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**Bird Populations and
Environmental Change**

Countryside Survey 2000 Module 5

Authors

A.M.Wilson and R.J.Fuller

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British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU
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SUMMARY

1. Birds are potentially valuable indicators of some aspects of the quality of the countryside for wildlife. Furthermore, trends in bird populations form one of the 15 *Quality of Life* headline indicators published annually by the UK Government. It is important to understand how bird populations are affected by spatial differences across the countryside in habitat availability and to changes across time in the quantity and quality of these habitats. This project, which was Module 5 of Countryside Survey 2000 (CS2000), sets a new baseline for achieving this. The bird counts were undertaken during the spring and summer of 2000.
2. The main aim of the CS2000 bird counts was to estimate the abundance of breeding birds in a large sample of the 1-km squares for which detailed information on land use, vegetation and habitat features were collected during the CS2000 Field Survey. These data were used to provide quantitative descriptions of bird assemblages at three different scales: Great Britain, individual countries of Great Britain and Environmental Zones. The six Environmental Zones are aggregations of ITE Land Classes chosen to reflect major environmental variation in the UK. These Environmental Zones were those used as a regional framework for reporting the main results of CS2000. The CS2000 bird counts were also used to generate Avifaunal Zones, each of which contained a distinctive breeding assemblage of birds. Preliminary analyses were undertaken of gradients and patterns in bird populations in 1-km squares in relation to summary data on landscape and habitat composition of individual squares.
3. Bird surveys were conducted using up to 4 km of line transect counts within each 1-km square, using the same methods to those adopted by the BTO/JNCC/RSPB Breeding Bird Survey (BBS). Numbers of birds were recorded separately for 200 m sections of the transects according to three distance bands either side of the observer. Densities of most bird species were estimated for Great Britain, individual countries and Environmental Zones using Distance Sampling techniques. An index of the abundance of each species within individual 1-km squares was derived from the frequency with which it was recorded in the 200 m transect sections i.e. the proportion of sections occupied. A comparison of density estimates and frequency indices for all species showed a close correspondence between these two measures with only colonial species (e.g. House Martin and several seabirds) or very widespread but low density species (e.g. Cuckoo) emerging as outliers.
4. A total of 336 squares was surveyed, with samples of between 29 and 93 in each of the Environmental Zones. The data were contributed by a combination of volunteer and contract workers. A total of 171 species was recorded. The birds detected in these squares were a good representation of terrestrial bird communities in Great Britain. There was a strong relationship between the number of each species recorded on the CS2000 bird counts and the latest British population estimates. The only species that were markedly under-recorded were certain colonial nesting seabirds. The dominant species in each of the Environmental Zones are listed. Chaffinch and Wren are the only species to feature in the top 10 for each of the six Zones while Meadow Pipit was the most abundant species in the three Zones covering the uplands and marginal uplands.
5. Cluster analysis suggested that there were similarities in bird assemblages between Environmental Zones 1 and 2 (English and Welsh lowlands), zones 3 and 4 (the English and Welsh uplands and the Scottish lowlands) and zones 5 and 6 (the Scottish uplands). There was a marked difference between Zones 1 and 2 and the remaining four Zones, indicating a fundamental divergence in the bird assemblages between the English and Welsh lowlands and the rest of Britain. However, Environmental Zone 6 was also found to differ strongly from the other zones in that the bird community there was dominated by relatively few species.
6. Avifaunal Zones were developed using cluster analysis to aggregate Land Classes into zones where bird assemblages were similar. This analysis suggests that between five and eight

Avifaunal Zones are identifiable, which are broadly similar to the Environmental Zones in that they show strong north-south and altitudinal differentiation. It is suggested that the concept of avifaunal zones is explored further, possibly using independent datasets, such as the *New Atlas of Breeding Birds* and the BTO/JNCC/RSPB Breeding Bird Survey.

7. The relationships between bird assemblages and environmental variables were explored in a preliminary way using Canonical Correspondence Analysis applied to the frequency indices. All these analyses were undertaken at the scale of individual 1-km squares. These analyses effectively identified major gradients in birds assemblages, in terms of species composition and the relative abundance of species, and identified those habitats and environmental attributes most closely related to these gradients. The results are presented mainly in the form of separate ordination diagrams for Great Britain, individual countries and Environmental Zones.
8. A great deal of detailed information for each individual species concerning their broad relationships with environmental variables can be derived from these diagrams. The patterns highlighted by these analyses were different at the three spatial scales and between the six Environmental Zones. At the scale of Great Britain, invariants, such as climate, altitude, easting and northing, were found to be very important determinants of bird assemblages. However, at the country and Environmental Zone scales, the effects of other factors, especially broad habitats could be seen more clearly. Dominant land-uses and habitats, notably the areas of arable, human settlement and broad-leaved woodland were frequently among the most important features affecting gradients in bird assemblages. The relationships between bird assemblages and environmental variables varied considerably between Environmental Zones.
9. Analyses were conducted for the 20 farmland and 40 woodland species that contribute to the Government's *Quality of Life* headline indicator. These analyses explored relationships between these species and a large suite of environmental variables, but excluding the invariants such as climate and topography. Farmland species that have not decreased since the 1970s tend to be ones associated with improved grassland or areas with substantial quantities of woodland or human settlements. Those farmland species that have declined strongly are often ones associated with arable-dominated landscapes. The woodland species show a more complex pattern with declining species being associated with a diversity of landscapes and woodland types.
10. Most of the environmental variables found to be significant in determining bird communities are already recorded systematically for the BTO/JNCC/RSPB Breeding Bird Survey. One possible exception is the length of linear features, such as hedgerows, dykes, walls and roads, which may be inadequately recorded by the BBS.
11. Our work could be readily repeated as part of any future Countryside Survey, particularly as all the transect routes were mapped. Repeating the bird counts alongside the Field Survey in future Countryside Surveys would enable changes in bird numbers to be related to changes in land cover and habitat quality as measured by the Field Survey. It is also recommended that careful consideration be given to how the Countryside Survey data could be more effectively integrated with the nationwide atlases of breeding and winter bird distribution that are periodically compiled by the British Trust for Ornithology.
12. The strength of the CS2000 bird data lies in understanding how large-scale pattern in the landscape affects bird communities rather than in understanding the micro-habitat relationships of birds or the effects of habitat management. The data can be used to model relationships between land-use and bird populations in ways that allow predictions of the broad consequences for bird populations of large-scale shifts in future land-use. Much previous work of this type has focused on lowland farmland habitats but the CS2000 data could be used to address a range of broad strategic land-use and habitat creation issues in both the lowlands and uplands. Examples of possible applications are given and recommendations are made about how this might be taken forward. Models need to be scale- and region-specific and they should draw on data from both the 1-km squares and 200 m transect sections. The models should incorporate CS2000 Land

Cover Map data as well as the CS2000 Field Survey data. The possibility of incorporating data from the CS2000 Vegetation Plots within 1-km squares into the models should also be explored.

1. INTRODUCTION

For many people, birds possess great intrinsic interest; they are certainly among the most popular of all wildlife groups. Moreover, it is widely recognised that birds can act as valuable indicators of the quantity and quality of habitats for wildlife in the countryside. One of the most striking illustrations is the linkages that have been identified between declines in British farmland bird populations and the intensification of agriculture in recent decades (Fuller 2000, Chamberlain *et al.* 2000). In this instance, changes in bird populations were instrumental in fuelling a wider debate about the environmental impacts of agriculture. Birds have a high profile in both Government and Non-Governmental Organisation (NGO) conservation initiatives in the United Kingdom. Birds are strongly represented in the UK Government's *Biodiversity Action Plan* which recognises 25 priority species plus a much larger number of species of conservation concern. The NGOs also maintain a list of *Birds of Conservation Concern* with red and amber-listed species. Among the 15 *Quality of Life* headline indicators published annually by the UK Government is one based on the population trends of breeding birds. Systematic monitoring of birds and research into their habitat associations is, therefore, an important component of Government and NGO efforts to conserve biodiversity and develop more sustainable land use practices. This report presents the results of surveys of breeding birds carried out in conjunction with Countryside Survey 2000. The data collected in this project provide a basis for assessing how future large-scale changes in land-use may affect bird populations in Britain.

The Countryside Survey methodology provides the most systematic approach to documenting large-scale changes in the landscapes, habitats, vegetation and land cover in Great Britain. Surveys have been undertaken in 1978, 1984 and 1990. Fieldwork for Countryside Survey 2000 (CS2000) was undertaken in 1998-99 (Haines-Young *et al.* 2000). The core of CS2000 is the field survey, which involves the collection of a wide range of environmental information from within 1km x 1km squares spread throughout Great Britain. The approach has been developed and implemented by the Centre for Ecology and Hydrology (CEH). Key elements of the methodology are as follows. The squares have been randomly selected using ITE Land Classes to stratify the sample (Barr *et al.* 1993). Repeat coverage of the same squares is undertaken, though the number of squares in the sample has been increased at each survey from 256 in 1978, to 508 in 1990 and to 568 in CS2000. Within each square, all patches of land, excluding very small areas, are mapped and coded with respect to land-use and vegetation. Boundary and other linear features are also coded and mapped. In addition, detailed vegetation data are collected from within each square using sample plots. This fieldwork, therefore, provides extremely detailed information on the extent, location and temporal changes of habitat, vegetation, land-use and land cover. The results of CS2000 are reported separately for six Environmental Zones (three in Scotland and three in England and Wales) which reflect major geographical variation in environmental conditions.

Surveys of breeding birds were undertaken in the year 2000 on a large sample of the 1-km squares covered by CS2000. This project forms Module 5 of CS2000. The purpose of this report is to summarise the approach and methods adopted and to present some preliminary analyses of associations between birds, habitats and other environmental features. In the longer term it is intended to use the data collected to establish models that would enable predictions to be made of how bird communities and species densities would be affected by future changes in landscape composition at different spatial scales. The models could be used to predict effects of specified land-use changes involving shifts in land cover or alteration of boundary features. Examples might include the effects of future changes in forest cover, changes in hedgerow density and shifts in the ratio of grassland to arable crops. Such predictions could be specific to Land Classes or regions. CS2000 is ideal for this purpose because it offers high quality habitat data for individual 1-km squares and the squares have been selected in a stratified random manner such that they form a representative sample of British landscapes. Hence, the derived models will be a major advance on previous work and will have general applicability across British landscapes.

An additional advantage of undertaking bird surveys on Countryside Survey squares is that eventually it should be possible to test whether bird population changes are linked to habitat change.

In the longer-term, this will make it possible to assess whether population trends derived from the national bird monitoring scheme - the BTO/JNCC/RSPB Breeding Bird Survey (BBS) - are driven by habitat change or by other factors.

This document reports on a preliminary analysis of gradients and patterns in bird populations in 1-km squares in relation to summary data on landscape and habitat composition of CS2000 squares.

The specific aims of the project were as follows:

- Estimate abundance of breeding birds in a large sample of CS2000 squares.
- Provide quantitative descriptions of bird assemblages associated with Land Classes.
- Undertake a preliminary analysis of gradients and patterns in bird populations in 1-km squares in relation to summary data on landscape and habitat composition of individual squares and adjacent squares.
- Create a bird abundance database that can be readily linked with the ITE landscape composition data for individual squares collected in 1988 and 1999. The database will be compatible with the Countryside Information System.
- Identify key habitat and landscape variables that appear to be important in determining bird abundance based on the preliminary analysis. Such variables might in future be routinely collected as part of the BTO/JNCC/RSPB Breeding Bird Survey.

2. METHODS

2.1 Sample Design

The sampling methods used for CS2000 are a stratified random sample, which ensures representativeness of the range of environments across Great Britain. The sample is stratified by the ITE Land Classes, ensuring a good geographical spread of survey squares across the country and a reasonable sample size in each of the Land Classes. The Countryside Survey sample is based on the original division of 32 Land Classes (Table 1), which were subsequently re-assigned to 40 Land Classes in 1998, allowing a distinction of those in England & Wales from those in Scotland (Table 2).

2.2 Field methods and estimation of bird abundance

The field methodology was the same as that used in the BTO/JNCC/RSPB Breeding Bird Survey (BBS) with the exception that it involved a more intensive coverage of the square than used in BBS. Unlike BBS, the aim was to obtain an estimate of the relative abundance of each species that was as representative as possible of the square as a whole. As far as the terrain and access allowed, observers walked four parallel transect lines north-south or east-west, each 1-km long. Ideally, transect lines were 200 m apart and the outer ones were positioned 200 m from the edge of the square. However, this was impractical in many squares and in such cases observers were asked to choose a route that effectively covered the square, excluding open water. Observers were provided with maps onto which they plotted the routes walked so that the actual coverage achieved within the square was fully documented and, hence, repeatable for future surveys. Birds were recorded in preselected distance bands either side of the transect (0-25 m, 25-100 m, >100 m). Individual squares were visited on two occasions during the spring (mainly April, May and June). Individual visits were at least four weeks apart. In some remote upland areas a single visit in May or June was considered adequate. A copy of the survey instructions appears in Appendix 1.

2.3 Data Analysis

ITE Land Classes are the foundation of the CS2000 sampling design and are used widely as a means of stratifying samples for extensive surveys. Environmental Zones (EZ) are the basic regional division used for presentation of the CS2000 results. The compositions of Land Classes in each of the Environmental Zones are listed in Table 2. There are six Environmental Zones in Great Britain (plus a seventh for Northern Ireland), 3 in England & Wales and 3 in Scotland (Figure 1). The zones, aggregations of the 1990 Land Classes, cover the range of environmental conditions that we find in the UK from the lowlands of the south and east, through to the uplands and mountains of the north and west.

The main aim of the analyses presented in this report was to identify the primary features of the bird assemblages associated with Environmental Zones, in particular the broad patterns of bird species composition and occurrence of individual species. The data were also used to examine whether Environmental Zones are effective divisions on which to report bird communities, or whether some other division, henceforth known as Avifaunal Zones, could be devised to provide more robust models of bird assemblages.

2.3.1 Analysis of species densities in relation to Environmental Zones and Countries

Estimates of species densities were calculated for each group of squares (Environmental Zones and countries) using distance sampling methods (Buckland *et al.* 1993). This approach allows a correction for species-specific and habitat-specific differences in detectability. The DISTANCE programme fits detection probability functions to model decline in detectability with increasing distance from the transect line. Counts of birds in the first two distance bands are used to make these estimates.

The similarity of bird assemblages in different Environmental Zones was assessed using Ward's minimum linkage cluster analysis (Jongman *et al.* 1995) applied to the density estimates derived from use of the DISTANCE software. This analysis produces a Dendrogram (tree diagram) that indicates how similar bird communities in the zones are, in particular whether any clusters of similar zones are apparent. The similarity between clusters is measured by the semi-partial R-square of the point where the branching off into clusters occurs, ranging from 1 (no similarity between clusters) to 0 (clusters are identical).

2.3.2 Identification of characteristic bird species in each Environmental Zone

Species frequency indices were used to identify which species were characteristic of each Environmental Zone, that is the species that are significantly more widespread in that zone than elsewhere. The frequency index represents the proportion of 200 metre transect sections in which each species was recorded. In calculating the frequency index for each species, records were used from all three distance bands. The index ranges from 1.0 (all sections occupied by the species) to 0 (species absent from the square). Hence, a species recorded in 17/20 sections will have a frequency of 0.85 while a species recorded in 3/20 sections would have a frequency of 0.15. Such frequency indices are positively correlated with the relative abundance of a species, except for the most widely distributed species whose abundance tends to be underestimated by the use of frequency (Blondel 1975). One-tailed Z-tests were used to test whether the frequency index was higher for a species in a particular Environmental Zone than the frequency index in the other five Environmental Zones combined. Species where the difference was statistically significant at the 10% level of significance are regarded as "characteristic" while those where the level of significance is greater than 5% are described here as "highly characteristic". These qualifying levels are fairly lax statistically, but in all cases, the frequency indices are, in fact, considerably higher than the average for the other five zones.

2.3.3 Analysis of relationships between bird assemblages and environmental gradients

The aim of this analysis was to explore broad relationships between bird assemblages in individual squares and the environmental characteristics of the squares. The characteristics of the squares were derived from the CS2000 square summary data. The variables used in this analysis are listed in Table 3. Potentially, a very long list of variables could be derived from the available CS2000 data. A short list of variables was chosen based on those considered to be of ornithological significance. Initially, it was hoped to incorporate land cover data from LCM2000 (Land Cover Map 2000) into the list of variables to provide contextual information for landcover in surrounding squares but unfortunately this proved not to be possible within the reporting period of Module 5.

The gradient analyses were undertaken at three different scales: (a) Great Britain, (b) countries - Scotland, England and Wales, (c) the six Environmental Zones. Canonical Correspondence Analysis (CCA) was used to relate bird community composition to the environmental variables. CCA is a multivariate method of direct gradient analysis that produces ordination axes of unimodal species responses that are linear combinations of the environmental variables (ter Braak 1986, Jongman *et al.* 1995). CCA is a widely applied method for directly relating patterns in the species composition of biological communities to habitat variation. In the analysis presented here it identifies (a) how variation in bird assemblages (in terms of patterns of broad species composition) relates to the environmental variables, and (b) how the abundance or frequency of individual species responds to the major environmental gradients at each of the three geographical scales. The results are displayed as visual ordination diagrams showing (a) how species are positioned in relation to the main axes and (b) the strength of the environmental variables in explaining the axes. Hence, these ordination diagrams convey information at both the community level and the individual species level. A fuller explanation of how to interpret the ordination diagrams is given in section 3.3. Tables present the correlations between the main axes and the environmental variables (the inter set correlations).

The same gradient analyses were performed for the farmland and woodland bird indicator species. The wild bird indicator is one of 15 indicators designed to show trends in a variety of factors affecting the quality of life in the UK (Gregory *et al* 1999). The headline indicator of wild bird populations is based on trends for 139 species but separate farmland and woodland indicators, based on 20 and 41 species respectively are also produced. To provide a greater insight into the potential impacts of changes in land use on these indicator species, environmental invariants, such as altitude, easting, northing, area of sea and climatic variables were excluded from these analyses.

Numbers of birds recorded will generally be too small to estimate densities within individual squares. Furthermore, there is the additional problem that the number of 200m transect sections varied between squares – in some cases it was not possible to survey all 20 sections. The species data used in CCA were frequency indices derived from the proportion of 200m transect sections in which each species was recorded, as described in section 2.2.2.

2.3.4 Derivation of Avifaunal Zones

Module 5 data were used to derive Avifaunal Zones, based on Land Classes, to see whether reporting of bird data by these divisions would be more informative than reporting by Environmental Zones. The frequency indices described in 2.2.2 were used in a Ward's minimum linkage cluster analysis to highlight clusters of Land Classes (1998 classes were used) with similar bird assemblages. The same CCA techniques used to describe relationships between bird assemblages and environmental variables for Environmental Zones were then applied to the Avifaunal Zones. If these CCA models explained a higher percentage of the relationship between bird frequency and environmental variables, it could be considered that Avifaunal Zones might be more effective divisions on which to report on bird communities within the Countryside Survey framework.

3. RESULTS

3.1 Survey coverage and representativeness

A total of 336 squares was surveyed for Module 5, with a total of 1976-km of transect lines walked over the two survey visits. The distribution of squares is shown in Figure 2. Upland squares (Environmental Zones 3, 5 and 6) were covered, on average, slightly later, to account for the later bird breeding season in these areas (Table 4). A much smaller proportion of upland squares were surveyed twice, which reflects the shorter bird breeding season and lower species diversity in these areas (Table 4) and, in some cases, their relative inaccessibility.

The coverage of each Environmental Zone was sufficient to allow comparison of the ornithological attributes of different zones. At least 29 squares were surveyed in each of the zones and at least 60% of squares were covered in four of them.

A total of 171 bird species was recorded in the CS2000 squares including most of the common breeding bird species found in Britain. Table 5 indicates the number of squares in which each species was noted, in England, Scotland and Wales, and in the three Environmental Zones within each country. Figure 3 shows a strong correlation ($R^2=0.73$) between the number of each species counted on the CS2000 Bird Counts (sum of the highest count across all squares) and the latest British population estimates (Stone *et al.* 1997). Although the data are plotted on a log-log scale in Figure 3, the clear relationship shown indicates that the Countryside Survey sample design and the level of coverage achieved under Module 5 of CS2000 provide a representative sample of terrestrial bird communities across Great Britain. The only species that were significantly under-recorded were some of the colonial nesting seabirds such as Kittiwake and the auks (indicated by diamond symbols in the figure).

As described in section 2.2.2, many of the analyses presented in this report are based on frequency indices, rather than population density estimates. A comparison of density estimates and frequency indices, based on data for all squares covered for Module 5 suggests that the relationship between frequency and population density is indeed very strong (Figure 4). Species that don't conform well to this relationship include colonial nesting species (Shag and House Martin are highlighted examples in Figure 4) and species that are very widespread, often obvious, but present in low densities (Cuckoo is highlighted as an example in Figure 4). This suggests that some species may be under-represented in the relationships between bird assemblages and environmental gradients, presented in section 3.3, while others may be over-represented. However, the effects of the small number of outliers in highlighting the overall influence of environmental variables on the whole bird community will be minimal.

The Countryside Survey sampling strategy is designed to ensure that there are reasonable sample sizes in all Land Classes. This inevitably results in some Land Classes, and, as a result, some Environmental Zones, being over-represented in the sample. This can clearly be seen in Figure 2, where the density of coverage in Environmental Zone 3 is much higher than zones 1 and 2, for example. The results presented in section 3.3 for Great Britain, England, Scotland and Wales are therefore based on data weighted by Environmental Zone, correcting for this unevenness in coverage. The weights were based on the proportion of Great Britain falling into each of the Environmental Zones. The weights applied to the sample are shown in Table 6.

It was not necessary to weight data used in the analysis by Environmental Zone in the same way because coverage within each zone was evenly spread geographically. The analysis for the farmland and woodland indicator species used the Great Britain weights shown in Table 6.

3.2 Species densities

Estimates of the mean density of birds per square kilometre for Great Britain, England, Scotland, Wales and the six Environmental Zones are given in Appendix 2. Note that some species were too scarce to produce density estimates for and so these results are presented for 120 of the 171 bird species recorded during Module 5 fieldwork.

The density estimates are of the number of individual birds and cannot easily be translated into overall breeding population estimates. For some species, especially large obvious species or flocking species, a large proportion of the population within the square may be detected during fieldwork while for other species the counts will be largely based on the number of singing males heard.

Lower and upper confidence limits for the density are presented for each species and group of squares along with the Akaike's Information Criterion (AIC) and Effective Sampling Width for each model. The AIC is a measure of the model fit; a higher value implies a more reliable model (Buckland *et al* 1993). The AICs tend to be small for the density estimates based on a small amount of data, therefore are very low for scarce species, especially in the Environmental Zone models. The Effective Sampling Width provides some measure of species detectability; a higher value implies that the surveyor detects a greater proportion of individuals.

Density estimates are used to indicate the 10 most numerous species in CS2000 squares in each of the six Environmental Zones (Table 7). Chaffinch and Wren were the only species to feature in the top 10 for all six Environmental Zones while Meadow Pipit was the most numerous species in all three zones covering uplands and marginal uplands (3, 5 & 6). Relative abundance curves are an effective way of describing community structure, highlighting whether a particular community is dominated by a few species or whether it is very diverse (James and Rathbun 1981). Cumulative species abundance curves for the six Environmental Zones, based on density estimates, are presented in Figure 5. These show that in Environmental Zones 1 to 5, between seven and nine species make up more than 50% of the bird community and 18 to 20 make up 75% of the community. This contrasts with Environmental Zone 6, the uplands of Scotland, where just three species (Meadow Pipit, Willow Warbler and Chaffinch) make up over 50% of the bird community, and 11 species make up 75% of the community.

Characteristic species were identified for each Environmental Zone based on frequency indices. These characteristic species are listed in Table 8. Species in bold are those deemed to be "highly characteristic" – where frequencies are higher (at 5% level of significance) in that Environmental Zone than elsewhere. The other species listed in the table also have much higher frequencies in that particular zone, although the differences are significant only to the 10% level. Due to the paucity of data for some scarce species, the characteristic species identified in Table 8 are essentially the characteristic common species. The Ptarmigan is, for example, largely restricted to Environmental Zone 6 but statistical tests lack power to identify differences in frequencies for such scarce species.

The characteristic species of Environmental Zones 1 and 2 show a great deal of overlap with the species found in highest densities there, as shown in Table 7. For the other four Environmental Zones however, some less common species are identified as "characteristic", for example Redstart and Curlew in zone 3, Dunlin and Arctic Skua in zone 5 and Ring Ouzel in zone 6. The species identified as characteristic of zones 3, 5 and 6 are generally restricted by habitat (most are upland specialists), or have a small range confined largely to one environmental zone – for example most of the British Arctic Skua population is found in zone 5.

Cluster analysis by Ward's method showed that the bird communities in Environmental Zones 5 and 6 are very similar while those in zones 1 and 2 and in zones 3 and 4 were also alike (Figure 6). Zones 3, 4, 5 and 6 formed a cluster with a semi-partial R-square of 0.21, suggesting that bird communities of environmental zones in upland England and Wales and those in Scotland shared many similarities. Zones 1 and 2, however, showed relatively little similarity with the other four zones, branching at a semi-partial R-square of 0.7.

3.3 Relationships between bird assemblages and environmental gradients

The analyses presented here are intended to explore and summarise some of the broad relationships between bird communities and environmental variables at different spatial scales. Further, more detailed, analyses are highly desirable to quantify these relationships (see discussion).

The percentage of the variance of the species-environment relation explained by each CCA model is shown in Figure 7. These show that the first two Axes generally explain a relatively high proportion the variance, over 50% in the case of the analysis for Great Britain and between 30% and 42% for the country and Environmental Zone divisions. These figures are appreciable given the breadth of species and environmental data incorporated into these models. For abundance or presence-absence data, these percentages are usually quite low, and, an ordination diagram that explains only a low percentage may be quite informative (ter Braak & Šmilauer 1998)

The correlations between the first two Axis of the CCA models and the environmental variables are in Appendix 3. Correlations greater than 0.5 are highlighted in bold. The ordination diagrams can be found in Appendices 4 to 15.

Only the first two ordination Axis are shown on the ordination diagrams for clarity. Axis 1 is the horizontal axis while Axis 2 is the vertical axis. The arrows (vectors) on the ordination diagrams show the ten most important environmental variables. The length of the arrows indicates their strength as predictors of bird assemblages while their proximity to each axis indicates their relationship to each individual axis. Bird species are plotted in ordination space so that their relationship with the axis, and more importantly to the key environmental variables, can be discerned directly from the ordination diagrams. For clarity, the species plots have been divided into 13 plots based on taxonomic groupings. Species recorded in at least ten squares in the respective country or Environmental Zone are annotated with larger symbols and larger font sizes for the species codes. We recommend that the relationships shown for species with small sample series (see Table 5) are treated with caution. Relationships for species with small sample sizes will be less reliable than those for more widespread species – sample sizes for each division can be found in Table 5.

Summaries of the main features of the CCA models for Great Britain, each of the three constituent countries, the six Environmental Zones and the farmland and woodland indicator species are given below. The CCA analyses effectively present an overview of relationships between each bird species and the main environmental variables. We do not describe relationships for each species or group individually because they can be assessed from the diagrams themselves.

(a) Great Britain (see Appendix 4)

The dominating effects of climate, altitude, latitude and longitude on bird communities in Great Britain are clearly seen in the CCA models. Of the 10 most significant environmental variables in the CCA model for Britain, six are invariants and of the four of the broad habitats displayed on the ordination diagram, the distributions of three (arable, shrub heath and bog) are heavily influenced by climate and altitude etc. The area of conifer woodland is an exception to this pattern, due largely to the afforestation with conifers of areas that would probably be naturally covered by deciduous woodland.

Axis 1 of the CCA model accounted for 36% of the variation in bird community structure across all 336 squares surveyed for Module 5. This Axis is essentially a reflection of the cline from northern/upland landscapes to southern/lowland landscapes, being most strongly correlated with geographic features such as northing and altitude and habitats such as shrub heath and bog. Axis 2 explains a further 15% of bird community variation and is a gradient from well wooded country to open areas.

The ordination diagrams show that upland species are clustered to the right of Axis 2 and above Axis 1 while seabirds were also to the right of Axis 2 but below Axis 1. The gradient along Axis 2

from birds of open farmland to the woodland specialists is particularly apparent in Appendix 4.14 with Corn Bunting at one end of this gradient and arboreal species such as the crossbills and Siskin at the other end.

(b) England (see Appendix 5)

Axis 1, which explains 22% of the variation in bird communities is positively correlated with altitude and associated upland habitats such as acid grassland, shrub heath and bogs. Axis 2 explains only 12% of the variation and is more a reflection of a cline from open habitats typical of coastal areas, such as sea, seashore (littoral rock) and arable land, to well wooded inland areas (broad-leaved woodland, conifer woodland). The species plots therefore show seabirds, coastal waders and many freshwater species clustered above and to the right of origin, woodland species below and left of the origin, and upland species close to Axis 1 to the right of origin.

(c) Scotland (see Appendix 6)

Twenty-five percent of variation in bird communities in Scotland is explained by Axis 1. This axis is most strongly correlated with northing and the typical habitats of northern Scotland, namely bog, shrub heath and montane habitats. Axis 2 explains a further 16% of variance and is negatively associated with altitude and area of conifer plantation while it is positively associated with habitat features typical of the lowland such as the lengths of all boundary features, area of arable and area of improved grassland.

Both upland and coastal species are clustered to the right of the ordination diagrams, along Axis 1, reflecting their greater abundance in the north of Scotland. Woodland species are clustered to the left of the ordination diagram, below the origin while farmland species are strongly clustered above and to the left of the origin. Separation of the finches and buntings (Appendix 6.14) into farmland and woodland species is particularly marked.

(d) Wales (see Appendix 7)

Axis 1 explained only slightly more variance (17%) than Axis 2 (14%) but the two axis appear to represent different gradients in environmental variation. The first axis is associated with a cline from coastal to inland squares, being positively associated with coastal habitats, a more maritime climate and negatively associated with easting. Axis 2 on the other hand is very strongly correlated with altitude and is therefore also strongly associated with altitudinal dependent habitats.

The ordination diagrams show upland species above and to the right of the origin, coastal species clustered below and to the right of the origin, farmland species below the origin and woodland species above and left of the origin.

(e) Environmental Zone One (see Appendix 8)

The CCA for Environmental Zone one was the least good of all models in terms of the amount of variation it explained. This may be because there is less environmental heterogeneity in this zone than in the others. The first axis explained 23% of variation while the second axis explained a further 11%. The first is positively related to arable land and coastal habitats and negatively correlated to broad-leaved woodland, altitude, urban areas and the length of boundary features. As all of this Environmental Zone is at relatively low altitudes, it appears that this axis reflects a cline from the most intensively farmed lowland, typical of flat areas of eastern England, to the more well wooded and undulating landscapes typical of inland areas of lowland England. Axis 2 is positively associated with northing, altitude, fen, marsh & swamp, and length of walls, while it is negatively associated with hedges and area of arable. This axis would appear to be correlated with features that reflect variations in lowland farmland between the south and the north of England.

Woodland species appear above and left of the origin in the ordination diagrams with conifer specialists closer to Axis 2 and broadleaved specialists closer to Axis 1. Farmland species are

scattered to the right of origin along Axis 1 while seabirds and other water birds are scattered to the right of origin above Axis 1.

(f) Environmental Zone Two (see Appendix 9)

The first axis in the CCA models accounts for 24% of the variance and is most strongly correlated with littoral rock, sea, bog, fen marsh & swamp, and is negatively correlated with broadleaved woodland, length of hedges and urban areas. As is the case for Environmental Zone One, this axis appears to reflect a cline from the most intensively farmed lowland, typical of coastal regions, to the more well wooded and undulating landscapes typical of inland areas of lowland England. Axis 2 accounts for a further 12% of the variance and is most positively correlated with easting, northing and area of woodland and negatively correlated with mean January temperature, sunshine hours, supralittoral rocks & sediment, and sea; suggesting that it represents a cline from coastal areas with a more oceanic climate in the southwest to the more well wooded pastoral landscapes in the north of England.

(g) Environmental Zone Three (see Appendix 10)

The CCA model for Environmental Zone Three explains a much higher proportion of the variation in bird communities than is the case with the other two English and Welsh Environmental Zones, with Axis 1 explaining 29% of the variance and Axis 2 explaining a further 12%. Axis 1 represents altitudinal changes in habitats and land use, being positively correlated with altitude and upland habitats such as acid grassland, shrub heath and bogs while negatively correlated with area of improved grassland and the lengths of boundaries and linear features. Axis 2 is a geographic location/climate axis, with strong correlations with temperature and sunshine and negative correlations with easting and northing, thereby identifying differences in the bird community structure between the uplands of Wales and the southwest of England and those in northern England. Upland species are, therefore, clustered towards the top right of the ordination diagrams, woodland species above and left of origin and farmland species left of origin.

(h) Environmental Zone Four (see Appendix 11)

Axis 1 explains 22% of variation in bird communities while Axis 2 explains 11%. The first axis is most strongly associated with length of grassy banks/strips, area of open habitats such as fen, marsh & swamp and bog and climate variables that represent a milder climate while is negatively correlated with easting, lengths of boundaries and area of woodland. The second axis is strongly correlated with altitude and associated habitats. In the ordination diagrams, woodland species tend to be above and left of origin, farmland species below and left of origin and upland and coastal species to the right of origin.

(i) Environmental Zone Five (see Appendix 12)

The CCA model for Environmental Zone Five explains much of the variation in bird communities with the first axis explaining 20% of the variance and second axis explaining a further 10%. The first axis represents the cline from well-vegetated inland areas to the more sparsely vegetated islands. Axis 2 reflects a gradient from farmland, typical of the valley bottoms, to the more well wooded areas at higher altitudes – typical of low lying hillsides. Seabirds and other waterbirds are clustered to the right of origin, upland species above and to the right of origin, woodland species to the left of origin and farmland species below and left of origin.

(j) Environmental Zone Six (see Appendix 13)

This proved to be the best model for the three Scottish Environmental Zones in terms of variation explained with Axis 1 explaining 29% of variation and Axis 2 a further 10%. Axis 1 is strongly correlated with altitude and a gradient between the most open and sparsely vegetated landscapes to the most well wooded while Axis 2, which is also correlated with altitude, appears to be more strongly associated with an altitudinal gradient in vegetation and land use.

In the ordination diagrams for Environmental Zone Six we find upland species above and right of the origin, woodland species left of the origin farmland species below the origin.

(k) Farmland Indicator Species (see Appendix 14)

Axis one is positively associated with area of bog; fen, marsh & swamp; acid grassland; and shrub heath and negatively associated with human sites; improved grassland; broadleaved woodland; and hedge and tree lines. This reflects a gradient from species that are often associated with semi-natural habitats, such as extensively managed grassland (Skylark & Lapwing) and wet areas (Reed Bunting) to species that are found their highest numbers in well wooded farmland, especially around areas of human habitation (Greenfinch, Goldfinch, Woodpigeon) or species that feed extensively on improved grassland (Rook and Jackdaw). Axis 2 is positively associated with grassland habitat and human habitation and strongly negatively associated with the area of arable, suggesting a gradient between pastoral and arable farming. Species whose distribution is closely tied to arable areas, such as Yellow Wagtail, Grey Partridge and Corn Bunting can be found towards the bottom of the ordination diagrams.

It is interesting to note that all these “arable specialists” are species that have shown population declines in recent decades. This may point to fundamental changes in arable farming methods, but possibly also to the loss of extensively managed grassland within arable areas. The species that have shown an increase in numbers since 1973 tend to be those associated most strongly with non-farmed habitats (human settlement or broadleaved woodland).

(l) Woodland Indicator Species (see Appendix 15)

Axis one is positively correlated with area of conifer woodland and area of shrub heath and is negatively associated with hedges and human sites. This is a clinal gradient, strongly reflecting changes in habitats from lowland to upland upland areas and from the south to the north of Britain. Species that are most abundant in southern Britain and the lowlands, such as Nightingale and Lesser Whitethroat are therefore found towards the left of the ordination diagram while upland and northern species, such as Tree Pipit, Siskin, Redpoll and Crossbill, are found to the right. Axis 2 is a gradient from more open habitats such as arable, fen, marsh & swamp through to broadleaved woodland. Scrub and open woodland species are found towards the top of the ordination diagram while broadleaved woodland specialists are found towards the bottom.

Unlike the ordination diagram for farmland indicator species, there are no clear patterns of association between individual species population trends and their location within the woodland indicator ordination diagram. It should be noted, however, that some of the woodland indicator species are in fact found largely outside of woodland. Nightingale and Lesser Whitethroat for

example are found largely in scrub in farmland while Tree Pipit is found mainly in open woodland, scrub and young plantations.

3.4 Validity of Avifaunal Zones

The clustering of Land Classes into Avifaunal Zones suggests that there are between five and eight clusters of Land Classes in terms of their bird assemblages (Figure 8). To ensure reasonable sample sizes in each Avifaunal Zone and to make more straightforward comparisons with Environmental Zones, it was decided that six Avifaunal Zones was the optimal number. The distribution of squares in each of these six proposed zones can be found in Figure 9. Note that this analysis is based on a clustering of Land Classes rather than individual squares and sample sizes for some Land Classes are rather small. These zones do show many similarities with Environmental Zones, especially in that they appear to be based largely on a cline in altitude and northing. The main difference between Environmental and these suggested Avifaunal Zones is that the latter cross country boundaries, whereas the former are specific to either England and Wales, or to Scotland.

The general characteristics of the Avifaunal Zones area as follows:

- Avifaunal Zone 1: generally in low-lying, but often undulating areas of England.
- Avifaunal Zone 2: includes many of the lowland coastal Land Classes along with flat, intensively farmed lowland, such as The Fens, Vale of York and Cheshire Plain. It could also be treated as three separate clusters: 2a, representing flat, intensively farmed lowlands; 2b, representing the intensively farmed midland plains; and 2c, representing coastal areas with lowlands to landward.
- Avifaunal Zone 3: represents the marginal uplands of southern Britain: Dartmoor, Exmoor, extensive parts of Wales, the southern Pennines, North York Moors and coastal areas of the Lake District and southwest Scotland.
- Avifaunal Zone 4: could potentially be grouped together with Zone 3. This includes steeper upland areas of England and Wales, together with low-lying hills of Scotland, typically, farmed or afforested. Interestingly, much of the eastern Scottish foothills and lowlands are included.
- Avifaunal Zone 5: this zones groups the genuine upland areas of Wales and the southern Pennines with the marginal uplands of Scotland, including most of the Scottish islands.
- Avifaunal Zone 6: genuine upland areas of Scotland.

The percentage of variance of the species-environment relation explained by the CCA models for the six Avifaunal Zones are presented in Figure 10. The mean percentage variance explained by the first two Axes is 37.6% compared with 35.6% in the models derived for the Environmental Zones.

3.5 Key Environmental Variables not measured adequately by the BTO/JNCC/RSPB Breeding Bird Survey

Most of the environmental variables found to be significant in determining bird communities are already recorded systematically for the BTO/JNCC/RSPB Breeding Bird Survey. One possible exception is the length of linear features, such as hedgerows, dykes, walls and roads, which may be inadequately recorded by the BBS. The reason for this is that the BBS habitat recording is based on presence or absence of particular habitats within each transect section. As a result of this, the BBS habitat recording method may give little indication of the density of linear features within a given square.

4. DISCUSSION

Data quality and repeatability

This report provides a descriptive analysis of the bird data collected under Module 5 of Countryside Survey 2000. The sample of 336 squares provides a sound basis for the long term monitoring of bird populations in relation to environmental change as a part of the Countryside Survey. The broad approach and methods are regarded as highly robust. Virtually all of the common terrestrial bird species found in Great Britain were represented in the Module 5 sample and a high proportion of them were found in a large number of squares. The species covered were found to represent the overall bird community of Great Britain very well, with obvious exceptions, such as under-recording of colonial seabirds.

The exercise could be readily repeated as part of any future Countryside Survey, particularly as all the transect routes were mapped. Repeating the bird counts alongside the Field Survey in future Countryside Surveys would enable changes in bird numbers to be related to changes in land cover and habitat quality as measured by the Field Survey. This would generate a more detailed understanding about how change in the countryside affects bird numbers than could be obtained from the annual BBS monitoring alone. Indeed, repeating bird counts as an integral part of the Countryside Survey would probably substantially aid the interpretation of the population trends as measured by BBS.

It is also recommended that careful consideration be given to how the Countryside Survey data could be more effectively integrated with the nationwide atlases of breeding and winter bird distribution that are periodically compiled by the British Trust for Ornithology. Atlases are undertaken at approximately 20 year intervals and it is likely that the next will take place towards the end of the current decade. In particular, there may be opportunities for a range of informative analyses that aim to use Land Cover Map data to explain large-scale patterns in bird distribution.

Bird community differences between Environmental Zones

Density estimates are used to show the main species in each of the six Environmental Zones and to highlight some of the differences between these zones. For example, the bird assemblage in Environmental Zone 6 is shown to be less diverse than in any of the other zones, with over 50% of the community comprised of just three species. The similarities in bird assemblages between the two zones of lowland England and Wales and between the marginal uplands and uplands of Scotland were perhaps to be expected. However, the fact that zones 3 and 4 are more similar to each other than either the zones in the same countries, or the zones representing the same general altitudinal ranges is interesting. This may partly reflect the fact that the distributions of many bird species in Britain are influenced by climatic conditions and are therefore linked to clinal changes in both altitude and latitude. Meadow Pipit and Willow Warbler, for example, are very numerous in Environmental Zones 3 and 4 but much less common in zones 1 and 2. Land use changes may have influenced and exaggerated these patterns. The Lapwing, for example, has disappeared from large areas of lowland England and Wales due to agricultural intensification, but is still relatively numerous in the marginal uplands of England and Wales and in the lowlands of Scotland (Wilson *et al.* 2001).

Avifaunal Zones

Unlike the Environmental Zones, the Avifaunal Zones are not constrained by political boundaries. Therefore, the Avifaunal Zones derived from the Land Classes may have distinct advantages over Environmental Zones for some purposes. It should be noted, however, that the difference between the variance of the species-environment relation explained by the CCA models for Avifaunal Zones when compared with Environmental Zones is trivial and it could be argued that the CCA models for Environmental Zones are just as informative as those for Avifaunal Zones. Furthermore, the derivation of the Avifaunal Zones based solely on Module 5 bird data may not be ideal as sample

sizes in some of the Land Classes are rather small. An additional point to be considered is that Avifaunal Zones will not necessarily be stable over a given period of time because the composition of bird communities may change due to many factors whereas Environmental Zones will be more stable. In this context, it would be interesting to assess whether climate change has an impact on the location and extent of Avifaunal Zones.

We consider that it would be desirable to explore the concept of avifaunal zones further, possibly using independent datasets, such as the *New Atlas of Breeding Birds* (Gibbons *et al.* 1993) and the BTO/JNCC/RSPB Breeding Bird Survey. We are unaware of any previous attempt to produce a complete ornithological zonation for Britain, though this has been attempted for upland birds (Stillman & Brown 1998) and birds have been integrated with other taxa to produce a biological zonation for Scotland (Carey *et al.* 1995). The advantages of developing a zonation of Britain for birds is that it could provide a regional framework for the development of bird conservation strategies. Avifaunal Zones could form a logical framework for analyses of relationships between land-use and bird assemblages.

Gradients in British bird assemblages in relation to environmental variation

This report provides a preliminary analysis, using CCA, of major gradients in British breeding bird communities in relation to major patterns in environmental variation. The CCA ordination diagrams clearly show that invariants (i.e. climate, altitude, longitude and latitude) are main influences on bird assemblages in Great Britain as a whole. However, when the data are analysed for country or environmental zone divisions, the reduced variation in the environmental invariants in these areas allows the effects of other factors, such as broad habitats, to be seen more clearly. Of these, it is perhaps not surprising that the dominant land uses, such as areas of arable, human settlement or broadleaved woodland, are frequently picked out by the CCA analyses as being among the most important features. The CCA diagrams for the Environmental Zones in particular highlight the broad habitats which have a large influence on bird assemblages, and it is at this scale that they are perhaps the most informative.

An important point that emerges from the analyses is that the relationships between bird assemblages and environmental variables differ considerably between Environmental Zones. One would anticipate that similar variation would exist between Avifaunal Zones. The extent of human settlement is, for example, very important in Environmental Zones 1 and 2 while in Environmental Zones 3 and 5, the area of improved grassland is an important factor. This suggests that changes in landuse, either in a very obvious way such as urban sprawl, or the more subtle changes brought about by intensification of grassland management, will have a large effect on the composition of bird assemblages.

The relationships between bird assemblages and environmental variables were scale-dependent as well as region-specific. There were major differences between the models created at the British, country and Environmental Zone scales. Whilst there is a need to understand how shifts in land-use may affect bird assemblages at both national and regional scales, a major conclusion is that future modelling of the effects of land-use change on birds (see below) should be conducted within a regional framework. This conclusion is reinforced by recent work on farmland bird populations which has demonstrated that species may show contrasting patterns of change in abundance and distribution in different regions (Chamberlain & Fuller 2001).

We have not discussed the relationships between individual species and environmental variables in any depth because a huge number of species-environment relationships are summarised within the ordination diagrams in Appendices 4 to 15. Those who are interested in particular species can use the individual diagrams at the appropriate scale to assess their broad relationships with environmental variables. The ordination diagram for the 20 farmland indicator species is perhaps the most informative of all the CCA analyses. By removing the environmental invariants from this model, we get a picture of which land use changes may have affected farmland birds in recent decades. This model shows a distinct clustering of the species that have not decreased since the early 1970s – species associated either with non-farmland habitats (woodland and human settlement)

or with improved grassland. The ordination diagram for woodland does not show such clear patterns, possibly because there are only two woodland broad habitats whereas there are several for farmland. Another relevant factor is that the probable causes of decline among woodland birds are more diverse than those among farmland birds (Vanhinsbergh *et al.* 2001). Nevertheless, many of the woodland species are widely distributed in hedgerow as well as woodland habitats (Fuller *et al.* 2001).

Future work based on Module 5 data

The Module 5 bird count data were gathered in a way that will make it adaptable to a range of analyses. The analyses presented in this report are all based on measures of abundance or frequency at the 1-km square scale or aggregations of 1-km squares. The strength of this approach is in providing information about the macrohabitat relationships of birds and, in particular, about how landscape composition (i.e. its make-up in terms of relative extent of different broad habitats) affects the relative abundance of birds and consequently the overall composition of bird communities. These data can be used to extend existing knowledge about how the broad composition of landscapes affects the composition of bird communities – this is a pre-requisite for understanding how future shifts in land-use are likely to affect bird communities.

The strength of the Module 5 data lies in understanding how large-scale pattern in the landscape affects bird communities. It should be recognised that the Module 5 data are of relatively little utility in seeking to understand the micro-habitat relationships of birds (for example how the foliage profile or quantity of dead wood affects abundance of woodland birds, or how crop height affects abundance of Skylarks). The data are also not appropriate for examining effects of most forms of habitat management on bird communities (e.g. effects of woodland harvesting systems, pesticide and fertiliser treatments on farmland). In general, much finer scale and targeted data, derived from experimental as well as observational approaches, are needed for understanding habitat management. Nonetheless, future analyses of Module 5 data could make much use of the finer level of detail available from the individual 200 metre transect sections. This allows a flexible approach to analytical methods and it is encouraging to note that the two treatments of the bird counts used in these preliminary analyses (densities and frequency indices) correspond well. Use of the individual transect section data would provide a level of bird-habitat modelling that was intermediate between landscape composition modelling and microhabitat modelling.

As far as we are aware, studies of landscape composition have been carried out only for lowland agricultural landscapes in Britain (Fuller *et al.* 1997, Gates & Donald 2000) but the Module 5 data have the potential to extend to all landscapes. It may also be possible to integrate information from CS2000 on broad habitat composition of landscapes with specific agricultural data such as that used in studies of spatial and temporal relationships of birds and agriculture (Gates *et al.* 1994, Chamberlain *et al.* 2000, Chamberlain & Fuller 2000, 2001, Siriwardena *et al.* 2001). Much of this previous work has been funded by DEFRA (formerly MAFF) and it has been valuable in identifying specific components of agricultural land-use linked with farmland bird declines. It has also tended to focus on explaining the declines of the 1970s and 1980s rather than taking a strategic view of how future changes in land-use may affect birds in farmed environments. The data from Module 5 could be used to create more powerful integrated models for predicting the implications of broad changes in land-use in combination with finer-scale changes in farm management practices. However, a strength of Module 5 is that the data are not restricted to lowland farmland, which is where much of the previous research has focused. Potentially, the data could be used to address a range of broad strategic land-use issues in both the lowlands and uplands. Some examples are given below. The Land Cover Map 2000 has an important role to play in any future modelling of this kind because it can be used to assess the landscape context within which the Module 5 data are positioned.

The Module 5 data could be used to gain insights to the broad changes in bird populations that might arise from various shifts in land-use or habitat creation initiatives. A wide range of policy issues and questions could be addressed at a strategic level. Models derived from the data could be applied to specific scenarios of land-use change as defined by policy specialists. Some of these

scenarios might relate to widely dispersed changes in the nature of the countryside, others might be more localised. The efficacy of the data for specific issues will depend to some extent on the sample sizes of appropriate squares that are available but, in principle, the potential applications are numerous. In some cases there may be opportunities for integrating insights gained from analysis of the Module 5 data with results from more intensive research. An example would be the effects of hedgerow creation where a considerable body of published information exists on relationships between bird densities and hedgerow type (see references in Fuller *et al.* 2001). Examination of broad shifts in land-use would be especially timely in view of the ongoing debate concerning the European Union's Common Agricultural Policy and, more specifically, the future shape of British agriculture following the current outbreak of Foot and Mouth Disease. Diverse examples of policy applications are outlined below.

- The integration of larger quantities of semi-natural habitat (e.g. hedgerows and small broad-leaved woods) into the British countryside as a means of buffering ecological impacts of agriculture. In particular, the relative effects of hedgerow and woodland creation could be explored. The alteration of patch and habitat diversity could be considered at different scales. An alternative scenario would be the creation of large areas of semi-natural habitat in certain regions at the expense of increasing production in other regions.
- Changes in the ratio of livestock to arable farming in different regions of Britain. Examination of the implications of a reduction in the amount of grazing in the marginal uplands would be especially interesting, possibly linked with expansion of scrub and woodland in these areas.
- Shifts in agriculture induced by climate change; the REGIS project (Loveland *et al.* 2000) offers relevant scenarios. The REGIS project aims to assess the impacts of future climate change on the agriculture, biodiversity, hydrology and coasts of East Anglia and the North West of England. The impacts will be explored for three future time periods: 2020, 2050 and 2080.
- The creation of large areas of semi-natural woodland in parts of lowland Britain and the expansion of broadleaved and coniferous woodland in different upland regions of Britain through planting and / or natural regeneration.

In summary, we suggest that the following avenues are considered for future development of the CS2000 Module 5 data. These approaches should result in the development of valuable tools for undertaking predictive policy-related work.

- a. Landscape composition models should be generated for breeding birds at spatial scales ranging from Great Britain to the regional scale. This could include the development of new Avifaunal Zones as one of the regional templates for the modelling.
- b. These models should be based on data derived both from the 1-km squares and 200 m transect sections. These would be complementary in terms of the information they provide. A variety of predictive modelling approaches would probably be employed: these might include regression, neural network and probabilistic methods.
- c. The models should incorporate CS2000 Land Cover Map data as well as the CS2000 Field Survey data. The possibility of incorporating data from the Vegetation Plots within 1-km squares into the models should be explored.

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Table 1. Characteristics of 1990 Land Classes

Land Class (1990)	Characteristics
1	Undulating country; varied agriculture; mainly grassland
2	Open gentle slopes; varied agriculture; often wooded or built-up
3	Flat arable land; mainly cereals; little native vegetation
4	Flat; intensive agriculture; otherwise mainly built-up
5	Lowland somewhat enclosed land; varied agriculture and vegetation
6	Gently rolling enclosed country; mainly fertile pastures
7	Coastal, with varied morphology and vegetation
8	Coastal, often estuarine; mainly pasture, otherwise built-up
9	Fairly flat; open intensive agriculture, often built-up
10	Flat plains with intensive farming, often arable/grass mixtures
11	Rich alluvial plains; mainly pen with arable, leys or built-up
12	Very fertile coastal plains with productive crops
13	Somewhat variable land forms; heterogeneous land use including urban
14	Level coastal plains with arable, otherwise often urbanized
15	Valley bottom with mixed agriculture, predominantly pastoral
16	Undulating lowlands, variable agriculture and native vegetation
17	Rounded intermediate slopes, mainly improvable permanent pasture
18	Rounded hills, some steeper slopes; varied moorlands
19	Smooth hills, mainly heather moors; often afforested
20	Midvalley slopes; wide range of vegetation types
21	Upper valley, rocky outcrops and bogs
22	Margins of high mountains, moorlands; often afforested
23	High mountain summits, with well drained moorlands
24	Upper steep mountain slopes, usually bog covered
25	Lowland with variable land use, mainly arable
26	Fertile lowlands with intensive agriculture
27	Fertile lowland margins with mixed agriculture
28	Varied lowland margins with heterogeneous land use
29	Sheltered coasts with varied land use, often crofting
30	Exposed coasts dominated by bogs
31	Cold exposed coasts with variable landuse and crofting
32	Windswept low hills covered with bogs

Table 2. Composition of the Environmental Zones by 1990 and 1998 Land Classes

1990 Land Class in Great Britain	England and Wales		Scotland	
	1998 Land Class	1998 Environmental Zone	1998 Land Class	1998 Environmental Zone
1	1e	2	n/a	n/a
2	2e	1	n/a	n/a
3	3e	1	n/a	n/a
4	4e	1	n/a	n/a
5	5e	2	7s	4
6	6e	2	7s	4
7	7e	2	7s	4
8	8e	2	7s	4
9	9e	1	25s	4
10	10e	2	13s	4
11	11e	1	n/a	n/a
12	12e	1	25s	4
13	13e	2	13s	4
14	7e	2	7s	4
15	15e	2	13s	4
16	16e	2	27s	4
17	17e*	3	18s	5
18	18e	3	18s	5
19	19e	3	19s	5
20	19e	3	19s	5
21	22e	3	21s	6
22	22e	3	22s	6
23	23e	3	23s	6
24	23e	3	24s	6
25	25e	1	25s	4
26	25e	1	26s	4
27	16e	2	27s	4
28	19e	3	28s	5
29	n/a	n/a	29s	5
30	n/a	n/a	30s	5
31	n/a	n/a	31s	5
32	n/a	n/a	32s	5

* Land Classes 17w1, 17w2 & 17w3 in Wales

Table 3. CS2000 variables used in Module 5 analysis

Environmental variable	Definition
easting	Great Britain national grid
northing	Great Britain national grid
altitude	mean for square in metres
mean sunshine hours	hours per day
mean January temperature	°C
snow days	mean number of days annually
mean annual temperature	°C
broadleaved, mixed and yew woodland	wooded or scrubby areas with canopy cover >20% and at least 20% of tree cover is deciduous or mixed
conifer woodland	wooded or scrubby areas with canopy cover >20% and at least 80% of tree cover is coniferous
linear features	hedgerows, lines of trees, walls, banks, ditches, road, tracks and railways
arable	includes horticulture, fallow, set-aside and annual grass leys
improved grassland	typically used for grazing and silage, often intensively managed less fertile and contain a wider range of plants species than improved grassland
neutral grassland	
calcareous grassland	dominated by grasses and herbs, on well-drained alkaline soils
acid grassland	dominated by grasses and herbs, on acid soils
bracken	stands greater than 0.25 hectares in extent dominated by >95% canopy cover of bracken
shrub heath	>25% cover of plants from the heath family or dwarf gorse species
fen, marsh & swamp	ground that is permanently, seasonally or periodically waterlogged, including fens, flushes, rush pastures, swamps and reedbeds
bog	wetlands that support vegetation that is usually peat-forming
open water	all standing freshwater, including man-made water bodies
rivers and streams	includes the channel that may support water fringe vegetation
montane habitats	vegetation that occur exclusively above the former natural tree-line on mountains
inland rock	both natural and artificial exposed rock, including excavations and quarries
human sites	urban and rural settlements, farm buildings, caravan parks, urban parkland and urban transport infrastructure
supralittoral rock	coastal rock above the high tide-line
supralittoral sediment	coastal sediments above the high tide-line
littoral rock	coastal rocks exposed by the tide
littoral sediment	coastal sediments exposed by the tide
sea	including estuaries and sea lochs
bank/grassy strip	total length in metres
fences	total length in metres
hedges	total length in metres
line of trees, shrubs and relict hedge	total length in metres
line of trees, shrubs and relict hedge and fence	total length in metres
remnant hedge	total length in metres
walls	total length in metres
Shannon H diversity index	measure of patch diversity. Shannon $H = -\sum P_i \ln P_i$, where P_i is the proportion of the square under habitat i

Table 4. Coverage of CS2000 squares for Module 5 by Environmental Zone

Environmental Zone	Squares surveyed (number surveyed twice in brackets)	Percentage of available squares covered	Transect length surveyed at least once (km)	Transect length surveyed twice (km)	Average visit date & standard deviation
EZ1	56 (53)	41	204.8	192.4	24 th May (s.d.=23 days)
EZ2	93 (84)	62	326.8	300.6	25 th May (s.d.=22 days)
EZ3	64 (39)	70	241.8	150.0	30 th May (s.d.=21 days)
EZ4	29 (16)	52	99.2	55.8	26 th May (s.d.=24 days)
EZ5	50 (13)	68	160.4	40.4	1 st June (s.d.=20 days)
EZ6	44 (20)	68	147.2	56.8	28 th May (s.d.=24 days)
All	336 (225)	60	1180.2	796.0	27 th May (s.d.=22 days)

Table 5. Number of squares in which each bird species was recorded in each Environmental Zone in CS2000 squares covered as part of Module 5.

Species	England				Scotland				Wales				Grand Total
	EZ1	EZ2	EZ3	Total	EZ4	EZ5	EZ6	Total	EZ1	EZ2	EZ3	Total	
Red-throated Diver						3		3					3
Black-throated Diver							1	1					1
Little Grebe	7	2		9	1			1			1	1	11
Great Crested Grebe	4	1		5									5
Fulmar		3		3	1	1		2					5
Cormorant	4	6	1	11	1	1		2		1		1	14
Shag		2		2	1	4		5					7
Grey Heron	16	12	5	33	5	8		13	1	8	1	10	56
Little Egret		1		1									1
Mute Swan	14	2		16	1			1		3		3	20
Whooper Swan					1			1					1
Pink-footed Goose					1			1					1
Greylag Goose	1	1	1	3	2	1	1	4		2		2	9
Canada Goose	15	9	6	30						6	2	8	38
Shelduck	4	3		7	1			1		7		7	15
Mandarin		1		1									1
Wigeon						1	1	2					2
Teal	1			1	2	4		6		2	1	3	10
Mallard	34	40	15	89	15	12	3	30	1	12	7	20	139
Shoveler	2			2									2
Tufted Duck	9	5		14	1	2		3			1	1	18
Eider					4	2		6					6
Goldeneye						1		1					1
Red-breasted Merganser						4	1	5					5
Goosander			1	1		2		2		2	1	3	6
Ruddy Duck	1	1		2									2
Red Kite	4			4	1		2	3		3	1	4	11
Hen Harrier						1	1	2					2
Montagu's Harrier			1	1									1
Goshawk	1	2		3							1	1	4
Sparrowhawk	21	15	1	37	5		3	8		2		2	47
Buzzard	18	33	16	67	22	18	10	50	2	11	18	31	148
Golden Eagle						1		1					1
Kestrel	28	21	13	62	11	3	9	23		3	5	8	93
Hobby		1	3	4			2	2			3	3	9
Merlin	3	1		4						1		1	5
Peregrine		6		6		1	2	3		1	1	2	11
Willow/Red Grouse			15	15	1	7	18	26					41
Ptarmigan							1	1					1
Red-legged Partridge	27	16	4	47	7			7					54
Grey Partridge	16	4	3	23	6			6					29
Pheasant	52	53	27	132	23	7	4	34		8	7	15	181
Water Rail		1		1									1
Corncrake					1			1					1
Moorhen	27	24	4	55	3			3		6		6	64
Coot	13	9		22						3	1	4	26

Species	England				Scotland				Wales				Grand Total
	EZ1	EZ2	EZ3	Total	EZ4	EZ5	EZ6	Total	EZ1	EZ2	EZ3	Total	
Ringed Plover		1		1		7		7		1		1	9
Dotterel							1	1					1
Golden Plover		2	7	9		9	6	15					24
Grey Plover										1		1	1
Lapwing	24	21	22	67	15	7	4	26	1	8	2	11	104
Sanderling										1		1	1
Dunlin						9		9		1		1	10
Snipe	3	3	16	22	6	9	7	22		1		1	45
Woodcock	1		1	2			1	1					3
Bar-tailed Godwit	1			1						1		1	2
Whimbrel	1	1		2		4		4		2		2	8
Curlew	7	19	30	56	9	15	12	36	2	4	2	8	100
Redshank	2	3	3	8	3	4		7		4	1	5	20
Greenshank						4	2	6		1		1	7
Green Sandpiper										1		1	1
Common Sandpiper	3	2	2	7	4	14	7	25	2	1		3	35
Arctic Skua						6		6					6
Great Skua						4		4					4
Black-headed Gull	8	13	12	33	4	1	2	7		4		4	44
Common Gull	3		2	5	5	11	4	20					25
Lesser Black-backed Gull	6	6	5	17	5	6		11		5	1	6	34
Herring Gull	2	15	2	19	9	19		28		10		10	57
Great Black-backed Gull	2	1		3	6	9		15					18
Kittiwake						1		1					1
Sandwich Tern		2		2									2
Common Tern	1	1		2		1		1					3
Arctic Tern						5		5					5
Guillemot		1		1									1
Black Guillemot					1			1					1
Puffin		2		2									2
Feral Pigeon	11	19	2	32	10	2		12		4	1	5	49
Rock Dove			1	1	5	5		10					11
Stock Dove	36	27	10	73	6	1		7			4	4	84
Woodpigeon	56	61	28	145	33	14	10	57	2	18	17	37	239
Collared Dove	32	44	8	84	9	2	1	12		11	3	14	110
Turtle Dove	12	3	1	16					1			1	17
Ring-necked Parakeet						1		1					1
Cuckoo	31	18	11	60	5	15	12	32		5	11	16	108
Barn Owl	2			2		1		1					3
Little Owl	11	8	2	21						3		3	24
Tawny Owl	6	3	2	11	2			2			2	2	15
Long-eared Owl	1			1									1
Short-eared Owl		1		1									1
Swift	25	26	10	61	7	1	2	10		9	8	17	88
Kingfisher	3	3		6	1			1					7
Green Woodpecker	36	21	2	59	1		2	3		6	5	11	73
Great Spotted Woodpecker	35	32	6	73	4	4	2	10	1	3	6	10	93
Lesser Spotted Woodpecker	3			3							1	1	4
Woodlark	1			1									1
Skylark	47	50	29	126	30	32	16	78	2	14	17	33	237

Table 5 Continued

Species	England				Scotland				Wales				Grand Total
	EZ 1	EZ 2	EZ 3	Total	EZ 4	EZ 5	EZ 6	Total	EZ 1	EZ 2	EZ 3	Total	
Sand Martin	5	8	3	16	10	6	3	19			1	1	36
Swallow	46	57	32	135	32	20	12	64	2	16	18	36	235
House Martin	22	31	7	60	12	4	3	19	2	7	7	16	95
Tree Pipit	6	3	8	17	3	11	11	25		6	10	16	58
Meadow Pipit	18	30	34	82	25	41	44	110		16	19	35	227
Rock Pipit		3		3	1	10		11		3		3	17
Yellow Wagtail	20	9		29									29
Grey Wagtail	10	7	6	23	5	7	4	16		4	5	9	48
Pied Wagtail	39	46	29	114	30	17	8	55	1	17	16	34	203
Dipper	3	2	4	9	1	3	2	6		1	3	4	19
Wren	56	64	37	157	32	32	28	92	1	21	24	46	295
Duncock	46	61	18	125	26	15	8	49	1	16	14	31	205
Robin	54	62	31	147	31	24	23	78	2	19	24	45	270
Nightingale	6			6									6
Bluethroat	1			1									1
Black Redstart		1		1									1
Redstart	6	5	10	21	1	3	1	5		4	12	16	42
Whinchat		2	8	10	1	10	12	23		2	8	10	43
Stonechat	3	7	7	17	5	14	12	31		9	6	15	63
Wheatear	6	7	16	29	6	18	21	45		5	12	17	91
Ring Ouzel			4	4			9	9			1	1	14
Blackbird	56	64	28	148	31	25	12	68	2	22	22	46	262
Fieldfare		1	1	2			1	1					3
Song Thrush	49	54	21	124	28	23	19	70	1	17	22	40	234
Mistle Thrush	44	37	16	97	12	7	12	31		9	12	21	149
Cetti's Warbler		1		1									1
Grasshopper Warbler		4	1	5	5	3	2	10		6	2	8	23
Sedge Warbler	15	15	4	34	19	3		22		10		10	66
Reed Warbler	9	5		14						2		2	16
Dartford Warbler	2			2									2
Lesser Whitethroat	16	16		32			1	1		2	2	4	37
Whitethroat	37	41	5	83	19	6	4	29		13	7	20	132
Garden Warbler	22	21	3	46	9	1		10		5	9	14	70
Blackcap	47	50	15	112	13	2	1	16	2	9	10	21	149
Wood Warbler		2		2	1	1	4	6		1	7	8	16
Chiffchaff	38	50	8	96	11	2	1	14	2	13	9	24	134
Willow Warbler	37	48	32	117	30	28	25	83		17	23	40	240
Goldcrest	32	26	20	78	20	16	20	56		9	16	25	159
Spotted Flycatcher	8	10	5	23	10	2	2	14		1	5	6	43
Pied Flycatcher	3	3	1	7						2	9	11	18
Bearded Tit	2			2									2
Long-tailed Tit	30	37	6	73	4	2	2	8		5	8	13	94
Marsh Tit	9	7	1	17						1	1	2	19
Willow Tit	5	2		7						1	1	2	9
Coal Tit	23	30	17	70	15	15	14	44		8	9	17	131
Blue Tit	52	61	24	137	30	13	8	51	1	18	17	36	224
Great Tit	49	55	18	122	26	13	8	47	2	15	18	35	204

Table 5 Continued

Species	England				Scotland				Wales				Grand Total
	EZ 1	EZ 2	EZ 3	Total	EZ 4	EZ 5	EZ 6	Total	EZ 1	EZ 2	EZ 3	Total	
Nuthatch	19	25	3	47	1			1		6	6	12	60
Treecreeper	15	20	4	39	8	2	4	14		2	6	8	61
Jay	26	22	3	51	1	4	2	7		4	9	13	71
Magpie	45	55	16	116	5	1		6	1	18	17	36	158
Chough										1		1	1
Jackdaw	41	53	22	116	29	7	1	37	1	19	11	31	184
Rook	43	42	26	111	16	6	1	23		8	7	15	149
Carrion Crow	54	61	27	142	30	8	10	48	2	20	23	45	235
Hooded Crow					3	16	10	29					29
Raven	1	10	9	20	4	10	12	26		4	12	14	62
Starling	42	47	24	113	25	13	1	39	1	10	6	17	169
House Sparrow	37	58	11	106	20	9	3	32	2	16	13	31	169
Tree Sparrow	5	8		13	6			6		2	2	4	23
Chaffinch	56	63	35	154	33	28	27	88	2	20	24	46	288
Brambling	1	2		3									3
Greenfinch	43	54	16	113	24	4	4	32		14	11	25	170
Goldfinch	40	47	17	104	18	7	5	30	2	15	12	29	163
Siskin	4	1	4	9	11	16	17	44		3	8	11	64
Linnet	38	43	12	93	20	6	4	30	2	16	10	28	151
Twite			5	5	1	4		5					10
Lesser Redpoll	5	2	1	8	7	12	9	28		3	5	8	44
Crossbill		2	3	5		4	4	8			3	3	16
Scottish Crossbill							4	4					4
Bullfinch	23	23	3	49	7	1	4	12		4	9	13	74
Yellowhammer	42	49	11	102	23	3	3	29	2	3	9	14	145
Cirl Bunting		1		1									1
Reed Bunting	17	16	7	40	12	7	6	25		8	1	9	74
Corn Bunting	10	8		18	1			1					19

Table 6. Weights applied to species and environmental data for each Environmental Zone in the CCA analysis

	EZ1	EZ2	EZ3	EZ4	EZ5	EZ6
England	1.5	0.9	0.5	-	-	-
Scotland	-	-	-	1.1	0.9	1.0
Wales	1.7	1.4	0.8	-	-	-
Great Britain	1.6	1.0	0.5	1.1	0.9	1.0

Table 7. The 10 most numerous bird species in each of the six Environmental Zones

Environmental zone	Rank		Density (birds per km²)
1	1	Wood Pigeon	60.4
	2	Chaffinch	44.1
	3	Blue Tit	43.3
	4	Blackbird	35.9
	5	Rook	35.2
	6	Wren	30.7
	7	Robin	29.9
	8	House Sparrow	28.9
	9	Starling	25.4
	10	Great Tit	20.4
2	1	House Sparrow	50.9
	2	Chaffinch	45.1
	3	Blackbird	43.3
	4	Wood Pigeon	42.5
	5	Wren	34.2
	6	Blue Tit	34.2
	7	Robin	31.7
	8	Starling	31.5
	9	House Martin	30.4
	10	Swallow	28.0
3	1	Meadow Pipit	50.4
	2	Rook	47.8
	3	Chaffinch	27.8
	4	Wren	20.7
	5	Robin	18.1
	6	Swallow	17.3
	7	Starling	15.3
	8	Skylark	14.8
	9	Carrion Crow	12.6
	10	Wood Pigeon	12.4
4	1	Chaffinch	42.2
	2	Meadow Pipit	36.0
	3	Wood Pigeon	33.4
	4	Blackbird	23.9
	5	Swallow	23.6
	6	Willow Warbler	23.1
	7	Starling	18.8
	8	Rook	18.0
	9	Wren	17.4
	10	Blue Tit	15.5
5	1	Meadow Pipit	44.5
	2	Herring Gull	26.3
	3	Skylark	17.4
	4	Starling	11.9
	5	Willow Warbler	10.4
	6	Chaffinch	10.1
	7	Wren	8.9
	8	Swallow	8.8
	9	Common Gull	7.6
	10	Oystercatcher	7.3
6	1	Meadow Pipit	55.1
	2	Willow Warbler	14.4
	3	Chaffinch	11.7
	4	Robin	8.3
	5	Wren	6.7
	6	Red Grouse	4.5
	7	Common Gull	4.5
	8	Swallow	4.5
	9	Siskin	3.7
	10	Skylark	3.3

Table 8. Characteristic bird species in each of the six Environmental Zones

<i>EZ1</i>	<i>EZ2</i>	<i>EZ3</i>	<i>EZ4</i>	<i>EZ5</i>	<i>EZ6</i>
Wood Pigeon Blackbird Blue Tit Great Tit Whitethroat Yellowhammer Skylark Red-legged Partridge Blackcap Green Woodpecker Pheasant Chaffinch Coot Turtle Dove Grey Partridge Moorhen Wren Yellow Wagtail Mute Swan Mistle Thrush Robin Stock Dove Magpie Rook Reed Warbler Linnet Jay Collared Dove Great Spotted Woodpecker Starling	Blackbird Carriion Crow Blue Tit Wren Magpie Dunnock Greenfinch Wood Pigeon House Sparrow Chaffinch Robin Jackdaw Chiffchaff Swallow Great Tit Collared Dove Blackcap Pheasant House Martin Starling Song Thrush Linnet Whitethroat Mallard Shelduck Goldfinch	Meadow Pipit Curlew Redstart Red Grouse	Tree Sparrow Snipe Sedge Warbler	Rock Pipit Hooded Crow Dunlin Oystercatcher Meadow Pipit Arctic Skua Arctic Tern Ringed Plover Great Skua Herring Gull Golden Plover Common Gull Wheatear	Meadow Pipit Ring Ouzel Siskin Red Grouse

The species are ranked from the “most Characteristic” downwards in each zone. Species in large bold font are “highly Characteristic”