source in winter. Long-term survey data recording the maximum weekly count of all bird species using garden feeders in the winter were analysed to see if there was any evidence that farmland granivores were becoming increasingly dependent on garden bird food. Specifically, it was expected that numbers of granivorous, but not non-granivorous, birds in gardens in winter will have increased over time relative to national population trends; and, that numbers of granivorous, but not non-granivorous, birds will have shown progressively earlier within-winter peaks as farmland food resources are depleted more rapidly.

(b) Broad Findings

Several farmland granivores showed increases in numbers at garden feeders over time, but this was also the case with the majority of non-granivores. There was no consistent evidence that farmland granivores had changed their seasonal abundance at garden feeders. However, there was a tendency for declining granivores to show negative or no significant association between numbers at garden feeders and size of the breeding population whereas the majority of other species showed significant positive associations. Furthermore, the timing of increases in numbers of birds at garden feeders closely matched the population decline of Yellowhammer and Reed Bunting. Although the number of feeding stations was significantly associated with numbers of granivores at feeders, this could not solely explain the increase in the numbers of farmland granivores over time.

These associations were considered separately in gardens from different landscape types which were assumed to differ in farmland food availability. There was no consistent evidence that increases in abundance or seasonal shifts in within-winter peaks at garden feeders were associated with food availability in the surrounding countryside.

In conclusion, there was no evidence that farmland granivores as a group were becoming increasingly dependent on garden bird food. There was however compelling evidence to suggest this was the case for at least two species, Reed Bunting and Yellowhammer.

(c) Publications Resulting

An abstract of a paper presented at the 4th European Ornithological Union Conference at Chemnitz, Germany in August has been published in Die Vogelwarte (Vol. 42, page 9).

(d) Strengths and Weaknesses of the Research

A strength was that the research was able to use unique data sets to test key hypotheses. Both GBFS and CBC provide large-scale, long-term monitoring data that provide an extremely valuable data resource. This research is the most comprehensive analysis of garden bird ecology carried out to date in the UK. A further strength of the data lies in the analyses used. We were able to implement novel statistical techniques to describe annual and seasonal patterns in garden bird abundance.

The main weakness of the research was that there were no direct measures of stubble area. Instead, landscape-scale data were used to infer stubble availability. This lack of detail meant that several assumptions were made about the availability of farmland food resources in relation to broad landscape classifications.

Gardens as a Winter Feeding Refuge for Declining Farmland Birds

Final Report

(a) The Grant

The project was lead by Dr Juliet Vickery. The original start date was 1st April 2002, but this was delayed, with the agreement of The Leverhulme Trust, until 1st October 2002. The project duration was 12 months. Dr Dan Chamberlain was the research assistant responsible for the majority of analyses and report writing under Dr Vickery's supervision. In addition, other BTO staff contributed: Greg Conway extracted temperature data and spatially linked these data to GBFS sites using GIS; Dr David Glue provided advice on GBFS methods and data sets; Mike Toms supervised computerization of GBFS records and provided background information on garden bird ecology; and several support staff transferred data from GBFS forms onto the database.

Full costs are given below:

	Grant	**Actual**
Research staff costs	33,277	37,703
Secretarial costs	2,040	1,544
Computing	1,300	1,300
Overheads	7,654	7,654
	44,271	48,201

BTO is prepared to make up the shortfall on this project from its own resources.

(b) Objectives

There have been population declines in several species of farmland bird over the past four decades. Decline in over-winter survival as a result of decreases in the area of cereal stubbles, a food-rich habitat, is thought to have been a major contributory factor in the population decline of several granivorous species. Many of these species exploit food provided by humans at garden bird feeders. The importance of garden bird food to birds in the wider countryside has never been assessed, but it is possible that garden bird food can act as a vital resource in times of food shortage in the wider countryside. Given that farmland food sources for granivorous species are declining, it may be expected that these species are becoming increasingly reliant on garden bird food. Three key hypothesis were proposed to assess these potential effects:

(i) The numbers of granivorous, but not non-granivorous, birds in gardens in winter will have increased over time relative to national population trends;

(ii) The numbers of granivorous, but not non-granivorous, birds in gardens in winter will have shown progressively earlier within-winter peaks in numbers as farmland food resources are depleted more rapidly;

(iii) The patterns of change numbers of granivorous, but not non-granivorous, birds in gardens in winter will vary in relation to (a) the abundance of seed resources in the surrounding landscape and (b) the distance of gardens from farmland seed resources.

(c) Research activity

The above hypotheses were addressed by analysing long term survey data collected from a large number of garden sites throughout Great Britain. The survey, the Garden Bird Feeder Survey (GBFS) entailed recording maximum count of all species seen at garden feeders during each week in the winter (October to March). Further more, the amount of food provided is measured indirectly by recording the number of feeding stations. GBFS data are the longest running continuous garden monitoring data set in existence in the United Kingdom. The distribution of GBFS sites has been selected to broadly represent different regions of England, Scotland and Wales and to reflect a balanced sample of rural and suburban sites.

GBFS trends were able to be put into context of wider population trends using Common Birds Census (CBC) data, a large (c. 200 sites per year), long-running survey (annual between 1962 and 2000) that determines relative population change from year-to-year for a large number of species. CBC data has been extremely influential in drawing attention to the declines of farmland birds and has been used as the basis for the Farmland Bird Index, one of the government's 15 Headline Indicators for the Quality of Life.

The data were analysed using Poisson regression modelling. Both annual changes and changes within-winter were analysed with the same analysis. This entailed use of some novel statistical techniques in order to successfully model the variation in the within-winter peaks in abundance shown in many species and how these peaks varied over time.

(d) Conclusions and achievements

Each of the above three hypotheses will be addressed in turn with particular reference to eight farmland granivores, House Sparrow, Tree Sparrow, Chaffinch, Greenfinch, Goldfinch, Linnet, Reed Bunting and Yellowhammer:

(i) Both granivorous and non-granivorous species tended to show increases in the abundance at garden feeders over time. Furthermore, the magnitude of increase, although greatest for Goldfinch and Yellowhammer, was no greater overall than for non-granivorous species. The amount of food provided had increased significantly over time and this could explain the increase in abundance in several species, this was not the case for most farmland granivores. Two species, Reed Bunting and Yellowhammer showed very close associations between declines in breeding populations and increases in abundance at garden feeders which was not the case for other farmland granivores. Temperature influenced the abundance of the majority of species at garden feeders, but these associations could not explain trends over time. Therefore, there was no evidence that farmland granivores as a group were becoming more dependent on garden bird food over time, but there was support for the hypothesis for the individual species Yellowhammer and Reed Bunting.

(ii) There was a general tendency for both farmland granivores and other species to show progressively earlier seasonal peaks in abundance at garden feeders. Furthermore, there were some granivores that showed a progressively later peak, Goldfinch, Linnet and Yellowhammer. Therefore, there was no support for the hypothesis that farmland granivores in gardens in winter will have shown progressively earlier within-winter peaks in numbers.

(iii) (a) Gardens were defined as either within arable or non-arable landscapes and as within autumn cereal or spring cereal dominated areas. It was assumed that these classifications represented differences in the abundance of seed resources in the surrounding farmland, where arable and spring cereal dominated landscapes had higher seed resources. Trends in the abundance of farmland granivores did not vary consistently either annually or seasonally in a way that may have reflected food abundance in the surrounding landscape. For individual species, Yellowhammer did show evidence of a greater abundance in spring cereal dominated areas and less of a response to the amount of food provided which could be indicative of greater food resources available in the surrounding landscape. (b) Gardens were defined as either rural or suburban. It was assumed that these classifications represented sites that were relatively close and distant to seed resources. Trends in the abundance of farmland granivores did not vary consistently either annually or seasonally in a way that may have reflected distance from farmland food resources in the surrounding landscape. For individual species, Goldfinch abundance was associated with the amount of food provided in suburban gardens only and Reed Bunting showed an earlier increase at feeders in rural landscapes. These trends may reflect the greater proximity of farmland food resources in rural gardens.

(e) Publications and dissemination

No full papers have been published from the project to date, but two manuscripts have been prepared and will be submitted shortly (these are included within the report). An abstract of a paper presented at the 4th European Ornithological Union Conference at Chemnitz, Germany in August has been published in Die Vogelwarte:

Chamberlain, DE, Vickery, JA & Glue DE (2003). Are granivorous farmland birds becoming dependent on garden bird food in the winter in the UK? Die Vogelwarte 42: 9.

Project information was disseminated through ecological conferences. The project rationale and predictions were presented at the International Ornithological Congress in Beijing, China, August 2002. Results were presented at he European Ornithologists Union Conference in Germany (see above) and at the British Ecological Society Annual Meeting in Manchester, September 2003.

(f) Future research plans in this field

The weakness of the research was associated with hypothesis (iii) in that a number of assumptions were made about bird behaviour and food availability in different landscapes. Spatially referenced analysis (for example in a GIS framework) and greater knowledge of the dispersal behaviour of birds would improve this aspect of the research.

Several projects on the ecology of urban birds are being carried out at the BTO. The techniques used in this analysis will be applied to other long-term data sets to determine if similar patterns are evident.

(g) Key words

Birds; Farmland; Gardens; Stubbles; Winter.

Part I: Annual and seasonal trends in the use of garden feeders by birds, with particular reference to declining granivorous species.

DE Chamberlain, JA Vickery, DE Glue & GJ Conway

ABSTRACT

Declines in granivorous farmland birds are likely to have been influenced by decreases in over-winter survival rates. Loss of food resources, particularly cereal stubbles, are thought to have caused decreases in survival. Provision of bird food in gardens is a common activity which may provide an alternative food source to farmland granivores in winter. Long-term survey data recording the maximum weekly count of all bird species using garden feeders in the winter were analysed to see if there was any evidence that farmland granivores were becoming increasingly dependent on garden bird food. Several granivorous farmland birds showed increases in numbers at garden feeders over time, but this was also the case with the majority of non-granivorous species. Similarly, the magnitude of increase was generally no higher for granivorous species, although Goldfinch *Carduelis carduelis* and Yellowhammer *Emberiza citrinella* did show exceptionally large increases in gardens. There was no consistent evidence that farmland granivores had changed their seasonal abundance at garden feeders. However, there was a tendency for declining granivorous species to show negative or no significant association between numbers at garden feeders and size of the breeding population whereas the majority of other species showed significant positive associations. Furthermore, the timing of increases in numbers of birds at garden feeders closely matched the population decline of Yellowhammer and Reed Bunting *Emberiza schoeniclus*. Although the number of feeding stations was significantly associated with numbers of granivores at feeders, the increase in feeding stations over time could not solely explain the increase in the numbers of farmland granivores over time.

1. INTRODUCTION

Declines in populations of farmland birds in Britain throughout the past four decades are well documented (Fuller et al. 1995, Siriwardena et al. 1998, Aebisher et al. 2000). As a group, farmland specialists (those species where the majority of the population derives most of their resources from farmland) are more likely to have shown declines, have shown greater losses in range and have shown greater magnitudes of decline than generalist species or species that specialize on other habitats (Fuller et al. 1995). Certain granivorous species, particularly those that commonly feed on the seeds of arable weeds such as Corn Bunting *Miliaria calandra*, Tree Sparrow *Passer montanus*, Linnet *Carduelis cannabina* and Reed Bunting seem to have been particularly affected.

There now seems little doubt that rapid changes in agricultural management (intensification), particularly during the 1970s, are closely associated with declines in many farmland bird species (Chamberlain et al. 2000). A whole suit of factors have the potential to affect farmland bird populations and the invertebrates and weeds on which they are dependent (Aebischer et al. 2000, Chamberlain et al. 2000, Robinson & Sutherland 2002). For granivorous species, decreases in food resources outside the breeding season have been strongly implicated in their declines. The switch from spring to autumn-sown cereals has led to a decrease in stubbles present over the winter. Stubbles following autumn-sown crops are typically ploughed very shortly after harvest, whereas for spring-sown crops, stubbles are commonly left over the winter (O'Connor & Shrubb 1986). For example, spring cereal area declined by almost 90% between 1969 and 1994 whereas the area of winter cereals increased by almost three-fold over the same period (MAFF June Census data). For many species, stubbles are a preferred foraging habitat in the winter (Evans & Smith 1994, Wilson et al. 1996, Gillings & Fuller 2001). In addition, increasing efficiency of agricultural machinery and increased cleanliness around the farmyard have also decreased the amount of spilt grain available to birds (O'Connor & Shrubb 1986, Shrubb 2003). However, more recently, over-wintered set-aside in the form of stubbles have provided an alternative preferred foraging habitat for a number of species (Buckingham et al. 1999) which may have contributed to the slowing and in some cases the reversal of declines in granivorous passerines.

A decrease in food resources outside the breeding season may be expected to impact on survival rates in granivorous species. Changes in annual survival rates can be analysed using recapture data from ringing studies. For several species, there is evidence that survival rates declined during periods of population decline and in some cases, the survival rate alone can accurately predict the observed change in population trajectory. Variations in survival rate over time closely matched population changes in Reed Bunting (Peach et al. 1999), Goldfinch and House Sparrow *Passer domesticus* (Siriwardena et al. 1999). Furthermore, changes in survival rate were likely to have been contributory factors affecting the population trajectories of Chaffinch *Fringilla coelebs*, Linnet and Bullfinch *Pyrrhula pyrrhula* (Siriwardena et al. 1999). For certain other granivorous species the same mechanisms may be operating, but ringing recovery data is too sparse to predict survival rates, although one localized study suggests that juvenile Skylark *Alauda arvensis* survival has also declined (Wolfenden & Peach 2001).

Given the decrease in the amount of stubble and other farmland seed and grain sources for granivorous birds in autumn and winter, an increase in the exploitation of alternative food may be expected. Where birds are close to human habitation, there is a high probability that bird food provided by humans will be available in household gardens. Bird feeding is a very commonplace activity, particularly in the winter. It is estimated that 75% of households provide food for birds at some time during the year (Cowie & Hinsley 1988). There is some evidence that granivorous species become more dependent on garden bird food as food supply becomes depleted in surrounding farmland. Gillings and Beaven (2003) found that reporting rates of Greenfinch *Carduelis chloris* and Goldfinch on farmland declined throughout the winter. Mortality must have contributed to this decline, but over the same periods there were marked increases in garden reporting rate for all three species. Brambling *Fringilla montifringilla* also showed this pattern in years when the beech mast crop was low. Correlations between the number of birds in gardens and an index of beech mast availability across years have been shown for several other woodland birds including Blue Tit, Great Tit, Coal Tit and Nuthatch (Glue 1982). Increases in Yellowhammers in gardens through the winter which correlated with declining food sources in the wider countryside have also been reported (Glue 1982). These results imply that use of garden bird feeders increases in response to lower food supplies in the surrounding countryside.

An increasing reliance on garden bird food in response to food depletion may be apparent between years as well as within each winter. If food resources on farmland have declined over time then those granivores that are most dependent on this food supply should exhibit evidence of an increased dependence on garden bird food. Therefore, it is predicted that use of garden feeders by granivorous species that mostly feed on farmland should increase. Given that, for severely declining species, the population decline will eventually impact on numbers of birds in gardens, the increase in use of garden feeders is not necessarily expected to be constant. If stubbles (and other seed-rich farmland food sources) are becoming scarcer over time, then depletion is likely to have become more rapid over time. This in turn should lead to a pattern of earlier exploitation of garden bird food within each winter.

The species that are most expected to show these effects are declining granivorous farmland specialists: Tree Sparrow, Goldfinch, Linnet, Reed Bunting and Yellowhammer. In addition, it is also predicted that other granivorous species that commonly feed on stubbles will also increase in use of garden feeders and show an earlier use of garden feeders. These species are House Sparrow, Chaffinch and Greenfinch. For these eight species (termed farmland granivores), an increase in use of garden feeders over time regardless of population trends, effects of temperature or changes in the amount of bird food provided is expected under the hypothesis. Brambling, Siskin *Carduelis spinus* and Bullfinch are granivorous species commonly recorded in gardens, but they are not expected to show these effects as they derive most of their food from woodlands in winter. For these and other species, no significant patterns in use of garden feeders over time or patterns matching breeding population trends are expected.

2. METHODS

The Garden Birds Feeder Survey (GBFS) is an annual survey, implemented in 1970, that monitors the weekly maximum count of birds observed at garden feeders (Glue 1982). GBFS sites are selected to ensure that they are broadly representative of a range of garden types with a consistent geographic distribution. There is a degree of site turnover from year to year, but new sites are selected from the same region and are of a similar type (e.g. rural or suburban) and size to the one that they have replaced.

Observers are requested to note numbers of all species seen at feeding stations within their garden through the week. The maximum number seen at any one time is recorded. A total of 1080 sites have been surveyed since the implementation of the scheme, although not all of these were included in the analysis (see below). Surveyors were asked to record the number of separate feeding stations in their garden each week. Four different types of feeding station were recorded; hanging feeders, table feeders, ground feeding stations and water sources.

3. ANALYSIS

Analyses were restricted to the 41 commonest species. Bird count was analysed in relation to year and week using log-linear Poisson regression. Year was expressed as a continuous variable and the quadratic of year was also entered to detect non-linear patterns in garden use over time. The majority of species show characteristic cyclical patterns of abundance over the season (Cannon 1998). Modelling this cyclical pattern was achieved using periodic logistic regression (Flury & Levri 1999) which expresses week number (1 to 26) as two separate trigonometric functions based on the sine and cosine function (sine week effect = $\sin(2\times\pi\times(\text{week}/26)$, cosine effect = $\cos(2\times\pi\times(\text{week}/26))$. Interactions between both week terms and year were included in the model to see if the within-winter pattern of garden use varied over time. Models were fitted initially with all terms. Non-significant interactions and then non-significant individual terms were sequentially deleted until only significant ($P < 0.05$) terms were left in the model. The final model is termed the minimum adequate model or MAM.

Analysing observations from the same garden site over sequential weeks and years necessitated use of a repeated measures model framework, where the 'subject' was the site and the repeated measures were both week and year. In formal terms, this means that the autoregressive function was fitted to each site and year combination. Likelihood ratio tests and parameter estimates were adjusted using general estimating equations which take into account the temporal autocorrelation among observations from the same site. Detection of inter-annual trends was a major goal of the analysis. Sites that were surveyed for short runs of years (<5) were not included in the analysis. This left a total of 458 sites, varying between 51 and 224 per year. Furthermore, the model fitting procedure requires at least one non-zero count per site. Sites where a given species was never recorded are omitted, hence sample sizes differ from species to species.

In order to see if trends in maximum count at garden bird feeders over time were associated with breeding population trends, annual indices of relative breeding population change were derived from Common Birds Census (CBC) data (Marchant et al. 1990) over the period of interest. Spearman rank correlations were used to see if use of gardens by birds was correlated with population trend. The CBC is unable to estimate population change for Black-Headed Gull *Larus ridibundus*, Feral Pigeon *Columba livia*, Rook *Corvus frugilegus* and Siskin. Furthermore, three species, Redwing *Turdus iliacus*, Fieldfare *Turdus pilaris* and

Brambling, are only winter visitors. This analysis was therefore carried out only on 34 species.

The influence of the number of feeding station on maximum bird count was analysed using the same model framework. Two models were fitted. First, the number of feeders per week replaced year terms (where significant), including interaction terms and quadratic terms, in the MAMs. Second, the number of feeders and interactions with week and year were added to MAMs. Model reduction was carried out as before. Model performance was compared using Aikaike's Information Criterion (AIC) to assess whether inter-annual variations could be explained by changes in feeding stations provided, or whether year was still significant when feeding station data were included. Not all sites provided feeding station data and feeding station data were available up until 1999/2000 only (1 year less than the bird data). There were 404 sites (out of 458) analysed in this sample.

Similarly, temperature was added to the models in order to assess whether changes in temperature over time could explain the observed patterns. Temperature data were obtained from the British Atmospheric Data Centre (www.badc.nerc.ac.uk), which provides daily meteorological data for several hundred weather stations throughout Britain. Daily minimum temperature data were converted to weekly mean data before analysis. The nearest weather station to each GBFS site in each week was identified using weather station and site grid references in a GIS. There were several sites where grid references were either not input or had been input incorrectly and for which no accurate location could be determined. There were 329 sites with grid references that were analysed with temperature data.

4. RESULTS

The proportion of sites in which a given species was recorded and the mean count where the species did occur, is given in Table 1 (scientific species names are also given). The most commonly occurring species (in terms of the percentage of gardens in which they occurred) were Robin *Erithacus rubecula*, Blackbird *Turdus merula*, Blue Tit *Parus caeruleus* and Greenfinch (100% occurrence) followed by Dunnock *Prunella modularis*, Song Thrush *Turdus philomelos*, Great Tit *Parus major*, Starling *Sturnus vulgaris*, House Sparrow and Chaffinch (>95%). By far the lowest occurrence was recorded in Linnet (9.8%). Means in Table 1 are based on only those sites where the species was recorded (these are the sites included in the log linear regression analyses) and are therefore inflated relative to the true mean incorporating all sites (although this bias is less the greater the proportion of sites in which the species was recorded and is non-existent for species where occurrence was 100%). For most species, less than one individual was recorded per week on average. However, the relatively large standard errors for several species indicate that large flocks were sometimes recorded (e.g. Black-headed Gull, Wood Pigeon *Columba palumbus*, Redwing, Fieldfare, Long-tailed Tit *Aegithalos caudatus*, Tree Sparrow, Goldfinch). The most numerous species were House Sparrow and Starling. The lowest average counts (<1.0) were recorded for Sparrowhawk *Accipiter nisus*, Blackcap *Sylvia atricapilla*, Goldcrest *Regulus regulus*, Redwing, Fieldfare, Treecreeper *Certhia familiaris* and Linnet. For Blackcap, Treecreeper and Linnet in particular, these figures indicate that they occurred in a small sample of gardens (<50%) and they were scarce where they did occur.

4.1 Annual Trends

The majority of the 41 species considered showed significant changes in maximum count at garden feeding stations over the 29 winters of the study. Annual and seasonal trends in garden use are shown in Fig. 1. Most species were increasing, particularly in the last ten years. This included Sparrowhawk, pigeons (Woodpigeon *Columba palumbus*, Collared Dove *Streptopelia decaocto* and Feral Pigeon), Corvids (Magpie *Pica pica*, Jay *Garrulus glandarius*, Carrion Crow *Corvus corone*, Rook and Jackdaw *Corvus monedula*), Great Spotted Woodpecker *Dendrocopos major*, Wren *Troglodytes troglodytes*, Long-tailed Tit, Treecreeper, Blackcap and several granivorous species (Chaffinch, Goldfinch, Greenfinch, Siskin, Brambling and Yellowhammer). There were relatively few species whose maximum count showed a significant annual decline. These species included Song Thrush, Starling and House Sparrow, but note that for the latter two species deviance was very high so the data are not likely to have a Poisson-distribution and the estimates may not be reliable. Only Blackbird, Great Tit, Tree Sparrow and Linnet showed no significant annual variation. Of the eight granivorous species predicted to increase numbers at garden feeders, five did show a significant increase (or an initial increase) over time, one species showed a significant decline and two species showed no significant annual pattern. For the remaining 33 species, 29 showed a recent increase, two showed a significant decline and two showed no significant annual trend. Therefore, granivorous farmland birds were no more likely to have increased numbers at garden bird feeders than other species.

Model fit was poor in some cases (full model details are in Appendix 1). This is evident for some cases in Fig. 1 where the fitted trend clearly does not closely match the observed mean. There may be statistical reasons why this is the case. The point in Fig. 1 are means per year and do not take into account sample size (which vary between 51 and 224 per point). Nevertheless, there were still some species where model fit was poor. In some instances, the model over-estimated (e.g. Dunnock) or under-estimated (e.g. Great Spotted Woodpecker) relative to counts. There were also several species where data were unlikely to have a Poisson-distribution, usually due to a high proportion of zero counts. This was particularly the case for Fieldfare, Redwing, Mistle Thrush *Turdus viscivorus*, Treecreeper, Goldcrest, Carrion Crow, Linnet and Brambling. Some of these species (especially Treecreeper and Linnet) also occurred in a low number of sites. Binomial models may provide better estimates of change in garden use over time in these species.

Percentage changes between 1970/71, 1980/81, 1990/91 and 2000/2001 as estimated from Poisson models (Appendix 1) are given in Table 2. Some species had shown huge increases in feeder count. Species that had increased by more than five-fold over the period of the survey were: Goldfinch, Yellowhammer, Sparrowhawk, Magpie, Rook and Long-tailed Tit. Many other species had more than doubled estimated feed count over the same period. There was, however, no suggestion that particular groups of species (e.g. taxonomic groups, groups defined in terms of predominant diet or grouped according to population status) showed greater or lesser magnitude of change. There were relatively few species that had shown declines over the period. Generally, rank order was in agreement when considering change over different periods. Exceptions occurred when the annual patterns in feeder count were strongly peaked or troughed, e.g. Jay, Bullfinch, Reed Bunting (Fig. 1).

CBC indices were derived at the UK level for all species where possible. CBC index from the previous breeding season was correlated against annual estimates of feeder count derived from Poisson models presented in Fig. 1 (parameter estimates are given in Appendix 1) for species showing significant annual change. Table 3 shows Spearman rank correlation coefficients for 30 species. Most species showed significant positive correlations. For the period 1970/71 to 1999/2000 (the latest CBC data available), 17 species showed significant positive correlations between CBC index and estimated garden count. For the period 1980/81 to 1999/2000 there were 22 such species. There were five species that were increasing their garden count whilst CBC index was declining, Marsh/Willow Tit *Parus palustris/montanus*, Treecreeper, Bullfinch, Reed Bunting and Yellowhammer. For Marsh/Willow Tit and Bullfinch this correlation was significant for the period 1980/81 to 1999/2000 only. Reed Bunting showed a significant negative correlation from 1970/71 onwards, but a significant positive correlation from 1980/81 onwards. This is due to the peaked pattern in garden usage over time in this species (Fig. 1). Blue Tit was the only species to have declined in its use of gardens but increased in CBC index (Table 3).

4.2 Seasonal Trends

The majority of species also showed variation in abundance within winter, typically numbers peaking at some time in mid-winter (Fig. 1). Species showing no significant within-season effects were Wren, Redwing, Goldcrest, Treecreeper, Rook and Brambling. Several species showed significant interactions between week (expressed as either sine or cosine) and year, indicating that the seasonal pattern of abundance at garden feeding stations varied over time. There were 26 species where a significant interaction was detected. For these species, mean weekly counts and values fitted from Poisson regression parameter estimates have been plotted for three separate winters, 1970/71, 1985/86 and 2000/2001 (Fig. 2). For the majority of species, greater numbers were coming into gardens earlier in the winter in 2000/2001. There were 17 species where estimated peak count date became increasingly earlier in the winter including House Sparrow, Chaffinch, Greenfinch and Goldfinch. There were five species where the estimated peak count became progressively later including Linnet. Four species showed differences in the shape of the relationship between years but no obvious difference in the date of peak count.

A more direct test of seasonal shifts was carried out by comparing mean peak dates in early and late periods. For each site, the week with the highest count, averaged over a five year period, was determined for 1970-75 and 1995-2000. These two groups of data were compared with a two-sample t-test for each species (Table 4). There were seven species where peak count week was significantly later in 1995-2000 than in 1970-75: Woodpigeon, Fieldfare, Blackcap, Brambling, Goldfinch, Siskin and Yellowhammer. There were eleven species where peak count week was significantly earlier in 1995-2000: Great Spotted Woodpecker, Collared Dove, Blue Tit, Great Tit, Coal Tit *Parus ater*, Marsh/Willow Tit, Magpie, Jackdaw, Starling, House Sparrow, Chaffinch and Greenfinch. There was no apparent link between changes in the timing of the peak count and species' population status. Peak count week for Paridae was significantly earlier, but no other species grouping showed consistent patterns.

4.3 Feeding Effort

Feeding stations are recorded as the number of separate units per site per week. These are divided into hanging feeders, feeding tables, ground feeding stations and water. No information is recorded on the type of food or the size of each feeding station (so there is an implicit assumption that the number of feeding stations correlates with food abundance). There were significant increases in the number of hanging feeders and the number of all feeding stations combined (hanging + ground + table) over time (Fig. 3). There was also significant variation within each winter, with provision of feeding stations showing a peak in mid-winter. For ground feeding stations, only effects of week were significant. There was a significant increase in the number of table feeders between 1970 and 2000 (Fig. 3). There were no significant annual or seasonal variations in the provision of water.

The effects of the number of feeders were incorporated into repeated measures models in order to identify whether provision of feeders was able to explain the annual and intra-annual variation in bird abundance. Of the 41 species analysed, all except Linnet and Black-Headed Gull showed a significant positive association with the number of feeders present. Linnet showed no significant association with any feeder type. Black-headed Gull showed positive associations with table and ground feeders but significant negative associations with the number of hanging feeders (perhaps indicating an avoidance of trees). Some species showed significant associations with only one type of feeder. These were: for ground feeding stations, Feral Pigeon, Woodpigeon, Collared Dove, Mistle Thrush, Redwing, Jackdaw, Rook, Tree Sparrow and Yellowhammer; for table feeders, Carrion Crow; and, for hanging feeders, Goldcrest, Jay and Goldfinch. Other species showed significant associations with several feeder types and with all feeders combined. All feeders combined, hanging feeders, ground feeders and table feeders were significantly correlated with each other. All feeders combined were used in the models, apart from those species listed above where individual feeder type was used.

There were 19 species where the number of feeders provided a better model (as measured by AIC) than year effects, implying that the variation in the number of feeders over time could explain the variation in garden bird count over time. These species were: Sparrowhawk, Black-Headed Gull, Feral Pigeon, Great Spotted Woodpecker, Pied Wagtail *Motacilla alba*, Dunnock, Wren, Robin, Song Thrush, Blackcap, Goldcrest, Coal Tit, Marsh/Willow Tit, Nuthatch *Sitta europaea*, Treecreeper, Magpie, Jay, Starling, House Sparrow and Bullfinch. There were four species where the original model (Fig. 1 and Appendix 1) described the greatest variation in the data, implying that variation in feeder count was not adequate in explaining the annual variation in bird count. These species were: Blackbird, Blue Tit, Greenfinch and Chaffinch (interestingly, four of the commonest species overall occurring in over 99% of sites). There were 16 species where the number of feeders were significant in addition to effects of year implying that variation in the number of feeders and other (unmeasured) factors associated with year can explain annual variation in bird count. These species were: Woodpigeon, Collared Dove, Redwing, Fieldfare, Mistle Thrush, Great Tit, Long-Tailed Tit, Carrion Crow, Rook, Jackdaw, Tree Sparrow, Brambling, Goldfinch, Siskin, Reed Bunting and Yellowhammer.

There were some patterns in species groups. There were eight granivorous species where food alone could not explain variations in garden feeder use over time: Tree Sparrow, Chaffinch, Brambling, Goldfinch, Linnet (which showed no association with any feeder type), Siskin, Reed Bunting and Yellowhammer. Similarly, *Corvus* species and thrushes (except Song Thrush) also showed additive effects of food supply.

4.4 Temperature

Mean minimum temperature per site was analysed with respect to year and week using a repeated measures model. There was a significant negative quadratic association between year and temperature over the study period (Fig. 4). This trend, whilst statistically significant, did not represent a large variation in temperature and the trend was largely driven by several winters of lower than average temperature in the 1980s. There was also a lot of scatter in the data and the model was a poor fit (dispersion = 7.99).

Temperature data were added to MAMs describing year and week trends (Appendix 1) following the same modelling approach as used for the feeder data. Maximum bird count at feeders was significantly negatively associated with minimum temperature in 38 species. Sparrowhawk was the only species to show a significant positive effect. Only Goldcrest and Linnet showed no significant effect of temperature. Temperature had a significant additive effect, whereby further significant variation was explained in the data by adding temperature to the model, in all species apart from Redwing and Fieldfare. For these two species, replacing the year term with temperature provided a better model (according to AIC) implying that variations in temperature were responsible for the observed annual trends. For species showing an additive effect, temperature is likely to be an important determinant of the numbers of birds using feeders, but it cannot explain trends in garden counts over time. Similarly, there were only two species, Wood Pigeon and Carrion Crow, where temperature replaced week terms in the model, implying that for these species, seasonal trends in gardens are closely associated with seasonal variations in temperature.

5. DISCUSSION

If granivorous farmland birds are becoming more dependent on garden bird food due to decreasing food resources in the surrounding countryside, two effects should be apparent. First, their use of garden feeders should increase over time across years, at least initially, regardless of population trends. Second, they should show evidence of higher numbers in gardens earlier in the winter over time across years.

Several farmland granivores showed increased numbers of individuals at garden feeders over time. These were Chaffinch, Greenfinch, Goldfinch and Yellowhammer. Initial increase followed by a later decline was observed in Reed Bunting. There were no significant annual trends for Tree Sparrow and Linnet. House Sparrow showed significant declines. However, there were recent increases in three finch species that were not expected to be affected by decrease in winter food resources on farmland: Brambling, Siskin and Bullfinch. Furthermore, there was a high proportion of non-granivorous species that showed increases. Of the remaining 30 species, 18 showed approximately linear increases, six showed an early decline followed by a more recent increase, two showed an initial increase followed by a decline, two showed an approximately linear decline and two showed no significant trend over time. Therefore, granivorous farmland species were no more likely to have shown increases in numbers at garden feeders than other species.

There were also no differences in the magnitude of increase between farmland granivores and other species. Goldfinch and Yellowhammer did show the greatest magnitude of increase between 1970 and 2000. However, several non-granivorous species also showed large increases including Sparrowhawk, Long-tailed Tit, Woodpigeon and several corvid species. Therefore, there was no evidence to suggest that farmland granivores had increased numbers attending garden feeders more than other species.

For many species, annual trends in numbers at garden feeders were closely associated with trends in the breeding population. For example, Sparrowhawk numbers have increased in gardens as the population has recovered from the severe effects of organochlorine pesticides (Newton 1986). Corvid species have increased in population possibly due to decreases in persecution and increases in exploitation of human habitats (Gregory & Marchant 1996) which is reflected in their increase in gardens. Some species that have declined also showed a decline in garden use, including House Sparrow and Song Thrush. There were only three non-granivorous species that showed a negative association with CBC index: Blue Tit, Treecreeper and Marsh/Willow Tit (the latter was a non-significant trend). For declining farmland granivores, two species showed no apparent increase in garden feeders over time (Tree Sparrow and Linnet) and three species showed a negative correlation with CBC index, Goldfinch (not significant), Reed Bunting and Yellowhammer. Both increasing granivores, Chaffinch and Greenfinch, also showed increases in gardens. Therefore, when comparing population trends, there is some evidence that garden use is independent of population trend for declining farmland granivores with the exception of House Sparrow. This species is closely associated with human habitation and it's definition as a farmland granivore is perhaps questionable. However, it is traditionally a bird of the stock yard and rather than decreasing stubbles, this species may have been particularly affected by increasing in harvesting efficiency and a general increase in tidiness around the farmyard (O'Connor & Shrubb 1986). Data for House Sparrow were highly over-dispersed and model fit was poor. However, there is much evidence from other sources that House Sparrows are declining in both garden and in the wider countryside (Crick et al. 2002), so these results are probably a reasonably good estimate of changes at garden feeders over time.

Simple correlations of garden numbers with CBC index reveal general directional associations. However, the points of inflexion of both population index and garden use would also be expected to be closely associated if increasing exploitation of garden feeders is caused by declining farmland resources for declining granivores. Plots of annual trend in garden use and CBC index for Goldfinch, Reed Bunting and Yellowhammer (species showing significant increases in garden use that have shown declines in population over the past 40 years) are shown in Fig. 5. For Goldfinch, the major decline in population in the late 1970s coincides with only a very slight increase in numbers in gardens. The main increase in gardens corresponds very well with a recovery in the breeding population in the 1990s. Note that this is evident in the significant positive correlation between CBC index and predicted numbers on garden feeders from 1980 onwards (Table 3). For Reed Bunting and Yellowhammer, the patterns more convincingly support the idea of increasing dependence on garden feeders, both showing increases in garden use at times of population decrease.

There were four farmland granivores that showed evidence of higher numbers at garden feeders earlier in the season according to the Poisson regression analysis: House Sparrow, Chaffinch, Greenfinch and Goldfinch. For the former three species, comparison of mean peak date using t-tests gave similar results. However, the result for Goldfinch was contradictory, showing a later peak with this analysis. Further more, Linnet and Yellowhammer, two declining farmland granivores showed later peaks. Given the contradictory results among farmland granivores and the many other species that showed earlier within-winter peak in number at garden feeders, it must be concluded that there was no evidence that farmland granivores had altered seasonal use of gardens in response to declining farmland food resources.

Temperature was a major determinant of the numbers of birds using garden feeders. In virtually all cases where there was a significant association, numbers were higher when temperatures were lower. A greater dependence on garden food in colder conditions is expected for most species. Only Sparrowhawk showed a positive association with temperature. This species showed an atypical seasonal pattern in gardens, at least in later years, with a peak in mean count relatively early in the winter (Fig. 2). It is unclear why this peak occurred but it may be associated with dispersing juveniles. Despite widespread associations between garden feeder count and temperature there was very little evidence that variations in temperature accounted for trends between years or within winters. There was no obvious annual trend in temperature data over the period of study. The two migrant thrushes, Redwing and Fieldfare, were the only species where variations in temperature could adequately account for variations in garden feeder counts over time.

Many species were positively associated with the number of feeding stations provided by survey participants. It is assumed that the number of feeding stations is directly correlated with the amount of food available. Furthermore, for a number of species, the increase in feeding stations matched closely the increase in numbers in gardens. There were 19 species where the increase in feeding stations could explain the increase over time (i.e. feeding stations replaced year terms in the MAMs). For several other species, the effects of feeding station number was additive to the effects of year. Interestingly, all granivorous farmland species apart from House Sparrow either belonged to this latter group or showed no association with the number of feeding stations. There is an implication therefore that, whilst increases in feeding stations are important, they are not the solely responsible for the increases observed at garden feeders for these species.

The increase in feeding effort may be a response to the increasing popularity of bird feeding generally (Cannon 1999). This is not necessarily on the part of the survey participants (who must feed birds as part of the survey), but may be due to a general increase in bird feeding in the surrounding habitats. In addition to the amount of food provided, it is also likely that the quality of food has improved over time. There is a far greater variety of commercially available bird food now than two or three decades ago. This includes specialist foodstuffs such as niger seeds and black sunflower hearts, both of which are specifically aimed at finches. Goldfinch in particular has a preference for these foodstuffs (pers. obs.) and this may have influenced their recent increase at garden feeders.

In addition to marked annual increases in food provision, there was also a marked seasonal pattern that matched the pattern of many bird species, with a peak in the number of feeding stations in mid-winter. This raises the question of whether birds are showing a mid-winter peak in response to increased food supply, whether the surveyors are increasing the amount of food as response to bird numbers or whether other cues are involved (e.g. more food may be provided when harsher conditions are perceived). Such effects are very difficult to tease apart.

The evidence that farmland granivores as a group have increased abundance at garden feeders due to a decrease in farmland food resources is weak. However, for two individual species, Reed Bunting and Yellowhammer, the trends in numbers at garden feeders, particularly in relation to population trends, the patterns are more compelling. In some cases, increased feeding may well have had an effect, but it is difficult to tease apart effects of increased food provision with increases due to external factors. Goldfinch in particular is likely to have benefited from increased food quality. Tree Sparrow and Linnet showed no trend in use of gardens over time, but both of these species (especially Linnet) were scarce and the model suffered from low sample sizes and lack of data. There may be alternative explanations for increases in winter populations. For example, increased numbers of granivorous species may be arriving from northern Europe, although there is no evidence for this from ring-recovery data (Wernham et al. 2002).

There is an implicit assumption in this research that farmland habitats are homogenous and that birds are able to freely move between farmland and gardens. Neither of these is likely to be true in reality. Resources on farmland are likely to differ geographically. For example, it is unlikely that similar trends will be evident in cereal dominated areas to pastoral areas where winter food resources have probably always been low. Furthermore, the location of the garden may have important effects. A garden that is adjacent to farmland may be more likely to be sensitive to depletion of resources in the surrounding countryside that a garden in a suburban setting. These issues will be addressed in future work.

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Table 1. Occurrence (number of sites where a species was recorded at least once as a percentage of the total) and mean count in sites where a given species was recorded at garden feeding stations between the winters of 1970/71 and 2000/01. The total number of sites was 458.

Species	% Occurrence	Mean ± SD	n
Sparrowhawk *Accipiter nisus*	61.6	0.09 ± 0.30	282
Black-headed Gull *Larus ridibundus*	55.7	0.89 ± 3.34	255
Great Spotted Woodpecker *Dendrocopus major*	57.2	0.27 ± 0.53	262
Feral Pigeon *Columba livia*	27.9	1.40 ± 4.58	128
Wood Pigeon *C. palumbus*	67.2	0.50 ± 2.01	308
Collared Dove *Stretopelia decaocto*	91.9	2.10 ± 4.14	421
Pied Wagtail *Motacilla alba*	83.0	0.15 ± 0.53	380
Wren *Troglodytes troglodytes*	88.2	0.16 ± 0.43	404
Dunnock *Prunella modularis*	99.6	1.72 ± 1.53	456
Robin *Erithacus rubecula*	100	1.31 ± 0.93	458
Blackbird *Turdus merula*	100	2.65 ± 2.99	458
Song Thrush *T. philomelos*	97.4	0.42 ± 0.70	446
Redwing *T. iliacus*	75.8	0.07 ± 0.86	347
Fieldfare *T. pilaris*	55.0	0.10 ± 1.69	252
Mistle Thrush *T. viscivorus*	62.4	0.23 ± 1.62	286
Blackcap *Sylvia atricapilla*	34.9	0.07 ± 0.33	160
Goldcrest *Regulus regulus*	54.1	0.04 ± 0.26	248
Blue Tit *Parus caeruleus*	100	4.38 ± 4.50	458
Great Tit *P. major*	99.8	2.22 ± 2.90	457
Coal Tit *P. ater*	94.8	0.88 ± 1.30	434
Marsh/Willow Tit *P. palustris/montanus*	46.1	0.30 ± 0.96	211
Long-tailed Tit *Aegithalos caudatus*	63.4	0.37 ± 1.42	290
Nuthatch *Sitta europaea*	37.8	0.37 ± 0.69	173
Treecreeper *Certhia familiaris*	13.3	0.05 ± 0.25	61
Jay *Garrulus glandrius*	39.7	0.42 ± 0.70	182
Magpie *Pica pica*	82.3	0.71 ± 1.34	377
Carrion Crow *Corvus corone*	59.6	0.24 ± 1.53	273
Jackdaw *C. monedula*	45.6	1.23 ± 3.36	209
Rook *C. frugilegus*	65.1	0.83 ± 5.68	298
Starling *Sturnus vulgaris*	98.7	11.09 ± 15.09	452
House Sparrow *Passer domesticus*	99.1	13.26 ± 13.75	454
Tree Sparrow *P. montanus*	28.8	0.87 ± 3.88	132
Chaffinch *Fringilla coelebs*	99.3	4.52 ± 7.83	455
Brambling *F. montifringilla*	54.4	0.12 ± 1.52	249
Greenfinch *Carduelis chloris*	100	4.06 ± 8.51	458
Goldfinch *C. carduelis*	64.4	0.41 ± 2.97	295
Linnet *C. cannabina*	9.8	0.08 ± 1.44	45
Siskin *C. spinus*	69.2	0.30 ± 1.26	317
Bullfinch *Pyrrhula pyrrhula*	54.8	0.11 ± 0.65	251
Reed Bunting *Emberiza schoeniclus*	24.7	0.18 ± 0.99	113
Yellowhammer *E. citrinella*	39.3	0.32 ± 1.72	180

Table 2: Change in estimated abundance derived from Poisson models between the given year (column heading) and 1999/2000, for species showing significant effects of year (week =1). Change is expressed as % change between the column year and 2000 (where 100% increase = double original value). Species are sorted according to the magnitude of change between 1970/71 and 1999/2000.

Species	1970	1980	1990
Goldfinch	2625	971	254
Yellowhammer	977	383	120
Sparrowhawk	827	240	59
Magpie	692	140	21
Rook	689	322	114
Long-tailed Tit	528	537	247
Carrion Crow	395	191	70
Black-headed Gull	388	19	-30
Chaffinch	375	151	49
Wood Pigeon	360	195	77
Siskin	329	179	72
Jackdaw	254	233	118
Feral Pigeon	193	113	49
Collared Dove	186	110	48
Brambling	178	105	48
Treecreeper	175	106	46
Blackcap	170	100	44
Reed Bunting	122	-53	-64
Greenfinch	85	25	83
Great Spotted Woodpecker	81	52	24
Wren	67	44	21
Coal Tit	45	98	72
Jay	42	-18	-28
Nuthatch	32	301	57
Goldcrest	23	133	119
Robin	22	25	17
Redwing	20	-35	-39
Bullfinch	-4	74	76
Fieldfare	-14	-75	-74
Blue Tit	-15	-11	-6
Dunnock	-19	6	14
Starling	-27	-38	-31
House Sparrow	-32	-32	-25
Mistle Thrush	-36	-56	-68
Pied Wagtail	-60	-27	-1
Song Thrush	-80	-68	-45

Table 3. Spearman correlation coefficients between CBC index and estimated garden bird abundance derived from Poisson regression. * P < 0.05, ** P < 0.01, *** P < 0.001 (otherwise not significant). Species not included either showed no significant trend in garden use with year (Blackbird, Great Tit, Tree Sparrow, Linnet) or do not have CBC index calculated (Black-Headed Gull, Feral Pigeon, Redwing, Fieldfare, Brambling, Rook, Siskin)

Species	Spearman's r 1970 – 2000 (n = 31)	Spearman's r 1980 – 2000 (n = 21)
Sparrowhawk	0.959***	0.869***
Great Spotted Woodpecker	0.744***	0.575**
Wood Pigeon	0.983***	1.000***
Collared Dove	0.890***	0.743***
Pied Wagtail	0.052	-0.022
Wren	0.253	0.790***
Dunnock	0.781***	0.332
Robin	0.515**	0.869***
Song Thrush	0.954***	0.853***
Mistle Thrush	0.965***	0.970***
Goldcrest	0.113	-0.362
Blackcap	0.964***	1.000***
Blue Tit	-0.880***	-0.723***
Coal Tit	0.337	0.657**
Marsh/Willow Tit	-0.139	-0.909***
Long-tailed Tit	0.478**	0.695***
Nuthatch	0.032	0.839***
Treecreeper	-0.892***	-0.747***
Jay	0.119	0.751***
Magpie	0.886***	0.632**
Carrion Crow	1.000***	1.000***
Jackdaw	0.923***	0.791***
Starling	0.741***	1.000***
House Sparrow	0.852***	0.927***
Chaffinch	0.884***	0.668***
Greenfinch	0.593***	0.877***
Goldfinch	-0.247	0.597**
Bullfinch	0.056	-0.778***
Yellowhammer	-0.989***	-1.000***
Reed Bunting	-0.389*	0.456*

Table 4. Mean peak count week ± SD (n) in early (1970-75) and late (1995-2000) periods. Peak count was determined by taking the average count per site per week and identifying the week with the highest mean for each species. *P < 0.05, **P < 0.01, ***P < 0.001.

Species	1970 - 1975 MEAN ± SD (n)	1995 - 2000 MEAN ± SD (n)	|T|
Sparrowhawk	14.45 ± 2.75 (59)	12.05 ± 6.43 (192)	4.09
Black-headed Gull	14.55 ± 4.43 (88)	13.96 ± 4.53 (133)	0.96
Great Spotted Woodpecker	16.34 ± 4.88 (74)	14.13 ± 6.45 (156)	2.88**
Feral Pigeon	14.77 ± 6.46 (44)	13.69 ± 6.37 (81)	0.89
Wood Pigeon	16.10 ± 5.38 (85)	18.20 ± 6.26 (192)	2.68**
Collared Dove	15.98 ± 6.44 (131)	11.32 ± 7.82 (228)	5.80***
Pied Wagtail	13.37 ± 5.78 (124)	14.34 ± 5.85 (202)	1.50
Wren	11.46 ± 6.89 (117)	12.05 ± 6.53 (222)	0.78
Dunnock	17.73 ± 5.34 (145)	17.76 ± 6.56 (237)	0.04
Robin	18.43 ± 5.06 (145)	18.15 ± 4.49 (238)	0.57
Blackbird	16.75 ± 5.34 (145)	16.65 ± 4.25 (258)	0.20
Song Thrush	16.35 ± 6.39 (145)	17.01 ± 5.38 (227)	1.07
Mistle Thrush	15.79 ± 4.83 (119)	15.86 ± 5.86 (169)	0.09
Fieldfare	13.81 ± 3.37 (81)	15.36 ± 3.85 (130)	2.84**
Redwing	14.76 ± 3.22 (90)	14.46 ± 4.00 (153)	0.65
Goldcrest	12.56 ± 4.35 (46)	14.37 ± 6.99 (100)	1.62
Blackcap	14.62 ± 3.45 (65)	17.80 ± 4.84 (160)	4.69***
Blue Tit	15.75 ± 5.52 (145)	12.25 ± 5.75 (238)	5.85***
Great Tit	15.50 ± 6.20 (144)	12.28 ± 6.27 (238)	4.88***
Coal Tit	13.63 ± 6.27 (140)	10.51 ± 6.01 (229)	4.77***
Marsh/Willow Tit	15.62 ± 6.33 (88)	13.35 ± 6.17 (101)	2.49*
Long-tailed Tit	14.67 ± 4.86 (86)	15.59 ± 5.00 (183)	1.42
Nuthatch	13.97 ± 6.24 (50)	13.10 ± 6.38 (101)	0.80
Treecreeper	16.03 ± 3.51 (22)	14.57 ± 4.41 (30)	1.28
Jay	14.41 ± 5.01 (48)	12.74 ± 6.39 (113)	1.61
Magpie	13.68 ± 4.96 (107)	12.12 ± 7.23 (217)	2.28*
Carriou Crow	14.25 ± 5.05 (81)	15.23 ± 6.36 (156)	1.21
Rook	16.27 ± 6.66 (68)	18.01 ± 6.17 (117)	1.80
Jackdaw	17.65 ± 5.46 (91)	15.40 ± 7.02 (174)	2.89**
Starling	15.29 ± 5.39 (145)	13.33 ± 5.66 (233)	3.35***
House Sparrow	13.12 ± 6.55 (145)	8.74 ± 6.49 (235)	6.36***
Tree Sparrow	16.91 ± 5.43 (45)	15.44 ± 5.47 (69)	1.40
Chaffinch	19.71 ± 4.37 (144)	17.79 ± 4.97 (237)	3.83***
Brambling	14.80 ± 3.87 (72)	17.03 ± 5.16 (148)	3.49***
Greenfinch	19.77 ± 4.71 (145)	14.79 ± 7.38 (238)	8.06***
Goldfinch	11.63 ± 5.77 (66)	18.61 ± 6.47 (201)	7.81***
Linnet	12.67 ± 5.57 (17)	14.69 ± 4.63 (25)	1.28
Siskin	18.03 ± 5.77 (70)	20.31 ± 4.92 (204)	3.20**
Bullfinch	14.18 ± 5.03 (90)	14.96 ± 5.93 (127)	1.01
Reed Bunting	17.66 ± 4.87 (67)	18.40 ± 4.90 (88)	0.94
Yellowhammer	16.03 ± 4.86 (35)	18.80 ± 4.75 (61)	2.46*

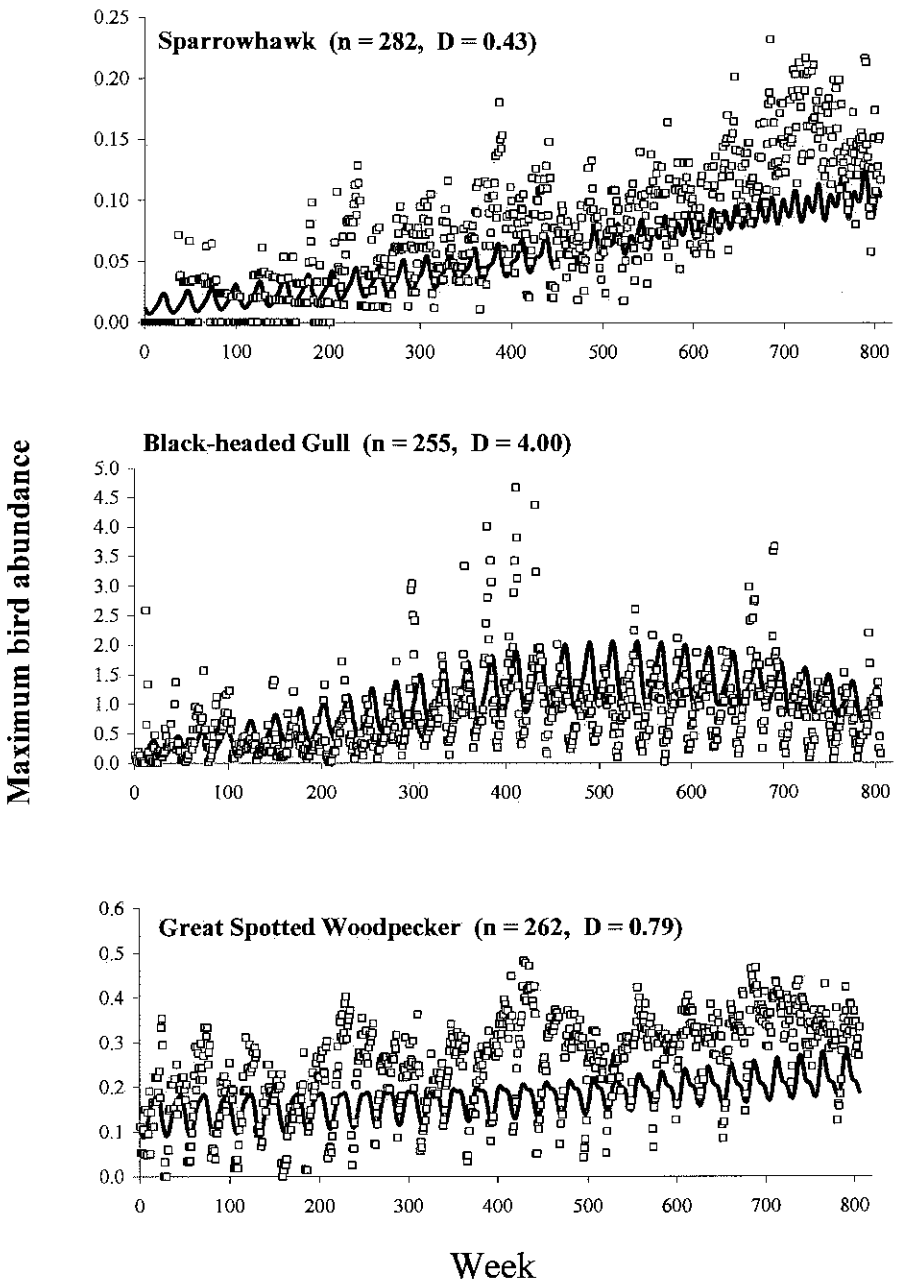
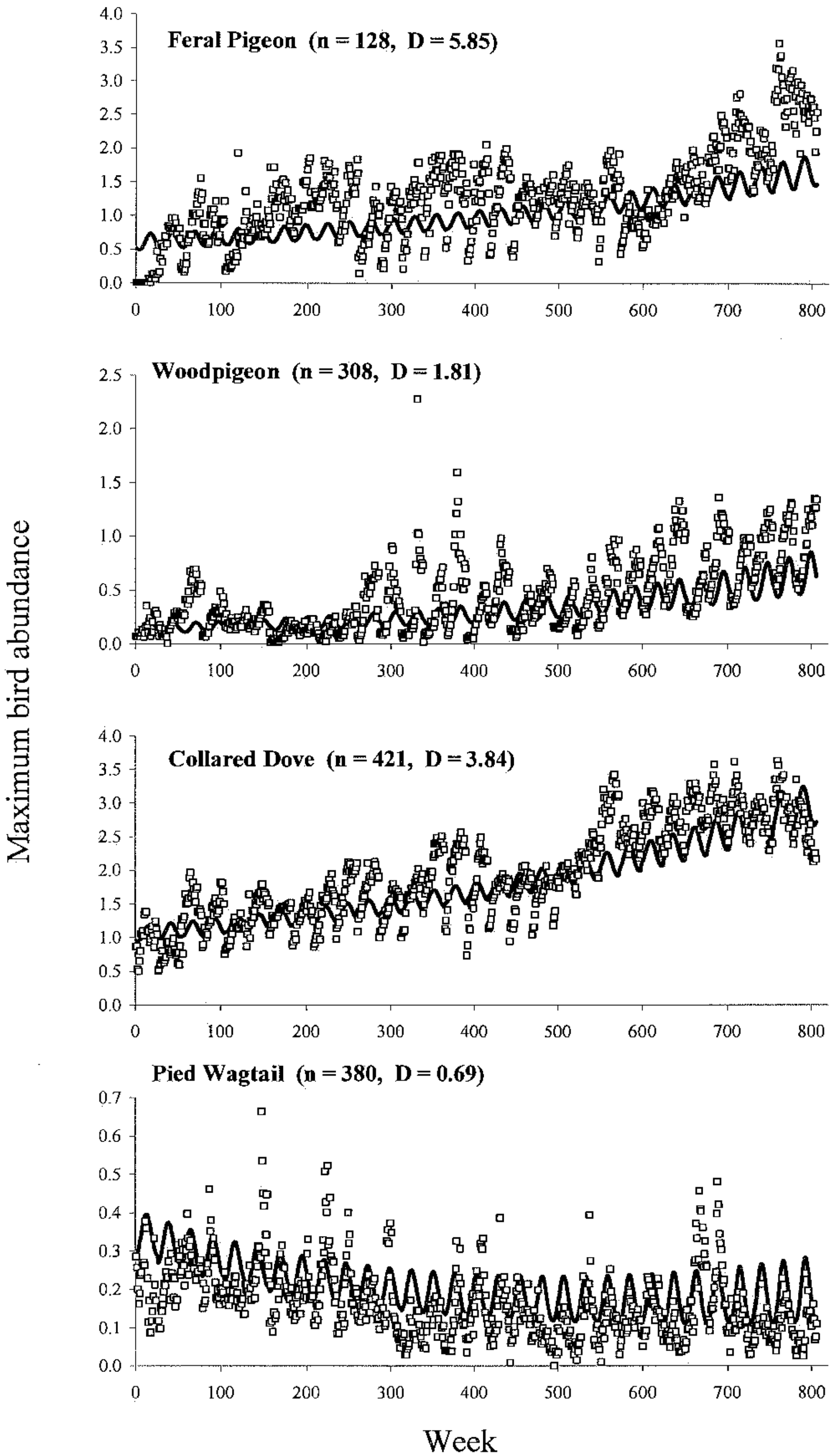


Fig. 1. Mean weekly maximum count of birds recorded at garden feeders (points) and trend lines fitted from Poisson regression. Week is expressed as a continuous variable where week 1 = September 1970 and week 806 = March 2001. Note however that this is for presentational purposes: week was not fitted a continuous trend across years, but within each year. Sample size (n) includes those sites where a given species was recorded on at least one occasion. D indicates the dispersal parameter (deviance/degrees of freedom). Full model details are given in Appendix 1.


Feral Pigeon (n = 128, D = 5.85)
Woodpigeon (n = 308, D = 1.81)
Collared Dove (n = 421, D = 3.84)
Pied Wagtail (n = 380, D = 0.69)
Maximum bird abundance
Week
0
100
200
300
400
500
600
700
800

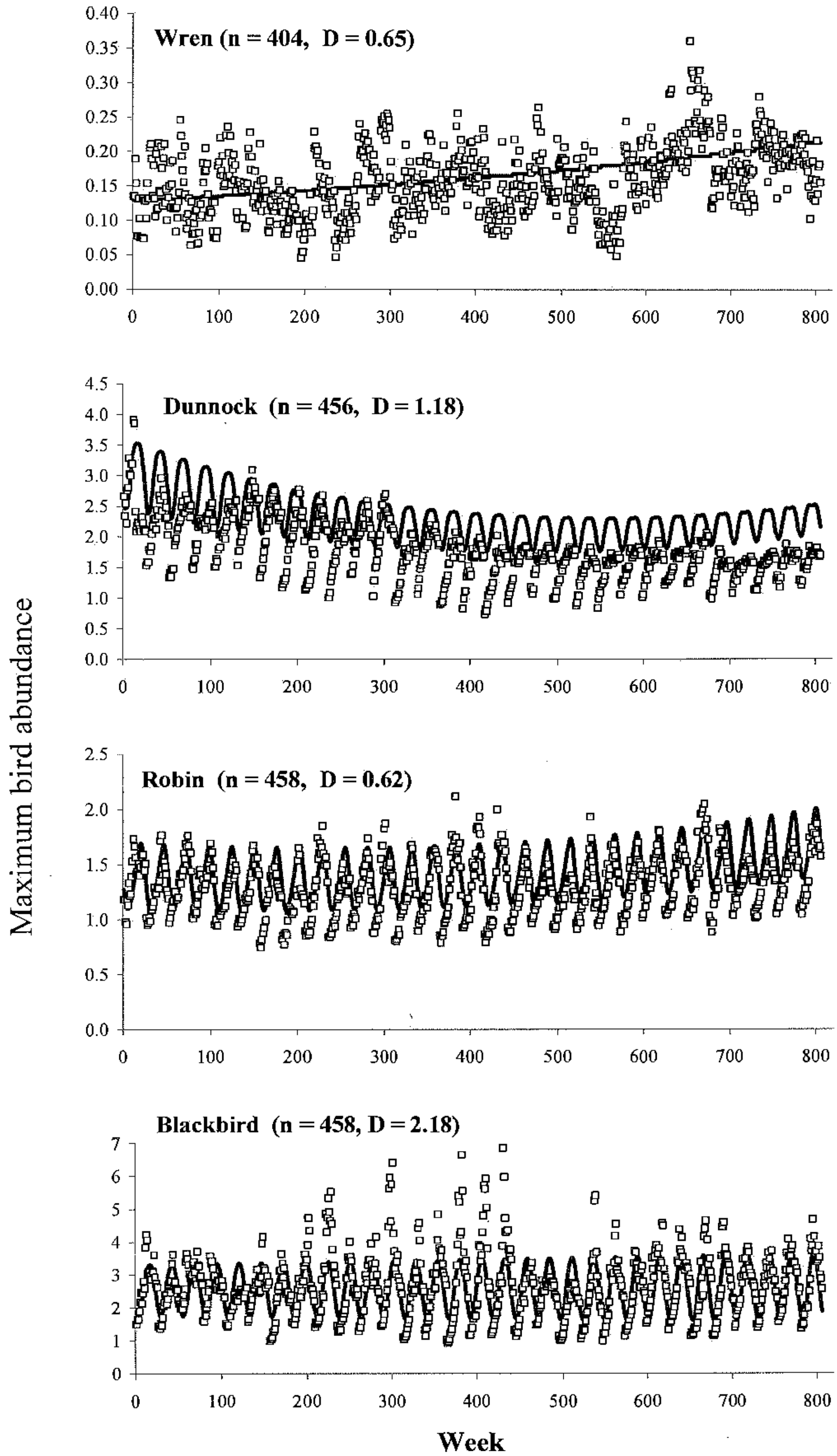
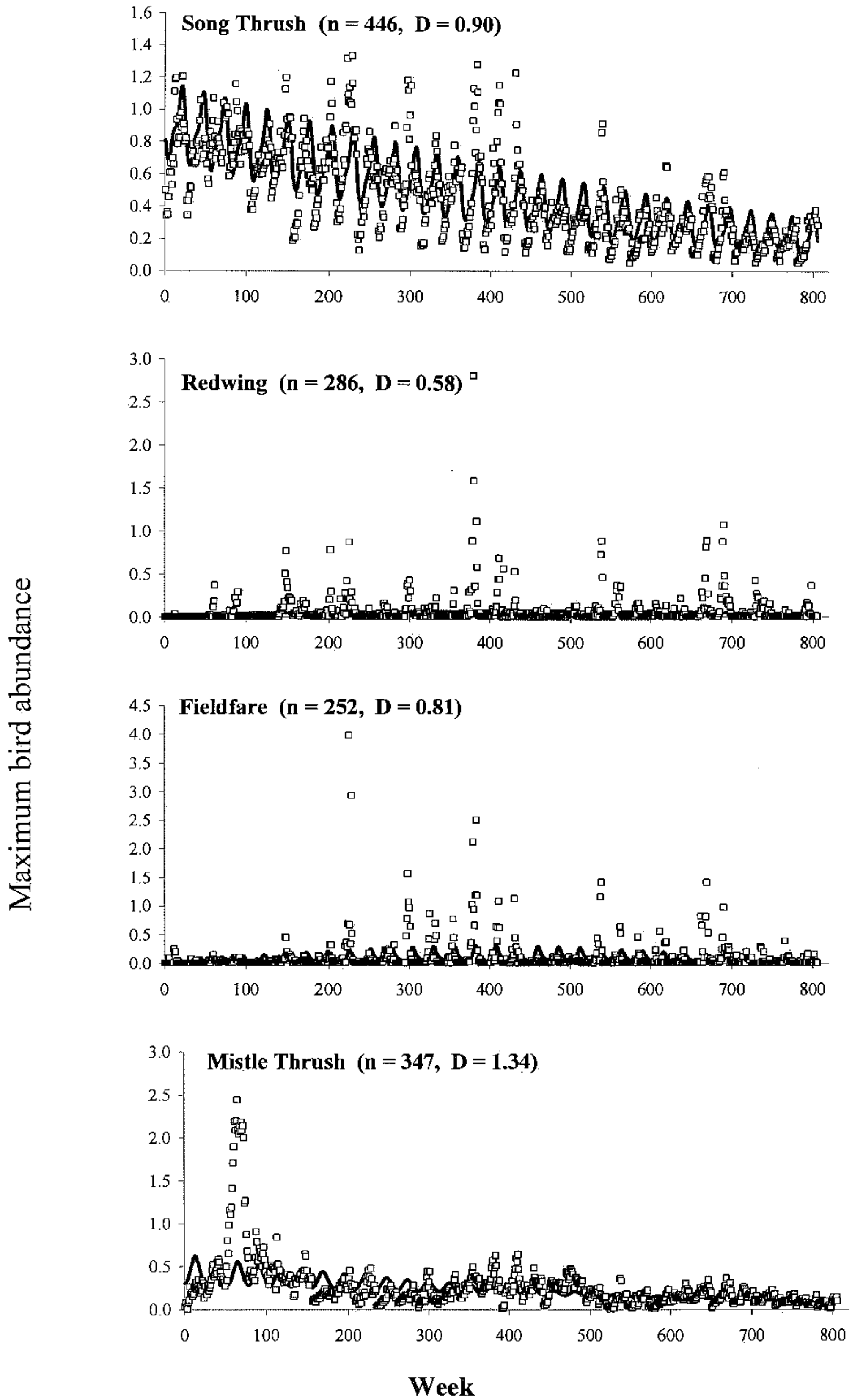


Fig. 1. Continued



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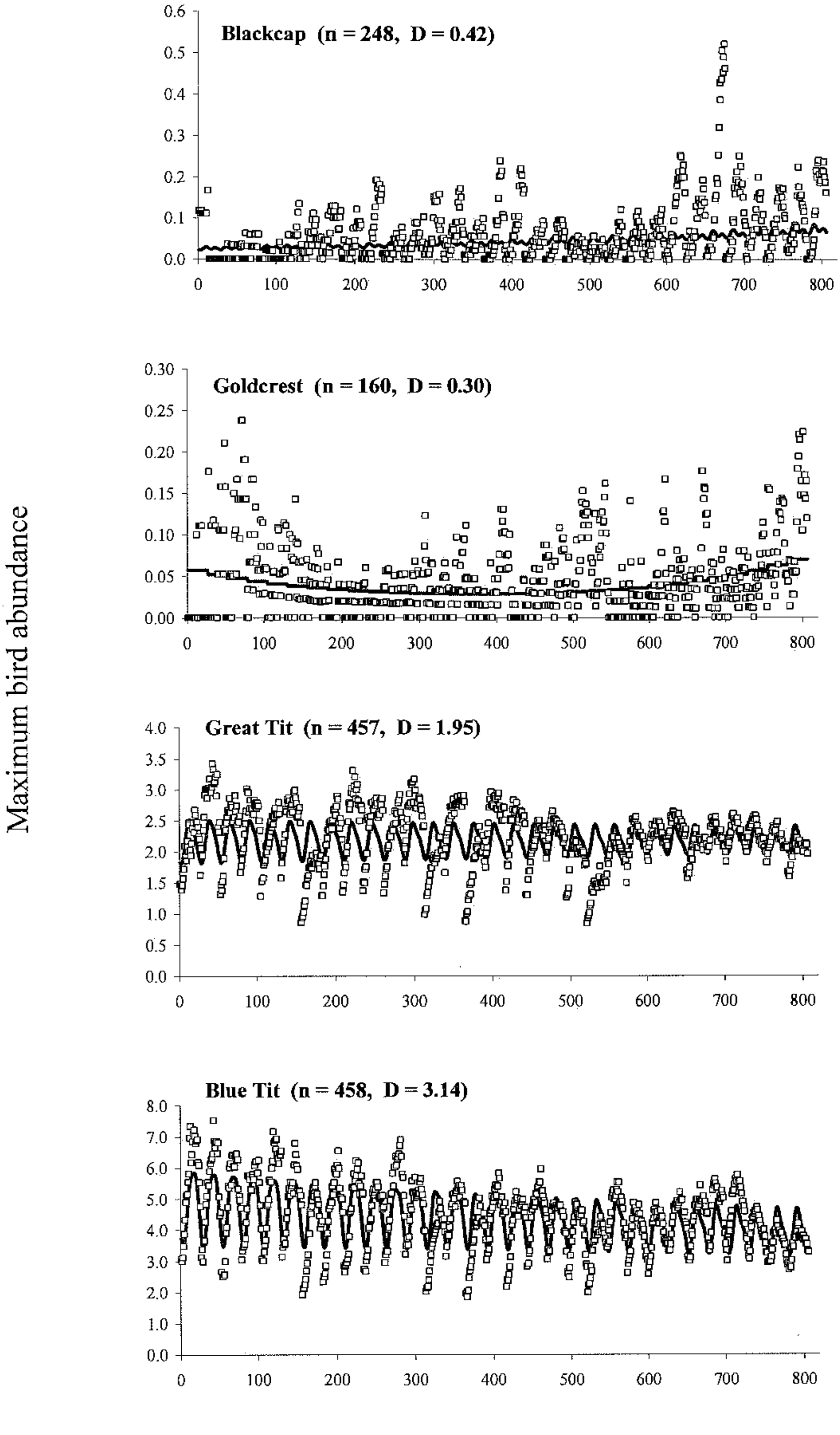

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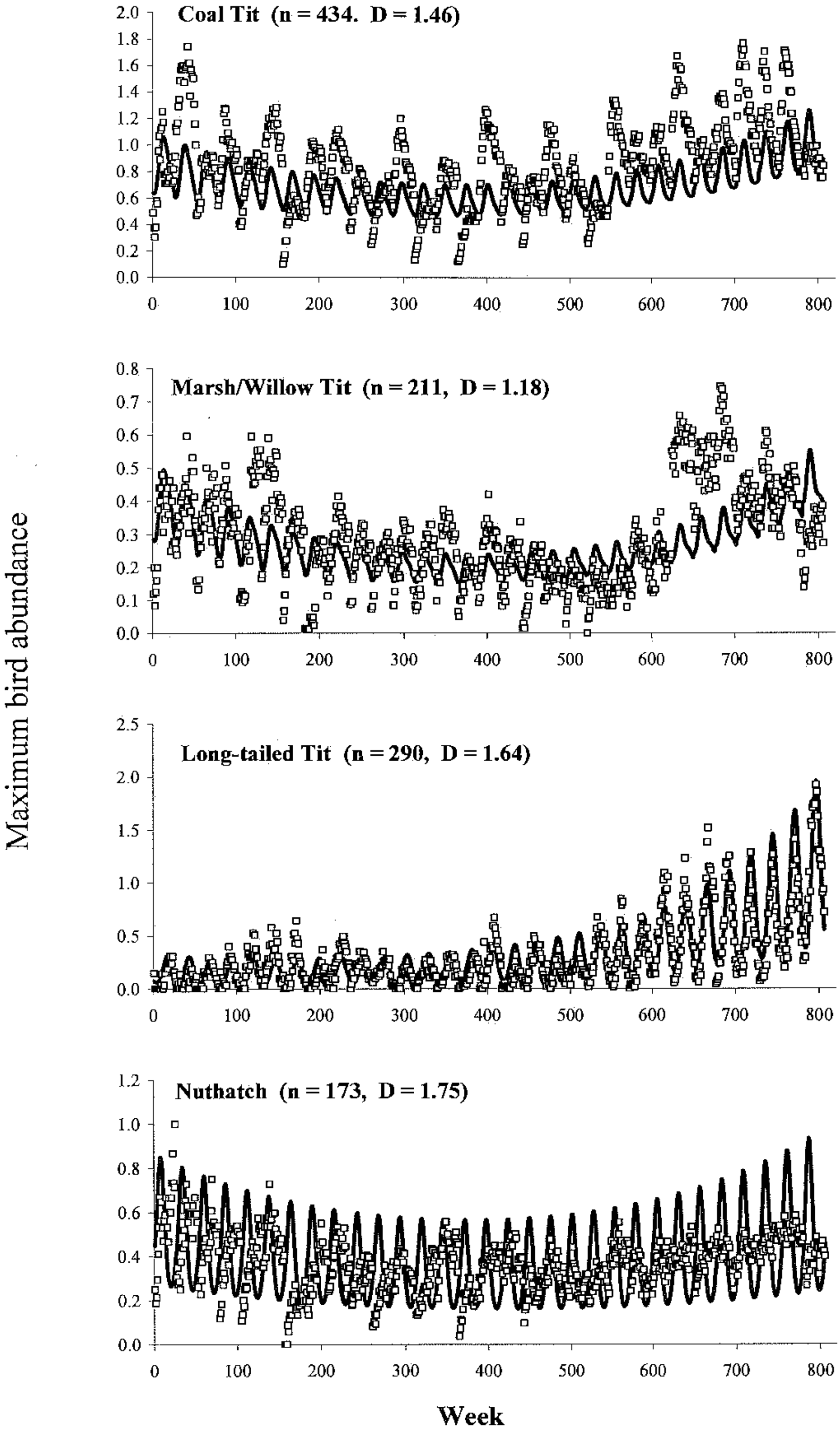

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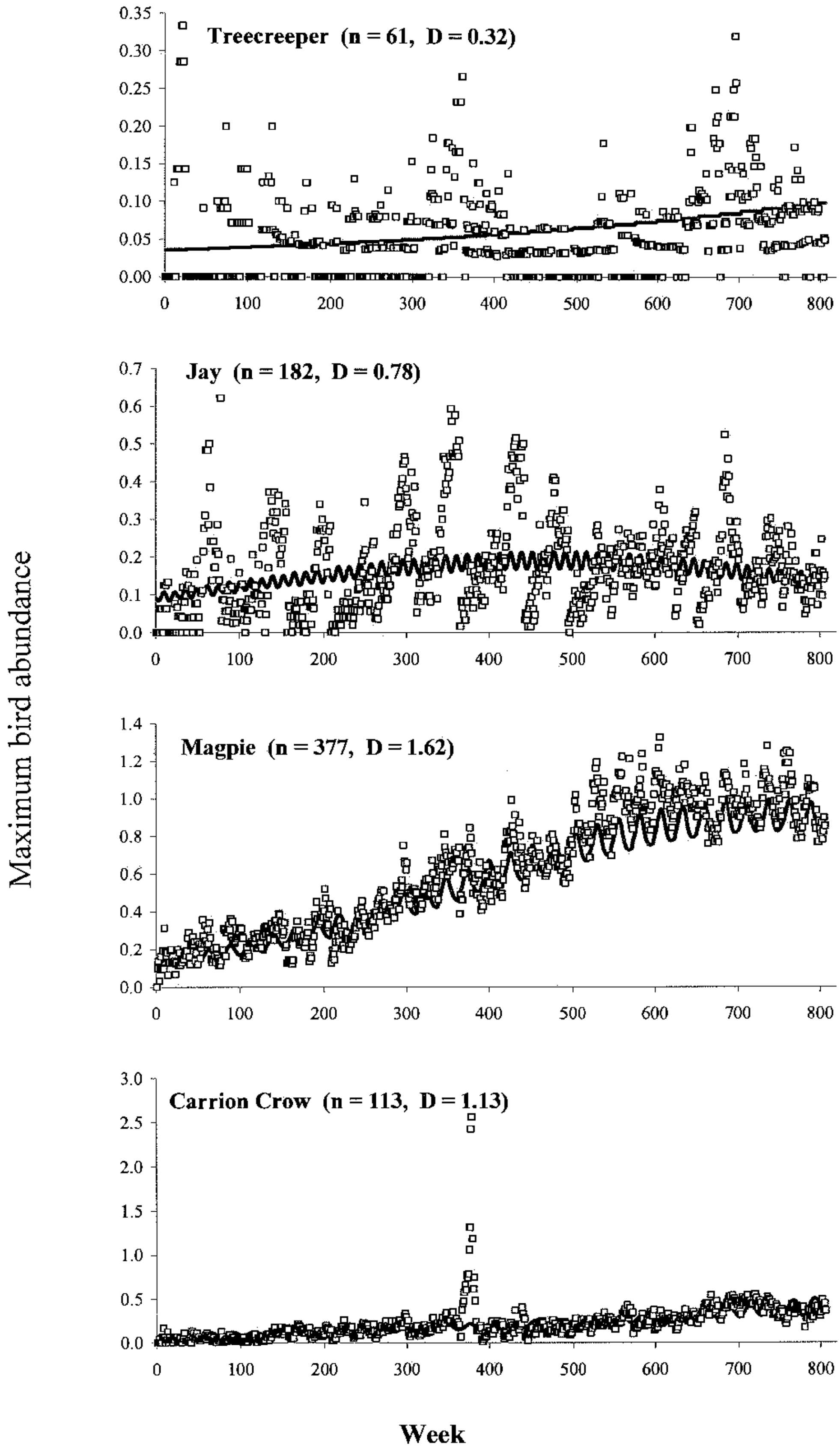

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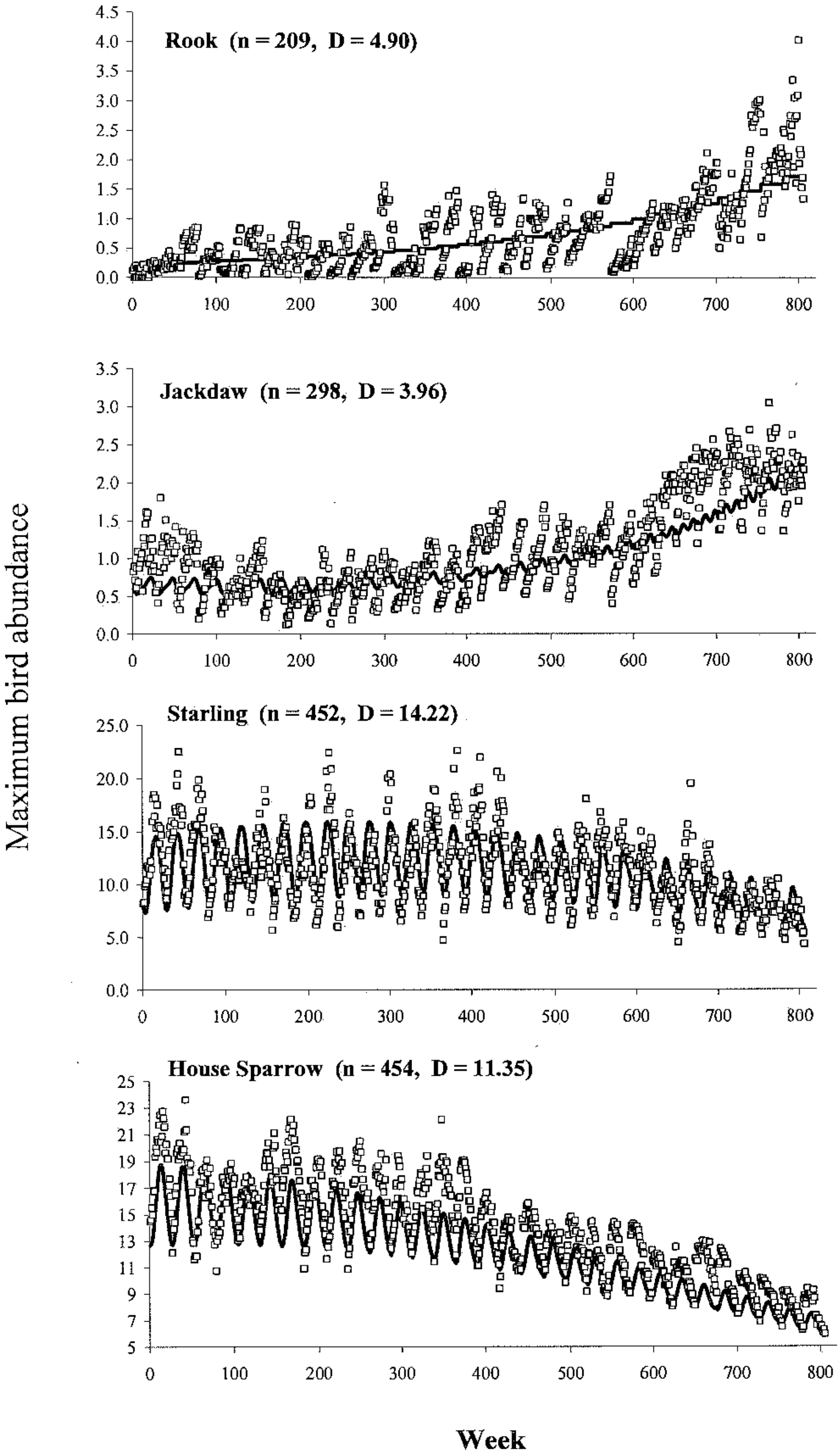
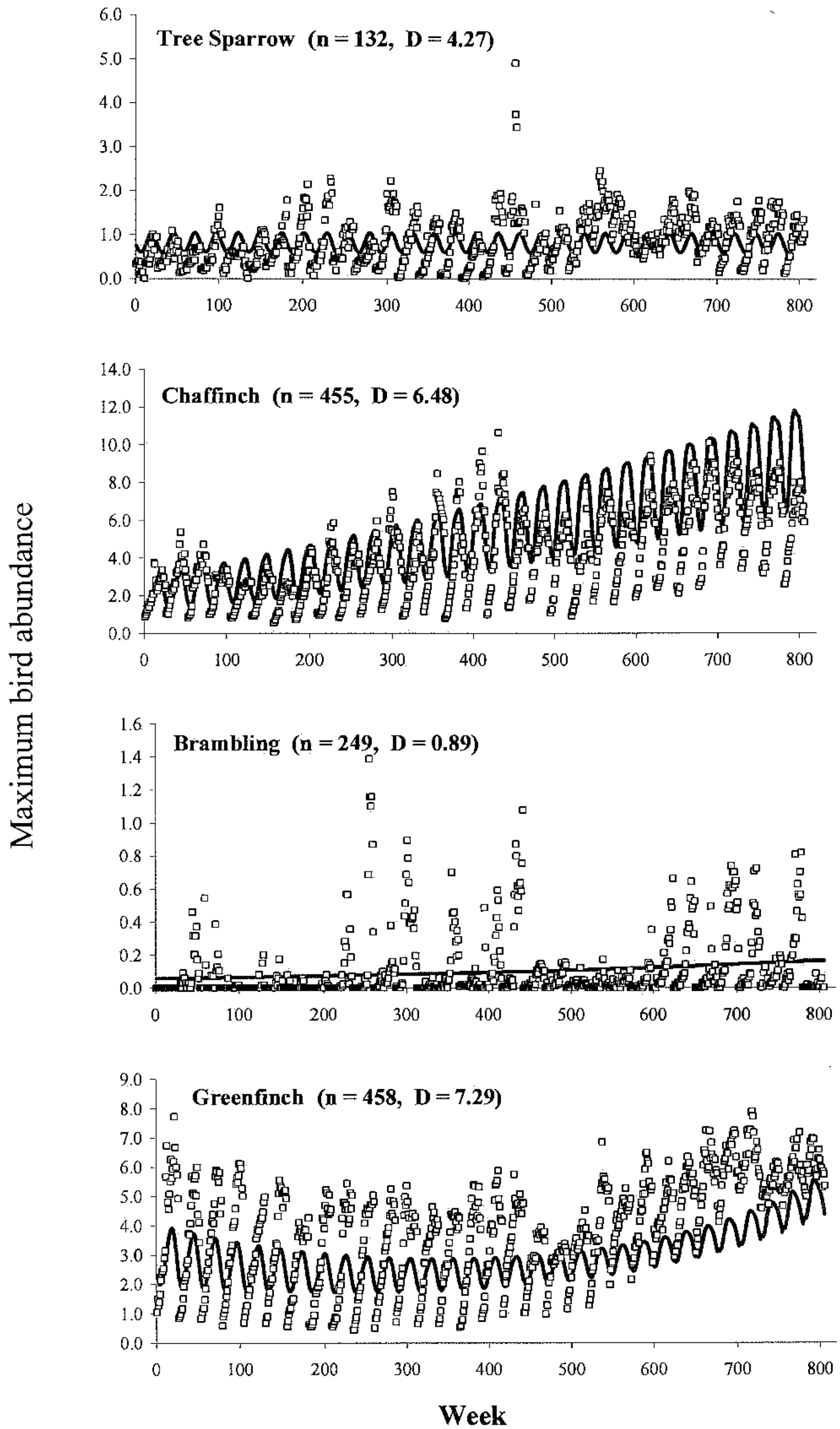


Fig. 1. Continued



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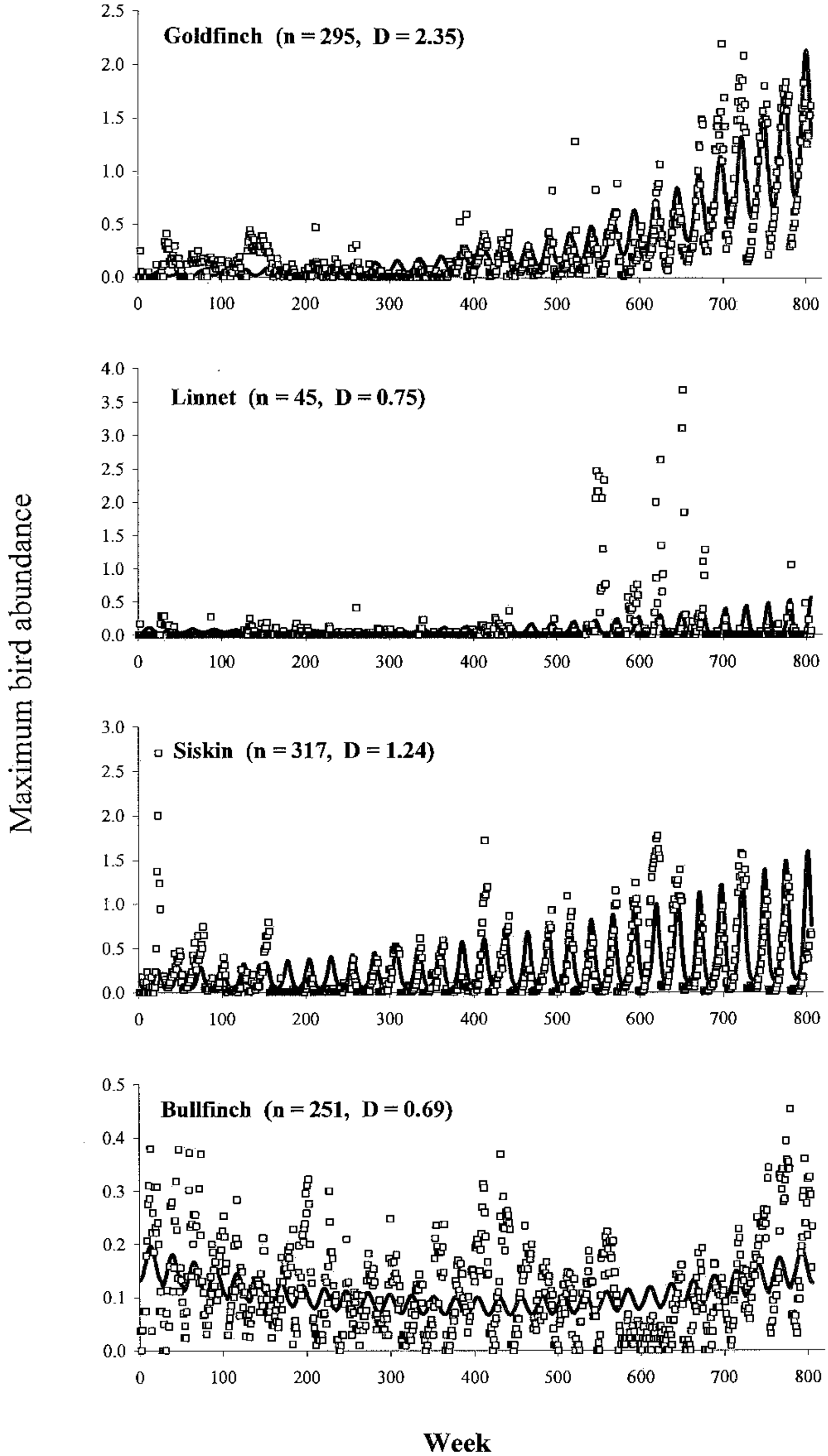

Fig. 1. Continued

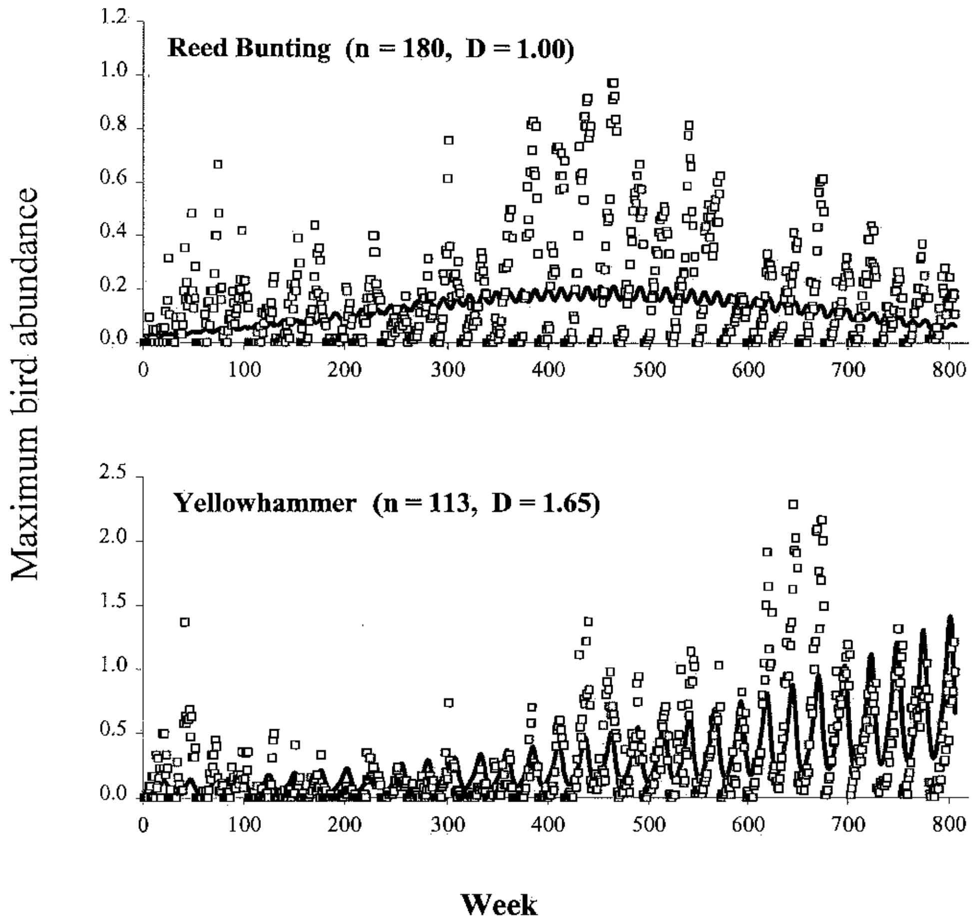

Fig. 1. Continued

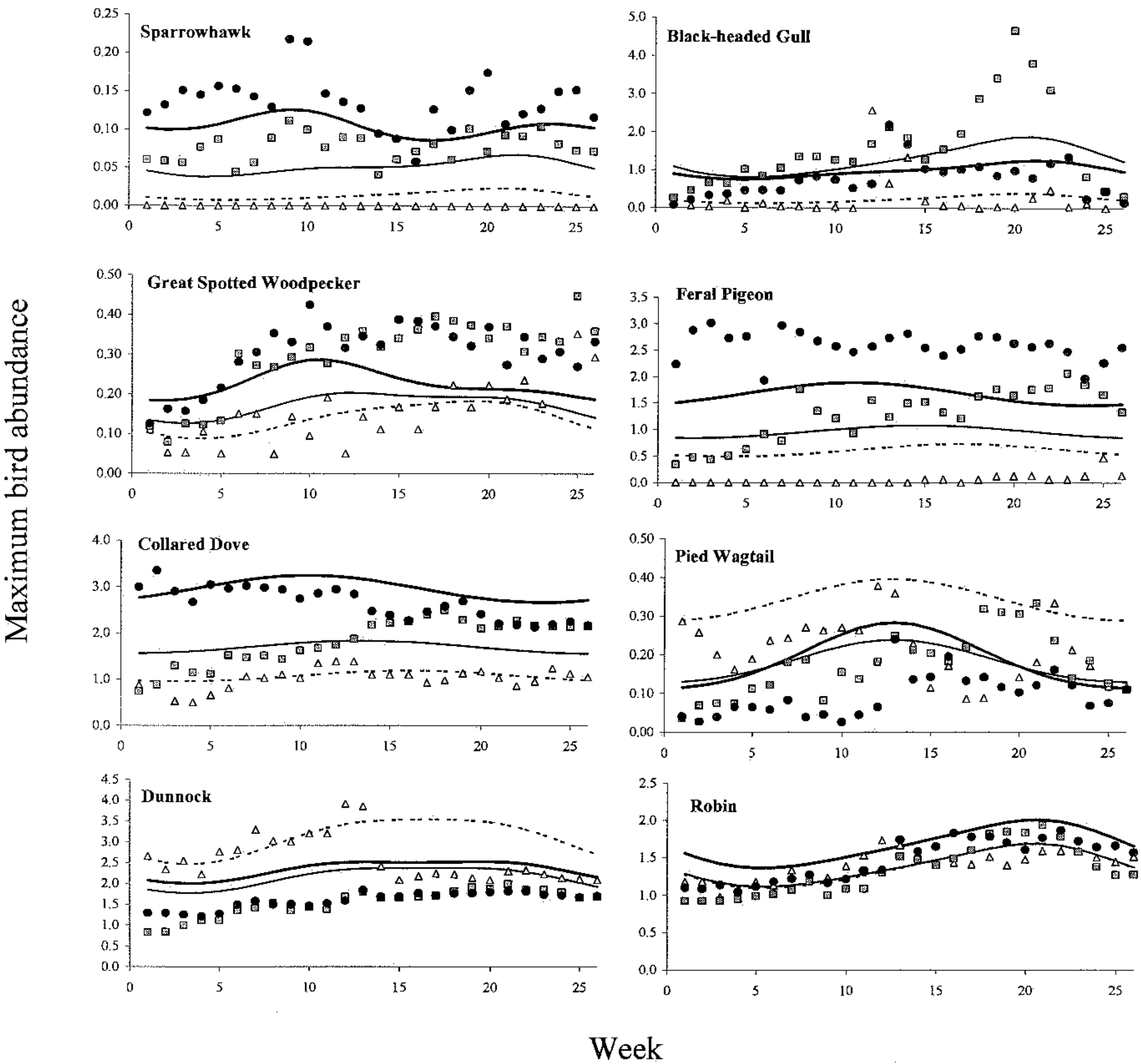

Fig. 2. Mean maximum weekly bird count in three winters, 1970/71 (triangles), 1985/86 (squares) and 2000/01 (circles) and trend lines fitted from Poisson regression (dashed line, thin line and thick line for each years respectively) for species showing significant interactions between week and year terms. Week 1 = early October, Week 26 = late March (exact dates vary from year to year).

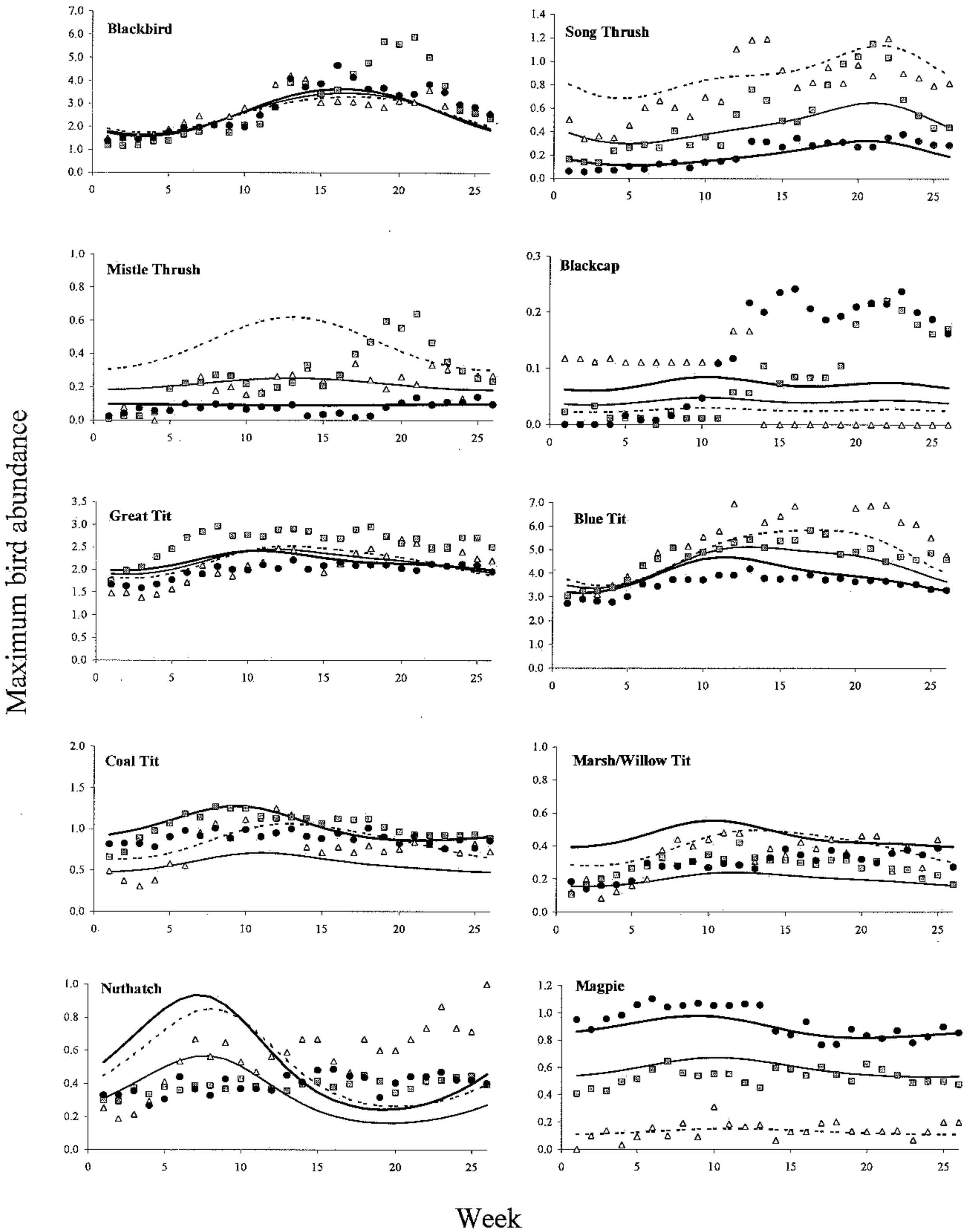

Fig. 2. Continued

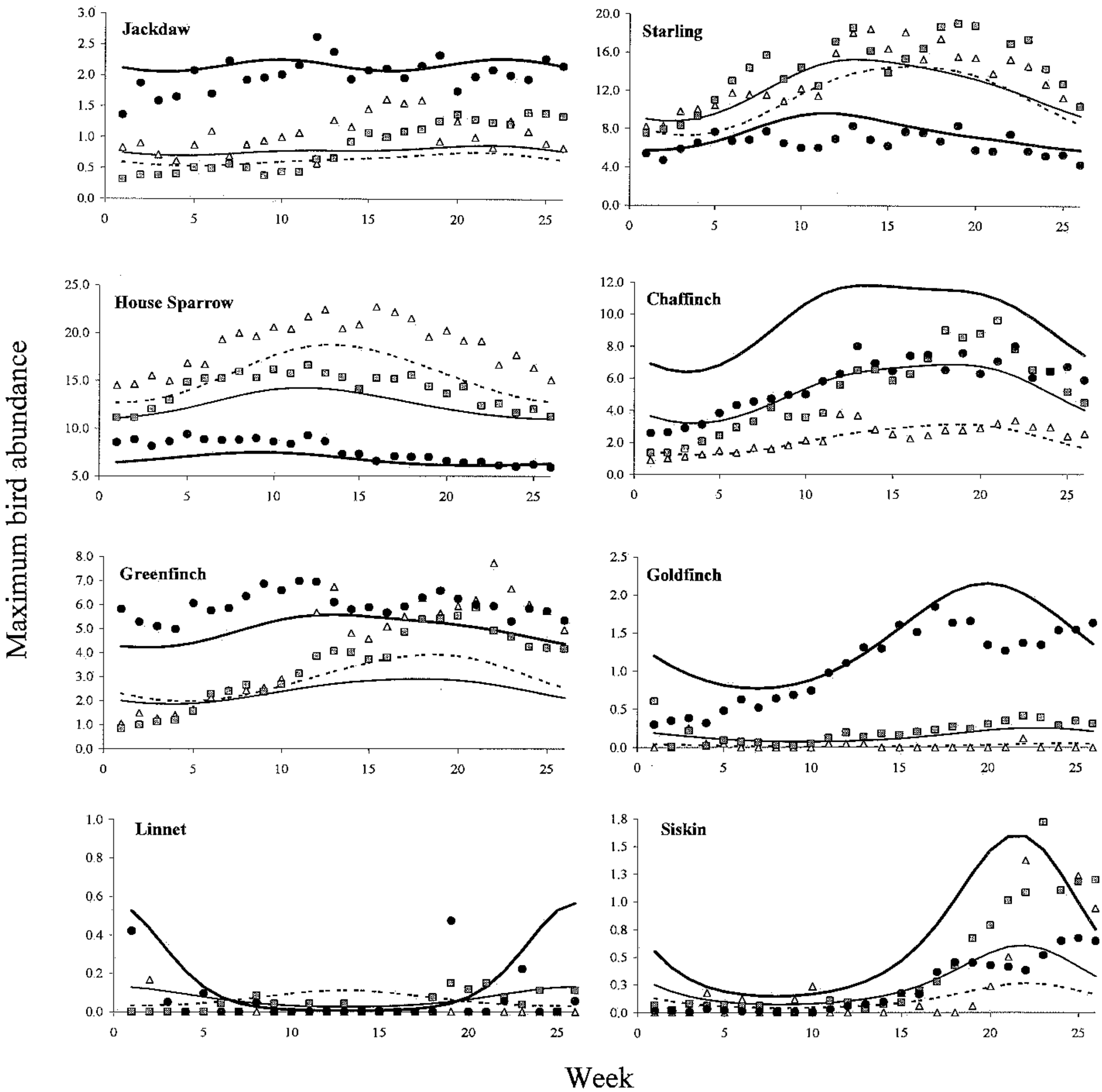

Fig. 2. Continued

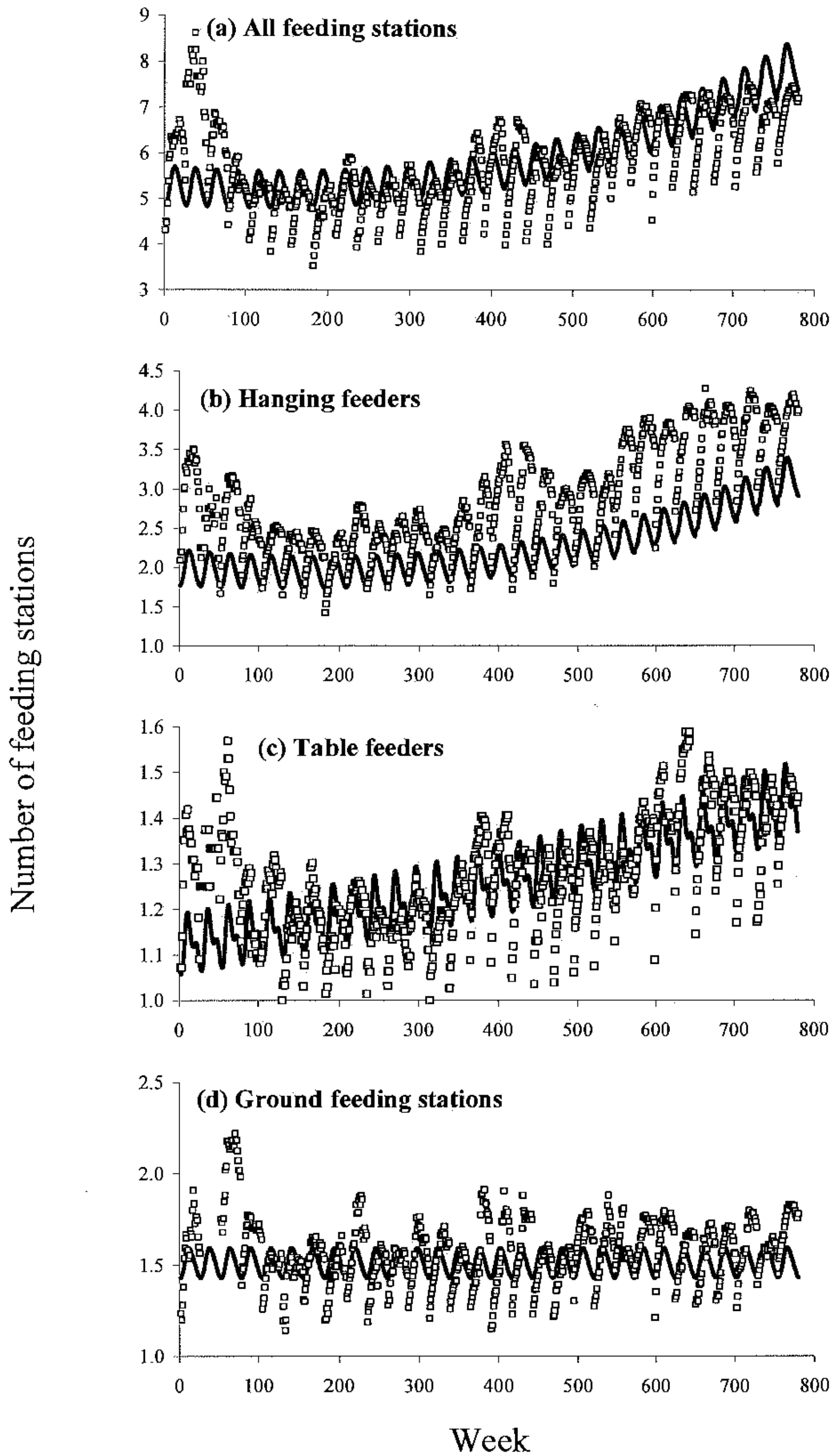

Fig. 3. Mean number of feeding stations per year and predicted feeding stations derived from a repeated measures Poisson regression model for (a) all feeding stations combined and (b) hanging feeders (c) table feeders (d) ground feeders. Week is expressed sequentially over all years where week 1 = October 1970 and week 780 = March 2000.

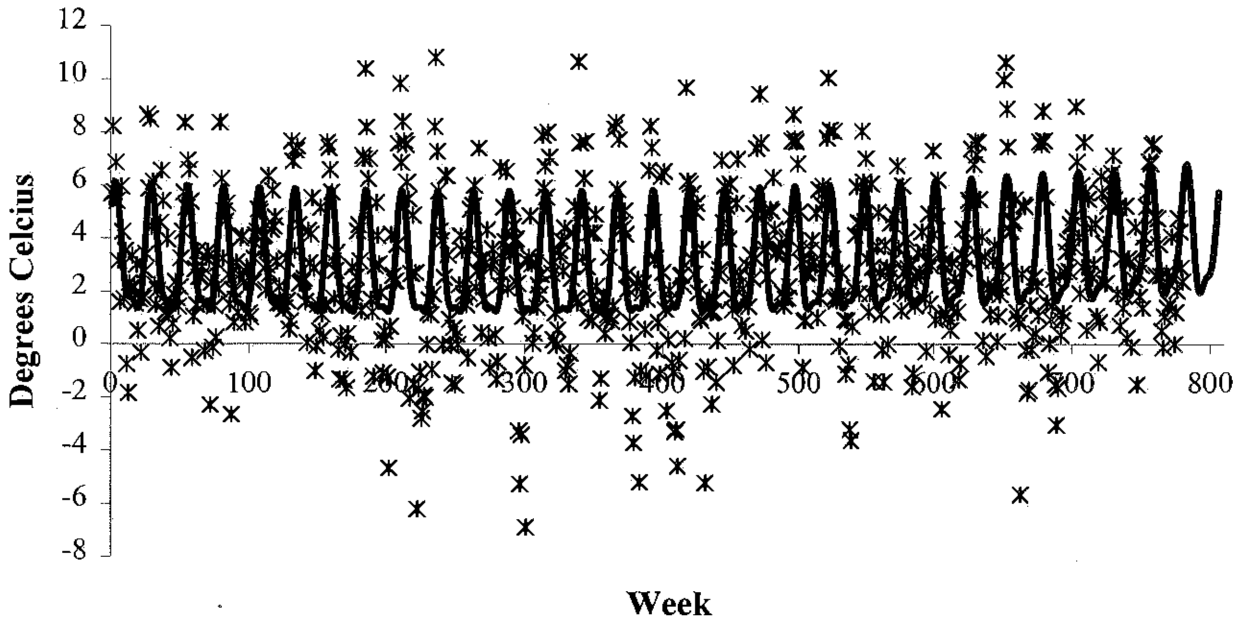

Fig. 4. Mean minimum weekly temperature between 1970/71 and 2000/01. Points are actual means calculated from the closest atmospheric recording center to each survey garden. The trend line was fitted from a regression model with a normal error distribution. Week 1 = October 1970, week 806 = March 2001.

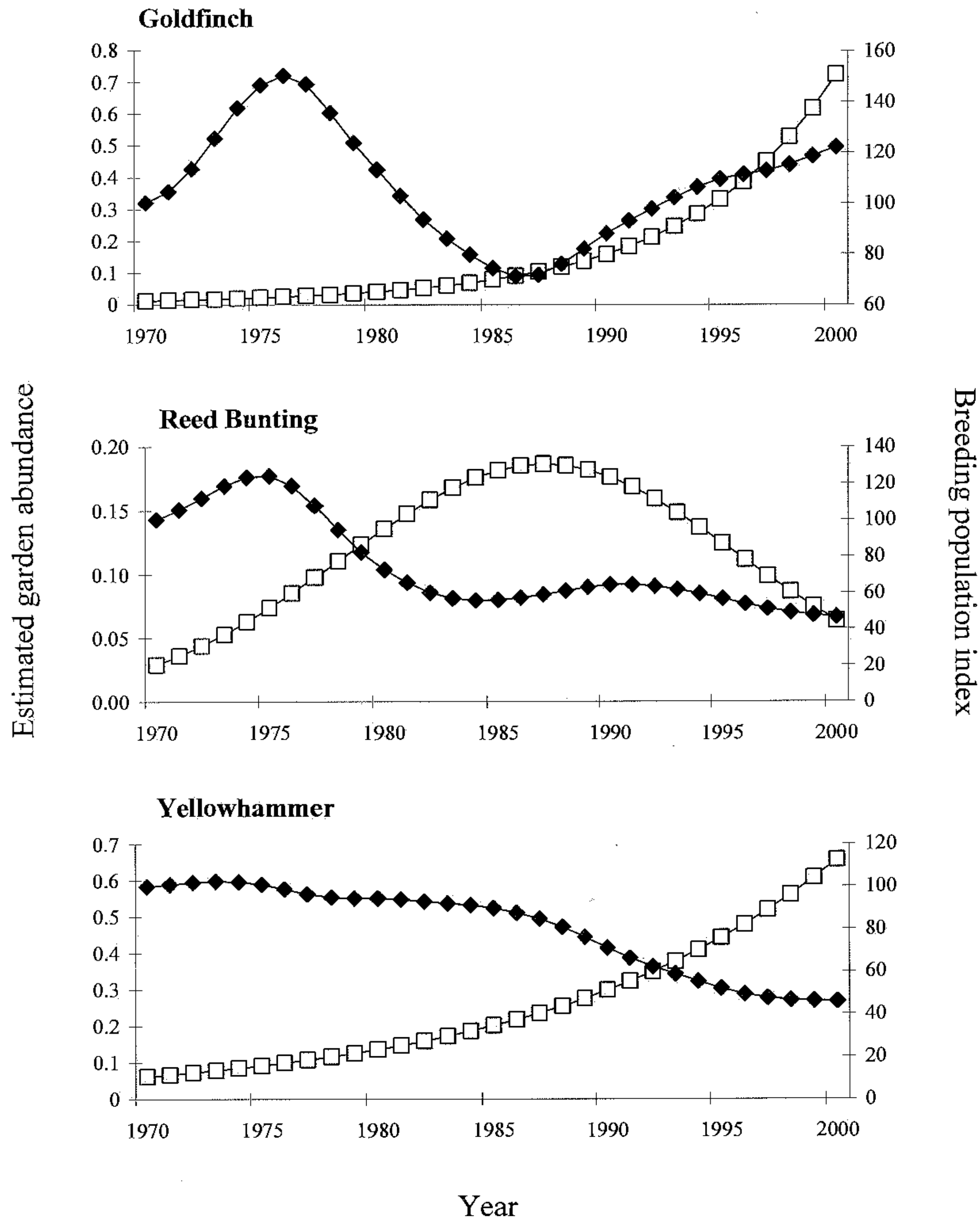

Fig. 5. Annual variations in estimated abundance birds at garden feeders derived from Poisson regression (white squares) and indices of relative population change from the previous breeding season, where 1970 is set at 100, derived from CBC data (black diamonds) for three granivorous farmland birds.

Appendix 1. Full model details

Table A1. Parameter estimates for significant ($P < 0.05$) variables, number of sites and model dispersion (deviance/degrees of freedom) for 41 species. Sweek = sin(2×π×(week/26)), Cweek = cos(2×π×(week/26)), Int = intercept, n = number of sites in model (number of sites with at least one non-zero count), D = deviance/degrees of freedom.

Species	Year	Year^2	Sweek	Cweek	Sweek *year	Cweek *year	Cweek *Sweek	Int	n	D
Sparrowhawk	0.307	-0.0014	-2.136		0.0224		-0.222	-18.97	282	0.43
Black-headed Gull	0.798	-0.0044	-1.387		0.0016		-0.143	-35.83	255	4.00
Great Spotted Woodpecker		0.0001	-1.133	-0.176	0.0120		-0.164	-2.496	262	0.79
Feral Pigeon		0.0002	-0.690	-0.114	0.0075		-1.491		128	5.85
Wood Pigeon		0.0003		-0.306				-3.464	308	1.81
Collared Dove		0.0002	-0.383	-0.080	0.0040			-0.921	421	3.84
Pied Wagtail	-0.276	-0.0015		0.534		-0.0099	-0.006	10.893	380	0.69
Wren		0.0001						-2.539	404	0.65
Dunnock	-0.179	0.0010	-0.242	-0.237	0.0016	0.0016	-0.079	8.765	456	1.18
Robin	-0.061	0.0004	-0.274		0.0009		-0.059	2.654	458	0.62
Blackbird			-0.121		-0.0018	-0.0029	-0.084	0.919	458	2.18
Song Thrush		-0.0003	0.491		-0.0100		-0.179	1.349	446	0.90
Mistle Thrush		-0.0003		-1.299		0.0130		0.633	347	1.34
Fieldfare	1.100	-0.0065	-1.054				0.575	-48.948	252	0.81
Redwing	0.481	-0.0028						-23.351	286	0.58
Goldcrest	-0.588	0.0035						21.188	160	0.30
Blackcap		0.0002				-0.0010	-0.214	-4.641	248	0.42
Blue Tit		-0.0001	-0.630	-0.171	0.0060		-0.108	1.753	458	3.14
Great Tit			-0.223	-0.303	0.0024	0.0022	-0.064	0.773	457	1.95
Coal Tit	-0.350	0.0021	-0.563	-0.545	0.0072	0.0043	-0.070	14.046	434	1.46
Marsh/Willow Tit	-0.572	0.0034	-0.548	-0.517	0.0062	0.0038	-0.108	22.477	211	1.18
Long-tailed Tit	-0.465	0.0031	-0.649	-0.508			-0.146	15.508	290	1.64
Nuthatch	-0.339	0.0020	0.319	-0.436	0.0035	0.0040	-0.084	13.172	173	1.05
Treecreeper		0.0002						-4.314	61	0.32
Jay	0.385	-0.0022					-0.239	-18.559	182	0.78
Magpie	0.489	-0.0025		-0.430	0.0008	0.0040	-0.034	-24.103	377	1.62
Carrion Crow	0.053			-0.172				-6.190	273	1.12
Rook		0.0004						-3.451	209	4.90
Jackdaw	-0.265	0.0018	-0.507		0.0050		-0.092	9.272	298	3.96
Starling	0.208	-0.0013	-0.855	-0.241	0.0087		-0.102	-5.826	452	14.2
House Sparrow	0.125	-0.0009	-0.308	-0.507	0.0039	0.0045	-0.019	-1.615	454	11.3
Tree Sparrow			-0.270					-0.231	132	4.27
Chaffinch	0.152	-0.0006	-0.894	-0.230	0.007		-0.169	-6.981	455	6.48
Brambling		0.0002						-3.810	249	0.89
Greenfinch	-0.321	0.002	-0.933	-0.121	0.0088		-0.059	13.756	458	7.29
Goldfinch		0.0008		2.561	-0.0054	-0.251		-7.746	295	2.35
Linnet				-7.483		0.0976		-2.850	45	0.75
Siskin		0.0003		0.494	-0.011		-0.142	-3.778	317	1.24
Bullfinch	-0.494	0.0029		-0.228				18.573	251	0.69
Yellowhammer	0.079		-0.717				-0.288	-8.321	113	1.65
Reed Bunting	1.114	-0.0064					-0.252	-50.174	180	1.00

Part II: Annual and seasonal trends in the use of garden feeders by birds in relation to garden type and landscape type.

DE Chamberlain, JA Vickery & DE Glue

ABSTRACT

There have been increases in abundance at garden bird feeders for some granivorous farmland birds. For some species, notably Reed Bunting and Yellowhammer, this has possibly been in response to decreasing food availability on farmland, especially as a result of declines in stubble area. The distance of a garden to these food resources and the amount of these resources in the surrounding landscapes may influence the annual and seasonal abundance of farmland granivores. These patterns were analysed according to three different classifications: whether gardens were within rural or suburban landscapes; whether gardens were within arable or non-arable landscapes; and, whether gardens were within landscapes dominated by spring or autumn sown cereals (which is assumed to reflect the amount of cereal stubble). There were several results that suggested that farmland granivores' use of garden feeders was influenced by resources in the surrounding landscapes. Rural gardens were expected to be closer to farmland food resources and have greater local (non-garden) food resources than suburban gardens. Greenfinch and Reed Bunting abundance at garden feeders showed earlier annual increases in rural gardens and Goldfinch showed greater effects of the number of feeding stations in suburban gardens. Gardens within non-arable landscapes were predicted to have lower farmland food resources than arable landscapes. Goldfinch abundance showed an earlier annual increase and an increasingly earlier winter peak in non-arable landscapes. Autumn cereal dominated areas were predicted to have lower farmland food resources than spring cereal dominated areas. Yellowhammer abundance showed a greater effect of the number of feeding stations in autumn cereal dominated areas. However, there were several results for farmland granivores where either no significant trends were detected or where results contrary to the predictions were detected. The evidence that farmland granivores are becoming increasingly dependent on garden bird food and that this is influenced by resources in the surrounding landscape was not strongly supported. The assumptions made about food availability in different landscape types and about the ranging behaviour of farmland birds could be questioned in some cases. More detailed data are required on stubble availability and other landscape attributes and further research is needed

into the use of different habitats by birds in winter in order to fully understand the factors influencing use of garden feeders by birds.

1. INTRODUCTION

Several granivorous farmland bird species have increased in abundance at garden bird feeders since the 1970s (Chamberlain et al. 2003). For some species, most notably Yellowhammer and Reed Bunting, the onset of increases in gardens coincides with a decline in the breeding population. For such granivorous species that show a preference for foraging on stubbles, this change in the use of garden feeders may be a response to a decrease in stubbles and other seed-rich food sources available on farmland in the winter. However, for other granivorous species the evidence for such an effect was not as strong as there was either no increase in numbers at garden feeders (House Sparrow, Tree Sparrow, Linnet) or the increase coincided with an increase in the breeding population (Chaffinch, Goldfinch, Greenfinch). Furthermore, there was no evidence that granivorous species changed their seasonal pattern of garden use in response to depletion of food resources in the surrounding landscape.

The availability of winter food resources to birds is unlikely to be homogenous. For example, there is a clear geographical polarization in the United Kingdom between pasture-dominated landscapes in the north and west and arable-dominated landscapes in the south and east (Chamberlain & Fuller 2000). In arable areas, seed and grain availability, particularly from cereal stubble, is likely to be relatively high. Indeed, several farmland granivores occur at higher densities and are more widespread within these landscapes (Chamberlain & Fuller 2001). Pasture-dominated landscapes often have small arable areas (to provide stock feed for example) and these 'arable pockets' can hold locally important populations of farmland granivores (Robinson et al. 2001). However, there have been declines in spring cropping in many regions due to replacement of spring with autumn-sown crops and due to a loss of arable farmland in pasture-dominated areas (Chamberlain et al. 2000). These changes have not been constant across the UK. There are still many areas in the north and west where spring cereals dominate as they are better able to cope with the harsher climatic conditions.

The location of a garden within a landscape is also likely to affect whether farmland birds are able to exploit garden bird food. Rural gardens that are adjacent to farmland are likely to be readily exploited by farmland birds. Gardens in more urbanized landscapes may not be used by farmland birds or they may only be used under certain conditions (e.g. if farmland food sources are especially scarce). It is not known how far farmland granivores are likely to disperse into suburban landscapes in the winter. There is an implication from survey data that Goldfinch, Greenfinch and Brambling move from farmland to gardens in response to food depletion (Gillings & Beaven 2003). Furthermore, research on individually radio-tracked granivores has shown that Tree Sparrows and Yellowhammers disperse over distances of at least 5km and 4km respectively (Calladine et al. 2003) within farmland. It therefore seems likely that movement from rural to suburban landscapes could take place.

In this study, annual and seasonal trends in bird abundance are compared between different garden and landscape types using Garden Bird Feeders Survey (GBFS) data in order to assess whether distance from farmland food resources and the amount of those resources has any influence on the use of garden feeders by birds, with particular emphasis on farmland granivores. It is assumed that rural gardens are closer to farmland food resources than suburban gardens. Therefore, if farmland granivores (particularly those species that are restricted to farmland as a breeding habitat, namely Tree Sparrow, Linnet, Reed Bunting and Yellowhammer) are becoming increasingly reliant on garden bird feeders, they will show a later increase (and a later change in within-winter patterns) in suburban than rural gardens. Furthermore, it is assumed that farmland food resources for granivores will be higher in arable than pastural landscapes. An earlier increase in gardens within pastural landscapes may therefore be expected, but given the generally low abundance of granivores within these landscapes (Chamberlain & Fuller 2001), it is also plausible to predict a low abundance and no significant trends. Finally, it is assumed that gardens in regions of recent high relative areas of spring cereal will have greater food resources than autumn-cereal dominated areas and that these resources will have changed less over time. Under such an assumption, a greater increase at garden feeders is expected in autumn cereal dominated areas. The influence of the number of garden feeders will also be analysed. It is predicted that for farmland granivores, there will be a greater effect of the number of feeders in gardens within landscapes where food availability is likely to be lower (suburban gardens, gardens in non-arable landscapes and gardens in areas dominated by autumn cereals).

2. METHODS

Survey methodology for collection of bird data and recording feeding stations under GBFS have been described in the previous paper (Chamberlain et al. 2003). For this analysis, these data were considered in relation to garden type and surrounding landscape.

Survey participants defined their garden as either rural or suburban. Rural gardens were defined as those situated in an area consisting of more than 50% open country, while suburban gardens were surrounded mostly by other houses and gardens (the latter sample included some gardens that most people would describe as "urban", but these were a minority and were included with suburban gardens to avoid problems of definition). Suburban gardens constituted around 60% of the sample.

Gardens were also classified according to the surrounding landscape type. Each 10-km square of the national grid has been classified into four different landscape types: arable, pastural, marginal upland and upland (Bunce et al. 1996). Each garden was identified as either within arable or non-arable landscape according to their grid reference. The majority of these non-arable gardens (85%) were in pastural landscapes, with only 13% and 2% in marginal upland and upland classes respectively. The availability of cereal stubble in the surrounding landscape may be a major determinant of bird numbers in gardens. There are no data available that quantify stubble area directly. However, because of its association with over-winter stubble, spring cereal area can be used as an indirect measure of cereal stubble availability. The area of spring cereal and winter cereal per 10-km square was derived from MAFF June Census data and SOAFD census data for 1988 and assigned to each site according to their grid reference. Sites where there was no spring or winter cereal in the surrounding 10-km square were omitted. Sites were defined according to the dominant cereal type. There were no spatially referenced agricultural data available for the duration of GBFS. However, it was assumed that 10-km squares where spring cereal area exceeded winter cereal area in 1988 had experienced little change since 1970/71 (the first year of GBFS) as the period of greatest change in spring cereal area was in the 1970s (Chamberlain et al. 2000).

3. ANALYSIS

The basic modelling approach was the same as used in the previous analysis of long-term trends (Chamberlain et al. 2003), considering variations in maximum weekly bird count in relation to year, $year^2$ and week expressed in trigonometric form using a repeated measures Poisson regression model. As previously, only sites with a minimum of five consecutive years of data were included, which gave a sample of 458 sites. A goal of the analysis was to determine if annual trends and within-winter trends varied according to garden and landscape type. Each landscape variable (garden type, landscape type and cereal type) was included as class variable in separate analyses. Poisson models including the class variable and interactions between the class variable and year and week terms were run. Model reduction was carried out as previously. Where significant interactions were found with the class variable, models were then run separately by class type. Each of the 458 sites had information on garden type. Due to missing data or missing grid references for sites, samples were reduced for other analyses. There were 322 sites that were defined according to landscape type and 309 sites that were defined according to cereal type.

The number of feeding stations per site was an important determinant of bird abundance for most species and variation in feeding stations over time could account for annual patterns in several species (Chamberlain et al. 2003). This variable was included in the above analyses to see if the effects of feeding station number varied between landscape types.

4. RESULTS

4.1 Garden Type

The distribution of GBFS sites classified according to garden type is shown in Fig. 1. The majority of suburban sites were in central Britain. Effects of garden type were assessed by adding it as a class variable to MAMs (initially without interaction terms). The majority of species (n = 26) were significantly more abundant at rural garden feeders. There were six species that showed a significantly higher abundance in suburban gardens: Black-headed Gull, Feral Pigeon, Wood Pigeon, Song Thrush, Starling and House Sparrow. There were nine species where there was no significant difference detected between rural and suburban gardens, which included most of the granivores. These species were Redwing, Carrion Crow, Brambling, Goldfinch, Linnet, Siskin, Bullfinch, Reed Bunting and Yellowhammer.

Interaction terms were added to the models to see if effects of year and week differed between garden types. There were 14 species that showed a significant interaction between year and garden type. Annual trends for rural and suburban gardens are shown separately for each species in Fig. 2. For most species, abundance was higher in rural than suburban sites. For Dunnock, Long-tailed Tit and Chaffinch, there were no major differences in the shape of the trend between garden types. Two species, Black-headed Gull and Reed Bunting, showed a peak in abundance around the middle of the survey period, but in both species this peak was later (markedly so for Reed Bunting) in suburban sites. Feral Pigeon, Wren, Rook and Greenfinch all showed an increasing trend over time in rural gardens, but no significant change, or relatively slight increase, in suburban gardens. Sparrowhawk, Great Spotted Woodpecker and Goldcrest showed recent increases on both garden types but the trends were converging. Similarly, Carrion Crow abundance was greater in rural sites earlier on in the period, but from the mid-1990s onwards, abundance in suburban sites was greater than in rural sites. Finally, House Sparrow showed declines in both garden types, but again the relative abundance in garden types had changed. At the start of the survey, House Sparrows were more abundant in suburban sites, but the most recent data suggest they are most abundant in rural sites.

There were 27 species that showed a significant interaction between garden type and week terms. The week where peak numbers were estimated to occur according to Poisson regression model parameters are given for three winters (1970/91, 1985/86 and 2000/01) in different garden types is shown in Fig. 3 for several species that showed clear seasonal peaks in abundance. Differences were typically small. Notable exceptions were Great Spotted Woodpecker which showed markedly earlier peaks in rural gardens in the first two winters, and Wren, which showed no trend in peak week over time, but which showed much earlier peaks in rural than suburban gardens. In both garden types, peak week tended to become earlier in later winters. In the most recent winter, peak in suburban gardens was earlier than in rural gardens in 10 species (including Greenfinch) and earlier in rural gardens in only three species.

For certain species, although patterns differed between garden types, there was no obvious seasonal peak in abundance. These were Dunnock, Mistle Thrush, Treecreeper, Jay, Rook and Linnet (not included in Fig. 3). Marsh/Willow Tit showed an increasingly earlier peak week in rural gardens, but abundance was very low and showed a constant seasonal pattern in suburban gardens. Goldfinch had very low abundance and approximately constant seasonal patterns in both gardens types in 1970/71 and 1985/86, but in 2000/01 there was a clear peak at week 21 for rural gardens and week 20 for suburban gardens. Reed Bunting showed clear peaks in abundance, but in each case the peak was equal (although the absolute abundance varied between years and garden types).

According to repeated measures Poisson regression models analyzing feeding station data in relation to year, week and garden type, there was a significantly higher number of feeding stations in rural than suburban gardens, although the magnitude of differences was small (estimated mean from Poisson parameter estimates: rural = 5.76, 95% CI = 5.41 – 6.12, n = 218; suburban =5.16, 95% CI = 5.06 – 5.26, n = 240). The number of feeding stations was added to models incorporating year, week and garden type. All species apart from Blackcap showed a significant effect of the number of feeding stations. In 13 cases, both garden type and the number of feeding stations were significant, but there was no significant effect of year, including the farmland granivores House Sparrow, Chaffinch and Greenfinch suggesting that garden type and feeding station data could explain annual variations. Effects of feeding station were additive for a further 14 species including Yellowhammer and Reed Bunting.

There were 13 species that showed a significant interaction between garden type and the number of feeding stations. When models were run separately by garden type, effects of feeding station number were additive to effects of year, week and garden type, although the parameter estimates for feeding station (i.e. the shape of the relationship) differed between garden types. This included the only granivore to show a significant interaction, Goldfinch. Exceptions included Feral Pigeon and Wren, both of which showed significant effects of feeding station number in suburban gardens but not rural gardens. If birds are more reliant on garden feeders due to a lower availability of food in the surrounding landscape, then they might exhibit greater effects of the number of feeders within gardens where food availability is lower. For species showing a significant interaction between garden type and the number of feeders, eight showed clear differences in the slope of the association between garden types. Great Spotted Woodpecker, Woodpigeon, Collared Dove and Rook showed greater responses to feeding station number in rural gardens. Robin, Song Thrush and Goldfinch showed a greater response in suburban gardens.

4.2 Landscape Type

The distribution of GBFS sites classified according to landscape type is shown in Fig. 4. As expected, arable sites dominated in the south and east and non-arable dominated in the north and west. Landscape type was added to Poisson models, initially without interaction terms, to determine if there were differences in overall abundance between birds at garden feeders at sites in arable landscapes and sites in non-arable landscapes. There were relatively few species where abundance in arable landscapes was significantly greater than that in non-arable landscapes. These species were Woodpigeon, Dunnock, Blackbird, Song Thrush, Goldcrest, Treecreeper and Greenfinch. There were 16 species where abundance in non-arable landscapes significantly exceeded that in arable landscapes: Sparrowhawk, Feral Pigeon, Pied Wagtail, Wren, Mistle Thrush, Blackcap, Blue Tit, Coal Tit, Marsh/Willow Tit, Jackdaw, Rook, Magpie, Tree Sparrow, Chaffinch, Siskin and Bullfinch. There were 18 species that showed no significant difference including the farmland granivores House Sparrow, Goldfinch, Linnet, Reed Bunting and Yellowhammer.

When year interactions were included in the models, there were 17 species that showed significant interactions. Trends estimated from Poisson regression for arable and non-arable landscapes separately are shown in Fig. 5. Trends were broadly similar, but showed differences in overall abundance between landscape types in Tree Sparrow, Dunnock, Blackbird, Robin (arable>non-arable), Nuthatch and Magpie (non-arable>arable). There were several cases where the landscape type with the higher estimated abundance changed over time. In Sparrowhawk, Carrion Crow and Goldfinch increasing trends were evident in both landscape types, but arable had the higher abundance in the 1970s whereas the most recent estimates estimated gardens in non-arable landscapes to have the highest abundance. For Great Spotted Woodpecker and Collared Dove the opposite pattern with respect to landscape type was observed. Bullfinch and Goldcrest showed declines in arable landscapes but increases in non-arable landscapes. Redwing showed no annual trend in non-arable landscapes but an increase in arable landscapes. House Sparrow showed declines in both landscapes, but the magnitude of decline was steeper in arable landscapes so abundance was now marginally greater in non-arable landscapes, whereas in the 1970s, arable landscapes clearly had a higher abundance. Linnet showed very low abundance and no annual trend in arable landscapes, but an overall mean increase in the past 10 years in non-arable landscapes, although this was due to a large increase in mid-winter peak. Linnet showed an unusual pattern in that there was a period of little seasonal variation in the early 1980s. It should be borne in mind that Linnet had very low rates of occurrence and so caution should be taken when interpreting these patterns.

There were 13 species where a significant interaction between landscape and week terms was detected. For several species, however, there were no clear differences in seasonal use over time although there were some subtle differences in the shape of the trend lines. Feral Pigeon, Magpie and Jackdaw showed approximately constant variation across each winter with no really identifiable peak in numbers. Great Spotted Woodpecker, Wren and Treecreeper showed clear peaks in arable landscapes, the former species showing an increasing earlier peak and the latter two no change in peak week over time. However, there were no seasonal trends in non-arable landscapes. Long-tailed Tit showed constant peak across all years and in both landscapes types. Goldfinch occurred at very low abundance and showed no seasonal trend until the most recent years when the peak in non-arable landscapes was on average three weeks earlier than in arable landscapes. For the remaining five species, differences in seasonal peaks between years and landscapes types were more pronounced (Fig. 6). Black-headed Gull and Starling showed progressively earlier peak weeks in both landscape types. Wood pigeon and Blackcap showed no seasonal trends, but peak week differed between landscape types. Peak week was earlier (but by only an estimated one week) in arable landscapes for Woodpigeon. Peak week was an estimated three weeks later in non-arable landscapes. Pied Wagtail showed no seasonal shift in peak week in non-arable landscapes and a progressively later peak week in arable landscapes (Fig. 6).

There was a significantly higher number of feeding stations in gardens in non-arable than arable landscapes (estimated mean from Poisson parameter estimates: arable = 5.26, 95% CI = 4.96 – 5.93, n = 160; non-arable =6.02, 95% CI = 5.77 – 6.27, n = 162). There were significant effects of the number of feeding stations on bird abundance in the majority of species. In some cases this effect was additive (Woodpigeon, Fieldfare, Carrion Crow, Siskin), but in several cases, there were significant effects of feeding station number but no significant effects of year. These were Feral Pigeon, Wren, Dunnock, Song Thrush, Blackcap, Coal Tit, Marsh/Willow Tit, Long-tailed Tit, Nuthatch, House Sparrow, Chaffinch, Brambling, Greenfinch and Yellowhammer. There was no significant effect of feeding station number on Starling abundance. Significant differences between landscape types were no longer evident with the addition of feeding station data for Siskin only.

Many species showed significant interactions between feeding station number and landscape type. When analysed separately by landscape type, effects of feeding station number was additive to effects of year and week, although the magnitude of parameter estimates varied (but not the direction) in Sparrowhawk, Great Spotted Woodpecker, Robin, Goldcrest, Blue Tit, Magpie, Jackdaw and Tree Sparrow. Sparrowhawk, Great Spotted Woodpecker, Blue Tit, Magpie and Jackdaw showed a greater effect in non-arable landscapes and Tree Sparrow showed a greater effect in arable landscapes. For Robin and Goldcrest, effects were non-linear in both. Collared Dove, Pied Wagtail, Mistle Thrush and Great Tit showed significant effects of feeding station number but no significant trends in year in non-arable landscapes. There was no effect of feeding station number in arable landscapes for Pied Wagtail and Goldfinch and no significant of feeding station number in non-arable landscapes in Redwing, Treecreeper, Jay, Rook, Bullfinch and Reed Bunting.

4.3 Spring and Autumn Cereals

The distribution of GBFS sites classified according to predominant cereal type in the surrounding landscape is shown in Fig. 7. The distribution of sites did not show any clear geographic patterns with respect to cereal type, although there was perhaps a slight tendency for spring cereal types to dominate in the west of Britain. When predominant cereal type was added to MAMs, many species (n = 21) showed no significant difference in abundance at garden feeders between sites in spring and autumn cereal areas, including the granivores House Sparrow, Tree Sparrow, Linnet and Reed Bunting. Autumn cereal areas held a significantly higher abundance of 15 species: Sparrowhawk, Great Spotted Woodpecker, Collared Dove, Robin, Mistle Thrush, Blackcap, Great Tit, Blue Tit, Treecreeper, Rook, Jay, Brambling, Greenfinch, Goldfinch and Siskin. There were only five species where abundance was significantly higher in spring cereal dominated areas: Feral Pigeon, Jackdaw, Starling, Chaffinch and Yellowhammer.

When interaction terms were added to the models, there were 16 species that showed significant interactions between year and cereal type. Cereal-specific trends are shown in Fig. 8. Several species showed broadly similar trends according to cereal type: Sparrowhawk, Woodpigeon, Song Thrush, Great Tit, Carrion Crow and Bullfinch. For Wren, Magpie and Long-tailed Tit, rates of increase were clearly greater in sites within spring cereal areas. For Nuthatch and Jackdaw, there were linear increases in abundance at feeders in sites in autumn cereal areas, but early declines followed by more recent increases in spring cereal areas. The thrushes, Blackbird, Fieldfare and Mistle Thrush all showed differing trends in abundance at gardens feeders according to cereal type: Blackbird increased in autumn cereal areas, but was stable after an initial decrease in spring cereal areas; Fieldfare showed relative stability in spring cereal areas but a peak in abundance in the 1980s in winter cereal areas; Mistle Thrush showed a stable trends at very low estimated abundance in spring cereal areas and a marked decrease in autumn cereal areas. There were only two farmland granivores to show a significant interaction, Greenfinch and Linnet. Greenfinch showed increases in both garden types, but sites in autumn cereal areas showed a linear increase, whereas those in spring cereal areas showed an increasing rate of increase in more recent years. Linnet showed apparent stability in both garden types, although within-winter estimates had relatively very large fluctuations, especially for spring cereal areas. As previously suggested, estimates derived for Linnet should be interpreted with caution due to the small sample size.

There were 19 species that showed a significant interaction between cereal type and week terms. As in previous analyses (Figs. 3 and 6), interactions were interpreted in terms of the week of estimated peak count in separate winters. There were seven species where there were no clear peaks in abundance (Magpie, Linnet) or where peak week was the same across all years and in gardens from both cereal types (Redwing, Long-tailed Tit, Jay, Jackdaw, Siskin). Black-headed Gull showed the same peak weeks in different cereal types, but there was a clear patterns for earlier peaks (from an estimated week 17 in 1970/71 to an estimated week 13 in 2000/01). Goldfinch occurred at very low abundance up until the 1990s, but there was a clear difference in peak week in 2000/01, when gardens in spring cereal dominated areas showed a peak in abundance in week 18, whereas the peak in autumn cereal dominated areas was week 20. For other species that showed a clear difference in peak week between gardens from different predominant cereal areas, peak weeks for three different winter area shown in Fig. 9. Four species showed no seasonal pattern in peak week, but a clear difference according to cereal type. Fieldfare and Tree Sparrow had earlier peak weeks in spring cereal dominated areas, Woodpigeon and Treecreeper had earlier peak weeks in autumn cereal dominated areas. There were increasingly earlier peaks over time in several species. Blackbird, Chaffinch and Greenfinch all showed this trend, and in each case peaks in spring cereal areas were marginally earlier than those in autumn cereal areas. Starling also showed earlier peaks over time, but the rate of change in peak week was greater in autumn than spring cereal areas (so spring cereal areas were initially earlier but in the most recent winter, the earliest peak was in the autumn cereal areas). Goldcrest showed an increasingly later peak over time for both cereal types. Pied Wagtail was the only species to show opposing trends over time according to cereal type. In spring cereal dominated areas, Pied Wagtail peak week had become progressively earlier over time, but in autumn cereal dominated areas, peak week had become progressively later.

There was a significantly higher number of feeding stations in gardens within autumn cereal dominated landscapes than spring cereal dominated landscapes (estimated mean from Poisson parameter estimates: autumn cereal = 5.98, 95% CI = 5.52 – 6.48, n = 160; spring cereal =5.42, 95% CI = 5.23 – 5.59, n = 149). Feeding station data was added to MAMs. For the 22 species showing no significant interaction between feeding station number and predominant cereal area, there were significant positive (or sometimes non-linear) effects of feeding station in each case. For 20 of these species, effects of feeding station were additive, i.e. no previously significant terms dropped out of the model as a consequence of the addition of feeding station data. This include the farmland granivores House Sparrow, Chaffinch, Greenfinch, Goldfinch and Reed Bunting. There were two exceptions, Redwing and Treecreeper, where there were no longer significant effects of year after the addition of feeding station data.

There were 19 species that showed an interaction between feeding station number and predominant cereal area. In most cases, feeding station number was additive to the models from each cereal area. These were Sparrowhawk, Collared Dove, Pied Wagtail, Robin, Mistle

Thrush, Blackcap, Goldcrest, Blue Tit, Long-tailed Tit, Magpie, Brambling and Yellowhammer. There was no significant effect of feeding station number in spring cereal dominated areas for Great Spotted Woodpecker, Jay, and Jackdaw and no significant effect in autumn cereal dominated areas in Feral Pigeon, Rook and Linnet. The magnitude of the effect of feeding station number was greater in spring cereal dominated areas for Pied Wagtail, Robin, Mistle Thrush, Blackcap, Blue Tit, Tree Sparrow and Brambling. The magnitude of the effect was greater in autumn cereal dominated areas in Yellowhammer only.

5. DISCUSSION

For many species, there were clear differences in the abundance of birds at garden feeders and garden and landscape type. For farmland granivores, use of garden feeders was expected to be influenced by the distance to farmland food resources and the amount of those farmland food resources. The following discussion focuses on these issues with particular emphasis on farmland granivores.

5.1 Annual Trends

It was assumed that rural and suburban gardens differed in their distance to farmland food resources. For four farmland granivores, there was no significant difference in overall abundance between these two garden types: Goldfinch, Linnet, Reed Bunting and Yellowhammer. The latter three species are farmland specialists that do not commonly breed in suburban habitat, so the lack of significant difference indicates that these species are able to exploit resources over large areas, a result that has previously been shown for Yellowhammer through radio-tracking studies (Calladine et al. 2003). For Tree Sparrow, Chaffinch and Greenfinch numbers in rural gardens were higher. This may reflect a greater reliance on farmland food resources, although the latter two species are very much generalists that are common in both suburban and rural habitat. House Sparrow is very much associated with human habitation and is less strongly linked with open farmland and stubbles than the other species. Of the eight farmland granivores, four showed significant interactions between year and garden type. If these species are becoming more reliant on garden bird food, rural gardens may be expected to show greater increases (at least initially), assuming that birds will travel further when there is increasing food depletion. This was not the case for the Chaffinch (similar increases in both garden types) and House Sparrow (declines in both, but declines steeper in suburban habitats). These patterns were evident for Reed Bunting (earlier increase in suburban gardens) and Greenfinch (no significant change in suburban gardens). Although many non-granivores showed increases in abundance at garden feeders, there was no consistent pattern for any species group, nor were patterns appreciably different to those observed for farmland granivores.

There was little evidence that broad landscape was associated with the use of garden feeders over time for farmland granivores. Arable landscapes would be expected to have the greater farmland food resources, but they had significantly greater abundance of only one granivore, Greenfinch. Tree Sparrow and Chaffinch were more abundant in non-arable landscapes and there was no significant difference for other species. Furthermore, there were few differences in trend between landscape types. Tree Sparrow and House Sparrow showed fairly similar trends over time in both landscapes. Only Goldfinch showed a more interesting result, the rate of increase in non-arable landscapes being greater than in arable, which could be a result of greater food stress in the non-arable habitat. Similarly, there were few results that supported the notion that granivores were becoming more reliant on garden feeders when gardens were defined according to the predominant cereal type. Chaffinch and Yellowhammer were significantly more abundant in landscapes where spring cereals dominated, but Greenfinch and Goldfinch were more abundant in autumn cereal dominated landscapes. Only Greenfinch showed an interaction between year and cereal type, but the rate of increase in abundance at garden feeders was greater in spring cereal landscapes (which were expected to have greater food resources).

5.2 Within-season Trends

Seasonal differences may also be expected according to distance to farmland food resources and the amount of those resources. If food availability has decreased over time in the ~~surrounding landscape then an increasingly earlier movement into gardens may be expected.~~ Furthermore, this increase may be earlier still in gardens that are within landscapes where food resources are depleted more quickly in the surrounding landscape. For many species, there were earlier peaks across all landscape types. For farmland granivores, suburban gardens, non-arable landscapes and autumn cereal dominated landscapes were expected to have lower food availability. Greenfinch showed a marginally earlier peak in suburban gardens and Goldfinch showed an earlier peak in non-arable landscapes, both of which could reflect lower food availability in the surrounding landscape. An earlier peak for Greenfinch in suburban gardens is not what would be predicted if distance to farmland resources is a major factor influencing abundance of birds at garden feeders. Rather a later peak or no significant change over time would be expected. There were no other species showing differences in the expected direction, but there were four farmland granivores that showed an earlier peak in spring cereal dominated areas, which, if the assumptions about food availability are correct, is not what was expected.

5.3 Influence of Number of Feeders

Associations with the number of feeders are expected to be more prevalent and of greater magnitude where food availability is lower, if granivorous species are dependent on garden feeders. There was evidence that abundance of several species (both granivores and non-granivores) was closely linked to feeder number. There were greater effects of feeder number in suburban gardens for Goldfinch and for Yellowhammer in autumn cereal dominated areas, suggesting that there is a greater response to feeder number where surrounding landscapes have lower food availability. However, for most granivores there was no difference between garden/landscape types and Tree Sparrow and Linnet showed the greater response in landscapes that were predicted to have greater food resources. Similarly, there were no consistent patterns in the association between bird abundance and feeder number in non-granivores.

5.4 Landscape and Food Availability

In this paper, assumptions have been made about the food availability in the landscapes surrounding gardens. The assumption that garden type is likely to reflect differences from farmland food resources was probably true on average. However, the classification of gardens into rural and suburban was based on the opinions of each surveyor rather than any independent assessment. It is easy to conceive of a situation where a garden was classified as suburban due to it being surrounded by other houses, but where farmland was still very close (e.g. on the edge of a town for example). A further potential issue is the assumption that birds will deplete farmland food resources first before switching to garden feeders. Given the high number of gardens that supply bird food (Cowie & Hinsley 1988) this may not be the case. However, as the majority of species (not just granivores) do show distinct seasonal peaks at garden feeders, it does seem likely that other food sources are being exploited at the beginning of winter.

The assumption that arable landscapes will have more food than non-arable landscapes for granivores is based on the preference of many of these species for cereal stubbles (Wilson et al. 1996), that many are more abundant in arable landscapes (Chamberlain & Fuller 2001) and that mixed farming, and hence cereals, have declined in non-arable landscapes (Chamberlain & Fuller 2000). This assumption is likely to be fairly robust. However, it may be erroneous to assume that farmland food availability is higher in arable landscapes where farmland is highly intensive, so there may be less of a difference in food availability between the two landscapes in later years.

The assumption that farmland food availability will be higher and will have decreased less in spring cereal dominated areas is largely based on the likelihood of stubbles being present in the surrounding landscapes. This may be generally true, but there are many differences in management and it should not be assumed that spring cereals are always associated with stubbles or that autumn cereals are never associated with stubbles. Furthermore, other arable crops can have stubbles that are preferred foraging habitats for several species (e.g. root crops, oilseed rape), although there are no data on sowing times available for crops other than cereals. A further complicating factor is the introduction of set-aside in the early 1990s, which was often in the form of stubble in rotation. This has been shown to be a preferred winter foraging habitat (Buckingham et al. 1999), but again spatially referenced data were not available. Finally, the classification adopted was a very simple one based on relative amounts. Actual areas of both spring and winter crops are also likely to have an influence on farmland food availability and therefore on use of garden feeders by birds. It may be more informative to consider spring cereal area as a continuous variable in regression models in any future analyses.

The above assumptions are probably generally true, but there will be much variation between sites due to the above caveats. Assumptions about food availability based on relative areas of spring and winter cereals are particularly questionable. For a truly comprehensive analysis, far greater detail on the exact amounts of cereal and other stubbles in the surrounding landscape and the distance of each site to the stubble resource is needed to assess the interactions between garden feeders, farmland food availability and the abundance of farmland granivores. A highly intensive analysis within a GIS framework may be the only way to achieve this goal.

A summary of significant associations between abundance of garden birds and either year, week within season and the number of feeders that gave support to the hypothesis that farmland granivores are becoming more dependent on garden feeders is shown in Table 1. To re-cap, farmland granivores are predicted to: have greater overall abundance where farmland food resources are greater, namely rural gardens, arable landscapes and spring cereal areas; have an earlier or greater rate of increase annually in rural gardens, non-arable landscapes and autumn-cereal dominated areas; show progressively earlier within-season peaks in garden feeder use in rural gardens, non-arable landscapes and autumn-cereal dominated areas; show greater effects (in terms of significance and magnitude of effect) in suburban gardens, non-arable landscapes and autumn-cereal dominated areas. There were only a few individual cases where these predictions were supported. In most cases there was no significant effect. It should be noted that for two species in particular, Tree Sparrow and Linnet, the data were very sparse, model fits were poor and very few significant results were detected. These species, especially Linnet, probably occur at abundance levels that are too low to detect significant effects.

Overall there more cases where a contradictory significant result was detected than cases where a prediction was supported (Table 1). This was especially the case for landscapes classified according to spring cereal area, further supporting the above contention that assumptions about food availability for this classification were the most questionable. In common with the analysis of general trends (Chamberlain et al. 2003), there was no evidence that farmland granivores as a group were becoming more dependent on garden feeders. However, there remains the possibility that this is the case for certain individual species. For both Yellowhammer and Reed Bunting, the overall patterns matched the predictions (Chamberlain et al. 2003) and there was some evidence that Reed Buntings had increased in rural gardens earlier than in suburban gardens and that Yellowhammers showed a greater response to the number of feeders in autumn cereal dominated areas and were more abundant in spring cereal areas.

The predictions on which Table 1 are based are heavily dependent on assumptions about food availability in different landscape types, some of which can be questioned. In addition, there are also implicit assumptions about how birds are likely to behave. Granivorous species often form large mobile flocks in winter. Exactly how these behave and over what distances they travel to find food is not known, but there is an assumption that food depletion, distance to food resources and the habitats within different landscapes all have an influence. Further studies which consider the ranging behaviour of farmland granivores with particular reference to stubble availability are currently being carried out (G.M. Siriwardena, pers. comm.). The results of these studies should enhance our understanding of resource use and depletion in farmland and should also allow clearer interpretations of the trends found in this study.

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Table 1. A summary of significant trends detected in the analyses for farmland granivores in garden classified according to landscape type. Overall indicates gross significant differences in abundance between garden/landscape types, Annual indicates associations with year, Seasonal indicates changing patterns of within-winter peaks over years, Feeders indicates significant effect of feeder number. A tick indicates support for the prediction that farmland granivores show a greater dependence on garden feeders in gardens where farmland food availability is lower in the surrounding landscape (see text for further details). A cross indicates a significant result contrary to the prediction. Blank cells indicate no significant effects.

	Garden type				Landscape type				Cereal type			
Species	Overall	Annual	Seasonal	Feeders	Overall	Annual	Seasonal	Feeders	Overall	Annual	Seasonal	Feeders
House Sparrow	X	X	X			X				x		
Tree Sparrow	✓			X	X						X	X
Chaffinch	✓				X				✓		X	
Greenfinch	✓	✓	X		✓				X		X	
Goldfinch				✓		✓	✓		X		X	
Linnet												X
Reed Bunting		✓										
Yellowhammer									✓			✓

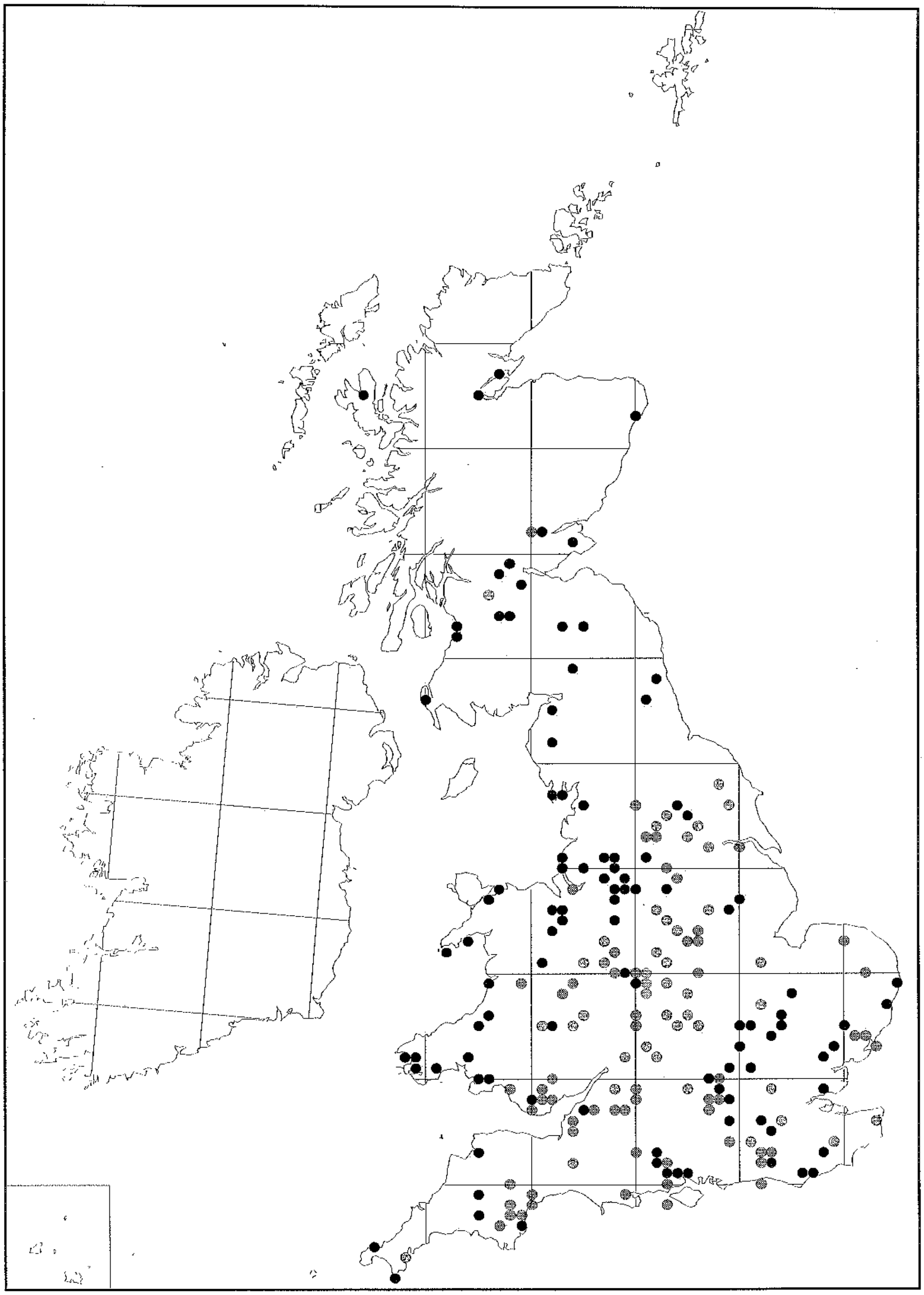


Fig. 1. The distribution of rural (black circles) and suburban (grey circles) gardens in the survey. Note that in some cases more than one garden is within a given 10-km square.

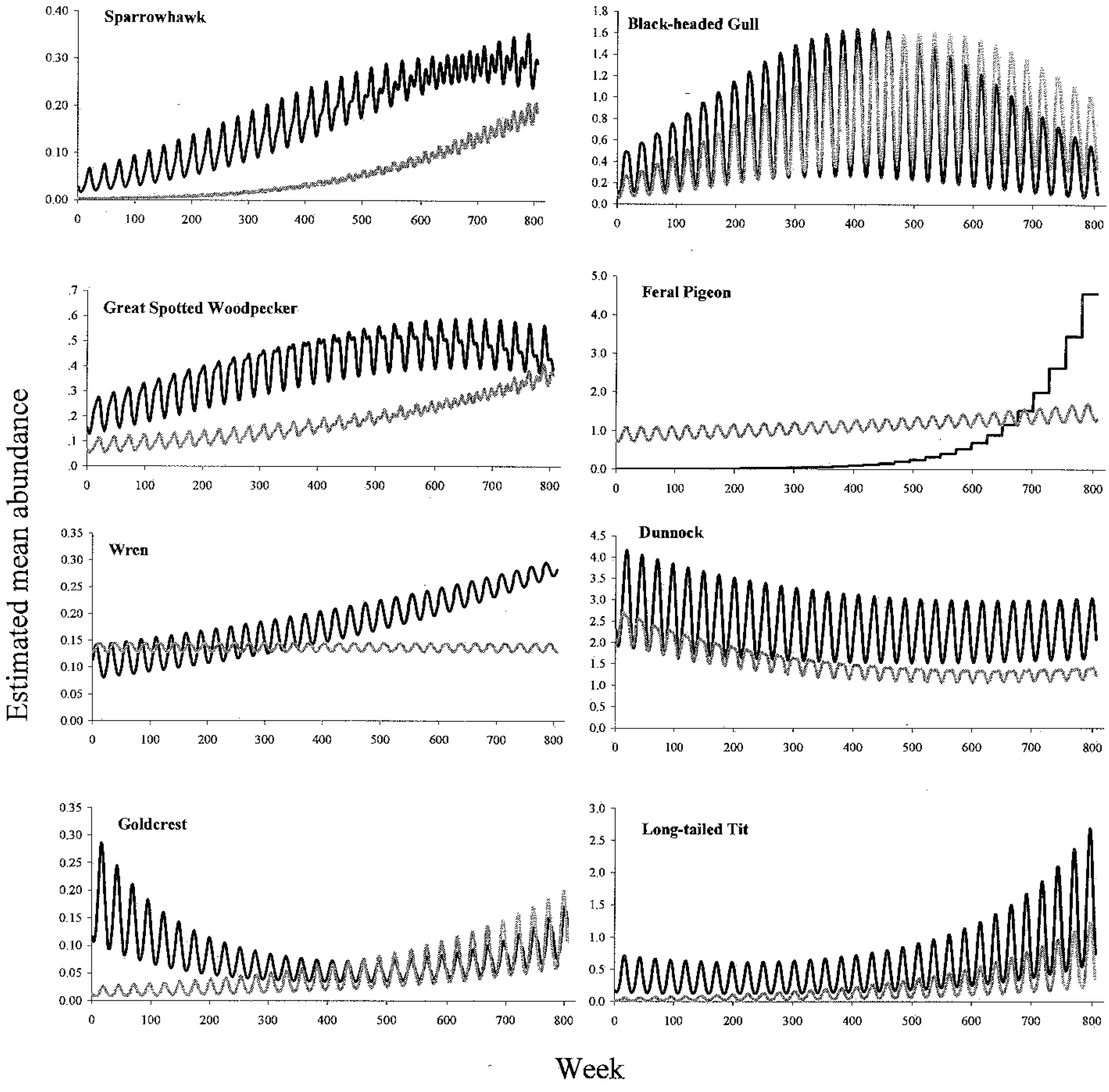
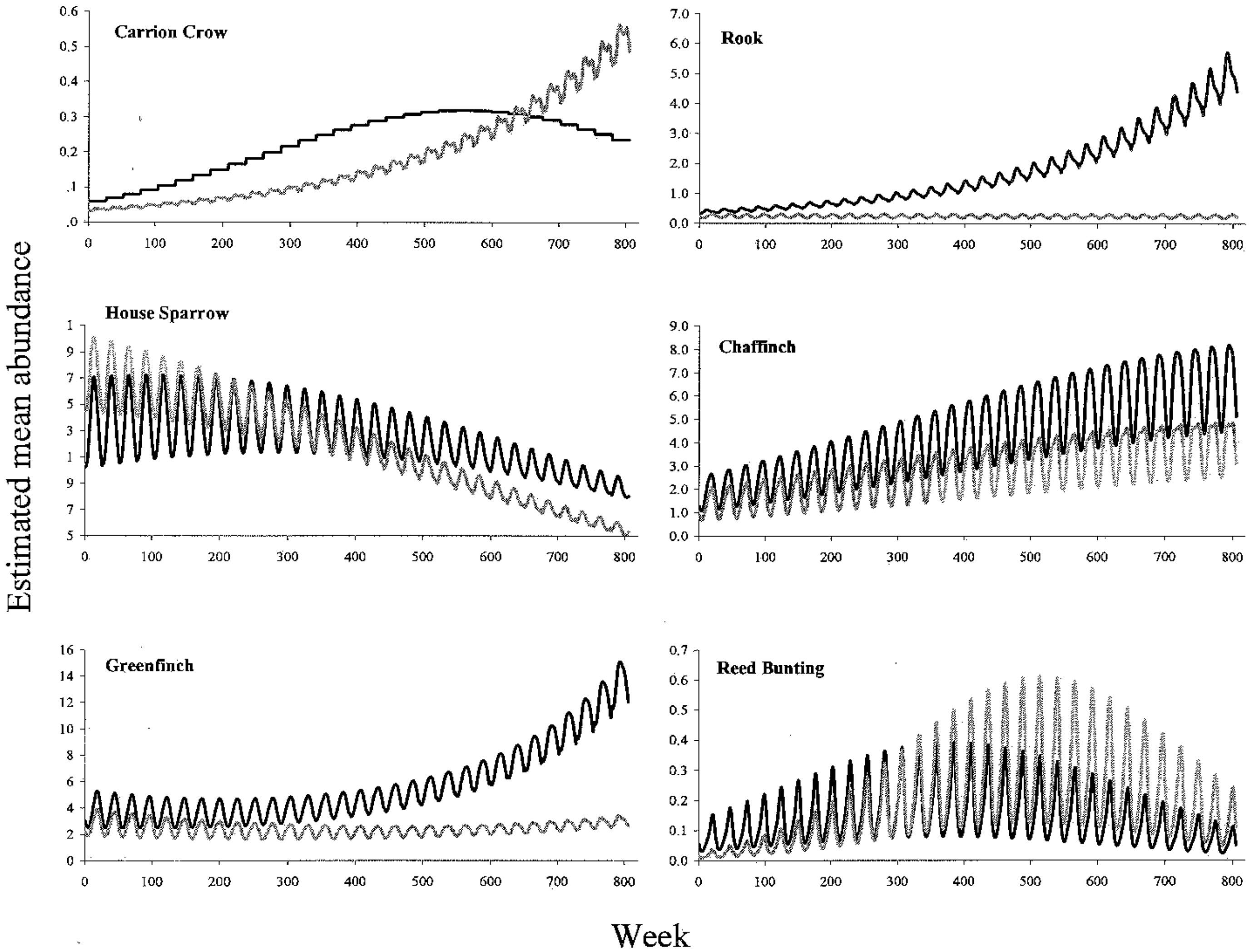


Fig. 2. Estimated maximum bird count at garden feeders in rural (black lines) and suburban (grey lines) sites. Trends have been fitted from Poisson regression. Week is expressed as a continuous variable where week 1 = September 1970 and week 806 = March 2001.



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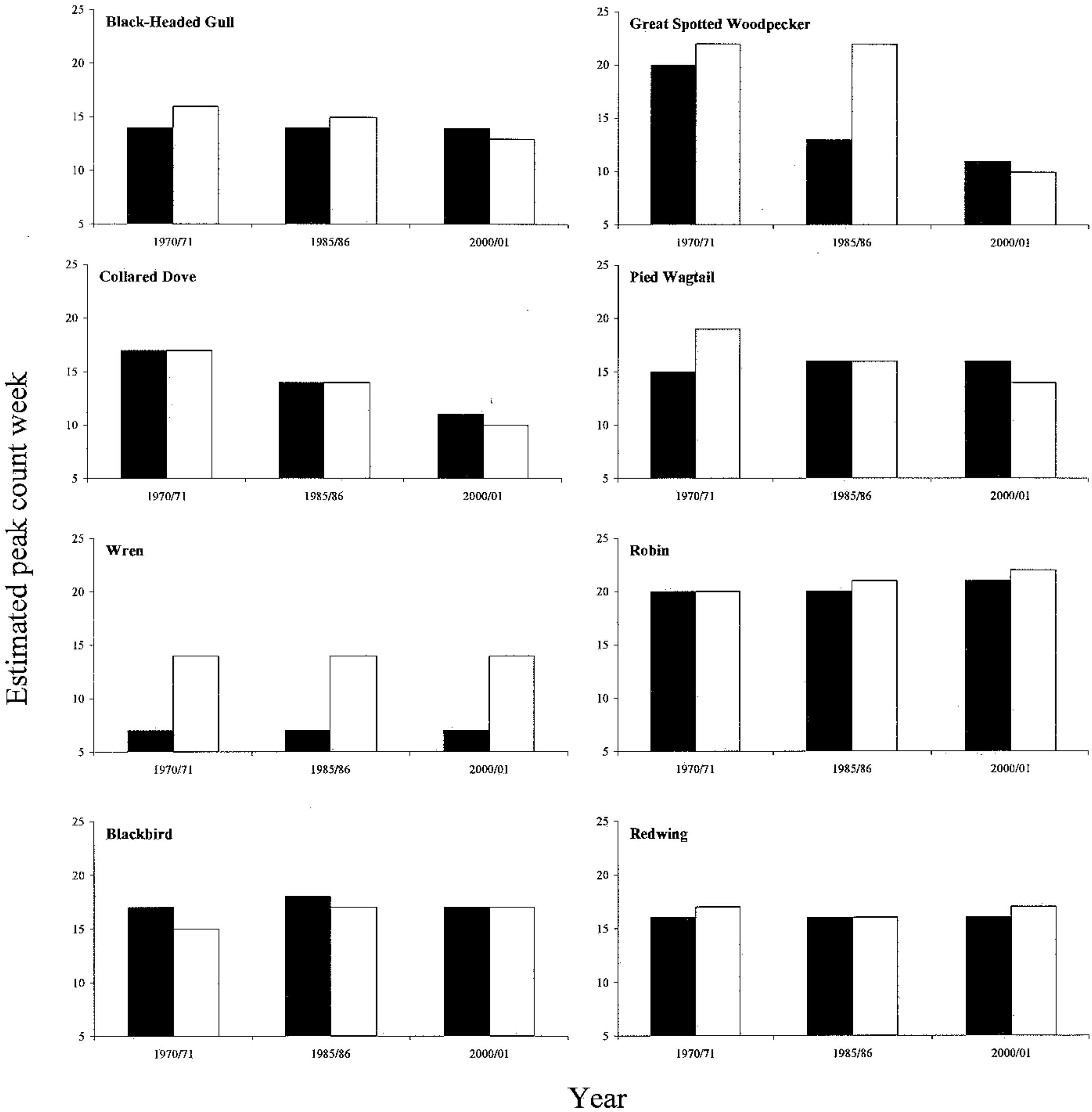
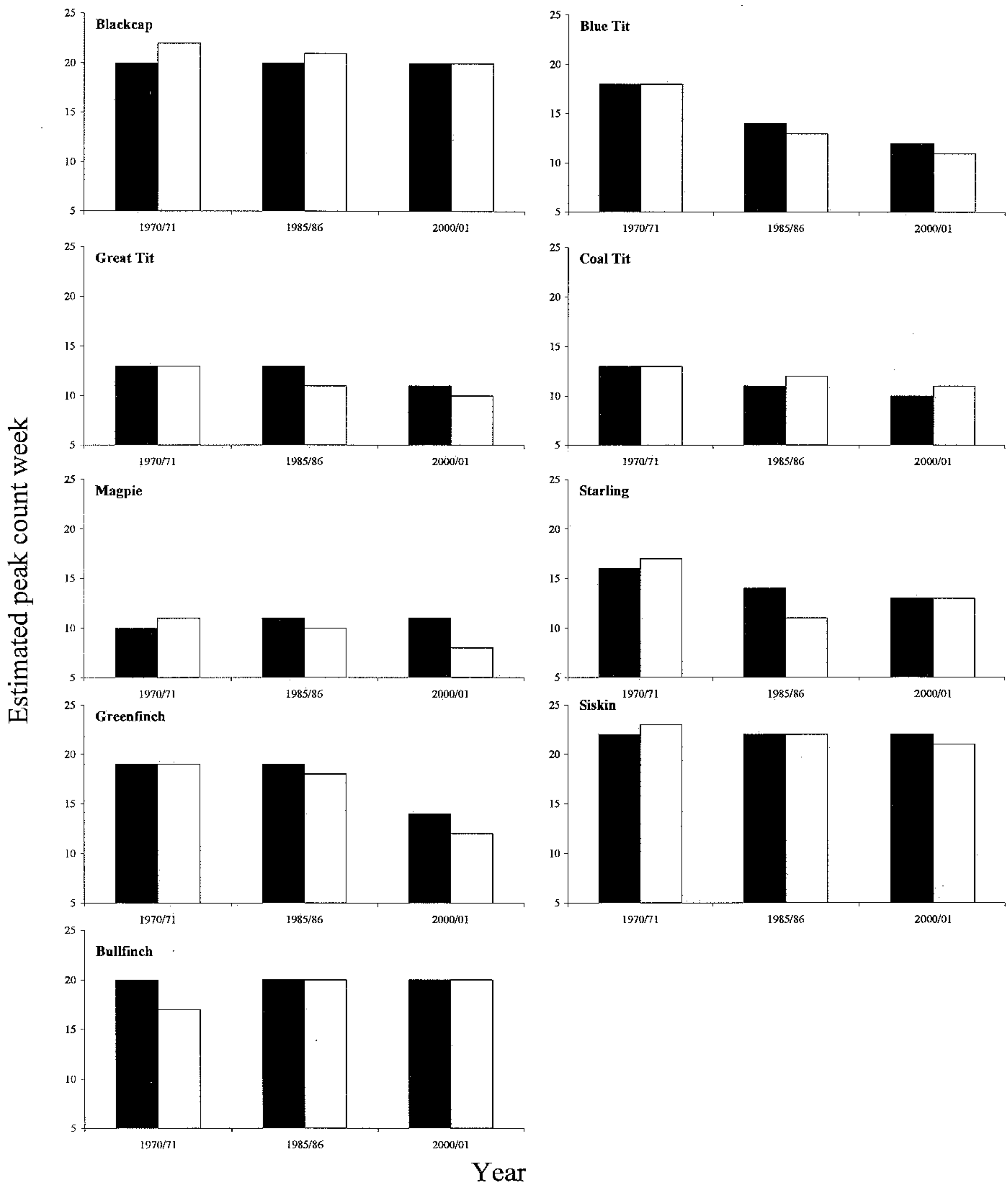


Fig. 3. Week of peak abundance at garden bird feeders in three separate winters for species showing significant interactions between garden type and week, estimated from Poisson regression models. Black bars = rural gardens, white bars = suburban gardens.



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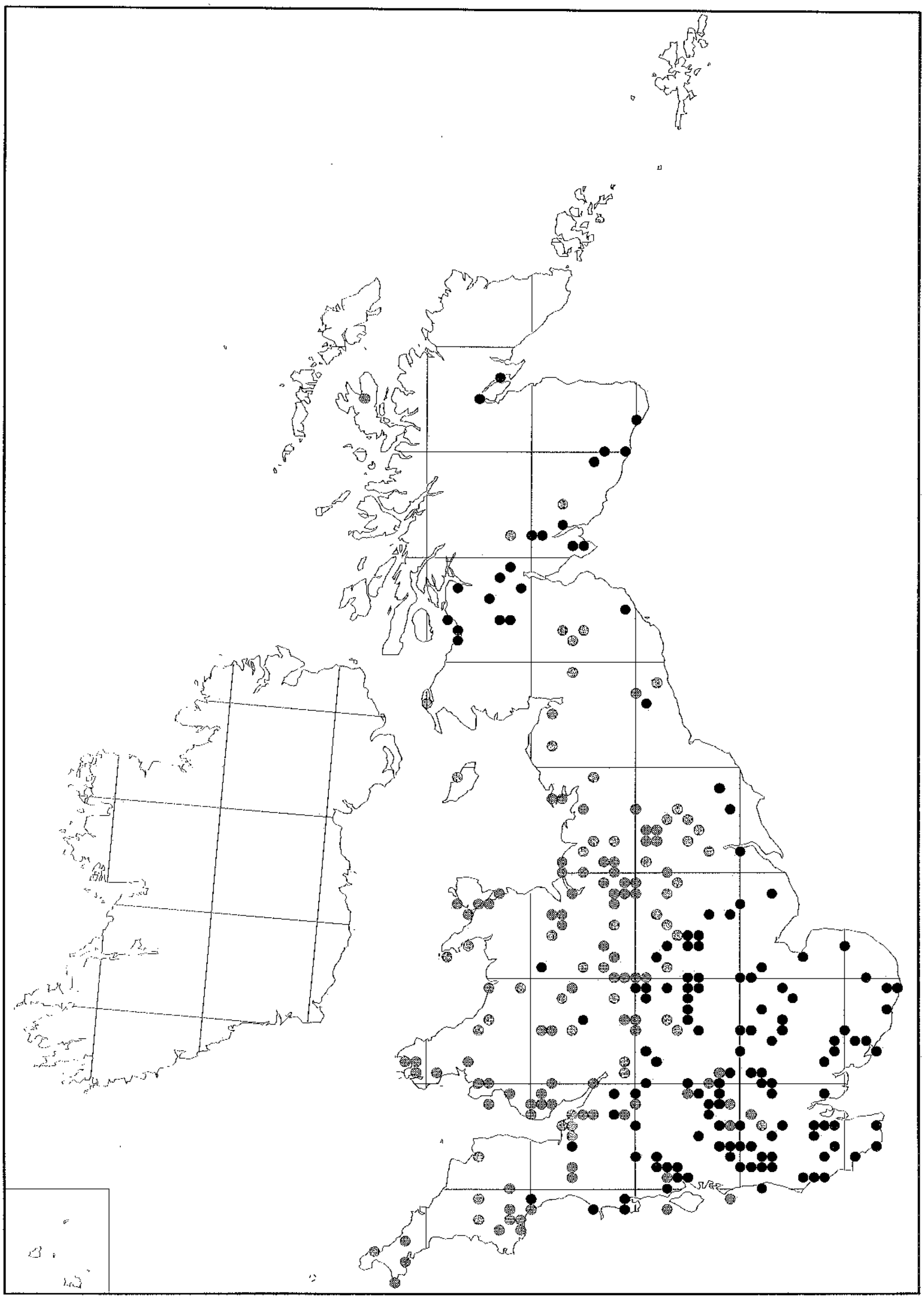


Fig. 4. The distribution of arable (black circles) and non-arable (grey circles) gardens in the survey. Note that in some cases more than one garden is within a given 10-km square.

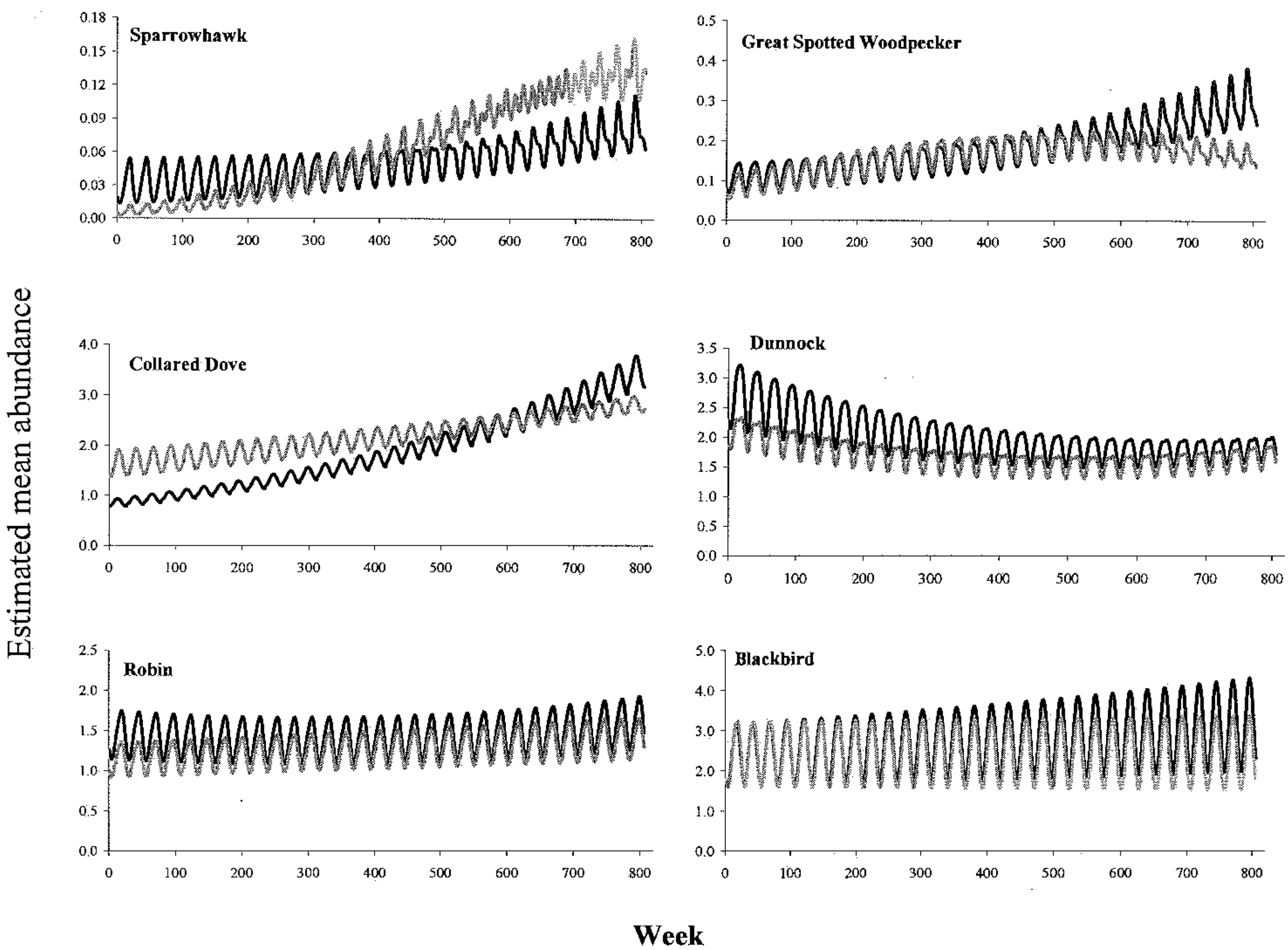
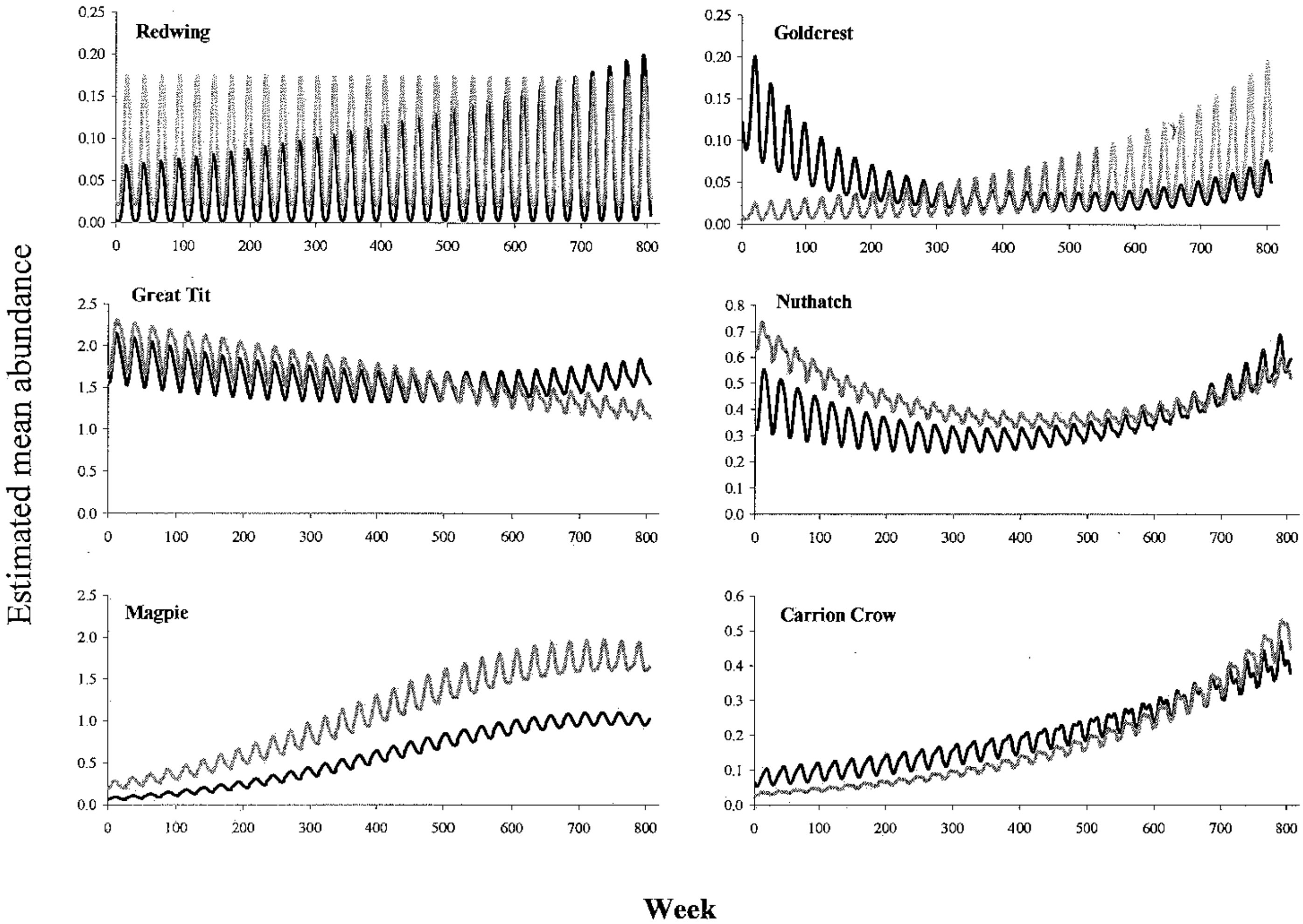


Fig. 5. Estimated maximum bird count at garden feeders in sites within arable (black lines) and non-arable (grey lines) landscapes. Trends have been fitted from Poisson regression. Week is expressed as a continuous variable where week 1 = September 1970 and week 806 = March 2001.



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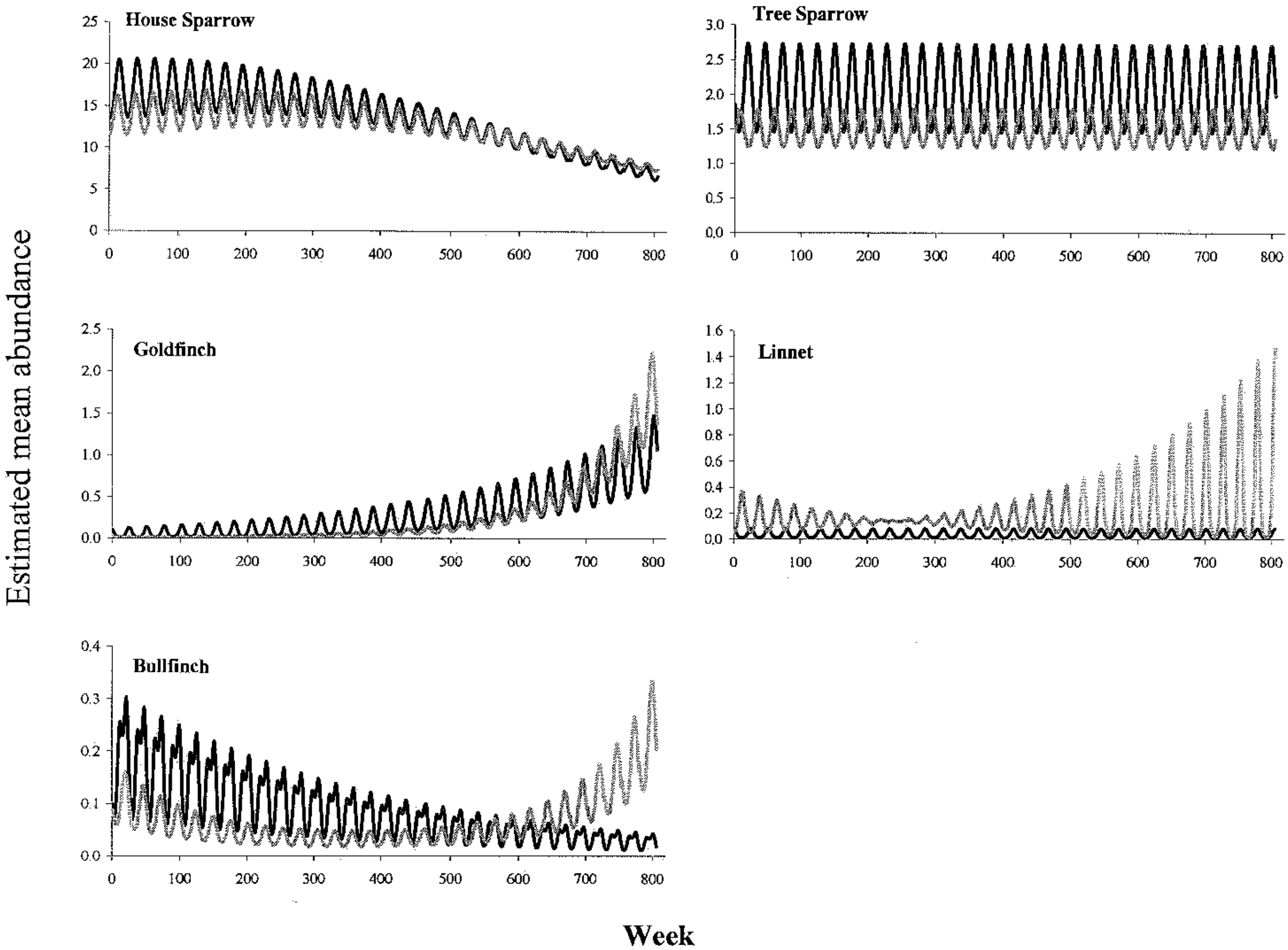

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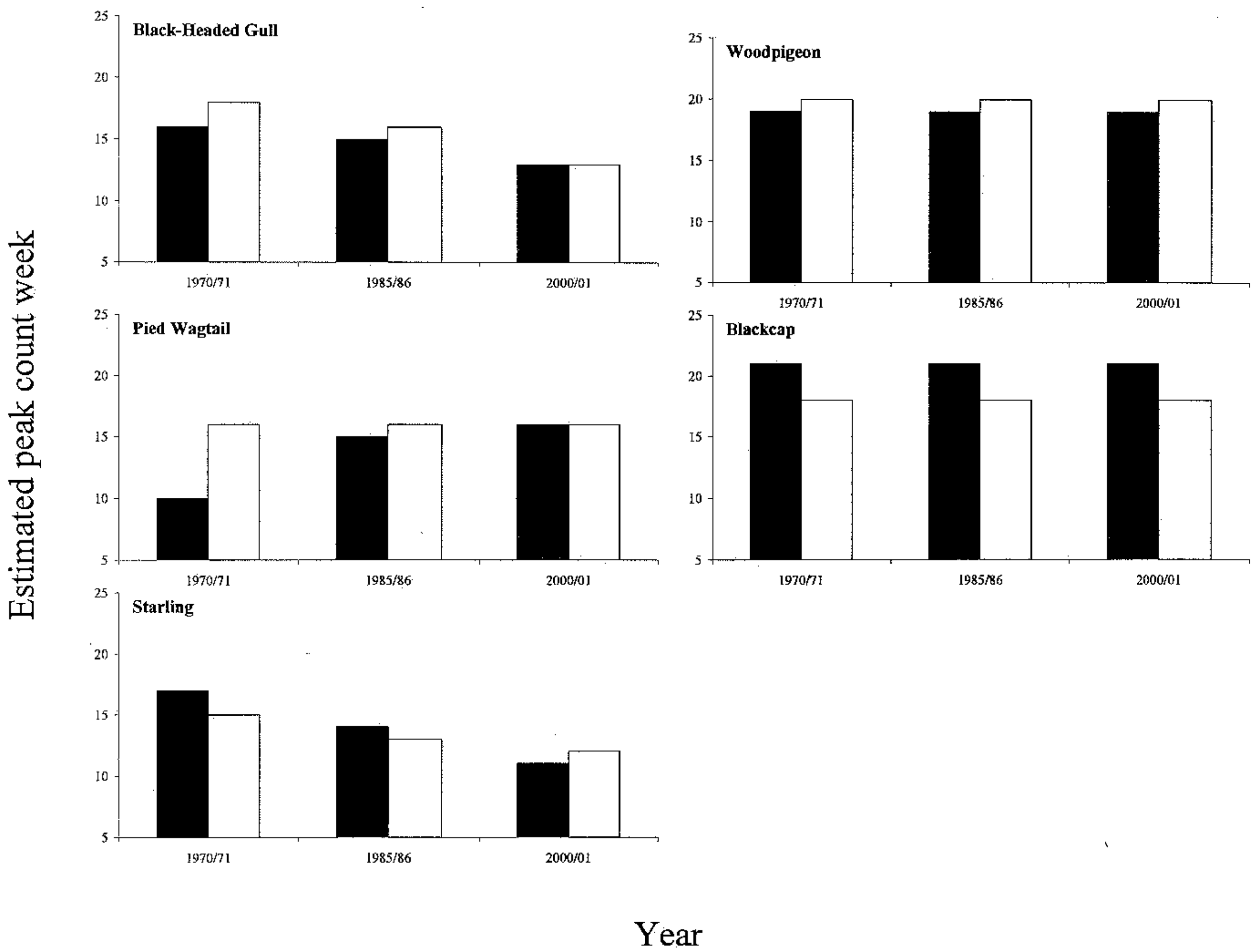

Fig. 6. Week of peak abundance at garden bird feeders in three separate winters for species showing significant interactions between landscape type and week, estimated from Poisson regression models. Black bars = arable, white bars = non-arable.

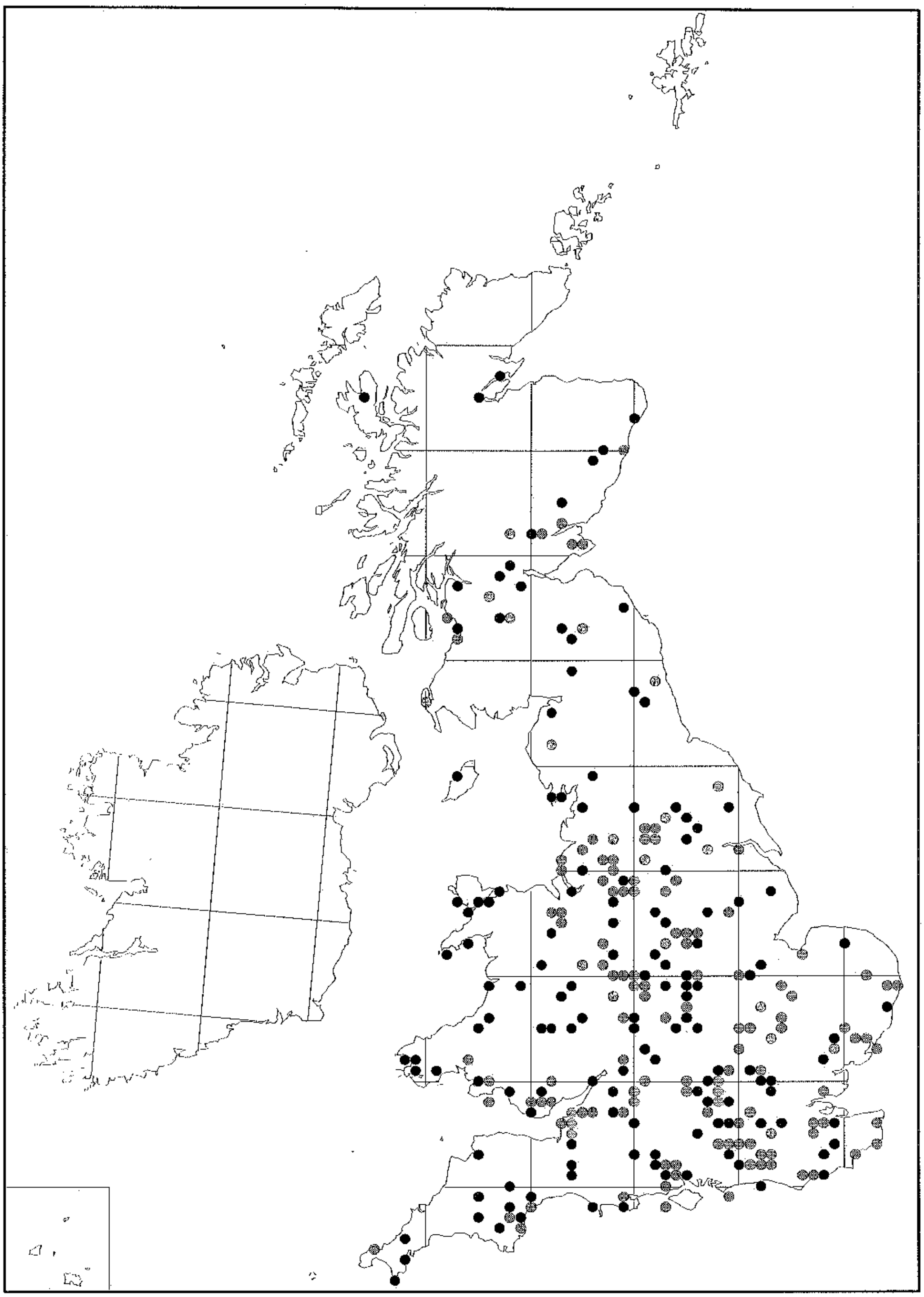

Fig. 7. The distribution of gardens in areas dominated by spring cereals (black circles) and autumn cereals (grey circles). Note that in some cases more than one garden is within a given 10-km square.

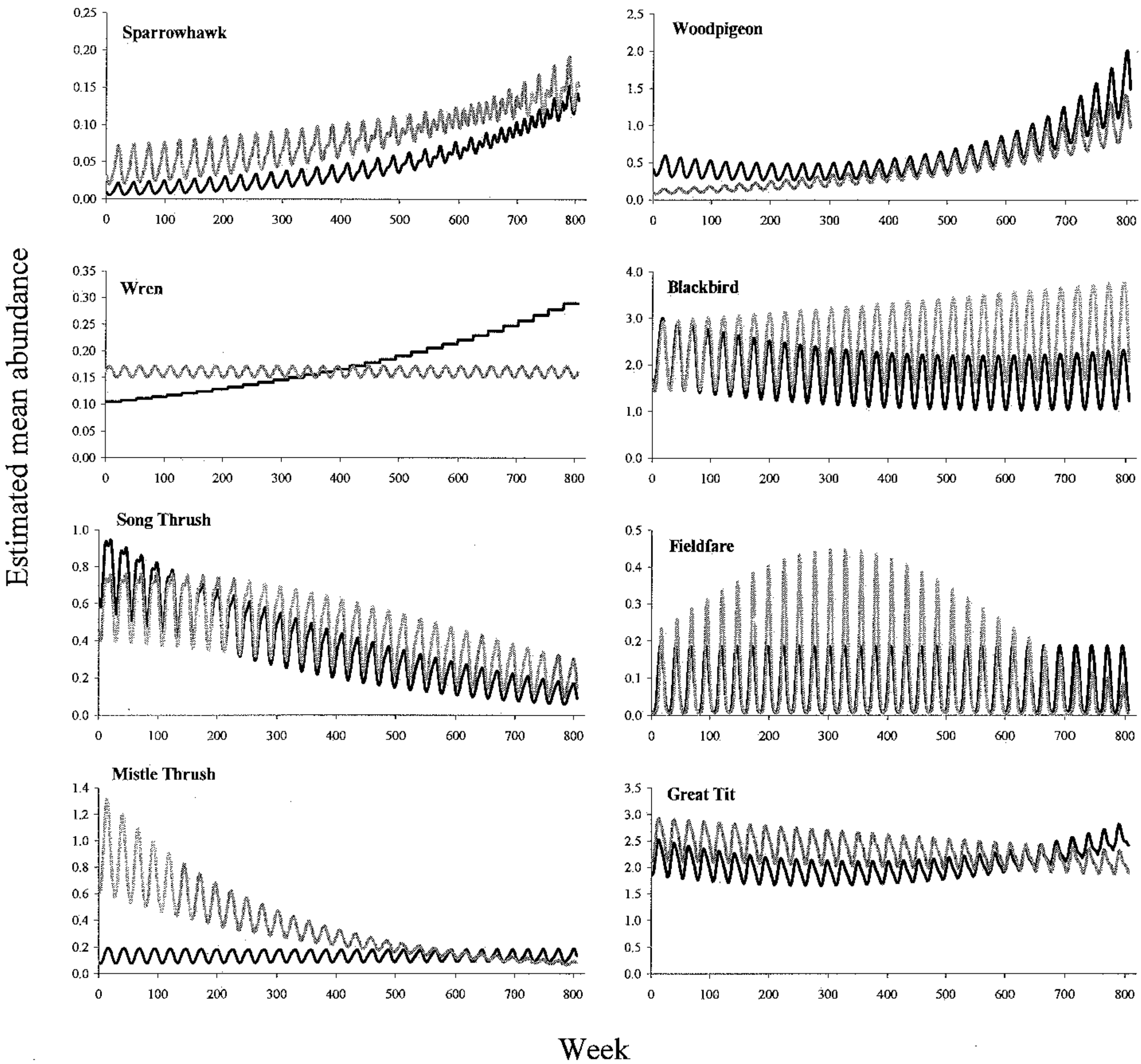

Fig. 8. Estimated maximum bird count at garden feeders in sites within areas where spring cereals are dominant (black lines) and where autumn cereals are dominant (grey lines). Trends have been fitted from Poisson regression. Week is expressed as a continuous variable where week 1 = September 1970 and week 806 = March 2001.

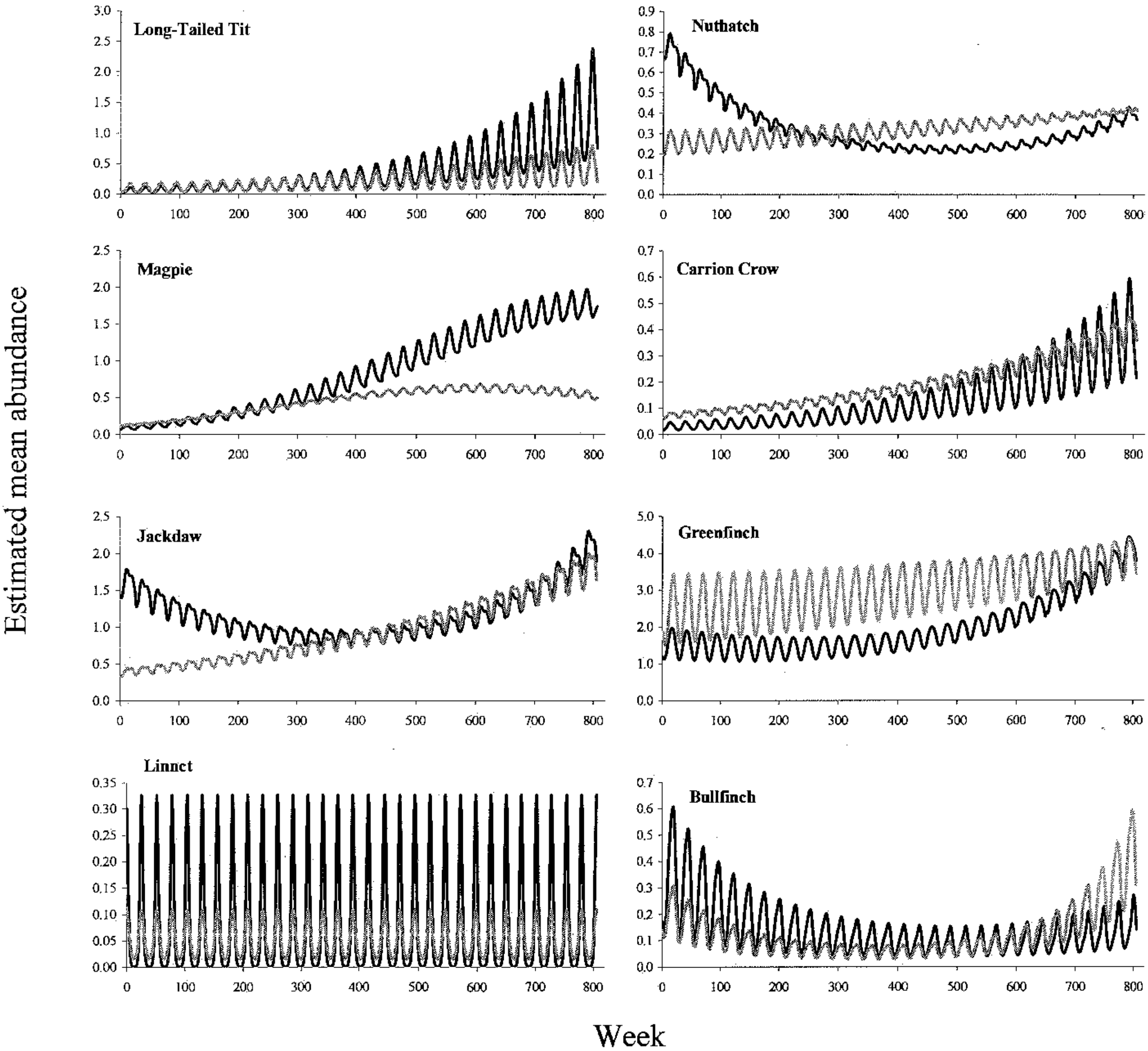

Fig. 8. Continued

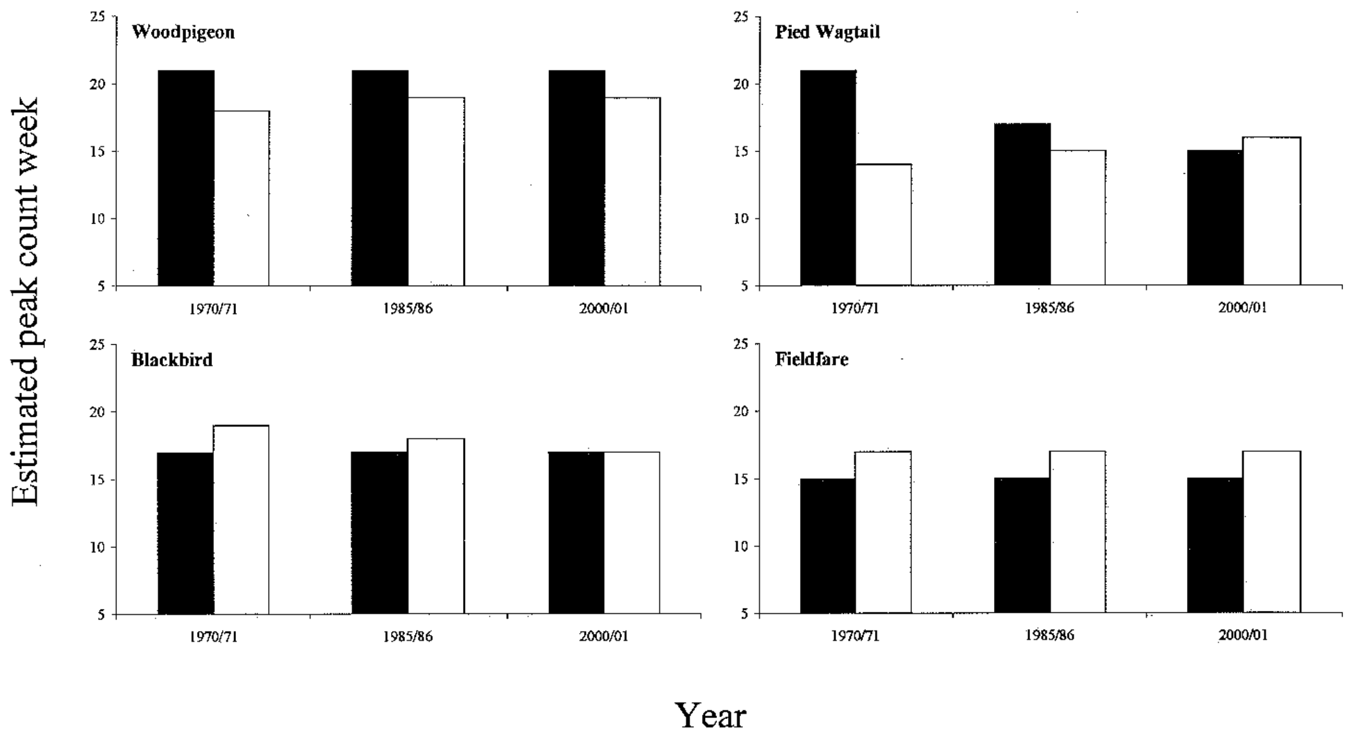

Fig. 9. Week of peak abundance at garden bird feeders in three separate winters for species showing significant interactions between local predominant cereal type and week, estimated from Poisson regression models. Black bars = spring cereal, white bars = autumn cereal.

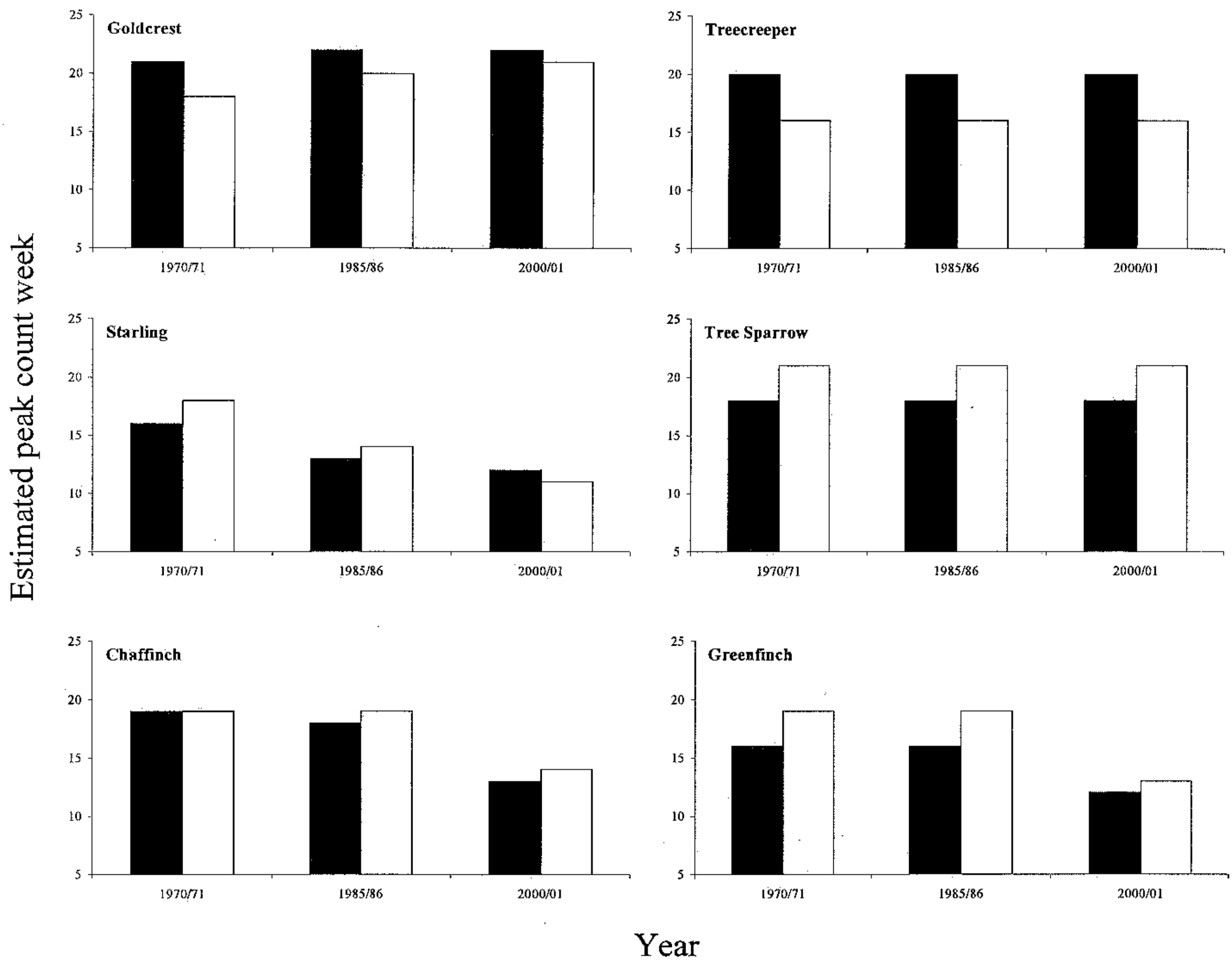

Fig. 9. Continued