British Trust for Ornithology

BTO Research Report 209

The Effects of Agricultural Management on Farmland Birds

Authors

D.E. Chamberlain[1], R.J. Fuller[1], M. Shrubb[2], R.G.H. Bunce[3], J.C. Duckworth[3], D.G. Garthwaite[4], A.J. Impey[1], A.D. M. Hart[4]

[1] British Trust for Ornithology, The Nunnery, Thetford, Norfolk, IP24 2PU
[2] Hill Crest, Llanwrtyd Wells, Powys, LD5 4TL
[3] Institute of Terrestrial Ecology, Merlewood Research Station, Grange-over-Sands, Cumbria
[4] Central Science Laboratory, Sand Hutton, York, YO4 1LZ

A report by the British Trust for Ornithology under contract to
Ministry of Agriculture Fisheries and Food

April 1999

British Trust for Ornithology, The Nunnery, Thetford, Norfolk, IP24 2PU
Registered Charity No. 216652

British Trust for Ornithology

The Effects of Agricultural Management on Farmland Birds

BTO Research Report No. 209

D.E. Chamberlain, R.J. Fuller, M. Shrubb, R.G.H. Bunce,
J.C. Duckworth, D.G. Garthwaite, A.J. Impey, A.D.M. Hart

Published in April 1999 by the British Trust for Ornithology
The Nunnery, Thetford, Norfolk, IP24 2PU, UK

ISBN 1-902576-12-8

CONTENTS

Page No.

Page No.

LIST OF TABLES

Page No.

Page No.

LIST OF FIGURES

Page No.

Page No.

Page No.

LIST OF APPENDICES

Page No.

1

Executive Summary

1. EXECUTIVE SUMMARY

The principal sections to which individual points relate are given in parentheses at the end of each point.

1. British farmland bird populations, more than those associated with any other habitat, have declined substantially over the last 30 years. This project aimed to establish the extent to which changes in the abundance and distribution of breeding farmland birds coincided with the timing, and the spatial pattern, of changes in agricultural management in lowland England and Wales. Analyses focused on a group of 21 'target species' characteristic of lowland farmland which included most of the declining farmland bird species. Analyses were conducted at national, regional and individual farm scales. As far as possible, the relationships with specific components of change in agricultural management were examined so as to give insight to likely causal factors at different scales. (Section 2)

2. Agricultural change is one of several hypotheses accounting for the large declines in farmland birds. A review is presented of the *potential* mechanisms by which agricultural change could have affected bird populations in recent decades and considers the available evidence. This provides a contextual background against which the findings of the project are presented and discussed. (Section 2)

3. The large changes in agriculture have been made possible by huge technological advances involving mechanisation, the use of artificial fertilisers and development of pesticides. These factors may themselves have been relevant to birds by, for example, altering food resources, but their consequences have been far-reaching by stimulating large-scale changes in timing of cultivation, the use of rotations and the types of crops. The broad changes in cropping, grassland management, livestock, non-crop habitat and farm/habitat diversity are described and potential implications for birds considered. Different species of birds may have been affected by different components of change in agricultural systems. It is likely that some species of birds will have been affected by several components of change in agriculture. (Section 2)

4. All available data were used to summarise the spatial and temporal trends that have occurred in agricultural management in England and Wales for the period 1960 to 1995. These data were used in subsequent analyses relating changes in bird distribution and bird abundance to changes in agriculture. Using MAFF June Census data, two broad agricultural regions were defined, based on counties: predominantly arable (referred to as "arable-east") and non-arable. The latter region was subdivided into predominantly pastoral ("pastoral-west") and mixed farmland ("mixed-south"). These regions were used in subsequent analyses. (Section 3)

5. The geographical patterns of change in 15 agricultural variables were examined at a 10 km square scale using data derived from the MAFF June Census for 1969 and 1988. The patterns are presented separately for each variable. Many of these variables showed extremely uneven geographical patterns of change. To gain a measure of overall spatial change in agriculture, Principal Components Analysis (PCA) was applied to the 15 variables. This identified that the major gradient of change concerned

cropping patterns, involving large increases in wheat and oilseed rape at the expense of barley, bare fallow and grass. There is a distinct region in eastern England that has shown this pattern of change, extending from Lincolnshire into the southern Midlands, the Home Counties and into parts of East Anglia. Changes in the diversity of crop and grassland habitats between 1969 and 1988 were geographically uneven. Marked decreases in diversity were evident in the English Midlands, the Welsh borders, Kent and parts of East Anglia. (Section 3)

6. Temporal changes in agriculture were examined quantitatively for 32 variables representing crop areas, livestock numbers, fertilizer application, grass production and pesticide usage. Some crops have increased substantially (e.g. wheat, oilseed rape) while others have decreased (e.g. barley, bare fallow, fodder roots). These changes have not taken place uniformly across England and Wales. There has been a general reduction in mixed farming, with grassland tending to replace arable in the west and north while arable has tended to replace grass in the south and east. (Section 3)

7. Many individual agricultural variables were strongly inter-correlated, making it difficult to interpret relationships between single variables and bird populations. The overall temporal change in agriculture was measured using an ordination technique applied to the agricultural variables for each year from 1962 to 1995. This showed that the period 1970 to 1988 was the main period of intensification. Change occurred throughout this period, but was especially rapid in the periods 1970 to 1975 and 1982 to 1988. Agriculture during the periods pre-1970 and post-1988 was relatively stable. (Section 3)

8. Spatial change in the ranges of farmland bird species and in avian species richness was examined in relation to spatial change in agricultural management. Change in bird distribution and species richness was measured using BTO Atlas data at the scale of 10 km squares from 1968 to 1972 and 1988 to 1991. Agricultural changes were examined at the 10 km square scale using data derived from the MAFF June Census for 1969 and 1988. Seven species showed range declines exceeding 5% between the two atlases and analyses focused on these: Grey Partridge, Lapwing, Turtle Dove, Yellow Wagtail, Tree Sparrow, Corn Bunting and Reed Bunting. Increases in range could be examined only for Yellow Wagtail and Corn Bunting. (Section 4)

9. Losses of the seven species were significantly greater in non-arable regions. Grass-dominated squares had the highest rates of species loss and arable-dominated squares the lowest. These patterns were the same for all species. These findings were consistent with those from logistic regression which demonstrated that each species was least likely to have disappeared from squares that had undergone large changes in cropping involving increases in wheat and oilseed rape and declines in barley, fallow and grass. The probability of species loss was greater in those squares where there had been relatively little change in cropping patterns. Yellow Wagtail increased in a greater proportion of squares in predominantly arable squares. No significant patterns

could be detected for Corn Bunting increase with respect to region or type of farmland. (Section 4)

10. Loss of species between the two atlases was modelled in relation to change in individual agricultural and non-agricultural variables (e.g. area of woodland) using logistic regression. Single best variables were identified; the best agricultural variables differed between species and tended to be ones that showed strong regional trends but in many cases non-agricultural variables were more closely associated with the probability of loss than agricultural variables. Lapwing, however, was an exception, being consistently associated with agricultural variables, especially ones related to grassland. (Section 4)

11. Geographical pattern of change in species richness was the same for absolute and relative changes in richness. Relative richness took account of the initial number of species recorded in a 10 km square. Overall richness (i.e. all species) tended to have declined more in non-arable than arable regions. However, changes in species richness between regions and farmland type were much stronger for the group of 21 target farmland species with a highly significant greater reduction in richness in non-arable regions. Declines in richness of farmland birds were most marked in south-west England, the Welsh borders and Wales. Changes in species richness were related to spatial change in agriculture using regression. Species richness tended to have changed most in those squares where there had been relatively little change in cropping patterns. (Section 4)

12. The analyses presented on spatial patterns focus on broad-scale relationships. Several potentially important factors could not be included in these analyses simply because data were unavailable at the 10 km square scale. These included the amount of spring sown cereals, usage of pesticides, usage of fertilisers and factors relating to grassland management. It is unlikely that many of the variables selected in the regression models were, in themselves, the causal factors behind changes in the ranges of species and changes in species richness. A possible exception was Lapwing, for which variables associated with change in grassland were consistently selected in the models. (Section 4)

13. The spatial analyses demonstrated that the largest losses of species and declines in farmland species richness had occurred in non-arable regions i.e. in predominantly grassland or mixed grass/arable areas occurring mainly in the west. Therefore, the greatest losses in terms of species distributions had occurred in those lowland regions where there had been least change in cropping (see point 5). Reasons for this pattern are discussed under point 27 below. (Sections 4 and 8.2)

14. Long-term changes in the abundance of farmland birds were examined in relation to (a) region, (b) farmland type, (c) specific components of change in agricultural management. The overall aim of these analyses was to obtain insights into which aspects of agricultural change, if any, may have driven the large declines in populations of several farmland birds. In addition, the closeness of fit was investigated between the general timing of agricultural intensification and the general timing of declines in farmland bird populations. It should be noted that these analyses were conducted for

the period since 1970 and that the possible earlier effects of post-war changes in agriculture on bird numbers have not been examined. (Section 5)

15. Linear models were fitted to the Common Birds Census (CBC) indices for the period 1970 to 1996 for 21 species using log-linear Poisson regression. Linear trends were used to compare population changes between regions and farmland types. Estimates of linear trends derived in this way were very similar to those of previous studies that have modelled non-linear trends using CBC data. Therefore, the linear models gave reasonable approximations of population trends. The data generally exhibited low levels of dispersion and serial autocorrelation. (Section 5)

16. All but four species showed an overall decline. However, a very rigorous approach was taken to identifying declining species, both at national and regional scales. Eight species showed very strong evidence of overall decline in that both their upper and lower confidence limits were negative and the model fitted the data. Two species - Stock Dove and Chaffinch - showed a significant increase. Three regions were defined on the basis of differences in agriculture: arable-east, mixed-south and pastoral-west region (see 4 above). Blackbird and Song Thrush declined more in the arable-east region than elsewhere. Greenfinch and Goldfinch declined in the arable-east region but showed little change elsewhere. On the other hand, Turtle Dove declined most in the pastoral-west region and Stock Dove increased most in the arable-east region. Population changes at the level of farmland type were broadly consistent with the regional analysis. Grey Partridge, Song Thrush, Greenfinch and Goldfinch declined most on arable farms. Skylark, Turtle Dove and Yellow Wagtail declined most on mixed or pastoral farms. Stock Dove and Chaffinch had increased most on arable farms. (Section 5)

17. Analysis of changes in density were undertaken to complement those of change in population level as measured by the CBC indices. Mean densities were calculated for two time periods: 1970 to 1973 and 1993 to 1996. In the arable-east region, densities of the following species had significantly declined: Grey Partridge, Skylark, Starling, Blackbird, Song Thrush, Tree Sparrow, Corn Bunting and Reed Bunting. The latter four species had declined by >50%. Three species had increased significantly: Kestrel, Whitethroat and Chaffinch. In the mixed-south counties the pattern of change was similar to that in the arable-east region, but there were relatively few changes in the pastoral-west region. (Section 5)

18. Ordination was used to generate (a) an overall measure of change in agricultural management between the early-1960s and mid-1990s (Section 3) and (b) a measure of overall change in farmland bird populations over the same period. The respective data used in these analyses were a wide suite of agricultural variables and the CBC population indices. Until 1970 there was no systematic change in either measure. From 1971 to 1988 there was major progressive change in agriculture. Between 1971 and 1977, however, there was little evidence of change in bird populations, but the period 1978 to 1988 was marked by major changes in bird populations. Post 1989 there has been relatively little broad change in agricultural management or bird populations. These analyses indicate that agricultural intensification broadly matches the period of bird population change but with a time lag in the response of birds. In

section 8.3 it is argued that such a time lag would be expected to occur if the changes in bird populations are actually a response to the progressive changes in agriculture, mainly for reasons of density-dependence. Repeating the analyses, using only the most accurately measured agricultural variables for the period 1974 to 1991, produced a very close temporal matching between the pattern of agricultural intensification and changing farmland bird populations. (Sections 5 and 8.3)

19. Linear regression was used to relate farmland CBC indices for 21 farmland bird species to specific measured changes in agricultural management together with some weather variables. The single strongest correlate was reported and analyses were conducted with and without time lags in the bird data. Across species, a wide range of agricultural variables was selected but weather variables were never selected. Only two species showed no significant relationships. The most striking feature of the analyses was that with time lags of one and two years several species showed relationships with timing of sowing of cereals - bird declines tended to be associated either with decrease in spring barley or with increase in winter barley. Most granivorous species showed such a relationship. These analyses were repeated using inter-annual changes in both the dependent and independent variables, which helps to detrend the data. With no time lag, weather variables featured as the strongest correlates for five species but for eight species there were no significant relationships. With a one-year lag, agricultural variables featured more frequently with winter cereals emerging as the strongest correlate for five species. With a two-year lag there were few consistent relationships across species. (Section 5)

20. Changes in bird populations and agricultural management were also examined at the scale of individual farms. Breeding bird censuses were conducted on 51 farms in the arable-east and mixed-south regions in 1996 to 1997 for which bird census data were available for the period 1971 to 1973 from the Common Birds Census. These two periods are referred to as the late and early periods respectively. A simplified territory mapping method was used with five visits spread between April and the end of June. Census maps from the early period were reanalysed to make them comparable with the late period. A questionnaire-based interview was conducted with each of the farmers (except one) to summarise information about past and current management. Many agricultural variables from the late period could be quantified in a continuous manner but the agricultural variables from the early period had to be summarised in categories. (Section 6)

21. The 51 farms were broadly representative of lowland landscapes because they broadly matched the expected distribution across ITE Land Classes within the two regions considered. Between the two periods, farms showed relatively large decreases in spring cereals, ley grass and hay. The farms showed relatively large increases in winter cereals, game cover, silage, sheep, artificial fertilisers and pesticides. The farms were relatively evenly balanced in terms of decreases and increases in new grass, permanent grass and root crops. Hedgerow length had changed rather little. Arable farms had significantly less spring cereal and rotational grass but more oilseed rape in the late period. There was little difference in the management of grass between early and late periods. Use of artificial fertiliser had significantly increased on grass farms. It was surprising that pesticide application did not show a significant difference

between early and late periods on those farms where accurate usage data were available. This differs strikingly from the national picture and may indicate that there is large variation between farms in pesticide use. (Section 6)

22. Analyses were undertaken within each time period to assess the extent to which species were associated with farming types and particular components of agriculture. In the early period, Turtle Dove, Skylark, Song Thrush and Tree Sparrow were more abundant on arable farms; Greenfinch was most abundant on mixed and arable and Chaffinch most abundant on pastoral. For the 21 target farmland species, mixed and arable farms held more species than pastoral. In the late period, Whitethroat and Yellowhammer had higher densities on arable and Skylark on mixed farms, but there were no longer differences between farm types in species richness or diversity, arable and mixed farms having declined in both measures between periods. For the late period, detailed analyses were possible relating agricultural variables to bird abundance across plots. A wide range of correlates emerged in these analyses which tended to reflect the preferences of species for arable or pasture farms. There was little evidence of strong links between pesticide application and species abundances. (Section 6)

23. For the full sample of 51 farms, nine species showed significant declines in density between the early and late periods: Grey Partridge, Turtle Dove, Skylark, Blackbird, Song Thrush, Tree Sparrow, Bullfinch, Corn Bunting and Reed Bunting. Five species increased significantly: Rook, Whitethroat, Greenfinch, Goldfinch and Chaffinch. These population changes parallel those from published CBC index trends. Species richness of the 21 target species decreased between early and late periods. When classified by farm type, arable farms showed far more significant changes in density (mostly decreases) than mixed or pastoral farms but this may have been a consequence of relatively large sample sizes for arable. Species richness declined more on arable and mixed farms than on pastoral farms. (Section 6)

24. Relationships between changes in bird abundance and changes in agricultural variables were examined between early and late periods using generalised linear modelling. The results generated by these models were complex and species-specific. It was not possible to generate valid models for the majority of species. However, for arable farms, models were produced for six species. Effects of agricultural variables were generally additive to (rather than replacing) those of period, indicating that other factors in addition to those included in the analysis must have caused the changes in bird abundance. There was no evidence that pesticide application rates were associated with changes in bird abundance. However, for four species on arable farms, fertiliser usage had a significant negative effect on abundance. These species were Skylark, Blackbird, Greenfinch and Yellowhammer. (Section 6)

25. Changes in agricultural variables were analysed by ordination. This generated a gradient from farms showing major loss of spring cereals and stubbles but an increase in winter wheat, to farms that had shown relatively little loss, or even an increase, in spring cereal. Densities of birds on the 10 farms with the highest scores on this gradient were compared with those for the 10 farms with the lowest scores. Three species - Grey Partridge, Turtle Dove and Corn Bunting - showed a significant

decrease only on farms that had lost spring cereal, but Reed Bunting showed the opposite pattern. (Section 6)

26. Trends in the use of pesticides were considered in relation to changes in CBC index of the 13 most severely declining bird species. The majority of species showed significant correlations between increasing pesticide use and population declines, both in terms of pesticides classified into general types (insecticide, fungicide or herbicide) and into specific chemicals. Fungicides tended to show the greatest number of highly significant correlations. However, effects of pesticides were not as strongly associated with bird declines as other agricultural management variables (Section 5). Risk assessment for direct toxicity of pesticides showed that those with the highest potential risk were not among those most closely associated with species declines. Direct toxicity of pesticides is therefore not likely to have been an important factor underlying the population declines. Indirect effects of pesticides are more likely, but it is questionable whether the simple correlative approach taken here can detect such effects. (Section 7)

27. There is an apparent contradiction between the results of the large-scale atlas analyses and those of the CBC data. At the **large scale**, species losses (i.e. local extinctions) have been most marked in predominantly pastoral areas. However, in terms of **local** changes in species richness, the main losses have been in arable areas and it is in these latter areas where rates of population decline for several species have been greatest. It is suggested that this is a consequence of several farmland species occurring at lower densities in western, grass-dominated areas than eastern arable-dominated areas. A pattern of modest reductions in numbers in the west, but of larger reductions in numbers in the east, may have led to a preponderance of local extinctions in the former. This process is illustrated by a simple model. Other possible factors relate to changes in agriculture. The widespread changes in grassland management throughout much of lowland Britain in recent decades may have widely reduced the quality of grassland as a habitat for birds. The increasing polarisation of agriculture towards grassland in western Britain and arable in eastern Britain may also have had a disproportionate effect on farmland birds within the predominantly grassland areas. Finally, source-sink effects may be operating whereby populations in the west are maintained by flow from source populations in the east. Under such a scenario, factors operating in the east could manifest themselves by marked population reductions in the west. However, there is, as yet, no evidence of the existence of source-sink dynamics among farmland birds. (Section 8.2)

28. The large scale declines in farmland bird populations closely match the period of agricultural intensification. There is no evidence from recent relevant studies of predator-prey relationships that predation has been a major factor driving these changes. Agricultural intensification remains the most plausible explanation for the farmland bird declines. (Section 8.3)

29. Caution must be used in seeking insights from the results of this project concerning the effects of specific components of agricultural change on bird populations. Nonetheless, two areas of change in agriculture emerge from the analyses. First, associations frequently emerged with the timing of sowing of cereal crops, especially for granivorous birds. This was the case for analysis of population changes shown by

CBC indices at the regional scale and in the analysis of population change on individual farms. Second, several relationships emerged with grassland management (improvement of rough grazing and livestock trends), especially for Lapwing. There were conspicuously few associations with pesticide use. This does not mean, however, that pesticide effects have not been important ecological factors in the declines of farmland birds. For methodological reasons it is unlikely that relationships would be detected with pesticides. It is suggested that more work is undertaken on the causes of bird population changes in pastoral farmland in western Britain where there have been many local extinctions of farmland species. More attention should also be given to the implications of the switch from spring-sown to autumn-sown cereals. (Section 8.4)

30. Mainly due to limitations imposed by data availability, this study cannot be regarded as a comprehensive account of relationships between recent changes in agricultural practices and recent changes in bird populations for several reasons. First, the focus was on species strongly associated with lowland farmland for which good quality data were available on both abundance and distribution. This excluded some species (e.g. Redshank and Snipe) known to have been affected by changes in grassland management. Futhermore, the study does not reveal how changes in farming practices may have affected wintering birds. Second, the study did not examine marginal upland areas where pasture improvement and increased grazing has affected some bird species. Third, available data are not fully representative of lowland pastoral systems in northern and western England and Wales. Consequently, effects of grassland management as an influence on bird population changes may be underestimated. Fourth, most of the analyses covered the post-1970 period though some important changes in farming practices occurred in the 1950s and 1960s. Nonetheless this study indicates that for the period 1962-1995 the most profound changes in farming practices occurred between the early-1970s and mid-1980s, which closely matches the measured declines in farmland bird populations. (Section 8.6)

2

General Introduction and a Review of the Potential Effects of Change in Lowland Agricultural Management on Farmland Birds

D.E. Chamberlain, R.J. Fuller & M. Shrubb

British Trust for Ornithology

2. GENERAL INTRODUCTION AND A REVIEW OF THE POTENTIAL EFFECTS OF CHANGE IN LOWLAND AGRICULTURAL MANAGEMENT ON FARMLAND BIRDS

2.1 Introduction

The broadest aim of this project is to establish the extent to which recent changes in the abundance and distribution of farmland birds in England and Wales coincide with the timing, and spatial pattern, of changes in agricultural management. As far as possible, relationships with specific components of agricultural change are examined so as to give insight to likely causal factors. The specific objectives of this project are described at the end of this section.

The decline in population size and contraction in range of a number of British farmland bird species over the past 20 to 30 years has been well documented (Marchant *et al.* 1990, Gibbons *et al.* 1993, Fuller *et al.* 1995, Baillie *et al.* 1997, Siriwardena *et al.* 1998a). Similar declines have also been recorded in other countries in north-western Europe (Hustings 1992, Tucker & Heath 1994). Fuller *et al.* (1995) report that of 28 species primarily associated with farmland in the UK, 24 have shown a contraction in range, and 15 out of 18 species which could be accurately censused showed a decrease in population size between the late-1960s and early-1990s. These declines were far greater than for species associated with other habitats such as woodland, uplands or wetlands over the same period (Fuller *et al.* 1995, Chamberlain & Crick 1999). Apart from their association with farmland, these species are ecologically diverse. They include ground nesting non-passerines such as Grey Partridge *Perdix perdix* (Potts 1986), Corncrake *Crex crex* (Green & Stowe 1993) and Lapwing *Vanellus vanellus* (Shrubb 1990); a granivorous non-passerine, the Turtle Dove *Streptopelia turtur* (Calladine *et al.* 1997); predators, including Barn Owl *Tyto alba* and Little Owl *Athene noctua* (Fuller *et al.* 1995); ground nesting passerines such as Skylark *Alauda arvensis* (Chamberlain & Crick 1999) and Corn Bunting *Miliaria calandra* (Donald & Evans 1994); and hedgerow or tree-nesting granivores such as Linnet *Carduelis cannabina* and Tree Sparrow *Passer montanus*. In addition, several other species that occur across a range of habitat types are showing the steepest declines on farmland, for example, Blackbird *Turdus merula*, Song Thrush *T. philomelos* and Bullfinch *Pyrrhula pyrrhula* (Siriwardena *et al.* 1998a). However, it should also be noted that some species have increased on farmland over the same period, including Stock Dove *Columba oenas*, Chaffinch *Fringella coelebs* (Siriwardena *et al.* 1998a) and a number of corvids (Gregory & Marchant 1996).

There have been great changes in the management of farmland in England and Wales over the last few decades (O'Connor & Shrubb 1986, Grigg 1989). These changes have affected all aspects of the farming landscape. Crop management and the type and relative abundance of different crops has changed markedly; grassland management has greatly altered; chemical inputs on farmland have increased substantially; the timing of farming operations has changed; non-crop habitats such as hedgerows and farm ponds have disappeared; and, there has been a reduction in the diversity of different types of agriculture per individual farm, with farms tending to either specialise in arable or livestock (Grigg 1989, Stoate 1996). The coincidence of this period of "intensification" of farm management and the decline of many farmland bird species has led to suggestions of a causal link between the two (O'Connor & Shrubb 1986, Fuller *et al.* 1995). The actual proposed mechanisms by which agricultural changes in management have affected bird populations are diverse (see below), but generally concern either effects on food supply (e.g. Potts 1986, Campbell *et al.* 1997, Evans *et al.* 1997), effects on suitable nesting habitat (Wilson *et al.* 1997), or direct effects of farming operations on bird mortality (Crick *et al.* 1994, Green 1995).

The purpose of this section is twofold. First, to provide a review of current understanding of how bird populations are affected by agricultural changes, including an outline of the potential mechanisms and evidence. Second, this review is presented as an essential background to the rest of the report and, it is hoped, will help place later analyses into context. Initially, however, we explore the full range of hypotheses - not just agricultural intensification - that may conceivably explain recent declines in farmland birds.

Alternative hypotheses to explain the declines in bird populations include effects of disease, weather and predation. The effects of disease on bird populations in general are poorly known (Loye & Zuk 1991). There is no evidence for increased rates of disease in British farmland birds, and it seems unlikely that disease would affect so many diverse species, or be restricted to the farmland habitat, unless conditions in this habitat are more stressful and so lead to greater susceptibility to disease (Fuller *et al.* 1995). There is no doubt that severe weather conditions do have at least short term effects on bird populations, as is well illustrated by the population crash seen in many British birds following the 1962 to 1963 winter (Marchant *et al.* 1990). However, recovery is typically rapid after such events. Baillie (1990) showed that the decline of the Song Thrush population could initially be explained by winter temperature, but this could not explain its continued decline over several years. There have not been any long runs of particularly severe winters in terms of frost or minimum temperature over the period of decline and, if anything, winters are becoming milder with mean temperatures increasing (Fig. 2.1a and b). There also have been no general trends in mean monthly March to July rainfall (Fig. 2.1c). It therefore seems unlikely that climatic changes have driven the population declines.

A number of predatory species have increased in recent years; this is a further potential factor driving population declines of farmland birds. Magpies *Pica pica* and Carrion Crows *Corvus corone* are common nest predators and can account for high levels of predation in open nesting passerines (e.g. Delius 1965, Hatchwell *et al.* 1996). These corvids have increased in number on farmland since the 1960s (Gregory & Marchant 1996), but in the Magpie at least, there is no evidence that population density has any effect on passerine nesting success (Gooch *et al.* 1991). Raptor numbers have increased steadily since the early-1970s after the catastrophic declines caused by the use of organo-chlorine pesticides (Newton 1979). These increases have been most evident in intensively farmed areas of eastern England where Sparrowhawks *Accipiter nisus*, the main avian predators of farmland passerines, were almost totally wiped out by the early-1960s (Newton 1986). Thus at a fairly wide geographical scale, impacts on populations may be expected to be more associated with arable farmland habitats. There is evidence that breeding populations of gamebirds can be affected by predator numbers (Redpath & Thirgood 1997, Tapper *et al.* 1996). There is, however, little evidence to suggest that increased numbers of Sparrowhawks affect breeding numbers of their prey (Newton 1993, Thomson *et al.* 1998), but presence of avian predators may affect the distribution of nesting birds on farmland (Norrdahl & Korpimaki 1998).

In the rest of this section, we present a general historical account of the main changes in agricultural management since the war, including some discussion of the technological and economic developments which have facilitated these changes. We also discuss which specific management factors have *potential* effects on bird populations and review the evidence for these effects with reference to published literature. The findings of this project are discussed in the context of these potential mechanisms in Section 8. Section 3 presents a more quantitative analysis of spatial and temporal patterns of change in agriculture.

2.2 Potential Implications for Birds of Technological Advances in Agriculture

Intensification of farmland has essentially been driven by changes in economics, and technological advances which have led to greatly increased yields. For example, both wheat and barley yields have shown a steady increase in Great Britain since 1950, with wheat showing a particularly steep increase between the mid-1970s and mid-1980s (Fig. 2.2). Other crops and grass have shown similar increases in yield over the same period (Wilkinson 1996). Improvements in farming technology in terms of machinery, the almost universal application of fertilizers and the development of new crop strains and pesticides, have probably been the main underlying causes behind the increased yields, although both social and particularly economic reasons have also contributed.

2.2.1 Mechanization

The increasing mechanization of farming has been accompanied by a reduction of the farm labour force in the UK (Fig. 2.3) and has meant that work is able to be done in a much shorter period of time. This has been a contributory factor to changes in cropping practices, particularly the autumn-sowing of crops and the decline in rotations. Previously, the work load meant that management operations needed to be spread out over a longer period, but large, fast-operating machines have removed this constraint (O'Connor & Shrubb 1986). The scale of farming has also changed in response to mechanization. Larger machines are more efficient working larger areas (Grigg 1989), hence the trend towards larger fields and larger farms which are more likely to specialize in a small number of crops.

One consequence of mechanization has been that there is now much less waste in crops during harvesting operations, particularly of cereals. Combine harvesters are very efficient at gathering the maximum amount of grain and very little is spilt in the fields. Similarly, transport and storage of grain allow little opportunity for wastage. Before the development of combine harvesters, there would have been much more grain available both in the fields and in the farmyard, where corn ricks and chaff heaps were probably good sources of winter food (O'Connor & Shrubb 1986). These had become virtually obsolete by 1960 (Shrubb 1997). More direct effects of mechanization have been the impact of faster, more efficient harvesters and mowers on ground nesting birds. The change to mechanized mowing has been a definite contributory factor in the decline of the Corncrake. Mowing machines are fast and they tend to be used from the perimeter to the centre of a field, thus Corncrakes (which are particularly reluctant to break cover) are trapped (Tyler *et al.* 1998). Furthermore, mowing of grass meadows has become progressively earlier (see below), so nests are likely to be destroyed. One reason for the survival of the populations in western Ireland and the Hebrides is that, until fairly recently, hay meadows were managed more traditionally. There is evidence that losses of Corn Bunting nests due to harvesting operations have increased (Crick *et al.* 1994), but this is probably more associated with increasingly earlier harvesting which has arisen due to the introduction of autumn-sown cereals, increased fertilizer use and the introduction of new crop strains, rather than mechanization *per se*.

2.2.2 Fertilizers

Inorganic fertilizers have been in use since the middle of the last century (Grigg 1989). However, it is only relatively recently that they have become the major source of plant nutrients supplied to crops and grass. Before the war, much nutrient was provided by farmyard manure. This is labour-intensive, requiring large cattle herds and being time-consuming (and unpleasant) to apply to crops. Another major source of nutrient was from the folded sheep flock which would have grazed fodder roots, a practice which has declined along with mixed farm rotations. The development of concentrated artificial fertilizers has meant a much faster and easier application: one ton of inorganic fertilizer contains as much nutrient as 25 tons of manure (Grigg 1989). Methods of fertilizer application have also changed, the direct injection of nitrogen for example, meaning that uptake is more efficient and so less is needed overall. Although the majority of plant nutrients is now provided by artificial means, a large proportion (up to 25%) still comes from animal dung, either in the form of manure or slurry, particularly in grassland enterprises (Grigg 1989). The amount of farmyard manure is likely to have decreased relative to that of slurry due to changes in stock management. Escalating input of inorganic fertilizers has been a principal cause of loss of semi-natural grassland in recent decades (Fuller 1987). Liming of grassland, though not technically a form of fertilization, is also widespread with approximately 10% of grassland receiving lime each year (MAFF data). Liming has undoubtedly reduced many acid grassland plant communities.

Increase in total nitrogen input and the higher reliance on inorganic fertilizer have been major drivers of change in the structure and floristics of lowland grasslands. These changes have been ubiquitous with profound implications for birds and their food resources. Grass fields treated with manure tend to hold higher densities of invertebrate feeders than untreated fields, probably due to increased activity of invertebrates at the soil surface (Tucker 1992). Artificial fertilizers and slurry are unlikely to be as beneficial as they are more concentrated and have less organic matter (manure having a high amount of straw). No study has yet investigated the effects of these latter treatments on birds, but high artificial fertilizer input decreases both the numbers of large invertebrates on grassland (Siepel 1990), and the diversity of plant species on grassland (Bunce *et al.* 1998) and field margins (Kleijn & Snoejng 1997), which has potential indirect impacts on birds by altering seed availabilities and associated invertebrate populations. A further impact of increased fertilizer use is that it enables crops and grass to grow more quickly. This may produce a dense sward which is unsuitable for some ground-nesting birds such as Skylark (Wilson *et al.* 1997), and this has also been a contributory factor to earlier or more frequent harvesting operations which may increase nest losses. Effects of changing grassland management practices are discussed further in 2.3.5 and 2.3.6.

2.2.3 Pesticides

The amount of active chemical used per unit area has decreased since the mid-1960s across a broad range of pesticides, but this is misleading as the chemicals used have become increasingly more efficient at killing the target organisms and also because methods of application have improved, so less active ingredient is wasted (Campbell *et al.* 1997, Thomas 1997). The proportion of area treated is probably a better measure of pesticide application in terms of effects on the ecology of farmland. This has increased in the four main types of pesticide (herbicides, insecticides, molluscicides and fungicides) since the early-1970s (Campbell *et al.* 1997). A further factor to consider is the increase in the diversity of chemicals, the number of different formulations on the official ACAS list rising from 37 in 1955 to 199 in 1985 (O'Connor & Shrubb 1986).

Herbicide use increased greatly in the 1970s in all arable crops and grass. More recently there has been a decrease in herbicide application on grass (Wilkinson 1996) which may be due to the persistence of chemicals rather than any real change in crop management (so less application is needed once the target weeds are eradicated from a field). In the 1950s herbicides would have been mainly post-emergent, particularly acting on broad-leaved weeds in cereals. The development of pre-emergent and grass herbicides has been very important in facilitating changes in cropping practice. Grass weeds in particular are an obstacle to continuous cereal cropping and were previously dealt with by the two periods of cultivation per season experienced in rotation, when grass that had germinated over winter was ploughed in before spring sowing. Pre-emergent herbicides remove competitive weeds and grasses at crop establishment and so have led to a serious reduction in their ability to set seed. The consequences of herbicide development have been a simplification of crop rotations with more continuous cropping, and no longer any need for fodder roots to be grown as a cleaning crop, and a replacement of spring-sown with autumn-sown cereals.

The use of compounds such as DDT and other organo-chlorine insecticides, which have directly toxic effects on wildlife, has become obsolete since the late-1960s, although they were not completely banned until 1981 (Ratcliffe 1980). However, there has still been an increase in application rates of other types of insecticide right up until the early-1990s (Campbell *et al.* 1997). In root crops, insecticides targeted at soil invertebrates and aphids have increasingly been applied to the soil in granular form so the chemicals are taken up through the root system. There was a rapid rise in insecticide use in the late-1970s due to an increase in the use of aphidicides in cereals. This was partly a consequence of the switch to autumn-sown crops and in particular the move to earlier sowing of these crops in the autumn which made them more susceptible to viral infection carried by aphids (Wilkinson 1996). Insecticide use has greatly increased on grassland due to the control of the Frit-Fly *Oscinella frit* on newly seeded grass, but the amount of grassland treated is insignificant compared to the extent of insecticide use on arable crops (Wilkinson 1996).

Until the late 1970s, most fungicide application was to potatoes to combat blight. Fungicides applied as a foliar spray have increased massively over the past two decades, rising by 757% between 1977 and 1990 (Wilkinson 1996), much of this increase being due to use on cereals. In common with insecticides, fungicide use has increased in response to changes in cropping practice, as autumn-sown wheat, particularly that which is sown relatively early, is more prone to attack from rust than spring-sown cereals.

In the 1950s and 1960s organo-chlorine pesticides had serious effects on many species of farmland bird, both by lethal poisoning and also by greatly reducing breeding performance. There were particularly marked effects on raptors which accumulated high concentrations of pesticide residues present in the tissues of their prey (Newton 1986), but high mortality also occurred in a range of other species (Moore 1987). As the toxic effects of pesticides such as DDT became apparent, legislation was passed to restrict their use and consequently birds such as the Sparrowhawk returned to areas where they had ceased to breed in the 1960s (Newton 1986). Increasing pesticide applications, however, may continue to have indirect effects on birds, i.e. effects that involve a reduction of the food supply (Campbell *et al.* 1997). A link between pesticide use and bird population decline has been most convincingly demonstrated in the Grey Partridge, where rigorous experimental work has shown that the loss of invertebrate prey has greatly reduced chick survival (Potts 1980, Potts 1986, Rands 1985, Potts & Aebischer 1995). There is circumstantial evidence to suggest that a number of other bird species are affected indirectly by pesticide use due to depletion of their prey or food plants (Campbell *et al.* 1997). It would seem unlikely that this has had widespread effects on the success of individual nesting attempts, as several species have shown improvements in nestling survival over time (Crick *et al.* 1997, Chamberlain & Crick 1999), but it is possible that there are effects on post-fledging survival. A further important but often overlooked effect of the increase in pesticides (particularly herbicides) is that it may have indirectly affected birds by allowing changes in the management of crops and grass (see below).

2.3 Changes in Cropping Patterns and Other Land Use on Farmland

2.3.1 Cereals

The area of cereals has increased over the whole of England and Wales since the 1950s (Grigg 1989), although this increase has been much greater in the east, and there have been declines in some predominantly pastoral farming areas (Shrubb *et al.* 1997). There are a number of reasons for the overall increase. Economic support has been high for cereals relative to other crops since the war, firstly through price-support from the British government and later the EC. Cereal production has also been greatly improved by the development of pesticides and fertilizers (Grigg 1989) and improvements in farm machinery (Wilkinson 1996). Barley increased after the war, largely replacing oats and fodder roots as a stock feed as it has a high protein content and because it lends itself to continuous cropping without the risk of disease incurred by oats in particular. Barley is associated with poorer soils than wheat and is probably more common on mixed farms, many of which have since converted to purely livestock enterprises. Wheat has also increased as a stock feed, but changes in cereal prices have meant that in recent decades this crop has been the more profitable, and hence commoner, cereal (Grigg 1989).

The 1970s saw the start of a major change in cereal cropping practice: the widespread increase of autumn sowing and the consequent decrease of winter stubble. Previously, a large proportion of harvested fields would have been ploughed and left until the spring. In some cases the stubble was left over winter to be ploughed in before planting the next crop in the spring. Undersowing of grass or clover was also a widespread practice which has declined with the increase in autumn sowing and the increasing separation of arable and pastoral enterprises. One of the major factors facilitating the switch to autumn-sown cereals was the development of pre-emergent and grass herbicides (see above). Furthermore, hardier strains of cereal have been developed which are more easily grown in the autumn (Grigg 1989). The majority of the wheat crop has been sown in the autumn since at least the early-1960s. By the mid-1980s, virtually all wheat was autumn-sown and currently less than 1% is sown in the spring. Spring-sown barley is still relatively common, accounting for 28% of the barley acreage in 1994 (MAFF June Census). The sowing of crops has become progressively earlier in the autumn as this tends to increase yield (Grigg 1989). However, this has meant that cereals are more prone to disease and consequently pesticide use has increased.

An important consequence of the trend towards autumn-sown cereals is that stubbles are much scarcer over the winter. Autumn-sown cereals are harvested July to August and sowing occurs soon afterwards in early autumn, thus stubbles and weeds are ploughed in and a developing crop is present over the winter. Stubbles are an important food source due both to the number of weed species present and also due to the presence of spilt grain after harvest. Donald and Evans (1994) showed that Corn Bunting density was highest on stubble fields in the winter and that density was twice as high on weedy stubbles as on "clean" stubbles with little weed cover. Similar preferences for cereal stubble and rape stubble have been shown in a number of other granivorous species (Green 1978, Evans & Smith 1994, Wilson *et al.* 1996).

As winter cereal develops earlier than spring-sown crops, the vegetation is higher and denser earlier in the spring (although different crop strains and increased fertilizer input have also undoubtedly increased sward density). This may have had important effects on Skylarks. In the early breeding season, winter cereals may actually be a preferred nesting habitat as the vegetation is too short on spring-sown crops. However, Skylarks will not nest in vegetation which is too dense or tall (Wilson *et al.* 1997), so later in the season when second clutches are being laid, Skylarks tend to switch to other field types including spring-sown cereals (Schläpfer 1988, Wilson *et al.* 1997). This would suggest therefore that the Skylark population is being affected by fewer breeding opportunities as a result of habitat change, rather than declines in reproductive success, and indeed the productivity of individual nesting attempts actually appears to be improving (Chamberlain & Crick 1999). Thus it would appear that Skylarks would benefit most from the availability of a range of field types within a small area. Chamberlain and Gregory (1999) found that Skylark density increased with the diversity of field types within 1 km squares, thus supporting this idea. Lapwings may have been similarly affected as they tend to avoid nesting in winter cereals (Shrubb 1990). A further advantage of spring-sown crops is the later harvesting, which may benefit late nesting species such as Corn Bunting (Donald 1997).

2.3.2 Oilseed crops

Oilseed crops were fairly commonly grown before WWII (Thirsk 1985), but it is only comparatively recently that they have been reintroduced on a large scale. The area of oilseed rape greatly increased in the UK from the early-1970s. EC subsidies made the crop highly profitable and facilitated its very rapid rise in England and Wales, which by the mid-1980s made it the third commonest arable crop in the country (Grigg 1989). Rape has replaced fodder roots as a break crop in many rotations and most of it is autumn sown. Linseed, which is mostly spring-sown, is a very recent introduction to British farming and has increased rapidly in eastern England since 1989, having experienced similar subsidies to oilseed rape. As oilseed crops have industrial uses, as well as use in foods, they may be classified as set-aside. Both rape and linseed are likely to become less common in the UK as changes in EC policy have led to the withdrawal of price-support for oilseed crops. There is evidence that oilseed rape may provide good feeding conditions relative to other modern crops (Campbell *et al.* 1997, Wilson *et al.* 1996) particularly for the Linnet (Moorcroft *et al.* 1997), and it is also a good nesting habitat for the Reed Bunting *Emberiza schoeniclus* (Burton *et al.* 1996). Similarly, linseed is likely to be amongst the most preferred crops for a number of species as it leaves a lot of spilt seed during harvest. Oilseed stubbles are good feeding areas outside the breeding season (Wilson *et al.* 1996), but as with cereal crops, there has been an increasing trend for autumn-sown oilseed rape.

2.3.3 Root crops

Fodder roots were grown as a cleaning crop as part of a traditional rotation, but have declined due to the general simplification of rotations and replacement with cereal-based animal feeds which are typically now bought in to livestock farms, rather than being produced by the farm itself. As a consequence, crops such as turnips, mangolds and swedes are virtually obsolete. In 1949, 9.1% of all crops in England and Wales were such fodder roots; in 1987 the figure was only 1.2% and it is likely to be lower still at present (Grigg 1989). Potatoes have decreased in area since the war due to abandonment of production by smaller growers, with an increasing concentration in larger holdings, particularly in the east of England which produces almost a third of the national potato crop (Grigg 1989). Similarly, sugar beet is concentrated into the eastern counties of England, but this crop showed an increase in acreage from WWII up until the early-1980s which was a response to improved varieties and more efficient harvesting techniques (Grigg 1989). The season for sugar beet is quite different to other common crops as it is sown in March and harvested between November and January so operations likely to provide food sources to birds (e.g. ploughing and harvesting) occur at different times of the year to winter-sown crops. The timing of the sugar beet harvest means that the following crop is likely to be spring-sown. Additionally, sugar beet crops are not normally grown in consecutive years due to the risk of disease, so use of this crop resembles more "old-fashioned" rotational farming. The stubble left after harvest may remain until the early spring (particularly in poor weather) and is likely to be a good food source for invertebrate feeders and may be one reason why eastern England supports large flocks of wintering plovers (S. Gillings pers. comm.).

2.3.4 Set-aside

Set-aside was introduced as a mandatory practice in 1992 (a voluntary scheme ran from 1988) in order to take land out of production and so reduce grain surpluses and to a lesser extent other crops (Firbank 1998). The area of land under set-aside has varied from year-to-year, but has typically been in the region of 10% of arable land. There are two main types of set-aside, although there are a number of rules governing the precise management of the land which cover a range of options (Firbank 1998). Rotational set-aside moves each year within the crop rotation, whereas non-rotational set-aside is left in place for at least two years. After the crop, a stubble is left for part of the winter instead of being cultivated. A green cover is allowed to regenerate (or is sometimes planted), but on rotational set-aside this is typically either cut or sprayed in the summer to prevent weeds setting seed.

Set-aside has a number of environmental benefits to birds and other wildlife (Firbank 1998). Rotational set-aside essentially fills the role of stubbles and fallow land which are now uncommon on the modern conventional farm. A number of bird species preferentially use set-aside, which is probably due to both food sources and vegetation structure (Henderson *et al.* 1998). Intensive studies of nesting Skylarks have shown that this crop is preferred (Poulsen *et al.* 1998) and also that reproductive success is higher compared to other crops due to the higher provisioning rate to nestlings in set-aside (Poulsen 1996). Despite the apparent value of set-aside to birds, there is as yet little evidence to suggest that its introduction has had beneficial effects on populations of declining farmland species (Henderson et al. 1998). The reason for this is the subject of some debate, but may include the fact that set-aside actually encompasses a range of management options, many of which create unsuitable habitat for birds (I. Henderson, pers. comm.).

2.3.5 Grass

In 1962 MAFF June Census Returns record that in England and Wales there were approximately 5.6 million ha of arable land (tillage plus temporary grass) and 4.3 million ha of permanent grassland, excluding rough grazing of which there was a further 1.4 million ha (excluding common grazings). In 1995 the comparable figures were 4.8 million ha of arable (excluding set-aside), 3.9 million ha of permanent grassland and 1.0 million ha of rough grazing. Hence, more than 40% of farmland in England and Wales is permanent grassland. Intensification has been just as strong a feature of grassland as it has of arable. In 1944, 15% of lowland grassland in England and Wales received fertilizer applications, but by 1984 this had risen to 80% (Fuller 1987). However, relatively little research has been undertaken on the impacts of changes in grassland management on birds and other wildlife.

The increased specialisation of farming, where formerly mixed farms have converted to wholly arable enterprises, has led to grass being replaced by cereals in arable regions. This has applied to improved permanent and temporary grassland and rough grazing, which have all declined relative to cereals since the 1960s. Conversely, improved grassland has increased in pastoral regions due to a decrease in fodder crops and the conversion of marginal land to permanent improved pasture, facilitated by the application of artificial fertiliser. Improved grassland is used for nesting by some species such as the Lapwing and Skylark, although it is not the most preferred crop for either of these species (Shrubb & Lack 1991, Wilson *et al.* 1997). It is of greater importance as a feeding area. For example, Lapwings prefer to nest in spring-sown cereals next to grass fields which provide good foraging for the chicks, and are particularly preferred when the vegetation is high enough for concealment (Galbraith 1988).

One of the main changes to have occurred in the post-war management of grassland has been the replacement of traditional hay meadows with grass grown for silage. This has been facilitated by the huge increase in fertiliser inputs. Widespread adoption of silage occurred from the 1960s and by the 1980s this was the dominant form of grass feed production in the UK (Wilkinson 1996). Silage grass is often cut two or more times in a season compared to the single late cut of hay and is typically cut too early for grass seed to set. The multiple cut of silage leads to increased yields over hay, but this is also due to increased fertilizer applications. Rye grass has tended to be the dominant variety in recent years due to its high dry matter content and high growth rate which allows multiple cuts.

The development of denser grass swards has resulted from the increased use of artificial fertilisers, with which many plant species are unable to compete. Fertilisers and herbicide applications have eradicated broad leaved weeds (Wilkinson 1996), thus modern silage grass has a much lower botanical diversity than traditional hay meadows. Skylarks do nest in silage, but there is always the risk of nest destruction. The regular mowing of a silage field may mean that there are opportunities for nesting when the vegetation on other crops has become too dense (Wilson *et al.* 1997). However, an unmown silage field is unlikely to provide suitable nest sites for ground nesting birds such as Lapwing (Shrubb & Lack 1991). The demise of traditional hay meadows has almost certainly been a major factor in the decline of the Corncrake, which prefers wet hay meadows which are cut late in the summer (Stowe *et al.* 1993, Green & Stowe 1993).

The decline in rough grazing and conversion to improved grass may have also contributed to the decline of other bird species in lowland farmland. The conversion of dry semi-natural grassland and sheepwalk may have contributed to the decline of species such as Stone Curlew *Burhinus oedicnemus*, Wheatear *Oenanthe oenanthe* and Whinchat *Saxicola rubetra* in lowland Britain (O'Connor & Shrubb 1986). Waders such as Snipe *Gallinago gallinago*, Lapwing and Curlew *Numenius arquata* nest in wet meadows as do passerines such as Yellow Wagtail *Motacilla flava*, particularly where there is tussocky grass (Lack 1992), and the drainage of this habitat may well have contributed to declines in these species (O'Connor & Shrubb 1986, Baines 1989). The intensive management of modern grass fields may also affect invertebrate prey populations and their availability. The Cirl Bunting *Emberiza cirlus* in particular may have been affected by decreases in unimproved pastures rich in Orthopteran prey (Evans *et al.* 1997).

Grass fields are important feeding habitats outside the breeding season (Fuller & Youngman 1979, Tucker 1992). Invertebrate feeders in particular show a preference for feeding in permanent grassland in the winter, as this supports a higher density of invertebrates than other crops (Tucker 1992). Also when cut, grass fields are likely to be used by species such as Starlings *Sturnus vulgaris*, Jackdaws *Corvus monedula* and Rooks *C. frugilegus* which prefer a short sward in which to forage. Traditional hay meadows are a good source of invertebrates and seeds as the single late cut allows weed and grass seeds to set, but the cuts are too early and frequent on silage fields and so they are of little value to seed-eaters. Similarly, clover leys are a good source of seeds which have greatly declined in recent years (O'Connor & Shrubb 1986).

The decline of temporary grass has arisen due to the decline of traditional rotational and mixed farming systems and the increasingly widespread adoption of continuous tillage cropping. The type of temporary grass has also changed. Just after the war much would have been one year clover leys, but by the early-1980s clover ley accounted for less than 1% of the area of all temporary grassland (O'Connor & Shrubb 1986). Longer period leys are now used, which are often regularly reseeded in rotation. Ley grass is important as a feeding area for invertebrate feeders, especially Rook (O'Connor & Shrubb 1986). Clover leys in particular are good food sources for Grey Partridges (Potts 1986) and buntings (O'Connor & Shrubb 1986) due to the abundance of sawfly larvae.

2.3.6 Livestock

There has been much change in the farming of livestock since 1945 (Grigg 1989). The number of cattle increased in England and Wales between 1945 and the mid-1970s, a trend which had started in the last century (Grigg 1989). This increase was linked to an increasing market for milk (helped by improving transport and storage) and an increase in milk output. This was due to a number of factors such as the increasing prevalence of specialist dairy (rather than beef) herds, improved feeds, disease control and improvements in milking technology (Grigg 1989). Since the 1970s there has been a decrease in cattle, partly due to EC dairy quotas, but probably also due to changing land use. A consequence of intensification in the English lowlands has been a decline in mixed farming. In the 1950s, many farms were still mixed enterprises in southern and central England, but now the majority specialise in arable agriculture. This has been facilitated by the fact that farms no longer need to produce their own farmyard manure due to the use of chemical fertilizers. Also, animal feeds are typically bought in, with grass silage produced on the farm rather than fodder roots, thus livestock farms do not rely on an arable component. This has resulted in further polarization of Britain into pastoral farmland in the north and west and arable farmland in the east, mixed farms now being uncommon in comparison with the decades immediately preceding the war (O'Connor & Shrubb 1986, Grigg 1989, Shrubb *et al.* 1997).

Although some level of grazing is essential in many grassland habitats to maintain swards acceptable to ground-nesting birds, such species are increasingly vulnerable to rising stocking densities, which cause both site desertion and nest losses due to trampling (Shrubb 1990, Fuller 1996). The risk of a nest being trampled is higher for cattle than for sheep (Shrubb 1990), but the grazing by cattle is less uniform and is more likely to provide suitable habitat for some species of wader, Yellow Wagtails and other ground-nesters, which prefer grass tussocks in which to nest. Changes in the management of pasture may have affected the breeding season of waders. Fertilizer inputs and land drainage have meant that cattle are put out to pasture earlier in the year. In the Netherlands this has been accompanied by waders nesting increasingly early, possibly as a response to the vegetation developing a suitable structure earlier (Beintema *et al.* 1985), or due to fewer replacement clutches being laid due to the increased grazing pressure (Shrubb 1990).

Sheep densities have increased since 1945, at which point numbers had been at their lowest for over a century (Grigg 1989), and the rise is continuing. In the 1960s and early-1970s numbers fell in central and eastern England due to the intensification of cereal farming, but since then there have been increases in both lowland and upland England and Wales (Fuller 1996, Fuller & Gough in press). To some extent this may have been due to grassland improvement (e.g. drainage and re-seeding), but the main reason is likely to be economic, the start of the increase in the mid-1970s coinciding with the introduction of the Hill Livestock Compensation Allowance (Fuller & Gough in press). Grass which has been subject to intensive grazing pressure by sheep has a very short sward which is unsuitable for any nesting species. In the uplands, overgrazing may present a serious problem to ground nesting birds for a variety of reasons (Fuller & Gough in press).

Both cattle and sheep pasture may be an important feeding habitat for invertebrate feeders where a short sward is preferred for feeding. Animal dung is likely to enrich the soil and be good for invertebrates. Also, the livestock themselves may present feeding opportunities for birds by disturbing insects, and it is not uncommon to see species such as Starling foraging in the path of grazing cattle (Feare 1984). In recent years there has been considerable concern about possible ecological side-effects of some anti-parasite drugs, especially the avermectins. These compounds are used as antihelmintic agents and for controlling ectoparasites in a range of livestock. Normally, livestock dung is rich in invertebrates and the concern is that excreted residues of avermectins have impacts on non-target, dung-breeding insects (e.g. McCracken 1993 and references therein). Many of these insects are important sources of food for birds including corvids, swifts *Apus apus*, hirundines, wagtails and waders (McCracken 1993). Other authors have argued that effects on coprophagous insects are, in fact, minimal due to availability of residue-free dung and mobility of the organisms involved (Halley *et al.* 1993, Wratten *et al.* 1993). However, more recent studies have continued to indicate that recommended doses can lead to reduced insect activity in cattle dung (Strong & Wall 1994; Strong *et al.* 1996; Floate 1998).

2.3.7 Hedgerows

The original function of hedges, to divide up land and enclose livestock, no longer applies on the modern arable farm where efficiency is maximised by larger fields and fewer crop types. Furthermore, increasing specialization means fewer farms have livestock. Also, hedgerows need to be maintained, and replacement with a fence will ultimately save time and money, so even in predominantly livestock regions, hedges are not a necessary requirement of farmland. Hedgerow removal has been occurring at a high rate since the war and although estimates vary (O'Connor & Shrubb 1986), it seems probable that close to 50% of hedgerow has been removed since 1945. Removal rates peaked in the 1960s and have declined since (Fig. 2.4), which must be in part due to the increasing awareness of their conservation value. Not surprisingly, hedgerows have shown the greatest rates of loss in areas where mixed farming has converted to arable, particularly in the Home Counties, Lincolnshire and Yorkshire (O'Connor & Shrubb 1986).

Hedgerow holds a higher diversity of birds than any other farm habitat (Lack 1992) and hedgerow removal will result in the loss of an important part of the farmland bird community. The number of species nesting on farmland increases up to a certain hedgerow density, but the density of individual breeding birds continues to increase linearly with increasing hedgerow density (Lack 1992). The majority of birds which use hedges for nesting are birds of woodland or woodland edge, so hedgerow dwellers tend not to be specialist farmland birds, but there are some notable exceptions including Tree Sparrow, Linnet and Whitethroat *Sylvia communis*. In these species and also in some species with more catholic habitat requirements such as Blackbird and Song Thrush, there have been substantial declines in the farmland population. A further factor to consider is that hedgerow structure may have undergone changes which make them less suitable for birds. For example, taller hedges and hedges with trees tend to have higher bird diversity (Parish *et al.* 1994) and higher densities of certain species (Green *et al.* 1994). Less sympathetic hedgerow management (e.g. too frequent or poorly timed cutting) and loss of trees may therefore have contributed to declines in farmland birds. However, a recent study of farms differing in amounts of habitat loss, especially hedgerow loss, indicates that bird populations have declined in the absence of habitat loss. This suggests that effects of hedgerow loss may be secondary to those of wider habitat degradation within farmland (Gillings & Fuller 1998).

Some studies of woodland species nesting on farmland have indicated that the farmland populations are merely "sinks" (Pulliam 1988) with little or no productivity. For example, Krebs (1971) showed that Great Tits *Parus major* nesting on farmland would rapidly fill vacant territories in adjacent woodland when the resident territory holder was removed. Similarly, non-territorial males would occupy vacated farmland territories, thus farmland would appear to be a sub-optimal habitat to woodland. Farmland populations of other species have also shown characteristics of a sink population e.g. Wren *Troglodytes troglodytes* (Williamson 1971), Woodpigeon *Columba palumbus* (Murton & Westwood 1974) and Mistle Thrush *Turdus viscivorus* (O'Connor 1986). Murton and Westwood (1974) suggested that hedgerow was an unproductive habitat for most species and therefore of little conservation value. However, a detailed study of reproductive success of Blackbirds has shown that although the farmland population shows some demographic characteristics of a sink population, productivity in woodland was not significantly different overall (Hatchwell *et al.* 1996), farmland territories being intermediate in productivity between good and poor woodland territories. In this species at least, hedgerow may be more important than previously thought, and this also shows that relying solely on population structure may be misleading when trying to determine habitat quality.

2.3.8 Changes in farm habitat diversity

A general result of the changes in land use and non-crop habitats over the past 30 or so years has been a reduction in farm habitat diversity. Pastoral farms now rarely have an arable component, as they will typically not grow their own fodder crops. Also, arable farms tend to have less temporary grass and permanent pasture, as solely arable enterprises tend to be more profitable in areas of predominantly tillage agriculture. A further factor which has reduced habitat diversity is the change in crop rotations. Pesticide and fertilizer developments have allowed the simplification of rotations and the introduction of continuous cropping. Ley grass is now uncommon in agriculture, its function previously being to rest the land from cultivation and help replenish the soil (particularly clover ley which is a good source of nitrogen) which now may be done by synthetic fertilizers. A further, now largely obsolete feature of arable rotations was root crops which had the function of cleaning the soil of weeds. This is no longer necessary with the development of pre-emergent herbicides, and also the main use for the root crop as fodder no longer exists. Oilseed rape has replaced both of these crops in a typical rotation, which often consists of just cereals and oilseed rape, possibly with a root crop in certain areas, and it is not uncommon for some farms to adopt continuous cereal cropping.

Birds may be affected by a reduction in habitat diversity when they require a mosaic of crop types which satisfy their nesting and feeding requirements under different conditions. For example, Skylarks appear to benefit most from the presence of a range of crops of differing sward structure (Schläpfer 1988, Wilson *et al.* 1997), and Skylark density is therefore higher in areas of higher crop diversity (Chamberlain & Gregory 1999). Similarly, Lapwings may nest in cereal crops, but once hatched, the young are preferentially taken to improved grassland (Galbraith 1988). A mix of habitats within a fairly small area may be advantageous to a number of ground nesting birds and the increasing trend for specialization into either arable or grass is likely to be detrimental to these species.

2.4 Discussion

The past three decades have seen major changes in the management of farmland. Many components of change in agriculture follow the same general pattern. The main underlying causes of these changes have been technological developments. The development of pesticides and fertilizers in particular, and also the increased efficiency of their application, has had widespread effects on farming practice, including changes in the timing of sowing of cereals, changes in crop rotations and the introduction of continuous cropping, and changes in the management and harvesting of improved grass. These changes are likely to have reduced habitat diversity on farms, and altered the availability of bird food sources and potential nesting habitat both spatially and temporally via a number of possible mechanisms.

There is much circumstantial evidence to support the contention that changes in farm management have contributed significantly to population declines in a number of species (Baillie *et al.* 1997). However, the majority of these studies have dealt with the effects of current farm management on habitat preferences and reproductive success. Inferences have then been drawn on the likely impact of changes in farm management given the current situation. Far fewer studies have sought more direct evidence of effects of changing management practices over time. The most notable exception to this is the work which has been carried out on the Grey Partridge (Potts 1986), where the factor which has had the most effect has been the increased use of herbicides which have removed food plants of invertebrate species which are vital prey of Grey Partridge chicks. There have also been additional factors responsible for the decline in this species which include loss of clover leys in rotation, loss or degradation of grassy field margins (Potts 1986) and an increase in predation due to a decline in keepering (Tapper *et al.* 1996). The reasons underlying the decline of the Corncrake over recent years are also reasonably well understood, and involve the intensification of grass management, which results in unsuitable habitat and management operations causing very high nest and chick mortality (Green & Stowe 1993, Green 1995). However, the Corncrake, unlike many of the other species so far considered, has been undergoing a decline for a much longer period (Hudson *et al.* 1990), and there are clearly factors responsible for its decline which are not associated with the general intensification of farmland over the past three decades. The change from manual labour and horse-powered hay cutting to mechanized mowing has been considered a factor in the Corncrake decline as far back as the late 19th Century (Lilford 1895, Norris 1947).

A few other species, although not subject to any rigorous analysis of historical changes, show some evidence from intensive studies on current habitat preferences and reproductive success to suggest that habitat change has affected population size. The decrease in spring-sown cereals and the decline in habitat diversity have been at least in part responsible for the decline of Skylarks (Wilson *et al.* 1997, Chamberlain & Gregory 1999) and Lapwings (Shrubb & Lack 1990, Hudson *et al* 1994). Cirl Buntings have shown a heavy reliance on cereal stubbles in the winter (Evans & Smith 1994), and on traditionally managed pasture in the breeding season (Evans *et al.* 1997), both of which have declined. However, the Corn Bunting has shown more complex and sometimes conflicting evidence for effects of habitat change on population size (Gibbons & Gates 1994, Donald 1997).

The work on the Grey Partridge is the only good evidence so far to suggest that recent declines in any species have been associated with increases in pesticides, despite the proposed links in several species (Campbell *et al.* 1997). Indeed, recent work has suggested that a number of species whose overall populations are declining are showing stable or even increasing nesting success (Crick *et al.* 1997, Chamberlain & Crick 1999), so pesticides would seem unlikely to be affecting populations, at least via nestling survival. An understanding of the relationship between Grey Partridge productivity and herbicide use was reached only after years of intensive work which also revealed that there were a number of other less important factors that had affected the population (Potts 1980, Rands 1985, 1986, Sotherton 1991, Potts & Aebischer 1995, Tapper *et al.* 1996). It is therefore likely that for a number of species, there may not be one, but several interacting factors which have affected populations.

2.5 Objectives of this Project

For the majority of farmland species, there is little strong evidence linking changes in specific management practices to changes in population size, and the majority of studies addressing such questions have considered spatial, rather than temporal effects of agricultural management, and with a few exceptions (Stowe *et al.* 1993, Gibbons & Gates 1994, Gates *et al.* 1994) have considered habitat relationships at the farm level. In this study we aim to analyse farmland bird-habitat relationships both spatially and over time at different spatial scales. Broad-scale relationships between population size, range change and habitat extent will be investigated at national and regional scales. The change in the bird community at the farm level will be investigated in relation to detailed changes in habitat extent and other management factors. The rationale is that changes in bird populations showing strong links with particular aspects of agricultural management should show similar relationships at different spatial scales. These analyses may give clearer insights into those particular aspects of change in agriculture which may have driven population changes in particular species since the 1970s.

The specific scientific objectives as stated in the contract with MAFF are as follows.

Objective 1: To analyse Common Birds Census (CBC), Atlas and BTO Rook survey data sets to produce regional population indices and regional changes in distribution for 21 selected bird species typical of farmland habitats over the past 20 to 30 years. These selected species, referred to henceforth as the "target" species, are listed in Table 2.1. These species were identified on the basis of the quality of the available data and whether the bird was considered characteristic of *lowland* farmland in England and Wales. Certain farmland species, although of great conservation concern, were too rare for any valid analysis (e.g. Stone Curlew and Cirl Bunting). Other common farmland species are typically poorly censused and so were not considered (e.g. Pheasant *Phasianus colchicus*, Woodpigeon and House Sparrow *Passer domesticus*). The representativeness of this group of target species to the lowland farmland bird community as a whole is discussed in later sections. Species that are relatively localised in *lowland* farmland (e.g. Curlew, Whinchat, Meadow Pipit *Anthus pratensis*, Sedge Warbler *Acrocephalus schoenobaenus*) were excluded and a high proportion of the lowland populations of these species is, in any case, associated with non-agricultural land. The target list includes all common farmland specialists for which there is evidence of decline; some other widespread, but relatively stable, species (e.g. Chaffinch) are included for comparison. The list includes all the widespread native specialist farmland species as defined in Fuller *et al.* (1995) with the exception of Barn Owl *Tyto alba*, Woodpigeon and Jackdaw.

Objective 2: To obtain agricultural practice data for the last 20 years, on a regional basis, for a range of activities that are likely to have an impact on bird populations and their distribution e.g. spring v autumn sowing of cereals, simplification of crop rotations, intensification of grassland management and use of pesticides.

Objective 3: To obtain new breeding population data in 1996 and 1997 for approximately 50 farms, where CBC data had been collected in at least five years between 1965 and 1975.

Objective 4: To collect broad agricultural practice data for at least the last 20 years for the farms referred to in Objective 3 by means of farm visits and the use of questionnaires compiled by experienced farm data gatherers.

Objective 5: To analyse databases collected by Objectives 1 to 4 to investigate whether changes in agricultural practices coincide with changes in population size and distribution of the 21 selected bird species typical of farmland habitats at the farm, regional and national scale.

Objective 6: Assess whether changes in bird populations which are associated with pesticide use have been caused by direct toxicity or other mechanisms e.g. reduced availability of food or nesting sites.

The sections of this report relate to the above objectives as follows:

Objective 1: CBC and BTO Atlas data were analysed at various scales to elucidate changes in regional and distribution at various scales. Section 4 describes changes in the distribution of farmland birds, as shown by BTO Atlas data, in relation to the spatial pattern of change in agriculture. Changes in abundance of breeding birds (regional and national scales) are analysed and presented in Section 5 in relation to the timing of changes in agriculture.

Objective 2: Section 3 describes, quantitatively, the temporal and spatial patterns of change in many components of agriculture since the 1960s. These data are used in the analyses that form the subjects of Sections 4 and 5.

Objective 3: New bird population data were collected in 1996 and 1997 for approximately 50 farms previously surveyed more than 20 years ago. These data are presented in Section 6.

Objective 4: Broad agricultural practice data were collected directly from farmers using a detailed questionnaire. This information is summarised and used in the analyses presented in Section 6.

Objective 5: An assessment of the relationships between change in bird distribution and spatial change in agriculture is given in Section 4. An assessment of the relationships between change in bird abundance and change in agriculture at national and regional scales is given in Section 5. An assessment of the relationships between change in bird abundance and change in agricultural practice at the individual farm scale is given in Section 6. An integration of the findings across different scales is given in Section 8.

Objective 6: Section 7 is concerned with the mechanisms by which pesticides may have affected bird populations.

2.6 Summary

1. British farmland bird populations, more than those associated with any other habitat, have declined substantially over the last 30 years. This project broadly aims to establish the extent to which changes in the abundance and distribution of farmland birds coincide with the timing, and the spatial pattern, of changes in agricultural management. As far as possible, the relationships with specific components of change in agricultural management are examined so as to give insight to likely causal factors.

2. Agricultural change is one of several hypotheses accounting for the large declines in farmland birds; there is, however, an increasing body of evidence that various aspects of change in agriculture have affected bird populations since the last war. This section provides a general introduction to the report by summarising the major changes that have occurred in post-war agriculture in Britain. *Potential* effects on birds of specific changes in management practices are considered and the available evidence considered. This provides a contextual background against which the findings of the project can be discussed.

3. The large changes in agriculture have been made possible by huge technological advances involving mechanisation, the use of fertilisers and development of pesticides. These factors may themselves have been relevant to birds by, for example altering food resources, but their consequences have been far-reaching by stimulating large-scale changes in timing of cultivation, mowing and harvesting, the use of rotations and the types of crops. The broad changes in cropping, grassland management, livestock, non-crop habitat and farm/habitat diversity are described and potential implications for birds considered.

4. Different species of birds may have been affected by different components of change in agricultural systems. It is likely that some species of birds will have been affected by several components of change in agriculture. Many of these components of agricultural systems have changed more or less in parallel so isolating the effects of specific management practices is difficult using correlative approaches.

Kestrel *Falco tinnunculus*	(K.)
Grey Partridge *Perdix perdix*	(P.)
Lapwing *Vanellus vanellus*	(L.)
Stock Dove *Columba oenas*	(SD)
Turtle Dove *Streptopelia turtur*	(TD)
Skylark *Alauda arvensis*	(S.)
Yellow Wagtail *Motacilla flava*	(YW)
Starling *Sturnus vulgaris*	(SG)
Rook *Corvus frugilegus*	(RO)
Whitethroat *Sylvia communis*	(WH)
Blackbird *Turdus merula*	(B.)
Song Thrush *T. philomelos*	(ST)
Tree Sparrow *Passer montanus*	(TS)
Chaffinch *Fringilla coelobs*	(CH)
Bullfinch *Pyrrhula pyrrhula*	(BF)
Greenfinch *Carduelis chloris*	(GR)
Goldfinch *C. carduelis*	(GO)
Linnet *C. cannabina*	(LI)
Corn Bunting *Miliaria calandra*	(CB)
Reed Bunting *Emberiza schoeniclus*	(RB)
Yellowhammer *E. citrinella*	(Y.)

Table 2.1 "Target" species considered in the analyses. Abbreviated species codes are given in parenthesis.

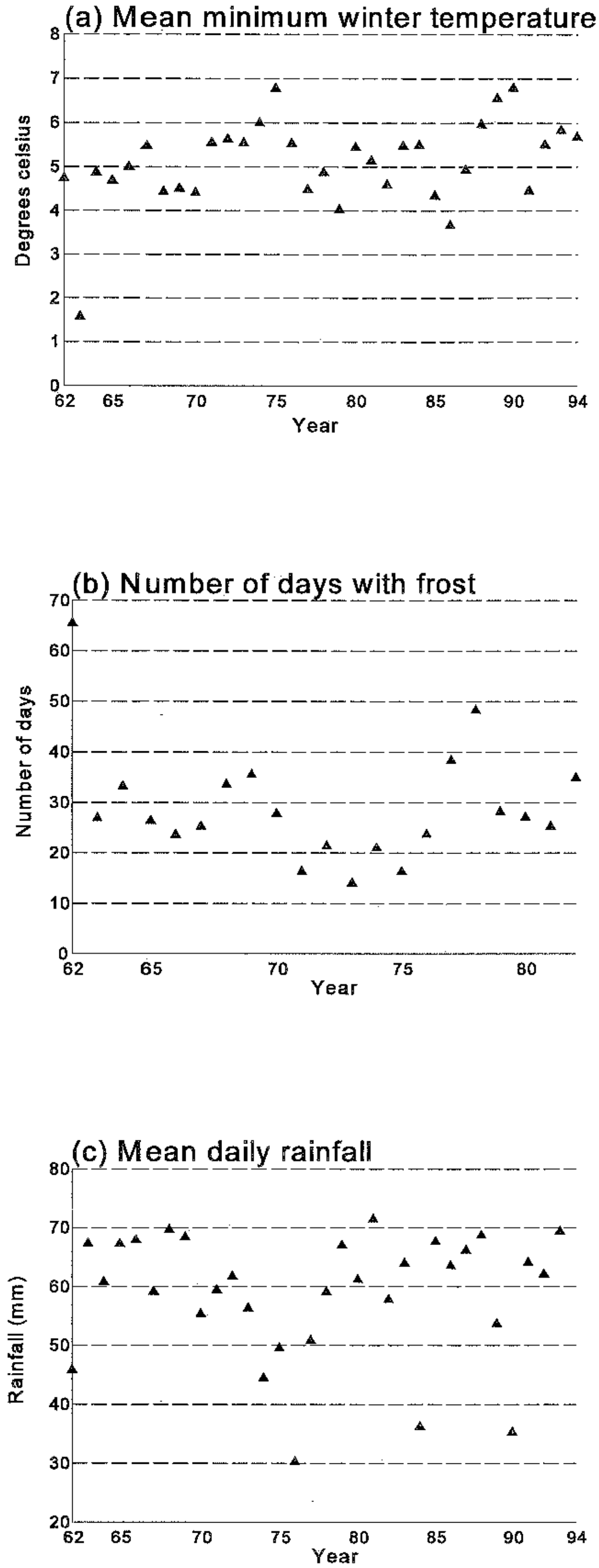

Figure 2.1 Annual trends in the mean minimum daily temperature in winter (November to February), the number of days recording frost in winter and the total daily spring and summer rainfall (April to July) in England and Wales. Data were only available on frost days until 1984. Source: Met Office.

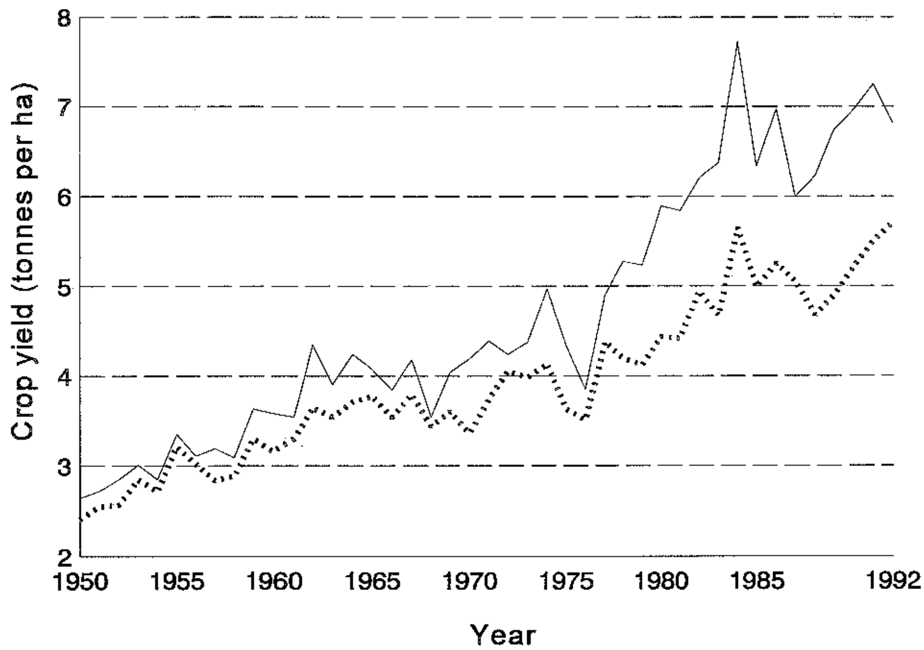

Figure 2.2 Annual cereal yields in the United Kingdom. Solid line = wheat, broken line = barley. Source: MAFF.

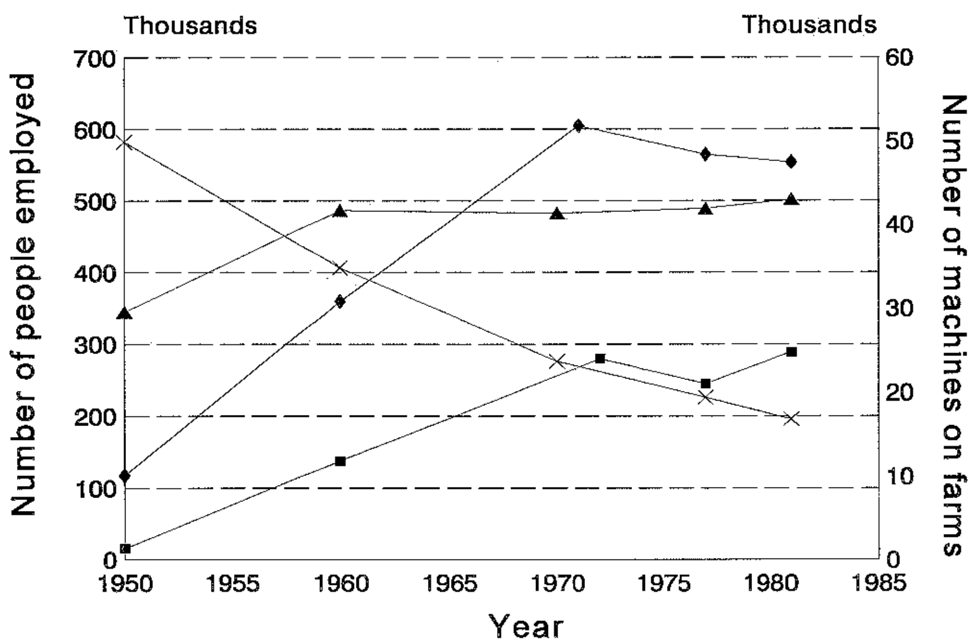

Figure 2.3 The number of farm labourers (×) employed and the number of machines used on farmland in the United Kingdom. Key: ▲ tractors ($\times 10^{-1}$), ♦ combine harvesters, ■ root harvesters. Source: MAFF.

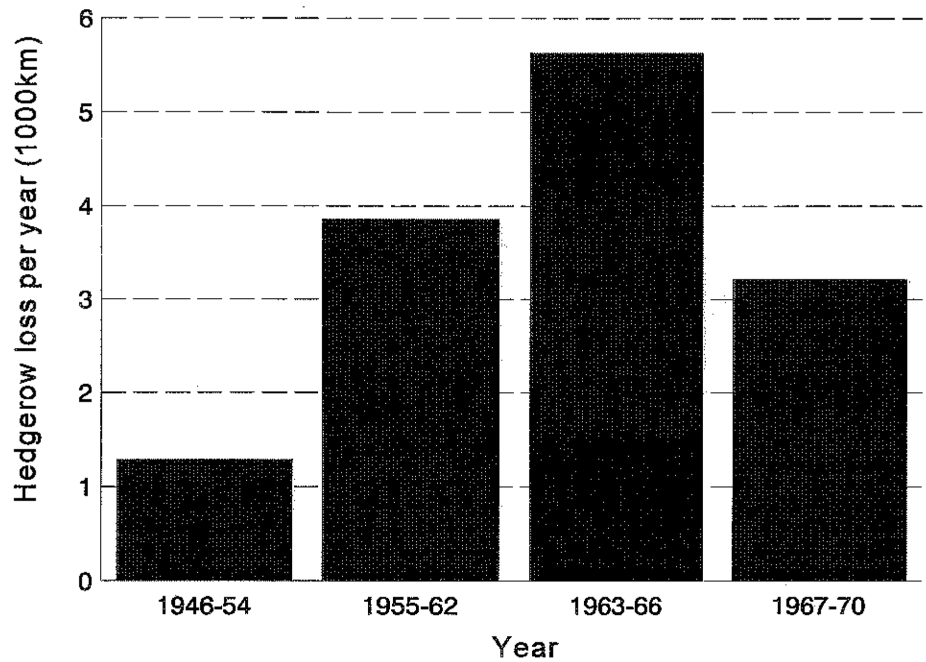

Figure 2.4 Rates of hedgerow loss in the UK, 1945-1970. Source: O'Connor & Shrubb (1986).

3

Temporal and Spatial Changes in Lowland Agricultural Management

D.E. Chamberlain[1], R.J. Fuller[1], R.G.H. Bunce[1],

J.C. Duckworth[2] & M. Shrubb[1]

[1] British Trust for Ornithology
[2] Institute of Terrestrial Ecology

3. TEMPORAL AND SPATIAL CHANGES IN LOWLAND AGRICULTURAL MANAGEMENT

3.1 Introduction

A number of studies have reviewed historical trends in farm management practices (O'Connor & Shrubb 1986, Potts 1986, Grigg 1989, Stoate 1996, Campbell *et al.* 1997, Donald 1997, Shrubb *et al.* 1997), which are discussed in detail in the previous section. Gates and Donald (in press) described spatial variation in agricultural variables using Principal Components Analyses (PCA) and used change in PCA space between 1969 and 1988 as a measure of overall habitat change. With this one exception, we are not aware of any other study which has attempted to analyse patterns of temporal and spatial change in agricultural management at the national or regional scale. In this section, we present data on changes in a large number of agricultural management variables over the past 30 years, and we attempt to identify patterns of change by reducing the large number of variables to axes of environmental variation using ordination procedures (Gauch 1982). The data from this section form the basis of a number of analyses considering the effects of agricultural change on bird abundance used in subsequent sections.

3.2 Methods

3.2.1 Data

The source of spatial habitat data was the MAFF Agricultural June Census, which details the area of land under a wide range of agricultural use. Data at the 10 km square level were used from 1969 and 1988, each of which falls within a period covered by the Breeding Bird Atlas (Gibbons *et al.* 1993 - see Section 4). Variables were selected on the quality of the data and consistency between the two censuses (there were, for example, certain variables such as temporary grassland which changed definition between the two censuses, so permanent and temporary grass were combined in one category of improved grass). All variables used in the analyses are defined in Table 3.1. Habitat diversity was calculated in each year using the Shannon index (Krebs 1980). MAFF June Census data were used to define predominantly arable and non-arable regions in England and Wales defined at the county level, where counties defined as "arable-east" were those where arable farmland occupied over 10 times the area of grassland in 1988. The counties in each region are listed in Table 3.2 and the geographical location of the regions is shown in Fig. 3.1. This definition is, with the exception of two counties (Bedfordshire instead of Oxfordshire), the same as the intensive arable definition used by Firbank (1998). Non-arable counties were divided into two regions, mixed-south and pastoral-west, the former representing the non-arable counties within the region of which Common Birds Census (CBC) indices are most representative (Fuller *et al.* 1985 - see Section 5), and the latter, all other counties in England and Wales. These three regions generally reflect predominantly arable, mixed and pastoral farmland. Note that all of the intensive counties lay within the area for which CBC indices are representative.

Annual changes in agricultural variables were derived from a number of sources: county-level summaries of MAFF June Census data; MAFF Pesticide Usage Survey Reports (e.g. Thomas 1997); ITE/ADAS review of agricultural management (Wilkinson 1996); ADAS British Survey of Fertilizer Practice; and data presented in O'Connor & Shrubb (1986). Variables considered, the years from which data were available, data sources and abbreviations used in subsequent analyses are shown in Table 3.3. Variables were selected on their likely relevance to bird populations where possible, but for some potentially important variables (e.g. areas of hay, silage, stubbles and undersown-cereals) no data sources were found. In some cases, it was only possible to obtain data from the whole of the UK, rather than just England and Wales. In these cases, we assume that temporal changes show similar patterns in England and Wales to those from the whole UK.

3.2.2 Analyses

The change in area of agricultural variables from MAFF data were determined between the two Atlas periods for each 10 km square. Only 10 km squares with an initial (i.e. 1969) minimum area of 5000 ha of *lowland* agricultural land were considered in these analyses, so 10 km squares with a large amount of urban, coastal or upland habitat were omitted. Habitat change was also described by carrying out PCA in order to try and reduce the large number of habitat variables to simpler gradients of habitat change. Axes were derived using the correlation matrix of variables, thus allowing consideration of variables measured on different scales (James & McCulloch 1990).

For annual agricultural data, underlying trends were identified using a smoothing procedure which uses a 4235H-twice running median (Velleman & Hoaglin 1981). This was done as there was often slight variation in the definition of MAFF statistics between years causing scatter. Also there were some instances where data for single years were unavailable which could be estimated using the smoothing procedure. Using this technique allows the determination of continuous underlying temporal trends and has the advantage of few assumptions compared to alternative parametric methods. Data were obtained between 1962 and 1996 where possible (to match up with the CBC data used in Section 5), but in a number of cases, data were only available for intermittent years within this period or only up until 1992. For these variables, missing values were interpolated from a straight line drawn between years with actual data, or data were extrapolated from the smoothed trend. Data on area of permanent grassland (at least five years old) and new grassland (seeded or re-seeded within the previous five years) were a particular problem as the definition changed in 1974 from more or less than seven years old to more or less than five years old. In order to produce a run of values, the difference between the mean of the earlier and mean of the later grassland definition was added onto every value after 1974 as a correction factor for both permanent and new grassland. We assume that the pattern of change is a good reflection of trends in grassland, but we acknowledge that the actual figures presented should not be taken as absolute values.

Many of the variables considered were correlated with one another (Appendix 3.1). This high degree of collinearity makes interpretation of relationships with bird abundance difficult, so it was decided to look at general gradients of agricultural change to allow an assessment of features which most strongly characterize those gradients. Smoothed agricultural variables were analysed by two ordination techniques. Firstly, for each variable separately, annual values (including estimated values) were ranked across years and then divided equally into three groups of relatively high, medium and low ranks. These ranked groups were then recorded as attributes which were present or absent for each year and ordinated using Detrended Correspondence Analysis (DCA) using the program DECORANA (Hill 1979), which was run using the default settings throughout, except that the down-weighting option was selected. Thus the data could be summarised in terms of attribute scores over years, giving an index of agricultural change. In this way, the category of the value rather than the actual value is important, so it matters less that certain values were estimated. Secondly, data with a large number of interpolated values (more than two) were dropped from the analysis and a PCA was carried out on data from 1974 to 1991, so only variables with a continuous run of several years of actual data were considered. PCA was carried out using the correlation matrix of variables (see above). Due to the "gappiness" of the data, it was not possible to disregard all interpolated values in this analysis as this would have made the sample sizes small and more seriously would have meant that a number of important variables (especially autumn and spring-sown barley) would not have been considered.

3.3 Results

3.3.1 Spatial changes in farming practice

The change in 15 agricultural variables between 1969 and 1988 in 10 km squares with a minimum farmland area of 5,000 ha, ranked into five categories of change of equal sample size, are shown in Figs. 3.2 to 3.16. The underlying reasons behind these changes are reviewed at length in Section 2. The total area of farmland showed no clear spatial pattern of change, but the majority of 10 km squares showed some decrease (Fig. 3.2), possibly due to urbanization.

The area of wheat has increased in almost every 10 km square considered (Fig. 3.3). The greatest increases have occurred mainly in a central band from north Lincolnshire southwards, whereas there has been little or no increase in wheat in the south-west, north-west, or Wales. Oilseed rape has also shown a very similar pattern of increase (Fig. 3.4). Barley has shown a pattern of decline which mirrors the increase in wheat and oilseed rape over much of the region (Fig. 3.5). The amount of spring and winter barley were not separated in the agricultural statistics in 1969, but it would seem likely that a decline for spring barley would follow similar regional patterns, but the decrease would be greater than for total barley. Bare fallow has shown similar declines to barley (but perhaps less so in East Anglia; Fig. 3.6), which is probably indicative of changes in crop rotations. Potatoes have also shown fairly similar patterns of decline (Fig. 3.7). Sugar beet has increased in Norfolk, Lincolnshire and East Yorkshire but decreased over much of the rest of the country (Fig. 3.8), although it was always fairly patchily distributed. Other root vegetables (mainly turnips and swedes) do not show a clear pattern of regional change but they have declined in parts of the south-west and north of England and in the Welsh borders and have increased locally in Lincolnshire, The Fens and western Midlands (Fig. 3.9). These crops underwent a substantial decline prior to 1969 (Grigg 1989 and see below). Other vegetables have shown a clearer east-west divide between increases and decreases in area (Fig. 3.10). Total tillage has increased in the Midlands and parts of eastern England (e.g. Lincolnshire), and decreased markedly in the west (Fig. 3.11).

Improved grassland has shown the opposite pattern to the change in the area of tilled land (Fig. 3.12). Rough grazing land has decreased most in Wales and the north and south-west of England and in a small area in East Anglia (Fig. 3.13), although generally, there are few 10 km squares in eastern England with much rough grazing. The number of sheep have tended to decrease in eastern England, but have shown large increases in most other regions, the greatest increases being in Wales (Fig. 3.14). Cattle numbers have increased the most in south-west England and decreased the most in the eastern English midlands and parts of East Anglia and the south-east (Fig. 3.15), although geographical patterns were less clear cut than for sheep. There may be different geographical trends evident if livestock density (rather than number) were able to be measured, but unfortunately, the data for grassland give no clue as to its use (e.g. hay, silage, or grazing) so this was not possible. Finally, orchards and other soft fruit have declined nationally, but most markedly in eastern England and south-west and western England (Fig. 3.16), where formerly fruit crops were relatively common.

The diversity index per 10 km square was determined for each period using the area of individual crop and grass variables from Table 3.1 (so not including total tillage, total farm area or livestock variables), but dividing total grass into permanent and temporary grass (the change in definition between the two years should matter little when considering habitat diversity). The diversity in 1969 is shown in Fig. 3.17a. There was a marked east-west trend, with the greatest diversity in East Yorkshire, the East Midlands, Lincolnshire and Norfolk. The distribution of diversity was apparently similar in 1988, with no change to the general pattern (Fig. 3.17b). The absolute change in diversity index of crop types between 1988 and 1969 was determined per 10 km square (Fig. 3.18a). The greatest losses in diversity were in the Midlands, the Welsh Borders, Kent, parts of East Anglia and north-west England. Elsewhere, there was some evidence of an increase in diversity in Lincolnshire and Humberside, probably due to a greater number of crops now being grown, and increases in Wales and the south-west of England. When considering the percentage change in diversity between the two time periods (i.e. relative to the original diversity of the square), a very similar pattern was evident (Fig. 3.18b). The change in diversity may be a reflection of changing farming practices, particularly the loss of mixed farming (O'Connor & Shrubb 1986).

The distribution of predominantly arable 10 km squares (at least 80% farmland area of arable crops), predominantly grass 10 km squares (80% area of improved grassland and rough grazing) and mixed farmland 10 km squares (intermediate in the area of arable and grass) in 1969 and 1988 are shown in Fig. 3.19. Between 1969 and 1988, predominantly arable 10 km squares had increased by 77% but predominantly grass 10 km squares and mixed farmland 10 km squares had declined by 17% and 7% respectively. A greater percentage of grass-dominated 10 km squares changed status, with 18.3% changing to either arable or (mostly) mixed 10 km squares between surveys, compared to 15.1% of mixed 10 km squares and 1.6% of arable 10 km squares. This difference was significant (G_2=29.3, $P<0.0001$). Mixed 10 km squares, however, changed the most in absolute terms (102 10 km squares compared to 53 for grass 10 km squares and two for arable 10 km squares). The 10 km squares which changed from arable to mixed were largely in the East Midlands, north Lincolnshire and East Yorkshire, coinciding with an area of increase in habitat diversity. However, in northern and western 10 km squares there was less change in the overall farming type of 10 km squares, and what there was tended to be grass 10 km squares changing to mixed 10 km squares.

The change in agricultural management between 1969 and 1988 was analysed using PCA to ordinate all farmland 10 km squares in the sample (i.e. minimum 5,000 ha farmland area), the goal being to identify habitat gradients made up of 10 km squares with varying levels of habitat change using all 15 variables in Table 3.1. The amount of variation between 10 km squares explained by the first three PCA axes and the eigenvectors of individual variables are shown in Table 3.4. The eigenvectors from the first three axes for each 10 km square were divided into five ranked groups of equal sample size and are shown in Fig. 3.20. The first axis (PRIN1) explained 34.7% of variation in the data and identifies a major pattern of change in cropping, in particular, 10 km squares which have experienced large increases in certain crop types (particularly wheat and oilseed rape) at the expense of barley, bare fallow and grass. 10 km squares showing this pattern of change have negative scores on this axis. PRIN1 shows a clear geographical pattern with most of the scores of greatest magnitude occurring from Lincolnshire southwards to the northern Home Counties and eastward to Essex and Suffolk, showing areas where the greatest changes in arable crops have occurred (Fig. 3.20a). 10 km squares towards the north and west of the region have experienced less change in arable crops apart from a small increase in barley, and an increase in grass area. The second axis, which explained 11.3% of variation in the data, was mainly associated with overall changes in the area of agricultural land, but there was no particular regional pattern to this (Fig. 3.20b). PRIN3, which explained 9.5% of variation in the data, was associated with changes in grassland and total farm area (Fig. 3.20c). A loss in grassland was most strongly associated with a decrease in the overall area of farmland compared to all other crop types ($r^2=0.31$, df=1089, $P<0.0001$). PCA analyses were repeated for arable and non-arable regions separately (Table 3.5). The axes, and in particular PRIN1, were similar to those in the overall analyses for each of the three regions.

3.3.2 Temporal changes in agricultural management

Smoothed trends for 32 agricultural variables are shown in Fig. 3.21. The total tilled area has increased slowly since 1962, but in the last few years there has been some decrease which may reflect the introduction of set-aside. Of the arable crops, there have been substantial increases in wheat and oilseed rape and decreases in oats, barley, root crops, potatoes and bare fallow. Sugar beet increased steadily up until the early 1980s and decreased slightly thereafter. We could find no data on temporal changes in the area of linseed, but we know that this crop has increased substantially since the late-1980s as it has become a more profitable industrial crop and also linseed is often sown as a cover crop within the set-aside scheme. We thus assume that the increase in linseed has followed the trend for set-aside, although there will have been very small amounts grown prior to this. Within cereal crops, there have been changes in the timing of sowing, with autumn-sown wheat and barley substantially increasing from the mid-1970s and spring-sown cereals decreasing to very low levels in recent years. Both new and permanent grass have shown relatively small decreases since the early-1960s, but rough grazing has decreased to a greater extent. Grass production has however increased, largely due to increases in silage production and associated decreases in hay and greater nitrogen inputs. Cereal production has also increased greatly. This has been facilitated by increases in both artificial fertilizer and slurry inputs. Cattle have tended to decrease in number, but sheep have shown a big increase, although this figure may be misleading in the context of this analysis as these figures include uplands where increases have been much greater than on lowland farmland (Fuller & Gough in press). Given that grass area is generally decreasing, there is likely to have been an even larger increase in the density of sheep. Finally, all types of pesticide have shown steep increases from the early-1970s onwards.

DCA of temporal change in agricultural variables grouped into high, medium and low categories produced one strongly dominant axis which accounted for 81.9% of variation in the data[1]. This gradient ranged from attributes with low scores such as low levels of herbicides and fertilizers and high area of spring wheat, which were prevalent earlier in the time period in question, to attributes with high scores, generally associated with more recent practices, such as high rates of fungicide application, high area of winter wheat and low area of barley (Table 3.6). The second axis accounted for 10% of variation in the data and was dominated by two variables which are recent introductions to agricultural management, set-aside and linseed. Variation in the trends represented by axis 1 over time are shown by plotting DCA scores against year (Fig. 3.22). This shows that scores increase most rapidly between 1970 and 1988, the period when variables with the greatest effect on the axis were changing the most i.e. these variables showed the greatest change in category within this period. Periods of relative stability occurred from 1962 to 1970 and 1988 to 1995, indicating periods of little change, especially in variables with most influence on the axis.

The above analysis is fairly simple in that it uses categorical data based on ranks and has some variables (mostly pesticide data) where many values were estimated. A further, more rigorous analysis using actual data was performed using PCA, considering only variables with a continuous run of smoothed data values and a maximum of two interpolated values from 1974 to 1991 (Table 3.7). The first axis explained 76.1% of variation in the data and represented a gradient from variables which had shown rapid rises in more recent years, especially wheat, oilseed rape, sheep numbers, silage production and artificial fertilizer application, to variables which had shown a rapid decrease over the same period such as spring barley, rough grazing, hay production and root crops (Table 3.7). The second axis explained 11.4% of variation in the data and was harder to interpret, but was dominated by sugar beet area and slurry application rates which have shown fairly steady rates of change over time. Other axes had eigenvalues of less than 5% and were not considered further. A plot of axis 1 against year revealed very similar patterns to that shown for DCA axis scores, with the period of greatest change between 1975 and 1986 for those variables having the greatest influence on the gradient (Fig. 3.23). However, periods of stability were less evident as this data set was curtailed at either end relative to the DCA analysis.

3.4 Discussion

There have been major changes in the management of farmland over the last 30 years. Wheat and oilseed rape in particular have shown substantial increases, whereas barley (especially spring-sown barley), bare fallow and fodder roots have declined. These changes have not been consistent across England and Wales, but show marked regional variation, with grassland replacing arable crops in north and west regions, and arable replacing grass in south and east regions. This has resulted in a loss of mixed farming and consequently a decrease in habitat diversity in grass-dominated regions. Livestock numbers have tended to increase in Wales (sheep) and south-west England (cattle), but decrease in central and eastern England.

A number of agricultural variables have shown similar spatial and temporal changes. For example, wheat and oilseed rape tended to increase and barley tended to decrease by similar relative amounts in the same 10 km squares. Also, a number of variables showed the same

[1]Data on fertilizer on grass could not be included in the final analysis, so only 31 variables were used for the DCA. However, as this variable was strongly correlated with fertilizer on tillage and a number of other variables (Appendix 3.1), it is unlikely that its omission will have any significant effect on the ordination axis.

periods of most rapid annual change and consequently there was a high degree of inter-correlation (Appendix 3.1). These consistent trends enabled ordination analyses to produce axes of environmental variation which were good summaries of the major overall changes in agricultural management. Spatially, the main axis of variation was from 10 km squares in East Yorkshire, south through Lincolnshire and the east midlands to the northern Home Counties, to 10 km squares in the west of Wales and south-west England, representing a gradient of increasingly arable 10 km squares, to 10 km squares which are almost wholly grassland. This axis is therefore a good index of the polarization of farmland into predominantly arable and pastoral regions. For annual changes at a national scale, a period of change was identified between 1970 and 1988. A number of different factors, including crop types and chemical inputs, were identified as showing similar trends, and so annual axis scores are likely to be a good general index of agricultural intensification. This axis was characterized by increases in pesticide and fertilizer use, winter-sown barley, oilseed rape and silage production, and by decreases in spring-sown barley, oats, root crops and rough grazing.

A large number of variables were considered in these analyses, but there were still some notable omissions. In the spatial analysis, there was little information on grass management, a fact exacerbated by the change in definition of new and permanent grass between 1969 and 1988. Changes in the area of grazing and the intensity of grass management (e.g. grass cut for silage or hay) are likely to be important factors for ground nesting species such as Skylark, Lapwing (Shrubb 1990) and possibly Yellow Wagtail, and the omission of this data may provide potential bias in any bird-habitat relationships at the 10 km scale. Estimates of grassland management were made using annual agricultural statistics, although in some cases these were indirect measures (e.g. silage production, which is dependent not just on the area of grass cut for silage, but also on fertilizer applications). There was no spatial data on the change in spring and autumn-sown cereals. Again, this was due to the recording of the June Census, the timing of sowing for barley only being recorded from 1977 onwards. Conversely, recording of grass and clover leys in rotation separately from new grass was carried out in 1969 but not 1988, although this in itself is indicative of habitat change, with leys being so scarce as not to warrant inclusion in the later census. Annual estimates of spring and autumn cereal areas were made, although there was little data in the early 1970s, a crucial period of change. Sowing regimes are likely to be important as they tend to be associated with the presence of stubbles, an important habitat for a number of bird species outside the breeding season (Wilson *et al.* 1996), and spring cereals provide an important nesting habitat for Skylarks, particularly later in the breeding season (Wilson *et al.* 1997). Crop rotations including grass leys tend to be associated with greater habitat diversity which is likely to increase Skylark density (Chamberlain & Gregory 1999), and possibly the density of a number of other species.

Generally, changes in cropping and annual changes in pesticide and fertilizer use were fairly well covered by the data, with perhaps more detail for variables associated with arable farming. Whilst most variables associated with crop and grass management having potential effects on bird populations (see Section 2) have been measured in some way, there was no adequate data available on abundance and quality of non-crop habitats, particularly hedgerows, which are a major feature affecting the farmland bird community (O'Connor & Shrubb 1986; see Section 2), or the level of urbanization.

Subsequent analyses will use both individual variables and ordination axes defined in this section to identify which spatial and temporal changes in agriculture most closely fit changes in bird distribution and abundance. These relationships may give an insight into key changes in agriculture affecting bird populations. In this context, however, three general points must be made. Firstly, the strong multi-collinearity with the variables measuring agricultural change (Appendix 3.1) indicate that many aspects of agriculture have changed more-or-less simultaneously. Therefore, the identification of single or particular factors is problematic. Secondly, such analyses of spatial and temporal relationships cannot be regarded as strong evidence of cause and effect; indeed, this problem is exacerbated by the multi-collinearity in the agricultural variables. Thirdly, as acknowledged above, some potentially important variables are missing from the data available to us.

3.5 Summary

1. This section uses all available data to summarise the spatial and temporal trends that have occurred in agricultural management in England and Wales for the period 1962 to 1996. These data are used in subsequent sections to relate changes in bird distribution and bird abundance to changes in agriculture.

2. Using MAFF June Census data, two broad agricultural regions were defined, based on counties: predominantly arable and predominantly non-arable. The latter region was subdivided into predominantly pastoral and mixed farmland.

3. The geographical patterns of change in 15 agricultural variables were examined at a 10 km square scale using data derived from the MAFF June Census for 1969 and 1988. The patterns are presented separately for each variable. Many of these variables showed extremely uneven geographical patterns of change. To gain a measure of overall spatial change in agriculture, Principal Components Analysis (PCA) was applied to the 15 variables. This identified that the major gradient of change concerned cropping patterns, involving large increases in wheat and oilseed rape at the expense of barley, bare fallow and grass. There is a distinct region in eastern England that has shown this pattern of change, extending from Lincolnshire into the southern Midlands, the Home Counties and into parts of East Anglia.

4. Changes in the diversity of crop and grassland habitats between 1969 and 1988 were geographically uneven. Marked decreases in diversity were evident in the English Midlands, the Welsh borders, Kent and parts of East Anglia.

5. Temporal changes in agriculture were examined quantitatively for 31 variables representing crop areas, livestock numbers, fertiliser application, grass production and pesticide usage. Some crops have increased substantially (e.g. wheat, oilseed rape) while others have decreased (e.g. barley, bare fallow, fodder roots). As indicated above, these changes have not taken place uniformly across England and Wales. There has been a general reduction in mixed farming, with grassland tending to replace arable in the west and north while arable has tended to replace grass in the south and east.

6. Many individual agricultural variables are strongly inter-correlated, making it difficult to interpret relationships between single variables and bird populations. The overall

temporal change in agriculture was measured using an ordination technique applied to the 31 variables for each year from 1962 to 1995. This showed that the period 1970 to 1988 was the main period of intensification. Agriculture during the periods pre-1970 and post 1988 was relatively stable.

Definition	Units
Wheat	difference in hectares (1988-1969)
Barley	"
Oilseed rape	"
Orchards and small fruit	"
Potatoes	"
Sugar beet	"
Other root vegetables	"
Other vegetables	"
Bare fallow	"
Total area of improved grassland	"
Rough grazing	"
Total tillage	"
All agricultural land	"
Cattle	difference in number of animals (1988-1969)
Sheep	"

Table 3.1 Definitions of variables of agricultural land use change used in analysing spatial changes at the 10 km square level. These data are adapted from the Parish Summaries of the MAFF Agricultural June Census and were provided by the University of Edinburgh Data Library.

Arable-east counties	Mixed-south counties	Pastoral-west counties
Bedfordshire	Avon	Cheshire
Cambridgeshire	Berkshire	Cleveland
Essex	Buckinghamshire	Cornwall
Hertfordshire	Derbyshire	Cumbria
Humberside/E. Yorks	Dorset	Devon
Lincolnshire	Gloucestershire	Durham
Norfolk	Greater London	Lancashire
Northamptonshire	Hampshire	Northumberland
Nottinghamshire	Herefordshire	North Yorkshire
Suffolk	Isle of Wight	South Yorkshire
	Kent	West Yorkshire
	Leicestershire	All Wales
	Oxfordshire	
	Somerset	
	Staffordshire	
	Surrey	
	Sussex	
	Warwickshire	
	West Midlands	
	Wiltshire	
	Worcestershire	

Table 3.2 Counties of England and Wales divided into regions of arable and non-arable agriculture, based on the ratio of arable to grass area. For further explanation see text.

Variable	Years available	Source	Units
Bare fallow	1962-92	MAFF[1]	area
Barley (total)	1962-92	MAFF[1]	area
Barley (autumn-sown)	1962, 67, 69, 74-92, 94	MAFF[1]	area
Barley (spring-sown)	1962, 67, 69, 74-92, 94	MAFF[1]	area
Cattle	1977-86, 88	MAFF[1]	total cattle+calves
Fertilizer application (tillage)	1970-94	ITE	kg/ha
Fertilizer application (grass)	1962-94	ITE	kg/ha
Grass production†	1970-89	ITE	tonnes dry matter
Permanent grass (>5 years old)	1962-92	MAFF[1]	area
Hay production†	1970-89	ITE	tonnes dry matter
New grass (<5 years old)	1962-92	MAFF[1]	area
Linseed†	1989-95	MAFF[1]	area
Oats	1962-92 (not 88)	MAFF[1]	area
Oilseed rape	1962-92	MAFF[1]	area
Rough grazing	1962-92	MAFF[1]	area
Set-aside†	1989-95	MAFF[1]	area
Sheep	1969, 77-92 (not 88)	MAFF[1]	total ewes+lambs
Silage production†	1970-89	ITE	tonnes
Slurry application	1969-91, 93 (not 86)	ADAS	area
Potato	1962-92	MAFF[1]	area
Sugar beet	1962-92	MAFF[1]	area
Total tilled land	1962-92	MAFF[1]	area
Turnip and swede	1962-92	MAFF[1]	area
Wheat (total)	1962-92	MAFF[1]	area
Wheat (autumn-sown)	1962, 67, 69, 74, 78, 82 , 87, 94	MAFF[1]	area
Wheat (spring-sown)	1962, 67, 69, 74, 78, 82 , 87, 94	MAFF[1]	area
Fungicides (total)	1974, 77, 82, 88, 90, 92, 94	MAFF[2]	spray hectares
Herbicides (total)	1974, 77, 82, 88, 90, 92, 94	MAFF[2]	spray hectares
Herbicides on cereals (pre-emergent)†	1960, 65, 70, 75, 80, 85	O&S	no. of chemicals
Herbicides on cereals (post-emergent)†	1960, 65, 70, 75, 80, 85	O&S	no. of chemicals
Insecticides (total)	1974, 77, 82, 88, 90, 92, 94	MAFF[2]	spray hectares
Seed dressings on cereals	1974, 77, 82, 88, 90, 92, 94	MAFF[2]	spray hectares

Table 3.3 Agricultural variables considered in the analyses of annual changes. Data are for England and Wales unless stated. Sources: MAFF[1] June Census Data; MAFF[2] Pesticide Usage Survey Reports (e.g. Thomas 1997); ITE review of agricultural management (Wilkinson 1996); ADAS British Survey of Fertilizer Practice; O&S, O'Connor and Shrubb (1986). †Data for all UK only.

Agricultural variable	PRIN1	PRIN2	PRIN3
Barley	+0.34	0.23	-0.12
Improved grassland	+0.32	-0.03	0.48
Bare fallow	+0.30	0.12	-0.11
Sheep	+0.27	-0.03	0.15
Cattle	+0.24	0.15	0.35
Potatoes	+0.16	0.33	-0.37
Root crops	+0.02	-0.08	0.18
Sugar beet	+0.01	0.46	-0.18
Orchards and small fruit	+0.02	0.07	-0.10
Total agricultural land	0.00	0.55	0.52
Rough grazing	0.24	0.30	-0.08
Vegetables	0.28	0.05	0.21
Total tilled land	0.33	0.42	-0.06
Oilseed rape	0.38	-0.09	0.13
Wheat	0.39	-0.01	0.20
Variance explained	34.7	11.3	9.5

Table 3.4 Principal Components Analysis on the change in area of various agricultural land use types per 10 km square between 1969 and 1988, considering squares with a minimum farmland area of 5,000 ha (n=1089). The eigenvectors of the variables from each of the first three axes (PRIN1-3), in order of the first axis, and the proportion of variation explained by each axis, are presented.

Agricultural variable	Arable-east			Mixed-south			Pastoral-west		
	PRIN1	PRIN2	PRIN3	PRIN1	PRIN2	PRIN3	PRIN1	PRIN2	PRIN3
Improved grassland	+0.34	0.11	0.44	+0.36	0.00	0.36	+0.31	-0.01	0.40
Bare fallow	+0.32	0.14	0.05	+0.30	0.10	-0.15	+0.34	-0.04	-0.18
Barley	+0.28	0.25	-0.19	+0.32	0.31	-0.16	+0.29	0.19	-0.09
Cattle	+0.21	0.22	0.37	+0.22	0.18	-0.13	+0.20	0.30	0.13
Sugar beet	+0.15	0.41	-0.30	+0.02	0.41	-0.08	0.22	0.12	0.28
Sheep	+0.10	0.08	0.12	+0.27	-0.02	0.44	+0.18	-0.20	0.30
Root crops	+0.02	-0.11	0.24	0.04	0.04	0.33	+0.17	0.18	0.17
Potatoes	0.01	0.18	-0.42	+0.08	0.46	0.01	+0.27	-0.09	-0.25
Vegetables	0.12	0.17	0.19	0.30	0.11	0.25	0.28	-0.18	0.04
Total agricultural land	0.15	0.59	0.19	+0.06	0.48	0.44	+0.04	0.47	0.49
Rough grazing	0.18	0.15	0.27	0.22	0.26	-0.33	0.18	0.56	-0.09
Orchard and small fruit	0.19	0.09	-0.28	+0.02	0.02	0.01	0.04	0.17	0.47
Total tilled land	0.35	0.46	-0.06	0.34	0.41	-0.07	0.29	0.43	-0.17
Wheat	0.44	0.03	0.25	0.39	0.03	0.30	0.38	0.02	0.06
Oilseed rape	0.45	-0.14	0.08	0.38	-0.02	0.20	0.38	0.06	0.14
Variance explained	23.6	15.0	13.6	27.6	13.4	10.0	39.8	11.3	11.1

Table 3.5 Principal Components Analysis on the change in area of various agricultural land use types per 10 km square between 1969 and 1988 in arable and non-arable regions, considering squares with a minimum farmland area of 5,000 ha. The eigenvectors of the variables from each of the first three axes (PRIN1-3), in order of the first axis in arable-east counties, and the proportion of variation explained by each axis, are presented. Sample sizes: arable-east=298 squares, mixed-south=512 squares, pastoral-west=279 squares.

Variable	DCA score
L grass	-0.76
L post-emergent herbicide	-0.75
L winter barley	-0.66
L winter wheat	-0.66
H spring wheat	-0.66
H rough grazing	-0.52
H oats	-0.52
H hay production	-0.52
L grass production	-0.52
L sugar beet	-0.52
L pre-emergent herbicide	-0.50
L fertilizer application	-0.42
L slurry application	-0.26
L sheep numbers	-0.20
L seed dressing	0.29
H grass production	5.66
H insecticide	5.66
H silage production	5.66
L potatoes	5.66
H set-aside	5.71
H linseed	5.71
L total barley	5.82
L ley grass	5.82
H total wheat	5.82
M set-aside	5.86
H fungicide	5.88
L cattle numbers	5.89
H oilseed rape	5.89
M linseed	5.94
L linseed	6.05
L set-aside	6.05

Table 3.6 Analysis of temporal change in agriculture by Detrended Correspondence Analysis scores of agricultural variables, showing only the 15 highest and lowest ranked variables on axis 1. Each variable has high, medium or low categories and has the prefixes **H**, **M** or **L** respectively. A total of 93 variables (31 variables each with high, medium and low categories) were considered in the analysis.

Variable	Axis 1	Axis 2
Silage production	-0.26	-0.08
Wheat area	-0.26	0.01
Oilseed rape area	-0.25	-0.12
Fertilizer (tillage)	-0.25	0.14
Sheep numbers	-0.25	-0.12
Fertilizer (grass)	-0.23	0.25
Winter barley area	-0.23	0.29
Slurry application	-0.01	0.59
Sugar beet	0.07	0.52
Bare fallow	0.18	-0.01
Permanent grass	0.19	-0.07
Total barley area	0.23	0.29
Oat area	0.24	-0.17
New grass area	0.24	0.10
Potato area	0.24	-0.05
Rough grazing area	0.25	-0.15
Hay production	0.25	0.03
Turnip area	0.26	0.15
Spring barley area	0.26	0.04

Table 3.7 PCA scores of smoothed annual agricultural variables between 1974 and 1991. Only data with a run of several years of annual data and a minimum of two interpolated values were used (see text).

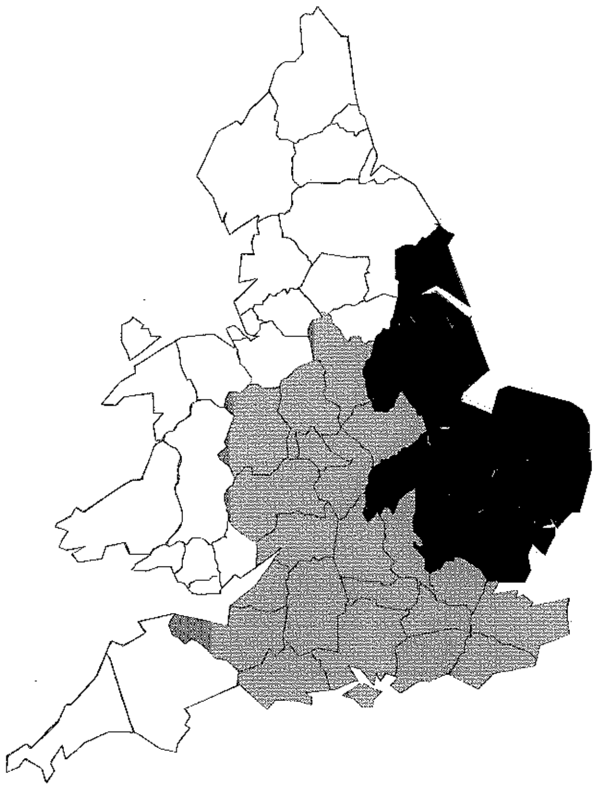

Figure 3.1 The distribution of 'arable-east' counties (black), 'mixed-south' counties (shaded) and 'pastoral-west' counties in England and Wales.

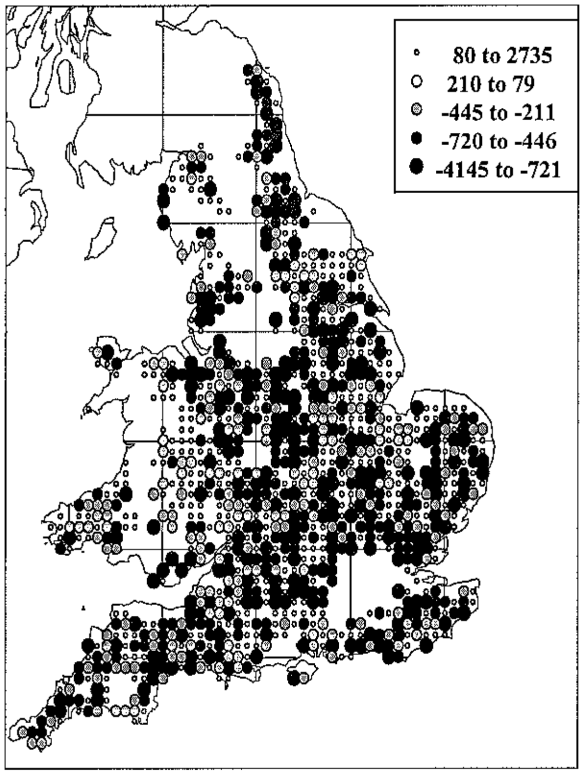

Figure 3.2 Change in the total area (ha) of farmland between 1969 and 1988 in 10 km squares in England and Wales with a minimum original (i.e. 1969) area of 5000 ha of farmland. Data have been ranked and placed into five groups of equal sample size.

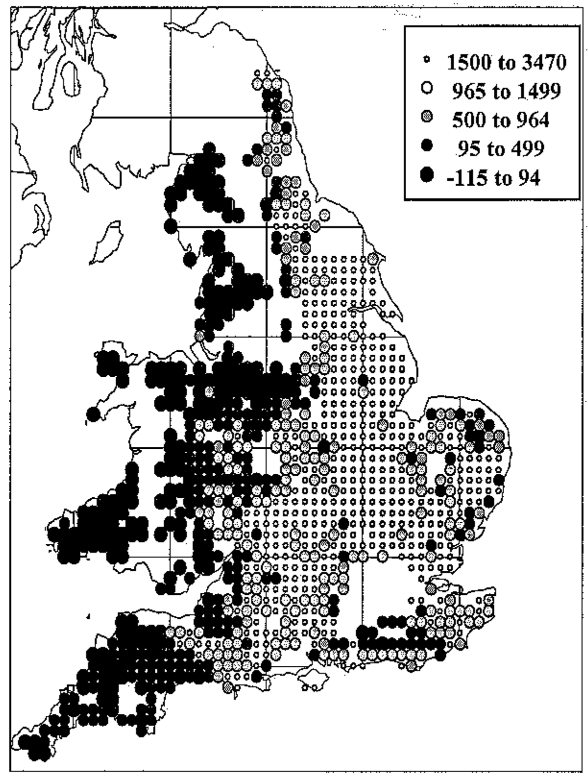

Figure 3.3 Change in the total area (ha) of wheat between 1969 and 1988 in lowland farmland 10 km squares in England and Wales.

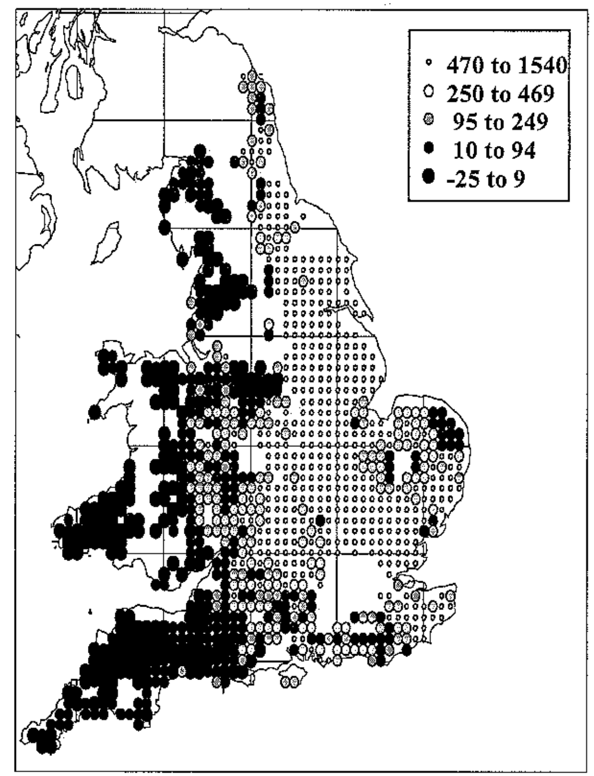

Figure 3.4 Change in the total area (ha) of oilseed rape between 1969 and 1988 in lowland farmland 10 km squares in England and Wales.

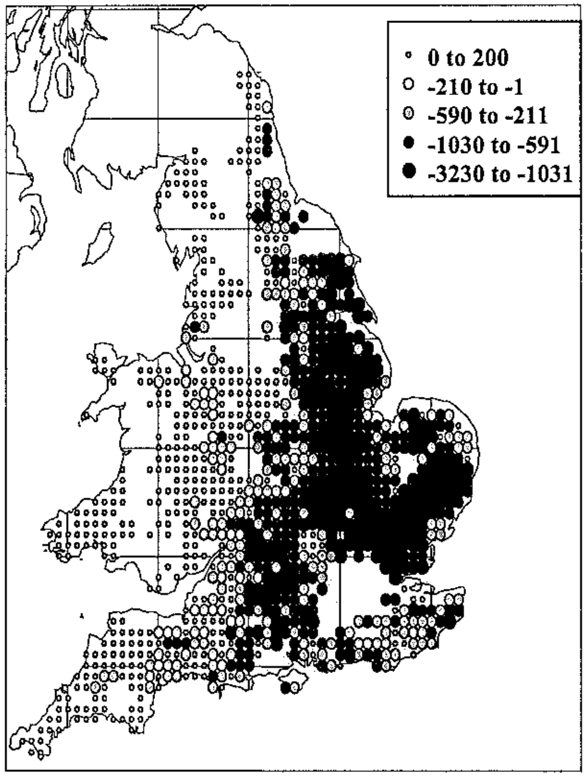

Figure 3.5 Change in the total area (ha) of barley between 1969 and 1988 in lowland farmland 10 km squares in England and Wales.

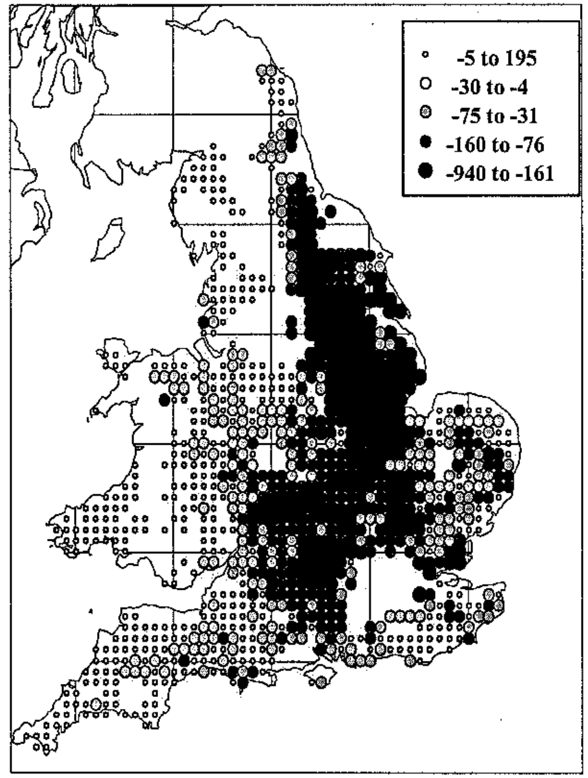

Figure 3.6 Change in the total area (ha) of bare fallow between 1969 and 1988 in lowland farmland 10 km squares in England and Wales.

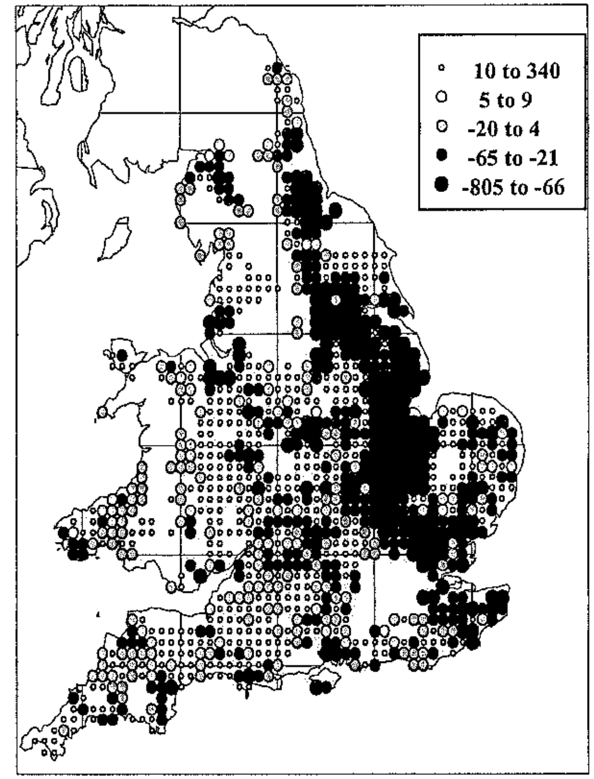

Figure 3.7 Change in the total area (ha) of potatoes between 1969 and 1988 in lowland farmland 10 km squares in England and Wales.

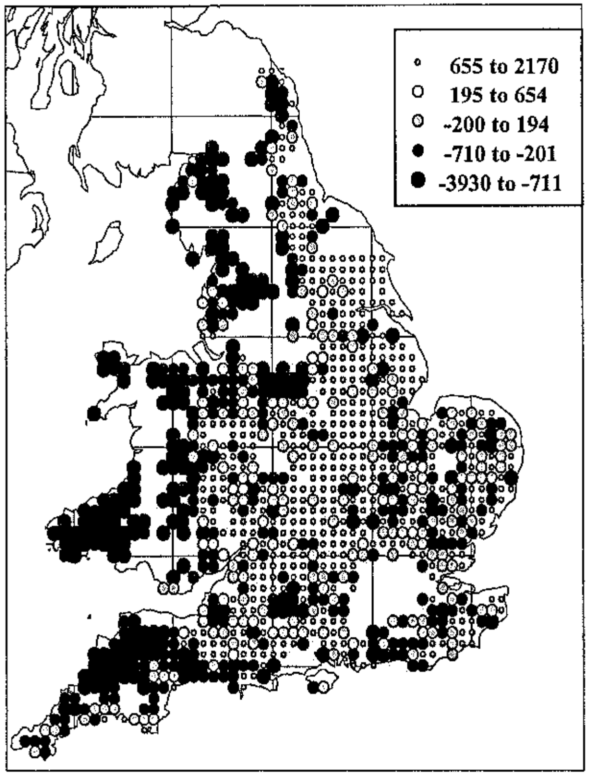

Figure 3.11 Change in the total area (ha) of tilled land between 1969 and 1988 in lowland farmland 10 km squares in England and Wales.

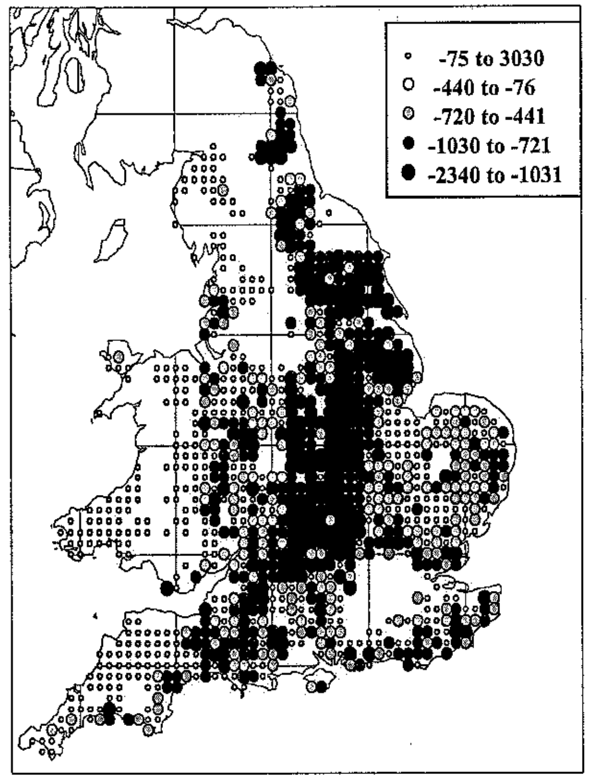

Figure 3.12 Change in the total area (ha) of improved grassland between 1969 and 1988 in lowland farmland 10 km squares in England and Wales.

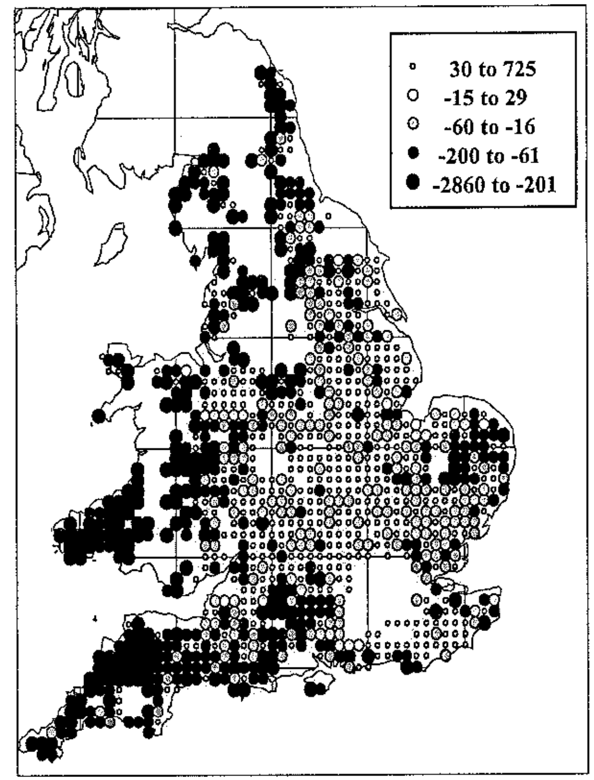

Figure 3.13 Change in the total area (ha) of rough grazing land between 1969 and 1988 in lowland farmland 10 km squares in England and Wales.

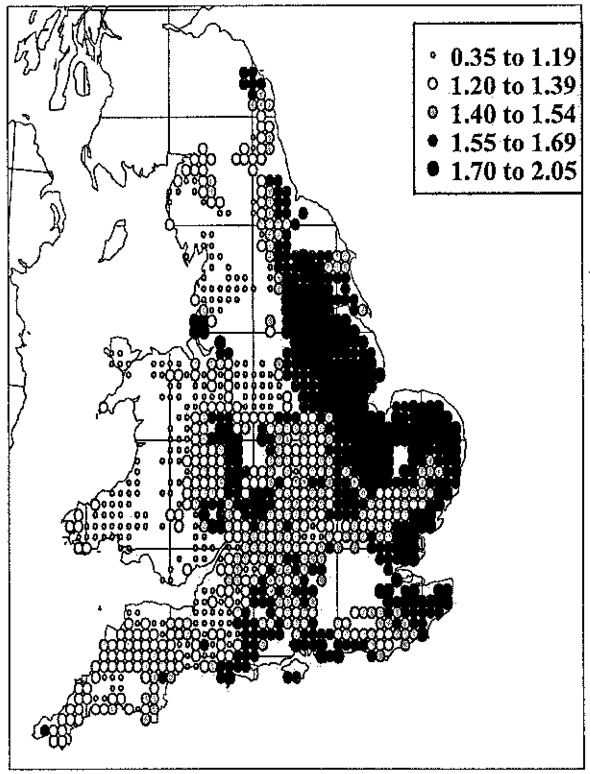

Figure 3.17a Habitat diversity in 1969.

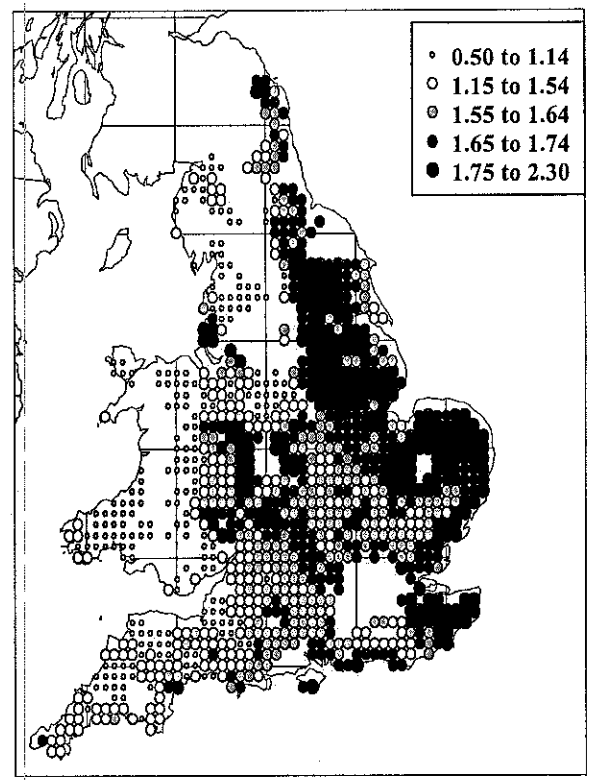

Figure 3.17b Habitat diversity in 1988.

Figure 3.17 The diversity of crops and grassland habitats per 10 km square in England and Wales, expressed as a Shannon index. (a) Habitat diversity in 1969; (b) habitat diversity in 1988.

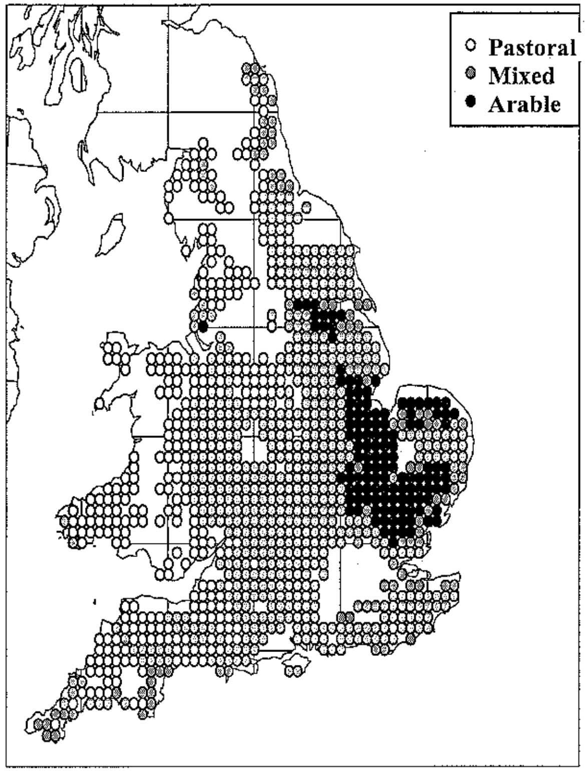

Figure 3.19a Predominant farm type in 1969.

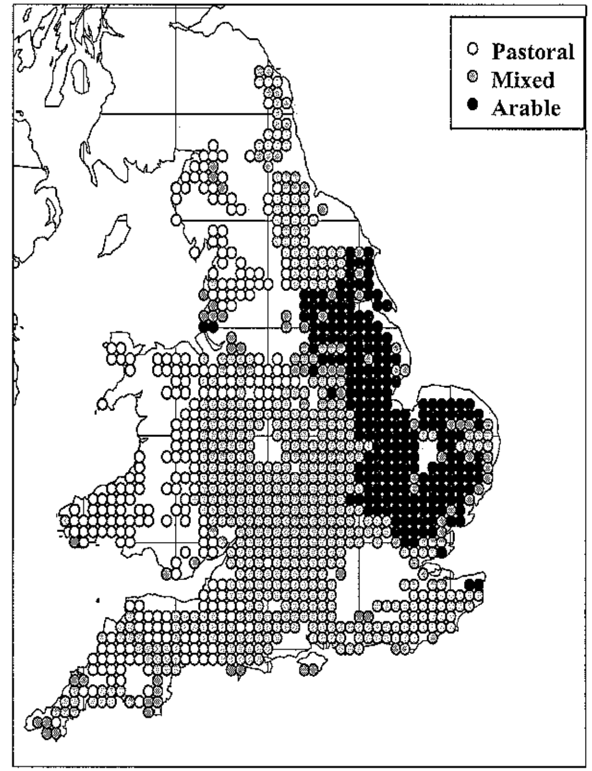

Figure 3.19b Predominant farm type in 1988.

Figure 3.19 The distribution of predominantly arable, mixed and pastoral farmland 10 km squares in England and Wales in (a) 1969 and (b) 1988.

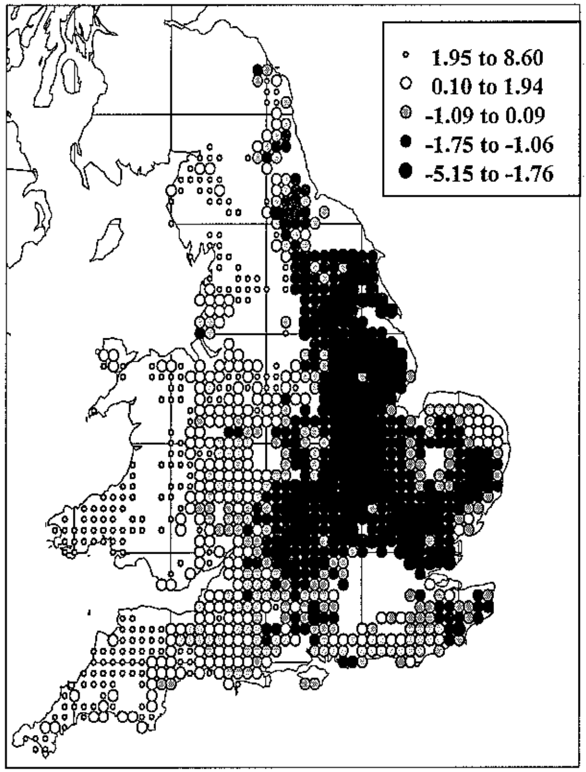

Figure 3.20a First PCA axis.

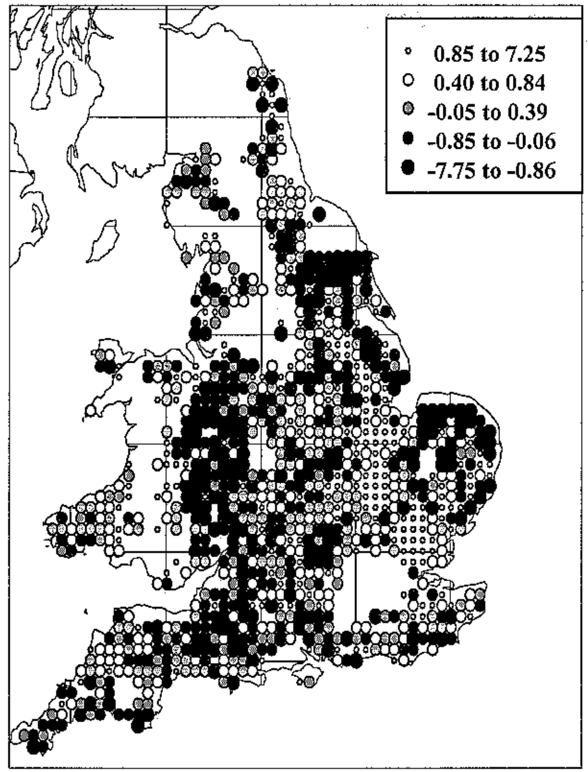

Figure 3.20b Second PCA axis.

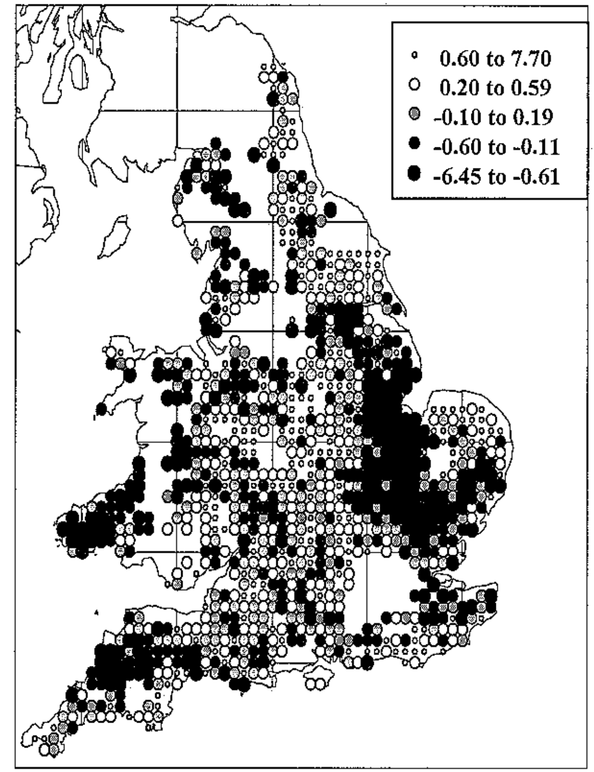

Figure 3.20c Third PCA axis.

Figure 3.20 PCA scores for 10 km squares for lowland farmland in England and Wales for the first three principal axes. Scores have been ranked into five groups of equal sample size

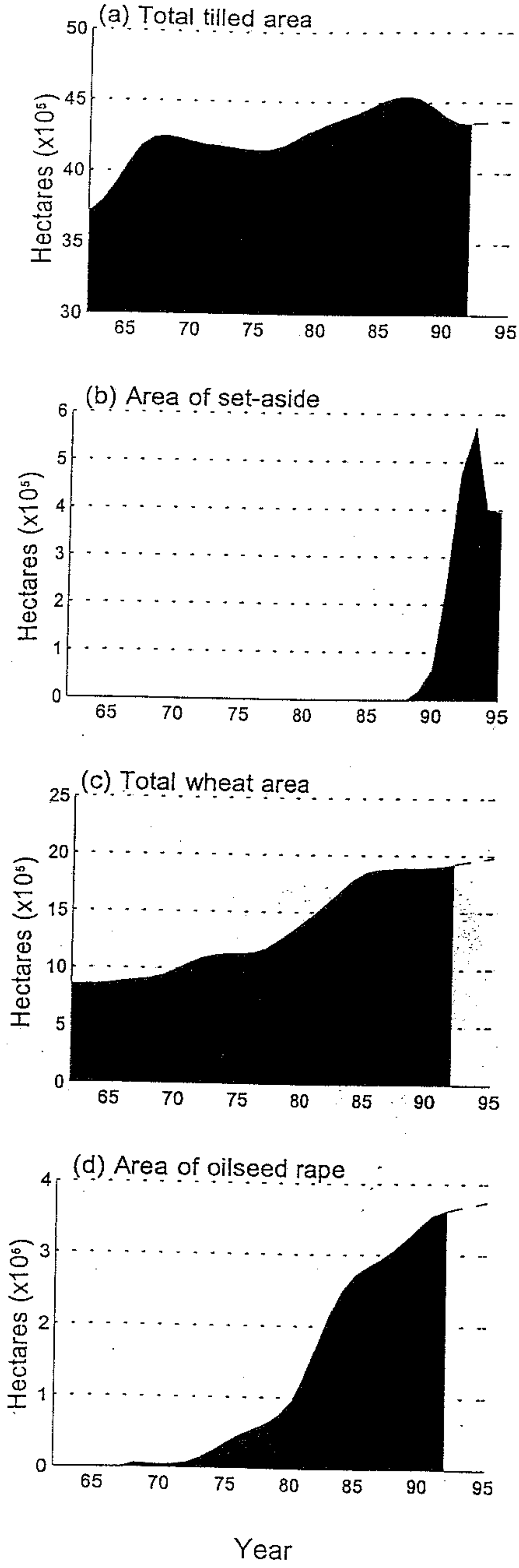

Figure 3.21 Annual trends in agricultural management variables for the whole of England and Wales or the whole UK (see Table 3.3). Variables with continuous runs of annual data have been smoothed to reveal underlying trends.

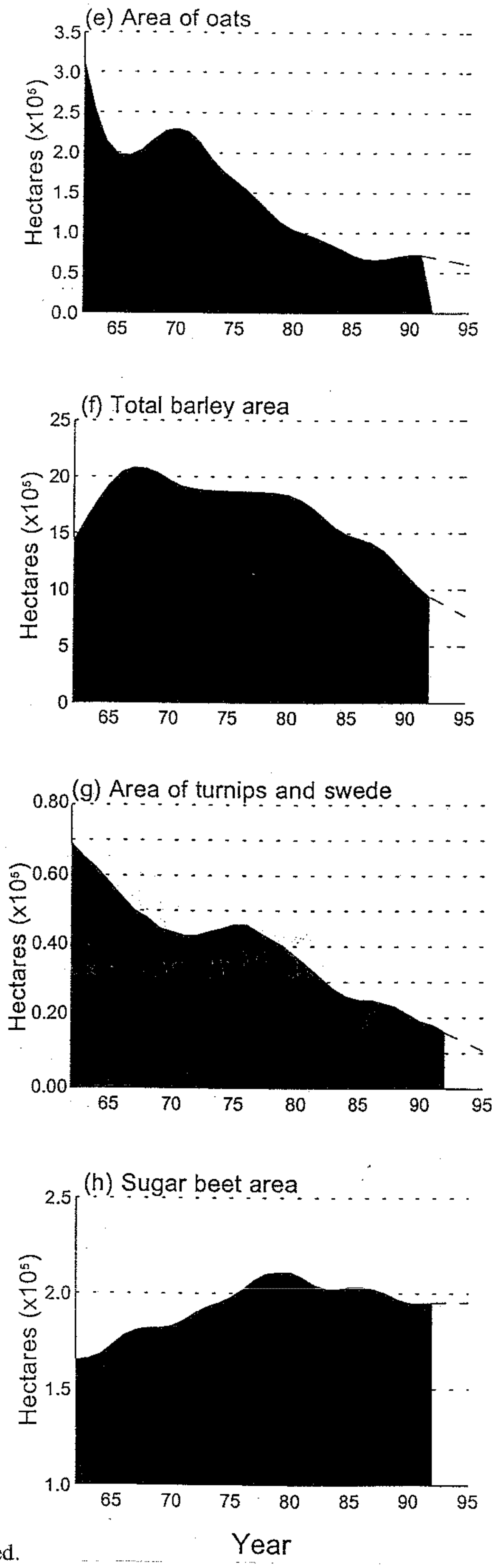

Figure 3.21 Continued.

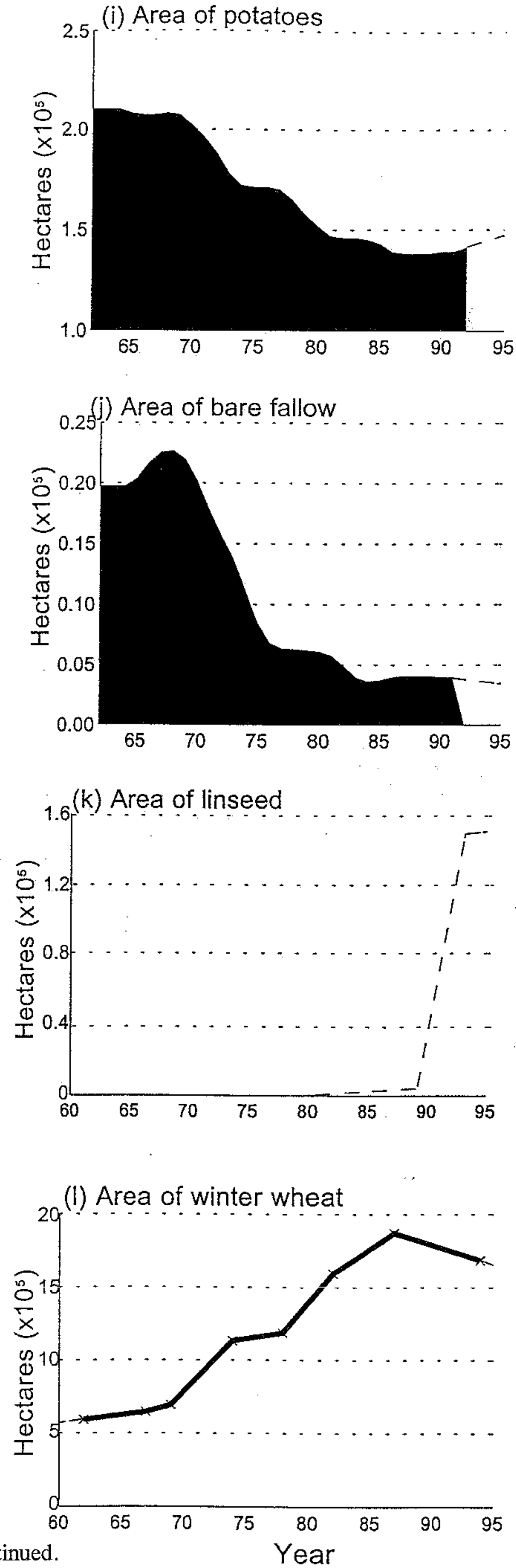

Figure 3.21 Continued.

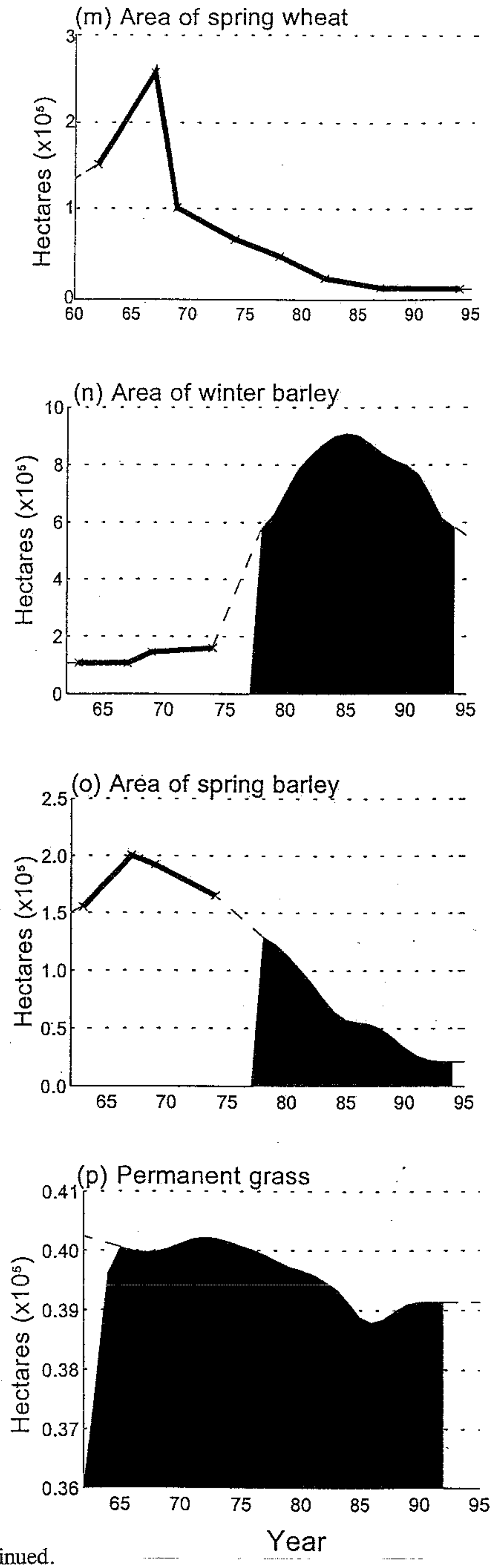

Figure 3.21 Continued.

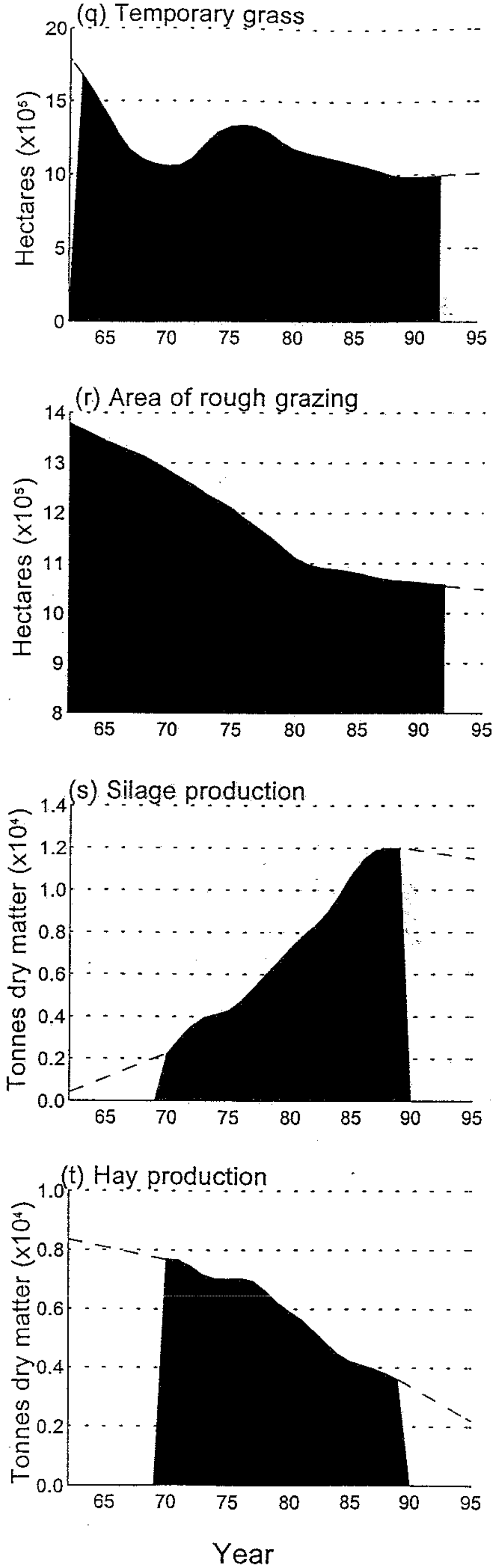

Figure 3.21 Continued.

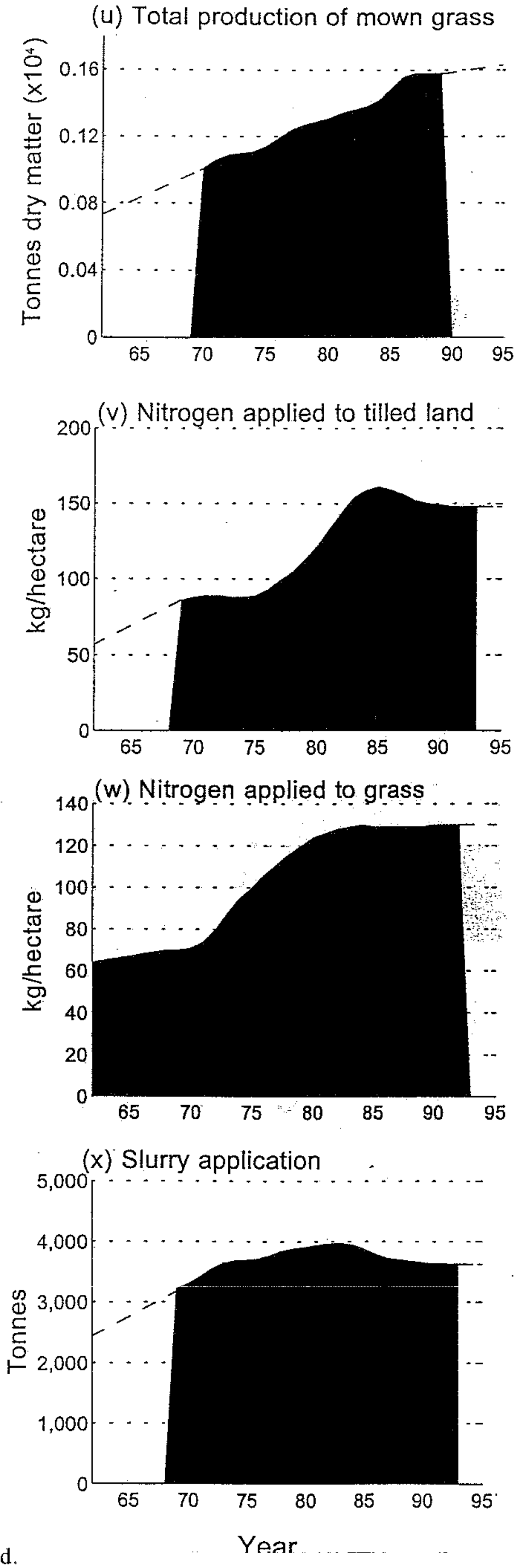

Figure 3.21 Continued.

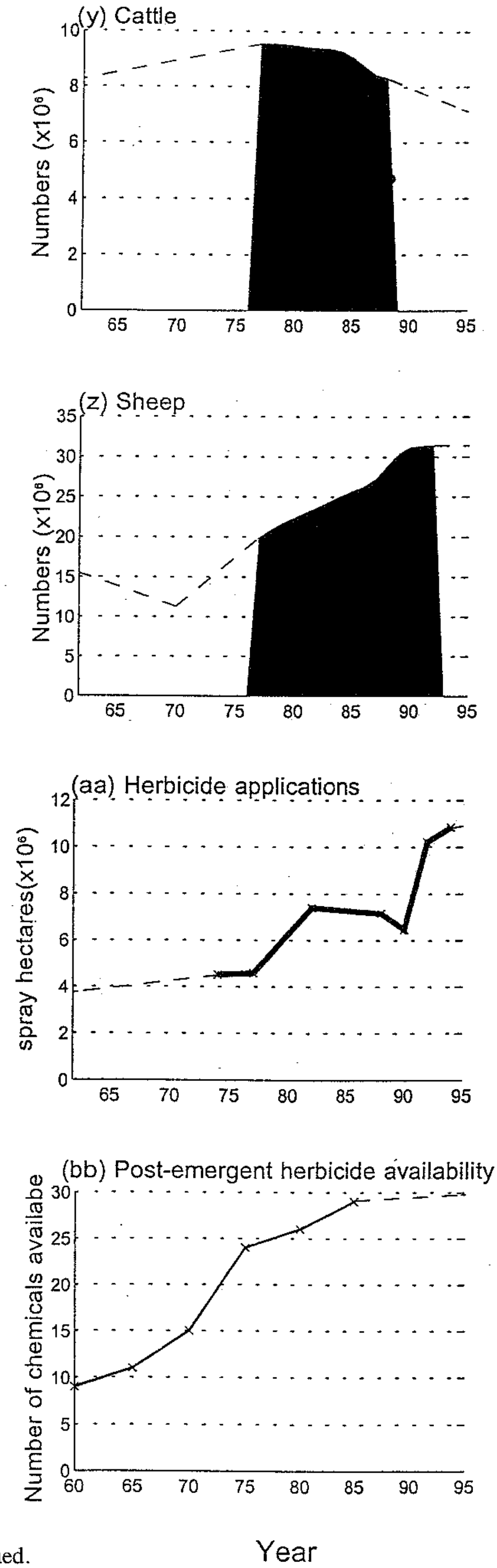

Figure 3.21 Continued.

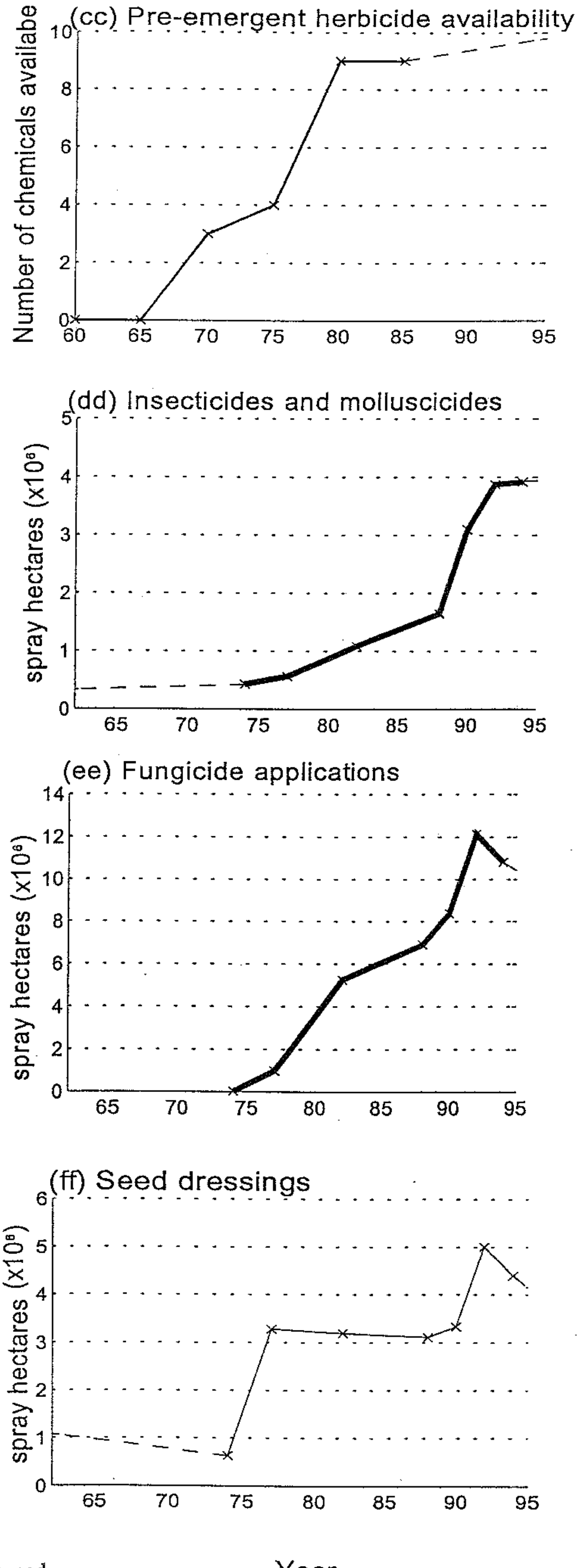

Figure 3.21 Continued.

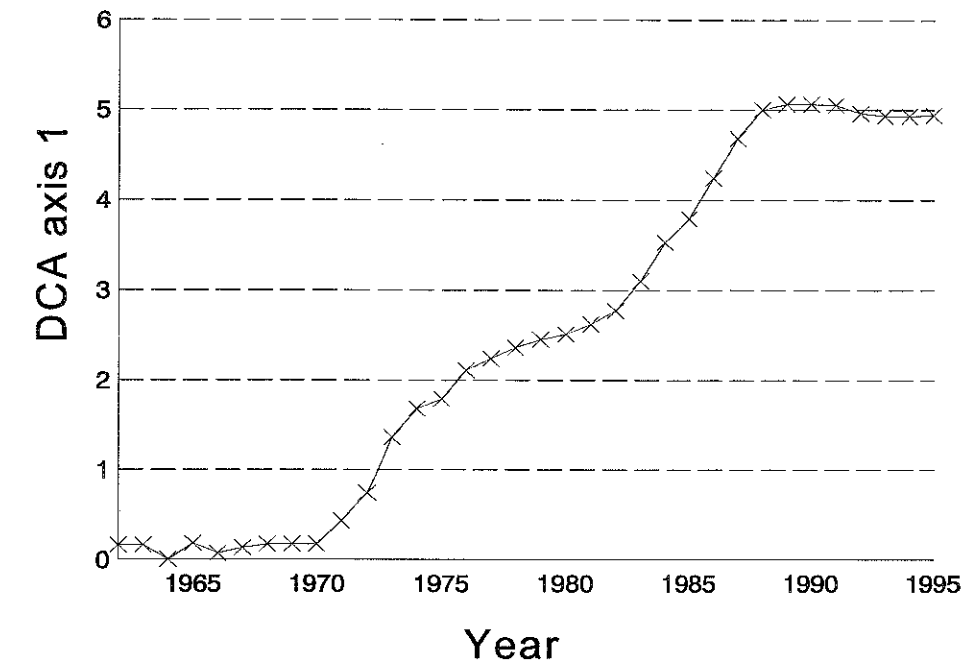

Figure 3.22 Annual scores from the first axis of Detrended Correspondence Analysis of agricultural variables grouped into high, medium and low categories based on Fig. 3.21.

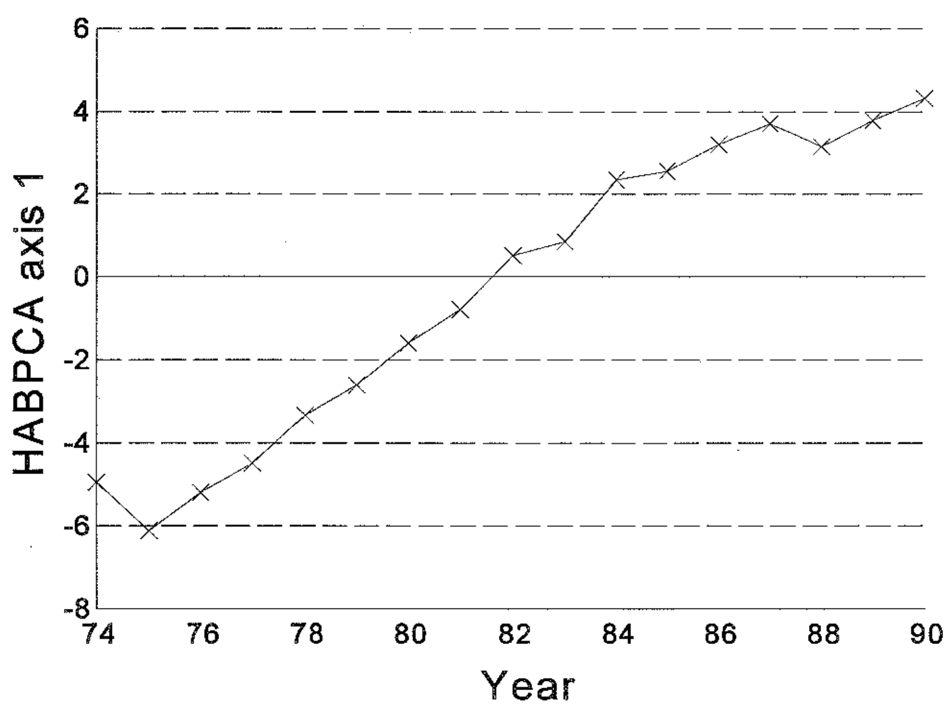

Figure 3.23 Annual scores from the first axis of Principal Components Analysis of agricultural variables, considering the 18 most accurately measured variables (Table 3.7).

APPENDIX 3.1 Correlation Matrices of Agricultural Variables

	Barley	Bare fallow	Cattle	Grass	Oilseed rape	Orchards/fruit	Potatoes	Root crops	Rough grazing	Sheep	Sugar beet
Area (farmland)	+++	ns	+++	+++	ns	ns	++	ns	+++	+++	+++
Barley		+++	+++	+++	---	ns	+++	ns	---	+++	+++
Bare fallow			+++	+++	---	ns	+++	ns	---	+++	ns
Cattle				+++	---	ns	+	++	---	+++	ns
Grass					---	ns	ns	ns	---	+++	ns
Oilseed rape						ns	---	-	+++	---	---
Orchards/fruit							++	-	---	++	ns
Potatoes								ns	---	+++	+++
Root crops									ns	---	---
Rough grazing										---	ns
Sheep											-

Table A3.1 Correlation matrix of agricultural change variables per 10 km square. Variable definitions are given in Table 3.1. Additionally, original (1969) habitat diversity, change in habitat diversity, PCA axes of agricultural change (Table 3.4), the original area of agricultural land, woodland and urban/suburban area (derived from the ITE Land Cover Map, Fuller & Parsell 1990), and altitude (derived from ITE Land Characteristics data, Ball *et al.* 1983) are included. Signs indicate direction of relationships. +/- $P<0.05$, ++/-- $P<0.01$, +++/--- $P<0.001$ (Pearson correlation coefficient). 1089 10 km squares were used in each correlation.

	Tillage	Vegetables	Wheat	PRIN1	PRIN2	PRIN3	Habitat diversity	Original diversity	Altitude	Original area	Suburban	Woodland
Area (farmland)	+++	+++	+++	ns	+++	+++	-	ns	++	ns	---	ns
Barley	---	---	---	---	+++	---	---	---	+++	---	---	+++
Bare fallow	---	---	---	---	+++	--	ns	---	+++	---	---	+++
Cattle	---	---	---	---	+++	+++	---	---	+++	++	---	++
Grass	---	---	---	---	ns	+++	---	---	+++	ns	---	+++
Oilseed rape	+++	+++	+++	+++	---	+++	+++	+++	---	+++	+++	---
Orchards/fruit	ns	ns	ns	ns	++	---	ns	---	+++	ns	ns	+
Potatoes	ns	---	---	---	+++	---	+++	---	+++	---	---	+++
Root crops	ns	ns	-	ns	---	+++	+++	--	-	---	ns	ns
Rough grazing	+++	+++	+++	+++	+++	-	+++	+++	---	---	+++	---
Sheep	---	---	---	+++	ns	+++	---	+++	---	---	+++	---
Sugar beet	+++	ns	-	ns	+++	---	++	+++	---	ns	ns	ns
Tillage		+++	+++	+++	+++	-	+++	+++	---	ns	+++	---
Vegetables			+++	+++	+	+++	+++	+++	---	+++	ns	---
Wheat				+++	ns	+++	+++	+++	---	+++	+++	---

Table A3.1 Continued.

	PRIN2	PRIN3	Habitat diversity	Original diversity	Altitude	Original area	Suburban	Woodland
PRIN1	ns	ns	+++	+++	---	+++	+++	---
PRIN2		ns	+++	---	ns	--	-	ns
PRIN3			---	ns	ns	+++	---	ns
Habitat diversity				+	---	ns	+++	---
Original diversity					---	--	+++	---
Altitude						+	---	+++
Original area							---	---
Suburban								---

Table A3.1 Continued.

	Barley	Fertilizer (tillage)	Fertilizer (grass)	Permanent grass	New grass	Hay	Oats	Oilseed rape	Potatoes
Bare fallow	+++	---	--	+++	+	+++	++	---	++
Barley		---	---	++	+++	+++	+++	---	+++
Fertilizer (tillage)			+++	---	---	---	---	+++	---
Fertilizer (grass)				-	ns	---	---	+++	---
Permanent grass					++	+++	+	---	+
New grass						+++	ns	---	+
Hay							+++	---	+++
Oats								---	+++
Oilseed rape									---

Table A3.2 Correlation matrix of annual agricultural variables (defined in Table 3.3). Sample size = 20 for each correlation. +/- P<0.05, ++/--P<0.01, +++/---P<0.001 (Pearson correlation coefficient).

	Rough grazing	Root crops	Spring barley	Sheep	Silage	Slurry	Sugar beet	Winter barley	Wheat
Bare fallow	+++	+++	+++	--	---	ns	ns	--	---
Barley	+++	+++	+++	---	---	ns	ns	--	---
Fertilizer (tillage)	---	---	---	+++	+++	+	ns	+++	+++
Fertilizer (grass)	---	---	---	+++	+++	+++	++	+++	+++
Permanent grass	++	+++	+++	--	---	ns	ns	--	---
New grass	+	+++	++	—	—	ns	ns	-	—
Hay	+++	+++	+++	—	—	ns	ns	—	—
Oats	+++	+++	+++	—	—	—	—	—	—
Oilseed rape	—	—	—	+++	+++	ns	ns	+++	+++
Potatoes	+++	+++	+++	—	—	—	-	—	—
Rough grazing		+++	+++	—	—	—	-	—	—
Root crops			+++	---	---	ns	ns	---	---
Spring barley				---	---	-	ns	---	---
Sheep					+++	ns	ns	+++	+++
Silage						ns	ns	+++	+++
Slurry							+++	++	ns
Sugar beet								+	ns
Winter barley									+++

Table A3.2 Continued.

4

Large-Scale Spatial Patterns: Relationships Between Change in Species Distributions and Change in Lowland Agriculture

D.E. Chamberlain & R.J. Fuller

British Trust for Ornithology

4. LARGE-SCALE SPATIAL PATTERNS: RELATIONSHIPS BETWEEN CHANGE IN SPECIES DISTRIBUTION AND CHANGE IN LOWLAND AGRICULTURE

4.1 Introduction

The distribution of all breeding bird species in Britain and Ireland has been estimated by visiting every 10 km square of the national grid in two Breeding Bird Atlas surveys, firstly between 1968 and 1972 (Sharrock 1976), and secondly between 1988 and 1991 (Gibbons *et al.* 1993). The change in species' geographical range can therefore be determined by considering the number of 10 km squares where a given species was either lost (present in the early survey, absent in the later survey), retained (present in both surveys) or gained (absent in the early survey, present in the later survey). Fuller *et al.* (1995) reported that 24 out of 28 (86%) species of farmland bird had shown a contraction in range between the two surveys. For species primarily associated with habitats other than farmland, a smaller proportion (51%) had declined in range, and the magnitude of these declines was less than that in farmland. There is therefore an implication that factors specific to farmland are affecting bird distributions in a number of species.

Atlas data have a wide range of potential applications (Donald & Fuller 1998). Data derived from the Breeding Birds Atlas surveys have been used to consider range size and abundance relationships (Gregory 1995), and to determine the distribution of species of conservation concern and the spatial variations in species richness to identify important bird areas (Brown *et al.* 1995, Williams *et al.* 1996). There have, however, been comparatively few studies relating bird distributions derived from the two Breeding Bird Atlases to habitat, and even fewer considering the effects of habitat change on change in bird distributions. Gates *et al.* (1994) modelled the effects of a large number of habitat variables (including agricultural data) on the abundance of selected farmland bird species using data from the later (1989 to 1991) Atlas survey. The models derived consisted of large numbers of variables and whilst they were often good predictors of abundance, many model variables were difficult to interpret in terms of likely ecological effects on birds. The models also failed to explain adequately the change in the distribution of species when applied to data from the early Atlas survey. This example illustrates that interpretation of such modelling approaches must be carried out with some caution, particularly when there is evidently a high degree of inter-correlation and many variables are effectively interchangeable with many other (possibly unmeasured) variables (Donald & Fuller 1998). Gibbons and Gates (1994) avoided this problem by considering specific hypotheses concerning likely factors affecting the change in range of Corn Buntings and Siskins *Carduelis spinus*. Whilst there was evidence that Siskins had increased due to an increase in conifer plantations, there was no evidence to suggest that changes in the area of barley, particularly that sown in the spring (see Section 2), was associated with Corn Bunting declines. Gates and Donald (in press) reduced a large number of habitat variables to axes of environmental variation using Principal Components Analysis (PCA) and related these to changes in the distribution of selected farmland bird species. They found that 10 km squares where a species had been lost were more similar in terms of habitat to 10 km squares where the species had never been recorded, implying that population declines have occurred in the least favoured habitats.

There is as yet little evidence that declines in range of any farmland species are strongly related to specific changes in agricultural practice, although as illustrated above, no studies have addressed this question directly, with the exception of Gibbons and Gates (1994) who considered only one farmland species and few habitat variables. In this section, we consider the effects of changes in a large number of spatially referenced habitat variables on the probability of loss of farmland species from 10 km squares between the two Atlas surveys, and we also consider habitat changes in relation to changes in species richness. Additionally, we consider changes in the abundance of nesting Rooks in relation to regional farming types using data derived from a specifically designed survey (Marchant & Gregory in press).

4.2 Methods

4.2.1 Bird data

Bird data describing species' geographical range were taken from two Atlas surveys of the UK and Ireland coordinated by the BTO during 1968 to 1972 (Sharrock 1976) and 1988 to 1991 (Gibbons *et al.* 1993). The methods differed slightly between the two surveys. In the early survey, the amount of a 10 km square surveyed and the time spent surveying was more-or-less left to the judgement of survey workers (Sharrock 1976). In the later survey, coverage was standardized by specifying a minimum number of eight tetrads (2×2 km squares) per 10 km square that had to be visited, with a set survey time of two hours per tetrad (Gibbons *et al.* 1993). Additionally, supplementary records of birds recorded outside the set time counts were available. There were variations in the number of tetrads visited per 10 km square (e.g. in some 10 km squares all tetrads were visited, whilst in others only the minimum number). This may be taken into consideration when analysing changes in species distribution by using a weighting procedure (see below). The tetrad-based survey approach meant that species abundance could be indexed per 10 km square for the later Atlas, when previously only presence/absence data were collected. As we are concerned with changes between the two Atlas periods, we will only consider the loss, retention or gain of a species from a 10 km square (which is not affected by differences in methodology between Atlas surveys). Additionally, the change in species richness (i.e. number of species present) per 10 km square was analysed in relation to farming practice, concentrating mainly on a group of 21 target species which are particularly associated with the farmland habitat (see Table 2.1).

A further, spatially referenced data set was available which recorded the abundance of Rook nests in two years, 1975 and 1997. Rooks have a highly aggregated nesting distribution and so are not well censused by the CBC (Marchant *et al.* 1990), but are sufficiently common to have registered little change between the two atlas periods (Gibbons *et al.* 1993). Specific Rook surveys have been carried out in 1975 and 1997, using methodology designed to account for the species' spatial distribution (Marchant & Gregory in press). These involved visits to randomly selected tetrads to record the number of Rook nests, thus unlike the atlas survey, data is available on the change in the abundance of nesting Rooks, although the period covered, between 1975 and 1997, is different.

4.2.2 Habitat data

The main source of habitat data was the MAFF Agricultural June Census, which details the area of land under a wide range of agricultural use. Only 10 km squares with a minimum

5,000 ha of farmland area were considered. Further details are given in Section 3. Data at the 10 km square level were used from 1969 and 1988, each of which falls within a period covered by the Atlas data. As agricultural statistics were used from only two years, 1969 and 1988, but Atlas data were collected over a number of years (1968 to 1972 and 1988 to 1991), the analyses assume that the agricultural census data is representative of land use within the respective Atlas periods. In addition to considering the effects of individual variables on the change in species distribution, axes of general agricultural change derived from PCA were used (see Section 3), and Shannon habitat diversity indices (Krebs 1980) were determined for each 10 km square using the habitats defined in Table 3.1. MAFF Census data only include agricultural land, but it is likely that other habitats in close proximity may affect birds on farmland, particularly when the area of farmland is small. For this reason, the proportion of woodland and urban land per 10 km square, derived from ITE land cover data (Fuller & Parsell 1990) and the median altitude per 10 km square derived from the ITE Land Characteristics data base (Ball *et al.* 1983) were considered in the analyses. The geographical distribution of these variables is shown in Fig. 4.1. Note that these values, unlike crop variables, are absolute measures rather than measures of change, having been determined for only a single time period. Atlas analyses were carried out at different geographic scales, considering firstly all farmland 10 km squares from England and Wales, and then in separate regions of arable and non-arable agriculture (see Table 3.2). The predominant farming type (arable, pastoral or mixed) was also defined at the level of the 10 km square, where arable land or pastoral land (improved grass + rough grazing) had to occupy at least 80% of the area of farmland for a given 10 km square to be defined as an arable or pastoral square respectively. Those 10 km squares which were intermediate in grass and arable area were defined as mixed.

4.2.3 Analyses

The number of 10 km squares occupied in both atlas surveys was determined for all species (which included both timed counts and supplementary records for the later survey). For species which had experienced the greatest change in the proportion of 10 km squares occupied, simple comparisons of losses in different regions defined using agricultural statistics were carried out. Many of the 21 target species (Section 2), whilst showing evidence of population declines, have not shown evidence of a contraction in range (Gibbons *et al.* 1993). Therefore, only those species with a range contraction of over 5% were considered for this analysis. There were seven such species: Grey Partridge, Lapwing, Turtle Dove, Yellow Wagtail, Tree Sparrow, Corn Bunting and Reed Bunting (Table 4.1). The number of 10 km squares where a bird species was lost, and the number of 10 km squares where a bird species was gained or retained between the two Atlas surveys were determined. 10 km squares where a species was not recorded in either survey were not considered in the analysis.

The number of Rook nests counted in each tetrad was determined for 1975 and 1997, considering only those tetrads that were covered in both years. The percentage change in the number of nests was determined for different regions, and confidence limits were derived using a bootstrapping procedure which randomly resampled all data (with replacement) 999 times. The 5th and 95th quantile of this distribution were taken as 95% confidence intervals. Full details are given in Marchant and Gregory (in press). Rook data were collected in 1975 and 1997, neither of which is close to years when agricultural data were available. It was therefore decided not to consider Rook data in relation to specific agricultural variables.

The loss or retention of a species was modelled in relation to changes in habitat variables using logistic regression procedures, selecting the single variable which maximised the deviance over a given sample of 10 km squares (the whole data set, and then data sets broken down by region). More complex modelling approaches were carried out, selecting a large number of variables and maximizing model fit (Appendix 4.1), but we were aware of a high level of collinearity in the data (see Appendix 3.1) which made interpretation of these multi-variable models difficult (see Donald & Fuller 1998, for a discussion of the difficulties of interpreting such analyses, with particular reference to Gates *et al.* 1994). However, the goal of the analysis was to identify the factors which best fitted population change, rather than to build predictive models from the data. Therefore, we decided initially to adopt the simplest approach. Analyses incorporating the effects of a range of agricultural variables on changes in bird distribution were considered by using PCA axes of environmental variation (given in Section 3).

The dependent variable in the models was the probability that a species would not be recorded in the second Atlas survey where it had been recorded in the first. Data were thus reduced to a binomial response where 1=loss of a species from a 10 km square and 0=stayed the same or gained a species. For the species selected for analysis, the proportion of 10 km squares which gained a species was usually very small (<1% of the total sample of 10 km squares) and it was not deemed worth considering the effects of agricultural management on the gain of species separately from the retention of species. There were two exceptions, Yellow Wagtail and Corn Bunting, which showed increases in 9.7% and 7.3% of 10 km squares in which they were recorded in either survey, respectively. In these cases, the probability that a 10 km square had gained a species was modelled separately from the probability of species loss. The independent variables were measures of change in various agricultural land use types per 10 km square between 1988 and 1969 (Section 3), and the change in total agricultural area and diversity index between 1988 and 1969. Area and diversity of habitat in the early survey and non-agricultural habitats (woodland, suburban/urban land and altitude) were not considered initially, but were included in a repeat analysis of species loss. Change in the number of species recorded (species richness) was determined in absolute terms (number recorded in early survey/number in late survey) and relative terms ((number recorded in new survey/number recorded in old survey)-1) per 10 km square. Change in species richness per 10 km square of all species recorded, and of the 21 target species, was also analysed in relation to habitat change using linear regression, selecting the single variable which resulted in the largest r^2 value. The variation in observer effort per 10 km square was taken into consideration by weighting both logistic and linear regression analyses according to the number of tetrads visited per 10 km square in the later survey. The effort taken for supplementary records was unknown, so only data from timed counts were used in the regression analyses. In many cases, this meant that the number of squares where a species was present was under-estimtated, but weighting by sample effort will effectively take this error into account as the difference between timed counts only and timed counts plus supplementary records significantly decreased with effort (Appendix 4.2). The variation in effort between 10 km squares was not known for the earlier survey, but this is less important given that we are dealing mainly with 10 km squares where a species was present in the early survey (although in a very small number of cases a 10 km square actually gained a species). The weighting procedure was carried out in order to take into account the possibility that birds were present in the late survey but were not recorded.

4.3 Results

4.3.1 Changes in bird distribution

Changes in range of 21 target species (Section 2) were calculated as the ratio of the number of 10 km squares in which a species was present in the early Atlas survey to the number in the late Atlas surveys. Overall percentage declines for selected species with the greatest range change (>5%) are shown in Table 4.1. Additionally, 10 km squares were classified according to the arable or non-arable region to which they belonged (Section 3), and predominantly arable and grass farmland defined at the 10 km square level. (Full details of national declines and distribution maps of all species are given in Gibbons *et al.* 1993). Declines were significantly greater in non-arable regions in all seven species (Table 4.1), and were greatest in the pastoral-west region in each species except Tree Sparrow. When comparing 10 km squares of different predominant farming type, similar patterns emerged to the regional analysis. Grass-dominated 10 km squares (which will mainly be in the pastoral-west region) had the highest rates of loss and arable-dominated 10 km squares (mainly in the arable-east region) showed the lowest rates of loss for each species. These differences were again highly significant with the exception of Reed Bunting. These analyses therefore indicate that losses in terms of presence/absence have been greatest in Wales and towards the north and west of England where the majority of grass-dominated 10 km squares occur.

4.3.2 Changes in the abundance of nesting Rooks

Rooks had shown an overall increase of 27% in the abundance of nests between 1975 and 1997. This increase was most pronounced in the mixed-south region, the only one to show a positive lower confidence interval (Table 4.2). There was a significant difference in the change in the number of nests between regions (G_2=55.13, $P<0.0001$). When considering farm type defined at the level of the 10 km square, trends were similar between farm types (Table 4.2), and the difference was not significant (G_2=0.14, ns).

4.3.3 Changes in bird distribution in relation to agricultural change

The variable which maximised the explained deviance in the logistic regression model for each species is shown in Table 4.3. In every model presented, the overall deviance explained was significant at $P<0.001$. A positive relationship indicated that an increase in the independent variable was associated with an increasing probability of species loss, and a negative relationship indicated a decreasing probability of loss with an increase in the variable, so where the variables were differences in land use type between the two periods (late-early), a positive relationship indicated that loss of a species was associated with an increase in land use area. Two data sets were used for the independent variables, one containing variables of change in agricultural management and one containing additional constant variables describing woodland and suburban area, altitude, the original area of agricultural land and original habitat diversity (results from these models are given in parenthesis when they explained a greater amount of the deviance in the model than the single best agricultural variable).

Considering all 10 km squares, species loss increased in 10 km squares which had increased in cattle (Lapwing), increased in sheep (Reed Bunting), changed little in oilseed rape (Yellow Wagtail and Tree Sparrow) and wheat (Corn Bunting), and in 10 km squares which had increased in improved grass (Grey Partridge) and barley (Turtle Dove) (Table 4.3). The crop and livestock variables selected tended to show similar geographical patterns of change, with wheat and oilseed rape increasing in central and eastern 10 km squares and changing little in the west and north, cattle increasing most in the west, and barley and grass increasing in the north and west (see Section 3). The original farm habitat diversity was a better predictor of Turtle Dove and Corn Bunting loss, woodland area was a better predictor of Grey Partridge loss and altitude was a better predictor of Reed Bunting loss than individual crop or livestock variables.

Variables selected in the arable-east region were different from those selected for the full data set, and there were generally less clear cut geographical trends (Table 4.3). Yellow Wagtail and Corn Bunting showed increasing probability of loss in 10 km squares which had increased in the area of sugar beet and potatoes respectively. Grey Partridge and Tree Sparrow were lost from 10 km squares which had increased in the area of other root crops. Lapwing was lost from 10 km squares which had decreased in rough grazing area, Turtle Dove was lost from 10 km squares which had decreased in the area of improved grassland and Reed Bunting was lost from 10 km squares which had increased in the area of root crops. Additionally, Turtle Dove tended to be lost at higher altitude 10 km squares and Tree Sparrow was more likely to disappear from 10 km squares which had an initially low total area of farmland. A problem with these models is that the numbers lost were typically very low (Table 4.1), and so they may not be very informative, particularly for Lapwing, Turtle Dove and Reed Bunting, which showed changes of less than 5% in this region.

Mixed-south counties showed similar variable selection to the whole data set (Table 4.3), variables typically showing similar geographical trends. Variables other than individual crop or livestock variables tended to be better predictors of species loss, showing the same trends as observed in the whole data set in Turtle Dove, Corn Bunting and Reed Bunting. Additionally, the area of woodland per 10 km square proved the best predictor in two species, Yellow Wagtail and Tree Sparrow, each showing an increase in losses from 10 km squares with a large woodland area. For pastoral-west counties, losses were generally associated with agricultural variables which had changed the most in west Wales and south-west England. Vegetables (associated with Grey Partridge and Reed Bunting loss), total tillage (Tree Sparrow), and wheat (Corn Bunting) had decreases, cattle numbers (Lapwing) had increased, and bare fallow (Turtle Dove and Yellow Wagtail) had changed little or increased in these areas. Better predictors were provided by woodland area (Grey Partridge), altitude (Tree Sparrow) and original farm habitat diversity (Corn Bunting) than individual farm crops.

One problem with the habitat data is that there was a high degree of collinearity (see Appendix 3.1). The effects of variables such as wheat and oilseed rape area were very similar and therefore essentially interchangeable. In order to simplify the analysis, PCA scores of agricultural change from the whole of England and Wales, and for arable and non-arable regions separately, were used to describe habitat variation. The first three PCA axes (PRIN1-3) were used as independent variables in a logistic regression model in place of agricultural change variables used in Tables 4.3 and 4.4, apart from change in habitat diversity, which was considered separately, as the PCA was used to describe trends in *individual* crop and livestock variables. The method was identical in all other respects to the previous analysis.

Over the whole of England and Wales, the first PCA axis (PRIN1) was selected in each species (Table 4.4). This showed that generally, species tended to be lost from 10 km squares which had increased in grass and barley and changed little in other crops, and tended to be retained in 10 km squares which had increased in the area of rape and wheat and decreased in the area of barley. However, other variables, including woodland area (Grey Partridge and Tree Sparrow), original habitat diversity (Corn Bunting), change in habitat diversity (Lapwing) and altitude (Reed Bunting) were better predictors of species loss than PCA axes. In both non-arable regions, PRIN1 was also selected in each species (Table 4.4), indicating the same patterns of loss with respect to cropping as observed in the whole data set. Effects of woodland, altitude and habitat diversity were similar to that observed when using individual change variables (Table 4.4), except PRIN1 proved to be a better predictor of Tree Sparrow loss than woodland area in pastoral-west counties. In arable-east counties, lesser PCA axes were better predictors of species loss. PRIN3, which was mainly associated with grassland and potato area, was selected for Grey Partridge, Turtle Dove and Reed Bunting, implying that these species were more likely to have been lost in 10 km squares which had decreased in grass area and increased in potato area (see Table 3.5). Grey Partridge and Yellow Wagtail showed some association with PRIN2, but the species showed opposite trends, the former showing a positive relationship (implying greater loss in 10 km squares which have decreased most in agricultural area and total tilled area) and Yellow Wagtail showing a negative effect. No significant effects of PCA axes were detected in Lapwing or Tree Sparrow. In five species, variables not associated with agricultural change were better predictors of species loss than PCA axes.

Tables 4.3 and 4.4 model the probability of losing a species between the two atlas surveys, as opposed to not losing a species (i.e. retaining or gaining a species). In the majority of species, the number of gains was very small (and can be determined by subtracting the sample size in Table 4.3 from that in Table 4.1 for each species/region). However, in two species, Yellow Wagtail and Corn Bunting, gains amounted to over 5% of all 10 km squares in which the species was recorded (Table 4.5). Yellow Wagtail increased in a significantly greater proportion of 10 km squares in arable-east counties and in 10 km squares which were predominantly arable (Table 4.5). However, there was no significant difference in the proportion of 10 km squares which had gained Corn Bunting, either between regions defined at the county level, or between farm types defined at the 10 km square level (Table 4.5). The effects of agricultural change on the probability of a 10 km square gaining a species between the two Atlas surveys was modelled using the same approach as Table 4.3, but all 10 km squares from which a species was lost were omitted from the analysis. For the whole data set, Yellow Wagtail was more likely to be gained in a 10 km square which had decreased in the area of rough grazing, and Corn Bunting was more likely to be gained in a 10 km square which had changed little in the area of oilseed rape (Table 4.6a). For regional analyses, Yellow Wagtail increased most in arable 10 km squares which had decreased in the number of sheep. In the mixed-south region, change in the area of barley was selected in both species but with opposite effects, Yellow Wagtail increases being associated with decreases in barley area, and Corn Bunting increases being associated with increases in barley area. In the pastoral-west region, increases were more related to changes in grassland, being associated with decreases in rough grazing (Yellow Wagtail) and improved grassland area (Corn Bunting). Corn Bunting increases showed similar patterns to those at a national scale, having associations with variables showing a similar geographical pattern of change to oilseed rape. This latter result seems contradictory to that in Table 4.3, as Corn Bunting appears to have both increased and decreased in 10 km squares which have changed little in oilseed rape area. Species gain was also analysed in relation to PCA axes (Table 4.6b). Yellow Wagtail gains tended to be related to PRIN2 and PRIN3, but for all 10 km squares and individual regions, woodland area or altitude were significantly better predictors of species gain. Corn Bunting gain was positively related to PRIN1 in all 10 km squares and in each region, a similar result to that observed for Corn Bunting loss (Table 4.4), indicating that this species was gained in 10 km squares similar to those from where it had been lost.

4.3.4 Changes in species richness

Change in species richness was calculated as the difference in the number of species per 10 km square between the two Atlas surveys, considering all species recorded, and 21 target species only (see Section 2). Fig. 4.2 shows absolute change in species richness per grid across the region. The areas showing the greatest loss of species tended to be in the non-arable regions. There was no significant difference in change in species richness between regions for all species (ANOVA $F_{2,1086}=1.73$, ns mean$\pm$sd (n): arable-east 1.74$\pm$10.47 species (298), mixed-south 0.54$\pm$10.33 species (512), pastoral-west 0.19$\pm$11.78 species (279)). There was a highly significant difference in species loss of target species between regions (ANOVA $F_{2,1086}=29.06$, $P<0.0001$; mean$\pm$sd (n): arable-east -0.33$\pm$1.12 species (298), mixed-south -0.72$\pm$1.35 species (512), pastoral-west -1.23$\pm$1.77 species (279)).

Species richness was also considered in relative terms (the ratio of species recorded in the old and new surveys per 10 km square), as species loss is in part a reflection of the number of species which are present initially. The percentage change of the richness of all species showed a more westerly bias (Fig. 4.3a) compared to absolute change, but there was little difference in the pattern of percentage change in species richness of target species compared to absolute change (Fig. 4.3b). The significance of percentage change between different regions showed similar trends to absolute change (all species: $F_{2,1086}=2.29$ ns; mean$\pm$sd (n): arable-east 2$\pm$13% (298), mixed-south 1$\pm$12% (512), pastoral-west 1$\pm$15% (279); target species $F_{2,1086}=35.59$, $P<0.0001$; mean$\pm$sd (n): arable-east -2$\pm$5% (298), mixed-south -4$\pm$7% (512), pastoral-west -7$\pm$10% (279)). Therefore relative species richness will not be considered further.

The habitat variables which showed the best fit (the highest r^2 value) to change in species richness between the two Atlas surveys are shown in Table 4.7a. For all farmland 10 km squares in England and Wales, the area of potatoes was the variable most closely associated with total species loss, with loss increasing in 10 km squares in East Yorkshire, Lincolnshire, The Fens and eastern East Anglia, which had decreased the most in potato area. In regional terms, species loss was higher in arable-east counties which had changed most in orchards and fruit and in mixed-south counties which had decreased in cattle. However, species loss was more closely associated with smaller areas of woodland and larger areas of suburban land respectively. Species richness in pastoral-west counties tended to decline more in 10 km squares of lower altitude. When considering the 21 target species only, species loss was closely associated with areas of little change in oilseed rape (all 10 km squares and mixed-south counties) and bare fallow (pastoral-west counties) and larger areas of woodland (arable-east counties). Note that this latter result contradicts that for all species in the same region.

When PCA axes were used instead of individual variables of change, PRIN1 was selected in most cases, with loss of all species and target species increasing in 10 km squares with higher PCA scores towards the north and west for all England and Wales, and both non-arable regions. However, non-agricultural variables were more closely correlated with the change in total species; total species loss increased with a larger area of woodland (all 10 km squares), a smaller area of suburban land (mixed-south 10 km squares) and at lower altitude (pastoral-west 10 km squares). In the arable-east region, total species loss was positively associated with PRIN3, indicating increased losses in 10 km squares which have lost most grass and increased in the area of potatoes (see Table 3.5). Loss of target species in this region increased in 10 km squares with a larger area of woodland, but were not significantly related to any PCA axis.

4.4 Discussion

Generally, the declining individual species considered showed similar patterns of change. Arable-east counties and arable-dominated 10 km squares which had generally increased in oilseed rape and decreased in barley were more likely to retain species, and pastoral-west counties and grass-dominated 10 km squares which had generally changed little in wheat and rape (typically from very low initial levels), but which had increased in the area of barley and improved grass were more likely to have lost species. These variables had a large influence on the first axis derived from PCA, and this was significantly related to the probability of loss over all 10 km squares in each of the seven species considered. Relationships between specific agricultural change variables and species loss showed the same general patterns, with the probability of loss being associated with agricultural variables which showed strong regional trends. Whether any of these associations represented causal relationships seems doubtful, as in the majority of cases it was difficult to envisage how selected variables could have affected change in species' distributions, given previous knowledge of habitat associations and the ecology of the species involved (see Section 2). It seems most likely that closely correlated variables were selected which may have been merely representative of the wider pattern of decline. The main exception to this was the Lapwing and its associations with grassland habitat. Loss of this species was associated with increases in cattle (all 10 km squares and pastoral-west counties) and decreases in rough grazing (arable-east counties). Increasing disturbance, nest destruction and creation of less suitable habitat due to higher stocking rates (including sheep) have been suggested as possible reasons for the decline of the Lapwing, as has the "improvement" of pasture land and consequent loss of rough grazing (Shrubb 1990, Hudson *et al.* 1994).

In many cases, variables describing change in individual crop or livestock components were less closely associated with species loss than other variables describing non-agricultural habitat. Larger areas of woodland in particular tended to increase the probability of loss from a 10 km square in a number of species. Similarly, species tended to be lost from 10 km squares at higher altitude and with a lower original diversity of farm habitat. All of these variables still tended to show similar geographical patterns to those agricultural variables selected in other models. Loss of habitat diversity was associated with increased losses of a number of species. This has been a potential factor in species declines (see Section 2), including the Lapwing (Hudson *et al.* 1994), but change in diversity was typically not the variable most closely associated with species loss, and tended to be selected only in comparison with PCA axes (Table 4.4).

The majority of species considered in this analysis are closely associated with lowland farmland, particularly arable and mixed farms (O'Connor & Shrubb 1986), the most notable exception being the Lapwing, which is a common (but declining) breeder in pastoral farmland in marginal uplands (Hudson *et al.* 1994). This was the only species where individual agricultural change variables were consistently more closely associated with species loss than non-agricultural habitat variables across all regions. Aside from Lapwing, the associations between habitat and species loss may have indicated that losses occurred in generally less favoured habitat, characterized by pastoral farming, relatively high altitude, large areas of woodland and low habitat diversity. This contention is supported by Gates and Donald (in press), who found that species tended to be lost from 10 km squares which were more similar to 10 km squares from which they had never been recorded, to those from which they were retained.

A small number of 10 km squares gained species between the two Atlas surveys. For the majority of species, this number was negligible, but for Yellow Wagtail and Corn Bunting, gains occurred in over 5% of 10 km squares. For Corn Bunting these gains occurred in equal proportion across regions and farm types, and gains tended to be in 10 km squares which were similar in habitat change to 10 km squares from which they had been lost. Yellow Wagtail increased on a greater proportion of 10 km squares in arable-east counties and in 10 km squares which were predominantly arable. Logistic regression analyses indicated that gains in this species were associated with 10 km squares which had declined in rough grazing and increased in sheep numbers (non-arable regions) and increased in vegetable area. It is difficult to ascertain whether these factors represent genuine causal effects on the shift in the Yellow Wagtail's range. The association between Yellow Wagtails and damp pastures is well known (Gibbons *et al.* 1993), but it does use arable fields, and locally appears to use potato fields in the East Midlands (A. Henderson pers. comm). The importance of arable farmland to this species is poorly known and a detailed study of its ecology in this habitat would be useful in helping to understand whether this range change has been a response to changes in arable agriculture. A problem with considering the gain of both of these species is that it was not possible to weight the analysis in terms of the number of 10 km squares visited in the earlier survey as this was unknown. If coverage was poor in these 10 km squares, then a "gain" in species may merely reflect non-detection of birds which were present in the first Atlas survey. Therefore, some caution is needed when these results are interpreted.

The only species for which spatially referenced data on change in abundance were available, the Rook, showed an increase between 1975 and 1997. This increase occurred in all regions but was greatest in the mixed-south region. The reasons for this increase are unclear (Marchant & Gregory in press). Changes in some aspects of farming practice may have been beneficial to Rooks, and they are one of the few species which seem to benefit from increased stocking rates (Chater 1996). This latter factor may go some way to explaining the greater increase in mixed-south compared to arable-east counties, but if stocking rates were solely responsible, similar (or greater) increases would be expected in pastoral-west areas, where increases in stocking densities have been greatest (Fuller & Gough in press). Also, when considering farming type at the 10 km scale, no significant differences in Rook increase were detected. It is likely that a number of other factors are also operating, not all of which may be associated with farm management. For example, increases in traffic are likely to have increased the amount of carrion available to Rooks (Marchant & Gregory in press). Unfortunately, it was not possible to relate changes in Rook abundance to changes in agricultural management, which may have revealed potential underlying causes of the population increase.

The decrease in species richness of all species recorded over all 10 km squares was most strongly related to a decrease in the area of potatoes. There were a few areas which showed high species loss, such as The Fens, east Norfolk, Suffolk and Kent, which were particularly associated with changes in the area of potatoes grown. On a regional basis, loss of species richness was associated with decreases in orchards/fruit in arable-east counties (particularly in Kent and East Anglia) and with decreases in cattle numbers in mixed-south counties, but these relationships were comparatively weak. It is unclear how these associations may reflect a causal relationship, and it seems more likely that selected variables are substituting for other unmeasured variables. Regional species loss was most strongly associated with non-agricultural variables, increasing with smaller areas of woodland in arable-east counties, with larger areas of suburban habitat in mixed-south counties, and at lower altitudes in pastoral-west counties. When considering target species only, variables selected represented the same general geographical variations observed in analyses of individual species loss, with species richness decreasing most in western and northern regions. The exception to this was in arable-east counties, where no agricultural variable was significantly associated with species loss, but species loss increased with increasing woodland area. Note that this is opposite to the effect of woodland on change in the richness of all species, which may arise due to there being a number of increasing woodland species which are considered in the calculation of the richness of all species, but target species concentrate mainly on farmland specialists, the majority of which are declining. When PCA axes were substituted for agricultural change variables, the first axis tended to be significantly associated with change in the richness of all species and of target species, indicating that in general, species richness has declined most in the north and west of England and Wales.

When analysing Atlas data in relation to habitat change, the scale of the analysis should be appropriate to the issues being addressed (Donald & Fuller 1998). This study has considered bird declines at a fairly coarse scale. Analyses of declines at smaller sampling units, namely CBC sites, have revealed that many species are undergoing significant population changes (Section 5), yet few species have disappeared from more than a few percent of 10 km squares, so this analysis can only consider the most severely declining species. At this level, the habitat data can detect only very broad-scale relationships with habitat area and livestock number, thus factors which operate at a finer scale will not be detected. There were also a number of potentially important variables which were not available at the 10 km square level. For example: there was no information on spring-sown crops in the early period which are potentially important for Lapwing (Hudson *et al.* 1994) and the granivorous species Tree Sparrow, Corn Bunting and Reed Bunting (Wilson *et al.* 1996); no information on the management of grassland (e.g. for silage or hay) which may affect ground nesting species, particularly Lapwing (Shrubb 1990); and, no information on changes in hedgerow length, which may be important nesting habitats for Tree Sparrow and Reed Bunting (Lack 1992, Green *et al.* 1994). There were few cases where potential causal effects of selected variables could be identified. The variables selected in the analysis may merely have been substituting for closely correlated variables which we could not estimate at the 10 km level.

Spatial autocorrelation (Legendre 1993), when sampling units in close proximity are more similar to each other than units which are spatially widely separated, is a potential problem when analysing Atlas data because adjacent 10 km squares cannot be considered as independent sampling units. A number of techniques are available for overcoming potential spatial autocorrelation, but it should be borne in mind that such techniques may obscure potentially meaningful biological relationships, as spatial autocorrelation does actually occur in nature (Donald & Fuller 1998). In this analysis, we have taken a fairly simple approach to try and detect general patterns of change in species' distributions, and we feel that these patterns are likely to be obscured if we attempted to eliminate spatial autocorrelation in the data. A more sophisticated modelling approach which took into account the effect of spatial autocorrelation did not reveal substantially different findings (Appendix 4.1).

It is possible that range contraction recorded in Atlas surveys may not be associated with changes in the immediate habitat, but is affected by habitat changes in other areas where the species persists (Donald & Fuller 1998). This could arise through source-sink effects, where habitat changes in the source population result in lower productivity which has subsequent effects on the size of sink populations in less favoured habitats (Pulliam 1988). In a number of species considered here, there were indications that losses occurred in 10 km squares which were predominantly pastoral, well wooded and of a higher altitude. It is possible that for species which are known to prefer lowland arable landscapes such as Corn Bunting (Donald *et al.* 1994) and Grey Partridge (Potts 1986), these losses represent source-sink effects. Gates and Donald (in press) also suggested that losses occurred in less suitable habitats in a number of species. However, there is as yet little evidence for source-sink effects in any bird species and such effects would be extremely difficult to prove (Pulliam 1988, Watkinson & Sutherland 1995).

The analysis of the change in both the distribution of individual species and of species richness (particularly of the target species) have shown that reductions in range had occurred most frequently in grass-dominated regions. However, analysis of population trends show that declines in arable-east counties have been greater than those in non-arable counties in a number of species (Section 5). Many species which we have considered, occur at lower abundance in non-arable regions, and may be at the edge of their geographical range, especially in the pastoral-west counties (see abundance maps in Gibbons *et al.* 1993). We acknowledge that this may not have always been the case and that prior to the main period of grassland intensification, population densities of some species in western pastoral areas may have been considerably higher than at present. However, data presented in Section 6 (Tables 6.4 and 6.5) suggest that for most farmland specialists the ratios of densities in predominantly pastoral areas to those in arable areas were similar in the early-1970s and mid-1990s. If abundance has declined by similar amounts throughout the whole region, then those squares with initially low abundance are more likely to lose species than those of high abundance, thus species may be more likely to be lost at the edge of their range. Analysis of CBC indices show that generally, species have decreased in density by similar proportions in arable and non-arable (particularly mixed-south) regions, yet absolute losses from 10 km squares differ, so an edge of range effect seems plausible. This issue is discussed further in Section 8.2.

These general patterns of change may be associated with agricultural and non-agricultural factors which we were unable to analyse. For example, the data considered here had much detail on land use associated with arable farmland, but relatively little on grassland management components which could be potentially crucial, such as the amount of silage grass compared to hay or pasture. In comparison with arable farms, the factors affecting bird populations on pastoral farms are relatively poorly understood, and this is an area in which further research would contribute greatly to our understanding of the patterns of decline in species distributions and species richness. We suggest, however, that the near-ubiquitous improvement of lowland grassland has had effects on bird populations that are just as profound as those of arable intensification. Large areas of grassland in western England are now managed in ways that are detrimental to ground nesting birds such as Skylark and Lapwing; consequently these species are now scarce over large areas of pastoral western farmland.

4.5 Summary

1. This section examines spatial change in the ranges of 21 farmland bird species and in avian species richness in relation to spatial change in agricultural management. Change in bird distribution and species richness was measured using BTO Atlas data at the scale of 10 km squares from 1968 to 1972 and 1988 to 1991. Agricultural changes were examined at a 10 km square scale using data derived from the MAFF June Census for 1969 and 1988. Seven species showed range declines exceeding 5% between the two atlases and analyses focused on these: Grey Partridge, Lapwing, Turtle Dove, Yellow Wagtail, Tree Sparrow, Corn Bunting, Reed Bunting. Increases in range could be examined only for Yellow Wagtail and Corn Bunting.

2. Declines of the seven species were significantly greater in non-arable regions. Grass-dominated squares had the highest rates of species loss and arable-dominated squares the lowest. These patterns were the same for all species. These findings were consistent with those from logistic regression analyses. These demonstrated that each species was least likely to have disappeared between the two atlases in those 10 km squares that had undergone large changes in cropping involving increases in wheat and oilseed rape and declines in barley, fallow and grass. The probability of species loss was greater in those squares where there had been relatively little change in cropping patterns. Yellow Wagtail increased in a greater proportion of squares in arable-east regions and in predominantly arable squares. No significant patterns could be detected for Corn Bunting increase with respect to region or type of farmland.

3. Changes in the abundance of nesting Rooks between 1975 and 1997 were determined using results from a separate species-specific survey. This revealed an overall increase in Rook abundance which was particularly evident in mixed-south counties. It was not possible to relate changes in Rook abundance to changes in specific management factors due to the differences in the timing of the bird and habitat data sets.

4. Loss of species between the two atlases was modelled in relation to change in individual agricultural and non-agricultural variables (e.g. area of woodland) using logistic regression. Single best variables were identified; the best agricultural variables differed between species and tended to be ones that showed strong regional trends but in many cases non-agricultural variables were more closely associated with the probability of loss than agricultural variables. Lapwing, however, was an exception, being consistently associated with agricultural variables.

5. Geographical pattern of change in species richness was the same for absolute and relative changes in richness. Relative richness took account of the initial number of

species recorded in a 10 km square. Overall richness (i.e. all species) tended to have declined more in non-arable than arable regions. However, changes in species richness between regions and farmland type were much stronger for the group of 21 target farmland species, with a highly significant greater reduction in richness in non-arable regions. Declines in richness of farmland birds were most marked in south-west England, the Welsh borders and Wales. Changes in species richness were related to spatial change in agriculture using regression. Species richness tended to have changed most in those squares where there had been relatively little change in cropping patterns.

6. The analyses presented here can only detect broad-scale relationships. It should be noted that several potentially important factors could not be included in these analyses simply because data are unavailable at the 10 km square scale. These include the amount of spring sown cereals, usage of pesticides, usage of fertilisers and factors relating to grassland management. It is unlikely that many of the variables selected in the regression models are, in themselves, the causal factors behind changes in the ranges of species and changes in species richness. A possible exception is Lapwing, for which variables associated with change in grassland were consistently selected in the models.

7. These analyses have demonstrated that the largest losses of species and declines in farmland species richness have occurred in non-arable regions i.e. in predominantly grassland or mixed grass/arable areas occurring mainly in the west. This finding was unexpected given previously published work; one might have predicted the greatest declines to have occurred in arable-dominated areas of the east where there have been the greatest changes in cropping and most marked intensification. We suggest several possible reasons for this observation, none of which is mutually exclusive. First, there is probably a strong "edge of range effect". Most farmland species occur at relatively low density in the more western regions (though we acknowledge this may not always have been the situation). Declines in density are, therefore, more likely to lead to local extinction than in eastern areas where densities are higher. Second, it is possible that source-sink effects may be operating whereby populations in the west are maintained by flow from source populations in the east. Under such a scenario, factors operating in the east could manifest themselves by marked population reductions in the west. Third, widespread intensification of grassland management, involving massive increase in synthetic fertilizer usage and a general switch from hay to silage, is very likely to have had major effects on bird populations especially in western Britain.

Species	Overall change	Arable-east	Mixed-south	Pastoral-west		Arable squares	Mixed squares	Pastoral squares	
Total 10 km squares	1089	298	512	279		221	628	240	
Grey Partridge	-13.9 (1039)	-10.5 (296)	-9.2 (502)	-27.8 (241)	***	-8.2 (219)	-11.1 (621)	-28.6 (199)	***
Lapwing	-7.2 (1064)	-2.7 (295)	-2.9 (512)	-21.0 (257)	***	-2.3 (218)	-6.5 (616)	-14.3 (230)	***
Turtle Dove	-19.2 (918)	-0.3 (297)	-21.8 (473)	-48.6 (148)	***	-0.5 (220)	-15.8 (577)	-69.4 (121)	***
Yellow Wagtail	-5.9 (777)	6.1 (245)	-10.8 (400)	-13.6 (132)	***	6.1 (179)	-7.2 (472)	-18.3 (126)	***
Tree Sparrow	-11.2 (948)	-5.1 (295)	-15.5 (484)	-9.5 (169)	***	-3.2 (218)	-11.9 (562)	-19.0 (168)	***
Corn Bunting	-14.4 (725)	-7.1 (253)	-11.5 (353)	-38.5 (117)	***	-4.8 (188)	-10.6 (461)	-60.5 (76)	***
Reed Bunting	-5.9 (1044)	-3.7 (298)	-4.7 (488)	-10.9 (258)	**	-4.5 (221)	-5.8 (602)	-7.7 (221)	ns

Table 4.1 The percentage change in occupied 10 km squares between the two Atlas periods (1968 to 1972 and 1988 to 1991) in England and Wales, in regions of predominantly arable and non-arable agriculture, and in 10 km squares of predominantly arable and non-arable agriculture. 10 km squares where a species was absent in both periods were omitted. Sample sizes indicate the number of occupied 10 km squares in the earlier period. $^{**}P < 0.01$, $^{***}P < 0.001$ (G-test).

	Number of tetrads	Nests counted 1975	Nests counted 1997	Percent change	Confidence limits
Arable-east	99	2351	2999	27.6	-8.3 to 74.4
Mixed-south	227	7301	10824	48.3	26.7 to 77.6
Pastoral-west	107	4155	5163	24.3	-4.8 to 68.3
Arable	73	1653	2226	34.7	-2.3 to 75.8
Mixed	272	9490	13183	38.9	17.0 to 65.5
Pastoral	88	2664	3577	34.3	-0.5 to 86.6

Table 4.2 The change in the numbers of Rook nests recorded per tetrad (2×2 km square) between 1975 and 1997 in regions of predominantly arable and non-arable agriculture, and in 10 km squares of predominantly arable, mixed and pastoral agriculture. Confidence limits were derived using a bootstrapping technique.

Species	All squares		Arable-east		Mixed-south		Pastoral-west	
Grey Partridge	improved grass+ (woodland+)	1046	root crops+	297	oilseed rape-	507	vegetables- (woodland+)	242
Lapwing	cattle+	1068	rough grazing-	298	root crops-	512	cattle+	258
Turtle Dove	barley+ (original diversity-)	927	improved grass- (altitude+)	298	vegetables- (original diversity-)	475	bare fallow+	154
Yellow Wagtail	oilseed rape-	835	sugar beet+	273	oilseed rape- (woodland+)	421	bare fallow+	141
Tree Sparrow	oilseed rape-	964	root crops+ (original area-)	298	oilseed rape- (woodland+)	486	total tillage- (altitude+)	180
Corn Bunting	wheat- (original diversity-)	768	potatoes+	264	wheat- (original diversity-)	381	wheat- (original diversity-)	123
Reed Bunting	sheep+ (altitude+)	1062	root crops- (altitude-)	298	root crops- (altitude+)	497	vegetables-	267

Table 4.3 The effect of agricultural land use change between 1969 and 1988 on the probability that a species would not be recorded in a 10 km square in the later survey where it had been recorded in the early survey. The single variables which explained the greatest amount of deviance were selected. Results in parenthesis include the additional variables of altitude, original area of agricultural land, the original habitat diversity of farmland, cover of woodland and cover of urban land where variable selection differed from the original model. Regressions were weighted by observer effort in each 10 km square. The sign indicates the direction of the effect of a variable on the probability that a species was lost from a 10 km square. The deviance explained was significant at $P<0.001$ in each case. Sample sizes show the number of 10 km squares where a species was recorded in either survey (i.e. gains are included).

Species	All squares		Arable-east		Mixed-south		Pastoral-west	
Grey Partridge	PRIN1+ (woodland+)	1046	PRIN3+	297	PRIN1+	507	PRIN1+ (woodland+)	242
Lapwing	PRIN1+ (change in diversity-)	1068	ns (change in diversity-)	298	PRIN1+	512	PRIN1+ (change in diversity-)	258
Turtle Dove	PRIN1+	927	PRIN3+	298	PRIN1+	475	PRIN1+	154
Yellow Wagtail	PRIN1+	835	PRIN2+ (change in diversity-)	273	PRIN1+ (woodland+)	421	PRIN1+	141
Tree Sparrow	PRIN1+ (woodland+)	964	ns (original area-)	298	PRIN1+ (woodland+)	486	PRIN1+	180
Corn Bunting	PRIN1+ (original diversity-)	768	PRIN1+ (change in diversity-)	264	PRIN1+ (original diversity-)	381	PRIN1+	123
Reed Bunting	PRIN1+ (altitude+)	1062	PRIN3+ (altitude+)	298	PRIN1+ (altitude+)	497	PRIN1+ (woodland+)	267

Table 4.4 The effects changes in various agricultural land use types as represented by three Principal Components axes (Section 3) on the probability that a species would not be recorded in a 10 km square in the later survey where it had been recorded in the early survey. Other details are as per Table 4.3. ns=no significant variables selected.

Species	Overall change	Arable-east	Mixed-south	Pastoral-west	P	Arable squares	Mixed squares	Grass squares	P
Total 10 km squares	1089	298	512	279		221	628	240	
Yellow Wagtail	9.7 (860)	13.1 (282)	7.0 (430)	10.8 (148)	*	13.5 (207)	8.5 (516)	8.0 (137)	*
Corn Bunting	7.3 (782)	5.9 (269)	8.9 (390)	4.9 (123)	ns	6.9 (202)	6/7 (494)	11.6 (86)	ns

Table 4.5 The percentage gain in occupied 10 km squares between the two Atlas periods (1968-72 and 1988-91) in England and Wales, and in regions of predominantly arable and non-arable agriculture, and 10 km squares of predominantly arable and non-arable agriculture. 10 km squares where a species was absent in both periods were omitted. Sample sizes indicate the number of occupied 10 km squares in either period. *$P < 0.05$, **$P < 0.01$ (G-test).

(a) Changes in individual crop and livestock variables.

Species	All squares		Arable-east		Mixed-south		Pastoral-west	
Yellow Wagtail	rough grazing- (wood+)	599	sheep-	224	barley- (woodland+)	288	rough grazing-	87
Corn Bunting	oilseed rape-	524	oilseed rape-	202	barley+	257	improved grassland-	65

(b) PCA axes

Species	All squares		Arable-east		Mixed-south		Pastoral-west	
Yellow Wagtail	PRIN3+ (wood+)	599	PRIN2- (altitude+)	224	PRIN3+ (woodland+)	288	PRIN2+ (woodland+)	87
Corn Bunting	PRIN1+	524	PRIN1+	202	PRIN1+	257	PRIN1+	65

Table 4.6 The effect of agricultural land use change between 1969 and 1988 on the probability that a species would be recorded in a 10 km square in the later survey where it had not been recorded in the early survey. The sign indicates the direction of the effect of a variable on the probability that a species was gained in a 10 km square. Other details are as per Table 4.3.

(a) Changes in individual crop and livestock variables.

	All squares	Arable-east	Mixed-south	Pastoral-west
Number of 10 km squares	1089	298	512	279
All species	potatoes---	orchards/fruit-- (woodland---)	cattle- (suburban land++)	ns (altitude--)
Target species	oilseed rape---	ns (woodland+)	oilseed rape---	bare fallow+++

(b) PCA axes

	All squares	Arable-east	Mixed-south	Pastoral-west
Number of 10 km squares	1089	298	512	279
All species	PRIN1+++ (woodland+++)	PRIN3+++	PRIN1+ (suburban land++)	PRIN1+ (altitude--)
Target species	PRIN1+++	ns (woodland++)	PRIN1+++	PRIN1+++

Table 4.7 The effects of agricultural change on change in species richness calculated over all species and for 21 target species only between the two Atlas surveys. The sign indicates the effect of a given variable on species loss, where +/- $P<0.05$, ++/-- $P<0.01$, +++/--- $P<0.001$. Other details are as in Table 4.3.

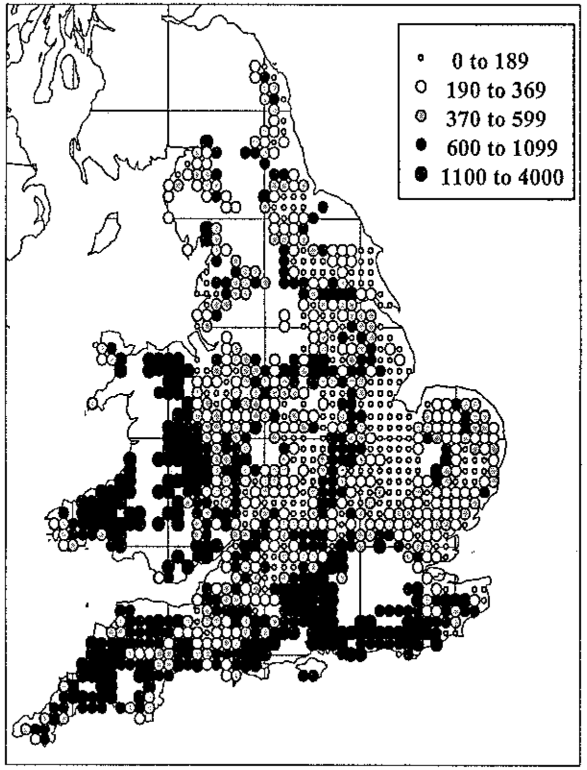

Figure 4.1a Woodland area (ha).

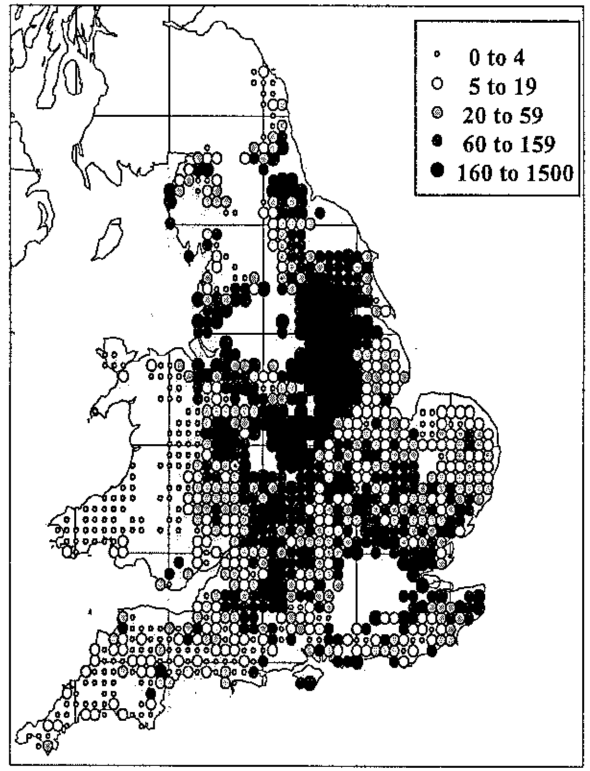

Figure 4.1b Suburban and urban land area (ha).

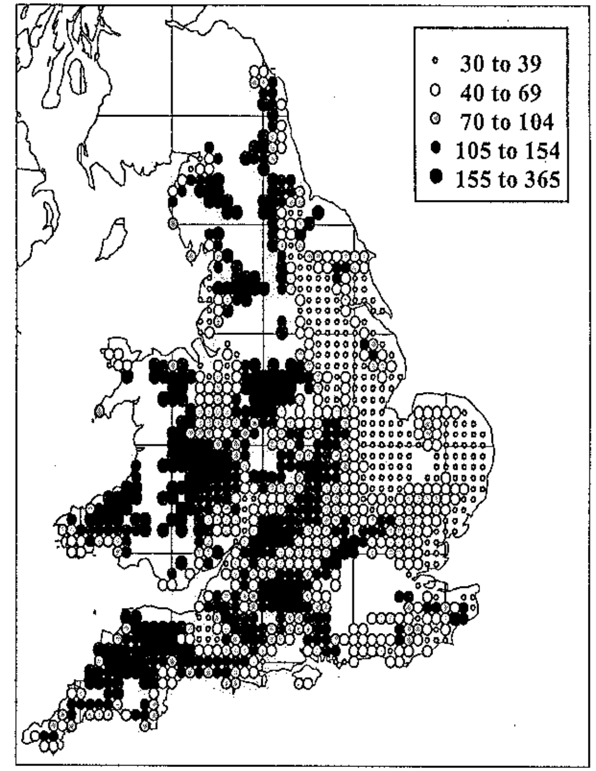

Figure 4.1c Median altitude (metres).

Figure 4.1 The distribution of non-agricultural variables considered in the analysis of bird distribution. (a) Woodland area; (b) Suburban and urban land area; (c) Median altitude (metres).

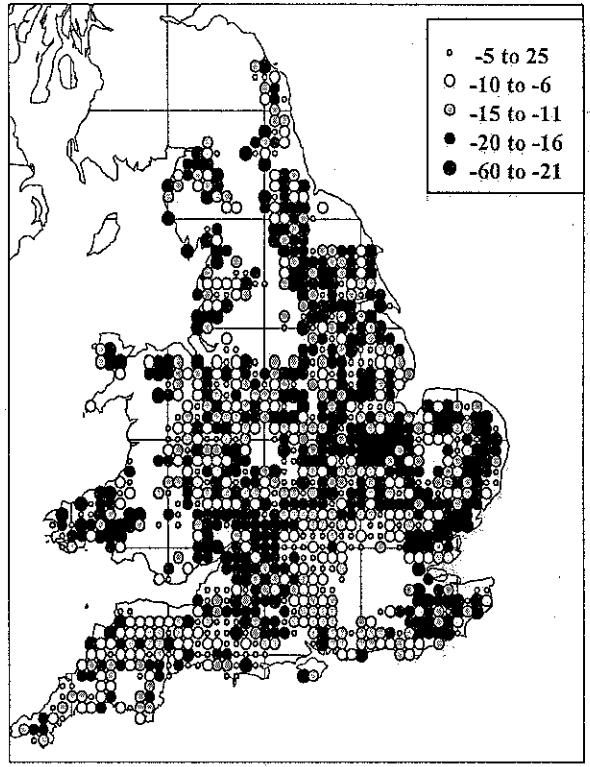

Figure 4.2a All species recorded.

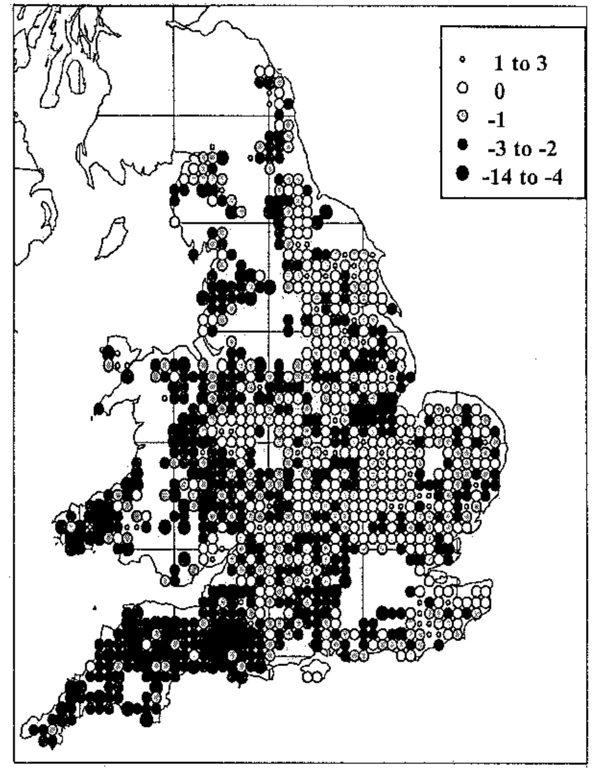

Figure 4.2b 21 target species only.

Figure 4.2 Absolute change in species richness per 10 km square between the two Atlas surveys. (a) All species recorded; (b) 21 target species only (see Section 2).

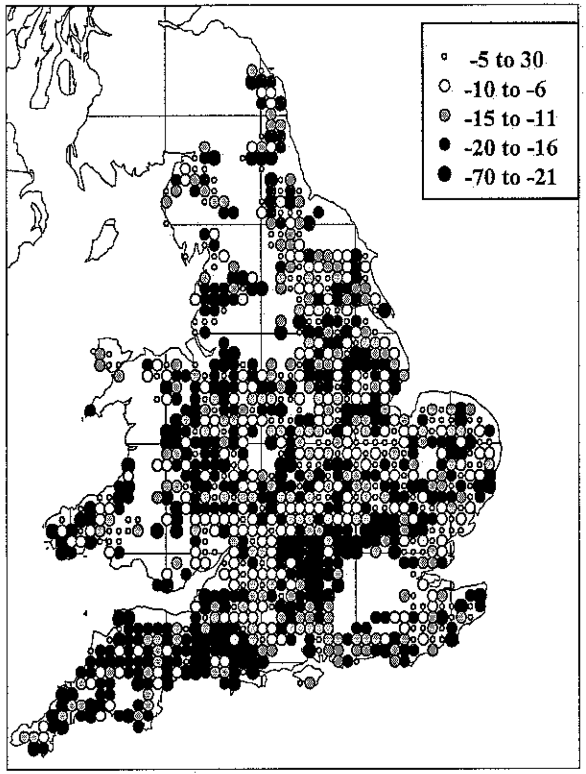

Figure 4.3a All species recorded.

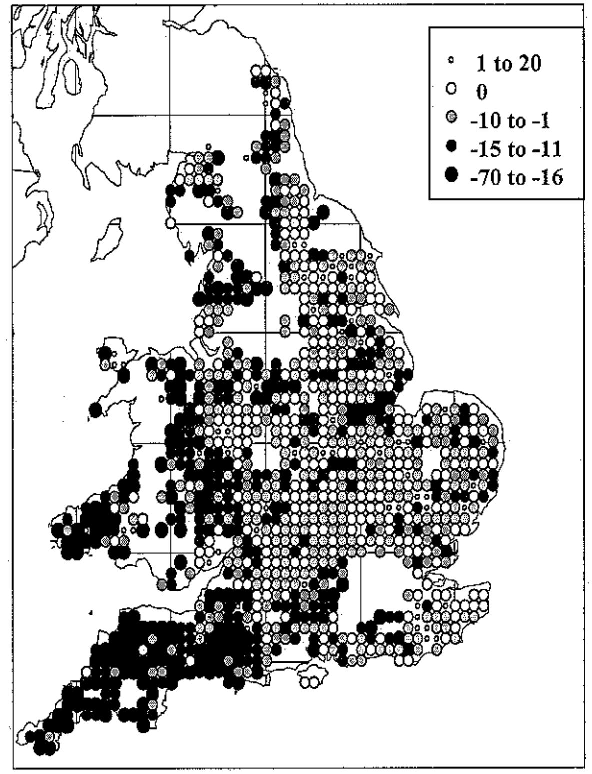

Figure 4.3b 21 target species only.

Figure 4.3 Relative change in species richness per 10 km square between the two Atlas surveys, expressed as the percentage change in species between the two periods. (a) All species recorded; (b) 21 target species only (see Section 2).

APPENDIX 4.1 Multivariate Logistic Regression Modelling of Species Loss

A rigorous modelling procedure was undertaken which was designed to identify models which could best predict the loss of species between the Atlas surveys using logistic regression procedures with a binomial response variable (i.e. 1 = loss of a species, 0 = no loss of a species between Atlas surveys). Variables were selected in the regression models using a forward selection procedure whereby variables were added to the model if they contributed a significant ($P<0.001$) increase in explained deviance. A potential problem with Atlas data is that spatial autocorrelation may occur (Donald & Fuller 1998), where 10 km squares in close proximity are more likely to be similar to one another than those widely separated. To reduce any possible effect of this, all regression models were constructed using only 1/4 of the 10 km squares, sampled from a regular grid so that no adjacent squares were used. The models derived were tested on the remaining 10 km squares by comparing the probability that a species was lost from a 10 km square as predicted by the model with the observed outcome. A species was predicted as being absent from a 10 km square if the probability was over 0.50. The model fit was determined using the "sensitivity" of the model, calculated as the proportion of actual losses which were correctly predicted. The models were weighted according to the observer effort in each 10 km square in the later Atlas survey (see Section 4.2.3). Only species which had decreased by 5% over the whole sample of 10 km squares were considered. As in the Results (Section 4.3), models were first carried out on variables of habitat change, and then with additional constant variables describing non-agricultural habitats or the original habitat composition of the 10 km square.

A large number of variables were selected for each species (Table A4.1 and A4.2), and these typically had highly significant ($P<0.001$) effects. A likely reason for this is that most of the variables considered were significantly correlated with one-another (Appendix 3.1). The first variables selected (explaining the greatest overall amount of deviance) was the same as that selected in single variable models using all 10 km squares (Table 4.2) in Lapwing, Turtle Dove, Yellow Wagtail and Reed Bunting considering only habitat change variables (Table A4.1), and in Grey Partridge, Lapwing, Yellow Wagtail, Corn Bunting and Reed Bunting considering effects of additional habitat variables (Table A4.2). Generally, model fits were poor, most models correctly predicting species loss in around 50% of remaining 10 km squares and the residual deviance indicating that a significant proportion of the variation could not be taken into account in a number of species with these models. Addition of the constant variables describing non-agricultural habitat and the composition of the habitat in the early Atlas survey made little difference to the large number of variables selected in the models or model fit.

Species	Model variables	Residual deviance	Sensitivity
Grey Partridge	total tillage+ root crops+ grass+ total area- sheep+	χ^2_{11}=43.5***	0.62
Lapwing	cattle+† rough grazing- oilseed rape- sugar beet- total tillage+ root crops- total area- grass+ diversity+ orchards/fruit+	χ^2_6=34.3***	0.48
Turtle Dove	barley+ vegetables- potatoes+ cattle+ orchards/fruit+ sugar beet- root crops- rough grazing+ wheat+ diversity-	χ^2_5=18.40**	0.58
Yellow Wagtail	oilseed rape- wheat+ potatoes+ root crops- sugar beet- vegetables+ total area-	χ^2_9=79.8***	0.44
Tree Sparrow	cattle+ total area+† oilseed rape- wheat+ orchards/fruit+ vegetables-† root crops+ total tillage- potatoes+ diversity- barley+ sheep-	χ^2_3=4.9 ns	0.37
Corn Bunting	sheep+ wheat- vegetables- orchards/fruit+ total tillage- grass- cattle+ total area+ barley- sugar beet-	χ^2_6=21.2**	0.67
Reed Bunting	sheep+ cattle+ total tillage+ oilseed rape- diversity- root crops- barley- bare fallow- potatoes+	χ^2_7=32.8***	0.29

Table A4.1 The effect of agricultural land use change between 1969 and 1988 on the probability that a species would not be recorded in a 10 km square in the later survey where it had been recorded in the early survey. Variables were selected using a forward selection procedure on data specially selected to reduce spatial autocorrelation. The first variable listed explained the greatest amount of deviance in the model. Regressions were weighted by observer effort in each square. The superscript indicates the direction of the effect of a variable on the probability that a species was lost from a 10 km square, where P<0.001 except †P<0.05. The significance of the residual deviance was determined from χ^2, where *P<0.05, **P<0.01, ***P<0.001.

Species	Model variables	Residual deviance	Sensitivity
Grey Partridge	woodland- root crops+ suburban+ original area-† barley- wheat- altitude+ potatoes- orchards/fruit-	χ^2_{11}=50.2***	0.61
Lapwing	cattle+† suburban- total area- original area- sugar beet- rough grazing- total tillage+ grass+ wheat- altitude+ sheep-	χ^2_9=72.8***	0.58
Turtle Dove	barley+ vegetables- altitude+ potatoes+ cattle+ woodland- rough grazing+ diversity- orchards/fruit+ sugar beet- total tillage+ root crops- oilseed rape-	χ^2_8=12.1 ns	0.54
Yellow Wagtail	oilseed rape- wheat+ woodland+ root crops- original area- diversity+† total tillage- cattle+ altitude- potatoes+ sugar beet- orchards/fruit+ vegetables+ grass- sheep+ suburban+	χ^2_5=12.1*	0.42
Tree Sparrow	woodland+ cattle+ suburban- wheat+ orchards/fruit+ barley+ total tillage- original area- sheep+ diversity- original diversity- potatoes+ root crops+ sugar beet+ rough grazing+†	χ^2_5=17.1**	0.32
Corn Bunting	diversity+ total tillage- sheep+ woodland+ orchards/fruit+ vegetables-	χ^2_{15}=75.4***	0.33
Reed Bunting	altitude+ woodland+ original area+ rough grazing+ sugar beet+ cattle+ oilseed rape- orchards/fruit- bare fallow- total tillage+ diversity- potatoes+ suburban-	χ^2_8=22.9**	0.40

Table A4.2 The effects of agricultural land use change between 1969 and 1988, altitude, original area of agricultural land, the original diversity of agricultural land, cover of woodland and cover of urban land on the probability of species loss between the two Atlas surveys. See Table A4.1 for further details.

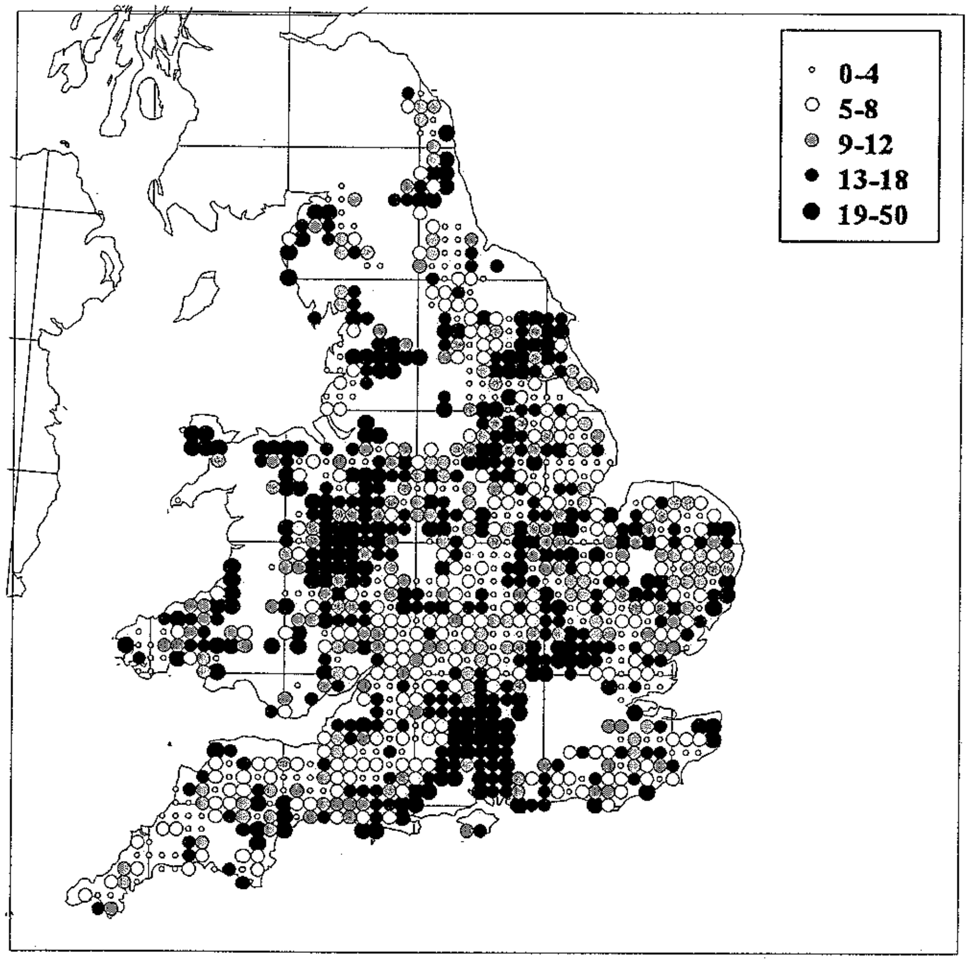

Figure A4.1 The difference in species richness (all species) between timed counts + supplementary records and timed counts only. The data have been ranked and placed into five groups of equal sample size.

APPENDIX 4.2 A Comparison between Timed Counts and Supplementary Records for Atlas Data

Using only timed counts typically under-estimated the number of occupied squares in the later survey in comparison with using timed counts and supplementary records. This is illustrated in Fig. A4.1, which shows the difference in species richness (of all species) calculated using the two data sets in the late atlas period. This under-estimation obviously occurs as observers were usually familiar with the 10 km squares surveyed, and often would have known about species which were present in a square but were not recorded during timed counts. A further point to note is that the areas where the addition of supplementary records greatly exceeded timed counts only were patchily distributed. This pattern arose as data from individual county-level atlases running at the same time as the Breeding Atlas were included in the supplementary records. The counties which this involved are given in the Breeding Atlas (Gibbons et al. 1993), and these clearly coincide with patches of high discrepancy between timed and supplementary counts shown in Fig. A4.1.

Inclusion of supplementary records was necessary when considering percentage change between the two atlas periods (e.g. Table 4.1). However, in regression analyses, two options are possible: include all records and do not take into account the sample effort; or, use only timed counts and weight the analysis by the number of tetrads visited. The latter approach is scientifically more desirable, as we can measure sample effort accurately and so the probability of species occurrence is given equal weight across all squares. For the former approach, there are many biases, as supplementary records were left to the individual observer and may have included data from extra visits, from local knowledge or from previously published atlas studies as described above.

Although use of timed counts only under-estimated species presence, this discrepancy reduced with increasing visit rate. Poisson regression analysis was used to consider the relationship between the number of tetrads visited and the difference between species richness calculated with and without supplementary records. Considering all species, there was a significant negative relationship between the difference in species richness and the number of tetrads visited over the whole period (1988-91) per 10 km square (Table A4.3), i.e. as effort increased, the difference in species richness between data sets with and without supplementary records decreased. When considering separate regions of predominant farming type (Chapter 3), a similar relationship was observed in the mixed-south region only. However, for all of these analyses, model fit was poor (high deviance) and so these results are unreliable. Model fits were much improved when considering only 21 target species (Table A4.3), and there were significant negative relationships for all data combined and for each individual region. Therefore, using the number of tetrads visited as a weighting variable in regression analyses in order to control for observer effort is justified.

(a) All species

Region	Parameter estimate		Deviance	n
All	-0.01	$\chi^2_{1087}=23.53$***	5.67	1089
Arable-east	-0.01	$\chi^2_{296}=1.80$ ns	5.10	298
Mixed-south	-0.02	$\chi^2_{510}=28.89$***	5.67	512
Pastoral-west	-0.01	$\chi^2_{277}=1.90$ ns	6.11	279

(b) Target species (n=21)

Region	Parameter estimate		Deviance	n
All	-0.04	$\chi^2_{1087}=41.98$***	1.49	1089
Arable-east	-0.07	$\chi^2_{296}=23.57$***	1.36	298
Mixed-south	-0.04	$\chi^2_{510}=23.43$***	1.43	512
Pastoral-west	-0.03	$\chi^2_{277}=8.43$**	1.67	279

Table A4.3 Estimates of the effect of the number of tetrads visited per 10 km square and the difference in the number of species recorded between timed counts plus supplementary records and timed counts only. Poisson regression with a log-link was used. n = number of squares. **P<0.01, ***P<0.001.

5

Large-Scale Temporal Patterns: Relationships Between Change in Abundance of Birds and Change in Lowland Agriculture

D.E. Chamberlain[1], R.J. Fuller[1], R.G.H. Bunce[2] & J.C. Duckworth[2]

[1] British Trust for Ornithology
[2] Institute of Terrestrial Ecology

5. LARGE-SCALE TEMPORAL PATTERNS: RELATIONSHIPS BETWEEN CHANGE IN ABUNDANCE OF BIRDS AND CHANGE IN LOWLAND AGRICULTURE

5.1 Introduction

The Common Birds Census (CBC) is a long-term monitoring scheme, running since 1962, which provides relative annual population estimates of a large number of British bird species (Marchant *et al.* 1990). This scheme has, above all others, been responsible for drawing attention to the population declines of several farmland bird species (Marchant *et al.* 1990, Fuller *et al.* 1995, Siriwardena *et al.* 1998a). Fuller *et al.* (1995) found that of 18 farmland species which could be accurately censused, 15 had shown a population decrease between 1968 and 1991, and population declines were far greater than in woodland over the same period. Siriwardena *et al.* (1998a), analysing the same data, found that out of 42 species considered, 12 had shown significant declines but 14 had increased in relative population size on farmland. However, the majority of declining species were farmland specialists, whereas increasing species tended to be generalists occurring in a wider range of habitats.

A number of studies have considered differences in regional and habitat-specific population trends. Gregory and Marchant (1996) considered changes in the density of corvids and found that Carrion Crow *Corvus corone*, Magpie, Jackdaw and Jay *Garrulus glandarius* had increased significantly on farmland and that the largest increases were in pastoral and mixed farmland habitat. In a similar study of granivorous passerines, it was found that declining species tended to show similar population trends, and declines tended to be greatest on arable farmland sites and in geographical regions associated with arable farmland (Marchant & Gregory 1994). In a study of the Skylark, it was found that population declines were steeper on farmland compared to marginal upland or coastal landscapes (Chamberlain & Crick 1999). There have been a number of studies which have used regression techniques to analyse the effect of specific environmental factors on population change. For example, it has been shown that sub-Saharan migrant populations are significantly related to rainfall in their wintering African quarters (Peach *et al.* 1991, Baillie & Peach 1992). Baillie (1990) also considered the effect of weather on a resident passerine, the Song Thrush, and found that much variation in relative population change could be explained by the number of freezing days in the preceding winter. However, this effect was not sufficient to explain the most recent declines. Donald (1997) considered the associations between change in relative population size of Corn Buntings and the annual variation in a number of agricultural variables. Significant correlations were shown with a large number of variables which themselves were often inter-correlated.

Measures of population change derived from CBC data need to be interpreted with a number of caveats in mind. Firstly, scarce species tend not to be estimated accurately by these methods, so valid analyses may only be carried out on species which occur on a relatively large number of CBC survey sites. Secondly, farmland CBC sites are not randomly distributed throughout the country, but show a strong south-eastern bias, so indices derived at the national level tend to be most representative of lowland habitats and predominantly arable farmland (Fuller *et al.* 1985). Finally, interpretation of relative population change derived from CBC data may be affected by temporal auto-correlation when decreases may be detected due to random drift in the data, rather than any genuine decline. There are methods to detect the degree of autocorrelation (see below), and its potential effects may be ameliorated by controlling for the effects of year (e.g. Peach *et al.* 1991, Donald 1997).

In this section, we consider indices of relative population change and changes in density derived from farmland CBC data from sites across England and Wales for a number of species. The significance of these changes in different habitats and regions is presented in order to identify which farm habitats are particularly associated with population change. We also consider possible effects of environmental factors by identifying which variables show the closest correlation with CBC index.

5.2 Methods

5.2.1 Bird data

Estimates of relative population change and change in breeding density were derived from CBC data for 21 target species (Section 2, Table 2.1). The CBC involves volunteer observers visiting census sites 10 times during the breeding season to determine the number and location of all bird territories using a territory mapping method. (Full survey methods can be found in Marchant *et al.* (1990)). The data are primarily used to calculate population indices which reveal relative changes from year to year, hence providing an estimate of population change. Currently there are c.200 sites covered under the CBC, the majority of which are either in farmland or woodland habitat, although a smaller number cover a variety of other "special" habitats. As CBC sites are not randomly distributed over the UK, estimates of change from the whole farmland CBC data set are unlikely to be representative of UK farmland as a whole (Fuller *et al.* 1985). The CBC is, however, broadly representative of lowland English farmland except the extreme north and south-west. For this reason, indices were derived from different regions and habitats in addition to the whole of England and Wales. Implications of the representativeness of CBC data for the interpretation of the results are considered in the Discussion (5.4).

5.2.2 Habitat data

The area of various crop types and other agricultural management variables were derived from county level data from various sources (see Section 3), but mainly from the MAFF June Census. Regions of differing predominant agriculture were identified, and PCA and DCA scores describing axes of environmental variation across years were analysed in relation to CBC index. Full details are given in Section 3. Farm type (arable, mixed or pastoral) is also defined at the level of the CBC site, using data collected as part of the survey, which includes an annual habitat survey which records crop types and changes in non-crop habitats.

5.2.3 Analyses

CBC population indices were determined using log-linear Poisson regression, a technique which involved modelling logarithms of bird counts using the software TRIM (ter Braak *et al.* 1994, Pannekoek & van Strien 1996). Two types of model were fitted to the data, a linear trends model, and a model incorporating individual site and year effects which reveal detailed year-to-year changes in CBC index. Linear trends were used to describe overall population change rates between 1970 and 1996 and to compare population change in different regions and habitats. These models inevitably obscure the detailed pattern of population change, but they provide a measure of central tendency and so the level of change determined between two given years will be less dependent on year-to-year variation. (Detailed year-to-year changes in CBC index are presented in Fuller *et al.* (1995) and Siriwardena *et al.* (1998a)). The estimates of change in CBC index were adjusted according to the dispersion parameter (the variance/mean, where 1 = no dispersion) and the serial correlation coefficient (where 0 = no degree of autocorrelation), the model being fitted using a Generalized Estimating Equations (GEE) approach (Pannekoek & van Strien 1996). Maximum Likelihood (ML) methods were also used as they provide a measure of model fit, testing whether annual changes are homogenous across sites (using χ^2 tests). However, this method is only accurate when there is no great degree of dispersion or serial correlation, which are fixed at 1 and 0 respectively in this model. Indices were derived for different predominant farming types defined at the site level (based on habitat data collected as part of the CBC) and at the county level (based on the ratio of arable to grass - see Section 3) and compared using Wald tests, which effectively test the homogeneity of slopes. These are not affected by the degree of dispersion or serial correlation, so the ML method was used to give an estimate of model fit in these cases. TRIM is limited in the number of year and covariate levels (i.e. habitats or regions) which can be analysed, which restricted the covariates to three and the number of years to 27.

Indices derived using the model incorporating site and year effects were analysed individually in relation to agricultural variables and using PCA on a matrix of species index by year between 1962 and 1996, considering three data sets: (i) all 21 target species; (ii) only species which showed no significant heterogeneity between sites, so removing those species with less reliable indices; and (iii) passerine species only, again omitting those species which showed significant heterogeneity between sites. Use of PCA enabled the identification of general patterns of change within the farmland bird community and therefore helped to identify groups of species whose populations were changing in similar ways.

General effects of agricultural change on bird populations were considered using axes of environmental variation from DCA and PCA (see Section 3). Principal axes derived from CBC indices were plotted against axes of environmental variation derived from DCA and PCA of agricultural statistics (referred to as HABDCA and HABPCA respectively) in order to identify coincidence in general patterns of change in bird abundances and agricultural management. CBC index for each species was correlated against individual agricultural variables in order to identify the single variable which showed the closest relationship with bird population change (i.e. the variable with the maximum r^2 value). More complex analyses, involving the selection of a large number of variables to identify the best predictive model (e.g. Fuller *et al.* 1997) was possible. However, our goal was not to make predictions based on the data, but to try and identify the most likely factor affecting bird populations, and therefore it was decided to adopt a simple approach to variable selection. As weather conditions may have effects on population dynamics (e.g. Baillie 1990, Greenwood & Baillie 1991, Thomson *et al.* 1997), total rainfall in the previous breeding season (April to July) and mean minimum daily temperature in the preceding winter (November to February) were also entered into the models. This procedure was repeated using year-to-year changes in both CBC index and agricultural variables rather than actual values. This helps to detrend the data, thus reducing any potential temporal autocorrelation. In all cases, bird data were related to agricultural data (including scores from ordination axes) in the same year, and also from one and two years previously. Considering time lags in this way may enable us to detect factors which have delayed effects on bird abundance. We argue that time-lagged models are realistic because effects of change in agriculture may influence population size in subsequent years by lowering recruitment through reduced productivity or survival (e.g. Thomson *et al.* 1997).

5.3 Results

5.3.1 Changes in population by region and farm type

Linear trends were fitted to bird count data for all farmland CBC sites in England and Wales using the GEE procedure, which adjusts estimates according to the degree of serial correlation and dispersion. Generally, data were slightly under-dispersed, but most values were close to one and so the effects of dispersion will be minimal (Table 5.1). The species showing the greatest over-dispersion (>30%) were Lapwing, Starling, Rook, Tree Sparrow and Linnet. Kestrel showed the greatest under-dispersion. Similarly, there was generally a low degree of serial autocorrelation in the data. The highest coefficient was in Rook, but there were also relatively high levels of serial correlation in a number of other species (e.g. Skylark, Blackbird, Reed Bunting, Yellowhammer). Model fit was examined using the ML method (which assumes that there is no significant dispersion or serial correlation). This showed that there were poor model fits (significant heterogeneity between sites) in eight species, Lapwing, Skylark (although this was only just significant at $P<0.05$), Starling, Rook, Whitethroat, Tree Sparrow, Linnet and Corn Bunting. Note that most of these species had relatively high degrees of dispersion and serial correlation. In such cases, confidence limits should be considered unreliable and so no valid test of population change may be made. In terms of estimates of change, there was little difference between models derived from GEE or ML methods, both showing the same significant and non-significant population changes, indicating a negligible effect of dispersion and serial correlation. Of the declining species, eight showed strong evidence of an actual (linear) decline in that the model fitted the data (non-significant goodness-of-fit test) and the upper confidence interval of population change was not positive: Kestrel, Grey Partridge, Turtle Dove, Blackbird, Song Thrush, Bullfinch, Reed Bunting and Yellowhammer (Table 5.1). There were two species, Stock Dove and Chaffinch, which showed a significant increase in population.

The annual population change rates (i.e. linear slopes) in different regions, and Wald tests to compare linear trends, are shown for species where there was significant model fit (Table 5.2). In cases where models did not fit (the same eight species as in Table 5.2), an estimate of annual change is still given, but standard errors and Wald tests were considered unreliable and so were omitted. A number of species showed declines across regions which were consistent with population change rates for England and Wales as a whole (Table 5.1), including Grey Partridge, Stock Dove, Turtle Dove, Blackbird, Song Thrush, Chaffinch and Bullfinch. Kestrel showed a significant population decline over the whole of England and Wales, but there was no evidence of change when considered by region (non-significant Wald test and 95% confidence intervals overlapping 0). Both Blackbird and Song Thrush showed significant differences in the rate of population change between regions, with the steepest declines occurring in the arable-east region. Turtle Dove showed significantly greater declines in pastoral-west counties than the other regions. Stock Dove had increased the most in the arable-east counties. Greenfinch and Goldfinch showed decreases in the arable-east counties but little change in either non-arable region. Yellow Wagtail had decreased substantially in the pastoral-west counties but had changed little in the arable-east counties.

Further analyses were carried out comparing population changes on different farming types, arable, mixed and pastoral, defined at the site level. These definitions are more-or-less equivalent to the predominant farming type (in terms of arable to grass ratio) of the three regions used in the above analysis, and results were correspondingly similar (Table 5.3). The change on grass-dominated farms was the most notably different from its larger-scale counterpart, pastoral-west counties. Grey Partridge, Stock Dove and Chaffinch showed little change on grass farms and Blackbird no longer showed a significant difference between farm types. Generally, declines were lowest and increases highest on pastoral farms for finch species. Grey Partridge and Song Thrush also declined least on pastoral farms. Conversely, several species showed higher rates of decline on pastoral and mixed farms, notably Turtle Dove, Skylark, and Yellow Wagtail.

5.3.2 Changes in density

Fig. 5.1 shows the percentage change in density estimates calculated from CBC sites for 21 farmland species in the arable and non-arable regions between 1970 to 1973 and 1993 to 1996. Mean densities per individual farm within each four year period were determined. The combined mean across all farms was compared between each period with unpaired t-tests for each species. In arable-east counties, there were significant declines in eight species: Grey Partridge, Skylark, Starling, Blackbird, Song Thrush, Tree Sparrow, Corn Bunting and Reed Bunting, with the latter four species showing less than half the density in the 1990s compared to the 1970s. Three species showed significant increases: Kestrel, Whitethroat and Chaffinch, each of which more than doubled in density between the two periods. In the mixed-south counties, the pattern of species change was similar to that in the arable-east counties, but there was no significant change in the density of Kestrel, Skylark or Reed Bunting, there was a significant decline in Turtle Dove and Bullfinch density, and a significant increase in Greenfinch density. In the pastoral-west counties, there were relatively few changes, with Tree Sparrow showing a significant decrease and Chaffinch and Goldfinch showing significant increases in density.

5.3.3 Principal components analysis of CBC indices

PCA analyses were carried out on CBC indices derived from a model incorporating year and site effects across years between 1962 and 1996. When including all 21 species, the first PCA axis represented a strong gradient from species showing evidence of increases (Stock Dove, Rook and Chaffinch) to species showing decreases, with Turtle Dove, Skylark, Blackbird, Song Thrush, Linnet, Bullfinch and Corn Bunting showing very similar axis scores and very similar patterns of decline (Table 5.4). Goodness-of-fit tests revealed that the model fit was questionable (significant χ^2 tests) in eight species (Table 5.1). When these were removed, there was very little difference to the eigenvalue of the first axis or the relative position of each species on the axis (Table 5.4). Finally, a consideration of passerine species only (again omitting species where the TRIM model fit was questionable) also gave similar gradients (Table 5.4). In each analysis, axis 2 accounted for between 16 and 18% of variation in the data. This axis was harder to interpret, but may have represented an axis from species which had shown the largest fluctuations to those that had shown more gradual change. Lower axes could not be meaningfully interpreted.

5.3.4 Relationships between the pattern of changes in agricultural management and bird populations

PCA scores for individual years derived from CBC indices for all 21 target species (Table 4.5) were plotted against HABDCA scores derived from agricultural variables between 1962 and 1995 (Section 3), considering only the first axis in each case. There was a high correlation ($r_{32} = -0.91$, $P<0.0001$) between the first axis scores of the bird and agricultural data, and most of the years tended to be in chronological order. However, this was neither a linear nor a simple curved relationship. Attempts were made to transform the data, and although this reduced some of the curvature, it was still not possible to fit a simple model. A decision was made not to fit a more complex model because the main aim was to describe the relationship rather than to develop predictive models, and it was felt the fitting of such a model would not further the interpretation.

Between 1962 and 1970 there were small changes in PCA score, but little change in HABDCA score (Fig. 5.2a), suggesting that bird numbers were fluctuating independently of agriculture. The lowest early PCA score, from 1963, was due to the crash in numbers of many resident species following the previous severe winter. Between 1971 and 1977 there was a steep increase in HABDCA score, but little change in PCA score, whilst between 1977 and 1982 there was a more gradual increase in HABDCA score combined with a steep decrease in PCA score. Between 1982 and 1988 the HABDCA scores increased sharply whilst the PCA scores continued to decrease. Finally there was a period of minor fluctuations but little major change in both PCA and HABDCA scores between 1989 and 1995, indicating a period of relative stability. The nature of this relationship, with a period of major change in HABDCA score and little change in PCA scores followed by the converse, suggests that a time lag may be involved between agricultural change and bird populations. Incorporation of a time lag of one year appeared to have little effect on the relationship (Fig. 5.2b). With a time lag of two years, a smoother relationship was given ($r_{32} = -0.94$, $P<0.0001$), which was less irregular and more sigmoidal in form (Fig. 5.2c). This was partly because the earliest PCA score that could be used was that from 1964 - i.e. the crash year of 1963 was not included.

The above analyses were repeated, but using HABPCA scores for agricultural variables in place of HABDCA scores, which meant that fewer but more accurately measured agricultural variables from a smaller range of years (1974 to 1991) were considered (see Section 3). The relationship was similar to the previous analysis but more linear in form, and there was again a strong linear correlation between the two ordination axes ($r_{17}=0.97$, $P<0.0001$) and years tended to appear in order, especially in the most rapidly changing part of the plot (Fig. 5.3).

5.3.5 Relationships between individual species and specific components of agricultural management

The CBC index for 21 species derived from models incorporating site and year effects (i.e. revealing detailed annual changes) was analysed in relation to the 19 best measured annual agricultural statistics with a maximum of two interpolated values (listed in Table 3.7), along with total rainfall and mean minimum winter temperature from the preceding year. Linear regression techniques were used, selecting the single variable which maximized r^2 (correlation matrices between CBC index and all agricultural variables are given in Appendix 5.1). A wide range of agricultural variables were selected across species, but rainfall and temperature were not selected in any (Table 5.5). For regression of habitat variables and CBC indices in the same year, nitrogen application to tillage was the most commonly selected variable, having significant negative effects on four granivores and positive effects on Stock Dove. New grass, hay production, total barley, silage production and turnip and swede area were selected in at least two species. With a time lag of one year in the agricultural data set, new grass, turnips and swedes and total barley tended to be selected for the same species as without a time lag. Winter or spring sown barley was more commonly selected, occurring in eight species, six of which were granivorous passerines. Apart from Stock Dove, declines in the other seven species were associated either with an increase in winter barley or a decrease in spring barley. Similar results were obtained with a lag of two years, particularly for the granivores and thrushes. Two species, Yellow Wagtail and Whitethroat, showed no significant variable selection. These are long-distance migrant species and the lack of significant relationships may indicate that population change is more associated with factors operating in their wintering grounds (e.g. Peach *et al.* 1991).

An alternative way to consider the effects of agricultural management on bird populations is to look at the relationship between inter-annual change in CBC index and inter-annual change in agricultural statistics. A problem with using absolute values is that generally decreasing species will inevitably be highly correlated with generally decreasing agricultural variables (Appendix 5.1). Using inter-annual changes should go some way to detrending the data and may provide a more accurate picture of the effects of agricultural management on bird populations. The single variable providing the best fit to inter-annual change in CBC index for each species is shown in Table 5.6. With no time lag, the temperature of the preceding winter had the most consistent effects on species, a drop in temperature coinciding with a decrease in CBC index in Skylark, Blackbird, Song Thrush, Chaffinch and Yellowhammer. No other variable was selected in more than one species, and there was no significant relationship between CBC index change and any variable in eight species. With a time lag of one year, there were more agricultural variables selected, with total cereal area or the area of winter cereals being negatively correlated with inter-annual change of five granivorous passerines: Goldfinch, Linnet, Bullfinch, Corn Bunting and Reed Bunting. Similar results were observed with a straightforward correlation of CBC index and crop area (Table 5.5). With a time lag of two years, there were fewer consistent variable selections.

5.4 Discussion

How representative of English farmland and of its associated bird populations are farmland CBC plots? This is an important question for the interpretation of the results presented here. Fuller *et al.* (1985) concluded that farmland CBC plots could not be regarded as representative of the farmland in the north of England and south-west England. Fig. 5.4 shows the distribution of CBC plots used in four pairs of years for calculation of population indices. In each case a concentration of plots is evident in central-eastern England. The distribution of plots is relatively sparse in northern England (Yorkshire, Northumberland, Cumbria, Lancashire), parts of western England (Cornwall, Devon, Somerset, Gloucestershire, Herefordshire & Worcestershire) and Wales. Despite the uneven distribution of plots, the samples for the pastoral region were not generally smaller than those for the arable region (see Tables 5.2 and 5.3). Nonetheless, it must be acknowledged that the data cannot adequately reflect population changes that may have occurred in predominantly grassland areas in northern and western areas. The implication is that the CBC probably measures population change in arable and mixed farming areas better than it does in grass-dominated areas.

Population trends were simplified using linear models in this analysis, mainly for ease of interpretation. Although these models fitted the data adequately in most cases, a better fit would normally have been provided by a more complex model incorporating individual year effects. Previous analyses have used methods to incorporate non-linear trends in CBC data over similar periods. Fuller *et al.* (1995) used quadratic regression to describe population trends. Siriwardena *et al.* (1998) used a smoothing technique to reveal underlying trends, and determined confidence intervals of change using a bootstrapping procedure. Estimates of change were very similar between these studies and the linear trends model used here (Table 5.7), indicating that in most species, population trends can be reasonably approximated by linear models. Generally, Siriwardena *et al.* (1998) gave less extreme estimates of population change, but the significance of the change tended to concur with the linear model approach. The most notable exception was Whitethroat, which was shown to have significantly decreased by Siriwardena *et al.* (1998a), but to have significantly increased in this study. This is a consequence of the time period considered, as Whitethroat showed a major population crash between 1968 and 1970 caused by factors in its wintering range (Baillie & Peach 1992). Siriwardena *et al.* (1998a) also detected a significant increase in Goldfinch, but we found no evidence of significant population change. Rook is not well covered by the CBC due to its colonial nesting habits and consequent patchy distribution, and was not analysed by either Fuller *et al.* (1995) or Siriwardena *et al.* (1998a). There have been specific surveys of this species designed to take into account its nesting distribution, and it has been estimated that the Rook population in England and Wales has increased by 38% between 1975 and 1997 (Marchant & Gregory in press). Linear models in this study estimated an increase of 117%, but models did not fit well due to a high degree of over dispersion, so the CBC index derived from TRIM is likely to over estimate population increase in this species.

There was some evidence that declines in relative population size and density were greater in arable or mixed counties/farm types than grass-dominated farms/regions in Grey Partridge, Blackbird, Song Thrush, Tree Sparrow, Linnet and Reed Bunting. This may imply that changes in the management of arable farms are in some way responsible for the overall population declines. For these species, the arable-east region held the highest density in the early-1970s, but in the mid-1990s densities were similar across different regions, so the arable-east counties have decreased most in absolute density. Grey Partridge is the only species where a strong link has been shown between the management of arable farmland and population decline, which is partly due to increased herbicide applications eradicating food plants essential for their invertebrate prey (Potts 1986). In this species, relative declines would therefore be expected to be more severe on arable-dominated farms. A number of other possible explanations may be put forward to explain the greater decline on arable/mixed farmland in the other species, including changes in sowing regimes, increased pesticide use and loss of farm diversity (Section 2). However, a number of other species where these factors could equally well apply showed no indication that declines were more consistently linked to any particular farm type or region. For example, it has been suggested that finches and buntings in particular may be affected by increases in herbicide applications and loss of stubbles outside the breeding season on arable farms (Section 2), but in Corn Bunting, declines were more associated with pastoral farms and declines were more or less equal across farming types and regions in Bullfinch and Yellowhammer. Furthermore, Chaffinch increased on all farming types. Therefore, it seems that there are no general patterns of decline across species with respect to region or farm type, and agricultural factors having a potential effect on bird abundance are likely to be species-specific.

When considering general axes of environmental variation, there was a clear relationship between the period of greatest change in agricultural management and overall bird population change, thus change in farm management seems to be a plausible explanation for the overall population declines. Also, although the magnitude of relative population change varied a lot between declining species, many show very similar patterns in the timing of change (Siriwardena *et al.* 1998). Attempting to identify individual variables which may have been responsible for declines in individual species was difficult as so many variables showed similar patterns of decline, and thus there was a high degree of collinearity in the data (Appendix 3.1 and 5.1). Consequently, a number of variables were selected as explaining the most variation in CBC index which were difficult to link to a likely mechanism causing an effect on the population of a given species. For example, there is evidence to suggest that the widespread decline in Skylarks is related to changes in sowing regimes, particularly the decline in spring cereals (Wilson *et al.* 1997), and the loss in farmland habitat diversity (Chamberlain & Gregory 1999). However, the area of turnips and swedes showed the closest correlation with Skylark CBC index. These have declined due to changes in crop rotations and their decreasing use as fodder crops (Section 3), but are unlikely to have ever been a crop favoured by Skylarks, so while the temporal pattern of turnip and swede area is indicative of general intensification, it does not seem likely to have had a causal effect on Skylarks. Similar conclusions could be drawn about variables selected in many other species.

There were, however, some relationships which supported hypotheses or earlier work on farmland birds. When considering inter-annual changes, there were five species which showed a significant relationship between relative population change and temperature in the preceding winter, suggesting effects of survival outside the breeding season on population size (Greenwood & Baillie 1991, Thomson *et al.* 1997). A possible consequence of changes in sowing regimes is a decrease in stubbles which may be a valuable food source outside the breeding season, particularly for granivorous species (Wilson *et al.* 1996). Effects of variables associated with stubbles may therefore be expected to operate with a time lag (i.e. the population is dependent on past events, not the habitat as it is when they occupy territories). A number of granivorous species showed some relationship with winter or spring cereals with a time lag of one and two years. When inter-annual changes were considered, similar relationships were observed with a time lag of one year. This supports the idea of a causal link between the population size of finches and buntings and changes in sowing regimes. Effects of sowing regimes may be expected to be greater in arable and mixed farmland, so declines may be expected to be greater in these farm types and corresponding regions for species showing significant effects of spring or winter barley. However, this was the case for only two species, Linnet and Reed Bunting. In other species, there was little concurrence between regional trends and effects of individual agricultural factors.

In considering the effects of agricultural change on bird populations, there has so far been an implicit assumption that year-to-year changes in causal agricultural factors will have a direct effect on population change, i.e. a change in a habitat variable will cause a proportional change in bird populations (either immediately, or with a delayed effect). An alternative mechanism, however, could involve an agricultural variable reaching a critical threshold before affecting bird populations. For example, let us assume a hypothetical causal effect of cereal stubble area on Corn Bunting populations (as suggested by Donald & Evans 1994). Initial declines of stubbles have little effect on Corn Bunting populations as enough suitable habitat will be available to the mobile flocks formed by this species outside the breeding season. However, once stubbles decrease to a certain area, the Corn Bunting population may no longer tolerate the reduced food sources and the population may crash. Such an effect would not be detected by considering correlations between agricultural variables and CBC index, but it may be revealed by considering more general patterns of change. The correlation between HABDCA score for change in agricultural variables and PCA score of CBC index showed a period of fairly rapid change in agricultural management but little change in CBC index across species between 1970 and 1977, followed by a rapid change in CBC index (Fig. 5.2). Such a pattern would be expected if bird populations responded to threshold levels in agricultural management change. This relationship also implies that this threshold may be defined by a number of interacting factors, rather than a single causal agent.

This section has sought to quantify the population trends in selected farmland bird species since 1970, and to determine whether these trends are more associated with particular types of agriculture, and whether population changes coincide with changes in agricultural management which may provide support for a causal effect. Whilst changes in the majority of bird species have coincided with the period of greatest overall change in agricultural management during the mid to late-1970s, it has proved difficult to pinpoint individual factors which could have a plausible effect on bird populations. Winter temperature is clearly an important determinant of inter-annual changes in population size for a number of species, but there is no evidence that winter temperature has had any effect on overall population change (Section 2). One factor which was consistently implicated and which has a possible causal mechanism affecting population size was change in sowing regime, revealed by significant effects of either winter or spring cereals on granivores. However, due to the collinearity in the data (Appendix 3.1 and 5.1) and the lack of corroborative evidence across different scales of analysis, these relationships can only be regarded as weak evidence of a link. Further evidence is needed at the farm level before drawing firmer conclusions on the effects of changes in agricultural management on population change.

5.5 Summary

1. This section examines long-term changes in the abundance of farmland birds in relation to (a) region, (b) farmland type, (c) specific components of change in agricultural management. The overall aim of these analyses is to obtain insights into which aspects of agricultural change, if any, may have driven the large declines in populations of several farmland birds. In addition, we investigate the closeness of fit between the timing of agricultural intensification and the timing of declines in farmland bird populations.

2. Linear models were fitted to the Common Birds Census (CBC) indices for the period 1970 to 1996 for 21 species using log-linear Poisson regression. Linear trends were used to compare population changes between regions and farmland types. Estimates of linear trends derived in this way were very similar to those of previous studies that have modelled non-linear trends using CBC data. Therefore, the linear models gave

reasonable approximations of population trends. The data generally exhibited low levels of dispersion and serial autocorrelation.

3. All but four species showed an overall decline. However, a very rigorous approach was taken to identifying declining species, both at national and regional scales. Eight species showed very strong evidence of overall decline in that both their upper and lower confidence limits were negative and the model fitted the data. Two species - Stock Dove and Chaffinch - showed a significant increase. Regions were defined as predominantly arable, predominantly mixed and predominantly grassland (see Section 3). Blackbird and Song Thrush declined more in the arable-east region than elsewhere. Greenfinch and Goldfinch declined in the arable-east region but showed little change elsewhere. On the other hand, Turtle Dove declined most in the pastoral-west region and Stock Dove increased most in the arable-east region. Population changes at the level of farmland type were broadly consistent with the regional analysis. Grey Partridge, Song Thrush, Greenfinch and Goldfinch declined most on arable farms. Skylark, Turtle Dove and Yellow Wagtail declined most on mixed or pastoral farms. Stock Dove and Chaffinch had increased most on arable farms.

4. Analysis of changes in density were undertaken to complement those of change in population level as measured by the CBC indices. Mean densities were calculated for two time periods: 1970 to 1973 and 1993 to 1996. Densities of the following species had significantly declined: Grey Partridge, Skylark, Starling, Blackbird, Song Thrush, Tree Sparrow, Corn Bunting, Reed Bunting. The latter four species had declined by >50%. In the mixed-south counties the pattern of change was similar to that in the arable-east region, but there were relatively few changes in the pastoral-west region.

5. Ordination was used to generate (a) an overall measure of change in agricultural management between the early-1960s and mid-1990s and (b) a measure of overall change in farmland bird populations over the same period. The respective data used in these analyses were a wide suite of agricultural variables and the CBC population indices. Until 1970 there was no systematic change in either measure. From 1971 to 1988 there was major progressive change in agriculture. Between 1971 and 1977, however, there was little evidence of change in bird populations, but the period 1977 to 1988 was marked by major changes in bird populations. Post 1989 there has been relatively little broad change in agricultural management or bird populations. These analyses indicate that agricultural intensification broadly matches the period of bird population change but with a time lag in the response of birds. Repeating the analyses, using only the most accurately measured agricultural variables for the period 1974 to 1991, produced a very close temporal matching between the pattern of agricultural intensification and changing farmland bird populations.

6. Linear regression was used to relate farmland CBC indices for 21 farmland bird species to specific measured changes in agricultural management together with some weather variables. The single strongest correlate was reported and analyses were conducted with and without time lags in the bird data. Across species, a wide range of agricultural variables was selected but weather variables were never selected. Only two species showed no significant relationships. The most striking feature of the analyses was that with time lags of one and two years several species showed

relationships with timing of sowing of cereals - bird declines tended to be associated either with decrease in spring barley or with increase in winter barley. Most granivorous species showed such a relationship. These analyses were repeated using inter-annual changes in both the dependent and independent variables, which helps to de-trend the data and is more likely to give an accurate picture. With no time lag, weather variables featured as the strongest correlates for five species but for eight species there were no significant relationships. With a one-year lag, agricultural variables featured more frequently with winter cereals emerging as the strongest correlate for five species. With a two-year lag there were few consistent relationships across species.

7. We conclude that large-scale shifts in agricultural management are a plausible explanation for the large declines that have occurred in farmland bird populations because there is a clear temporal matching, but perhaps with a time lag, between the periods of greatest change in agriculture and birds. We suggest that threshold models, perhaps relating to critical amounts of habitat, may be relevant in explaining the lag in response of birds.

8. We conclude that there are few consistent patterns of decline across species with respect to region and farm type: some species have declined more in arable than mixed/pasture regions but others show the opposite pattern. This suggests that different processes have operated for different species. Identifying specific factors that may be responsible for the declines is problematic because of the high level of intercorrelation between agricultural variables. Many of the variables selected in the regression models are probably not causal. However, two points can be made. First, there is evidence that winter weather is important in determining short-term change in numbers of several farmland species. Second, changes in the timing of sowing are especially frequent correlates of population change in farmland birds, notably among granivores.

Species	No. sites	%Change	95% Confidence limits	Dispersion	Serial correlation	Goodness-of-fit
Kestrel	274	-36.49	-55.03 to -17.95	0.55	0.02	ns
Grey Partridge	250	-75.08	-82.00 to -68.16	0.87	0.13	ns
Lapwing	229	-47.65	-60.53 to -34.77	1.33	0.22	***
Stock Dove	205	70.07	29.05 to 111.09	0.84	0.09	ns
Turtle Dove	169	-82.44	-87.63 to -77.25	0.86	0.07	ns
Skylark	340	-52.82	-57.86 to -47.78	1.07	0.30	*
Yellow Wagtail	134	-4.03	-46.82 to 38.76	0.96	0.14	ns
Starling	292	-58.62	-65.72 to -51.52	1.48	0.22	***
Rook	56	116.58	2.76 to 230.40	7.17	0.48	***
Whitethroat	300	113.60	69.17 to 158.03	1.10	0.12	**
Blackbird	367	-43.17	-47.05 to -39.29	0.86	0.27	ns
Song Thrush	349	-76.45	-79.70 to -73.20	0.86	0.21	ns
Tree Sparrow	222	-89.37	-92.74 to -86.00	1.39	0.24	***
Chaffinch	359	29.61	20.79 to 38.43	0.79	0.24	ns
Bullfinch	259	-81.06	-85.49 to -76.63	0.75	0.06	ns
Greenfinch	318	-6.84	-21.48 to 7.80	0.96	0.20	ns
Goldfinch	309	-14.20	-31.51 to 3.11	0.99	0.11	ns
Linnet	314	-57.13	-65.95 to -48.31	1.34	0.25	***
Corn Bunting	121	-84.98	-91.45 to -78.51	1.19	0.24	***
Reed Bunting	237	-55.36	-66.34 to -44.65	1.05	0.29	ns
Yellowhammer	303	-36.37	-44.84 to -27.90	0.95	0.29	ns

Table 5.1 Estimated population change of selected species on farmland in England and Wales between 1970 and 1996. Population indices were calculated using log-linear Poisson regression on CBC data. Population change rates, confidence intervals, dispersion and serial correlation were determined using the GEE method, goodness-of-fit was determined using the ML method (see Section 5.2.3 for further details). Significant goodness-of-fit indicates that the model was a poor fit to the data. *P<0.05, **P<0.01, ***P<0.001 (χ^2 test).

Species	Arable east	n	Mixed-south	n	Pastoral-west	n	Wald test
Kestrel	1.05±1.51	66	-2.25±1.86	143	-3.59±2.16	65	ns
Grey Partridge	-6.23±1.00	56	-6.34±1.32	121	-3.84±1.35	73	ns
Lapwing	-5.79	47	-3.00	110	-1.68	72	n/a
Stock Dove	2.69±0.92	98	1.98±1.11	113	0.43±1.63	44	ns
Turtle Dove	-5.48±0.67	72	-10.32±1.48	86	-22.96±6.04	11	***
Skylark	-3.27	84	-2.66	169	-3.24	87	n/a
Yellow Wagtail	1.36±2.02	42	3.19±2.30	59	-7.31±2.53	33	***
Starling	-2.01	65	-4.53	143	-2.94	84	n/a
Rook	9.08	7	3.09	33	5.27	16	n/a
Whitethroat	3.24	81	3.53	150	0.40	69	n/a
Blackbird	-2.49±0.25	86	-2.46±0.30	181	-1.23±0.35	100	***
Song Thrush	-7.41±0.44	81	-5.73±0.58	176	-3.14±0.67	92	***
Tree Sparrow	-9.81	60	-8.58	105	-7.93	57	n/a
Chaffinch	1.44±0.30	86	0.99±0.34	177	0.97±0.39	96	ns
Bullfinch	-7.09±0.79	70	-6.14±1.13	137	-5.57±1.34	52	ns
Greenfinch	-2.83±0.47	80	2.02±0.61	162	-1.57±0.77	76	***
Goldfinch	-3.20±0.76	73	0.35±0.90	161	-0.50±1.13	75	***
Linnet	-6.14	81	-1.29	152	-4.04	81	n/a
Corn Bunting	-7.52	35	-7.62	63	-5.67	23	n/a
Reed Bunting	-6.46±0.76	66	-0.68±0.95	117	-3.94±1.03	54	ns
Yellowhammer	-1.32±0.36	84	-2.61±0.48	156	-0.26±0.64	63	ns

Table 5.2 Estimated annual percentage population change rate (±s.e.) of selected species on farmland in regions of differing predominant agriculture in England and Wales between 1970 and 1996. N = number of sites in which the species was recorded in at least one year. Population indices were calculated using log-linear Poisson regression on CBC data fitted using the ML method. Wald tests detect significant differences in trend between regions. Wald tests were not valid (n/a) and no reliable estimate of the standard error was made if there was a significant goodness-of-fit test. *P<0.05, **P<0.01, ***P<0.001.

Species	Arable	n	Mixed	n	Pastoral	n	Wald test
Kestrel	1.79±3.21	43	-0.43±3.37	154	-4.77±3.65	79	ns
Grey Partridge	-8.22±1.78	42	-4.75±1.90	158	-0.88±2.68	48	*
Lapwing	-8.16	26	-5.35	137	3.08	72	n/a
Stock Dove	5.85±1.86	31	2.61±1.98	115	1.06±2.04	50	*
Turtle Dove	-4.35±1.58	38	-6.68±1.72	94	-16.24±3.71	13	**
Skylark	-1.78±0.45	55	-3.29±0.50	197	-3.34±0.63	86	**
Yellow Wagtail	7.18±1.50	26	-3.16±1.89	68	-5.77±3.12	27	***
Starling	-0.78	44	-3.09	163	-4.18	86	n/a
Rook	-0.57	10	4.79	29	23.07	17	n/a
Whitethroat	4.06	55	2.83	178	1.98	61	n/a
Blackbird	-1.60±0.42	56	-2.21±0.45	208	-1.77±0.50	106	ns
Song Thrush	-7.71±0.89	51	-6.10±0.95	205	-3.84±1.09	94	***
Tree Sparrow	-6.13	35	-10.69	141	-1.00	40	n/a
Chaffinch	2.40±0.49	56	1.32±0.53	204	0.72±0.56	101	**
Bullfinch	-6.83±1.40	34	-6.77±1.56	152	-5.12±1.78	64	ns
Greenfinch	-4.39±0.94	52	-0.61±1.00	187	2.21±1.15	80	***
Goldfinch	-3.45±1.61	47	-1.55±1.69	168	0.44±1.75	84	*
Linnet	-4.55	53	-5.10	179	1.92	82	n/a
Corn Bunting	-5.65	30	-7.40	80	-14.89	10	n/a
Reed Bunting	-7.18	35	-4.59	141	3.78	62	n/a
Yellowhammer	-0.67±0.51	52	-1.76±0.58	186	-2.02±0.81	59	ns

Table 5.3 Annual percentage population change rates (±s.e.) in three different farm types defined at the level of the CBC site. N = number of sites in which the species was recorded in at least one year. Rates of change were calculated from linear trends fitted by log-linear Poisson regression of CBC index on year between 1970 and 1996. Wald tests were not valid (n/a) if there was no fit of a linear trends model (significant χ^2 goodness of fit test). Wald tests detect significant differences in trend between farm types. *P<0.05, **P<0.01, ***P<0.001.

Species	All data	Species with reliable indices	Passerines with reliable indices
Rook	-0.28		
Chaffinch	-0.24	-0.27	-0.29
Stock Dove	-0.21	-0.24	
Greenfinch	0.05		
Kestrel	0.06	0.08	
Whitethroat	0.09	0.10	0.08
Yellow Wagtail	0.12	0.14	0.15
Goldfinch	0.13	0.17	0.20
Yellowhammer	0.15	0.18	0.22
Lapwing	0.16		
Reed Bunting	0.17	0.23	0.29
Grey Partridge	0.23	0.26	
Starling	0.24		
Corn Bunting	0.26		
Linnet	0.26		
Bullfinch	0.26	0.32	0.38
Blackbird	0.27	0.33	0.39
Song Thrush	0.27	0.33	0.38
Turtle Dove	0.28	0.34	
Skylark	0.28		
Tree Sparrow	0.28		
% Variation	56.3	54.6	56.8

Table 5.4 Principal Components Analysis scores from the first principal axis of CBC indices between 1962 and 1996 in order of scores on the axis for all data. Species with reliable indices are those with no significant heterogeneity between sites (see Table 5.1).

Species	Year n	Year n-1	Year n-2
Kestrel	new grass+++	new grass+++	fertilizer (tillage)---
Grey Partridge	hay production+++	turnips & swedes+++	turnips & swedes+++
Lapwing	new grass+	new grass++	total barley+++
Turtle Dove	turnips & swedes+++	turnips & swedes+++	spring barley+++
Stock Dove	fertilizer (tillage)+++	winter barley+++	rough grazing---
Skylark	turnips & swedes+++	turnips & swedes+++	fertilizer (tillage)---
Yellow Wagtail			
Starling	total barley+++	total barley+++	turnips & swedes+++
Rook	turnips & swedes---	turnips & swedes---	fertilizer (tillage)+++
Whitethroat			
Blackbird	silage production---	spring barley+++	spring barley+++
Song Thrush	rough grazing+++	rough grazing+++	fertilizer (grass)---
Tree Sparrow	hay production+++	total wheat---	fertilizer (tillage)---
Chaffinch	total barley---	oilseed rape+++	oilseed rape+++
Greenfinch	fertilizer (tillage)---	winter barley--	winter barley--
Goldfinch	new grass+	winter barley-	winter barley--
Linnet	fertilizer (tillage)---	winter barley---	winter barley---
Bullfinch	fertilizer (tillage)---	winter barley---	rough grazing+++
Corn Bunting	silage production---	spring barley+++	spring barley+++
Reed Bunting	fertilizer (tillage)---	winter barley---	winter barley---
Yellowhammer		total barley+	total barley++

Table 5.5 The effects of agricultural variables on CBC index for England and Wales, including time lags of one and two years in the environmental data set. Variables which had the maximum r^2 value out of all single variable models were selected for each species. Sample size = 20 for each analysis. +/- $P<0.05$, ++/-- $P<0.01$, +++/--- $P<0.001$, sign indicates positive or negative correlation.

Species	Year n	Year n-1	Year n-2
Kestrel			permanent pasture+
Grey Partridge	potatoes+		silage production-
Lapwing			slurry application+
Stock Dove	permanent pasture++	bare fallow+	bare fallow--
Turtle Dove		fertilizer (tillage)-	
Skylark	winter temperature+		
Yellow Wagtail	bare fallow++		
Starling		potatoes+	silage production-
Rook	fertilizer (tillage)++	sugar beet-	new grass-
Whitethroat	hay production+	silage production-	hay production-
Blackbird	winter temperature++		fertilizer (grass)-
Song Thrush	winter temperature++	hay production-	
Tree Sparrow		turnips and swedes+	
Chaffinch	winter temperature+		hay production-
Greenfinch	turnips and swedes++	hay production-	slurry application+
Goldfinch	total wheat--	total barley--	potatoes--
Linnet		winter barley-	potatoes--
Bullfinch		total barley--	bare fallow++
Corn Bunting		total wheat-	total wheat+
Reed Bunting	new grass++	winter barley-	winter barley---
Yellowhammer	winter temperature+++		

Table 5.6 The effects of inter-annual changes of agricultural variables on inter-annual changes in CBC index, including time lags of one and two years in the environmental data set. Variables which had the maximum adjusted r^2 value out of all single variable models were selected for each species. Sample size = 20 for each analysis. +/- $P<0.05$, ++/-- $P<0.01$, +++/--- $P<0.001$, sign indicates positive or negative correlation.

	Population change estimate (%)		
Source	This study	Fuller *et al.* (1995)	Siriwardena *et al.* (1998a)
Period	1970-1996	1968-1991	1968-1995
Kestrel	-37	-33	n/a
Grey Partridge	-75	-73	-74*
Lapwing	-48†	-47	-38†
Stock Dove	70	296	162*
Turtle Dove	-82	-72	-65†
Skylark	-53†	-54	-49
Yellow Wagtail	-4	-11	n/a
Starling	-59†	-16	-40
Whitethroat	114†	-18	-38
Blackbird	-43	n/a	-41*
Song Thrush	-76	n/a	-63*
Tree Sparrow	-89†	-85	-83
Chaffinch	30	n/a	28*
Bullfinch	-81	n/a	-45*
Greenfinch	-7	-6	3
Goldfinch	-14	6	59
Linnet	-57†	-56	-41
Corn Bunting	-85†	-76	-61†
Reed Bunting	-55	-59	-27*
Yellowhammer	-36	-5	-26*

Table 5.7 A comparison of population change rates on farmland CBC sites using different methods of analysis of CBC indices. This study uses indices derived for England and Wales. The other two use data from the whole of the UK. n/a not considered in analysis, * significance of changes detected the same for both this study (linear trends model) and the methods of Siriwardena *et al.* (1998a), † confidence limits unreliable due to poor model fit.

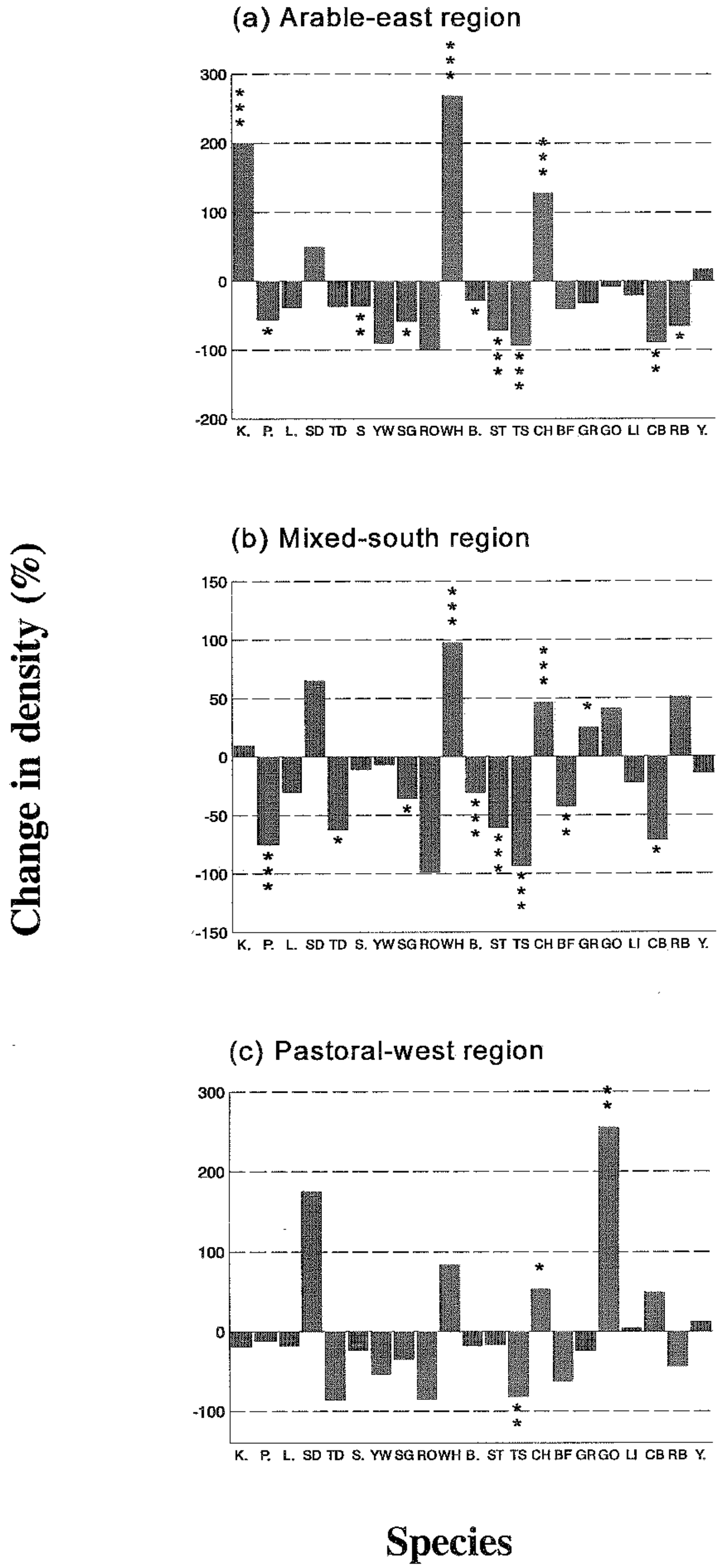

Figure 5.1 Percentage change in density between the periods 1970-73 and 1993-96 of 21 selected species on CBC sites in arable and non-arable regions of England and Wales (see Section 3). *P<0.05, **P<0.01, ***P<0.001 (t-test). Abbreviated species codes are given in Section 2, Table 2.1. Sample sizes (number of CBC sites): (a) 53-72, (b) 119-147, (c) 63-81.

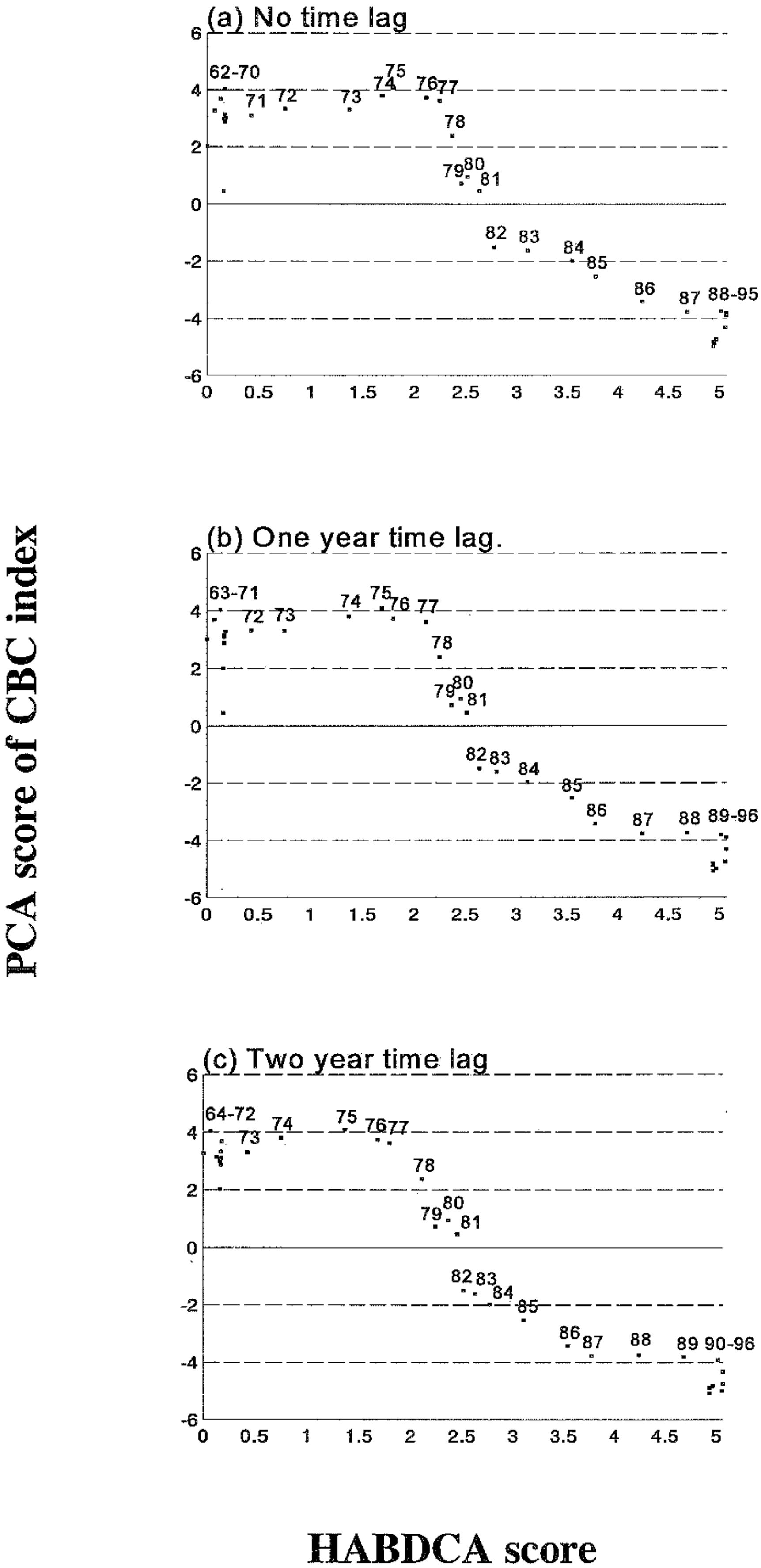

Figure 5.2 The relationship between the first axis of PCA of CBC indices, and the first axis from HABDCA (agricultural variables) (Section 3). Years corresponding to PCA axis scores (i.e. bird data) are given on the figure. (a) No time lag; (b) One year time lag in the agricultural data; (b) Two year time lag in the agricultural data.

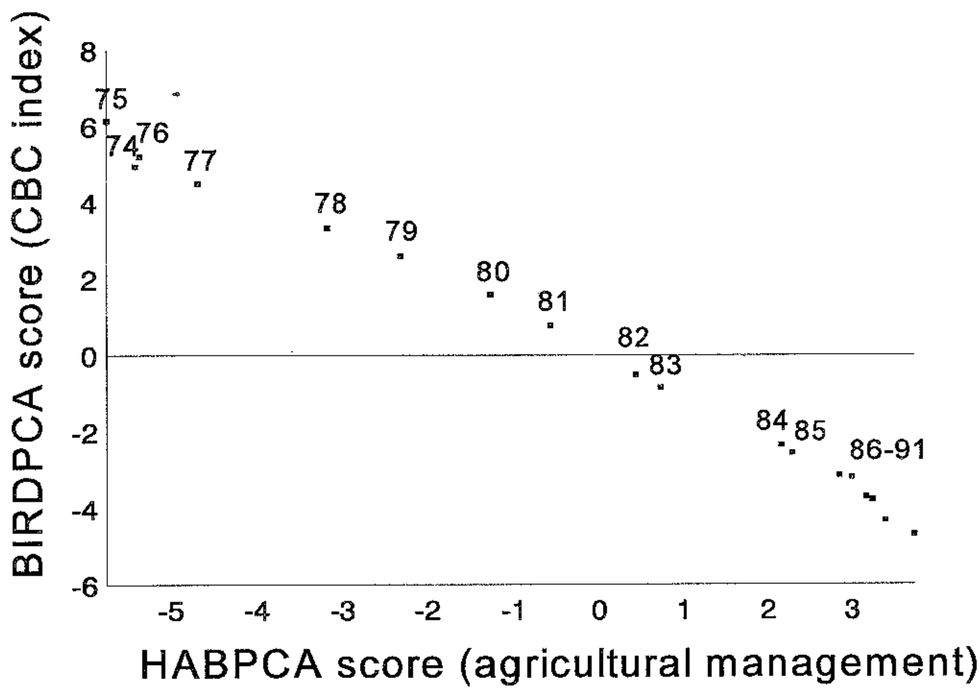

Figure 5.3 The relationship between the first axis of PCA of CBC index, and the first axis from HABPCA (agricultural variables) (Section 3) between 1974 and 1991. Years corresponding to PCA axis scores (i.e. bird data) are given on the figure.

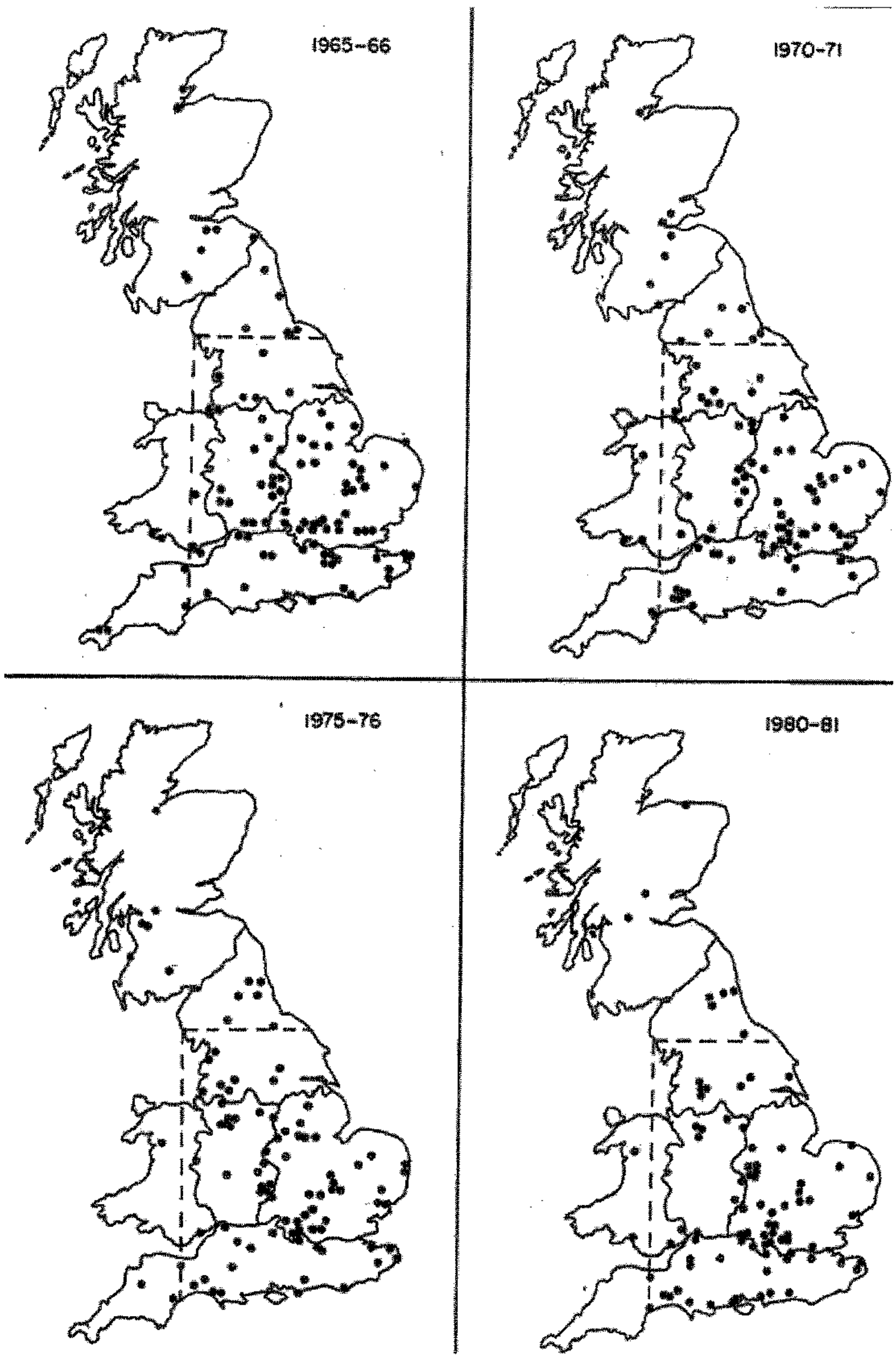

Figure 5.4 The distribution of CBC plots in Great Britain used in the calculation of population changes of birds in four pairs of years. The broken lines are the easting 3000 and the northing 5000 of the National Grid within which farmland CBC plots are considered to be broadly representative of farmland. This figure is drawn from Fuller *et al.* (1985) which discusses the representativeness of farmland CBC plots in relation to agricultural practice.

APPENDIX 5.1 Correlation matrix of annual agricultural variables and CBC index

	Bare fallow	Barley	Wheat	Rape	Rough grazing	Slurry	Oats	Sheep	Potatoes	Sugar beet
Kestrel	+	+++	---	---	+	ns	ns	--	+	ns
Grey Partridge	+	+++	---	---	+++	ns	+++	---	+++	ns
Lapwing	ns	+++	-	--	ns	ns	ns	--	ns	+
Stock Dove	--	---	+++	+++	---	ns	---	+++	---	ns
Turtle Dove	+++	+++	---	---	+++	ns	+++	---	+++	ns
Skylark	++	+++	---	---	+++	ns	+++	---	+++	ns
Yellow Wagtail	ns	ns	ns	ns	ns	+	ns	ns	ns	+
Starling	ns	+++	---	---	+	ns	ns	---	+	ns
Rook	---	---	+++	+++	---	ns	---	+++	---	---
Whitethroat	ns	ns	ns	ns	ns	-	ns	ns	ns	ns
Blackbird	+++	+++	---	---	+++	-	+++	---	+++	ns
Song Thrush	+++	+++	---	---	+++	-	+++	---	+++	-
Tree Sparrow	++	+++	---	---	+++	ns	+++	---	+++	ns
Chaffinch	---	---	+++	+++	---	ns	---	+++	---	ns
Bullfinch	+++	+++	---	---	+++	-	+++	---	+++	ns
Greenfinch	++	+	---	--	+++	--	+++	--	++	ns
Goldfinch	+	+	---	--	++	ns	+	--	+	ns
Linnet	++	+++	---	---	+++	ns	+++	---	+++	ns
Corn Bunting	+++	+++	---	---	+++	ns	+++	--	+++	ns
Reed Bunting	++	++	---	+++	-	-	+++	---	+++	ns
Yellowhammer	ns	+++	ns	-	ns	ns	ns	-	ns	ns

Table A5.1 Correlations between the 19 best measured variables (Table 3.7), temperature and rainfall. Sample size = 20 for each correlation. +/- P<0.05, ++/--P<0.01, +++/---P<0.001 (Pearson correlation coefficient). Correlations between the 18 best measured variables (Table 3.7), temperature and rainfall. Sample size = 20 for each correlation. +/- P<0.05, ++/--P<0.01, +++/---P<0.001 (Pearson correlation coefficient).

	Silage	Hay	Spring barley	Winter barley	Fertilizer (tillage)	Fertilizer (grass)	Root crops	Permanent grass	New grass	Temperature	Rainfall
Kestrel	---	+++	++	-	---	ns	+++	++	+++	ns	-
Grey Partridge	---	+++	+++	---	---	---	+++	++	+++	ns	ns
Lapwing	--	++	++	ns	ns	ns	++	+	+++	-	ns
Stock Dove	+++	---	---	+++	+++	+++	---	-	--	ns	ns
Turtle Dove	---	+++	+++	---	---	---	+++	+++	+++	ns	-
Skylark	---	+++	+++	---	---	---	+++	+++	+++	ns	-
Yellow Wagtail	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Starling	---	+++	+++	ns	--	-	+++	++	+++	ns	ns
Rook	+++	---	---	+++	+++	+++	---	---	---	ns	ns
Whitethroat	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Blackbird	---	+++	+++	---	---	---	+++	+++	+++	ns	-
Song Thrush	---	+++	+++	---	---	---	+++	+++	++	ns	-
Tree Sparrow	---	+++	+++	---	---	---	+++	+++	+++	ns	-
Chaffinch	+++	---	---	+++	+++	+++	---	---	---	ns	ns
Bullfinch	---	+++	+++	---	---	---	+++	++	+++	ns	-
Greenfinch	---	++	++	---	---	---	+++	++	+	ns	ns
Goldfinch	--	++	+	--	---	ns	+++	+	+++	ns	-
Linnet	---	+++	+++	---	---	---	+++	+++	+++	ns	--
Corn Bunting	---	+++	+++	---	---	---	+++	+++	+++	ns	-
Reed Bunting	---	+++	+++	---	---	---	+++	++	+++	ns	--
Yellowhammer	-	+	+	ns	ns	ns	+	ns	+	ns	ns

Table A5.1 Continued.

	Bare fallow	Barley	Wheat	Sheep	Potatoes	Hay	Spring barley	Fertilizer (tillage)	Root crops	Permanent grass	New grass	Temperature	Rainfall
Grey Partridge	ns	ns	ns	ns	+	ns	ns	ns	ns	ns	ns	ns	ns
Lapwing	ns	ns	ns	ns	ns	ns	-	ns	ns	ns	ns	-	ns
Stock Dove	ns	-	++	ns	ns	ns	ns	ns	ns	-	ns	ns	-
Turtle Dove	ns	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Skylark	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	+	+	ns
Yellow Wagtail	++	ns	-	ns	ns	ns	ns	ns	ns	+	ns	ns	ns
Rook	ns	ns	ns	-	ns	ns	ns	++	ns	ns	ns	ns	ns
Whitethroat	ns	ns	ns	ns	ns	+	ns	ns	ns	ns	ns	ns	ns
Blackbird	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	++	ns
Song Thrush	+	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	++	ns
Tree Sparrow	ns	ns	ns	ns	ns	+	ns	ns	ns	ns	ns	ns	ns
Chaffinch	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	++	ns
Greenfinch	ns	ns	ns	ns	ns	ns	ns	--	++	ns	ns	ns	ns
Goldfinch	ns	+	--	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Linnet	ns	ns	ns	-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Reed Bunting	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	+	ns
Yellowhammer	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	+++	ns

Table A5.2 Correlation matrix of annual agricultural variables and CBC index expressed as inter-annual changes. Other details are as per Table A5.1. Species showing no significant correlations (Kestrel, Starling, Bullfinch and Corn Bunting) and agricultural variables showing no significant correlations (oilseed rape, rough grazing, fertilizer on grass, slurry application, oats, sugar beet, silage production and winter barley) are excluded from the table.

6

Relationships Between Change in Bird Populations and Change in Agriculture on Individual Farms

D.E. Chamberlain[1], D.G. Garthwaite[2], A.J. Impey[1] & R.J. Fuller[1]

[1] British Trust for Ornithology
[2] Central Science Laboratory

6. RELATIONSHIPS BETWEEN CHANGE IN BIRD POPULATIONS AND CHANGE IN AGRICULTURE ON INDIVIDUAL FARMS

6.1 Introduction

In previous sections we have considered potential effects of changes in agricultural management on bird populations at wide geographic scales (i.e. national and regional). However, these analyses were sometimes limited by the available data, with no information on certain habitats suspected of having important effects on bird populations (see Section 3.4). Also, it is clear from previous studies (see Section 2) that habitat change can operate at local scales, involving sometimes quite subtle changes in agricultural management.

A large number of studies have considered bird-habitat relationships at the farm scale (e.g. Lack 1992, Green *et al.* 1994, Parish *et al.* 1994, Petersen 1996, Fuller *et al.* 1997, Wilson *et al.* 1997, Stoate *et al.* 1998, Gillings & Fuller 1998, Chamberlain & Fuller in press). The density and size of hedgerows are some of the most important features determining the make up of bird communities on farmland (Lack 1992). Typically, higher, wider hedgerows and hedgerows with trees support the greatest number of species (Parish *et al.* 1994), the highest numbers of birds (Lack 1992), and the highest densities of a number of individual species, especially those more associated with woodland or woodland edge habitats such as thrushes, tits, Wren and Robin *Erithacus rubecula* (Green *et al.* 1994, Fuller *et al.* 1997). Generally, species primarily associated with farm habitats show preferences for shorter hedgerows, such as Whitethroat, Linnet and Yellowhammer (Green *et al.* 1994).

Effects of crop and grass types on bird densities are relatively less common compared to effects of landscape structure (e.g. hedges, ponds and adjacent woodland). Fuller *et al.* (1997) considered the effects of farm habitat on 12 bird species and found only two, Skylark and Yellowhammer, which were significantly associated with variables relating to the farming system, both showing positive associations with cereal area. As Skylark is a ground nester, its abundance is affected by field diversity, intensity of grazing (Chamberlain & Gregory 1999) and the availability of certain crops (Wilson *et al.* 1997) more so than other species. However, even in this species, the density of hedgerow is the most consistent predictor of bird density on farmland, Skylark showing strong preferences for open habitats with few hedgerows (Chamberlain & Gregory 1999). Although structural components of hedgerows tend to have the strongest effects on bird density and species richness (Parish *et al.* 1994, MacDonald & Johnson 1995), adjacent field use may also have some influence. For example, Parish *et al.* (1994) found that species richness was higher in hedges adjacent to permanent pasture, and Green *et al.* (1994) found positive effects of oilseed rape and negative effects of spring-sown cereals adjacent to hedgerows in a number of species.

There is evidence to suggest that Grey Partridge abundance is affected by the use of pesticides on farmland via effects on chick survival (Potts 1986). For example, field margins with reduced herbicide applications ("conservation headlands") increase brood sizes and chick survival relative to farms with a conventional spray programme (Rands 1986). In other species, the evidence for an effect of pesticides is less good. Organic farms, which experience no pesticide input, tend to hold higher bird densities (Fuller 1997) and tend to have improved productivity (Petersen 1996, Wilson *et al.* 1997) compared to conventionally managed farms for a number of species. However, in these studies, it is difficult to separate out the effects of pesticide applications from effects of cropping regime or structural aspects: organic farms tend to have higher, wider hedges with more trees (Chamberlain *et al.* 1999) which may benefit a number of species (Lack 1992), and they are more likely to have traditional rotations incorporating spring-sown cereals, which are likely to be beneficial to Skylarks (Chamberlain *et al.* 1999, Wilson *et al.* 1997) and Lapwings (Hudson *et al.* 1994). Green *et al.* (1994) considered the effects of adjacent conservation headlands on the occurrence of a number of species and found few significant effects, except that Robin, Song Thrush and Greenfinch tended to be more likely to occur in hedges adjacent to sprayed than unsprayed autumn-sown cereals.

Whilst there is a reasonable amount known about the factors affecting bird abundance within and between farms, there has been little consideration of the effects of changing farm management over time on bird communities at the farm level. Fuller *et al.* (1997) considered the effects of farm habitat variables on a number of species over several years, but were primarily attempting to identify consistent predictors of bird density rather than determine relationships between habitat change and bird population change. However, they did note that cereal area was a significant predictor of Skylark density until the 1980s but not subsequently, which they suggested may have been due to changes in crop management making this habitat less preferred. Gillings and Fuller (1998) considered the effects of habitat change on the abundance of 38 bird species across a number of farmland plots over a 20 year period. They found that declines in species were not generally associated with changes in the extent of broadly defined habitats such as hedgerows, woodland, grassland and ponds, and suggested that declines in the quality, rather than the extent, of certain habitats, may have had more influence on farmland bird declines.

In this study, we consider the effects of agricultural management on a number of bird species at the farm level in two periods, 1971 to 1973 and 1996 to 1997, and analyse changes in bird abundance in relation to management changes between these two periods. A wide range of habitat information specific to the farms concerned was used in the analyses, including the area of a range of crops, pesticide and fertilizer inputs, sowing regimes (e.g. autumn or spring-sown crops and the presence of grass leys in rotation) and the extent of non-crop habitats such as hedgerows and ponds. The analysis therefore incorporates more detail than previous studies, considering the whole management regime on farms rather than focusing on individual habitats (e.g. Green *et al.* 1994) or defining habitats at a fairly crude level with no management information (e.g. Gillings & Fuller 1998).

6.2 Methods

6.2.1 Bird census

The sample of CBC plots used to determine indices of relative population change (Section 5) is not constant, but varies from year to year as observers drop out and are replaced by new volunteers and new sites, although a small number of plots has been censused for a long run of years. A total of 42 farmland plots within southern England, the majority of which were in the arable-east and mixed-south regions (Section 3, Fig. 3.1), that had been censused in at least one year between 1971 and 1973 but not subsequently, were selected for re-census. These years were chosen as many farmland species were apparently stable at this time, having recovered from the effects of the severe winter of 1962/63, but were yet to show any sign of a population decline (Siriwardena *et al.* 1998a). A further nine farmland plots were identified which had been surveyed continuously since the early-1970s. The geographical distribution of the plots is shown in Fig. 6.1. Census visits were carried out to these plots in 1996 and 1997 using a territory mapping method (Bibby *et al.* 1992). This was identical to that used in the CBC (Marchant *et al.* 1990; Section 4), except that five, rather than 10 visits were carried out between mid-April and the end of June (a few farms received fewer than five visits). The measure of bird abundance was based on a modified method of identifying clusters of bird registrations (i.e. individual birds identified) which for convenience we refer to as "territories". Each territory was based on a minimum of two registrations, unlike the CBC which uses a minimum of three. We consider this preferable to merely using average count of registrations per visit, which is more likely to include non-breeding birds or migrants which are not resident on a given site. As long as errors are constant, this method will be accurate for comparative purposes. Data from the census visits in the 1970s were re-analysed using the adjusted methodology, taking only five visits between mid-April and the end of June (where more than five visits occurred in this period, visits were selected for analysis at random). Density of individual species (territories/ha) was determined for each farm. Shannon diversity indices (Krebs 1980) and the number of species recorded in each year per farm (referred to as species richness) were also determined. The two periods considered, 1971 to 1973 and 1996 to 1997, will be referred to as the early and late period respectively.

6.2.2 Habitat data

Information on both the current and past management carried out on each farm was gathered by interview with the farmer. The information was recorded on specially designed questionnaires (Appendix 6.1) and covered the period 1965 to 1997. In some cases, very accurate data were gathered on crop areas (the term "crop" being applied loosely here and referring to all field types including grass), application rates of pesticides and fertilizers, levels of drainage and management of non-crop habitats such as hedges, ponds and farm woods. However, due to the time period involved, many farmers questioned were only able to give approximate indications of management practices in the early-1970s, the particular period of interest. Habitat maps made by the original observers in the early-1970s were used to determine precise areas for which relevant data were available (although not all observers made accurate habitat maps), so for areas of crops there were often two possible sources of data. Data extracted from maps was always used in preference to data from the historical survey when available. However, for management data not recorded on maps, such as pesticide and fertilizer inputs, the questionnaire was the only source of data, which meant that there were fewer farms with adequate information for these variables. Farms were classified into either arable, mixed or pastoral on the basis of the proportion of grassland to arable area. If over 80% of the area was occupied by either land use type then the farm was classified accordingly. Otherwise, farms were designated as mixed. In total, 50 farms had at least some habitat data collected, with only a single farm having no relevant habitat map and no cooperation from the landowner.

Many habitat variables occurred on a relatively small number of farms or were not recorded sufficiently accurately enough to permit detailed analysis. There was much greater detail on habitat use in the data from the later period, which were initially analysed separately as continuous variables. It was decided that variables which were recorded accurately on fewer than 25% of the sample of farms would not be considered in this analysis (Table 6.1). Data from the historical survey was of a categorical nature on the majority of farms in the early period. This will be considered further using more complex analyses when the effects of agricultural change on bird abundance are analysed (see below).

There was only a single set of habitat data per farm to represent up to two (1996 to 1997) or three (1971 to 1973) years. The areas of crop types often change from year to year (for example, due to crop rotations), so using an exact figure may be misleading. Because of this, and the approximate (and sometimes anecdotal) nature of the historical data, habitat extent, pesticide application rates and fertilizer application rates were classified into groups. This was done by using data from the whole sample of farms (i.e. from both early and late periods) to determine the 33rd and 66th percentiles and the mean for each category of crop/grass area, pesticide application rates (spray hectares of herbicides) or fertilizer inputs (kg/ha of nitrogen). These latter two variables could have been represented by alternatives (fungicide or insecticide; potassium or phosphate respectively), but these tended to be correlated, so the variable with information from the most plots was used. Levels of each category were defined in relation to these quantities, where 0=none present, and up to either two (more or less than the overall mean) or three further levels (less than 33rd percentile, between 33rd and 66th percentile and greater than 66th percentile), making the best estimate possible from the information given. Some variables were classed as present or absent. The number of levels varied depending on the accuracy of the data and how much a given category was known to vary from year to year. The quality of information varied between predominant farming types (e.g. more detail on grass management on grass dominated farms), so the definitions of some variables differ between arable/mixed and pastoral farms. Table 6.2 gives all variables defined in this way and the number of levels of each variable. Despite these simplified habitat categories, there were still a number of farms where it was not possible to make estimates of the level of a given habitat type or the change experienced over time. The number of crop or grass types present (habitat richness) and Shannon diversity indices were determined for each farm, the latter only when accurate data on the area of crops was available.

6.2.3 Analysis

Initially, simple comparisons of bird density, species richness and species diversity between habitats within periods, and between periods, were made using t-tests and ANOVA. In cases where the bird density data departed severely from a normal distribution, non-parametric tests were used (as a rule of thumb, this was used on species where the number of zero values exceeded the number of non-zero values). The frequency of occurrence of different levels of categorical habitat variables (Table 6.2) between periods were analysed using contingency tables. The effects of agricultural management measured as continuous variables (Table 6.1) on species density or presence/absence, species richness and species diversity in 1996 to 1997 was analysed with regression, selecting the single variable which explained the greatest amount of variation in the bird data (that which had the highest r^2 value). If the density data were not distributed approximately normally, then presence/absence was analysed in relation to habitat using logistic regression. This approach was not possible for the early data set, as few variables were accurately estimated as continuous variables.

Selected habitat data expressed as class variables (those with fewest missing values - Table 6.2) were analysed with respect to bird abundance using the GENMOD procedure in SAS (SAS Institute 1996) in order to determine whether there was any evidence of changes in agricultural habitat affecting bird populations. Two different types of analysis were used, each with different dependent variables; bird count and presence/absence data (note that the term "abundance" is used generally to describe either measure). Independent variables and model error structures also differed between each analysis. Arable and pastoral farms were analysed separately. This was deemed appropriate in view of the differences in population trends shown by some species within different farm types (Section 5).

Agricultural management variables classified into different levels of area or application rate and period (early or late) were analysed in relation to total bird count per period, weighted for the number of years surveyed per period by multiplying count by (number of visits/total number of possible visits per period). Therefore, a farm which had been visited in two years in the early period at five visits per year would have its count adjusted by 10/15. In addition to the variables described, there are likely to be unmeasured variables associated with individual farms which affect the occurrence of birds (e.g. geographic location, altitude and farm size). In this model, these effects could be incorporated using farm as a dummy categorical variable, so the effects of management can be considered when variation caused by unmeasured site-specific factors is taken into account. Bird counts were modelled using the GENMOD procedure in SAS (SAS Institute 1996) with a Poisson error distribution and a log-link function. The models were fitted with intercept terms which meant that parameter estimates produced were set relative to a given category level which was fixed at zero. In these models, parameter estimates for crop categories are relative to level 0 (i.e. no crop present), and period is relative to the early period. For example, if a crop of level 1 had a parameter estimate of -0.5, then this has a relatively lower abundance of birds than those farms with none of that particular crop present. Back-transformation of the link function gives the proportion of birds expected on that category level, which in this case would be $e^{-0.5} = 0.607$ times as many birds on level 1 as level 0.

In order to get an indication of whether variation in crop type was responsible for changes between periods, the model was run using different sets of independent variables. The effects of farm and period were analysed without and with the effects of crop type (Model A and B respectively). Only farms which had adequate data for both periods were considered in the models. If the effect of period was significant alone under Model A, but was replaced by a significant crop variable under Model B, then the variation between periods could be explained by changes in the effects of crop type. If a given agricultural factor was significant along with the effect of period, then it had an effect on bird abundance irrespective of the change in category between periods (although this doesn't necessarily mean that the factor is not partly related to change in bird abundance, rather that a significant amount of variation between periods remains unexplained).

Presence or absence of species was also analysed in relation to period and habitat. The number of visits on which a particular species was recorded and the total number of visits to each farm per period was determined. The GENMOD procedure was used to analyse the data using a logistic regression model with binomial errors and a probit-link function for selected species where the Poisson regression models used above were not adequate (either the model failed to converge on a solution or parameter estimates had relatively very large standard errors, several orders of magnitude greater than the mean). The proportion of visits on which a particular species was present was used as the independent variable (i.e. using the events/trials model syntax in SAS). Models were run on different sets of independent variables as described above.

The change in category of habitats used in the Generalized Linear Model (Table 6.2) was determined between the two periods and placed into one of three groups, increase, decrease or remained the same. Habitat change was then analysed using Detrended Correspondence Analysis (DCA - Hill 1979) in order to try and identify groups of farms which had changed over time in similar ways. The first axis was used to group farms according to their DCA score. Comparisons of bird density between groups of farms defined in this way were carried out using paired t-tests.

6.3 Results

6.3.1 Management of farmland

The landscape type (arable, pastoral or marginal upland - Bunce *et al.* 1993) and land class (Bunce *et al.* 1996) of each 1 km square containing the largest area of a given farm was identified. The representativeness of the sample was examined by comparing the proportion of sample squares of each landscape type and land class with the proportion occurring in the whole of the census region (arable-east and mixed-south regions). Out of the total of 51 farms, 32 were in arable landscapes, 17 in pastoral landscapes and two in marginal upland landscapes. The expected numbers of squares were 37, 13 and one respectively, so there is slight over-representation of arable landscapes and under-representation of pastoral landscapes in the sample. In practice, this makes very little difference as many analyses will separate predominantly arable and pastoral farms. The observed and expected numbers of censused squares based on the more detailed land classes are shown in Fig. 6.2. Generally, expected and observed values were similar, although there was some over-representation of mixed, fairly well wooded farmland landscapes (Class 1) and arable farming on chalk soils (Class 2) and under representation of intensive arable farming on flat plains (Class 3). There was no significant overall departure from the expected distribution (χ^2_6=7.10, ns; Class 9 and 12 and Class 5, 8, 10, 15 and 17 were combined to avoid low expected values).

The percentage of farms showing either increases or decreases in the more common habitat variables (those occurring on 10 or more farms) are shown in Fig. 6.3 for farms where data was available for both periods (a maximum of 46 farms). This analysis makes use of both actual estimates, and of cases where a farmer reported an increase or a decrease in a given variable but could not make any estimate of an actual figure. Farms where missing values occurred in either one of the two periods were omitted. The largest proportion of relative decreases occurred in spring cereals, ley grass and hay. Farms showed the greatest increases in winter cereals, game cover, silage, sheep, artificial fertilizers and pesticides. A number of variables showed similar numbers of increases and decreases, such as new grass, permanent grass, root crops, stubble and fallow (although for the latter two, set-aside, which some farmers apparently recorded as stubble or fallow, may have distorted the trend). This indicates the polarization of farms into arable and grass-dominated enterprises. For example, both grass types have increased on grass farms but decreased on arable farms. A notable feature of the sample was that hedgerow length had changed on very few farms.

The number of crop types differed between farm types, with mixed farms (unsurprisingly) having the most number of habitat types (Table 6.3). However, the number of crop types on arable farms was more similar to that on mixed farms than pastoral farms. The difference was significant only in the late period, but there was an indication of a similar though weaker trend in the early period ($P<0.065$). In part, this may have been due to less detail in the early data set, and for this reason it is not meaningful to compare means between periods. Very similar results were achieved when a diversity index of habitats was calculated.

Fig. 6.4 shows the habitat extent of different crop types for early and late periods categorized into levels of habitat area for arable farms (see Table 6.2). This includes all farms irrespective of whether data was missing for either period (so sample sizes are not necessarily the same as in Fig. 6.3). Spring cereals differed significantly between periods, having decreased in area and being absent from the majority of plots in the later periods, with 53% of arable farms having spring cereals present in the early period, but only 15% in the late period (Fig. 6.4b). There was some tendency for an increase in other arable crop types (Fig. 6.4d) and a decrease in the area of stubbles present over winter (Fig. 6.4e), although differences were not significant ($0.10>P<0.05$ in each case). The presence of ley grass used in rotation decreased significantly between the two time periods, occurring on 30% of farms with an arable component in the early period, but only 10% in the late period (Fig. 6.4f). One crop which has replaced grass in rotation is oilseed rape (Fig. 6.4g). This was present on comparatively few farms during the two years of the late survey period, with only six farms having the crop present. However, 61% of arable farms reportedly had recently used the crop in their current rotation, compared to only 7% in the early period, a significant difference.

There was little difference in the type or management of grassland between periods (Fig. 6.5). There were fewer farms with higher categories of permanent grass in the later period in both pastoral and arable farms (Fig. 6.5a & b), but there was no significant difference in frequency between periods. This was also the case when farm types were combined ($\chi^2_3=4.03$ ns). New grass was uncommon across all plots in both periods and there was no significant difference between periods (Fig. 6.5c). There was no significant difference in the number of either cattle or sheep between periods (Fig. 6.5d & e). When all forms of livestock (i.e. also including horses, ponies and pigs) were considered in terms of stocking units, there was a slight overall increase in grazing, but again this was not significant (Fig. 6.5f). Fewer pastoral farms had arable crops present (usually root crops or cereals for stock feed) in the later period, but the proportion, from 61% to 44% of farms, did not differ between periods (Fig. 6.5g). Whether grass was cut for hay or silage also did not differ between farms (Fig. 6.5h & i), although silage had shown an increase in occurrence from 44% to 72% of plots. These figures in themselves do not necessarily reveal anything about the intensity of grass management, especially as sometimes both silage and hay were taken from the same field at different times of the year (hay in this case meaning grass cut for drying and not necessarily traditional herb-rich hay meadows). There was no apparent change in the maximum (i.e. weather permitting) number of cuts grass was likely to experience per year between periods, with a single cut being the most common management practice in the majority of the farms surveyed (Fig. 6.5j). There was a weak tendency for the first grass cut (of any grass type) to be earlier in the season in 1996 to 1997 (Fig. 6.5k), but this was not quite significant ($P<0.07$). However, there were differences in the timing of cutting between grass types, with silage being cut significantly earlier than hay (this includes only those cases where a given field was cut for only one grass type in a year) (Fig. 6.5l).

There was no significant difference in fertilizer use between periods when considering all farm types (χ^2_1=0.45 ns). However, artificial fertilizer did show a significant change over time when considering pastoral farms only (Fig. 6.6b), having increased in application rate since the 1970s. The frequency of farmyard manure and slurry use showed no evidence of differing between periods (Fig. 6.6c & d). There was no apparent trend in pesticide use on arable farms over time for either herbicides, fungicides or insecticides (Fig. 6.7). The different pesticide types showed very similar trends. Molluscicides are a relatively recent technological development and did not occur in the early period. They were, however, used on 58% (17/29) of farms in the late period where the data were available. These data appear to show a different pattern to that shown in Fig. 6.3, which showed that most farms had increased in pesticide use. The difference in pattern arises because when we consider (albeit crudely) the magnitude of change in Fig. 6.7, a number of farms, although experiencing increases in pesticides, did not change category between periods, i.e. the increase in application rate was not enough to exceed the overall mean and so enter the "above average" category. Therefore, although there have been general increases as revealed by Fig. 6.3, the magnitude of these increases has been small (Fig. 6.7).

6.3.2 Factors influencing species abundance, species richness and species diversity on farms within periods

The density of the 21 target species (Section 2) was analysed in relation to farm type in the two periods (1971 to 1973 and 1996 to 1997) separately using analysis of variance in species where data were distributed approximately normally, and using non-parametric Kruskal-Wallis tests otherwise. Initially, both year and farm type were considered, but in no case was a significant difference between years detected within each period, so the analysis was repeated comparing mean densities across years between farm types. In the early period, six species showed significant differences between farm types (Table 6.4). Turtle Dove, Skylark, Song Thrush and Tree Sparrow showed the highest densities on arable farms and Chaffinches showed the highest densities on pastoral farms. Greenfinches had equally high density on arable and mixed farms compared to pastoral farms. There was no significant difference in species diversity nor overall species richness between farm types. However, when considering only the target species, mixed and arable farms held significantly more species than pastoral farms.

In the late period, the number of arable farms had increased somewhat, but overall there was no change in the proportion of farm types (χ^2_2=0.90 ns). Three species showed significant differences in density between farm types (Table 6.5). Whitethroat and Yellowhammer had the highest densities on arable farms and Skylark had the highest densities on mixed farms. For these species, the density on arable farms was significantly greater than on pastoral farms in each case, but there were no significant differences between arable and mixed farms (Scheffe post-hoc tests). There was no significant difference between farm types in either species diversity or species richness, including species richness of target species only. This was due to a decrease in species occurrence on arable and mixed farms between the two periods (see below).

The effects of agricultural management on birds in 1996 to 1997 were initially analysed across all farm types, and then separately within farm types using regression techniques. Species densities and species richness were very similar on arable and mixed farms in most cases (Tables 6.4 and 6.5) and so these categories were combined to increase sample sizes. Where density did not approximate to a normal distribution due to large numbers of zero counts, presence/absence was analysed using logistic regression. Species abundance tended to increase on larger farms in Grey Partridge, Lapwing, Turtle Dove and Corn Bunting and decrease in Song Thrush, Greenfinch and Reed Bunting in at least one year (Table 6.6a). Densities of Reed Bunting and Stock Dove decreased with increasing total hedgerow length. Species density or occurrence was affected by grassland type in five species in at least one year. Area of permanent pasture was negatively associated with the density of Whitethroat and Yellowhammer. The area of new grass showed positive effects on the density of Kestrel and Goldfinch in single years and Blackbird in both years. Fallow land increased the probability of occurrence of Lapwing and Rook as well as having positive effects on both species richness and diversity in one year. Arable crops had comparatively weaker effects. Vegetable area was positively associated with Turtle Dove presence and winter wheat area was positively associated with Whitethroat density in one year each. Set-aside showed positive effects on Skylark density in both years. Chaffinch and Stock Dove showed some evidence of a link with fertilizer use, being negatively associated with phosphate application rates. Both species richness and species diversity were positively related to the area of fallow land in 1996. In 1997, pesticide applications had a positive effect on species richness (fungicide) and species diversity (herbicide). These results may reflect a higher species richness and diversity on arable and mixed farms (compare Table 6.5). For example, fungicide use and fallow land will be absent or very low on pastoral farms.

Many of these relationships may merely indicate species preferences for either arable or pastoral farm types, so relationships were examined separately for each predominant farm type. In arable farms (including mixed farms), relationships were very similar to that detected on all farms in Grey Partridge and Chaffinch, and in most other species a common variable was selected in the two data sets in at least one year (Table 6.6b). Generally, farm area was less often selected as having significant effects on species density. Fertilizer inputs had the most widespread effects across species, showing negative associations with Stock Dove, Chaffinch, Linnet and Yellowhammer abundance and species richness in at least one year. There was also an indication that farms with greater herbicide inputs had a higher Rook occurrence and greater species diversity, but there were negative effects of herbicides (Tree Sparrow occurrence) and insecticides (Goldfinch density). On pastoral farms, fewer significant relationships were detected (Table 6.6c). However, some results of note included the positive effects of herbicide application rates and negative effects of permanent grass area in several species, which may imply that grass-dominated farms with a small arable component hold higher densities.

The above relationships can only give a very general indication of possible bird-habitat relationships, particularly for pastoral farms where sample sizes were much reduced. Spurious correlations may of course arise due to a high degree of collinearity in the data, and it is possible that this could have been explored further with more complex regression techniques. However, this problem can never really be overcome and it was thought best to initially opt for the simplest approach. Furthermore, interpretation of the relationships which were detected should be considered in the light of the increased probability of type I errors caused by multiple comparisons. With these caveats in mind, there were some general patterns to emerge. Over the whole data set, relationships tended to illustrate preferences for predominant farming type. For example, Skylark, Whitethroat, Blackbird and Yellowhammer were more associated with arable farm habitat variables. Within arable farms, arable crop area was relatively unimportant compared to non-crop habitats. Overall, there was little indication that pesticide application rates were associated with species abundance and only weak evidence of an effect of herbicide inputs on species diversity.

6.3.3 Changes in species abundance, richness and diversity

The change in species density (territories/ha) between the early-1970s and 1996 to 1997 was determined for individual farmland plots which had been censused in the early-1970s but not subsequently. The difference in mean density per period was analysed with a paired t-test with the null hypothesis that the change in density was 0 (Table 6.7). Farms where a particular species was not recorded in either survey were omitted. Nine species have shown significant declines in density: Grey Partridge, Turtle Dove, Skylark, Blackbird, Song Thrush, Tree Sparrow, Bullfinch, Corn Bunting and Reed Bunting. Five species showed significant increases between the two time periods: Rook, Whitethroat, Greenfinch, Goldfinch and Chaffinch. These findings are in general agreement with analyses of CBC indices (Section 5), which is unsurprising as these farms form a subset of those plots from which indices are determined. Twelve of the farms considered experienced large changes in land use such that their farm type classification changed between the two periods. When these farms were omitted and the analysis repeated, very similar results were obtained, with only Greenfinch no longer showing a significant increase (Table 6.7), indicating that the significant changes in bird density were not due to broad scale changes in farming type in the majority of species.

Farms were classified into predominant farm type and the difference in density was again analysed with paired t-tests (Table 6.8). Farms were divided into arable, mixed or pastoral based on the ratio of arable:grass on the plot in 1997, where either category had to exceed 80% or else the farm was defined as mixed. The majority of significant results were detected in arable categories, although this in part may have been due to the larger sample sizes. When the analysis was repeated, but using the ratio of arable:grass in the early period to determine farm types, very similar relationships were detected.

Species richness was determined for each separate year. The difference in species richness between early (1970 to 1973) and late (1996 to 1997) periods was analysed using analysis of variance which also incorporated the effects of individual farms and the effects of individual year nested within each period. There was no significant difference between individual years within each period ($F_{3,163}=0.19$ ns), so mean richness across years was analysed in relation to farm and period only. There was no significant difference between early and late groups when all species were considered ($F_{1,44}=1.36$ ns). However, when considering only the 21 target species, there was a significant difference in species richness between the two periods ($F_{1,44}=7.86$, $P<0.008$) with a greater number of species being recorded in the earlier surveys (mean$\pm$s.d. (n): early period$=14.24\pm2.92$ (46); late period $= 13.02\pm2.73$ (49)). There was a significant difference in species richness between individual farms ($F_{49,94}=2.46$ $P<0.002$).

Changes in species richness were considered in relation to the predominant farming type (combining mixed and arable farms). Farms where the change in land use was such that the category of farm type changed between pastoral and either arable or mixed between the two periods were not included in the following analysis. There was still a significant overall decrease in species richness when removing these farms (paired t-test: $t_{34}=2.15$, $P<0.04$). There was a significant effect of period ($F_{1,34}=8.70$, $P<0.006$) and farm type ($F_{1,34}=60.27$,

$P<0.0001$), with arable/mixed farms showing an overall higher species richness, but also a significant decrease between the two periods (mean±sd: arable early period = 14.90±2.43 (25), arable late period = 13.43±2.90 (28); pastoral early period = 11.49±2.93 (12), pastoral late period = 11.41±2.23 (11)). The effect of individual farm was again significant ($F_{39,34}=6.28$, $P<0.0001$).

6.3.4 Generalized linear modelling of bird abundance and habitat change

Firstly, we consider the effects of individual farm and period (early or late) on bird counts for selected species (Model A), and whether changes in bird count are associated with changes in agricultural management expressed as categories (Model B). The results of the Poisson regression using species count per period for models with and without crop type as a categorical variable for arable/mixed farms are shown in Table 6.9. Initially, total pesticide and fertilizer use were included in the models, but due to missing data in these variables, sample sizes were reduced. For those species where a valid model could be fitted, there was no evidence of an effect of either pesticide or fertilizer application. For most species (those with the smallest sample sizes), the models either did not converge on a solution even when excluding pesticide and fertilizer data, or the standard errors were so high that parameter estimates were effectively meaningless. Six species yielded valid results under both models. When the effects of period and farm were considered without the effect of crop type (Model A), five species showed a significant decrease between early and late periods, Blackbird, Linnet, Song Thrush, Skylark and Yellowhammer. Farm was significant in each species apart from Blackbird, i.e. Blackbird was the only species whose numbers did not vary significantly between sites. When crop types were added to the models, the effect of period remained in Blackbird, Song Thrush and Skylark. For Linnet, the addition of the extra variables resulted in no significant variable detected. Yellowhammer was the only species where the effect of period was replaced by another variable, winter cereals. However, these had positive effects on Yellowhammer counts, so it seems unlikely that this could be associated with the overall decline detected under Model A. Winter cereals had effects in a further two species, but this was in addition to a difference between periods. Relative to none present, both Blackbird and Skylark tended to have reduced counts on farms with larger areas of winter cereal. Spring cereals had significant effects on bird counts in three species, Blackbird, Chaffinch and Skylark. There was a tendency for higher counts on farms with larger areas of spring cereals, but counts tended to be relatively low on farms with small areas of spring cereal compared to farms with none of this crop. Blackbird and Chaffinch showed negative associations with a large area of permanent pasture and with large numbers of livestock (note that these two variables are likely to be correlated). There was also a positive effect of the presence of ley grass in rotation on Blackbird counts.

There was no evidence of an effect of pesticide application rate in conjunction with other crop types on arable/mixed farms, but as a check, the above analyses were repeated using models with farm, period and herbicide application rate class only. Once again, models did not converge in the majority of species. Only one species, the Blackbird, showed a significant effect of pesticide application class, but farms with below average application rates were associated with lower counts of Blackbirds (parameter estimate relative to above average application rate=-1.31±0.64, $\chi^2_1=4.50$, $P<0.035$). No significant effect of pesticide was detected in Skylark, Whitethroat, Chaffinch, Greenfinch and Yellowhammer, but only nine farms had enough data for analysis. A similar approach was carried out for artificial fertilizer use (Table 6.10). Adequate models were produced in eight species, but there were no significant effects on the abundance of Whitethroat, Song Thrush, Chaffinch or Goldfinch. There were significant effects of fertilizer application in Skylark, Blackbird, Greenfinch and Yellowhammer, with lower bird counts being associated with higher fertilizer applications in each case. There was also a significant difference between period for each species except Greenfinch, which showed no change over time when considering the model without the effect of fertilizer.

The effects of farm, farm period and habitat category on bird numbers were considered as above for pastoral farms only, but considering a different set of independent variables (Table 6.2). The model converged on a solution in only two species, Blackbird and Chaffinch. When considering period and farm only, both species showed evidence of a significant decrease between periods (parameter estimates: Blackbird 1.10±0.16, χ^2_1=48.56, P<0.0001; Chaffinch 0.40±0.18, χ^2_1=5.06, P<0.04, sample size was 15 farms each) and also a significant difference in count between farms. Addition of crop types to the model resulted in no difference to the results for Blackbird, and for Chaffinch there was no longer any effect of period detected, but no crop types were selected in either case.

There were a number of species where the above models did not converge on a final solution. These were typically the scarcer species which would have shown a large number of zero counts and a low range of counts where they did occur. When zero counts were omitted, Poisson regression was still often not adequate in modelling the distribution of these species. In these cases it was therefore decided to model presence/absence using logistic regression. Even with this approach it was not possible to consider the effects of farm as a dummy variable as this produced parameter estimates with standard errors many orders of magnitude higher than the mean due to over-parametization of the models. Table 6.9 showed that there were often significant differences between individual farms. Part of this variation may have been caused by farm size, so this was used as an offset variable in the model (to control for possible effects of farm size on the probability of a bird being present). However, without farm as a class variable, the effect of period in the model is effectively unpaired and so the test is not as rigorous as the previous Poisson model.

Significant variables selected using models with and without period as a class variable, and parameter estimates relative to no crop present are shown in Table 6.11 for the eight species on arable/mixed farms where the model converged on a solution and significant effects were detected. Six species showed a significant decrease in the probability of being present on a farm between the two periods: Grey Partridge, Lapwing, Turtle Dove, Tree Sparrow, Bullfinch and Reed Bunting. Whitethroat showed an increased probability of presence in the later period. There were only six species which showed an effect of crop type under Model B, and in each case this was in addition to the effect of period, indicating that much of the variation in the probability of occurrence over time was not explained by effects of crop type. Grey Partridge and Turtle Dove showed an increased probability of presence at larger areas of winter cereals and root crops. Yellow Wagtail tended to occur less on farms with permanent pasture. Bullfinch occurrence was lower on farms in which stubbles were present over the winter. Reed Bunting was positively associated with small areas of spring cereals and occurred on fewer farms which had ley grass in rotation or which had small areas of new grass. Five species, Kestrel, Stock Dove, Starling, Greenfinch and Goldfinch showed no effect of any variable under either model. No valid model was produced for Rook and Corn Bunting.

On pastoral farms, relatively few species showed effects of either period or crop type (Table 6.12). Of the nine species where a valid model could be fitted, four showed no effect of any variable: Starling, Song Thrush, Goldfinch and Linnet. Stock Dove and Greenfinch showed an increase in occurrence between early and late periods. There was no indication that differences between periods may have been caused by effects of crop type. Bullfinch had a higher probability of occurrence on farms with some arable crops. The presence of grass cut for hay increased Greenfinch presence and decreased Stock Dove presence. Farms where grass was cut for silage were more likely to have Whitethroat and Stock Dove, as were farms with small areas of new grass for the latter species. Whitethroat occurrence was lower on farms with relatively large numbers of livestock. No valid model was produced for Kestrel, Grey Partridge, Lapwing, Turtle Dove, Skylark, Yellow Wagtail, Rook, Tree Sparrow, Reed Bunting and Corn Bunting.

6.3.5 Ordination of habitat change

Axes of environmental variation were derived from the change in habitat categories analysed in Tables 6.9 to 6.12 using DCA. The axis scores for nine habitat categories considered for the first three axes are shown in Table 6.13. The first axis clearly shows a gradient which represents the replacement of spring cereals and associated stubbles with winter cereals. The other axes are harder to interpret and will not be considered further. The eigenvalues produced by the DCA were low (<5%) indicating that most of the variation in the data could not be explained by the axes. However, low eigenvalues do not necessarily preclude the identification of meaningful axes of environmental variation (Gauch 1982). Two groups of 10 farms with the highest and lowest axis scores were identified, representing a group of farms which had decreased their area of spring cereals and stubbles over winter and increased their area of winter cereal, and a group of farms showing largely no change in winter or spring cereals or stubbles, with a very few showing some increase in spring cereals at the expense of winter cereals. The mean change in bird density was calculated for each group, and tested against the null hypothesis that the change in density was 0 (following the methods used in Table 6.7). The mean change in density for each species and the significance of the change for farms grouped as highest or lowest on the first DCA axis are given in Table 6.14. There were slightly more species showing significant differences in the farms with highest axis scores compared to the farms with lowest axis scores. Grey Partridge, Turtle Dove and Corn Bunting showed a significant decrease only in farms with the highest axis scores, which implies that there is an association between decreases in spring cereals and declines in the abundance of these species. One species, the Reed Bunting, showed a significant decline only in farms of the lowest axis score. Generally, however, changes were similar between the two groups of farms, and significant changes in density were observed in both for Whitethroat (increasing), Blackbird, Song Thrush, Tree Sparrow and Bullfinch.

6.4 Discussion

6.4.1 Changes in farm management

Generally, changes in crop type at the farm level were similar to those across lowland England and Wales (Section 2). Spring cereals, ley grass and to a lesser extent stubbles, had declined, reflecting the decrease in spring sowing and the changes in crop rotations. Winter cereals (mostly winter wheat) had increased on the majority of farms. There was less evidence of change in land use on pastoral farms, but there was some tendency for a decrease in arable crops and the amount of grass cut for hay in accord with the national trend, the latter resulting in generally earlier cutting of grass for silage. There was little evidence that livestock numbers had changed, although it was not usually possible to determine stocking densities in the early periods from the questionnaires, which may have more important effects on birds than numbers *per se*.

The use of artificial fertilizers has increased greatly across England and Wales, at least on tilled land, over the past 25 years. On arable farms, there was no evidence of a similar increase at the farm level, but fertilizer inputs had increased on pastoral farms, a factor enabling increases in silage. Use of slurry and farmyard manure (presence/absence) showed no change between early and late periods. National statistics show some increase in the former, with a peak in application around the mid-1980s, but no reliable national statistics exist for farmyard manure applications (Brian Chambers, pers. comm.). The majority of farmers in this study were unable to give accurate figures on amounts applied, so we cannot draw any conclusions about application rate.

National trends for pesticides have shown very large increases in application rate in terms of area treated between the early-1970s and mid-1990s. Generally, a greater number of individual farms had reported some increase in all main types of pesticide, but there was hardly any change for those farms where an estimate of the actual application rate could be made, i.e. application rate had increased, but by small amounts (compare Figs 6.3 and 6.7). The exception to this was molluscicides, which had increased becaue they were not available in the early-1970s. Historical data on pesticide use was amongst the most poorly recorded, and a reasonable estimate in terms of spray hectares of pesticide could only be made on nine farms. It is nevertheless somewhat surprising that the trends differ so markedly from the national picture. This may suggest large variations between farms in changes in rate of application of pesticides over the last 20 to 30 years. The number of pesticide products available nationally and their efficacy has greatly increased over this time span (Campbell *et al.* 1997) which has led to a decrease in the actual weight of pesticides applied to farmland (Thomas 1997), so ideally it would be more useful to consider the actual products applied on each farm, which may have revealed greater differences between the two periods. Unfortunately, it was not possible to get this level of detail from the historical survey.

There was very little change in hedgerow, farm woods and ponds. Indeed, there were instances of farmers restoring hedges and ponds, so in some cases these had increased. National data on changes in hedgerow length have proved elusive for the period of this survey, but in the previous decades, the rate of hedgerow loss probably peaked in the mid-1960s and has declined since (Section 2), so it seems likely that the majority of changes in total hedgerow length occurred before the early-1970s (and hence before many of the observed population changes in farmland bird species). However, this does not exclude the possibility of changes in hedgerow management affecting bird populations as we don't know how hedgerow quality (e.g. height, thickness) has changed (Gillings & Fuller 1998).

6.4.2 Changes in bird populations

Changes in the abundance of individual species were in general agreement with national changes detected by analysing CBC indices (Section 5), showing that this sub-sample of farms is representative of population changes in the whole sample of farmland CBC plots for lowland England and Wales in the majority of species. Whether changes over time were significant sometimes differed in different data sets. For example, Whitethroat, Greenfinch and Goldfinch showed significant increases in density on individual farms between the early-1970s and 1996 to 1997, but there was no significant change in CBC index over the same period. Similarly, when considering separate farm types, results were in broad agreement, although changes in abundance and presence/absence over time (derived from Poisson and logistic regression respectively) were in closer agreement with the national CBC trends than were changes in density on individual farm types.

The number of target species recorded on individual farms had decreased between the two periods, with farms in the early period recording on average 1.2 species more. This change only occurred on arable/mixed farms, which had lost an average of just over 1.5 species per farm. Pastoral farms held fewer species overall, but there was virtually no change over time, and in the late period there was no significant difference in species richness between farm types. Overall farming type was also strongly linked to the density of a number of species. In the early period, Skylark, Song Thrush and Greenfinch had significantly higher densities on arable and mixed farms but Chaffinch had significantly higher densities on grass farms. In the 1990s, significantly higher densities of Skylark, Whitethroat and Yellowhammer occurred on arable and mixed farms. This may be associated with overall habitat preferences, particularly for Skylark and Yellowhammer which are known to prefer cereal crops (Fuller *et al.* 1997, Wilson *et al.* 1997, Stoate *et al.* 1998, Kyrkos *et al.* 1998). Also, the greater number of habitats is likely to increase the chances of a given farm having specific habitat requirements for different individual species. More diverse farmland may also be beneficial as it may provide a range of conditions which can be exploited at different times of the year. For example, Skylarks tend to occur at higher densities on more diverse farmland (Chamberlain & Gregory, 1999) as they need well developed crops such as winter wheat in which to nest early in the breeding season, but later on they require the availability of other habitat types such as spring barley, which has a less well developed sward (Wilson *et al.* 1997).

Bird abundance (including density, count and presence/absence) varied significantly in relation to different levels of cereal crops on arable farms in a number of species. The abundance of Grey Partridge, Turtle Dove (presence/absence), Whitethroat (density) and Yellowhammer (count) were positively associated with winter cereal area, but Blackbird and Song Thrush (count) showed the opposite effect. High areas of spring cereals increased the occurrence of Reed Bunting and the numbers of Skylarks, but had a negative effect on Chaffinch counts. However, a low area of spring cereals was associated with significantly lower Skylark counts. The extent of cereal crops therefore seems important to a number of species, but the exact relationships are unclear. An association between bird abundance and winter cereals may indicate a preference for intensive cereal farming. An avoidance of the largest areas of winter cereals may imply that a more mixed farm is favoured, as in Blackbird and Song Thrush. Spring cereals would be expected to be favoured by Skylarks (good nesting and habitat) and Reed Bunting (associated with winter stubbles), but another seed-eater, Chaffinch, tended to have lower counts at higher areas of spring cereal. Spring cereal had decreased the most compared to other crop types, so these changes may relate to the fact that Reed Bunting and Skylark have decreased in abundance over time and Chaffinch has increased. However, effects of period were not wholly explained by effects of spring cereal, so this alone is unlikely to be the reason behind the population change.

Other crops were relatively less important in determining bird abundance. Farms with root crops tended to have a higher probability of occurrence of Grey Partridge than those without. Both Turtle Dove and Yellow Wagtail showed an association between the probability of occurrence and the area of vegetables in a single year, as did species diversity. Skylark densities showed positive associations with the area of set-aside, a result observed in a number of studies (Poulsen *et al.* 1998, Henderson *et al.* 1998, Browne *et al.* in press) which probably arises both to vegetation characteristics and higher invertebrate abundance compared to most farmland crops (Henderson *et al.* 1998, Poulson *et al.* 1998). Fallow land had positive effects on the presence of Lapwing, Turtle Dove and Rook in at least one year, and was also significantly related both to species richness and species diversity across all farm types. Fallow land is that which is left after cropping, and is used in rotations as a break (although it may be less common now than 25 to 30 years ago). The ecological difference between fallow and set-aside is debatable and to some extent will vary depending on the management of individual farms (although the economic distinction, that set-aside land is subsidized, is clear). However, it seems likely that fallow and rotational set-aside will enjoy similar ecological benefits.

A number of species showed negative relationships with the area of permanent grass, particularly on pastoral farms. There was little evidence for positive effects of any type of grass. As a nesting habitat, grass is only of value if ungrazed or very lightly grazed and mown late in the season. There were few farms where this was the case in this study, hence farms with a large area of grass tended to support lower numbers of species. There may have been some evidence of positive effects of an arable component on pastoral farms, although this tended to manifest itself as a relationship with herbicide input rather than directly with arable crops. On arable farms, there was less evidence of relationships with grass area, although lower Blackbird and Chaffinch counts were associated with higher areas of permanent grass and higher stocking rates.

On arable farms, a number of species occurred at higher densities and had higher abundance on farms with lower artificial fertilizer inputs. Higher fertilizer inputs are likely to increase sward height and density of crops and grass. Two field nesting species, Lapwing and Skylark, showed evidence of lower density or abundance on arable farms with higher fertilizer inputs, which may be indicative of poorer nesting habitat as both species are known to avoid well developed crops (Hudson *et al.* 1994, Wilson *et al.* 1997). There is also some evidence that higher fertilizer inputs may have an adverse effect on the field boundary vegetation (Kleijn & Snoejng 1997) and therefore possibly associated invertebrate species. Fertilizer inputs had not increased greatly on arable farms between the two periods and the effects of fertilizer were additive to the change in species abundance over time in the four species showing a significant effect of fertilizer input, so changes in bird abundance between periods on arable farms cannot be wholly explained by changes in artificial fertilizer use.

There was very little evidence to suggest that pesticides have affected bird abundance. Some significant correlations between application rate and species density were detected, but in most cases, this was likely to be associated with other factors rather than with a causal effect of pesticides (for example, greater pesticide use occurred on farms with a greater arable area). A confounding factor is that pesticides have become increasingly efficient at killing the target organisms and methods of application have improved, so less active ingredient is wasted (Campbell *et al.* 1997), therefore application rates alone may not be an adequate measure of the intensity of use. An indirect effect of pesticides has been suggested as having effects on a number of species, but there is little concrete evidence for this (Campbell *et al.* 1997). One exception is the Grey Partridge, where intensive studies have revealed an effect of herbicides on the food plants of important invertebrate prey species (Potts 1986). Given that pesticide effects are likely to be subtle and indirect, it is not surprising that no effects on bird abundance were found in this small sample of farms. The issue of detecting pesticide effects is considered further in Section 7.

It has been suggested that the diversity of farmland habitat has declined and that this has been a major contributory factor to the decline of the Skylark in particular (Chamberlain & Gregory 1999, Wilson *et al.* 1997). The data for the early period was not considered accurate enough for comparison of farm habitat richness between periods, as it seemed likely that only the main crop types had been recorded in the early-1970s, hence the observed habitat richness was much lower. A number of results have implied that a diversity of habitats is beneficial in certain species, either because mixed farms tended to hold high densities or because density was often related to arable components in pastoral farms. A greater diversity of habitat use is likely to benefit certain species as it will provide a greater choice of resources which may be needed under different conditions. However, it is not just the diversity *per se* which is important, but also the components which make up the diversity. For example, a Skylark's territory with winter cereal, spring cereal and set-aside would seem to provide a good mix of early and late season nesting opportunities with a good source of food. However, this has the same habitat diversity as an equal area of winter cereal, oilseed rape and silage grass, which is likely to be a relatively poor territory. This example illustrates that it is difficult to assess the value of a farm by taking crops in isolation, as interactions between habitats are also likely to be very important for some species. This argument could be extended to consider pesticide applications, fertilizer inputs and other management practices which have potential effects on bird populations. The results here can give some pointers as to which crops are important, but obtaining a detailed picture on reasons for population changes is likely to depend on a number of interacting factors. The fact that there was little overall evidence for effects of period being explained by changes in crop areas may be partly a consequence of this.

6.5 Summary

1. This section examines changes in bird populations and agricultural management at the scale of individual farms. Breeding bird censuses were conducted on 51 farms in predominantly arable and mixed farming regions in 1996 to 1997 for which bird census data were available for the period 1971 to 1973 from the Common Birds Census. These two periods are referred to as the late and early periods respectively. A simplified territory mapping method was used with five visits spread between April and the end of June. Census maps from the early period were reanalysed to make them comparable with the late period. A questionnaire-based interview was conducted with each of the farmers (except one) to summarise information about past and current management. Many agricultural variables from the late period could be quantified in a continuous manner but the agricultural variables from the early period had to be summarised in a categorical way.

2. The farms were likely to be representative of lowland landscapes because they broadly matched the expected distribution across ITE Land Classes within the regions considered. Overall between the two periods farms showed the greatest relative

decreases in spring cereals, ley grass and hay. The farms showed relatively large increases in winter cereals, game cover, silage, sheep, artificial fertilisers and pesticides. Farms were relatively evenly balanced in terms of decreases and increases in new grass, permanent grass and root crops. Hedgerow length had changed rather little. Arable farms had significantly less spring cereal and rotational grass but more oilseed rape in the late period. There was little difference in the management of grass between early and late periods but use of artificial fertiliser had significantly increased on grass farms. It was surprising that pesticide application did not show a significant difference between early and late periods on those farms where accurate usage data were available. This differs strikingly from the national picture and may indicate that there is large variation between farms in pesticide use.

3. Analyses were undertaken within each time period to assess the extent to which species were associated with farming types and particular components of agriculture. In the early period, Turtle Dove, Skylark, Song Thrush and Tree Sparrow were more abundant on arable farms; Greenfinch was most abundant on mixed and arable and Chaffinch most abundant on pastoral. For the 21 target farmland species, mixed and arable farms held more species than pastoral. In the late period, Whitethroat and Yellowhammer had higher densities on arable and Skylark on mixed farms but there were no longer differences between farm types in species richness or diversity, arable and mixed farms having declined in both measures between periods. For the late period detailed analyses were possible relating agricultural variables to bird abundance across plots. A wide range of correlates emerged in these analyses which tended to reflect the preferences of species for arable or pastoral farms. There was little evidence of strong links between pesticide application and species abundances.

4. Between periods for the full sample of farms, nine species showed significant declines in density: Grey Partridge, Turtle Dove, Skylark, Blackbird, Song Thrush, Tree Sparrow, Bullfinch, Corn Bunting and Reed Bunting. Five species increased significantly: Rook, Whitethroat, Greenfinch, Goldfinch and Chaffinch. These population changes parallel those from published CBC index trends. Species richness of the 21 target species decreased between early and late periods. When classified by farm type, arable farms showed far more significant changes in density (mostly decreases) than mixed or pastoral farms but this may have been a consequence of relatively large sample sizes for arable.

5. Relationships between changes in bird abundance and changes in agricultural variables were examined between early and late periods using generalised linear modelling. The results generated by these models were complex and species-specific. It was not possible to generate valid models for the majority of species. However, for arable farms, models were produced for six species. Effects of agricultural variables were generally additive to (rather than replacing) those of period, indicating that other factors in addition to those included in the analysis must have caused the changes in bird abundance. There was no evidence that pesticide application rates were associated with changes in bird abundance. However, for four species on arable farms, fertiliser usage had a significant negative effect on abundance. These species were Skylark, Blackbird, Greenfinch and Yellowhammer.

6. Changes in agricultural variables were analysed by ordination. This generated a gradient from farms showing major loss of spring cereals and stubbles but an increase in winter wheat, to farms that had shown relatively little loss, or even an increase, of spring cereal. Densities of birds on the 10 farms with the highest scores on this gradient were compared with those for the 10 farms with the lowest scores. Three species - Grey Partridge, Turtle Dove and Corn Bunting - showed a significant decrease only on farms that had lost spring cereal, but Reed Bunting showed the opposite pattern.

7. It is hard to draw general conclusions from the results of these analyses because many of the significant results are species-specific. Nonetheless, there is more evidence of fertiliser effects than of pesticide effects on changes in bird abundance. This does not mean that pesticides have not affected abundance of farmland birds; it is likely that any effects are too subtle to be detected by the data available for these analyses. Several of the analyses suggest that changes in cereal cropping, including timing of sowing, have been important to several farmland birds.

Variable	Data set for analysis
winter wheat (ha)	arable
winter barley (ha)	arable
vegetable crops (ha)	arable
crops for game cover (ha)	arable
set-aside (ha)	arable
fallow land (ha)	arable
new grass <5 years old (ha)	both
permanent pasture >5 years old (ha)	both
cattle number	both
sheep number	both
nitrogen input (kg/ha)	both
potassium input (kg/ha)	arable
phosphorous input (kg/ha)	arable
herbicide application (spray hectares)	both
fungicide application (spray hectares)	arable
insecticide application (spray hectares)	arable
woodland (ha)	both
ponds (number)	both

Table 6.1 Continuous variables considered in the analysis of effects of agricultural management on bird abundance in 1996 to 1997 which were recorded accurately on at least 25% of farms. Whether the variable was analysed with respect to abundance on arable/mixed farms only, or both arable/mixed and grass farms, is indicated. Each variable was used in the analysis of all farms with the exception of game cover crops. No continuous data were available for the early period, 1971 to 1973.

Variable	Levels	Farm type applicable
Spring cereals†	0-3	Arable
Winter cereals†	0-3	Arable
Root crops†	0-3	Arable
Other crops on arable farms	0-3	Arable
Set-aside	presence/absence	Arable
Stubble (not set-aside) or fallow land present over winter†	presence/absence	Arable
Ley grass in rotation†	presence/absence	Both
Permanent pasture (>5 years old)†	0-3 1-3	Arable Pastoral
New grass (<5 years old)†	0-2	Both
Grass cut for silage (first cut)†	presence/absence	Pastoral
Grass cut for hay (first cut)†	presence/absence	Pastoral
All arable crops on grass farms†	presence/absence	Pastoral
Sheep (numbers)†	0-3 presence/absence	Pastoral Arable
Cattle (numbers)†	0-3 presence/absence	Pastoral Arable
Artificial fertilizer application (kg/ha nitrogen)†	high/low	Both
Pesticide application rate (spray hectares of herbicide)†	high/low	Arable
Oilseed rape in rotation	presence/absence	Arable
Date of first grass cut	before or after mid-June	Both
Farmyard manure application	high/low	Both
Slurry application	high/low	Both

[1]Definitions of level of extent:
0-2: 0 absent; 1 less than the mean; 2 more than the mean.
0-3: 0 absent; 1 less than 33rd percentile; 2 between 33rd and 66th percentile 3 greater than 33rd percentile.
1-3: 1 less than 33rd percentile; 2 between 33rd and 66th percentile; 3 greater than 33rd percentile.
high/low: high more than the mean; low less than the mean.

Table 6.2 Habitat area, pesticide and fertilizer application rates defined in levels of extent[1]. † variables with fewest missing values used in Generalized Linear Model analysis (Tables 6.9 to 6.12). The variables were classified into these categories both for the early (1971 to 1973) and late (1996 to 1997) periods.

Period	Arable farms	Mixed farms	Pastoral farms	ANOVA
Early	2.44±1.64 (18)	2.50±1.35 (10)	1.43±0.65 (14)	$F_{2,39}$=2.95 ns
Late	3.36±1.65 (22)	4.36±1.22 (11)	2.20±1.70 (15)	$F_{2,45}$=6.11**

Table 6.3 Mean habitat richness (i.e. number of separate crop types) in different predominant farm types.

Species	Arable	Mixed	Pastoral	
Number of farms	17	14	13	
Kestrel	0.07±0.08	0.07±0.06	0.11±0.13	$F_{2,41}$=0.75 ns
Grey Partridge	0.26±0.22	0.25±0.32	0.14±0.17	χ^2_2=3.24 ns
Lapwing	0.33±0.37	0.33±0.39	0.53±0.63	χ^2_2=0.60 ns
Stock Dove	0.17±0.19	0.26±0.37	0.11±0.14	$F_{2,41}$=1.18 ns
Turtle Dove	0.44±0.81	0.29±0.39	0.08±0.19	χ^2_2=8.57*
Skylark	1.45±0.89	1.17±0.85	0.65±0.75	$F_{2,41}$=3.32*
Yellow Wagtail	0.08±0.12	0.13±0.17	0.09±0.19	χ^2_2=1.51 ns
Starling	0.62±0.91	0.86±1.35	2.19±3.91	$F_{2,41}$=1.85 ns
Rook	0	0.03±0.09	0	χ^2_2=2.42 ns
Whitethroat	0.26±0.17	0.26±0.17	0.29±0.30	$F_{2,41}$=0.14 ns
Blackbird	2.69±1.52	2.29±1.32	2.06±1.03	$F_{2,41}$=0.88 ns
Song Thrush	0.93±0.40	0.61±0.29	0.50±0.38	$F_{2,41}$=5.84**
Tree Sparrow	0.65±0.54	0.46±0.43	0.23±0.41	χ^2_2=9.99**
Chaffinch	1.01±0.71	1.15±0.67	1.78±0.98	$F_{2,41}$=3.73*
Bullfinch	0.26±0.15	0.18±0.11	0.17±0.15	$F_{2,41}$=1.95 ns
Greenfinch	0.47±0.20	0.47±0.37	0.20±0.19	$F_{2,41}$=4.75*
Goldfinch	0.30±0.24	0.35±0.31	0.40±0.41	$F_{2,41}$=0.39 ns
Linnet	0.79±0.55	0.78±1.10	0.40±0.39	$F_{2,41}$=1.21 ns
Corn Bunting	0.23±0.41	0.28±0.38	0.05±0.11	χ^2_2=3.66 ns
Reed Bunting	0.40±0.52	0.28±0.21	0.19±0.33	$F_{2,41}$=1.14 ns
Yellowhammer	0.89±0.78	0.74±0.43	0.43±0.49	$F_{2,41}$=2.13 ns
Species richness (all spp)	36.24±8.19	39.64±8.17	37.05±8.73	$F_{2,41}$=0.67 ns
Species richness (target spp)	14.96±2.19	15.61±2.28	11.72±2.92	$F_{2,41}$=9.74***
Species diversity	3.13±0.25	3.19±0.20	3.12±0.27	$F_{2,41}$=0.33 ns

Table 6.4 Species density (territories/10 ha), species diversity and species richness in different predominant farming types in the early period (1971 to 1973). F values from ANOVA are given except in cases where the data departed severely from a normal distribution, in which case χ^2 values from Kruskal-Wallis tests are given.

Species	Arable	Mixed	Pastoral	$F_{2,45}$
Number of farms	23	11	14	
Kestrel	0.08±0.09	0.15±0.16	0.10±0.10	$F_{2,45}=1.74$ ns
Grey Partridge	0.09±0.13	0.09±0.15	0.02±0.05	$\chi^2_2=4.17$ ns
Lapwing	0.12±0.21	0.55±1.11	0.20±0.39	$\chi^2_2=1.92$ ns
Stock Dove	0.33±0.33	0.40±0.39	0.35±0.26	$F_{2,45}=0.15$ ns
Turtle Dove	0.08±0.13	0.03±0.04	0.02±0.04	$\chi^2_2=1.22$ ns
Skylark	0.87±0.53	0.92±0.85	0.27±0.34	$F_{2,45}=5.65$**
Yellow Wagtail	0.11±0.18	0.02±0.03	0.04±0.07	$\chi^2_2=3.06$ ns
Starling	0.54±0.60	1.66±1.51	1.44±2.44	$F_{2,45}=2.54$ ns
Rook	0.31±0.70	0.61±1.07	1.84±3.87	$\chi^2_2=1.50$ ns
Whitethroat	0.73±0.47	0.44±0.25	0.23±0.28	$F_{2,45}=8.00$**
Blackbird	1.19±0.73	1.59±1.09	1.76±1.06	$F_{2,45}=1.88$ ns
Song Thrush	0.19±0.16	0.29±0.45	0.26±0.15	$F_{2,45}=0.60$ ns
Tree Sparrow	0.09±0.19	0.01±0.02	0.04±0.11	$\chi^2_2=3.58$ ns
Chaffinch	1.60±1.04	2.00±1.03	2.22±1.06	$F_{2,45}=1.53$ ns
Bullfinch	0.10±0.12	0.11±0.10	0.11±0.10	$F_{2,45}=0.02$ ns
Greenfinch	0.42±0.28	0.74±0.70	0.56±0.37	$F_{2,45}=2.01$ ns
Goldfinch	0.36±0.26	0.57±0.57	0.69±0.48	$F_{2,45}=2.99$ ns
Linnet	0.59±0.38	0.48±0.39	0.42±0.31	$F_{2,45}=1.00$ ns
Corn Bunting	0.10±0.23	0.02±0.05	0.01±0.01	$\chi^2_2=3.20$ ns
Reed Bunting	0.13±0.18	0.05±0.07	0.11±0.18	$F_{2,45}=1.03$ ns
Yellowhammer	0.70±0.53	0.64±0.45	0.29±0.38	$F_{2,45}=3.41$*
Species richness (all spp)	37.80±10.51	41.56±9.86	39.06±7.87	$F_{2,45}=0.54$ ns
Species richness (target spp)	13.46±3.05	13.50±2.27	11.93±2.46	$F_{2,45}=1.58$ ns
Species diversity	3.19±0.22	3.16±0.11	3.07±0.22	$F_{2,45}=1.89$ ns

Table 6.5 Species density (territories/10 ha), species diversity and species richness in different predominant farming types in the late period (1996 to 1997).

(a) All data

	1996	1997	Data distribution
Sample size	26	26	
Kestrel		new grass+	normal
Grey Partridge	farm area+++	farm area++	binomial
Lapwing	fallow+	farm area+	binomial
Stock Dove	phosphate-	hedgerow length-	normal
Turtle Dove	farm area++	vegetables++	binomial
Skylark	set-aside+	set-aside+++	normal
Yellow Wagtail	sheep+	vegetables++	binomial
Starling			normal
Rook	herbicide+	fallow++	binomial
Whitethroat	winter wheat++	pasture--	normal
Blackbird	new grass++	new grass++	normal
Song Thrush	farm area-		normal
Tree Sparrow	ponds+	ponds+	binomial
Chaffinch	phosphate-	phosphate-	normal
Bullfinch		ponds+	normal
Greenfinch	farm area-		normal
Goldfinch	new grass+++		normal
Linnet	woodland+		normal
Corn Bunting	farm area+		binomial
Reed Bunting	farm area-	hedgerow length--	normal
Yellowhammer	pasture-	pasture-	normal
Species richness	fallow++	fungicide++	normal
Species diversity	fallow++	herbicide++	normal

Table 6.6 The effects of agricultural variables on bird abundance, species richness of 21 target species and species diversity of all species recorded in 1996 and 1997. Details of independent variables used are given in Table 6.1. Densities were analysed with regression if data approximated to a normal distribution. Strongly skewed data with many zero values were analysed using a binomial response (presence/absence) with logistic regression. The single variable which explained the most variation is shown if significant ($P<0.05$). Sign indicates direction of relationship, +/- $P<0.05$, ++/-- $P<0.01$, +++/--- $P<0.001$.

(b) Arable/mixed farms

Species Sample size	1996 18	1997 18	Data distribution
Kestrel		winter wheat-	normal
Grey Partridge	farm area++	farm area++	binomial
Lapwing	fallow area+	vegetable area+	binomial
Stock Dove	phosphate-	hedgerow length-	normal
Turtle Dove	farm area+	vegetable area+	binomial
Skylark		set-aside++	normal
Yellow Wagtail		vegetable area+	binomial
Starling			normal
Rook	herbicide++	fallow area+	binomial
Whitethroat	winter wheat++	winter wheat++	normal
Blackbird			normal
Song Thrush		new grass+	normal
Tree Sparrow	herbicide-		binomial
Chaffinch	phosphate--	phosphate-	normal
Bullfinch	new grass+	vegetable area+	normal
Greenfinch	winter wheat-	winter wheat--	normal
Goldfinch	insecticide--		normal
Linnet	phosphate-		normal
Corn Bunting			binomial
Reed Bunting	farm area-	hedgerow length--	normal
Yellowhammer	farm area-	phosphate-	normal
Species richness	phosphate--	vegetable++	normal
Species diversity	set-aside-	herbicide+	normal

Table 6.6 Continued.

(c) Pastoral farms

Species	1996	1997	Data distribution
Sample size	9	9	
Kestrel	nitrogen+		normal
Grey Partridge	farm area+	farm area+	binomial
Lapwing	farm area+	farm area+	binomial
Stock Dove			normal
Turtle Dove			binomial
Skylark	farm area+	farm area++	normal
Yellow Wagtail	farm area+	farm area+	binomial
Starling		nitrogen+++	normal
Rook		sheep+	binomial
Whitethroat	pasture-	pasture-	normal
Blackbird	pasture-	nitrogen+	normal
Song Thrush	pasture---	pasture-	normal
Tree Sparrow			binomial
Chaffinch			normal
Bullfinch	herbicide++	farm area-	normal
Greenfinch		nitrogen++	normal
Goldfinch	herbicide+++		normal
Linnet		hedgerow length+	normal
Corn Bunting	farm area+		binomial
Reed Bunting	ponds++		normal
Yellowhammer	herbicide++		normal
Species richness	sheep-		normal
Species diversity		cattle+	normal

Table 6.6 Continued.

Species	Mean difference ±s.e. (n)	|t|	P for no change in farm type
Kestrel	0.03±0.14 (39)	1.25 ns	ns
Grey Partridge	-0.21±0.23 (35)	5.37***	***
Lapwing	-0.18±0.80 (33)	1.27 ns	ns
Stock Dove	0.07±0.78 (43)	0.56 ns	ns
Turtle Dove	-0.32±0.62 (33)	3.01**	**
Skylark	-0.48±0.63 (43)	4.96***	***
Yellow Wagtail	-0.04±0.21 (28)	1.22 ns	ns
Blackbird	-0.90±1.31 (45)	4.61***	***
Song Thrush	-0.47±0.41 (45)	7.75***	***
Whitethroat	0.31±0.45 (44)	4.49***	**
Starling	-0.07±2.84 (43)	0.16 ns	ns
Rook	2.10±3.34 (17)	2.60*	*
Tree Sparrow	-0.52±0.53 (39)	6.07***	***
Greenfinch	0.14±0.39 (44)	2.40*	ns
Goldfinch	0.16±0.42 (45)	2.50*	*
Linnet	-0.14±0.80 (45)	1.19 ns	ns
Bullfinch	-0.08±0.15 (41)	3.68***	**
Chaffinch	0.57±0.92 (45)	4.17**	**
Corn Bunting	-0.37±0.27 (18)	5.68***	***
Reed Bunting	-0.23±0.29 (37)	4.90***	***
Yellowhammer	-0.15±0.53 (42)	1.83 ns	ns

Table 6.7 The difference in mean density (territories/10 ha) between 1970 to 1973 and 1996 to 1997 on individual farmland plots. Farms where the density was zero in both periods have been omitted. Significance levels are also given for a repeat analysis, where 12 farms which changed predominant farming type between the two periods have been omitted. *P<0.05, **P<0.01, ***P<0.001.

	Arable	Mixed	Pastoral
Kestrel	ns (19)	ns (9)	ns (10)
Grey Partridge	--- (19)	ns (7)	-- (8)
Lapwing	-- (16)	ns (6)	- (10)
Stock Dove	ns (20)	ns (9)	+ (13)
Turtle Dove	ns (18)	ns (7)	ns (7)
Skylark	--- (22)	ns (8)	- (12)
Blackbird	--- (22)	ns (9)	ns (13)
Song Thrush	--- (22)	- (9)	- (13)
Whitethroat	+++ (22)	ns (9)	ns (12)
Yellow wagtail	ns (16)	ns (5)	ns (6)
Starling	ns (21)	ns (9)	ns (12)
Rook	+ (8)	ns (9)	
Tree Sparrow	--- (22)	ns (9)	ns (7)
Greenfinch	ns (22)	ns (9)	++ (12)
Goldfinch	ns (22)	ns (9)	+ (13)
Linnet	ns (22)	ns (9)	ns (13)
Bullfinch	-- (20)	ns (9)	ns (11)
Chaffinch	+ (22)	ns (9)	+ (13)
Corn Bunting	-- (11)		
Reed Bunting	-- (19)	- (9)	ns (8)
Yellowhammer	ns (22)	ns (8)	ns (11)

Table 6.8 Significance of t-tests between early and late periods in separate farm types (considering the mean density over individual years in each period). Farm type was defined according to habitat extent in 1997. Farms where the density was zero in both periods have been omitted. Sample sizes are given in brackets. Analyses with small sample sizes (n<5) are left blank. Sign indicates direction of a significant relationship, where + or - are respectively increases or decreases between early and late periods. +/- P<0.05, ++/-- P<0.01, +++/--- P<0.001.

Species	Model	Number of farms	Significant variables	Habitat class variable level	Parameter estimate
Skylark	A	25	Farm***		
			Period***		0.91±0.14***
	B	23	Farm***		
			Period***		1.02±0.30***
			Winter cereals**	1	1.38±0.55*
				2	-2.33±1.56 ns
				3	-2.30±2.16 ns
			Spring cereals***	1	-0.99±0.70**
				2	-0.24±1.08 ns
				3	0.63±0.39*
Blackbird	A	25	Period***		0.99±0.16***
	B	23	Farm***		
			Period***		1.61±0.26***
			Spring cereals***	1	-0.98±0.58 ns
				2	-2.25±0.76 ns
				3	0.39±0.41 ns
			Winter cereals***	1	0.95±0.48*
				2	-2.35±0.79**
				3	-2.86±1.10**
			Permanent grass**	1	-0.02±0.51 ns
				2	0.13±1.07 ns
				3	-4.07±1.37**
			Ley grass*		0.83±0.40*
			Livestock*		-1.99±0.82*
Song Thrush	A	24	Farm***		
			Period***		2.00±0.17***
	B	22	Period***		2.52±0.84***

Table 6.9 The effect of period and habitat class on the frequency of territories of selected species on arable/mixed farms analysed using a Generalized Linear Model with a Poisson error term and log-link function. Details on habitat class variables are given in Table 6.2. Model A considers the effects of farm and period. Model B considers farm, period and nine habitat variables defined into different levels based on the area per farm. Sample size represents the number of farm pairs analysed (i.e. one farm per period). Variables which were significant in the overall model, and the significance of individual parameter estimates relative to the lowest class level, are given. *P<0.05, **P<0.01, ***P<0.001.

Species	Model	Number of farms	Significant variables	Habitat class variable level	Parameter estimate
Chaffinch	A	25	Farm***		
	B	23	Farm***		
			Spring cereals***	1	0.13±0.55 ns
				2	-1.92±0.81*
				3	0.59±0.40 ns
			Permanent pasture*	1	0.04±0.60 ns
				2	1.10±1.15 ns
				3	-5.00±1.75**
			Livestock*		-1.85±0.84*
Linnet	A	22	Farm**		
			Period**		0.52±0.20**
	B	21	none		
Yellowhammer	A	25	Farm**		
			Period***		0.61±0.14***
	B	23	Farm**		
			Winter cereals*	1	4.53±2.78 ns
				2	3.19±3.53 ns
				3	6.45±7.68 ns

Table 6.9 Continued.

Species	Number of farms	Significant variables	Parameter estimates
Skylark	19	Farm***	
		Period***	0.80±0.11***
		Fertilizer application***	-2.17±0.53**
Blackbird	19	Farm***	
		Period***	0.99±0.17***
		Fertilizer application**	-1.87±0.69**
Greenfinch	17	Farm***	
		Fertilizer application*	-2.79±1.64
Yellowhammer	19	Farm***	
		Period***	0.61±0.17***
		Fertilizer application*	-1.77±0.81*

Table 6.10 The effect of artificial fertilizer application rate, farm and period on the numbers of selected species for arable/mixed farms analysed using a Generalized Linear Model with a Poisson error term and log-link function. Models used farm, period and fertilizer application class as independent variables. Parameter estimates are bird counts on farms with greater than the mean application rate relative to bird counts on farms with less than the mean application rate. Further details are given in Table 6.9.

Species	Model	Significant variables	Habitat class variable level	Parameter estimate
Grey Partridge	A	Period***		0.94±0.27***
	B	Period**		1.13±0.35**
		Winter cereals*	1	-0.17±0.82 ns
			2	0.63±0.72 ns
			3	1.55±0.71*
		Root crops*	1	1.01±0.65 ns
			2	1.82±0.77*
			3	0.26±0.60 ns
Lapwing	A	Period*		0.61±0.28*
	B	none		
Turtle Dove	A	Period***		1.01±0.27***
	B	Period**		1.02±0.36***
		Winter cereals	1	1.74±0.85*
			2	2.19±0.87*
			3	1.79±0.85*
		Root crops	1	-1.35±0.60*
			2	1.87±0.86*
			3	0.68±0.52 ns
Yellow Wagtail	A	none		
	B	Permanent pasture*	1	-1.49±0.64*
			2	0.15±0.67 ns
			3	-0.43±1.17 ns
Whitethroat	A	Period***		-0.98±0.23***
	B	Period***		-1.26±0.39***
Tree Sparrow	A	Period***		1.79±0.32***
	B	Period***		2.21±0.50***
Bullfinch	A	Period**		0.72±0.25**
	B	Period***		1.17±0.33***
		Stubble*		-0.87±0.37*

Table 6.11 The effect of period and habitat class on the probability of occurrence (i.e. presence/absence) of selected species on arable/mixed farms analysed using a Generalized Linear Model with a binomial error term and probit-link function. Model A considers the effects of period. Model B considers period and nine habitat variables defined into different levels based on the area per farm (Table 6.2). The total area of farm was used as an offset variable. Sample size was 24 farms per period for each model. Variables which were significant in the overall model, and the significance of individual parameter estimates relative to the lowest class level, are given. *$P<0.05$, **$P<0.01$, ***$P<0.001$.

Species	Model	Significant variables	Habitat class variable level	Parameter estimate
Reed Bunting	A	Period***		0.81±0.29**
	B	Period**		0.78±0.37*
		Spring cereals*	1	1.35±0.54*
			2	0.96±0.97 ns
			3	-0.34±0.70 ns
		Ley grass*		-1.37±0.58*
		New grass*	1	-1.18±0.77 ns
			2	1.11±0.89 ns

Table 6.11 Continued.

Species	Model	Significant variables	Habitat class variable level	Parameter estimate
Stock Dove	A	Period**		-0.95±0.33**
	B	Period*		-0.91±0.43*
		New grass*	1	3.59±1.59*
			2	0.67±0.47 ns
		Hay*		-1.13±0.50
Whitethroat	A	none		
	B	Livestock***	2	-3.02±1.03**
			3	-3.01±0.82***
		Silage***		2.23±0.60***
Greenfinch	A	none		
	B	Period*		-1.15±0.56*
		Hay*		1.23±0.61*
Bullfinch	A	none		
	B	Arable crops		0.96±0.47*
Yellowhammer	A	none		
	B	Silage*		1.64±0.74*

Table 6.12 The effects of period and habitat class on the probability of occurrence of selected species on pastoral farms. Sample sizes were 14 farms per period for each model. Other model details are as per Table 6.11.

Habitat variable	Axis 1	Axis 2	Axis 3
Winter cereal	210	15	17
Permanent grass	123	153	-112
Sheep	75	14	185
Cattle	63	-4	117
Root crops	9	44	31
Ley grass	-7	-106	-94
New grass	-36	-101	-57
Stubbles	-89	-14	110
Spring cereal	-97	204	17
Eigenvalue (%)	2.6	1.2	0.7

Table 6.13 Scores for the first three axes derived from Detrended Correspondence Analysis of categorical change in nine farm habitat variables (Table 6.2) between 1970 to 1973 and 1996 to 1997, in the order of the first axis.

Species	Highest axis scores	Lowest axis scores
Kestrel	0.00±0.07 ns	-0.01±0.10 ns
Grey Partridge	-0.27±0.26**	-0.18±0.26 ns
Lapwing	-0.21±0.52 ns	-0.06±0.22 ns
Stock Dove	0.05±0.19 ns	-0.46±1.41 ns
Turtle Dove	-0.11±0.14*	-0.26±0.47 ns
Skylark	-0.62±0.92 ns	-0.28±0.52 ns
Yellow Wagtail	0.05±0.21 ns	-0.04±0.10 ns
Starling	-0.36±0.99 ns	0.67±1.33 ns
Rook	0.02±0.05 ns	0.60±1.10 ns
Whitethroat	0.54±0.42**	0.29±0.41*
Blackbird	-1.14±1.26*	-1.48±1.20**
Song Thrush	-0.71±0.39***	-0.52±0.36**
Tree Sparrow	-0.36±0.44*	-0.68±0.69*
Chaffinch	0.49±0.88 ns	0.76±1.26 ns
Bullfinch	-0.10±0.12*	-0.15±0.15*
Greenfinch	0.04±0.36 ns	0.09±0.36 ns
Goldfinch	-0.03±0.30 ns	0.00±0.40 ns
Linnet	-0.35±0.78 ns	-0.54±1.33 ns
Corn Bunting	-0.26±0.30*	-0.17±0.25 ns
Reed Bunting	-0.28±0.45 ns	-0.23±0.18**
Yellowhammer	-0.22±0.67 ns	-0.02±0.51 ns

Table 6.14 Mean (±s.d.) difference in density between 1970 to 1973 and 1996 to 1997 on farms grouped according to scores on axis 1 of DCA (see Table 6.13). N=10 farms for each group.

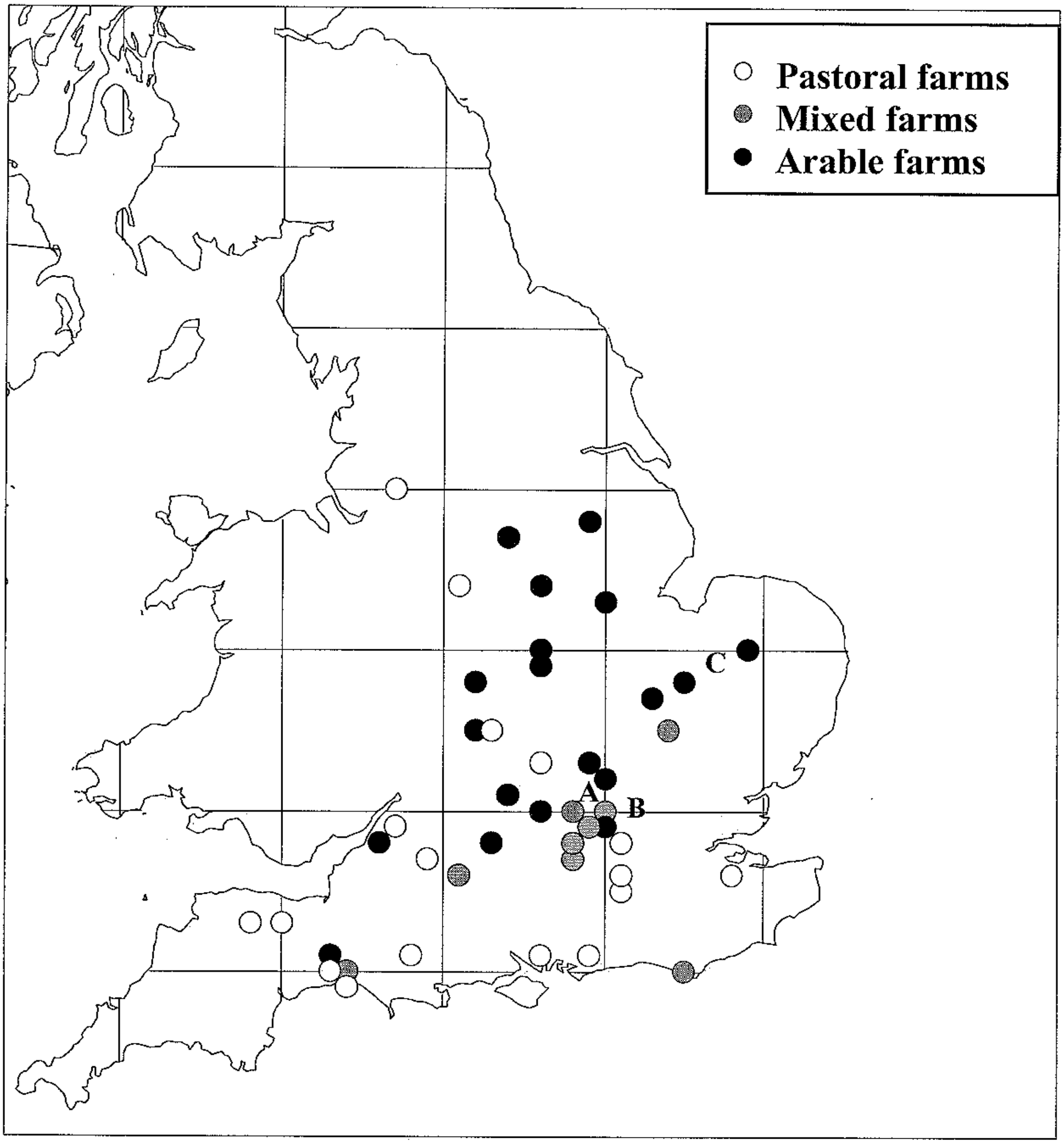

Figure 6.1 The distribution of farmland plots used in the survey. Letters indicate two plots in one 10 km square. A = one arable, one mixed farm; B = one arable, one mixed farm; C = both arable farms .

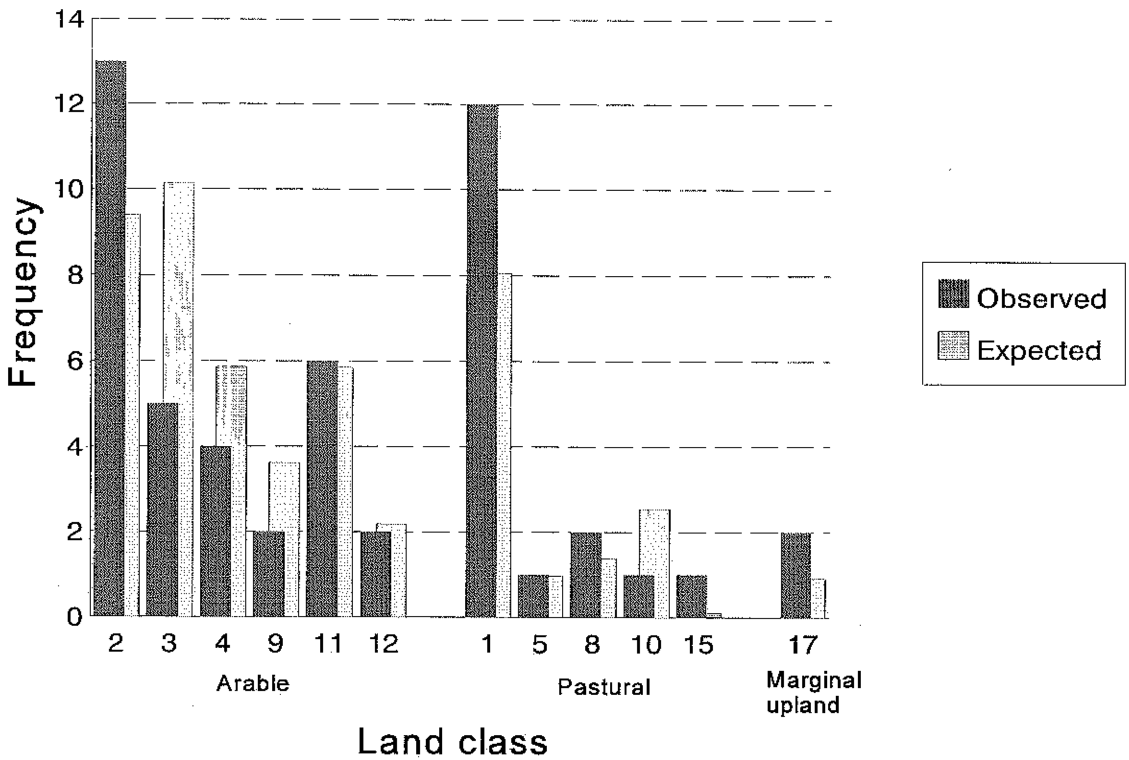

Figure 6.2 Farmland plots classified according to ITE Land Classification system (Bunce *et al.* 1996) and ITE landscape type (Bunce *et al.* 1993).

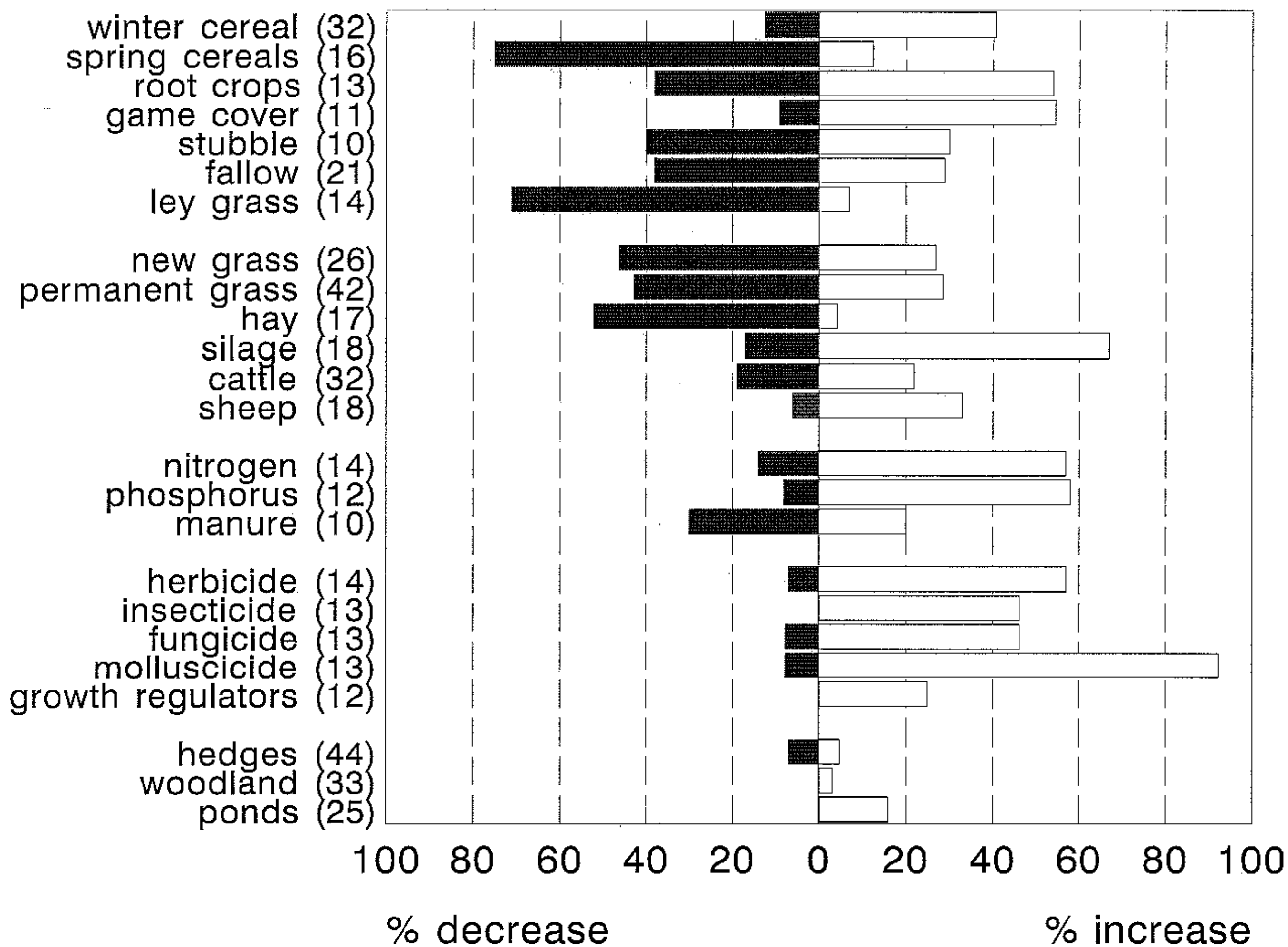

Figure 6.3 The percentage of farms experiencing increases or decreases in various aspects of farm management between the two periods. Numbers in brackets are the number of farms where the factor was known/applicable in both periods (out of a maximum 46 farms). Occurrence on a minimum of 10 farms was required for inclusion in the figure.

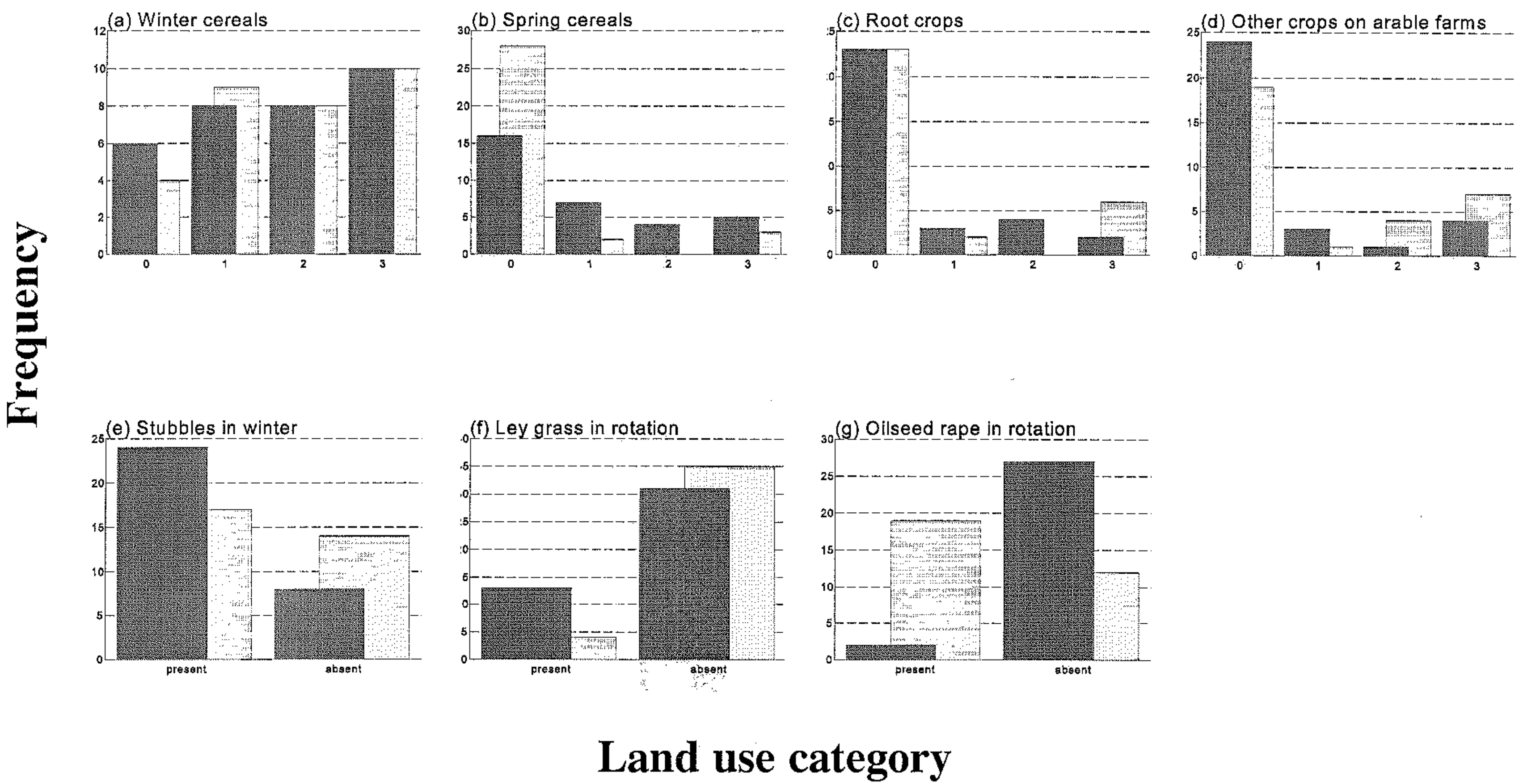

Figure 6.4 The extent of crops on arable farms in early and late periods defined according to categories of area or presence/absence (see Table 6.2). In each case, dark shading=early period, light shading=late period. (a) Winter cereals $\chi^2_3=0.44$ ns; (b) spring cereals $\chi^2_2=9.32$, $P<0.01$, levels 2 and 3 combined to avoid low expected frequencies; (c) root crops $\chi^2_2=0.18$ ns, levels 2 and 3 combined; (d) other crops $\chi^2_2=3.82$ ns, levels 2 and 3 combined; (e) stubbles in winter $\chi^2_1=2.81$ ns; (f) ley grass in rotation $\chi^2_1=4.75$, $P<0.04$; (g) oilseed rape in rotation $\chi^2_1=19.49$, $P<0.0001$.

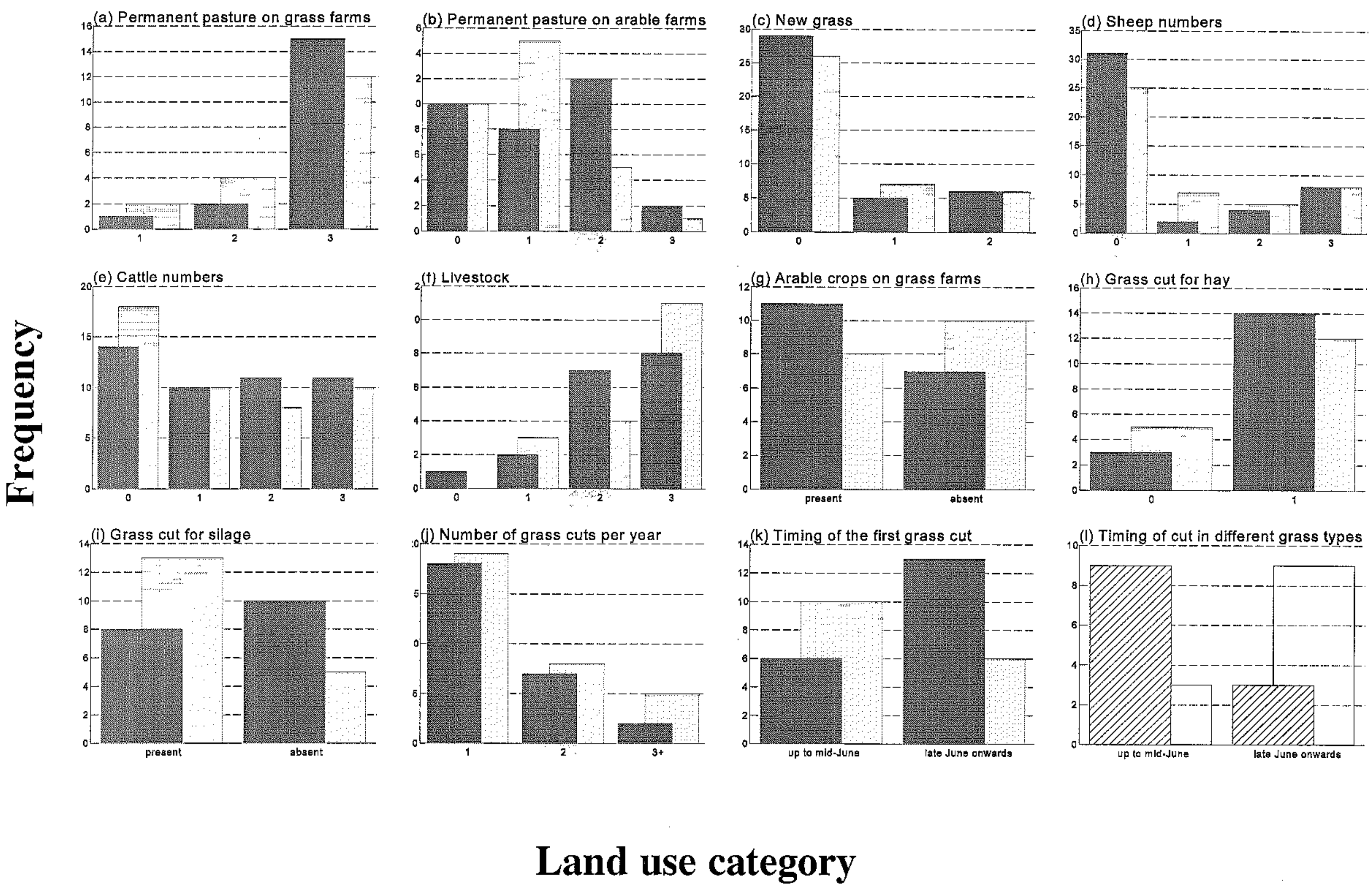

Figure 6.5 The extent of grass crops, livestock and arable crops on pastoral farms in early and late periods defined according to categories of area or presence/absence (see Table 6.2). With the exception of 5(k), dark shading=early period, light shading=late period. (a) Permanent pasture on gass farms $\chi^2_1=0.66$ ns, levels 1 and 2 combined; (b) permanent pasture on arable farms $\chi^2_2=5.45$ ns, levels 2 and 3 combined; (c) new grass $\chi^2_2=0.51$ ns, levels 2 and 3 combined; (d) sheep numbers $\chi^2_3=3.53$ ns; (e) cattle numbers $\chi^2_3=1.02$ ns; (f) livestock on grass farms $\chi^2_2=1.29$ ns, levels 0 and 1 combined; (g) arable crops on grass farms $\chi^2_1=1.00$ ns; (h) grass cut for hay $\chi^2_1=0.50$ ns; (i) grass cut for silage $\chi^2_1=2.86$ ns; (j) number of grass cuts per year $\chi^2_2=0.96$ ns; (k) timing of first grass cut (either silage or hay) $\chi^2_1=3.35$ ns; (l) timing of first grass cut in different grass types, where hatched bar=silage and white bar=hay, $\chi^2_1=6.00$, $P<0.02$.

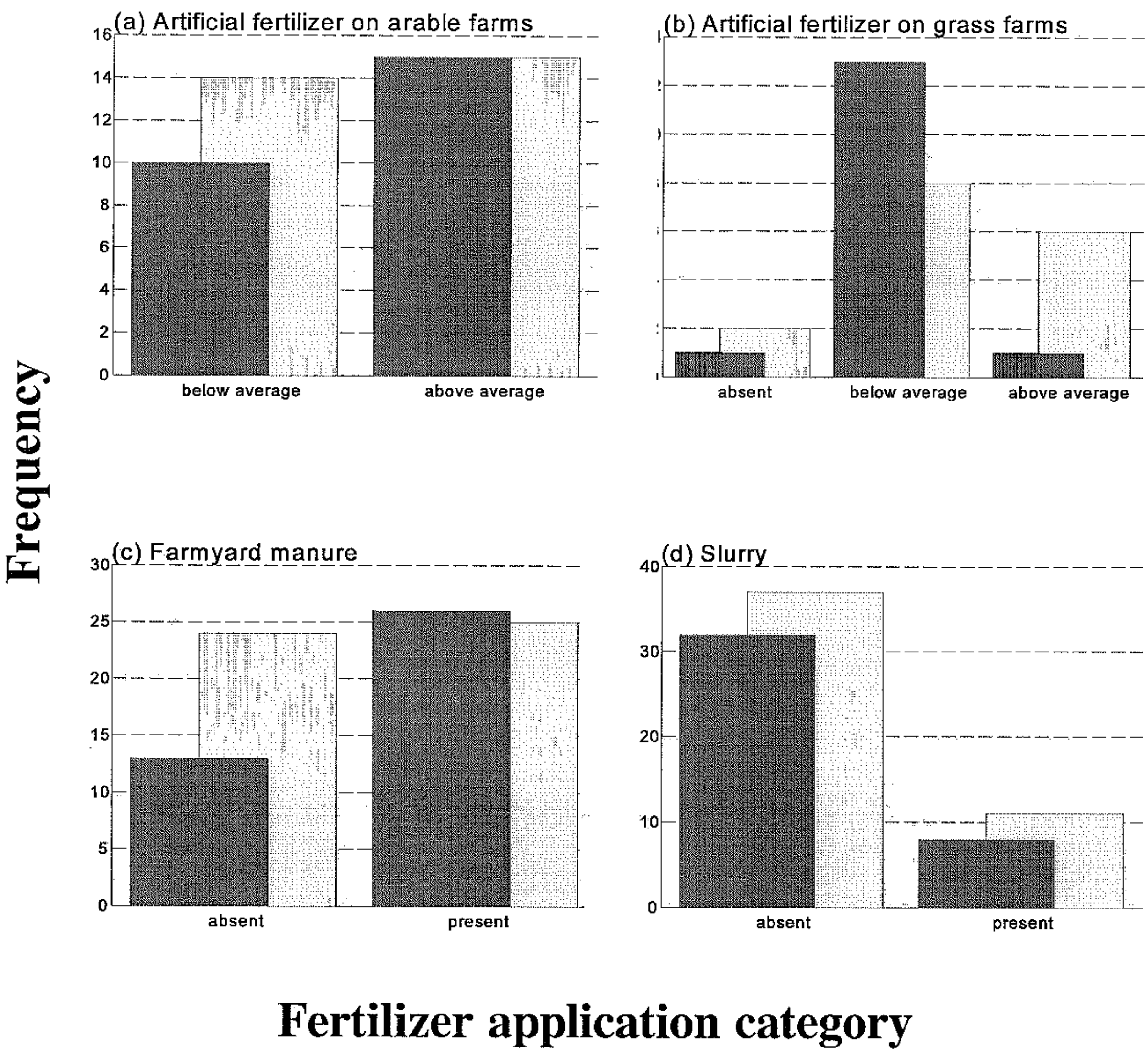

Figure 6.6 Fertilizer use on farms classified into levels of application rate. Dark shading=early period, light shading=late period. (a) Artificial fertilizer on arable farms $\chi^2_1=0.37$ ns; (b) artificial fertilizer on pastoral farms (Fisher exact test $P<0.05$, levels 0 and 1 combined); (c) farmyard manure $\chi^2_1=2.18$ ns; (d) slurry $\chi^2_1=0.13$ ns.

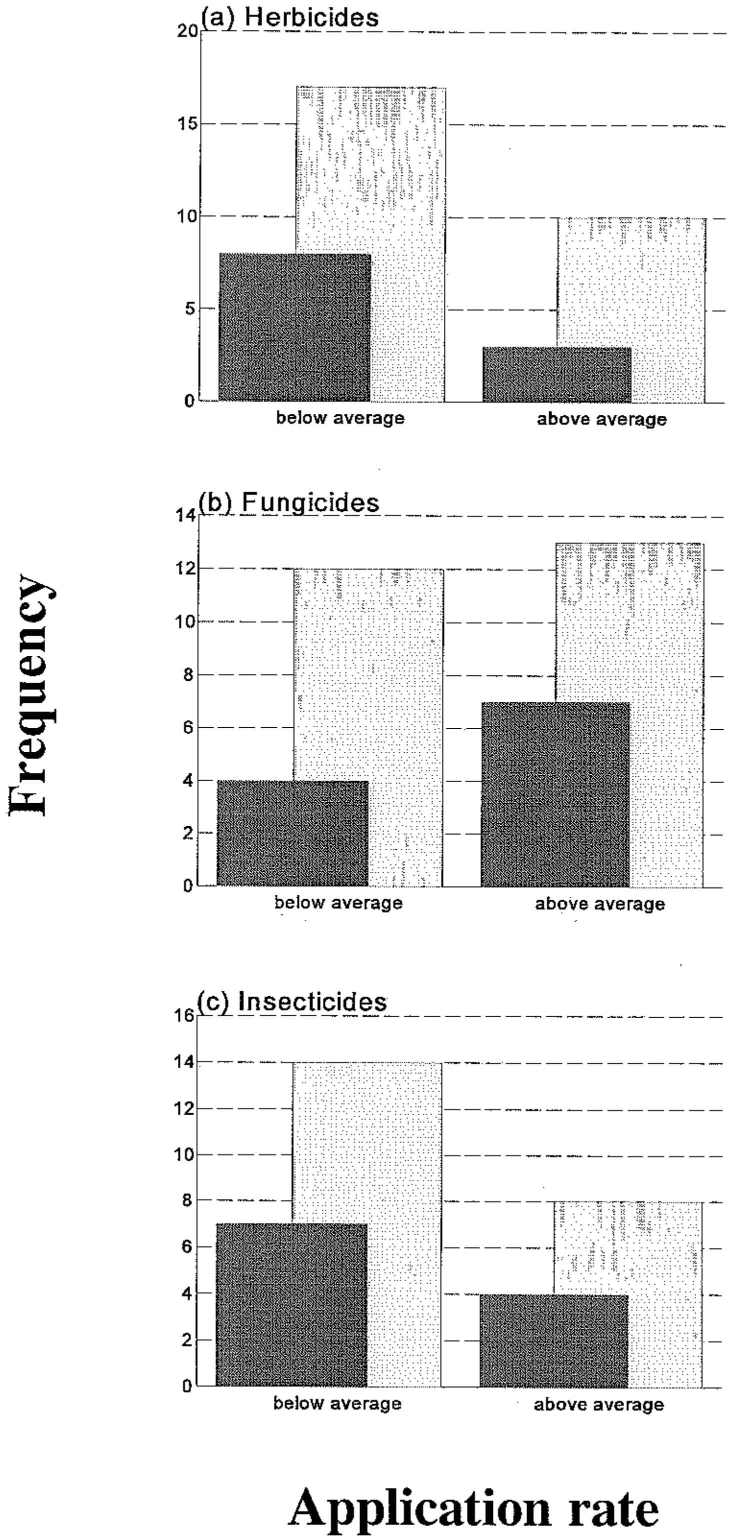

Figure 6.7 Pesticide use on arable farms classified into levels of application rate. Dark shading=early period, light shading=late period. (a) Herbicide $\chi^2_1=0.36$ ns; (b) fungicide $\chi^2_1=0.43$ ns; (c) insecticide $\chi^2_1=0$ ns.

APPENDIX 6.1 Sample Questionnaire from the Habitat Survey

When the survey farms were identified, land owners were approached for permission to carry out the survey visits and also to ask if they would be willing to take part in an historical survey of habitat management. Only a single farmer refused to cooperate in the management survey, but the bird survey was still carried out on this plot. In many cases, a survey plot encompassed land owned by a number of different farmers, and so there was often more than one questionnaire completed per survey site, with a total of 64 questionnaires completed altogether. In some cases a questionnaire was completed with interviews with up to five farm owners, land owners and farm workers. Due to the time span involved, there were some cases where no information could be gathered from the early-1970s, as farms had changed ownership since. Questionnaires were completed by personal interview with the farmer (undertaken by DGG), with the interviewer completing the forms. A sample form is attached.

CSL/BTO FARMLAND BIRD SURVEY 1997

FORM 1

REFERENCE NUMBER	COUNTY	PARISH	DATE	SURVEYOR
251	Berks	____	7.8.97	D.G.

	CROP/CROPTYPE	AREA (AC/~~HA~~)	REMARKS	CBC
01	W. BARLEY	8		
02	"	42		
03	W. WHEAT	36		
04	"	10		
05	GRASSLAND	5		
06	COMMON	70		
07	SPRING OSR	12		
08	POTATOES	9		
09	SPRING OSR	9		
10	"	11		
11	WINTER WHEAT	16.5		
12	" BARLEY	38		
13			T= 266.5	
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				

CSL/BTO FARMLAND BIRD SURVEY 1997

FORM2

BREAK CROPS

What is your current crop rotation system, eg. 2 wheats, 1 barley, break crop.

OSR (WINTER OR SPRING) / WW / W BARLEY (IE. 2 CEREALS 1 OSR

When did you first use this system. SINCE 1976

In which year did you last use grass leys in rotations. NEVER ON CBC PLOT

Which break crops do you currently use eg. grass ley, beet, potatoes, pulses (please specify), osr, linseed.

OSR (OCC. SMALL AREA OF POTATOES)

Tick one or more of the above, list any other break crops separately.

In which year did you first grow each of the break crops currently grown.

1976 OSR

Which rotational systems have you used before, and during which periods.

← CONTINUOUS W. BARLEY | 2 CEREALS + 1 OSR →

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995

COVER CROPS

Do you grow cover crops for game. YES

If so what crops do you grow (please name each crop, the approximate area and the time in field).

30 ACRES / YEAR GREEN MANURE. MUSTARD / OSR
FROM M7 → M11

When did you first introduce cover crops and have the annual areas grown remained unchanged.

SINCE 1975 – NO CHANGE

CSL/BTO FARMLAND BIRD SURVEY 1997

FORM3

AUTUMN SOWING

In which year did you first plant cereal crops in the autumn. SINCE 1966

What crops are currently autumn sown. WHEAT / BARLEY / OSR

In which year were each of these crops first drilled in the autumn.

BARLEY 1966
WHEAT 1975/76
OSR "

What proportion of your current total acreage is sown in the autumn. 61% OF TOTAL CBC PLOT

How has this changed between the mid sixties and the present day (record the proportion of autumn sowings in each of the six time spans).

← 50% OF CROPPED AREA → ← 90% OF CROPPED AREA →

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995

FALLOW LAND (STUBBLES) IN THE WINTER

What proportion of your land is left fallow up until the Spring. 10% OF CROPPED AREA

How has this changed over the years, please record the proportion of fallow land left in each of the six time spans.

← 50% → ← 10% →

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995

What proportion of bare land would have been stubbles, and therefore uncultivated during each of the six time spans.

50% OF FALLOW LAND WOULD HAVE BEEN STUBBLES ↔ NO STUBBLES

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995

CSL/BTO FARMLAND BIRD SURVEY 1997 FORM4

SET ASIDE

Is the set aside land on your farm permanent or rotational. ROTATIONAL/FLEXIBLE

If rotational is the land ploughed, cut or treated with a herbicide prior to sowing the next crop. ALL 3

When do you plough, cut or spray the field (naturally regenerated set aside only). N/A

Is the land left to naturally regenerate or sown with an industrial crop, if cropped please specify crop(s).
INDUSTRIAL
OIL SEED RAPE

Is a herbicide used to control weeds on naturally regenerated set aside, please specify timing and product(s).
N/A

Is the permanent set aside bordering natural wildlife corridors eg. hedges, woodland or rivers.
N/A

When did the permanent set aside period begin, does it include woodland.
N/A

If either permanent or naturally regenerated set aside are mown is the cut material removed or left.
N/A

Is the land grazed over winter. N/A

FARM POLICY

Is the farm management policy the same for all fields or are those included in the CBC treated differently.

NO DIFFERENCE – HOWEVER THERE IS COMMON LAND WITHIN CBC PLOT

Is your current farm management policy likely to change over the next two years.

PRICING STRUCTURES MAY CAUSE CHANGE

CSL/BTO FARMLAND BIRD SURVEY 1997 FORM5

GRASSLAND UTILISATION

What proportion of the farm is currently grassland and how has this changed over the six time spans.

COMMON LAND IS THE ONLY AREA OF GRASSLAND

← 26% →

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995

How has the age of grassland changed over the six time spans, please express this in terms of the proportion of grass less than five years old.

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995
0%	0%	0%	0%	0%	0%

What is the current management practice, ensiling, hay making or grazing.

GRAZED ONLY

How has this changed over the six time spans. Please indicate at which time ensiling first started and if hay making has been phased out when hay was last made.

NO CHANGE

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995

How many cuts of silage are now made, how does this compare with hay making. Please indicate the timing and number of cuts.

NO SILAGE

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995

FIELD DRAINAGE

FREE DRAINING

When did you first start to drain fields on the farm (mole drains).

When did you complete drainage of fields on the farm. Please indicate the area or specific CBC fields drained in each time span.

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995

CSL/BTO FARMLAND BIRD SURVEY 1997 FORM6

LIVESTOCK

What range of livestock graze on the holding.

CATTLE 30 COWS / 70ACS

How have stocking rates changed over the six time periods. Please indicate for each how stocking rates have changed over the time spans (number of each species grazed/stocking densities etc.).

NO CHANGE – 0.43 COWS / ACRE!

1966	1970		1971	1975		1976	1980		1981	1985		1986	1990		1991	1995	

FERTILISER INPUTS

Are you currently using natural or artificial fertilisers or a combination of the two. Are these broadcast or incorporated, please indicate the approximate timing of applications.

COMMON LAND – 2CWT/AC 34.4% N EVERY OTHER YEAR. 30YRS PLUS
OSR – SEWAGE SLUDGE – SPRING 10T/ACRE
BARLEY – 1CWT/AC MURIATE OF POTASH. 1CWT/AC UREA. SEWAGE SLUDGE 10T
WHEAT – SEWAGE SLUDGE 10T/AC MID BROADCAST & PLOUGHED IN. 1CWT/AC
MURIATE OF POTASH SPRING/. 2CWT/AC UREA (46% N). NITRAM 2CWT/AC

If using natural fertilisers please specify the type used. eg. well rotted farm yard manure, slurry, chicken manure

SEWAGE SLUDGE SPRAYED ON AND PLOUGHED IN.
LIMITED USE OF FYM. USED ON POTATOES. NOT A LARGE AREA.

How has your current policy changed over each of the time spans, please indicate any changes from natural to artificial fertilisers eg. the proportional change from span to span.

NO CHANGE IN ARTIFICIALS
SEWAGE SLUDGE FROM 1987

ARTIFICIAL FERTILISERS →

SEWAGE SLUDGE →

1966	1970		1971	1975		1976	1980		1981	1985		1986	1990		1991	1995	

CSL/BTO FARMLAND BIRD SURVEY 1997

FORM7

PESTICIDE INPUTS

What is your current pesticide policy. Please indicate, for each of the major crops grown on your holding the number of sprays applied. For example the number of herbicide, fungicide, insecticide and growth regulator applications made to a "typical" field of each crop. For each of the time spans please indicate how this has changed.

NO CHANGE IN PESTICIDE INPUTS — CURRENT USE IS TYPICAL

CROP		1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995
WHEAT	H			2	2	2	1 AU 1 SP
	F			2	2	2	2
	I			1	1	1	1
	G			1	1	1	1

CROP		1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995
WINTER BARLEY	H	2	2	2	2	2	1 AU 1 SP
	F	1	1	1	1	1	1
	I	1	1	1	1	1	1
	G	1	1	1	1	1	1

CROP		1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995
SPRING BARLEY	H	1	1	1	1		
	F	1	1	1	1		
	I	0	0	0	0		
	G	0	0	0	0		

CROP		1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995
SPRING OSR	H			1	1	1	1
	F			1	1	1	1
	I			1	1	1	1
	G			0	0	0	0

CROP		1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995
WINTER OSR	H			1	1	1	1
	F			1	1	1	1
	I			1	1	1	1
	G			0	0	0	0

CROP		1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995
POTATOES	H			1	1	1	1
	F			5	5	5	5
	I			2	2	2	2
	G			0	0	0	0

GRASS (COMMON) NO SPRAYS

CSL/BTO FARMLAND BIRD SURVEY 1997

FORM8

MOLLUSCICIDE USAGE

When did you first use molluscicides. 1991 – 1993

What proportion of molluscicides are broadcast please indicate how has this changed over the six time spans.

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995
					MB

NON CROP AREAS

HEDGEROWS

How has the number of hedges changed over time. Please indicate for each of the time spans whether the number of hedges has remained the same, decreased or increased.

NO CHANGE IN LENGTH

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995

Has the hedgerow management policy changed over time. For example has the timing of cuts or the cutting height changed over time, are the hedgerow bases now sprayed.

TRIMMED ONCE A YEAR IN NOVEMBER. 20' HIGH PRE MID 60's NOW 6' HIGH. NO SPRAYS TO HEDGE BASE.

WOODLAND

NONE ON CBC PLOT. UNTIL 1993

How has the area of woodland changed over time. Please indicate the current area and approximate areas in each of the time spans.

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995
					4 Acs

PONDS

0 PONDS – STREAM

How has the number of ponds changed over time. Please indicate the current number and approximate numbers in each of the time spans.

1966 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995

Are the ponds managed for wildlife, shooting, fishing or other recreational activities.

7

Pesticides

A. Hart

Central Science Laboratory

7 PESTICIDES

7.1 Introduction

This section focuses on whether changes in pesticide use have contributed to causing the declines seen in farmland bird populations. There are two main elements to the approach. First, we use regression analysis to identify correlations between trends in the CBC index for declining species and increases in the use of pesticides. Second, we examine which types of pesticides show such correlations. We then assess whether these correlations could be the result of direct toxic effects (poisoning due to ingestion of pesticide by birds) or indirect effects (due to pesticides removing plants or invertebrates which birds depend upon for food).

To have contributed significantly to the decline of bird populations a pesticide would have to: be toxic to birds and applied at sufficient rate to cause substantial mortality ***or*** cause indirect effects e.g. by removing plants or invertebrates used as food by birds, ***and*** have increased in use by a substantial amount during the period from about 1978 to the mid-1980s, when population declines were strongest (Section 5).

7.2 Methods

The analysis focussed on examining possible causes of population declines. We concentrated on 13 species which showed the strongest evidence for population declines as revealed by analyses of CBC indices (Section 5). Eight stable or declining species were not considered: Kestrel, Stock Dove, Yellow Wagtail, Rook, Whitethroat, Chaffinch, Greenfinch and Goldfinch. We also restricted our attention to the 99 pesticides which showed the largest increases in use between 1974 and 1988. We focussed on this period because the major population declines occurred during this time. Note that, throughout this chapter, the measure of use is 'area treated' and this includes multiple treatments (e.g. if one hectare is treated twice with the same spray the area treated is two hectares).

We analysed correlations at two levels: with the use of individual pesticides, and with use of pesticides grouped into fungicides, herbicides and insecticides. The Pesticide Usage Survey Group at CSL provided data on pesticide use for all arable crops in England and Wales. The data related to eight growing seasons: those ending at the harvests in 1974, 1977, 1982, 1988, 1990, 1992, 1994 and 1996. For the analyses of individual pesticides, correlations were tested with CBC indices for the same years as the pesticide surveys and, separately, with the CBC indices one and two years after the survey. This was to allow for possible delays between the use of pesticides and their effects on bird populations. R^2 statistics were used to identify the 10 pesticides mostly strongly correlated with the CBC index for each species.

To assess the plausibility of direct toxic effects on birds, we calculated simple indices of risk. These were based on data from acute toxicity tests (LD50s), and therefore relate to the risk of mortality resulting from short-term exposures in the order of one day or less. We obtained LD50s for 36 of the 99 pesticides, from publicly-available sources (*UK MAFF Disclosure Documents*, the 10th edition of *The Pesticide Manual*, and Luttik and Aldenberg, 1997). In cases where more than one LD50 was available for the same pesticide, the lowest reported value was taken (as is current practice in regulatory risk assessment). As a result, the risk indices are likely to be more conservative for those pesticides with the most LD50s. An alternative would be to use a fixed point from the distribution of values (e.g. the median or the 95 percentile) or use only LD50s for a standard species (e.g. Bobwhite Quail *Colinus virginianus*) but the published data are not comprehensive enough to permit this.

Ideally, one would also examine longer-term exposures and other types of effect, but this would require the use of dietary (LC50) and reproductive (NOEC) toxicity data which were available for only a small minority of the pesticides. Also, it was originally intended to compute indices of potential risks to plants and invertebrates, as a means of assessing potential for indirect effects on birds. However, it became apparent that data on toxicity to non-target plants and invertebrates are available for relatively few pesticides. Therefore, indices were computed only for potential direct risks to birds from short-term exposures.

Risk indices were based on worst-case assumptions about toxicity and exposures, and were obtained in different ways depending on the formulation of the pesticide. Some pesticides are partly used as sprays and partly as granular formulations or seed treatments, though in most cases one formulation is strongly predominant over the other. For the purpose of this analysis, we decided to treat each pesticide as entirely comprising whichever formulation accounted for most hectares treated.

For **pesticide sprays**, the risk index was a toxicity-exposure ratio (TER) as used in regulatory risk assessment. Toxicity was taken as the lowest available avian LD50 for the pesticide, as stated earlier. Exposure was calculated for each of the 13 species, following the approach in the EPPO risk assessment scheme for terrestrial vertebrates (EPPO, 1994). The calculation can be represented by the following equation:

$$DD = FIR \times FDR \times C / W$$

Where:

DD = daily dose (mg active substance/kg body weight/day).

FIR = food ingestion rate per day (in dry weight) estimated using Nagy's equation for passerine or non-passerine species, as appropriate.

FDR = fresh to dry weight ratio, based on average water content for the relevant types of foods, obtained from the United States Environmental Protection Agency's (US EPA) Wildlife Exposure Factors Handbook.

C = pesticide concentration, based on Kenaga's estimates of the 'typical' level of pesticide residues on relevant types of food immediately after pesticide application. This was calculated using data on the average application rate (kg/ha) for each pesticide in the Pesticide Usage Survey for 1988 (this is taken to be most relevant to the period when population declines were strongest; application rates have declined for some pesticides during the 1990s).

W = average adult body weight was obtained for the species, from Dunning (1993): taking the smaller sex in species where the sexes differ in weight.

The main food types for each species were taken from Gooders (1986). For each species it was assumed that the diet was entirely comprised of that food type which gave the highest predicted pesticide residues, and that all of it came from treated fields. As only the application rate changed between pesticides, the relative exposure of the 13 species was the same for every pesticide. In every case, the highest exposure was for the Tree Sparrow (average body weight 22 g, diet 100% small insects).

Exposure for **seed treatments and molluscicide pellets** was estimated using the same method as for sprays, with the following exceptions: The diet was assumed to be 100% treated seed or pellets, for every species; the concentration of pesticide on the seed or bait was set equal to the highest recommended application rate for that pesticide, obtained from manufacturers' product information. The highest daily dose was obtained for the Linnet (average body weight 15.3 g) and this was used to calculate the risk index. Again this is a worst-case estimate. Treated seeds are unlikely to be a preferred food for most of these species, although current CSL research shows a wide range of species do take agricultural seed at least occasionally. There is little information on whether birds take molluscicide pellets as food, and this also is under research. However, given that pellets have some nutritional value it seems better to treat them as seed, rather than as an inert material.

The risk index for **granular pesticides** was completely different. Granules have no nutritional value but birds may take them accidentally with food, or intentionally as grit. Current regulatory risk assessments often estimate exposure from granules using information on the number of grit particles found in bird gizzards, but this requires knowledge of the amount of pesticide per granule which is not publicly available for most products. We therefore used an alternative approach which is included in the EPPO scheme and is also used by the US EPA. The risk index was taken simply as the amount of pesticide active substance per unit area, expressed as the number of Linnet LD50s per square metre. The Linnet was used as it was the smallest of the 13 species and therefore gave the worst-case values by this method. Granular pesticides are sometimes applied by incorporation into the soil which will greatly reduce their availability to birds, but this has not been taken into account in the risk index.

Note that for the TERs calculated for sprays, seeds and pellets, lower values indicate higher risk, whereas the risk index for granules increases with increasing risk. We reiterate that the calculations are based on worst-case conditions which would be expected to occur very rarely in practice. In regulatory assessments, they serve only as an initial indication of risk which is then refined using additional information. In this project these indices are used as an index of relative potential risk; they are not intended as a measure of actual risk.

7.3 Results

7.3.1 Area treated

Pesticides were ranked by increase in area treated between 1974 and 1988 and the top 99 were selected for analysis. The 99th was heptenophos, for which area treated increased by 10,927 ha between 1974 (when it was not used at all) to 1988. Those pesticides which increased by over 200,000 ha are listed in Table 7.1. The list is dominated by fungicides and herbicides: insecticides generally showed smaller increases during this period. The highest insecticide is dimethoate with an increase of 335,000 ha. A molluscicide, methiocarb, also shows a large increase (614,000 ha).

7.3.2 Correlations with individual pesticides

Correlations were computed between the CBC index for each species and area treated for all 99 selected pesticides, with time delays of zero, one and two years as explained above. This provided a total of 3,861 correlations. For this many independent correlations one would expect about 193 to be significant at the $P<0.05$ level by chance alone. In this case the number would be higher, because the correlations at different time lags are not independent and we have pre-selected declining species and pesticides for which use was increasing. It is not surprising, therefore, that a large proportion of the correlations exceeded the $P<0.05$ level. Only the top 10 negative correlations for each species/time lag combination were examined (a total of 390): all of these had an R^2 over 0.5 (i.e. $r > 0.71$, with n=8), and 367 had an R^2 over 0.7 (i.e. $r > 0.83$). This result could be assessed more formally, but it is not our purpose to assess statistical significance. The large number of strong positive correlations implies that a substantial proportion of individual pesticides showed changes in area treated over time which were broadly similar to changes in the CBC index for at least one of the declining species.

Some pesticides showed strong negative correlations with the CBC indices for 10 or 11 of the 13 species tested (Table 7.2). Again this is not surprising given the number of correlations tested and the pre-selection of the data. The purpose of computing the correlations is to identify those pesticides showing the strongest associations with population declines, so that possible mechanisms can be considered. Table 7.2 also shows that the pesticides showing the strongest association with population declines were predominantly herbicides and fungicides, in roughly equal proportions. The only insecticide showing strong associations with more than one species was fonofos. This is used primarily as a seed treatment on wheat. The area treated with this pesticide increased by only 30,000 ha between 1974 and 1988 (also shown in Table 7.2), which is very small compared to the total area of arable crops in England and Wales (about 4.2 million ha in 1988). It seems safe to conclude that, even if fonofos were causing direct or indirect bird mortality, it is unlikely to have made a significant contribution to widespread population declines. Although other insecticides are used on larger areas, they show weaker associations with population declines.

7.3.3 Correlations with classes of pesticides

If a number of pesticides were affecting bird populations by the same mechanisms, we might expect a correlation with their combined treated area, rather than with their individual treated areas. We therefore examined correlations between CBC data and the combined treated areas for the three main classes of pesticides: insecticides, herbicides and fungicides. This was done at two scales: on a national scale using the CBC index and national pesticide surveys (Section 5), and on a local scale using the surveys done for this project (Section 6).

All three classes of pesticide show significant correlations at national level for most of the declining species (Table 7.3). It is interesting that this is true of all three of the pesticide classes: if anything the correlations were stronger for fungicides than for insecticides and herbicides. If populations were declining due to indirect effects of pesticides, insecticides and/or herbicides would be expected to show the strongest correlations (see below). Even for the Grey Partridge, for which evidence of significant indirect effects due to herbicide and insecticide use already exists (Campbell *et al.* 1997), Table 7.3 shows a stronger association with fungicide use. This suggests that incidental correlations between increasing pesticide use and population declines are strong enough to mask any correlation caused by indirect effects. Very few correlations were found at local level for any pesticide class (Table 7.3), although the sample sizes are small.

7.3.4 Risk indices for direct effects

As mentioned above, toxicity data were available only for 36 of the 99 pesticides selected for analysis. Table 7.4 shows the risk indices obtained for (a) sprays, and (b) seed treatments, molluscicide pellets and granular pesticides. We emphasise again that the risk indices are based on worst-case assumptions, and are intended simply as relative indices of the potential risk of mortality from short-term exposures.

Of the sprayed pesticides, the four with the highest potential risk are all insecticides (Table 7.4a). Three of these have TER<1, but only one of these (dimethoate) showed a substantial increase in area between 1974 and 1988 (approaching 10% of the total area for arable crops in England and Wales). Dimethoate gave one of the 10 highest correlations with population decline for one of the 13 species examined (Table 7.2), which was the Yellowhammer. Much lower toxicity-exposure ratios are obtained for the seed treatments and molluscicide pellets (Table 7.4b), indicating a relatively higher risk than the sprayed pesticides. This reflects the relatively high concentrations of pesticide applied to these materials. Taken together, the use of these pesticides increased by over a million hectares between 1974 and 1988, or about 25% of the total arable area. Methiocarb has the lowest TER and the largest increase in use, and was among the top 10 pesticides associated with population decline for one species (Table 7.2), the Reed Bunting. It seems unlikely that these pesticides have actually contributed significantly to population declines, because: the indices represent worst-case assumptions, as mentioned earlier; pellets may be of low attractiveness as food; the pesticide showing the biggest increase in use (methiocarb) is strongly avoided by birds in laboratory tests and, very few poisoning incidents have been reported involving the approved use of these compounds. Nevertheless, seed treatments and molluscicide pellets may deserve more attention as possible sources of direct effects. Risks for methiocarb have been examined in detail recently, in a unpublished UK regulatory review.

Risk indices were obtained for only two granular pesticides (Table 7.4b). Both indicate a very high number of LD50s per unit area on treated fields, and both pesticides are known to cause occasional poisoning incidents in the UK and (more frequently) in North America. However, neither showed a large increase in treated area between 1974 and 1988.

The pesticides for which the indices suggest the highest potential risk of direct effects are not among those most closely associated with species declines (Table 7.2), nor are they among those which increased most during the period when populations were declining (Table 7.1). However, it must be remembered that toxicity data were available for only 36 of the 99 pesticides considered. The overall potential for direct effects is therefore somewhat greater than indicated by the results presented here.

7.4 Conclusions

For many individual pesticides there are strong correlations between increases in use (area treated) and declines in populations of farmland birds. For most of the declining species, decreasing population indices are correlated with increases in the overall areas treated with pesticides. These relationships are as strong for fungicides as they are for herbicides and insecticides, even though the latter are more likely to cause indirect effects by removing the plants and insects which birds feed on. This is true even for the Grey Partridge, for which there is good evidence of indirect effects. The above results suggest that while indirect effects of pesticides may be contributing to population declines, their effect is not distinguishable from incidental correlations caused by the general intensification of agriculture during 1974-1988. If indirect effects have contributed significantly to population declines, then herbicides are likely to have contributed more than insecticides as their use increased more in the period when populations declined most. Fungicides are also less likely to have contributed to indirect effects as they are usually, though not always, of lower toxicity to plants and invertebrates.

It is widely assumed that direct effects of pesticides on birds are relatively unimportant (e.g. O'Connor 1992, Campbell *et al.* 1997), and this is supported by the low frequency of reported poisoning incidents. In principle, pesticides capable of causing substantial direct effects should have been identified and removed or restricted by existing regulatory procedures. Only a small proportion of sprayed pesticides are toxic enough to present a potential risk of direct effects, even in worst-case conditions. More toxicity data would be required to determine the combined treated area for all sprays capable of causing direct effects, but this data is not publicly available. Seed treatments and molluscicide pellets present a relatively high potential risk of direct effects and are used on fairly large areas. Some granular pesticides present a high potential risk of direct effects, but they are used on relatively small areas. These pesticides may merit more attention as possible contributors to population declines, though again there are very few reported incidents of mortality.

Pesticide	Increase in	Pesticide type
Carbendazim	1,895,828	Fungicide
Chlormequat	1,594,167	Growth regulator
Propiconazole	1,535,367	Fungicide
Isoproturon	1,515,829	Herbicide
Fenpropimorph	1,286,506	Fungicide
Prochloraz	1,261,670	Fungicide
Ioxynil	1,009,908	Herbicide
Bromoxynil	959,360	Herbicide
Flutriafol	892,050	Fungicide
Metsulfuron-methyl	884,185	Herbicide
Chlorothalonil	881,276	Fungicide
Triadimenol	779,854	Fungicide
Tridemorph	702,138	Fungicide
Methiocarb	613,864	Molluscicide
Choline chloride	516,847	Herbicide
Fluroxypyr	475,794	Herbicide
Mancozeb	471,945	Fungicide
Pirimicarb	398,964	Insecticide
Fuberidazole	379,873	Fungicide
Thiabendazole	376,571	Fungicide
Trifluralin	339,846	Herbicide
Glyphosate	337,267	Herbicide
Dimethoate	335,914	Insecticide
Clopyralid	331,698	Herbicide
Triadimefon	330,300	Fungicide
Fenpropidin	326,698	Fungicide
Mecoprop	317,177	Herbicide
Maneb	310,476	Fungicide
Metamitron	276,877	Herbicide
Diflufenican	269,436	Herbicide
Benazolin	258,041	Herbicide
2-chloroethylphosphonic	255,117	Growth regulator
Linuron	238,366	Herbicide
Chlorotoluron	225,683	Herbicide
Captafol	223,002	Fungicide
Cypermethrin	216,666	Insecticide
Pendimethalin	208,924	Herbicide
Diethyl mercuric	202,099	Fungicide
Hymexazol	202,099	Fungicide

Table 7.1 Pesticides for which area treated increased by over 200,000 ha between 1974 and 1988, classified according to pesticide type.

Active substance	No. of species	Increase in area treated,	Pesticide type
Fuberidazole	11	379,873	Fungicide
Carbendazim	10	1,895,828	Fungicide
Chlormequat	10	1,594,167	Growth regulator
Iprodione	9	153,933	Fungicide
Isoproturon	9	1,515,829	Herbicide
Triadimenol	9	779,854	Fungicide
Metamitron	7	276,877	Herbicide
Trifluralin	7	339,846	Herbicide
Fonofos	6	29,674	Insecticide
Chloridazon	5	107,110	Herbicide
Sulphur	5	165,701	Fungicide
Metalaxyl	4	188,099	Fungicide
Metribuzin	4	19,905	Herbicide
Bentazone	2	39,546	Herbicide
Clopyralid	2	331,698	Herbicide
Cyanazine	2	88,061	Herbicide
Fluazifop-P-butyl	2	155,185	Herbicide
Fluroxypyr	2	475,794	Herbicide
Mancozeb	2	471,945	Fungicide
Oxadixyl	2	51,591	Fungicide
Propiconazole	2	1,535,367	Fungicide
Terbuthylazine	2	73,930	Herbicide
2-chloroethylphosphonic acid	1	255,117	Growth regulator
Alpha-cypermethrin	1	73,948	Insecticide
Chlorothalonil	1	881,276	Fungicide
Diflufenican	1	269,436	Herbicide
Dimethoate	1	335,914	Insecticide
Diquat	1	176,917	Herbicide
Ethofumesate	1	40,719	Herbicide
Fenpropidin	1	326,698	Fungicide
Fentin hydroxide	1	45,900	Fungicide
Hymexazol	1	202,099	Fungicide
Mepiquat	1	174,800	Growth regulator
Metazachlor	1	63,507	Herbicide
Methiocarb	1	613,864	Molluscicide
Pirimicarb	1	398,964	Insecticide
Thiram	1	121,392	Fungicide
Vinclozolin	1	66,110	Fungicide

Table 7.2 Number of species for which individual pesticides showed strong correlations between area treated and bird populations. For each species, the 10 pesticides showing the strongest negative correlations were identified. The tables show the number of species for which each pesticide appeared in the top 10. These results refer to correlations between area treated and CBC index in the following year. Broadly similar results were obtained when correlations were calculated between area treated and CBC index in the same year, or two years later, except that in these cases no insecticide appeared in the top ten correlations for more than two species.

Species	Insecticide	Fungicide	Herbicide
Grey Partridge	+	++	*
Lapwing	+	++	
Turtle Dove	++	++	++
Skylark	*	+	++
Blackbird	++	++	++
Song Thrush	+	++	++
Starling	++	++	+
Tree Sparrow	++	++	*
Linnet		+	+
Bullfinch	+	++	++
Yellowhammer	++	++	++
Reed Bunting		+	+
Corn Bunting	++	++	++

Table 7.3 Species showing evidence of decreases in population with increasing pesticide use at different scales. + $P < 0.05$, + + $P < 0.01$ at national scale (CBC index); * $P < 0.05$ at both local and national scale. Species showing stable or increasing populations at the national level were examined only at local scale: of these the Chaffinch showed a negative correlation with insecticide use ($P<0.05$) but other species showed no significant negative correlation.

(a) Pesticide sprays (only those with TER<100 are shown)

Pesticide	Risk index (toxicity)	Increase in area	Pesticide type
Chlorpyrifos	0.39	50,916	Insecticide
Dimethoate	0.58	335,914	Insecticide
Triazophos	0.67	69,960	Insecticide
Pirimicarb	1.92	398,964	Insecticide
Bromoxynil	7.88	959,360	Herbicide
Mecoprop	8.44	317,177	Herbicide
Chlormequat	8.93	1,594,167	Growth regulator
Diquat	11.25	176,917	Herbicide
Ioxynil	12.66	1,009,908	Herbicide
Mecoprop-P	13.51	58,650	Herbicide
Linuron	14.20	238,366	Herbicide
Fenpropidin	21.68	326,698	Fungicide
Cyanazine	23.75	88,061	Herbicide
Trifluralin	70.08	339,846	Herbicide
Isoproturon	79.03	1,515,829	Herbicide
Diclofop-methyl	96.35	158,377	Herbicide

(b) Treated seeds, molluscicide pellets and granular pesticides

Pesticide	Increase in	Risk index	Risk index	Pesticide type
Methiocarb	613,864	0.0001		Molluscicide
Fonofos	29,674	0.03		Insecticide
Metaldehyde	104,802	0.05		Molluscicide
Hymexazol	202,099	0.30		Fungicide
Thiram	121,392	0.32		Fungicide
Aldicarb	38,737		11517	Nematicide
Carbofuran	26,273		16339	Insecticide

Table 7.4 Indices of the potential risk of direct effects on birds for (a) sprayed pesticides and (b) treated seeds, molluscicide pellets and granular pesticides. See text for details.

8

General Discussion and Conclusions

D.E. Chamberlain & R.J. Fuller

British Trust for Ornithology

8. GENERAL DISCUSSION AND CONCLUSIONS

8.1 Scale Effects and the Measurement of Population Change

Before attempting to draw out conclusions from this project, we make some general points concerning the different scales and different measures of change in bird populations that have been used in this project and we discuss the representativeness of the group of species considered. Later sections of this general discussion compare the broad results from the different scales and datasets that have been analysed.

An important feature of this project is that it has involved analyses of changes in farmland bird populations at different spatial scales. The main scales used were national (lowland England and Wales), regional (defined by type of farming), and local (10 km squares and individual farms). Correlates that are consistent across these scales are obviously worth close attention as potential factors driving bird population changes. Therefore, in interpreting the results of this study, we give special emphasis to agricultural factors that emerge as major correlates with species richness or individual species at more than one scale. However, it should not be assumed that the same "driving factors" will be evident at each scale. Increasingly it is recognised that in studies of bird-habitat relationships different factors may emerge as significant at different scales (Wiens 1989, Fuller 1994, Jokimaki & Huhta 1996, Bohning-Gaese 1997). Some factors, such as climate, tend to operate over large geographical areas while others, such as microhabitat structure, operate at a much finer scale. Scale-specific relationships can also arise due to scale dependencies in the variance of the independent variables (i.e. habitat variables) and in the resolution with which the different factors underlying habitat selection can be measured.

In the case of relationships between birds and agricultural variables, scale effects are potentially important in the following ways. At the broad national scale (here this is lowland England and Wales) one might expect changes in birds to show the strongest relationships with broad shifts in crop types (e.g. change in the relative abundance of arable and grassland). At the regional level, where regions are defined by major farming types, there may be a greater chance of detecting effects of changes in management associated with the predominant farming system. For example, these might include pesticide and fertiliser inputs, or changes in timing of cultivation. One might predict that, at the farm scale, the chance of detecting relationships with specific management factors would be increased still further, though this depends on the variance in the data. However, an important caveat concerning farm scale analyses is that bird populations may be affected by factors operating in the wider environment. For example, numbers of some species on individual farms may be affected more by winter feeding opportunities in the surrounding countryside (e.g. through availability of stubbles) than by the attributes of the sample farms themselves.

The project has analysed changes in the status of breeding birds using three different measures i.e. presence-absence in grid squares, population trends as shown by CBC indices and density of birds on CBC plots. This raises the general question as to whether these are effectively measuring the same thing. To what extent would one expect these different measures to show the same relationships with underlying changes in agriculture? The first of the above measures gives an estimate of change in range (i.e. in the proportion of 10 km squares occupied within a defined area) whereas the second and third measures relate to changes in bird abundance.

There is no clear reason why changes in abundance should be not be measured in much the same way by indexing and density. The main question is whether changes in abundance will be reflected by changes in range.

Donald and Fuller (1998) showed that there is a broad relationship between changes in range and changes in abundance. However, they pointed out that in a minority of species, changes in range and abundance can be in the opposite direction. An example of a farmland species showing this pattern is Stock Dove for which CBC indices show a large increase during the 1980s and 1990s (Siriwardena *et al.* 1998a) yet there was an overall range contraction of 7% in Great Britain between the two atlases (Gibbons *et al.* 1993). The seven species for which atlas data were used to model changes in range (Section 4) each showed a contraction of range and a decrease in abundance. Despite the fact that changes in range and in population usually occur in the same direction, changes in range are a rather insensitive measure of population change. This is especially true for changes in common species. Donald and Fuller (1998) presented data suggesting that a threshold may occur whereby marked contractions of range become apparent when a population has declined by 60% or more. This means that the analyses presented in Section 4 can only focus on species that have shown the most severe population declines. Furthermore, the measures of change in species richness derived from atlas data will tend to under-estimate the scale of changes in the farmland bird assemblage. The implication is that an absence of any measured change in species range or in species richness within a particular region or habitat cannot be taken as evidence of absence of a real change at the population level. One of the clearest examples is Skylark, which shows extremely little change in range between the two atlases, yet it has declined by more than 50% since the 1960s on lowland farmland (Fuller *et al.* 1995).

While atlas data may be a relatively blunt instrument with which to examine relationships between birds and agriculture, these analyses are important for two reasons. First, atlas data allow patterns to be examined over large continous areas in ways that other data sets do not. This makes it possible to identify objectively areas that have undergone different patterns of change with respect to bird species composition. Second, range contractions measured by presence-absence data represent local extinctions - the endpoint of local population decline. The atlas data therefore show where the losses of farmland birds have been most extreme.

8.2 Changes in Species Richness and Individual Species in Relation to Farmland Type and Region

Change in species richness of farmland birds was examined at two scales in relation to region or type of farming. At the widest geographical scale, the atlas data showed that species richness had declined most in the predominantly grass region. Unexpectedly, species richness had declined most in those areas where there had been least change in cropping patterns (Section 4). Intuitively, this result might suggest that species losses had occurred more in areas where agricultural intensification had been least. However, such a conclusion would not be justified because a high level of intensification has occurred both within arable and grassland systems. This result was in contrast to that from the individual farms (Section 6), where change in species richness showed a farm type effect with a stronger decline on arable and mixed farms.

Each of the seven species analysed in detail using atlas data disappeared from more squares in the non-arable regions than the arable region. In line with this finding, disappearances from squares were more frequent in grass-dominated than arable-dominated squares. Analysis of population trends as shown by CBC indices indicated that several species had declined most in the arable-east regions and on arable farms. But one species, Turtle Dove, showed a different pattern, having decreased most in the pastoral-west region. Analysis of densities showed a similar pattern with decreases mainly evident in the arable-east and mixed-south regions. At the scale of individual farms, there was far more evidence of species declines on arable than on mixed and pastoral farms. In summary, there is an apparent contradiction between the results of the large-scale atlas analyses and those of the CBC data. At the large scale, species losses (i.e. local extinctions) have been most marked in grassland areas. However, in terms of local changes in species richness, the main losses have been in intensive arable areas and it is in these latter areas where rates of population decline for most species have been greatest. Some possible reasons for these apparent contradictions were outlined in the discussion of Section 4 but we amplify them here.

We suggest that a major cause is that grass-dominated areas may now be sub-optimal for many breeding farmland birds. The abundance maps in Gibbons *et al.* (1993) clearly show that by the late-1980s many farmland birds were less abundant in the west of lowland England and Wales than in the east. This is the case for Grey Partridge, Lapwing, Turtle Dove, Skylark, Linnet, Tree Sparrow, Yellowhammer, Reed Bunting and Corn Bunting. Presumably for most species, these broad gradients in density would have been evident in the early-1970s because the CBC data indicate that population reductions of most species have occurred mainly in the intensive eastern regions. Data presented in Tables 6.4 and 6.5 also broadly support this. Furthermore, several species have been clearly associated mainly with arable rather than pastoral farming for many years (e.g. Grey Partridge - Potts (1986), Skylark - Fuller *et al.* (1997), Yellowhammer - Kyrkos *et al.* (1998)). For many species, therefore, grass-dominated areas have probably long supported lower densities of several farmland birds than have mixed and arable-dominated areas. Consequently a trend of modest reductions in numbers in grass-dominated areas but larger reductions in numbers in arable and mixed areas may have led to a preponderance of local extinctions in the former. This process is illustrated by a simple model in Fig. 8.1.

We think that Fig. 8.1 gives the most likely explanation of the observed results but other explanations may be operating simultaneously. In particular there are two aspects of agricultural change reviewed in Sections 2 and 3 that are especially relevant. First, it is wrong to assume that agricultural intensification has been most profound in the intensive arable areas. There have been widespread fundamental changes in grassland management throughout much of lowland England and Wales in recent decades. These have resulted in considerable uniformity of management of lowland grassland with substantial associated increases in yield and vegetation density. There have probably been major implications for biodiversity associated with grassland systems but the subject has been little researched. Second, the increasing polarisation of agriculture towards grassland in western Britain and arable in eastern Britain may have had a disproportionate effect on farmland birds within the predominantly grassland areas. The reason is that many species are primarily associated with arable systems (see above). There is evidence that this process has been operating in at least one species - the Yellowhammer. Declines were first noticed in the west and Kyrkos *et al.* (1998) suggest that these were caused by a reduction in the area of cereal.

Finally, it is possible that source-sink dynamics (Pulliam 1988) could be relevant, though there is no evidence whatsoever that large-scale spatial dynamics of this kind are operating for farmland birds in Britain. This would require that populations in non-arable areas are effectively maintained by immigration from more productive areas within arable areas. A population reduction in the latter area could lead to the cessation of emigration of 'surplus individuals'.

8.3 The Temporal Relationship Between Agricultural Intensification and Farmland Bird Declines

Fuller *et al.* (1995) pointed to the 1970s as being a decade when farmland bird populations started to decline rapidly and major changes occurred in British agriculture. This timing is consistent with the hypothesis that agricultural intensification is the main factor underpinning the farmland bird declines. Furthermore, Fuller *et al.* (1995) argued that structural changes on farmland involving loss of non-crop habitat, especially hedgerows, were unlikely to be the principal cause because these changes were well advanced by the mid-1970s. A problem with the latter view is that it assumes these habitats are saturated with birds and that a decline in habitat area will automatically be followed by a decline in birds. It is entirely possible, however, that there may be a critical threshold, in terms of reduction of habitat area, that has to be passed before a bird population response can be detected (we return to this subject below). Notwithstanding this possibility, a more recent analysis (Gillings & Fuller 1998) has lent support to the argument that loss of non-crop habitat is not the principal cause of the farmland bird declines. Gillings and Fuller (1998) found that bird populations had declined on individual farms irrespective of whether there had been habitat loss, although declines tended to be more severe when habitat loss had occurred. Fuller *et al.* (1995) and Gillings and Fuller (1998) argue that changes in habitat quality probably underlie the declines. Habitat quality in this context often means reduction in the abundance or availability of food (see Section 2). Farming practices are likely to be major determinants of habitat quality.

This project is the first critical examination of the temporal relationships between changes in farming practices and changes in populations of farmland birds. We have attempted to synthesise all available temporally-referenced data on agricultural change so as to allow a quantitative examination of the hypothesis that large-scale changes in agriculture should have been followed by large-scale changes in bird populations. Individual species are affected by different components of agriculture (Fuller *et al.* 1995), therefore some differences between species in the exact timing of population changes may be expected. Here we discuss the overall pattern of change in farmland bird populations as revealed by ordination of the agricultural data and ordination of the CBC population level data (Section 5; Figs. 5.2, 5.3). In an analysis using all available agricultural data for the period 1962 to 1995, we show that major change in agriculture occurred during the period 1971 to 1988 with relative stability before and after. From 1978 onwards a major shift in bird populations commenced which was especially marked for approximately six years but continued until the late-1980s. These analyses were repeated using those agricultural data for which the best annual data are available covering the period 1974 to 1991. This also produced a close fit between the timing of change in bird populations and timing of major changes in farming. Trends for individual species are presented in Siriwardena *et al.* (1998a) and show clearly that many species start to decline markedly in the period 1974 to 1976 and this is supported by analysis of turning points. Most species, therefore, appear to have started to decline some three to five years after agricultural intensification really commenced.

We suggest that the delay between the onset of agricultural change and the onset of bird population declines is exactly what would be expected if a causal link between the two operated through indirect mechanisms such as food reduction. There are several reasons for thinking this. Population effects could arise from reduced breeding productivity, reduced overwinter survival, or both. Analyses by Siriwardena *et al.* (1998b) indicate that, in general but with some exceptions, population changes have tended to be driven by survival rather than breeding output. For a period of time, density-dependent factors may have compensated for reduced breeding production or overwinter survival. In cases where the problem was initially one of overwinter survival, this may have been accompanied by a short-term density-dependent increase in breeding production. Such a process may have been possible so long as both breeding production and overwinter survival were not being squeezed simultaneously by changing habitat quality and provided that the initial effects on breeding output or productivity were not too great. These requirements would probably have been met because the pattern of agricultural intensification was a progressive phenomenon. Many of the changes in cropping patterns and crop management were more or less continuous through the 1970s and 1980s (see Fig. 3.21); the nature of change in habitat quality was not episodic or abrupt. Eventually, however, some critical threshold would have been overtaken when compensation was no longer possible.

Another factor likely to introduce a time lag is the functional response of bird populations to changing food supplies in the farmland environment. Nothing is known about the exact nature of these functional responses for farmland birds. However, typical forms of functional response involve an increase in consumption rate that is either initially linear or curvilinear but which rapidly decelerates often reaching a plateau with no change in consumption rate over a wide range in food density (Begon *et al.* 1990). A substantial decline in food resources, for example the density of seeds in winter, may have been necessary before foraging rates were affected. Coupled with this, many farmland birds are extremely gregarious and mobile in their ability to search for food; this is especially true of granivorous species in winter. Consequently they may have been able to exploit alternative food supplies or increasingly patchy food supplies quite successfully for a period of time.

Was there any other large-scale change operating over the period 1970 to 1990 that could have produced population declines specifically in farmland birds and following the broad patterns described by Figs. 5.2 and 5.3? Fuller *et al.* (1995) concluded that there was a need to learn more about the role of changing predation pressure as a possible mechanism producing widespread declines in farmland birds. Recently there has been new evidence demonstrating that population levels in Grey Partridge can be affected by predation in lowland farmland environments (Tapper *et al.* 1996). However, in this species there is also strong evidence that the declining populations have been driven primarily by agricultural change which has led to reduction in the insect food supply of partridge chicks (Potts 1986, Potts & Aebischer 1995). In the Grey Partridge, the effects of predation appear to be additional to those of agriculture. Other recent studies of long runs of annual data on songbirds and predators have been unable to demonstrate a link between the two. In a study of 23 songbird species using British CBC data, Thompson *et al.* (1998) found no difference in year to year population changes at sites with and without Magpies and Sparrowhawks. Additionally, but somewhat less relevant to the farmland bird decline issue, Newton *et al.* (1997) were unable to find any convincing evidence that Sparrowhawks had depressed densities of songbirds in a Surrey wood. These studies do not give any support to the hypothesis that changing predation pressure has caused the farmland bird declines. We believe that the large-scale shifts in agricultural management, starting in the 1970s but continuing into the 1980s, remain the most plausible explanation for the large declines that have occurred in farmland bird populations.

8.4 Evidence Relating to Specific Mechanisms Driving Bird Declines

If agricultural intensification remains the strongest candidate for having driven the farmland bird declines, what does this project tell us about how different species have been affected? Intensification has involved more or less simultaneous change in many aspects of farming (Section 3). Models sought to relate changes in either the distribution (Section 4) or in the abundance (Section 5) of individual species to this complex of agricultural variables. A 'single best predictor' approach was taken, this being regarded as most robust in searching for patterns within and across species. In the event, extremely few general patterns emerged across species. This is consistent with the view that species have been affected by many different components of agricultural change (Fuller *et al.* 1995) which is perhaps to be expected because the declining farmland species show a considerable diversity of ecological attributes (Snow & Perrins 1998).

Four considerations need to be borne in mind with the species-specific analyses. First, the large number of correlations between agricultural variables and bird population changes (see Table A5.1) makes it impossible to be sure which, if any, of these relationships is especially important. In many cases it is hard to identify a plausible biological link. We have stressed that selection of particular variables cannot in itself signify a causal relationship. Second, inadequate data are available for some aspects of change in agriculture that may have been important for birds - this is perhaps exemplified most clearly by pesticides (see below) but it also applies to hedgerow management. Third, in reality, combinations of factors related to agricultural change have probably been important in causing population changes. For example, extensive and intensive studies of Skylarks are showing that this species has probably been affected by a complex of inter-related factors including the loss of traditional rotations, the reduction in spring sowing, the increasing density of crop vegetation and increased grazing pressure (Schläpfer 1988, Wilson *et al.* 1997, Henderson *et al.* 1998, Chamberlain & Gregory 1999). Fourth, relationships with some agricultural variables may not show consistent relationships across time. This could come about if population size started to change in response to the introduction of a new favourable crop type or habitat. For example, the introduction of oilseed rape or set-aside might cause an increase in some species which had initially declined in response to the loss of some other crop types which remained rare.

In the early stages of the project we (D.E. Chamberlain, R.J. Fuller, M. Shrubb, R.G. Bunce) attempted to summarise the probable relationships between bird populations and changes in agriculture in the form of an impacts table. In some cases we could not make clear predictions of the likely impacts of certain agricultural changes, even when we had a good understanding of the ecology of the species concerned. This exercise was abandoned as being too subjective and having too many uncertainties. We subsequently attempted a refinement by examining the timing of change in many different components of agriculture in relation to the timing of change in species populations with special regard to the turning point analyses of Siriwardena *et al.* (1998a). This approach also proved unsatisfactory because it was still open to differences of interpretation and was, therefore, insufficiently repeatable. Furthermore, for the reasons discussed above, one would not necessarily expect very close temporal matching between population changes and key environmental changes. In Table 8.1 we have adopted a very conservative approach to identifying potential mechanisms by which agricultural change may have affected bird populations. This focuses just on ecologically plausible hypotheses that have been advanced in the literature concerning how different components of change in agriculture may have impacted on species populations. These hypotheses, and current evidence for them, are reviewed in Section 2. This approach almost certainly means that the potential importance of some factors may be understated simply because relatively little attention has been paid to them in the literature. We suspect this is the case for effects of fertilizers which have received far less attention than pesticides for example. The components of agricultural change are identified at the broadest level. Those potential impacts for which evidence has been generated from the present project in the form of significant associations (Sections 4 to 6) are shown as solid circles in Table 8.1. It should be noted that this table only considers potential mechanisms underlying declines; potential positive effects of some changes in agriculture such as set-aside (Henderson *et al.* 1998) are not included.

For reasons discussed above, caution should be exercised before homing in on particular cells in Table 8.1. However, we wish to highlight the following general patterns and findings. First, associations frequently emerged with the timing of sowing of cereal crops, especially for granivorous birds. This was the case for analysis of population changes shown by CBC indices at the regional scale and in the analysis of population change on individual farms. Second, several relationships emerged with grassland management (improvement of rough grazing and livestock trends), especially for Lapwing. Third, there were conspicuously few associations with pesticide use. This does not mean that pesticide effects have not been important ecological factors in the declines of farmland birds. The available data on pesticides were relatively crude compared, for example, with data on changes in crop areas. Annual data were unavailable and the potential efficiency of pesticides (this has obviously changed hugely over the last 30 years) could not be taken into account in the statistical analyses.

8.5 Wider Implications

This project has identified several broad areas that are worth closer attention in the future. First, we suggest that more work is undertaken on the causes of bird population changes in western Britain where there have been many local extinctions of farmland species. In particular it is desirable to focus on (a) the effect on bird populations of the reduction in the area of cereals within predominantly grassland systems and (b) the effects of the intensification of grassland management on birds and their food resources. The latter is currently the focus of a joint project between BTO, CABI Bioscience and IGER funded by MAFF that commenced in November 1998. Second, we suggest that far more attention is given to the implications of the switch from spring-sown to autumn-sown cereals, and the wider changes in crop rotations of which this was a part. The relevant mechanisms could be loss of stubbles and associated autumn and winter food supplies, and loss of suitable nesting and feeding habitat for some species in spring and late winter.

We suggest that little is to be gained by focusing research effort on further analysis of the historical data. This is partly because of the methodological constraints described above. It is also partly because the nature of farming has changed so much that rather different factors will be influencing the status of species today than those which initiated the population declines. It is highly questionable whether *exact* mechanisms behind the historical declines can ever be pinned down for most species and, indeed, to what extent this is necessary. In most cases the likely relevant principal components of agricultural change have been identified (see Section 2, also Fuller *et al.* 1995). In trying to develop solutions, future work will be most profitable if it focuses on realistic opportunities for manipulating farmland environments in ways that may bring ecological benefits. In this context, the prescriptions embedded in the Arable Stewardship Scheme are clearly important focus areas for future research, together with Integrated Crop Management and organic farming. Both autecological and extensive studies have a continuing role to play in developing our understanding of factors that limit the distribution and abundance of declining farmland birds at a variety of scales.

8.6 Final Comment about the Scope of the Study

Some concluding comments are appropriate about certain limitations imposed by the scope of the study. These relate to the species analysed, the geographical and habitat coverage and the time period examined. This report does not claim to be a comprehensive examination of changes in distribution and abundance of birds in relation to post-war changes in farming practices.

The selection of the target species for these analyses (Section 2.5, Table 2.1) was dictated partly by the quality of data available and partly by the desire to focus on *breeding* species that are strongly associated with *lowland* farmland. We acknowledge that the target species do not include all bird species potentially affected by post-war changes in agriculture. For example, certain breeding waders including Redshank, Snipe (Smith 1982) and Curlew (Fuller 1995) have undergone substantial declines as a consequence of drainage and grassland improvement. Other species such as several ducks, Whinchat, Sedge Warbler and Grasshopper Warbler *Locustella naevia* may also have been affected locally by drainage of wet meadows and rank marshy areas. Corncrake *Crex crex* has widely declined in Britain mainly as a result of the mechanisation of grass cutting (Green 1996). Furthermore, British lowland farmland supports large numbers of wintering Lapwings, Golden Plovers *Pluvialis apricaria*, thrushes (notably Redwing *Turdus iliacus* and Fieldfare *Turdus pilaris*), Skylarks, finches and buntings. Changes in numbers and distribution of these species in relation to agriculture have not been studied because their winter population trends are unknown.

The project has focused on lowland farmland, mainly because relatively little data are available on uplands and marginal uplands. There appear to have been large reductions in populations of ground-nesting birds in upland edge areas of northern England which may be associated with pasture improvement and subsequent changes in livestock grazing (Baines 1988, 1989, Fuller & Gough in press). Similarly, populations of Twite and other passerines may have declined in the Pennines as a consequence of land-use change (Brown *et al.* 1995, BTO unpublished data). These population changes and their causes have not been covered by the present study. Within lowland farmland some habitats have probably been better covered than others. In particular, little data are available for grassland systems in parts of northern and western England and Wales (see Section 5). Intensification of grassland management has been no less profound than intensification of arable farming over recent decades. Massive increases in fertiliser inputs have been ubiquitous in lowland grassland management causing increasing structural and floristic uniformity in vegetation. It is likely that this aspect of change in agricultural practice has been underestimated as a factor contributing to declines in bird populations.

Finally we wish to stress that post-war impacts of agriculture on bird populations will not be confined to the period covered by this study (i.e post-1970). Grassland improvement commenced well before 1970, herbicide usage was widespread by then and hedgerows were probably being destroyed at a higher rate in the 1960s than at any time before or since. This study indicates, however, that overall changes in farming practices since the early 1960s have been most marked between the early-1970s and the mid-1980s and that this matches closely the major measured changes in farmland bird populations.

Species	Autumn sowing	Ley grass	Improvement of rough grazing	Hay to silage	Livestock	Manure	Artificial fertilizer	Pesticides	Hedgerow	Crop diversity
Potential effect[2]	F_w, N*	F_a	F_a	F_a, N*	N	F_a	N	F_a	N	F_a, N
Grey Partridge	○	○						○		
Lapwing	○		●	○	●	○	○	○		○
Turtle Dove								○		
Skylark	●			○	○		●	○		○
Yellow Wagtail			○		●					
Starling			○			○		○		
Rook		○	○							
Whitethroat									○	
Blackbird			○			○		○	○	
Song Thrush			●			○		○	○	
Tree Sparrow	○			●				○	○	
Chaffinch	○			○					○	
Greenfinch	●			○					○	
Goldfinch	●			○					○	
Linnet	●			○				○	○	
Bullfinch								○	○	
Corn Bunting	●	○		○						
Reed Bunting	●	○		○				○	○	
Yellowhammer	○	○		○					○	

Table 8.1 Broad components of agricultural change[1] potentially causing population declines in farmland birds (see text for more explanation). Only the target species considered in this report are listed, with the exception of Kestrel and Stock Dove for which we could find no clear hypotheses or evidence of negative impacts. ○ Evidence or hypothesized link in the literature (see Section 2). ● Significant association in the expected direction generated from this project (see Sections 4 to 6).

[1] Autumn sowing = switch from spring to autumn sown cereals with associated reduction in overwinter stubbles.

Ley grass = reduction in rotations involving a ley grass phase.

Improvement of rough grazing = drainage, reseeding and increased nitrogen inputs.

Hay to silage = switch from hay to silage with associated earlier cutting of grass and reduction in seed availability.

Livestock = increased stocking rates, especially of sheep.

Manure = reduction in use of farmyard manure with consequences for soil invertebrates.

Artificial fertilizer = increase in use of synthetic fertilizer with associated increase in density of vegetation.

Pesticides = increase in applications of and diversity of pesticides.

Hedgerow = reduction in non-crop habitat, especially hedgerows.

Crop diversity = reduction in crop diversity as a consequence of the increasing specialization of farming enterprises and of the simplification of rotational systems.

[2] F_a=food (all year), F_w=food (outside breeding season), N=nesting habitat, N^* only for Lapwing and Skylark

Table 8.1 Continued.

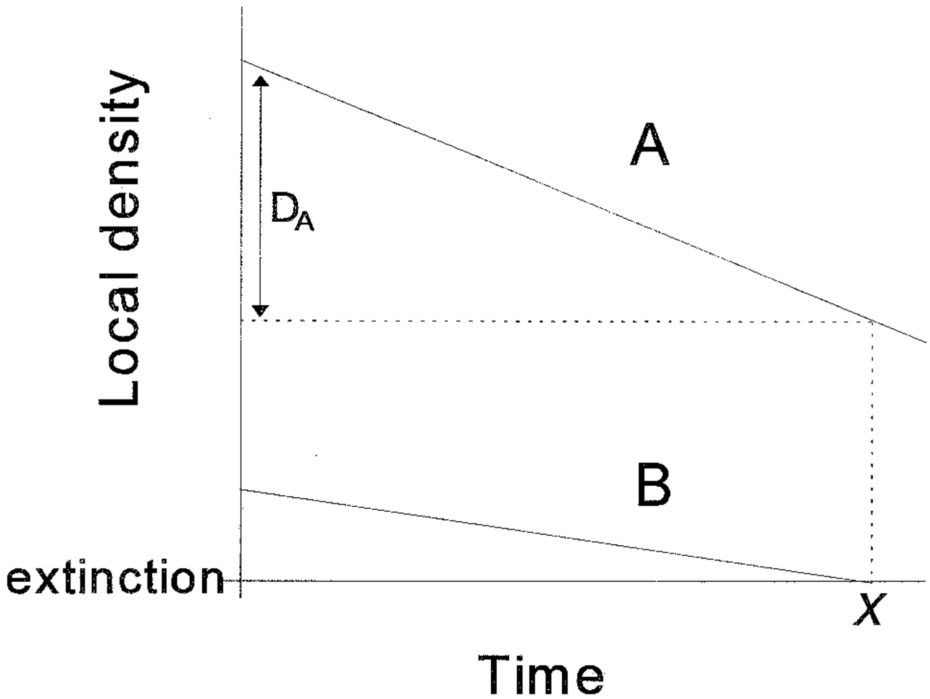

Figure 8.1 Effect of initial density and rate of population decline on local extinction. A and B are two hypothetical species populations. A has a higher rate of decline but population B is declining from a relatively low initial starting density and becomes extinct at point X, when the density of B has merely declined by D_A. A and B could represent populations in different regions (e.g. arable and non-arable), populations in different habitats or different species in the same habitat / region.

Acknowledgements

A large number of people have helped with this project in a variety of ways.

We warmly thank the many volunteer workers who have spent may hours collecting the data upon which the analyses contained within this report are based. The contributors to the two BTO breeding bird atlases and to the Common Bird Census are too numerous to list individually but we thank them all. Nonetheless, we would like to mention those who undertook the mapping surveys of farms in 1996 and 1997 which contributed to the data in Section 7: David Atkinson, Dawn Balmer, Richard Bland, Chris Bradshaw, Alison Bunning, George Edmonds, David Emery, Peter Evans, Peggy Gordon, Peter Hewitt, Ms A M Knapp, Judith Knight, Geoff Mawson, Steve Moores, Geoff Nobes, Major John Powell, Des Sussex, Ian Taylor, Dr Colin Whiteman, Peter Wilson and Stuart Winter.

Thanks to Ben Fraser who was an excellent field assistant working on the surveys of individual farms in 1996 and 1997. Steve Holloway was responsible for the early organisation of the farm surveys. Other BTO staff who have helped with various aspects of the project are: Nick Carter, Nigel Clark, Simon Gillings, Su Gough, Ian Henderson, John Marchant, Will Peach, Nicola Read, Gavin Siriwardena and David Thomson.

We are grateful to Brian Chambers (ADAS) and Miles Thomas (CSL) for their advice on availability of fertiliser data and the development of the farm questionnaire respectively. Gavin Stark (ITE) provided data on ITE land classes. Mike Shrubb's participation in the project was voluntary and we are most grateful for his advice on interactions between birds and agriculture throughout.

We would like to thank all the farmers and land owners who allowed survey work to be carried out on their land.

The University of Edinburgh Data Library provided the 10-km square agricultural data which are adapted from the Parish Summaries of the Agricultural Census for England and Wales. These are Crown Copyright and are reproduced by permission of the Controller of Her Majesty's Stationery Office.

The Common Birds Census is funded by the BTO and the Joint Nature Conservation Committee (on behalf of English Nature, Countryside Council for Wales, Scottish Natural Heritage, Environment and Heritage Service in Northern Ireland).

This project was funded by the Ministry of Agriculture, Fisheries and Food.

References

Baillie, S.R. (1990) Integrated population monitoring of breeding birds in Britain and Ireland. *Ibis,* **132**, 151-166.

Baillie, S.R. & Peach, W.J. (1992) Population limitation in Palaearctic-African migrant passerines. *Ibis,* **134** (Suppl.), 120-132.

Baillie, S.R., Gregory, R.D. & Siriwardena, G.M. (1997) Farmland bird declines: patterns processes and prospects. BCPC Symposium Proceedings: *Biodiversity and Conservation in Agriculture,* **69**, 65-87.

Baines, D. (1988) The effects of improvement of upland grassland on the distribution and density of breeding wading birds (Charadriiformes) in Northern England. *Biological Conservation*, **45**, 221-236.

Baines, D. (1989) The effects of improvement of upland, marginal grasslands on the breeding success of Lapwings *Vanellus vanellus* and other waders. *Ibis,* **131**, 497-506.

Ball, D.F., Radford, G.L. & Williams, W.M. (1983) *A Land Characteristic Data Bank for Great Britain.* ITE occasional paper of ITE Project 534. Institute of Terrestrial Ecology, Huntingdon.

Begon, M., Harper, J.L. & Townsend, C.R. (1990) *Ecology - Individuals, Populations and Communities*. 2nd Edition. Blackwell Scientific Publications, Oxford.

Beintema, A.J., Beintema-Hietbrink, R.J. & Müskens, G.J.D.M. (1985) A shift in the timing of breeding in meadow birds. *Ardea*, **73**, 83-89.

Bibby, C.J., Burgess, N.D. & Hill, D.A. (1992) *Bird Census Techniques*. Academic Press, London.

Bohning-Gaese, K. (1997) Determinants of avian species richness at different spatial scales. *Journal of Biogeography*, **24**, 49-60.

Braak, C.J.F. ter, Strien, A.J. van, Meijer, R. & Verstrael, T.J. (1994) Analysis of monitoring data with many missing values: which method? In: Hagemeijer, W. and Verstrael, T. (eds.) *Bird Numbers 1992. Distribution, Monitoring and Ecological Aspects,* pp 663-673. Proc. 12th Int. Conf. International Bird Census Council and European Ornithological Atlas Committee. Beek-Ubbergen: Sovon.

Brown, A.F., Crick, H.Q.P. & Stillman, R.A. (1995) The distribution, numbers and breeding ecology of Twite *Acanthis flavirostris* in the south Pennines of England. *Bird Study*, **42**, 107-121.

Brown, A.F., Stillman, R.A. & Gibbons, D.W. (1995) Use of breeding bird atlas data to identify important bird areas: a northern England case study. *Bird Study*, **42**, 132-143.

Browne, S.J., Vickery, J.A. & Chamberlain, D.E. (in press) Densities and population estimates of breeding Skylarks (*Alauda arvensis*) in Britain in 1997. *Bird Study*.

Bunce, R.G.H., Howard, D.C., Hallam, C.J., Barr, C.J. & Benefield, C.B. (1993) *Ecological Consequences of Land Use Change*. Department of Environment, London.

Bunce, R.G.H, Barr, C.J., Clarke, R.T., Howard, D.C. & Lane, A.M.J. (1996) ITE Merlewood land classification of Great Britain. *Journal of Biogeography*, **23**, 625-634.

Bunce, R.G.H., Carey, P., Howard, D.C., Van de Poll, H.M., Roy, D., Hill, M.O., Wilson, P., Smart, S.M., Rothery, P., Metcalfe, J. & Duckworth, J. (1998) *Ecological Factors Controlling Biodiversity in the British Countryside (ECOFACT). Module 6 - Understanding the Causes of Change in Biodiversity in Britain and England and Wales*. Institute of Terrestrial Ecology, Merlewood.

Burton, N.H.K., Watts, P.N., Crick, H.P.Q. & Carter, N. (1996) *The Effects of Pre-harvesting Operations on Birds Nesting in Oilseed Rape* Brassica napus. BTO Research Report No 171. British Trust for Ornithology, Thetford.

Calladine, J.R., Buner, F. & Aebischer, N.J. (1997) *The Summer Ecology and Habitat Use of the Turtle Dove: a Pilot Study*. English Nature Report No 219. EN, Peterborough.

Campbell, L.H., Avery, M.I., Donald, P., Evans, A.D., Green, R.E. & Wilson, J.D. (1997) *A Review of the Indirect Effects of Pesticides on Birds*. JNCC Report No. 227. Joint Nature Conservation Committee, Peterborough.

Chamberlain, D.E. & Crick, H.Q.P. (1999) Population declines and reproductive performance in Skylarks *Alauda arvensis* in different regions and habitats of the United Kingdom. *Ibis* 141: 38-51.

Chamberlain, D.E. & Gregory, R.D. (1999) Coarse and fine-scale habitat associations of breeding Skylarks *Alauda arvensis* in the UK. *Bird Study* 46: 36-47.

Chamberlain, D.E., Wilson, J.D. & Fuller, R.J. (1999). A comparison of bird populations on organic and conventional farm systems in southern Britain. *Biological Conservation* 88: 307-320.

Chamberlain, D.E. & Fuller, R.J. (in press). Density-dependent habitat distribution in birds: issues of scale, habitat definition and habitat availability. *Journal of Avian Biology*.

Chater, A.O. (1996) Colonies of the Rook *Corvus frugilegus* in the north Ceredigion 1975-1994. *Welsh Birds*, **1 (3)**, 3-21.

Crick, H.Q.P., Dudley, C., Evans, A.D. & Smith, K.W. (1994) Causes of nest failure among buntings in the UK. *Bird Study*, **41**, 88-94.

Crick, H.Q.P., Baillie, S.R., Balmer, D.E., Bashford, R.I., Dudley, C., Glue, D.E., Gregory, R.D., Marchant, J.H., Peach, W.J. & Wilson, A.M. (1997) *Breeding Birds in the Wider Countryside: their Conservation Status (1971-1995)*. BTO Research Report No 187. British Trust for Ornithology, Thetford.

Delius, J.D. (1965) A population study of Skylarks *Alauda arvensis*. *Ibis*, **107**, 466-490.

Donald, P.F. (1997) The Corn Bunting *Miliaria calandra* in Britain: a review of current status, patterns of decline and possible causes. In: Donald, P.F. & Aebischer, N.J. (eds) *The Ecology and Conservation of Corn Buntings* Miliaria calandra, pp 11-26. UK Nature Conservation no. 13. Joint Nature Conservation Committee, Peterborough.

Donald, P.F. & Evans, A.D. (1994) Habitat selection by Corn Buntings *Miliaria calandra* in winter. *Bird Study*, **41**, 199-210.

Donald, P.F. & Fuller, R.J. (1998) Ornithological atlas data: a review of uses and limitations. *Bird Study*, **45**, 129-145.

Donald, P.F., Wilson, J.D. & Shepherd, M. (1994) The decline of the Corn Bunting. *British Birds*, **87**, 106-132.

Dunning, J.B. (1993) *CRC Handbood of Avian Body Masses*. CRC Press, Boca Raton.

EPPO (1994) Decision-making scheme for the environmental risk assessment of plant protection products. Chapter 11. Terrestrial vertebrates. *EPPO Bulletin*, **24**, 37-87.

Evans, A.D. & Smith, K.W. (1994) Habitat selection of Cirl Buntings *Emberiza cirlus* wintering in Britain. *Bird Study*, **41**, 81-87.

Evans, A.D., Smith, K.W., Buckingham, D.L. & Evans, J. (1997) Seasonal variation in breeding performance and nestling diet of Cirl Buntings *Emberiza cirlus* in England. *Bird Study*, **44**, 66-79.

Feare, S. (1984) *The Starling*. Oxford University Press, Oxford.

Firbank, L.G. (1998) *Agronomic and Environmental Evaluation of Set-Aside. Volume 1. Overview*. ITE, Merlewood.

Floate, K.D. (1998) Off-target effects of ivermectin on insects and dung degradation in southern Alberta, Canada. *Bull. Ent. Res.*, **88**, 25-35.

Fuller, R.J. (1994) Relating birds to vegetation: influences of scale, floristics and habitat structure. In E.J.M. Hagemeijer & T.J. Verstrael (eds.) *Bird Numbers 1992. Distribution, monitoring and ecological aspects. Proc. 12th Int. Conf. IBCC and EOAC*. Pp 19-28. Statistics Netherlands, Vooburg/Heerlen & Sovon, Beek-Ubbergen.

Fuller, R.J. (1995) Changes in breeding populations of Curlews and Lapwings in central Buckinghamshire, 1981-1990. *Buckinghamshire Bird Report for 1994*, 11-16.

Fuller, R.J. (1996) *Relationships Between Grazing and Birds with Particular Reference to Sheep in the British Uplands.* BTO Research Report no. 164. British Trust for Ornithology, Thetford.

Fuller, R.J. (1997) Responses of birds to organic arable farming: mechanisms and evidence. *Proc. Brighton Crop Protection Conference - Weeds,* pp 897-906. Brighton Crop Protection Council, Farnham.

Fuller, R.J. & Youngman, R.E. (1979) The utilization of farmland by Golden Plovers wintering in southern England. *Bird Study,* **26**, 37-46.

Fuller, R.J., Marchant, J.H. & Morgan, R.A. (1985) How representative of agricultural practice in Britain are Common Birds Census farmland plots? *Bird Study*, **32**, 56-70.

Fuller R.J., Gregory, R.D., Gibbons, D.W., Marchant, J.H., Wilson, J.D., Baillie, S.R. & Carter, N. (1995) Population declines and range contractions among lowland farmland birds in Britain. *Conservation Biology*, **9**, 1425-1441.

Fuller, R.J., Trevelyan, R.J. & Hudson, R.W. (1997) Landscape composition models for breeding bird populations in lowland English farmland over a 20 year period. *Ecography,* **20**, 295-307.

Fuller, R.J. & Gough, S. (in press) Changes in sheep numbers in Britain: implications for bird populations. *Biological Conservation.*

Fuller, R.M. (1987) The changing extent and conservation interest of lowland grasslands in England and Wales: a review of grassland surveys 1930-84. *Biological Conservation,* **40**, 281-300.

Fuller, R.M. & Parsell, R.J. (1990) Classification of TM imagery in the study of land use in lowland Britain: practical consideration for operational use. *International Journal of Remote Sensing*, **10**, 1901-1919.

Galbraith, H. (1988) Effects of agriculture on the breeding ecology of Lapwings *Vanellus vanellus. Journal of Applied Ecology*, **25**, 487-503.

Gates, S. & Donald, P.F. (In press) Distributional changes of British farmland birds in relation to environmental suitability. J. Appl. Ecol.

Gates, S., Gibbons, D.W., Lack, P.C. & Fuller, R.J. (1994) Declining farmland bird species: modelling geographical patterns of abundance in Britain. In: Edwards, P.J., May, R. and Webb, N.R. (eds) *Large-Scale Ecology and Conservation Biology*, pp 153-177. Blackwell Scientific Publications, Oxford.

Gauch, H.G. (1982) *Multivariate Analysis in Community Ecology*. Cambridge University Press, Cambridge.

Gibbons, D.W. & Gates, S. (1994) Hypothesis testing with ornithological atlas data: two case studies. In: Hagemeijer, W. and Verstrael, T. (eds.) *Bird Numbers 1992. Distribution, Monitoring and Ecological Aspects,* pp 39-48. Proc. 12th Int. Conf. International Bird Census Council and European Ornithological Atlas Committee. Beek-Ubbergen: Sovon.

Gibbons, D.W., Reid, J.B. & Chapman, R.A. (1993) *The New Atlas of Breeding Birds in Britain and Ireland: 1988-1991.* Poyser, London.

Gillings, S. & Fuller, R.J. (1998) Changes in bird populations on sample lowland English farms in relation to loss of hedgerows and other non-crop habitats. *Oecologia*, **116**, 120-127.

Gooch, S., Baillie, S.R. & Birkhead, T.R. (1991) Magpie *Pica pica* and songbird populations, retrospective investigation of trends in population density and breeding success. *Journal of Applied Ecology*, **28**, 1068-1086.

Gooders J. (1986) *Field guide to the birds of Britain and Ireland.* Kingfisher Books: London.

Green, R. (1978) Factors affecting the diet of farmland Skylarks *Alauda arvensis*. *Journal of Animal Ecology*, **47**, 913-928.

Green, R.E. (1995) The decline of the Corncrake *Crex crex* in Britain continues. *Bird Study*, **42**, 66-75.

Green, R.E. (1996) Factors affecting the population density of the Corncrake *Crex crex* in Britain and Ireland. *Journal of Applied Ecology*, **33**, 237-248.

Green, R.E. & Stowe, T.J. (1993) The decline of the Corncrake *Crex crex* in Britain and Ireland in relation to habitat change. *Journal of Applied Ecology*, **30**, 689-695.

Green, R.E., Osbourne, P.E. & Sears, E.J. (1994) The distribution of passerine birds in hedgerows during the breeding season in relation to characteristics of the hedgerow and adjacent farmland. *Journal of Applied Ecology*, **31**, 677-692.

Greenwood, J.J.D. & Baillie, S.R. (1991) Effects of density-dependence and weather on population changes of English passerines using a non-experimental paradigm. *Ibis*, **133** (suppl.), 121-133.

Gregory, R.D. (1995) Phylogeny and relations among abundance, geographical range and body size of British breeding birds. *Philosophical Transactions of the Royal Society of London B*, **349**, 345-351.

Gregory, R.D. & Marchant, J.H. (1996) Population trends of Jays, Magpies, Jackdaws and Carrion Crows in the United Kingdom. *Bird Study*, **43**, 28-37.

Grigg, D. (1989) *English Agriculture. An Historical Perspective*. Blackwell, Oxford.

Hagemeijer, E.J.M. & Verstrael, T.J. (eds.) Pp. 19-28. Proc. 12th Int.Conf. IBCC and EOAC. Statistics Netherlands, Voorburg/Heerlen & SOVON, Beek-Ubbergen.

Halley, B.A., Vandenheuvel, W.J.A., Wislocki, P.G. & Wardhaugh, K. (1993) Environmental impact of avermectin usage in livestock. In: R.Herd & L. Strong (eds) Proc. Invitational Workshop at Columbus, USA. *Veterinary Parasitology*, **48**, 109-125

Hatchwell, B.J., Chamberlain, D.E. & Perrins, C.M. (1996) The demography of Blackbirds *Turdus merula* in rural habitats: is farmland a sub-optimal habitat? *Journal of Applied Ecology*, **33**, 1114-1124.

Henderson, I.G., Cooper, J. & Fuller R.J. (1998) Spatial and temporal utilization of set-aside by birds in summer on arable farms in England. In: L.G. Firbank (ed.) *Agronomic and Environmental Evaluation of Set-Aside. Volume 4 Birds and Modelling*. Institute of Terrestrial Ecology, Merlewood.

Hill, M.O. (1979) *DECORANA: A FORTRAN Program for Detrended Correspondence Analysis and Reciprocal Averaging*. Section of Ecology and Systematics, Cornell University, Ithaca, New York.

Hudson, A.V., Stowe, T.J. & Aspinall, S.J. (1990) Status and distribution of Corncrakes in Britain in 1988. *British Birds*, **83**, 173-187.

Hudson, R., Tucker, G.M. & Fuller, R.J. (1994) Lapwing *Vanellus vanellus* populations in relation to agricultural changes: a review. In: *The Ecology and Conservation of Lapwings* Vanellus vanellus, pp1-26. UK Nature Conservation No 9. Joint Nature Conservation Committee.

Hustings, F. (1992) European monitoring studies on breeding birds: an update. *Bird Census News*, **5**, 1-56.

James, F.C. & McCulloch, C.E. (1990) Multivariate analysis in community ecology and systematics: panacea or Pandora's box? *Annual Review of Ecology and Systematics*, **21**, 129-166.

Jokimaki, J. & Huhta, E. (1996) Effects of landscape matrix and habitat structure on a bird community in northern Finland: a multi-scale approach. *Ornis Fennica*, **73**, 97-113.

Kleijn, D. & Snoejng, G.I.J. (1997) Field boundary vegetation and the effects of agrochemical drift: botanical change caused by low levels of herbicide and fertilizer. *Journal Applied Ecology*, **34**, 1413-1425.

Krebs, C.J. (1980) *Ecology: the Experimental Analysis of Distribution and Abundance*. Harper and Row, New York, USA.

Krebs, J.R. (1971) Territory and breeding density in the Great Tit *Parus major*. *Ecology*, **52**, 2-22.

Kyrkos, A., Wilson, A.D. & Fuller, R.J. (1998) Farmland habitat changes and abundance of Yellowhammers. *Bird Study*, **45**, 232-246.

Lack, P. (1992) *Birds on Lowland Farms*. HMSO, London.

Legendre, P. (1993) Spatial autocorrelation: trouble or new paradigm? *Ecology*, **74**, 1659-1673.

Lilford, Lord (1895) *The Birds of Northants*. Porter, London.

Loye, J.E. & Zuk, M. (1991) *Bird-Parasite Interactions*. Oxford University Press, Oxford.

Luttik, R. & Aldenberg, T. (1997) Extrapolation factors for small samples of pesticide toxicity data: special focus on LD50 values for birds and mammals. *Environmental Toxicology and Chemistry*, 16, 1785-1788.

MacDonald, D.W. & Johnson, P.J. (1995) The relationship between bird distribution and the botanical and structural characteristics of hedges. *Journal Applied Ecology*, **32**, 492-505.

Marchant, J.H., Hudson, R., Carter, S.P. & Whittington, P.A. (1990) *Population Trends in British Breeding Birds*. British Trust for Ornithology, Thetford.

Marchant, J.H. & Gregory, R.D. (1994) Recent population changes among seed-eating passerines in the United Kingdom. In: Hagemeijer, W. and Verstrael, T. (eds.) *Bird Numbers 1992. Distribution, Monitoring and Ecological Aspects*, pp 87-96. Proc. 12th Int. Conf. International Bird Census Council and European Ornithological Atlas Committee. Beek-Ubbergen, Sovon.

McCracken, D.I. (1993) The potential for avermectins to affect wildlife. *Veterinary Parasitology*, **48**, 273-280.

Marchant, J.H. & Gregory, R.D. (in press) The numbers of nesting Rooks *Corvus frugilegus* in the United Kingdom in 1996. *Bird Study*.

Moorcroft, D., Bradbury, R.B. & Wilson, J.D. (1997) The diet of nestling linnets *Carduelis cannabina* before and after agricultural intensification. *Proc. Brighton Crop Protection Conference - Weeds*, pp 923-928. Brighton Crop Protection Council, Farnham.

Moore, N.W. (1987) *The Bird of Time*. Cambridge University Press, Cambridge.

Murton, R.K. & Westwood, N.J. (1974) Some effects of agricultural change on the English avifauna. *British Birds*, **67**, 41-67.

Newton, I. (1979) *Population Ecology of Raptors*. Poyser, Berkhamsted.

Newton, I. (1986) *The Sparrowhawk*. Poyser, Calton.

Newton, I. (1993) Predation and limitation of bird numbers. *Current Ornithology*, **11**, 143-194.

Newton, I., Dale, L. & Rothery, P. (1997) Apparent lack of impact of Sparrowhawks on the breeding densities of some woodland songbirds. *Bird Study,* **44**, 129-135.

Norrdahl, K. & Korpimäki, E. (1998) Fear in farmlands: how much does predator avoidance affect bird community structure. *Journal of Avian Biology*, **29**, 79-85.

Norris, C.A. (1947) Report on the distribution and status of the Corncrake. *British Birds*, **40**, 226-244.

O'Connor, R.J. (1986) Dynamical aspects of avian habitat use. In: Verner, J., Morrison M.L. & Ralph, C.J. (eds). *Wildlife 2000: Modelling habitat relationships of terrestrial vertebrates,* pp 235-240. University of Wisconsin Press, Madison, Wisconsin.

O'Connor RJ. (1992) Indirect effects of pesticides on birds. *British Crop Protection Conference – Pests and Diseases* – 1992. Pp. 1097-1104. BCPC, Farnham

O'Connor, R.J. & Shrubb, M. (1986) *Farming and Birds*. Cambridge University Press.

Pannekoek, J. & Strien, A.J. van (1996) *TRIM* (*Trends & Indices for Monitoring data*). Statistics Netherlands, Voorburg.

Parish, T., Lakhani, K.H. & Sparks, T.H. (1994) Modelling the relationship between bird population variables and hedgerow, and other field margin attributes. I. Species richness of winter, summer and breeding birds. *Journal of Applied Ecology,* **31**, 764-775.

Peach, W.J., Baillie, S.R. & Underhill, L. (1991) Survival of British Sedge Warblers *Acrocephalus schoenobaenus* in relation to West African rainfall. *Ibis,* **133**, 300-305.

Petersen, B.S. (1996) *The Distribution of Birds in Danish Farmland.* Pesticides Research No. 17. Ministry of Environment and Energy, Copenhagen.

Potts, G.R. (1980) The effects of modern agriculture, nest predation and game management on the population ecology of partridges (*Perdix perdix* and *Alectoris rufa*). *Adv. Ecol. Res*, **11**, 1-79.

Potts, G.R. (1986) *The Partridge: Pesticides, Predation and Conservation*. Collins, London.

Potts, G.R. & Aebischer, N.J. (1995) Population dynamics of the Grey Partridge *Perdix perdix* 1793-1993: monitoring, modelling and management. *Ibis*, **137** (Suppl.), 29-37.

Poulsen, J.G. (1996) Behaviour and parental care of Skylark *Alauda arvensis* chicks. *Ibis*, **138**, 525-531.

Poulsen, J.G, Sotherton, N.W. & Aebischer, N.J. (1998) Comparative nesting and feeding ecology of Skylarks *Alauda arvensis* on arable farmland in southern England with special reference to set-aside. *Journal of Applied Ecology*, **35**, 131-147.

Pulliam, H.R. (1988) Sources, sinks and population regulation. *American Naturalist*, **132**, 652-661.

Rands, M.R.W. (1985) Pesticide use on cereals and the survival of Grey Partridge chicks: a field experiment. *Journal of Applied Ecology*, **22**, 49-54.

Rands, M.R.W. (1986) The survival of gamebird (Galliform) chicks in relation to pesticide use on cereals. *Ibis*, **128**, 57-64.

Ratcliffe, D. (1980) *The Peregrine Falcon*. Poyser, London.

Redpath, S.M. & Thirgood, S.J. (1997) *Birds of Prey and Red Grouse*. HMSO, London.

SAS Institute (1996) *SAS/STAT Users Guide*. Version 6.1. SAS Institute Inc., Cary, North Carolina.

Schläpfer, A. (1988) Populationsökologie der Feldlerche *Alauda arvensis* in der intensiv genutzen Agrarlandschaft. *Ornithologische Beobachter*, **85**, 309-371.

Sharrock, J.T.R. (1976) *The Atlas of Breeding Birds in Britain and Ireland*. Poyser, Calton.

Shrubb, M. (1990) Effects of agricultural change on nesting Lapwings *Vanellus vanellus* in England and Wales. *Bird Study*, **37**, 115-127.

Shrubb, M. (1997) Historical trends in British and Irish Corn Bunting *Miliaria calandra* populations - evidence for the effects of agricultural change. In: Donald, P.F. & Aebischer, N.J. (eds) *The Ecology and Conservation of Corn Buntings* Miliaria calandra, pp 27-41. UK Nature Conservation no. 13. Joint Nature Conservation Committee, Peterborough.

Shrubb, M. & Lack, P.C. (1991) The numbers and distributions of Lapwings *V. vanellus* nesting in England and Wales in 1987. *Bird Study*, **38**, 20-37.

Shrubb, M., Williams, I.T. & Lovegrove, R.R. (1997) The impact of changes in farming and other land uses on bird populations in Wales. *Welsh Birds*, **5**(1), 4-26.

Siepel, H. (1990) The influence of management on food size in the menu of insectivorous animals. In: Sommeijer, M.J. and van der Blom, J. (eds.). *Experimental and Applied Entomology*. Nederlandse Entomologische Vereniging, Amsterdam.

Siriwardena, G.M., Baillie, S.R., Buckland, S.T., Fewster, R.M., Marchant, J.H. & Wilson, J.D. (1998a) Trends in the abundance of farmland birds: a quantitative comparison of smoothed Common Birds Census indices. *Journal of Applied Ecology*, **35**, 24-43.

Siriwardena, G., Baillie, S.R. & Wilson, J.D. (1998b) Variation in the survival rates of some British passerines with respect to their population trends on farmland. *Bird Study* 45: 276-292.

Smith, K.W. (1982) The status and distribution of waders breeding on wet lowland grasslands in England and Wales. *Bird Study*, **30**, 177-192.

Snow, D.W. & Perrins, C.M. (1998) *The Birds of the Western Palaearctic*. Concise Edition. Oxford University Press.

Sotherton, N.W. (1991) Conservation headlands: A practical combination of intensive cereal farming and conservation. In: Firbank, G.L., Carter, N., Darbyshire, J.F. & Potts, G.R. (eds) *The Ecology of Temperate Cereal Fields*, pp 399-412. Blackwell Scientific Publications, Oxford.

Stoate, C. (1996) The changing face of lowland farming and wildlife Part 2: 1945-1995. *British Wildlife*, **7**, 162-172.

Stoate, C., Moreby, S.J. & Szczur, J. (1998) Breeding ecology of farmland Yellowhammers *Emberiza citrinella*. *Bird Study*, **45**, 109-121.

Stowe, T.J., Newton, A.V., Green, R.E. & Mayes, E. (1993) The decline of the Corncrake *Crex crex* in Britain and Ireland in relation to habitat. *Journal of Applied Ecology*, **30**, 53-62.

Strong, L. & Wall, R. (1994) Effects of ivermectin and moxidectin on the insects of cattle dung. *Bull. Ent. Res.*, **94**, 403-409.

Strong, L., Wall, R., Woolford, A. & Djeddour, D. (1996) The effect of faecally excreted ivermectin and fenbendazole on the insect colonization of cattle dung following the oral administration of sustained release-boluses. *Veterinary Parasitology*, **62**, 253-266.

Tapper, S.C., Potts, G.R. & Brockless, M.H. (1996) The effect of an experimental reduction in predation pressure on the breeding success and population density of Grey Partridges *Perdix perdix*. *Journal of Applied Ecology*, **33**, 965-978.

Thirsk, J. (1985) The agricultural landscape: fads and fashions. In: Woodell, S.R.J. (ed.) *The English Landscape: Past, Present and Future*. Oxford University Press, Oxford.

Thomas, M.R. (1997) *Review of Usage of Pesticides in Agriculture and Horticulture Throughout Great Britain 1984-1994*. Pesticide Usage Report 100. MAFF, London.

Thomson, D.L., Baillie, S.R. & Peach, W.J. (1997) The demography and age-specific annual survival of Song Thrushes during periods of population stability and decline. *Journal of Animal Ecology*, **66**, 414-424.

Thomson, D.L., Green, R.E., Gregory, R.D. & Baillie, S.R. (1998) The widespread declines of songbirds in Britain do not correlate with the spread of avian predators. *Proceedings of the Royal Society of London, Series B*, **265**, 2057-2062.

Tucker, G. M. (1992) Effects of agricultural practices on field use by invertebrate feeding birds in winter. *Journal of Applied Ecology*, **29**, 779-790.

Tucker, G.M. & Heath, M.F. (1994) *Birds in Europe: Their Conservation Status*. BirdLife Conservation Series no. 3. BirdLife International, Cambridge.

Tyler, G.A., Green, R.E. & Casey, C. (1998) Survival and behaviour of Corncrake *Crex crex* chicks during the mowing of agricultural grassland. *Bird Study*, **45**, 35-50.

Velleman, P.F. and Hoaglin, D.C. (1981) *Applications, Basics and Computing of Exploratory Data Analysis*. Duxbury Press, Boston.

Watkinson, A.R. & Sutherland, W.J. (1995) Sources, sinks and pseudo-sinks. *Journal of Animal Ecology*, **64**, 126-130.

Wiens, J.A. (1989) *The Ecology of Bird Communities*. (Two Volumes). Cambridge University Press.

Wilkinson, M. (1996) *Changes in Farming Practice 1978-1990.* Unpublished report by ADAS to ITE as part of the ECOFACT Programme funded by MAFF.

Williams, P., Gibbons, D.W., Margules, C., Rebelo, A., Humphries, C. & Pressey, R. (1996) A comparison of richness hotspots, rarity hotspots and complementary areas for conserving diversity of British birds. *Conservation Biology*, **10**, 155-174.

Williamson, K. (1971) Habitat preferences of the Wren on English farmland. *Bird Study*, **16**, 53-59.

Wilson, J.D., Taylor, R. & Muirhead, L.B. (1996) Field use by farmland birds in winter: an analysis of field type preferences using resampling methods. *Bird Study*, **43**, 320-332.

Wilson, J.D., Evans, J., Browne, S.J. & King, J.R. (1997) Territory distribution and breeding success of Skylarks *Alauda arvensis* on organic and intensive farmland in southern England. *Journal of Applied Ecology*, **34**, 1462-1478.

Wratten, S.D., Mead-Briggs, M., Gettinby, G, Ericsonn, G. & Bagott, D.G. (1993) An evaluation of the potential effects of ivermectin on the decomposition of cattle dung pats. *Vet. Rec.*, **133**, 365-371.