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An analysis of the occurrence of rare birds in Britain in relation to weather

by

A. Austin, N.A. Clark, J.J.D. Greenwood & M.M. Rehfisch

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AN ANALYSIS OF THE OCCURRENCE OF RARE BIRDS IN BRITAIN IN RELATION TO WEATHER

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LIST OF CONTENTS

Page No.

LIST OF TABLES

Page No.

Page No.

LIST OF FIGURES

Page No.

LIST OF APPENDICES

EXECUTIVE SUMMARY

1. This report represents an attempt to discover the likely effects of global climatic change on the populations of rare birds breeding in Britain by exploring the effects of annual variations in weather conditions on the numbers both of species that have bred in the last two decades and of species that have recently occurred only as vagrants but which might colonise Britain in future.

2. All rare species that have bred on at least four occasions and for which there are adequate data were included in the analyses. They were divided into predominantly northern and predominantly southern species and the variations in their numbers were analysed in relation to appropriate subsets of weather data. For eight of the species, the data were broken down on a county-by-county basis and analysed in relation to local weather.

3. All but two vagrant species originating in the Old World for which there were 100 or more records during 1958-90 were included. The records for spring and autumn were analysed separately.

4. Meteorological records for 42 stations in Britain and rainfall indices for two areas of the Sahel were used. The British data were divided seasonally, in a way relevant to the annual cycle of the birds.

5. Relationships between bird numbers and weather were explored using simple correlations, analyses of covariance, and multiple regressions.

6. Weather had little detectable effect on the numbers of some species, but this does not mean that they will not be affected by climate change.

7. Summer rainfall tends to benefit breeding species. Breeding species that overwinter in Britain tend to be reduced by cold winters. Those that overwinter in Africa do better when Sahelian rainfall is high and British summers warm. We suggest reasons for such correlations.

8. Other correlations involving breeding species, such as both negative and positive correlations with frequency of frosts and the generally positive effect of cool weather in March on residents, have less obvious explanations.

9. Correlations between the occurrence of passage migrants and British weather are not easy to explain, perhaps because the truly relevant weather is that in the core of the species' ranges.

10. Rare passage migrants that overwinter in Africa are, counterintuitively, commoner after dry winters in the Sahel. This may be an artefact of changing observer effort.

11. We discuss the likely effects on these birds of various scenarios of climatic change, in the light of these results. Some species would benefit, others would decline. For a number of southern species, the effect would depend on whether the benefit of higher temperatures outweighed the disadvantages of drier conditions. Northern species would probably decline.

12. For species affected by Sahelian weather, the effects of climate change would depend on the balance between higher temperatures and higher rainfall.

13. The effects of climate change on passage birds are difficult to assess from our results.

14. It would be valuable to extend these analyses and to complement them with analyses of distributional data.

1. INTRODUCTION

There now seems general agreement that, as a result of human activities affecting atmospheric gases, there will be global climatic changes over the next century (see, *eg*, Houghton *et al.* 1990), though their magnitude and precise nature remain uncertain (see, *eg*, Mason 1992). Part of the uncertainty stems from ignorance of the purely physical processes involved (there is even debate about which are the most important 'greenhouse gases' - see Emsley 1992). Even more obscure, and only belatedly recognised, is the major significance of living organisms (in addition to man) in determining the amount of CO_2 in the atmosphere, a reflection of the meagre support for environmental biology throughout the world (Lovelock 1992). Such changes may have dramatic ecological effects (see Vitousek 1992 and associated papers for recent reviews of some of these). Birds and other wildlife will be affected. What these might be have been briefly considered by Boorman *et al.* (1989), Cannell & Hooper (1990), and Hudson (1990). None of these authors conducted new analyses, however, so this report has been produced to do so, in respect of one particular area: the effects of weather on rare birds.

That weather affects bird numbers is undisputed, there being much evidence for Britain (Cawthorne & Marchant 1980; Dobinson & Richards 1964; Elkins 1983; Greenwood & Baillie 1991; Marchant *et al.* 1990). There is also evidence that weather on the wintering grounds affects the breeding populations of Palaearctic-African migrants (Baillie & Peach 1990; Cavé 1983; den Held 1981; Kanyamibwa *et al.* 1990; Marchant *et al.* 1990, Marchant 1992; Møller 1989; Peach *et al.* 1991; Svensson 1985). Furthermore, there is some evidence that the northern limit to the ranges of some North American birds is temperature-limited (Root 1988a, b, 1989; but see Castro 1989, Repasky 1991) and that changes of range of various species have resulted from climatic changes during the last century (see reviews by Campbell & Lack 1985; Marquiss & Newton 1990; Welty & Baptista 1988).

Rare species are perhaps of most interest to those concerned with the wildlife impact of climatic change, since changes in their status - from rarity to either extinction or abundance - will be particularly striking. Furthermore, many rare breeders are at the limits of their geographical ranges, so might be especially sensitive to environmental changes. Fortunately, not only is the status of bird populations better documented than that of the populations of other wildlife, but the status of rare species is particularly well known. Information about the scarcest breeders is routinely collated on a national basis, while many county bird reports cover both the scarcest and the not-quite-so scarce in detail. Records of rare passage migrants are also routinely collated. These data sets, and meteorological records, have provided the foundation of this report. We thank the thousands of volunteers who are responsible for gathering them and the organisations responsible for collating them.

Rare migrants are of interest because if they turn up in Britain more frequently, there is more chance of them becoming established as breeding birds. The analyses presented here aim to determine what relationships, if any, exist between numbers of breeding and passage birds recorded annually in Britain, and weather. The results may aid prediction of responses of these birds to future changes in climate. One might predict that species with predominantly northern distributions would be less abundant in warm years, for example, and *vice versa* for more southerly distributed species. We are concerned here with the effects on bird numbers of weather over periods of weeks or months within different years. The numbers of migrants may be influenced by weather immediately before and during the migration, as evidenced not only by the numbers of migrants seen (which may be a biased sample) but by those detected by radar (Nisbet & Drury 1968). This subject has been well studied and reviewed (Alerstam 1990; Elkins 1983) and we shall not consider it further.

Scientific names of the species considered are given in Tables 1.1, 1.2, 1.3, 1.4. Those of other species are given in the text on the first occasion the species is mentioned.

2. METHODS

2.1 Selection of species

2.1.1 Breeding species: national populations

The numbers of all species with less than 300 pairs breeding in Great Britain and Northern Ireland are assessed by the Rare Breeding Birds Panel (RBBP) and reported each year in British Birds (Spencer *et al.* 1992). We used the data published by the RBBP for all years available (1973-89), including corrections to the totals for individual years that were published by the Panel in subsequent years. We left out all species that bred on less than four occasions during the period in question, since we judged that chance variations in their numbers would overwhelm any systematic effects of weather. (These were Black-winged Stilt *Himantopus himantopus*, Spotted Sandpiper *Tringa macularia*, Black Tern *Chlidonias niger*, Shorelark *Eremophila alpestris*, Bluethroat *Luscinia svecica* and Parrot Crossbill *Loxia pytyopsittacus*.) White-tailed Sea Eagle *Haliaeetus albicilla* was excluded as it has been re-introduced into Britain; Marsh Warbler *Acrocephalus palustris* and Roseate Tern *Sterna dougallii* were excluded as their main breeding colonies were not included in the RBBP's reports; and Snow Bunting *Plectrophenax nivalis* and Dotterel *Charadrius morinellus* were excluded because of the known unreliability of published population estimates (Batten *et al.* 1990). Snowy Owl *Nyctea scandiaca* was left out since it has not bred since 1975. The pattern in variation in numbers of Cranes *Grus grus* breeding in Britain - none before 1981, one or two pairs (at the same locality) every year since - is such as to make it unlikely that meaningful weather effects would be apparent, so this species was also left out of the analysis. Finally, Woodlark *Lullula arborea*, Quail *Coturnix coturnix*, Corncrake *Crex crex* and Pochard *Aythya ferina* were omitted because the RBBP did not gather records for them prior to 1984 (Woodlark) and 1986 (the others). The full list of species covered is shown in Tables 1.1 and 1.2, with their scientific names and the codes used to refer to them in other tables. The tables are divided according to whether the birds overwinter mainly in Europe or in subSaharan Africa. (Note that Scarlet Rosefinch, which winters mainly in Asia, is included with the European species and Red-necked Phalarope, which winters mainly in the Indian Ocean, is included with the African species.)

For most of the species selected, the population estimate used was the maximum number of breeding pairs gauged from the number of birds holding territories during the summer. It was considered that this would be a more reliable figure than the number of confirmed breeding records because evidence of definite breeding is extremely difficult to obtain for many of the species, especially for small passerines breeding in remote areas. The maximum number of 'singing' males was used to estimate the numbers of Bittern and Spotted Crake holding territories because both these species live in reed beds and are difficult to observe. Even numbers of calling birds may be inadequate indices of population in these species - in Spotted Crakes because the birds fall silent after pairing, in Bitterns because 'booming' males are very mobile so that a single bird may give the illusion of being several (Spencer *et al.* 1993).

Most of these species bred only or mostly just in the north or in the south of Britain (defined as north or south of 53°20'N, which divides Great Britain into two approximately equal parts). Since these two groups also have generally northerly or southerly distributions in Europe as a whole, they may be expected to respond differently to climatic changes. We therefore carried out separate analyses of breeding birds in the north and the south, using appropriate subsets of the weather data.

2.1.2 Breeding species: county data

For some rare species, reliable data are available in county bird reports. To give a representative selection of species, we originally selected seven species from the RBBP list (Hobby, Avocet, Quail, Black Redstart, Redwing, Dartford Warbler and Cetti's Warbler) plus one that is not quite so scarce (Grasshopper Warbler *Locustella naevia*). However, comparison of county reports with the RBBP reports, and subsequent discussion with members of the RBBP, showed that Quail, Black Redstart, Redwing and Grasshopper Warbler were consistently underreported in at least some counties and that the reporting rate of Quail was probably further confounded by observers being especially vigilant in "Quail-years" and the years immediately succeeding them. In view of this, we replaced these with four species for which we believed the reported county totals to be more reliable, three from the RBBP list (Slavonian Grebe, Common Scoter, and Wood Sandpiper) and one not so scarce (Whimbrel *Numenius phaeopus*). These were selected because they have a northerly distribution, so might be expected to be especially sensitive to climatic warming.

2.1.3 Passage migrants

The British Birds Rarities Committee (BBRC) reports all accepted records of rare birds that migrate through, or occur as vagrants, in Britain and Ireland. Their data for 1958-90, published in British Birds and by Dymond *et al.* (1989), formed the basis for our analysis. We omitted American species, partly because their occurrence in Britain is unlikely to be influenced by long-term patterns of British weather and partly because, unlike species originating in Europe (or even northern Asia) the likelihood of them successfully colonising Europe is small. (Note that the first three species listed in Table 2.1.3 and the Sabine's Gull, though largely American, also occur in Greenland, Siberia, or both.) Of the remaining 218 species, we excluded 143 for which there were less than 100 records over the entire 33-year period (for which chance variations might overwhelm systematic effects of weather). We omitted one species for which the number of records is thought to be unduly influenced by variable observer effort devoted to seawatching in southwest Ireland, *ie* Cory's Shearwater *Calonectris diomedea*. We also omitted Golden Oriole, which breeds in such large numbers in Britain that it is not clear which of the records of the BBRC refer to passage birds and which to British breeders. The lists of passage migrant species included, with their scientific names and short codes, and divided according to wintering areas, are shown in Tables 1.3, 1.4 and 2.1.3.

Annual and seasonal patterns of occurrence of the BBRC species have been reported by Dymond *et al.* (1989). As did they, we included all records from January to June inclusive as "spring" records and those from July to December inclusive as "autumn" records.

2.2 Weather data

2.2.1 The data used: Britain

The BTO holds weather records for 42 meteorological stations throughout Great Britain and Northern Ireland, selected so as to provide comprehensive coverage (Figure 1). In previous analyses (*eg* Greenwood & Baillie 1991) we have found the data from these stations not only to be useful predictors of changes in bird numbers but also to be so highly intercorrelated that increasing the number of stations contributing to the national (or even regional) analyses would only marginally have increased precision.

The variables initially selected for the analysis were:

TMEAN:	monthly mean of daily mean screen temperature
TE30:	monthly mean of daily mean earth temperature at 30cm ('temperature')
RAINT:	monthly total rainfall ('precipitation')
RAIND:	number of days per month with ≥0.2mm rain
WETD:	number of days per month with ≥1.0mm rain ('wet days')
SNOWD:	number of days per month with snow lying at 0900 hrs
GRASSD:	number of days per month with minimum grass temperature of ≤0°C ('frost')

For the analyses of populations of breeding birds, we calculated means of the weather variables across all 42 stations, or all stations in the north or in the south (defined above) for species concentrated in north or south. Table 2.2.1 shows the means and variation in these variables during the study period. For county analyses, we used the data for the station in each county, so that the analyses for the counties were independent of each other. (Occasionally, a county that held birds had no weather station; weather data from an appropriate neighbouring county were then used).

2.2.2 The data used: Sahel

To provide measures of weather conditions experienced by birds passing through, or wintering in, the Sahelian zone of Africa we used two indices of rainfall provided by the Climatic Research Unit (University of East Anglia). Each was derived from a large number of weather stations lying between 20°W and 5°E, SAHELA being for 10°N-17°N and SAHELB for 3°N-10°N. Each comprised annual means of the rainfall anomalies (annual departures from the long-term mean) for the individual stations. In the analyses, we used the data for the year immediately preceding (and overlapping with the first part of) the period in which the birds were overwintering.

2.2.3 Seasonality

The number of birds breeding in a particular year might be expected to be influenced most by the breeding output in the previous season and the subsequent mortality. Breeding seasons vary somewhat between species, but, to simplify the analysis, we used the same seasonal divisions for all breeding species that overwinter in Europe. Weather variables were measured for each of the five periods:

1. March in the year preceding the breeding year in question (*ie* preparation for the previous year's breeding).
2. April, May and June in the preceding year (*ie* the breeding season)
3. July, August, September and October in the preceding year (*ie* late breeding, early autumn).
4. November, December, January and February (winter).
5. March immediately preceding the breeding season in question (*ie* preparation for that breeding season).

British weather in periods 1, 4 and 5 is unlikely to have much direct effect on numbers of those species that overwinter largely in Africa rather than Europe, so these periods were omitted from the analyses for these species. Sahel rainfall data were included instead.

Numbers of spring migrants might be expected to be affected by weather in much the same way as numbers of breeding birds, so the weather variables used for their analyses were the same as for breeding birds. For autumn migrants, however, we omitted periods 1, 2 and 3 (above) and included:

6. April, May and June of the current year.
7. July, August, September and October of the current year.

For autumn migrants wintering mainly in Europe, we thus used weather for periods 4, 5, 6, and 7, the four periods immediately preceding (and, for period 7, overlapping with) the migration. For those wintering mainly in Africa, we used the Sahel rainfall indices and British periods 6 and 7.

2.2.4 Reduction in number of variables

The first step in the analysis was to reduce the number of weather variables in number - otherwise the analytical models would be grossly overparameterised. An obvious way to reduce the number of variables is to carry out a Principal Components or similar analysis, so that the bird numbers may then be related not to the original variables but to a smaller number of components that summarise the majority of the variation. This often has the disadvantage that the exact meaning of the reduced components is unclear. Our experience with weather data is that the different weather variables usually fall into subsets with such high internal correlation that one can use one of them to index the variation of the whole subset. This has most of the advantages of using Principal Components, as well as involving the use of variables whose meaning is clear.

In the data set used, the two temperature variables were highly correlated with each other; so were the three rainfall variables; snow and frost were also well correlated, at least in winter. To choose between the variables in each set, we examined the data, to see which tended to explain most of the variation in numbers over the greatest number of species - since we were interested in exposing as much as possible of the effects of weather on rare bird numbers. We did this by regressing numbers of breeding birds on all weather variables simultaneously, using multiple regression. Table 2.2.4 summarises the results of these analyses. Since TE30 was more often a significant variable than was TMEAN, it was chosen as the measure of temperature to use in further analyses. Similarly, and because there was no snowfall in seasons 2 and 3, GRASSD was chosen over SNOWD. RAINT was retained as the best measure of rainfall but, because WETD produced more significant regressions for breeding species wintering in Africa, this variable was retained for analyses for such species.

2.3 Statistical methods

2.3.1 Data transformation

Because the numbers of each species tend to be highly skewed, we transformed them to $\log_{10}(x+1)$ before most of the analyses. Untransformed data were used only for the calculation of mean number and standard deviations, as purely descriptive statistics.

2.3.2 Simple correlations

Initial explorations of the associations with weather variables of national breeding populations and of numbers of passage migrants were carried out by calculating Pearson correlation coefficients. For this we used procedure CORR in SAS version 6 (SAS Institute 1989) implemented on the BTO Prime minicomputer.

2.3.3 Multiple regressions

The analyses were extended by applying multiple regression. If one carries out an experiment in which several quantitative factors are varied in a balanced factorial design, multiple regression analysis allows the separate linear effects of these factors on the variable of interest to be assessed. All the factors are held in the analysis and the interpretation of the results is relatively straightforward. Multiple regression may also be used for data exploration when the factors are not under experimental control. Its value then is that it can reveal which factors seem to have the strongest effects, each effect being assessed while the effects of other factors are held constant not by the experimenter but by the analysis. In such circumstances, however, one must bear in mind that the results in respect of one factor may still be sensitive to the amount of variation in other factors and may vary according to the way in which the final model is built up. Thus, although multiple regression analyses are powerful tools for exploring data sets such as those used in this report, the results must be regarded as indicators rather than firm proofs.

For this report, we used the STEPWISE procedure in SAS, using the stepwise method for model selection. This is a modification of the forward-selection technique in which, starting from a model incorporating no independent variables, one adds them in turn, at each stage adding the variable that produces the largest overall F value corresponding to a test of significance of the R^2 (the coefficient of multiple determination) at that stage. If no variable produces an F corresponding to a set significance level, model fitting is terminated. The stepwise modification involves scanning the model at each stage to check that all variables are still associated with an F value corresponding to a set significance level. Any that are not are dropped from the model. This results in the dropping of variables that are good predictors of the dependent variable at an early stage but which become poor predictors when other variables are added. We used the default values of $P=0.15$ for both inclusion of new variables and elimination of those no longer useful.

To assess the strength of the effect of each independent variable, we examined the significance levels corresponding to the F values for each variable included in R^2 made at the stage at which that variable was added to the model. The total R^2 was used as an indication of the overall effect of weather on numbers.

2.3.4 Analysis of covariance

For the species for which county-by-county data were available, multiple regression was applied to the data for each county individually. This has the advantage of showing up any county-specific effects of weather. It suffers from not providing an immediate way of combining information across counties, which would illuminate common patterns. To do this, we applied the SAS procedure GLM, which fits general linear models, to the data for all counties together. The fitted models, for each weather variable in turn, were of linear regression of numbers on weather, common across all counties, with constant differences between counties - a standard analysis of covariance approach. This method is a powerful way of looking for common trends. The two methods thus complement each other. Unfortunately, methods for combining them are not available.

2.3.5 Interpretation of results

Very large numbers of statistical tests have been carried out in this investigation. Even if the weather variables examined had no effects on the numbers of the species in question, one in twenty of the test results would be significant. A formal way around this problem is to adjust the level of the test statistics taken to be significant, so that one applies an experimentwise significance level rather than an individual one. The disadvantage of this procedure, particularly when the data sets for individual species are small, in a statistical sense, is that it makes it unlikely that even quite marked effects will then produce significant results, especially when, as here, the number of tests is so very large, that the adjustment to the criterion level is very great. We have therefore chosen to quote the significance levels unadjusted. One should not, therefore, take much notice of individual tests with $P<0.05$ (* in the tables) or $P<0.01$ (**), though $P<0.001$ (***) should not be lightly ignored. It is more important to look for general patterns, such as species numbers being positively correlated with rainfall in all five seasons or nine out of ten species in a group showing a correlation with the same variable, even if the individual correlations are weak. To aid such interpretations we have both tabulated our results fairly fully and summarised numbers of positive and significant associations in the tables.

In this respect, it is important to use the results of both the Pearson correlation analyses and the multiple regressions together. The former suffer from the confounding of independent variables but have the advantage of providing measures of every possible association. The multiple regressions avoid the problem of confounding but (since variables are only included if $P<0.15$) only provide measures of association for the variables that are the most important for an individual species.

3. RESULTS

3.1 Breeding birds (national populations)

3.1.1 Breeding birds that winter in Europe

These species are listed in Table 1.1, including the codes used to refer to them in other tables, their mean numbers, standard deviations of numbers, minima and maxima. Some of them are almost complete resident but others may move (usually south) in winter. Serin, in particular, may even move as far as North Africa, though they do not normally cross the Sahara. British winter weather conditions are thus directly relevant to most of these species.

Table 3.1.1.1 presents the Pearson correlation coefficients between the abundances of these species and the weather variables. Table 3.1.1.2 presents the results of the multiple regression analyses. The two tables largely support each other. They suggest that in general these species do well after warm winters (period 4). Their numbers also tend to be higher both in years in which March is cool and in the year afterwards (periods 5 and 1 respectively). Frosts are important to some species but in either direction: there are no general trends. With exceptions, these species tend to benefit from higher rainfall at most times of year.

In addition to the individual differences between species there is some evidence of a general difference between those that have a generally northern breeding distribution in Britain and those that breed mainly in the south: the former tend to have larger populations following cooler summers (periods 2 and 3) while the converse is true for the southern species (Table 3.1.1.3). As the Table shows, such broad differences between northern and southern species do not seem to occur at other times of year or in respect of other variables. There is, however, an average difference in the proportions of the variances in numbers that are explained by the weather variables entering the multiple regression. Mean R^2 values are 0.75 for southern species and 0.47 for northern ($t_s=2.9$, 21 d.f., $P<0.01$) suggesting that the former group tend to be more susceptible to the effects of weather.

For more detailed consideration, it is convenient to divide the species into waterbirds and landbirds. One waterbird, the Pintail, breeds in both north and south Britain. It appears to benefit from rain in March and possibly also in winter; higher temperatures, especially in early summer, may benefit it.

Several other waterbirds breed mainly in the north. Rain, especially in March, may benefit Goldeneye (as may low temperatures). The effect of March rainfall on Scaup is less clear: there is a strong positive multiple regression of numbers on March rainfall in the year of breeding but a weak negative one (with a non-significant positive Pearson correlation) for the previous March. Scaup numbers are depressed by frosts in the previous breeding season and winter. Whooper Swans and Black-necked Grebes probably benefit from higher rainfall. Slavonian Grebes seem to suffer from frosts in late summer - but frosts earlier in the breeding season seem to produce larger numbers in the following year. There are no obvious effects of weather on the numbers of Red-necked Grebes and Common Scoters.

Rain also seems generally beneficial for wetland birds in the south - possibly all year for Mediterranean Gull, late summer for Little Gull and in March for Bittern. Mediterranean Gulls seem to breed in larger numbers following frosty winters so long as they are not generally cold (*ie* cold nights but warm days). Little Gulls may do better after early summers that are cool. Bitterns are reduced in numbers following frosty years, especially frosty late summers and winters. There is no evidence in the data for weather effects on Avocets.

Both of the land birds that are not concentrated in either north or south, Goshawk and Brambling, do better in rainy years. Goshawks appear to benefit (like Mediterranean Gulls) from frosty but warm winters.

Rain also probably benefits some northern land birds - Purple Sandpiper, Redwing and (in summer) Scarlet Rosefinch. The last seems to increase after cool summers but Lapland Buntings decrease after frosty late summers. There are no clear effects of weather on Fieldfares in these data.

Southern land birds apparently benefitting from rain are Cetti's Warbler, Serin and (mostly) Cirl Bunting; March rain especially is good for the first of these and for Firecrests. High temperatures benefit Cetti's Warblers in late summer and Firecrests year round. Cirl Buntings may benefit from warm, frost-free winters. Another southern specialist, Dartford Warbler, does well in warm, dry years. Red Kites, like Mediterranean Gulls and Goshawks, do better after frosty but warm winters. There is no evidence in these data that weather has much effect on Black Redstarts.

3.1.2 Breeding birds that winter in Africa

Tables 12, 3.1.2.1 and 3.1.2.2 present the results for the species that largely winter in Africa. They generally seem to attain larger numbers after warmer years, especially warmer (and perhaps frost-free) late summers. Rain seems generally immaterial in early summer but may be more often beneficial than not in late summer. Numbers tend to be higher following high rainfall in the Sahel. In general, the correlations with weather seem weaker than for the species that overwinter in Europe - but since a different suite of weather variables is involved the comparison is perhaps not a fair one.

Amongst the southern species, the effects of temperature (and other weather variables) are similar to those amongst the southern species that overwinter in Europe (Table 3.1.2.3 and T3). The number of northern species overwintering in Africa is too small to make comparison meaningful. R^2 values differ between southern and northern species in the same way as for the species overwintering in Europe (means 0.35 and 0.25). Although the difference is apparently smaller (and not significant t_s=0.05, 15d.f., $P \approx 0.5$), two-way analysis of variance shows no significant difference between the two overwintering classes in the size of the north-south difference (interaction $F_{1,39}$=0.2, $P \approx 0.7$) and an overall significant north-south difference ($F_{1,39}$=5.8, $P \approx 0.020$)

Turning to individual species, there is no evidence from these data that weather has marked effects on the numbers breeding in Britain of Marsh Harrier, Montagu's

Harrier, Osprey, Spotted Crake, Stone Curlew, Black-tailed Godwit, Wood Sandpiper, Red-necked Phalarope, Golden Oriole, or Red-backed Shrike.

There is weak evidence that the Ruff population is larger following years with warmth in early summer and frosty (but not cold) autumns. Sahel rainfall appears to sustain populations of Temminck's Stint, Honey Buzzard, and Hoopoe. Some evidence suggests that the last species also benefits from early summer coolness and late summer warmth. There is weak evidence that rain throughout the summer benefits Hobby and Wryneck; late summer frosts disfavour the latter.

3.2 Breeding birds (county analyses)

3.2.1 General

The results of the county-by county analyses are shown in Tables 3.2.2-3.2.9. For each species are shown the results of the multiple regressions for each county (and the numbers of each that are positive or negative), the results of the analyses of covariance of all the county data together (but not lumped) and the results of the national analyses (already considered above).

3.2.2 Slavonian Grebe (Table 3.2.2)

The county analyses confirm that this species may be affected by frosts differently at different times of year (though the ancova and the national analyses for period 3 contradict each other). Like the national data, they produce no clear results for temperature and precipitation, though perhaps suggest that the late summer rain is detrimental.

3.2.3 Common Scoter (Table 3.2.3)

The national data for this species suggested no obvious effects of weather variables. The county analyses suggest that warmer and wetter conditions may benefit it.

3.2.4 Avocet (Table 3.2.4)

The national data for this species also suggested no obvious effects of weather. The county data provide no clearer picture in respect of temperature and frosts, but point to rainfall being beneficial.

3.2.5 Cetti's Warbler (Table 3.2.5)

The county analyses strongly confirm that this species benefits from warmer weather (especially in winter), the evidence for which in the national analyses is somewhat equivocal. The county analyses also suggest that frosty weather, as such, may be bad for Cetti's Warbler. Here, however, the results are confused: for the winter period (period 4), the r value for the national data is positive ($P<0.05$) and Norfolk has a positive partial regression ($P<0.01$); but no other counties have significant partial regressions and the analysis of covariance of the county data shows a negative relationship ($P<0.01$).

The county analyses confirm that Cetti's Warblers benefit from higher rainfall.

3.2.6 Dartford Warbler (Table 3.2.6)

The positive effects of warm, frost free conditions that were shown by the national figures are confirmed by the county analyses. Those of dry conditions, though not contradicted, are not confirmed.

3.2.7 Whimbrel (Table 3.2.7)

National data were not available for this species, which breeds on northern moorlands and winters in Africa. The county analyses suggest that it breeds in larger numbers in years that follow warm, dry anticyclonic summers - but the evidence is not strong.

3.2.8 Wood Sandpiper (Table 3.2.8)

The county analyses provide no clearer picture of the effects of weather on this species than did the national analyses.

3.2.9 Hobby (Table 3.2.9)

The county-by-county analyses strengthen the evidence that summer rainfall benefits this species. They provide rather weak evidence that warmer, anticyclonic summers also benefit it. Given the number of counties involved, it is not surprising that the evidence from different counties is not always concordant.

3.3 Passage migrants

Tables 1.3, 1.4 and 2.1.3 show the species of passage migrants that we considered, with their numbers in both spring and autumn. The results of the Pearson correlation analyses are shown in Tables 3.3.1-3.3.6 and those of the multiple regressions in Tables 3.3.7-3.3.12.

The most consistent pattern of associations is for bird numbers to be larger subsequent to seasons with more frosty days. Since these correlations are independent of associations with temperature: they persist in the multiple regression analyses.

Among the species that overwinter in Europe (Tables 1.3, 3.3.7, 3.3.8, 3.3.1, 3.3.2) spring numbers tend to be higher following frost in the previous early summer and the current March (and perhaps the previous March); autumn numbers tend to be higher after frosty summers. In species wintering outside Europe (Tables 1.4, 2.1.3, 3.3.9, 3.3.10, 3.3.11, 3.3.12, 3.3.3, 3.3.4, 3.3.5, 3.3.6), spring numbers are generally higher following a frosty summer in the previous year, while autumn numbers are higher if the current summer has been frosty. The effects are especially strong for autumn passage of birds that winter neither in Europe or Africa. If one examines the results for individual species, one finds that the cases of apparent negative correlations are sporadically distributed both between and within species and none is significant at $P<0.001$. No species seems to suffer from frosty weather in summer.

Pearson correlation coefficients often indicate that passage numbers are higher following cold seasons but such trends disappear in the multiple regression, suggesting that the apparent correlations are a by-product of low mean temperatures sometimes being associated with frosty conditions. In both spring and autumn passage of birds wintering in Europe, and in spring (but not autumn) passage of birds wintering in Africa, the multiple regressions suggest that more species than not occur in larger numbers following warmer seasons. A particularly strong association occurs for the autumn passage of Gyr Falcon, in relation to warmth in the March of the same year. This is supported by similar (but weaker) correlations of spring numbers with winter warmth in Gyr Falcon and with March warmth in Serin; but autumn numbers of Serin are apparently lower if the late summer has been warm.

Rainfall in Britain, measured as total precipitation and (for species wintering north of Europe) by number of wet days, does not have major effects over whole suites of species. Autumn passage of birds wintering in Europe may be greater following wetter years; autumn passage of birds wintering in Africa may be greater following wetter early summers - but spring passage of these species may be poorer following wet late summers. Spring passage of species wintering in neither Europe nor Africa may be reduced if the previous early summer has been wet. Clearly, the effects, if any, of rainfall differ between species. The distribution of significant results is, furthermore, sporadic within species. The Serin is the clearest case, with four positive multiple regression coefficients and seven (out of nine) positive Pearson coefficients, which fits with the apparently beneficial effects of rainfall on the Serin breeding population. Four species have all their Pearson coefficients negative - White Stork, White-winged Black Tern, Melodious Warbler, and Scarlet Rosefinch. (The only multiple regressions entering at $P<0.15$ for these species are two negatives and one positive for White Stork autumn passage).

For the species that winter in Africa, numbers of passage birds in both spring and autumn tend, contrary to expectation, to be lower following years with high rainfall in the Sahel. This is consistent across both Sahelian zones and across species; contrary results are sporadic and none is significant at $P<0.001$.

4. DISCUSSION

4.1 Breeding birds on which weather has no obvious effects

Weather has no effects detectable from the data to hand on the breeding numbers of Red-necked Grebe, Common Scoter, Avocet, Fieldfare, Black Redstart, Marsh and Montagu's Harriers, Osprey, Spotted Crake, Stone Curlew, Black-tailed Godwit, Wood Sandpiper, Red-necked Phalarope, Golden Oriole and Red-backed Shrike. For Common Scoter, Wood Sandpiper, Spotted Crake and Black Redstart the reason may be that the available counts are poor: nests of the first three species are particularly difficult to find, while Black Redstarts are notoriously under-recorded because they occur mainly in industrial sites, which are occupied sporadically and difficult for birdwatchers to search. Red-necked Grebe and Fieldfare are scarce, so variation in their numbers may be determined largely by chance (though this must also apply to many other species, which are as scarce or even scarcer). Red-backed Shrike numbers have declined very rapidly, as in other parts of western Europe (Batten *et al.* 1990), so the major determinant of its numbers is this long-term decline rather than annual weather variation, though the long-term decline may itself be determined partly by climatic changes. The lack of detectable weather effects is less easy to explain for the other species but, even for these, it would be unwise to conclude that their numbers will not be affected by future climatic change: the analyses we have conducted could not reveal either the more subtle effects of weather variation nor the long-term effects of climatic changes. Thus, for these species, we can make no predictions about the possible effects of climate change, rather than concluding that there will be none.

4.2 Interpretation of the apparent effects on breeding birds

The general tendency for breeding birds, at least those whose populations are centred largely in the south, to be depressed by cold winters is not unexpected, given previous knowledge of the effects of cold weather on birds. Indeed, one might be surprised that the effects were not more obvious in these data. However, unlike the current analysis, the analyses that show strong effects of winter weather on the populations of British breeding birds have included data for 1962/3 (Marchant *et al.* 1990; Greenwood & Baillie 1991), which had particularly severe effects (Dobinson & Richards 1964). RBBP records do not go back that far. Other winters with generally low temperatures may have less dramatic effects on bird populations because periods of freezing are broken by brief thaws (Cawthorne & Marchant 1980).

It is also not surprising that warm summers, especially late summers, appear to benefit species that overwinter in Africa, since these will generally be less well fitted to cool conditions than are species that overwinter in Europe. It is also easy to explain the beneficial effects of warm, dry weather on Dartford Warblers, in the light of what we know of the species - restricted in Britain to southern heathlands and typically hit hard by cold winters (Batten *et al.* 1990). But some of the other effects of temperature on individual species are less readily explained. Nor is it obvious why cool March weather generally benefits resident species. Indeed, one might have predicted that the reverse would have been the case.

The frequency of frosts (independent of temperature) has different effects on different species. One could produce 'explanations' for some of these but they would be little more than 'just-so stories'. It seems likely, in any case, that the occurrence of frosts is an indicator of other (perhaps several) factors associated with anticyclonic conditions (calm, settled weather, generally dry).

The generally beneficial effects of rainfall on rare species breeding in Britain, especially resident species, is paradoxical at first sight. Studies of the effects of rainfall on birds usually conclude that it is detrimental, interfering with feeding and wetting plumage. However, such studies are not numerous and the results may not be generally applicable. Rainfall promotes plant growth and may ultimately improve food supplies for birds, both seeds and insects (and, for predators, other birds), so rainfall that is not persistent and which is not associated with particularly cold conditions could well improve survival over the course of the year. In the specific case of the Partridge *P. perdix* in southern England, chicks appear to survive better in wetter conditions, perhaps because insect activity is reduced when the weather is very dry. For ground-feeders, the benefits will arise through the ground being softer, even if the actual abundance of good is not affected.

The benefits of Sahelian rainfall on birds that breed in Britain but overwinter in Africa are not unexpected, given existing knowledge. There is a good deal of evidence that populations of a number of commoner species are adversely affected by Sahelian drought (Winstanley *et al.* 1974; Berthold 1974; den Held 1981; Berthold *et al.* 1986; Marchant *et al.* 1990) though the evidence for general effects is not always strong (Marchant 1992) and may be contradictory (Svensson 1985). Furthermore, survival rates have now been shown to depend on Sahelian rainfall in a number of species (Cavé 1983; Kanyamibwa *et al.*, 1990; Baillie & Peach 1990; Peach *et al.* 1991). Swallow *Hirundo rustica* survival is also better in years when rainfall is high on the southern African wintering grounds (Møller 1989). One assumes that the benefits to birds of good rains in Africa are that they result in better food supplies.

The apparently greater susceptibility to weather of species that breed mainly in the south than those that breed mainly in the north (indicated by larger mean R^2) should be treated with caution. It may be simply a result of the weather in the south being more variable (as it is for all but one of the variables that we have used).

4.3 Interpretation of the apparent effects on passage birds

The interpretation of the analyses rests on the assumption that variations in British weather are correlated with those on the birds' breeding grounds. Most of the species breed in other parts of Europe (though some breed further east), so this assumption is justified, even if the correlation is sometimes weak. The consistent tendency for passage migrants to be more frequent subsequent to seasons with more frosty days, independent of temperature effects, probably indicates some effect of anticyclonic weather with which frosts are generally associated (especially in summer). Note that the effects are unlikely to be immediate effects of weather or weather systems on migratory behaviour, since they operate over periods of months - more individuals are recorded in spring following frosty weather in the previous summer. Such weather in Britain is most likely during prolonged anticyclones over much of Europe.

More detailed consideration of the ecology and biogeography of individual species is required to explain the apparently variable effects of rainfall on them. It is striking that they do not show the near-uniformity of the breeding species, most of which seem to benefit from rainfall. It is even more striking, counterintuitive, and counter to studies of breeding populations that passage migrants should be less frequent when Sahel rainfall has been good. It is important to note that the effect is consistent across both Sahelian zones, which cover the whole range in west Africa of most of these species (since few migrants penetrate the forested areas to the south), so it cannot be explained by the birds using areas adjacent to those from which rainfall data have been obtained. If they did, it would be conceivable that rainfall in these areas was negatively correlated (because of variations in the penetration of the seasonal rainfall belts), so that birds benefitting from rain would show negative correlations with rain in the area from which the rainfall data had been obtained. Since this is not the case, a puzzle remains. As with frosty weather, the effects cannot be direct effects on migratory behaviour, since the number of birds recorded in autumn is related to the previous winter's conditions in Africa and most such autumn birds will be young ones, bred in the intervening summer. Perhaps in dry years birds move out of the Sahel early or move towards the west coast and more of them pass through western Europe in the spring; if they then tend to breed in western Europe to a greater than usual extent, that would also produce more young passing through Britain in the autumn. If this interpretation were to be correct, years of good passage in Britain would in fact be years when the species had been facing particularly difficult conditions on the breeding grounds, rather than the converse.

It is possible that the apparent negative correlation between the numbers of passage migrants and Sahelian rainfall is an artefact, arising as follows. The number of birdwatchers interested in rarities has increased during the past three decades, which may have caused the number of rare birds recorded to have increased. At the same time, Sahelian rainfall has tended to decline. Although inspection of the data shows both of these correlations with time to be weak, they may be, at least in part, responsible for the unexpected negative correlation between numbers and rainfall.

4.4 Climatic change scenarios for Britain and their likely effects on breeding birds

We have been asked to comment on the likely effects on rare birds of the following scenarios of climatic change, as indicated by our analyses of the relationships between birds and weather. They have been derived from CCIRG (1991). To relate them to the scale of weather variation underlying our analyses, note that the national mean values (for the weather stations we used) during 1973-89 for screen temperature (°C) and precipitation (cm) were:

	Temperature				Precipitation			
Period	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Period minimum	4.1	9.5	12.0	3.2	27	35	38	59
Period maximum	7.0	11.4	14.3	6.3	121	70	94	97

1. Britain will become generally warmer by a best estimate of 1.4°C by 2030 and 2.4°C by 2050. There will be no other changes.

   Warmth in itself, especially in winter, would benefit rare birds that are largely restricted, as breeders, to the south of Britain. From our results, Red Kite, Mediterranean Gull, Ruff, Garganey, Hoopoe, Wryneck, Firecrest, Cetti's Warbler, Cirl Bunting, Dartford Warbler, and Serin would be the most likely to benefit. Pintail, a scarce but widespread breeder, would probably benefit. Northern breeding species would probably tend to decline: the Scarlet Rosefinch is, from the results presented here, the most likely to do so whereas Common Scoter and Whimbrel might do better under warmer conditions.

If the higher temperatures led to a greater evapotranspiration that had similar effects to reduced rainfall, northern species, especially of waterbirds, would certainly suffer. Black-necked Grebe, Common Scoter, Whooper Swan, Scaup, Purple Sandpiper, Redwing and Scarlet Rosefinch would be the most likely species to decline. Bittern, Little Gull, Goshawk, Brambling and Serin also would be likely to decline, so might Avocet. For Mediterranean Gull, Pintail, Cetti's Warbler and Cirl Bunting (and possibly Hobby and Wryneck), potential benefits of higher temperatures might be reduced (or reversed) by the drier conditions. For Dartford Warblers they would probably be reinforced.

It is not clear whether this scenario would be associated with increases in anticyclonic conditions. Since the effects on birds of such conditions, as revealed by correlations with frost, are also unclear, we are unable to comment on the significance of this element of our results in the context of climate change.

2. Temperature increase as in (1) with increase in precipitation, especially in the west in winter. However, greater evapotranspiration will produce generally drier soils than at present, particularly in the east.

   The results of this scenario would be much as the last. Since the west of Britain is not the stronghold of many of these rare breeders, the benefits of the increased rainfall there might be few - though Cirl Buntings might do well in the warm, wet conditions and so would other southern species that seem to do well in wet years if the increased temperatures allowed them to spread west.

3. Temperature increase as in (1) but a distinct north-south divide for precipitation: *ie* generally drier in the south and wetter with more cloud cover than at present, in the north and north west.

   The increased rainfall in the north might benefit some of the northern species that would be hit by decreasing rainfall in scenario (1) but they would still be adversely affected by the increased temperatures. The net result is difficult to predict.

4. Conditions change as in (1) and (2), combined with a greater frequency of hot summers (*ie* summers like 1976 become a 1 in 10 occurrence rather than a 1 in 100 as at present).

   For most of the species considered here, the increased drought would be detrimental. (The Dartford Warbler is a clear exception.) Most of the northern species would probably be lost, since they do best in cool, damp conditions. The outcome for the southern species, many of which do best in warm, wet conditions, is difficult to predict - except that occasional extremes tend to cause difficulties for most living organisms.

5. Conditions as in (2) and (4) but winters have longer mild periods, *ie* disrupts dormancy for many plants and insects.

   This would give further benefit to most of the southern species.

6. Generally warmer with less distinction between seasons and more unpredictable patterns of rainfall and sunshine.

   Our data do not allow us to assess the effects of such a change, insofar as it differs from (1).

7. A general rise in sea level of 20cm by 2030 and 30cm by 2050 with a resulting loss of intertidal habitat.

   This is outside the scope of this report. The issue has been covered by Boorman *et al.* (1989).

8. A rise in atmospheric carbon dioxide from the present 350ppmv to 450ppmv by 2030. This will have a direct effect upon the growth of many plant species and an indirect effect upon the populations of many animals.

   This is also outside the scope of this report.

4.5 Changes in the Sahel and their effects on British birds

A likely scenario of climatic change in the Sahel in winter is that temperatures will rise by about 4°C (with possibly greater increases in summer), probably accompanied by increased rainfall (Mason 1992). For British breeding birds that winter in Africa, most of which winter in the Sahel or nearby, the effects will depend critically on how these changes balance out in terms of their opposing effects on evapotranspiration. Their results are therefore unpredictable.

4.6 Climatic change and passage birds

The effects of weather on passage birds are strongest in terms of number of frost days, though the causal connection between frost days and bird numbers is obscure. Sahel rainfall also has clear effects of obscure origin. British rainfall has effects on numbers of passage migrants that might be easier to understand but which are less clear-cut and less general. This makes the prediction of the effects of climate change on bird numbers difficult. Furthermore, the main effects may well be brought about not by weather over months (with which we have here been concerned) but by weather, especially wind force and direction, over brief but critical periods during the migration periods, which has major effects on bird migration (Elkins 1983; Alerstam 1990), but about which our analyses provide no information.

4.7 General considerations

It cannot be too strongly emphasised that the 'predictions' made above are no more than the best assessments that can be made given the data used. They cannot be taken with any more certainty than can the various predictions of climatic change. Indeed, they may be less certain, for several reasons. One is the quality of the data, which arise from the voluntary efforts of observers in their spare time, supported by a few hours per week of professional time for additional data collation. Although the information on variation in bird numbers is better than that for virtually any other group of organisms, its precision is still fairly low. The weather data are of high quality, but what of their relevance? Because there have been so few studies of the sort described here, our understanding of the effects of weather on bird populations remains limited, so we cannot be sure that we have applied (or even have available) the most relevant meteorological data. This is a problem that cannot be overcome by throwing all conceivable weather measurements into an analysis, since the number of potential explanatory variables then far exceeds the amount of ornithological data available to be explained.

One way to overcome such problems would be to draw into the analysis information on the ecologies and geographical ranges of the species in question. This would help to identify what weather variables might be of most importance for a species prior to analysis of the weather data themselves; it would help to identify suites of species that might be expected to respond to weather in similar ways; and it would allow spatial correlations with climate to be used to test the temporal correlations with weather.

Even if the weather variables we have used are relevant, there may have been insufficient annual variation during the period covered by the analysis to allow reliable prediction of the results of the climatic changes envisaged in 4.4 (above). This is particularly true for temperature, where the differences between the warmest and coolest years were only 2 or 3°C (see 4.4, above).

Another consideration is the complexity of the system and the specificity of the questions being asked. The processes leading to changes in bird populations brought about by climatic changes are considerably more complex than those leading to the climatic changes in the first place. Given that even the broad outlines of the climatic changes are a matter of considerable uncertainty, despite the effort devoted to their study, it is not surprising that the answers to questions about the likely fate of individual bird species are also uncertain. It is important to appreciate that, because of differences in their ecologies, different species may react differently to the same environmental change, as has been demonstrated clearly by studies of the changes in distribution of a variety of organisms during the global warming of the late-Quaternary (Graham & Grimm 1990). It is thus essential to ask questions about individual species, even if they are not easy to answer. But even for species that have been intensively studies, firm prediction of the impact of climatic change on numbers is impossible (Rodenhouse 1992).

Birds are subject to the additional uncertainty that they move about, so their numbers may be determined by events outside of Britain. This is especially true of scarce passage migrants and of rare breeding species, which may represent just the overspill of more central populations, an overspill whose magnitude may depend very much on conditions at the centre of the species' range. Thus, to make better predictions we need to consider weather conditions in other parts of Europe. And for the migrants we need fuller consideration of conditions on the wintering grounds.

Svensson (1985) has pointed out that it is difficult to know how Palaearctic-African migrants might be affected by conditions in the Sahel, not only because we do not know about the direct causal links involved but also because changes in the Sahel may alter the competitive balance between migrants and resident species. Migrants currently make use of a seasonal abundance of food that is not fully utilised by the residents, since the populations of the latter are constrained by shortages at other times of year. Svensson suggests that, under some circumstances, increased Sahelian rainfall might benefit residents sufficiently that their numbers increase to such an extent that they compete effectively with migrants, thus causing migrants to decline even though the environment for birds in general has improved. Such an outcome would be particularly likely if the seasonality of the Sahel were to diminish as a result of global climatic change.

Thus, long-term changes in bird populations might be the reverse of those predicted from considerations of the immediate impact of variations in weather, if they cause changes in the strength of competition or other biological interactions. This applies within Britain as much as in the Sahel and makes the prediction of long-term changes from the immediate effects of weather particularly difficult. Not only do we not have direct information nor sufficient knowledge of the ecological interactions amongst even comparatively well-studied organisms such as birds, we have no general principles to guide us. Thus, many ecologists would assume that the positions of ecotones (the boundaries between habitats) would be particularly susceptible to the effects of climatic change, as this affected the competitive balance between species, but S. Ferson (in Atkinson 1992) has produced theoretical arguments that they may be resistant to moderate changes precisely because of the ecological interactions between species.

Birds only infrequently suffer mass mortality because of weather conditions in Britain (Elkins 1983). Indeed, this is true throughout the world, for birds are warm-blooded, well insulated and relatively waterproof; furthermore they are mobile enough to be able to escape many adverse conditions. What they are dependent on is their habitat, so it is likely that major effects of climatic change on bird populations will be mediated via changes in their habitats. These will be both natural and brought about by human intervention, as agricultural and silvicultural practices are adjusted to changing climates and markets (the latter caused by changing climates elsewhere in the world). Since bird habitat does not vary markedly from year to year in response to weather, the current analyses can tell us nothing about what such effects might be.

Thus, our deeper understanding of the likely impacts of climatic change on bird populations requires that we study not only the immediate impacts of weather variations but also that we explore the correlations between bird distributions and climatic variables across Europe, since these reveal the patterns of long-term adjustment in which the effects of competitors and habitat change have played their part alongside the more direct effects of weather.

4.8 Further Work

These analyses have shown that it is possible to explain the variation in numbers of some rare birds in terms of weather variables and, thence, to make some predictions of the likely effects of possible climatic changes. It would be useful to extend the analyses by obtaining the data on a county-by-county basis for a much larger number of species and to strengthen the county-by-county analyses by using meteorological data from a larger number of stations (at least one per county). For passage migrants, it is clearly important to extend the analyses by incorporating meteorological data from their breeding ranges in Europe, since these are more relevant than British data. The effects of Sahelian rainfall should be more critically examined by using time-series approaches to remove trends in both rainfall and number of bird records and by correcting the number of records for observer effort. The annual numbers of records of species of American and Asian origin would provide a useful index of observer effort.

It would be valuable to complement analyses of the apparent effects of weather on numbers with geographically-based analyses. That is to say, analyses of the relationship between bird distributions and climatic variables should allow one to predict the effects of climatic change on species' ranges. BTO is currently (in collaboration with ITE) examining the effects of landuse on the distribution of British birds, using bird data mapped on 2x2km and 10x10km bases, and is developing expertise in the analysis of such spatial data. Limited climatic data are being incorporated into the current models but it would be valuable to include considerably more. It would be particularly valuable to use separate data for the late 1960s and late 1980s, since distributional data are available for these two periods, making it possible in principle to study the effects of climatic change directly.

Data on the distributions of breeding birds throughout Europe will become available during 1993, on a 50x50km base. Providing comparable climatic data are available, it would be particularly valuable to use these data sets to assess the correlations between bird distributions and climate, especially for species that are on the edge of their range in Britain but more widespread in continental Europe.

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Code	Name	Scientific name	Where	N	Mean	S.D.	Min.	Max.
SLAGR	Slavonian Grebe	*Podiceps auritus*	North	16	64	16.3	37	87
RENGR	Red-necked Grebe	*Podiceps grisegena*	North	17	0.7	1.0	0	3
BLNGR	Black-necked Grebe	*Podiceps nigricollis*	North	17	22	10.0	11	40
BITTE	Bittern	*Botaurus stellaris*	South	13	37	9.9	22	51
WHOSW	Whooper Swan	*Cygnus cygnus*	North	17	1	2.3	0	9
PINTA	Pintail	*Anas acuta*	Both	16	25	8.2	11	41
SCAUP	Scaup	*Aythya marila*	North	17	1	1.8	0	5
COMSC	Common Scoter	*Mellanita nigra*	North	17	100	37.4	35	159
GOLDE	Goldeneye	*Bucephala clangula*	North	17	37	32.1	3	90
REDKI	Red Kite	*Milvus milvus*	South	17	44	13.8	26	69
GOSHA	Goshawk	*Accipiter gentilis*	Both	17	61	51.3	4	176
AVOCE	Avocet	*Recurvirostra avosetta*	South	17	225	106.3	125	521
PURSA	Purple Sandpiper	*Calidris ferruginea*	North	17	1	1.3	0	4
MEDGU	Mediterranean Gull	*Larus melanocephalus*	South	17	4	4.1	0	15
LITGU	Little Gull	*Larus minutus*	South	16	0.1	1.1	0	4
BLARE	Black Redstart	*Phoenicurus ochruros*	South	8	91	21.4	68	119
FIELD	Fieldfare	*Turdus pilaris*	North	17	6	3.2	2	13
REDWI	Redwing	*Turdus iliacus*	North	17	33	23.1	6	79
CETWA	Cetti's Warbler	*Cettia cetti*	South	17	162	85.3	1	316
DARWA	Dartford Warbler	*Sylvia undata*	South	17	342	161.7	116	367
FIREC	Firecrest	*Regulus ignicapillus*	South	17	65	48.9	2	175
BRAMB	Brambling	*Fringilla montifringilla*	Both	17	2	3.0	0	10
SERIN	Serin	*Serinus serinus*	South	17	0.4	0.4	0	1
SCARO	Scarlet Rosefinch	*Carpodacus erythrinus*	North	17	0.9	1.4	0	5
LAPBU	Lapland Bunting	*Calcarius lapponicus*	North	17	1	3.6	0	14
CIRBU	Cirl Bunting	*Emberiza cirlus*	South	10	79	47.9	26	167

Table 1.1 Numbers of rare breeding birds (wintering in Europe) in the United Kingdom during 1973-89. Where = whether the species breeds predominantly in the north or south of the country; N = number of years for which records were available. See text for criteria used to include species in this list.

Code	Name	Scientific name	Where	N	Mean	S.D.	Min.	Max.
GARGA	Garganey	*Anas querquedula*	South	10	62	19.5	40	98
HONBU	Honey Buzzard	*Pernis apivorus*	South	17	6	4.3	2	20
MARHA	Marsh Harrier	*Circus aeruginosus*	South	17	25	17.1	6	66
MONHA	Montagu's Harrier	*Circus pygargus*	South	17	6	4.6	1	15
OSPRE	Osprey	*Pandion haliaetus*	North	17	26	16.4	7	54
HOBBY	Hobby	*Falco subbuteo*	South	17	195	90.5	60	390
SPOCR	Spotted Crake	*Porzana porzana*	Both	17	7	5.9	0	21
STOCU	Stone Curlew	*Burhinus oedicnemus*	South	14	96	32.5	45	143
TEMST	Temminck's Stint	*Calidris temminckii*	North	16	3	1.9	1	7
RUFF	Ruff	*Philomachus pugnax*	South	17	17	15.3	0	69
BLTGO	Black-tailed Godwit	*Limosa limosa*	South	17	59	16.4	26	87
WOOSA	Wood Sandpiper	*Tringa glareola*	North	17	4	2.7	1	12
RENPH	Red-necked Phalarope	*Phalaropus lobatus*	North	16	24	10.0	5	40
WRYNE	Wryneck	*Jynx torquilla*	South	17	9	5.9	1	21
HOOPO	Hoopoe	*Upupa epops*	South	17	0.2	1.5	0	4
SAVWA	Savi's Warbler	*Locustella luscinioides*	South	17	15	8.8	1	30
GOLOR	Golden Oriole	*Oriolus oriolus*	South	17	21	11.1	1	41
REBSH	Red-backed Shrike	*Lanius collurio*	South	17	21	11.1	1	41

Table 1.2 Numbers of rare breeding birds (wintering in Africa) in the United Kingdom during 1973-89. Where = whether the species breeds predominantly in the north or south of the country; N = number of years for which records were available. See text for criteria used to include species in this list.

Code	Name	Scientific name	Spring					Autumn				
			N	Mean	S.D.	Min.	Max.	N	Mean	S.D.	Min.	Max.
WHBDI	White-billed Diver	*Gavia adamsii*	33	3	1.9	0	7	33	0.7	1.0	0	4
KINEI	King Eider	*Somateria spectabilis*	33	3	2.8	0	11	33	2	2.0	0	7
GYRFA	Gyrfalcon	*Falco rusticolus*	33	2	1.7	0	7	33	1	1.2	0	4
CRANE	Crane	*Grus grus*	30	9	8.9	0	38	30	33	96.9	0	500
NUTCR	Nutcracker	*Nucifraga caryocatactes*	*					33	11	54.7	0	315
ARCRE	Arctic Redpoll	*Carduelis hornemanni*	33	0.9	2.2	0	10	33	4	7.1	0	32
SERIN	Serin	*Serinus serinus*	28	10	9.2	0	30	28	7	4.6	0	16
PARCR	Parrot Crossbill	*Loxia pytyopsittacus*	33	2	5.3	0	19	33	4	18.4	0	106

Table 1.3 Numbers of scarce passage migrants wintering in Europe recorded in Britain and Ireland during 1958-1990 in spring (January-June) and autumn (July-December). N = number of years for which records were available. Asterisks show species for which the annual mean frequency was less than 0.1 during the season in question. Species for which there were less than 100 records in total have been omitted.

Code	Name	Scientific name	Spring					Autumn				
			N	Mean	S.D.	Min.	Max.	N	Mean	S.D.	Min.	Max.
LITBI	Little Bittern	*Ixobrychus minutus*	33	4	3.8	0	18	33	1	1.4	0	5
NIGHE	Night Heron	*Nycticorax nycticorax*	33	6	9.6	0	43	33	2	1.7	0	6
LITEG	Little Egret	*Egretta garzetta*	33	11	10.1	0	47	33	9	23.4	0	113
PURHE	Purple Heron	*Ardea purpurea*	28	10	6.3	1	24	28	4	2.4	0	10
WHIST	White Stork	*Ciconia ciconia*	28	7	8.5	0	31	28	2	2.7	0	11
BLAKI	Black Kite	*Milvus migrans*	33	3	3.8	0	14	33	0.8	1.1	0	4
REFFA	Red-footed Falcon	*Falco vespertinus*	33	8	7.4	0	35	33	3	2.1	0	8
BLWST	Black-winged Stilt	*Himantopus himantopus*	33	3	6.3	0	25	33	1	2.0	0	7
TEMST	Temminck's Stint	*Calidris temminckii*	28	30	21.6	2	78	28	30	12.9	8	52
BRBSA	Broad-billed Sandpiper	*Limicola falcinellus*	33	3	3.2	0	12	33	1	1.1	0	4
GUBTE	Gull-billed Tern	*Gelochelidon nilotica*	33	3	2.5	0	9	33	3	2.7	0	13
CASTE	Caspian Tern	*Sterna caspia*	33	2	1.6	0	6	33	4	3.3	0	13
WWBTE	White-winged Black Tern	*Chlidonias leucopterus*	33	4	2.8	0	13	33	11	7.6	1	28
ALPSW	Alpine Swift	*Apus melba*	33	5	3.6	0	17	33	3	2.1	0	9
BEEEA	Bee-eater	*Merops apiaster*	33	7	7.1	0	21	33	3	5.0	0	26
HOOPO	Hoopoe	*Upupa epops*	28	95	40.1	31	200	28	25	15.4	4	78

Cont./

Table 1.4 Numbers of scarce passage migrants wintering in Africa recorded in Britain and Ireland during 1958-1990 in spring (January-June) and autumn (July-December). N = number of years for which records were available. Asterisks show species for which the annual mean frequency was less than 0.1 during the season in question. Species for which there were less than 100 records in total have been omitted.

Code	Name	Scientific name	Spring					Autumn				
			N	Mean	S.D.	Min.	Max.	N	Mean	S.D.	Min.	Max.
SHTLA	Short-toed Lark	*Calandrella brachydactyla*	33	3	1.6	0	6	33	7	4.4	0	20
RERSW	Red-rumped Swallow	*Hirundo daurica*	33	3	3.7	0	18	33	2	5.6	0	30
TAWPI	Tawny Pipit	*Anthus campestris*	28	4	2.2	0	8	28	19	11	5	50
RETPI	Red-throated Pipit	*Anthus cervinus*	33	2	2.3	0	10	33	3	2.7	0	10
BLUTH	Bluethroat	*Luscinia svecica*	28	62	120.1	5	590	28	33	28.0	8	110
AQUWA	Aquatic Warbler	*Acrocephalus paludicola*	*					28	22	21.5	5	100
GRRWA	Great Reed Warbler	*Acrocephalus arundinaceus*	33	3	2.1	0	7	33	0.8	0.9	0	3
ICTWA	Icterine Warbler	*Hippolais icterina*	28	10	11.1	2	60	28	61	38.4	18	160
MELWA	Melodious Warbler	*Hippolais polyglotta*	28	2	2.4	0	11	28	29	15.9	5	65
SUBWA	Subalpine Warbler	*Sylvia cantillans*	33	6	6.9	0	32	33	1	1.6	0	6
BARWA	Barred Warbler	*Sylvia nisoria*	28	0.3	0.5	0	2	28	103	54.2	15	200
LEGSH	Lesser Grey Shrike	*Lanius minor*	33	2	1.6	0	7	33	1	1.2	0	5
WOOSH	Woodchat Shrike	*Lanius senator*	33	8	5.1	1	20	33	6	3.5	1	13
ORTBU	Ortolan Bunting	*Emberiza hortulana*	28	13	17.3	1	92	28	31	12.1	17	60

Table 1.4 (Continued)

Code	Name	Scientific name	Spring					Autumn				
			N	Mean	S.D.	Min.	Max.	N	Mean	S.D.	Min.	Max.
WHRSA	White-rumped Sandpiper	*Calidris fuscicollis*	33	0.2	0.4	0	1	33	9	6.8	1	27
BAISA	Baird's Sandpiper	*Calidris bairdii*	33	0.1	0.4	0	2	33	4	3.3	0	12
LOBDO	Long-billed Dowitcher	*Limnodromus scolopaceus*	33	0.7	1.0	0	3	33	4	3.7	0	13
LOTSK	Long-tailed Skua	*Stercorarius longicaudus*	28	27	75.6	0	397	28	43	41.6	7	150
SABGU	Sabine's Gull	*Larus sabini*	28	6	7.0	0	30	28	66	70.5	8	310
RICPI	Richard's Pipit	*Anthus novaeseelandiae*	28	1	0.9	0	3	28	42	38.5	4	150
ASHWA	Greenish Warbler	*Phylloscopus trochiloides*	33	0.6	0.8	0	3	33	5	4.4	0	18
ARCWA	Arctic Warbler	*Phylloscopus borealis*	*									
PALWA	Pallas's Warbler	*Phylloscopus proregulus*	*					33	15	23.6	0	123
YEBWA	Yellow-browed Warbler	*Phylloscopus inornatus*	28	0.1	0.4	0	1	28	88	126.9	1	600
REBFL	Red-breasted Flycatcher	*Ficedula parva*	28	5	3.0	0	12	28	71	39.5	27	180
ROCST	Rose-coloured Starling	*Sturnus roseus*	33	2	1.9	0	8	33	4	2.8	0	13
SCARO	Scarlet Rosefinch	*Carpodacus erythrinus*	28	8	10.2	0	46	28	21	14.8	2	52
RUSBU	Rustic Bunting	*Emberiza rustica*	33	3	2.5	0	8	33	3	2.3	0	9
LITBU	Little Bunting	*Emberiza pusilla*	33	2	1.7	0	5	33	10	9.6	1	40
YEBBU	Yellow-browed Bunting	*Emberiza chrysophrys*	*					33	4	2.7	0	9

Table 2.1.3 Numbers of scarce passage migrants wintering outside Europe and Africa recorded in Britain and Ireland during 1958-1990 in spring (January-June) and autumn (July-December). N = number of years for which records were available. Asterisks show species for which the annual mean frequency was less than 0.1 during the season in question. Species for which there were less than 100 records in total have been omitted. Cory's Shearwater was also omitted since numbers depend critically on variable recording effort.

		North				South			
		Mean	s.d.	min	max	mean	s.d	min	max
Temperature	**1**	4.9	0.9	2.9	6.7	5.7	1.1	3.6	7.4
	2	10.9	0.4	9.9	11.7	12.2	0.6	10.9	13.4
	3	13.9	0.5	12.8	14.8	15.4	0.7	14.1	16.8
	4	4.6	0.7	2.9	6.2	5.5	0.7	2.8	6.6
Rain	**1**	69	23	32	118	62	25	8	125
	2	56	11	33	80	54	12	23	76
	3	80	15	38	106	65	18	39	118
	4	83	12	54	107	73	16	44	109
Frost	**1**	15.2	3.8	8.1	21.8	14.1	3.8	6.9	21.6
	2	17.9	4.4	7.7	24.2	14.6	4.4	5	23.2
	3	7.6	3.7	1.9	14.3	5.8	3.2	0.8	11.7
	4	64.0	8.6	46.9	86.3	58.7	9.3	39.3	87.4

Table 2.2.1 Means, standard deviations, minima and maxima of weather variables in the north and south of Britain during 1973-89. The values used to calculate these four parameters and the means across all weather stations in each part of the country. Temperatures are in °C, rainfall in cm, frost in number of days: for fuller definitions see text.

TABLE 2.2.4

Preliminary analyses of the associations between bird numbers and weather variables, as revealed by stepwise multiple regression in which all variables were available.

The tables give the number of significant relationships ($P < 0.05$), summed over all species, for :

A. National populations of breeding birds that winter in Europe.

B. National populations of breeding birds that winter in Africa.

C. Populations of breeding birds that winter in Europe, on a county-by-county basis.

D. Populations of breeding birds that winter in Africa, on a county-by-county basis.

Weather variables and seasons are explained in the text (section 2.2), the abbreviations for the former being:

TMEAN	screen temperature
TE30	temperature (as used in this report)
RAINT	precipitation (as used in this report)
RAIND	days with ≥0.2mm rain
WETD	wet days (as used in this report)
SNOWD	days with snow
GRASSD	frost (as used in this report)

Cont/

Table 2.2.4 (Continued)

A. National populations of breeding birds that winter in Europe.

	SEASON					
	1	2	3	4	5	Total
TMEAN	1	3	3	3	2	12
TE30	3	4	3	4	0	14
RAINT	9	2	6	1	5	23
RAIND	3	2	3	1	5	14
WETD	2	2	2	2	5	13
SNOWD	3	-	-	3	3	9
GRASSD	2	2	3	4	1	12

B. National populations of breeding birds that winter in Africa.

	SEASON		
	2	3	Total
TMEAN	2	1	3
TE30	2	3	5
RAINT	1	1	2
RAIND	0	2	2
WETD	1	4	5
GRASSD	0	2	2
SAHELA	0		0
SAHELB	1		1

Cont/

Table 2.2.4 (Continued)

C. Populations of breeding birds that winter in Europe, on a county-by-county basis.

	SEASON					
	1	2	3	4	5	Total
TMEAN	2	2	0	2	1	7
TE30	1	3	2	7	2	15
RAINT	3	5	4	1	5	18
RAIND	2	1	5	5	4	17
WETD	4	1	3	1	0	9
SNOWD	5	-	-	1	1	7
GRASSD	3	6	3	11	2	25

D. Populations of breeding birds that winter in Africa, on a county-by-county basis.

	SEASON		
	2	3	Total
TMEAN	1	1	2
TE30	1	7	8
RAINT	1	4	5
RAIND	2	6	8
WETD	5	3	8
GRASSD	0	4	4
SAHELA	5		5
SAHELB	4		4

Code	Where	Temperature					Frosts					Precipitation				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
SLAGR	North	0.09	0.27	0.36	-0.03	-0.13	0.32	0.26	-0.60*	0.19	0.02	0.05	-0.28	0.23	-0.10	0.06
RENGR	North	-0.49*	0.05	-0.23	0.22	-0.05	0.31	-0.17	-0.05	-0.20	0.06	0.39	-0.02	0.47	-0.03	0.35
BLNGR	North	-0.26	-0.23	-0.23	0.02	-0.04	0.02	-0.29	0.03	0.04	-0.02	0.57*	0.48	0.32	0.08	0.29
BITTE	South	0.48	0.21	0.09	-0.05	0.50	-0.38	0.03	-0.53	-0.17	-0.50	0.21	-0.27	-0.18	0.26	0.35
WHOSW	North	-0.38	-0.05	-0.33	0.31	-0.02	-0.03	-0.05	-0.14	-0.29	0.05	0.48	0.10	0.25	0.13	0.46
PINTA	Both	0.09	0.38	-0.31	-0.00	0.21	-0.36	-0.37	-0.31	0.10	-0.17	0.67**	-0.32	0.47	-0.06	0.74***
SCAUP	North	-0.27	-0.04	-0.43	0.39	0.13	-0.01	-0.36	0.11	-0.37	-0.11	0.37	0.10	0.23	-0.19	0.55
COMSC	North	0.11	-0.24	-0.15	-0.02	-0.22	0.05	0.33	0.19	-0.10	0.40	-0.33	0.01	-0.38	0.08	-0.32
GOLDE	North	-0.34	-0.18	-0.18	-0.11	-0.22	0.04	-0.03	-0.23	0.16	0.02	0.69**	0.15	0.60*	0.08	0.70**
REDKI	South	-0.39	0.05	0.10	0.03	-0.09	0.07	0.14	0.15	0.48	-0.05	0.37	0.27	0.23	-0.13	0.42
GOSHA	Both	-0.42	0.03	-0.05	0.06	-0.19	0.11	0.07	-0.04	0.16	-0.04	0.47	0.13	0.65**	0.08	0.62**
AVOCE	South	-0.37	0.11	0.00	0.37	0.05	0.10	0.09	0.26	0.15	-0.04	0.24	0.16	0.35	-0.33	0.17
PURSA	North	-0.30	-0.23	-0.25	0.10	-0.05	-0.04	0.10	-0.07	-0.11	0.06	0.54*	0.17	0.52*	0.03	0.48
MEDGU	South	-0.40	0.31	0.36	0.08	0.04	0.18	0.19	0.03	0.50*	-0.16	0.40	0.17	0.27	-0.09	0.40
LITGU	South	-0.35	-0.42	-0.29	0.23	-0.06	0.14	-0.01	0.20	-0.27	-0.24	-0.11	0.18	0.27	0.23	0.22
BLARE	South	-0.83*	-0.28	0.03	-0.26	-0.47	0.37	0.17	0.29	0.44	-0.11	0.17	0.43	0.39	0.49	0.78*

Cont./

Table 3.1.1.1 Pearson correlation coefficients between annual breeding populations of rare breeding species that overwinter in Europe and weather variables in five time periods. (Levels of significance shown by * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$). The total numbers of positive and negative associations are also shown for each species. Bird numbers were log-transformed prior to the analyses. The weather variables and time periods are defined in the text.

Code	Where	Temperature					Frosts					Precipitation				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
FIELD	North	-0.07	0.49*	-0.07	0.39	0.30	0.24	0.02	0.17	-0.32	-0.19	0.20	-0.31	0.40	0.08	0.27
REDWI	North	-0.10	-0.19	-0.37	0.04	-0.01	-0.10	0.08	0.21	-0.14	0.22	0.48*	0.26	0.40	0.38	0.09
CETWA	South	-0.23	0.13	0.41	-0.19	-0.08	-0.18	0.42	-0.33	0.50*	-0.17	0.37	0.02	0.26	0.13	0.52*
DARWA	South	-0.15	0.20	0.24	0.51*	0.07	0.09	-0.14	0.26	-0.50*	-0.02	-0.36	-0.02	0.43	-0.01	-0.27
FIREC	South	-0.31	0.43	0.10	0.26	0.02	-0.03	0.19	0.06	0.14	-0.22	0.34	-0.08	0.52*	-0.08	0.55*
BRAMB	Both	-0.01	-0.09	0.22	-0.41	-0.19	-0.30	0.11	-0.23	0.51*	0.19	0.66**	0.25	0.17	0.31	0.42
SERIN	South	-0.14	-0.19	0.10	-0.13	-0.08	0.16	0.42	0.19	0.39	0.10	0.25	0.38	0.22	0.00	0.21
SCARO	North	-0.11	-0.16	-0.19	-0.00	-0.20	0.01	-0.12	-0.03	0.00	0.07	0.38	0.27	0.50*	-0.10	0.24
LAPBU	North	0.14	0.12	0.21	-0.25	-0.26	-0.39	-0.04	-0.70**	0.38	-0.06	0.17	-0.28	-0.05	0.01	0.41
CIRBU	South	0.67*	0.58	0.13	0.19	0.13	-0.38	-0.30	-0.33	-0.16	0.22	0.19	-0.09	0.41	-0.32	-0.53
Total +		6	14	13	15	9	15	15	13	15	11	23	17	23	15	23
Total -		20	12	13	11	17	11	11	13	11	15	3	9	3	11	3

Table 3.1.1.1 (Continued)

Species Code	Where	Temperature					Frosts					Precipitation					Total R^2
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
SLAGR	North						0.22**	0.10**	-0.36***					0.12*			0.85
RENGR	North	-0.24												0.13			0.57
BLNGR	North											0.33*	0.12				0.45
BITTE	South								-0.29***	-0.09						0.30*	0.68
WHOSW	North	-0.11			0.16*							0.23*					0.50
PINTA	Both		0.18***		0.03		-0.10*				0.03*				0.03	0.55**	0.92
SCAUP	North		-0.02*				-0.02	-0.16***		-0.34***		-0.04**		-0.08		0.30***	0.96
COMSC	North										0.16	-0.13					0.28
GOLDE	North											0.09				0.49	0.57
REDKI	South				0.38**					0.23***			0.08	0.09*			0.77
GOSHA	Both	-0.03*			0.11***	-0.18**	0.03**			0.05***			0.08**	0.43***			0.96
AVOCE	South	-0.14													-0.19		0.32
PURSA	North											0.29*					0.29
MEDGU	South	-0.04			0.51***					0.25***		0.02		0.10*	0.02*		0.94
LITGU	South		-0.18**											0.38**	0.08		0.64
BLARE	South	-0.70			-0.03			-0.09								0.19	1.00
FIELD	North		0.24*														0.24
REDWI	North											0.23*					0.23
CETWA	South			0.30***		-0.05	0.06					0.05*				0.27**	0.78

Cont/

Table 3.1.1.2 Results of multiple regressions of annual breeding populations of rare breeding species that overwinter in Europe and weather variables in five time periods. Figures are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$. ** for $P<0.01$, *** for $P<0.001$), using the 'stepwise' method. Signs indicate the direction of the association. The total numbers of positive and negative associations are given for each variable and the total R^2 values for each species. Bird numbers were log-transformed prior to the analyses. The weather variables and time periods are defined in the text.

Species Code	Where	Temperature					Frosts					Precipitation					Total R^2
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
DARWA	South			0.13	0.26*												0.39
FIREC	South	-0.07*	0.17**		0.13**				-0.04		0.13					0.31***	0.85
BRAMB	Both			0.06**							0.10*	0.44***			0.07*		0.79
SERIN	South	0.06	-0.08*					0.18*		0.18*			0.18**	0.15***		-0.04	0.87
SCARO	North												0.17	0.25*			0.42
LAPBU	North								-0.49**								0.49
CIRBU	South	0.45**		-0.04**			0.02**	-0.08**					0.01**	0.19**	0.00	-0.21**	1.00
Total +		2	3	3	7	0	4	2	0	4	4	8	6	9	5	7	
Total -		7	3	1	1	2	2	3	4	2	0	2	0	1	1	2	

Table 3.1.1.2 (Continued)

		South		North	
		+	-	+	-
Temperature	1	2	9	3	9
	2	8	3	4	8
	3	10	1	2	10
	4	7	4	6	6
	5	6	5	2	10
	Total	33	22	17	43
Frosts	1	7	4	7	5
	2	8	3	5	7
	3	8	3	5	7
	4	7	4	4	8
	5	2	9	8	4
	Total	32	23	29	31
Precipitation	1	9	2	11	1
	2	7	4	8	3
	3	10	1	10	2
	4	5	6	8	4
	5	9	2	11	1
	Total	40	15	48	11

Table 3.1.1.3 Numbers of positive and negative correlations (including non-significant ones) between numbers of rare breeding species that overwinter in Europe and weather variables, according to whether the species breed predominantly in the north or south of Britain.

Code	Where	Temperature		Frosts		Precipitation		Wet Days		Sahel	
		2	3	2	3	2	3	2	3	2	3
GARGA	South	0.72*	-0.15	-0.62	-0.20	-0.09	0.37	-0.08	0.40	0.50	0.48
HONBU	South	0.27	0.06	0.09	-0.11	-0.41	0.43	-0.39	0.45	0.52*	0.53*
MARHA	South	0.08	0.25	0.19	0.02	0.19	0.25	0.18	0.28	-0.12	-0.13
MONHA	South	-0.01	0.00	0.23	-0.01	0.15	0.19	0.09	0.26	-0.03	-0.03
OSPRE	North	-0.02	-0.01	0.04	0.30	0.36	0.18	0.32	0.22	-0.19	-0.18
HOBBY	South	0.12	0.16	0.25	0.05	0.20	0.37	0.11	0.47	-0.14	-0.13
SPOCR	Both	0.08	0.22	0.04	-0.25	0.17	0.38	0.02	0.27	-0.06	-0.32
STOCU	South	-0.01	-0.24	-0.03	0.00	-0.33	0.38	-0.22	0.45	0.05	0.06
TEMST	North	0.10	0.14	-0.29	-0.22	-0.33	0.05	-0.18	0.03	0.68**	0.69**
RUFF	South	0.39	-0.09	-0.13	0.40	-0.06	0.32	-0.13	0.28	0.27	0.29
BLTGO	South	-0.05	0.21	0.20	-0.24	0.03	-0.15	0.20	-0.20	0.30	0.30
WOOSA	North	-0.16	-0.02	0.05	-0.33	0.11	-0.05	0.16	-0.00	0.16	0.15
RENPH	North	0.06	0.03	0.29	-0.46	-0.26	0.08	-0.30	0.20	0.38	0.37
WRYNE	South	-0.01	0.52*	0.08	-0.58*	0.02	-0.05	0.08	-0.03	0.05	0.02
HOOPO	South	0.02	0.63**	-0.22	-0.68**	-0.29	-0.06	-0.22	-0.09	-0.23	-0.27
SAVWA	South	-0.06	0.17	0.45	-0.29	0.17	-0.20	0.19	-0.23	-0.16	-0.18
GOLOR	South	0.02	0.23	0.92	-0.27	-0.05	0.23	-0.03	0.30	0.29	0.28
REBSH	South	0.02	0.23	0.92	-0.27	-0.05	0.23	-0.03	0.30	0.29	0.28
Total +		11	13	13	5	9	13	9	13	11	11
Total -		7	5	5	13	9	5	9	5	7	7

Table 3.1.2.1 Pearson correlation coefficients between annual breeding populations of rare breeding species that overwinter in Africa and weather variables in two time periods. (Levels of significance shown by * for P<0.05, ** for P<0.01, *** for P<0.001). The total numbers of positive and negative associations are also shown for each species. Bird numbers were log-transformed prior to the analyses. The weather variables and time periods are defined in the text.

Species Code	Where	Temperature		Frosts		Precipitation		Wet Days		Sahel		Total R^2
		2	3	2	3	2	3	2	3	A	B	
GARGA	South	0.53**		-0.30*								0.82
HONBU	South			0.12							0.28**	0.40
MARHA	South											—
MONHA	South											—
OSPRE	North					0.18						0.18
HOBBY	South					0.19			0.22*			0.41
SPOCR	Both						0.15					0.15
STOCU	South								0.21			0.21
TEMST	North										0.49**	0.49
RUFF	South	0.22*			0.16*							0.38
BLTGO	South			-0.20								0.20
WOOSA	North											—
RENPH	North				-0.20				0.13			0.32
WRYNE	South				-0.33***		0.14*	0.15**				0.63
HOOPO	South	-0.09**	0.16**		-0.47*		0.06*		-0.47*	0.06*	0.05*	0.89
SAVWA	South											—
GOLOR	South											—
REBSH	South											—
Total +		2	1	1	1	2	3	1	3	1	3	
Total -		1	0	1	2	0	0	0	0	0	0	

Table 3.1.2.2 Results of multiple regressions of annual breeding populations of rare breeding species that overwinter in Africa and weather variables in two time periods. Figures are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$. ** for $P<0.01$, *** for $P<0.001$), using the 'stepwise' method. Signs indicate the direction of the association. The total numbers of positive and negative associations are given for each variable and the total R^2 values for each species (— indicates that no variables entered the regression for that species). Bird numbers were log-transformed prior to the analyses. The weather variables and time periods are defined in the text.

		South		North	
		+	-	+	-
Temperature	2	2	3	8	5
	3	3	2	10	3
Precipitation	2	3	2	6	7
	3	4	1	9	4
Wet Days	2	3	2	6	7
	3	4	1	9	4
Frosts	2	3	2	9	4
	3	2	3	4	9
Sahel	A	3	2	8	5
	B	3	2	8	5

Table 3.1.2.3 Numbers of positive and negative correlations (including non-significant ones) between numbers of rare breeding species that overwinter in Africa and weather variables, according to whether the species breed predominantly in the north or south of Britain.

Weather Variable	CT	HI	SU	GR	TR				Total		Ancova	National analyses	
									+	-		r	partial R^2
Temperature 1											+	0.09	
Temperature 2					0.10**				1		-	0.27	
Temperature 3											+	0.36	
Temperature 4				0.45**					1		+	-0.03	
Temperature 5											+	-0.13	
Precipitation 1											-	0.05	
Precipitation 2		-0.13	0.20*	-0.09					1	2	-	-0.28	
Precipitation 3					-0.36***					1	-*	0.23	0.12*
Precipitation 4					-0.17***					1	-	-0.10	
Precipitation 5				0.20**					1		-	0.06	
Frost 1											+	0.32	0.22**
Frost 2											+	0.26	0.10**
Frost 3											+	-0.60*	-0.36***
Frost 4	-0.26*		-0.15		0.25***				1	2	-	0.19	
Frost 5			0.15*		-0.05*				1	1	-	0.02	
Total R^2	0.26	0.13	0.50	0.74	0.93								

Table 3.2.2 Results of county-by-county analyses of relationships between numbers of breeding Slavonian Grebe and weather variables (see text for definitions of the latter). Figures in the bulk of the table are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, and *** $P<0.001$, using the 'stepwise' method. Signs indicate the direction of the associations. Also given are the numbers of counties showing positive and negative partial R^2 values and the total R^2 for each county. (— indicates that no weather variable was significant at $P<0.15$). Ancova indicates the directions of the associations between numbers and the weather variables, as shown by analysis of covariance of all the counties taken together. The figures for national analyses refer to the results obtained from Pearson correlation analyses (r^2) and multiple regression analyses (partial R^2) for the humped national data sets. Bird numbers were log-transformed prior to all analyses. For explanation of county codes, see Appendix 1.

Weather Variable	CT	HI	SU	SC	TR	SH	DR		Total		Ancova	National analyses	
									+	-		r	partial R^2
Temperature 1											-	0.11	
Temperature 2											+	-0.24	
Temperature 3				0.15*		0.01*			1		+	-0.15	
Temperature 4				0.37**					2		+	-0.02	
Temperature 5						0.14**					-	-0.22	
Precipitation 1			0.30*			0.14**			2		+	-0.33	-0.13
Precipitation 2				0.01					2		-	0.01	
Precipitation 3				0.48**					1		+	-0.38	
Precipitation 4											+	0.08	
Precipitation 5											+	-0.32	
Frost 1			0.08			-0.00*			1	1	+	0.05	
Frost 2						-0.04**				1	-	0.33	
Frost 3						-0.66**				1	-	0.19	
Frost 4			-0.29***							1	-**	-0.10	
Frost 5											-	0.40	0.16
Total R^2	—	—	0.67	1.0	—	1.0	—						

Table 3.2.3 Results of county-by-county analyses of relationships between numbers of breeding Common Scoter and weather variables (see text for definitions of the latter). Figures in the bulk of the table are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, and *** $P<0.001$, using the 'stepwise' method. Signs indicate the direction of the associations. Also given are the numbers of counties showing positive and negative partial R^2 values and the total R^2 for each county. (— indicates that no weather variable was significant at $P<0.15$). Ancova indicates the directions of the associations between numbers and the weather variables, as shown by analysis of covariance of all the counties taken together. The figures for national analyses refer to the results obtained from Pearson correlation analyses (r^2) and multiple regression analyses (partial R^2) for the humped national data sets. Bird numbers were log-transformed prior to all analyses. For explanation of county codes, see Appendix 1.

Weather Variable	SK	NK	ES	KE					Total		Ancova	National analyses	
									+	-		r	partial R^2
Temperature 1		0.05**							1		-	-0.37	-0.14
Temperature 2		0.03*							1		+	0.11	
Temperature 3			0.30**						1		+	0.00	
Temperature 4		0.03*							1		-	0.37	
Temperature 5											-	0.05	
Precipitation 1			0.17**						1		+**	0.24	
Precipitation 2	0.36***								1		+*	0.16	
Precipitation 3											+	0.35	
Precipitation 4			0.17**								-	-0.33	-0.19
Precipitation 5		0.29***							2		+**	0.17	
Frost 1		0.12**							1		+	0.10	
Frost 2	-0.35***									1	-	0.09	
Frost 3											+	0.26	
Frost 4		0.44***							1		+*	0.15	
Frost 5	0.07								1		+	-0.04	
Total R^2	0.78	0.96	0.64	—									

Table 3.2.4 Results of county-by-county analyses of relationships between numbers of breeding Avocet and weather variables (see text for definitions of the latter). Figures in the bulk of the table are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, and *** $P<0.001$, using the 'stepwise' method. Signs indicate the direction of the associations. Also given are the numbers of counties showing positive and negative partial R^2 values and the total R^2 for each county. (— indicates that no weather variable was significant at $P<0.15$). Ancova indicates the directions of the associations between numbers and the weather variables, as shown by analysis of covariance of all the counties taken together. The figures for national analyses refer to the results obtained from Pearson correlation analyses (r^2) and multiple regression analyses (partial R^2) for the humped national data sets. Bird numbers were log-transformed prior to all analyses. For explanation of county codes, see Appendix 1.

Weather Variable	HA	NK	DO	SX	DV	SK	CA	GM	KE	CO	OX	ES	Total		Ancova	National analyses	
													+	-		r	partial R^2
Temperature 1															+	-0.23	
Temperature 2															+	0.13	
Temperature 3															+	0.41	0.30***
Temperature 4				0.69***		0.45***	0.58**		0.93*		0.48**	0.45***	6		+**	-0.19	
Temperature 5															+*	-0.08	-0.05
Precipitation 1	0.16		0.30		0.48**	0.11**						0.11**	5		+	0.37	0.05*
Precipitation 2					0.09**								1		-	0.02	
Precipitation 3		0.13					-0.27			0.31*	-0.05		2	2	+	0.26	
Precipitation 4															+	0.13	
Precipitation 5			0.16		-0.06*	0.06*						0.06*	3	1	+	0.52*	0.27**
Frost 1					-0.08*			-0.98*			-0.09*			3	-	-0.18	0.06
Frost 2															-	0.42	
Frost 3					-0.10	-0.10*						-0.10*		3	+	-0.33	
Frost 4		0.42**											1		-**	0.50*	
Frost 5					-0.16*	-0.08**			-0.05		-0.11*	-0.08**		5	-	-0.17	
Total R^2	0.16	0.55	0.46	0.69	0.97	0.80	0.85	0.98	0.97	0.31	0.72	0.80					

Table 3.2.5 Results of county-by-county analyses of relationships between numbers of breeding Cetti's Warbler and weather variables (see text for definitions of the latter). Figures in the bulk of the table are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, and *** $P<0.001$, using the 'stepwise' method. Signs indicate the direction of the associations. Also given are the numbers of counties showing positive and negative partial R^2 values and the total R^2 for each county. (— indicates that no weather variable was significant at $P<0.15$). Ancova indicates the directions of the associations between numbers and the weather variables, as shown by analysis of covariance of all the counties taken together. The figures for national analyses refer to the results obtained from Pearson correlation analyses (r^2) and multiple regression analyses (partial R^2) for the humped national data sets. Bird numbers were log-transformed prior to all analyses. For explanation of county codes, see Appendix 1.

Weather Variable	HA	SR	DO	SX	DV	CO			Total		Ancova	National analyses	
									+	-		r	partial R^2
Temperature 1											+	-0.15	
Temperature 2											+	0.20	
Temperature 3											+	0.24	0.13
Temperature 4			0.35	-0.11					1	1	+	0.51*	0.26*
Temperature 5				0.20*					1		+	0.07	
Precipitation 1			-0.14							1	-	-0.36	
Precipitation 2											+	-0.02	
Precipitation 3											+	0.43	
Precipitation 4					-0.50*					1	-	-0.01	
Precipitation 5				-0.15						1	-	-0.27	
Frost 1											-	0.09	
Frost 2					-0.21*					1	+	-0.14	
Frost 3				0.15*					1		-	0.26	
Frost 4		0.30*			-0.17*				1	1	-	-0.50*	
Frost 5											-	-0.02	
Total R^2	—	0.30	0.49	0.61	0.89								

Table 3.2.6 Results of county-by-county analyses of relationships between numbers of breeding Dartford Warbler and weather variables (see text for definitions of the latter). Figures in the bulk of the table are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, and *** $P<0.001$, using the 'stepwise' method. Signs indicate the direction of the associations. Also given are the numbers of counties showing positive and negative partial R^2 values and the total R^2 for each county. (— indicates that no weather variable was significant at $P<0.15$). Ancova indicates the directions of the associations between numbers and the weather variables, as shown by analysis of covariance of all the counties taken together. The figures for national analyses refer to the results obtained from Pearson correlation analyses (r^2) and multiple regression analyses (partial R^2) for the humped national data sets. Bird numbers were log-transformed prior to all analyses. For explanation of county codes, see Appendix 1.

Weather Variable	CT	HI	SU	SH					Total		Ancova
									+	-	
Temperature 2											+
Temperature 3											+
Wet Days 2	-0.12									1	-
Wet Days 3											-
Precipitation 2		-0.19	-0.13*							2	-
Precipitation 3			-0.07							1	+
Frost 2			-0.43***						1		+
Frost 3											+
Total R^2	0.12	0.19	0.63	—							

Table 3.2.7 Results of county-by-county analyses of relationships between numbers of breeding Whimbrel and weather variables (see text for definitions of the latter). Figures in the bulk of the table are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, and *** $P<0.001$, using the 'stepwise' method. Signs indicate the direction of the associations. Also given are the numbers of counties showing positive and negative partial R^2 values and the total R^2 for each county. (— indicates that no weather variable was significant at $P<0.15$). Ancova indicates the directions of the associations between numbers and the weather variables, as shown by analysis of covariance of all the counties taken together. The figures for national analyses refer to the results obtained from Pearson correlation analyses (r^2) and multiple regression analyses (partial R^2) for the humped national data sets. Bird numbers were log-transformed prior to all analyses. For explanation of county codes, see Appendix 1.

Weather Variable	CT	HI	SU	GR	TR	SH			Total		Ancova	National analyses	
									+	-		r	partial R^2
Temperature 2											+	-0.16	
Temperature 3					0.23*				1		+*	-0.02	
Wet Days 2											-	0.16	
Wet Days 3											-	-0.00	
Precipitation 2											-	0.11	
Precipitation 3						-0.17					-	-0.05	
Frost 2	-0.13									1	-	0.05	
Frost 3										1	-	-0.33	
Total R^2	0.13	—	—	—	0.23	0.17							—

Table 3.2.8 Results of county-by-county analyses of relationships between numbers of breeding Wood Sandpiper and weather variables (see text for definitions of the latter). Figures in the bulk of the table are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, and *** $P<0.001$, using the 'stepwise' method. Signs indicate the direction of the associations. Also given are the numbers of counties showing positive and negative partial R^2 values and the total R^2 for each county. (— indicates that no weather variable was significant at $P<0.15$). Ancova indicates the directions of the associations between numbers and the weather variables, as shown by analysis of covariance of all the counties taken together. The figures for national analyses refer to the results obtained from Pearson correlation analyses (r^2) and multiple regression analyses (partial R^2) for the humped national data sets. Bird numbers were log-transformed prior to all analyses. For explanation of county codes, see Appendix 1.

Weather variable	NH	LI	LE	KE	LO	SR	HA	SX	CO	NK	WM	HF	GL	WC
Wet Days 2														
Wet Days 3						0.17								
Temperature 2														
Temperature 3	-0.12													
Precipitation 2	0.55**												-0.16	
Precipitation 3								0.14			-0.85			
Frost 2	0.12*									-0.24*		0.29		-0.33*
Frost 3												-0.11		
Total R^2	0.79	-	-	-	-	0.17	-	0.14	-	0.24	0.85	0.40	0.16	0.33

Cont./

Table 3.2.9 Results of county-by-county analyses of relationships between numbers of breeding Hobby and weather variables (see text for definitions of the latter). Figures in the bulk of the table are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, and *** $P<0.001$, using the 'stepwise' method. Signs indicate the direction of the associations. Also given are the numbers of counties showing positive and negative partial R^2 values and the total R^2 for each county. (— indicates that no weather variable was significant at $P<0.15$). Ancova indicates the directions of the associations between numbers and the weather variables, as shown by analysis of covariance of all the counties taken together. The figures for national analyses refer to the results obtained from Pearson correlation analyses (r^2) and multiple regression analyses (partial R^2) for the humped national data sets. Bird numbers were log-transformed prior to all analyses. For explanation of county codes, see Appendix 1.

Weather variable	OX	WT	WK	HT	BD	DV	SO	SK	ES	CA	Total		Ancova	National analyses	
											+	-		r	partial R^2
Wet Days 2						-0.16						1	+**	0.11	
Wet Days 3			0.34*			-0.84*				0.31	3	1	+	0.47	0.22*
Temperature 2								0.25*	0.23*		2		+*	0.12	
Temperature 3												1	+*	0.16	
Precipitation 2									0.31**		2	1	+*	0.20	0.19
Precipitation 3							-0.17				1	2	+	0.37	
Frost 2		0.24			0.31*						4	2	+	0.25	
Frost 3												1	+	0.05	
Total R^2	-	0.24	0.34	-	0.31	1.0	0.17	0.25	0.54	0.31					

Table 3.2.9 (Continued)

Species Code	Temperature					Frosts					Precipitation				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
WHBDI	-0.13	-0.19	-0.01	0.03	-0.05	0.42*	0.56***	0.23	0.27	0.13	0.26	-0.12	0.05	0.95	0.47**
KINEI	0.12	-0.14	0.07	0.39*	0.04	0.35	0.57***	0.41*	-0.13	0.28	0.04	-0.19	-0.05	-0.05	0.15
GYRFA	0.20	-0.06	0.09	0.41*	0.19	-0.09	0.20	0.03	-0.25	0.19	0.21	0.07	-0.46**	0.04	0.03
CRANE	0.21	-0.13	0.26	0.20	-0.08	-0.03	0.51**	-0.01	0.10	0.35	0.24	-0.09	0.01	0.37*	0.23
NUTCR†															
ARCRE	0.13	-0.16	0.03	-0.19	-0.45*	0.13	0.21	-0.06	0.27	0.47**	-0.27	-0.25	-0.12	-0.29	-0.11
SERIN	0.27	-0.23	0.17	0.45*	0.11	0.03	0.62***	0.34	-0.10	0.28	0.40*	0.01	0.12	-0.02	0.30
PARCR	-0.13	-0.23	-0.01	-0.21	-0.16	0.32	0.34	-0.02	0.42	0.08	-0.01	-0.12	-0.01	-0.07	0.11
Total +	5	0	5	5	3	5	7	4	4	7	5	2	3	3	6
Total -	2	7	2	2	4	2	0	3	3	0	2	5	4	4	1

Table 3.3.1 Pearson correlation coefficients between annual numbers of spring passage migrants (wintering in Europe) on weather in five time periods. (Levels of significance shown by * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$.) The total numbers of positive and negative associations are also shown for each species. Bird numbers were log-transformed prior to the analyses. Species marked † were too infrequent in spring to be included. The weather variables and time periods are defined in the text.

Species Code	Temperature				Frosts				Precipitation			
	4	5	6	7	4	5	6	7	4	5	6	7
WHBDI	0.23	-0.22	-0.42*	0.05	0.13	0.35	0.54**	0.28	0.05	0.30	0.11	-0.20
KINEI	0.44*	0.35	-0.19	-0.05	-0.33	-0.01	0.30	0.66***	-0.04	0.08	-0.05	-0.24
GYRFA	-0.02	0.37*	0.23	-0.02	0.06	-0.32	0.12	0.03	-0.17	0.17	-0.52**	0.15
CRANE	-0.50**	-0.11	0.21	0.10	0.62***	0.06	0.13	0.10	-0.25	0.46*	-0.28	0.16
NUTCR	-0.15	-0.16	-0.05	0.22	0.09	0.03	-0.21	-0.24	-0.23	-0.10	0.40*	0.06
ARCRE	0.39*	0.17	0.25	0.13	-0.24	0.20	0.17	0.08	0.07	0.07	-0.16	0.09
SERIN	0.27	0.18	-0.12	-0.15	-0.06	0.35	0.33	0.64***	0.22	0.09	0.26	-0.12
PARCR	0.20	0.04	0.29	-0.12	0.13	-0.13	-0.19	0.27	-0.15	0.25	0.09	0.29
Total +	5	5	4	4	5	5	6	7	3	7	4	5
Total -	3	3	4	4	3	3	2	1	5	1	4	3

Table 3.3.2 Pearson correlation coefficients between annual numbers of autumn passage migrants (wintering in Europe) on weather in four time periods. (Levels of significance shown by * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$.) The total numbers of positive and negative associations are also shown for each species. Bird numbers were log-transformed prior to the analyses. The weather variables and time periods are defined in the text.

Species Code	Temperature		Frosts		Precipitation		Wet Days		Sahel	
	2	3	2	3	2	3	2	3	A	B
LITBI	-0.15	0.18	-0.12	-0.17	0.02	-0.35	0.19	-0.32	0.12	-0.20
NIGHE	0.03	0.12	0.30	0.05	-0.01	-0.13	-0.13	-0.01	-0.27	-0.12
LITEG	-0.06	0.24	0.35	0.36*	0.05	-0.18	-0.08	-0.14	-0.43*	-0.32
PURHE	-0.35	0.03	0.61***	0.33	-0.05	-0.02	-0.07	0.01	-0.37	-0.40*
WHIST	0.06	0.27	0.39	0.29	-0.18	-0.02	-0.25	-0.06	-0.44*	-0.27
BLAKI	-0.12	-0.06	0.57***	0.36*	-0.21	0.19	-0.21	0.25	-0.48**	-0.36*
REFFA	-0.03	0.06	0.39*	0.13	-0.21	-0.18	-0.22	-0.14	-0.37*	0.15
BLWST	-0.16	-0.06	0.18	0.33	0.20	-0.06	0.09	0.01	-0.20	-0.06
TEMST	-0.36	-0.03	0.74***	0.45*	-0.24	0.01	-0.23	0.02	-0.67***	-0.19
BRBSA	-0.29	-0.10	0.56**	0.52**	-0.06	-0.00	-0.11	-0.00	-0.76***	-0.09
GUBTE	0.07	-0.10	-0.28	0.13	0.09	-0.11	0.13	-0.17	0.26	-0.00
CASTE	-0.03	0.05	0.25	0.32	-0.11	0.14	0.01	0.08	-0.25	-0.49**
WWBTE	0.21	0.32	0.13	0.08	-0.22	-0.19	-0.24	-0.20	-0.20	-0.04
ALPSW	-0.36*	0.09	0.42*	0.34	0.25	-0.24	0.15	-0.28	-0.57***	-0.18
BEEEA	-0.15	-0.17	0.33	0.23	-0.05	0.08	-0.08	0.01	-0.52**	0.02
HOOPO	-0.24	0.06	0.11	0.14	0.03	-0.14	0.21	-0.11	-0.02	-0.06
SHTLA	-0.25	0.27	0.41*	0.08	0.26	-0.20	0.20	-0.17	-0.36*	-0.16
RERSW	-0.12	0.22	0.43*	0.18	-0.07	-0.14	-0.11	-0.11	-0.29	-0.11
TAWPI	-0.27	0.27	0.65***	0.09	-0.13	-0.22	-0.13	-0.16	-0.58**	-0.10
RETPI	-0.30	-0.25	0.39*	0.50**	-0.17	0.04	-0.06	0.04	-0.32	-0.04
BLUTH	-0.29	0.22	0.74***	0.24	-0.30	-0.16	-0.33	-0.13	-0.53**	-0.09
AQUWA†										
GRRWA	0.08	0.18	0.07	-0.32	-0.34	-0.20	-0.20	-0.18	0.04	0.03
ICTWA	-0.40*	0.24	0.42*	0.24	0.28	-0.14	0.20	-0.14	-0.48**	-0.37
MELWA	-0.23	-0.10	0.39	0.21	-0.10	-0.13	-0.12	-0.07	-0.39*	0.08
SUBWA	-0.10	0.08	0.51**	0.32	-0.08	0.30	-0.16	0.30	-0.47**	-0.32
BARWA	0.04	0.36	0.04	-0.41*	-0.01	-0.32	-0.06	-0.29	0.04	-0.28
LEGSH	0.18	0.32	-0.21	0.00	0.26	0.05	0.21	-0.12	0.17	-0.04
WOOSH	0.15	0.14	0.08	0.22	0.16	0.06	0.06	0.04	-0.15	-0.02
ORTBU	-0.17	0.39*	0.58**	-0.09	0.17	-0.07	0.04	-0.22	-0.52**	0.16
Total +	8	21	26	24	11	8	11	9	5	5
Total -	21	8	3	5	18	21	18	20	24	24

Table 3.3.3 Pearson correlation coefficients between annual numbers of spring passage migrants (wintering in Africa) on weather in two time periods. (Levels of significance shown by * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$.) The total numbers of positive and negative associations are also shown for each species. Bird numbers were log-transformed prior to the analyses. Species marked † were too infrequent in spring to be included. The weather variables and time periods are defined in the text.

Species Code	Temperature		Frosts		Precipitation		Wet Days		Sahel	
	6	7	6	7	6	7	6	7	A	B
LITBI	0.15	-0.14	-0.15	0.15	-0.10	0.16	0.01	0.12	0.43*	-0.08
NIGHE	-0.08	0.21	0.33	0.19	0.04	0.16	-0.07	0.07	-0.45**	-0.18
LITEG	-0.06	-0.07	0.03	0.26	0.20	0.28	0.15	0.26	-0.33	0.13
PURHE	-0.29	0.31	0.60**	0.21	0.14	-0.26	0.02	-0.25	-0.44*	-0.29
WHIST	-0.22	-0.03	0.49*	0.35	-0.24	-0.37	-0.05	-0.28	-0.36	-0.15
BLAKI	0.01	-0.19	0.36	0.31	-0.30	0.23	-0.34	0.25	-0.46**	-0.05
REFFA	-0.22	0.09	0.26	0.12	0.06	-0.19	0.10	-0.25	-0.32	0.18
BLWST	0.07	-0.07	-0.32	-0.07	0.38	0.18	0.36	0.09	0.23	-0.24
TEMST	-0.24	0.23	0.73***	0.25	0.00	-0.20	-0.12	-0.18	-0.60***	-0.06
BRBSA	0.17	0.03	0.22	0.20	-0.25	0.38	-0.26	0.24	-0.18	0.07
GUBTE	0.00	-0.15	-0.29	-0.04	-0.06	-0.31	0.03	-0.28	0.12	0.01
CASTE	-0.20	-0.30	0.06	0.24	0.13	-0.23	0.14	-0.12	-0.06	-0.12
WWBTE	-0.27	-0.10	0.39*	0.05	-0.04	-0.06	-0.11	-0.06	-0.19	-0.40
ALPSW	-0.24	0.16	0.16	-0.20	0.24	0.03	0.19	0.06	-0.08	0.05
BEEEA	-0.32	-0.04	0.11	0.11	0.53**	0.07	0.39*	0.04	-0.18	-0.22
HOOPO	-0.46*	-0.39	0.10	0.50*	0.24	-0.54	0.40*	-0.39	-0.04	0.03
SHTLA	-0.37*	0.10	0.75***	0.28	0.11	0.10	0.01	0.06	-0.53**	-0.17
RERSW	-0.16	-0.04	0.30	0.29	-0.04	0.02	-0.11	0.06	-0.35*	-0.17
TAWPI	-0.40*	0.12	0.61**	0.23	0.27	-0.11	0.19	-0.09	-0.56**	0.03
RETPI	-0.31	0.03	0.41*	0.09	0.05	-0.13	-0.01	-0.02	-0.06	-0.02
BLUTH	-0.07	-0.16	-0.41*	-0.30	0.37	0.24	0.40*	0.35	0.58**	0.04
AQUWA	-0.13	0.05	0.62**	0.40*	-0.28	-0.19	-0.35	-0.09	-0.42*	0.19
GRRWA	0.36	0.17	-0.20	-0.25	-0.24	0.18	-0.22	0.27	0.11	-0.09
ICTWA	-0.31	-0.02	0.64***	0.55**	0.02	-0.10	-0.07	-0.05	-0.56**	-0.22
MELWA	-0.14	-0.15	0.52**	0.32	-0.18	-0.01	-0.13	-0.01	-0.51**	-0.17
SUBWA	-0.07	-0.10	0.23	0.19	0.04	0.12	-0.03	0.17	-0.32	-0.22
BARWA	-0.44*	-0.04	0.57**	0.39	0.23	-0.04	0.12	0.03	-0.46*	-0.17
LEGSH	0.17	-0.02	-0.16	-0.04	0.05	-0.10	0.03	-0.04	-0.02	0.10
WOOSH	-0.35	-0.20	0.23	0.01	0.06	-0.12	0.11	-0.05	0.29	-0.13
ORTBU	-0.15	-0.07	0.25	0.59**	0.08	-0.12	0.13	-0.08	-0.33	0.12
Total +	7	11	24	24	20	13	17	14	6	11
Total -	23	19	6	6	10	17	13	16	24	19

Table 3.3.4 Pearson correlation coefficients between annual numbers of autumn passage migrants (wintering in Africa) on weather in two time periods. (Levels of significance shown by * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$.) The total numbers of positive and negative associations are also shown for each species. Bird numbers were log-transformed prior to the analyses. The weather variables and time periods are defined in the text.

Species Code	Temperature		Frosts		Precipitation		Wet Days	
	6	7	6	7	6	7	6	7
WHRSA	-0.11	0.00	0.02	-0.06	0.13	-0.15	0.20	-0.06
BAISA	0.03	-0.01	0.12	-0.18	-0.17	-0.12	-0.20	-0.01
LOBDO	-0.33	-0.11	0.41*	0.13	-0.02	-0.03	-0.02	-0.01
LOTSK	-0.10	0.24	0.62***	0.19	-0.06	0.03	-0.18	0.02
SABGU	-0.13	0.09	0.53**	0.20	-0.32	0.12	-0.30	0.18
RICPI	-0.11	0.13	0.50**	0.28	-0.18	0.00	-0.21	-0.04
GSHWA	-0.03	-0.12	0.22	0.25	-0.13	-0.22	-0.20	-0.13
ARCWA†								
PALWA†								
YEBWA	0.00	-0.23	0.32	0.05	-0.24	0.08	-0.23	0.18
REBFL	0.05	0.20	0.30	-0.01	-0.38	-0.03	-0.34	0.02
ROCST	-0.19	0.02	0.38*	0.16	0.07	-0.17	-0.00	-0.18
SCARO	-0.33	0.20	0.66***	0.36	-0.05	-0.12	-0.09	-0.17
RSUBU	-0.23	-0.13	0.60***	0.49**	-0.18	0.01	-0.34	0.10
LITBU	0.13	0.12	0.27	0.39*	-0.24	0.05	-0.24	0.03
YEBBU†								
Total +	4	8	13	10	2	6	1	6
Total -	9	5	0	3	11	7	12	7

Table 3.3.5 Pearson correlation coefficients between annual numbers of spring passage migrants (wintering outside Europe or Africa) on weather in two time periods. (Levels of significance shown by * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$.) The total numbers of positive and negative associations are also shown for each species. Bird numbers were log-transformed prior to the analyses. Species marked † were too infrequent to be included. The weather variables and time periods are defined in the text.

Species Code	Temperature		Frosts		Precipitation		Wet Days	
	6	7	6	7	6	7	6	7
WHRSA	-0.13	0.11	0.34	0.18	0.01	-0.05	-0.05	-0.08
BAISA	-0.26	-0.20	0.33	0.46*	0.24	-0.18	0.21	-0.14
LOBDO	-0.29	0.03	0.56**	0.42*	0.02	-0.07	-0.03	-0.03
LOTSK	0.05	0.10	0.61**	0.43*	-0.33	0.12	-0.36	0.10
SABGU	-0.12	0.12	0.61**	0.41*	-0.12	-0.07	-0.13	-0.16
RICPI	-0.42	0.10	0.49*	0.31	0.46*	-0.04	0.37	-0.14
GSHWA	-0.10	-0.16	0.39*	0.62***	0.01	0.17	-0.01	0.16
ARCWA	-0.20	0.06	0.52**	0.08	0.03	0.02	0.01	-0.02
PALWA	-0.37*	-0.29	0.45*	0.54**	0.12	0.04	0.05	0.13
YEBWA	-0.33	0.14	0.76***	0.42*	0.15	-0.87	0.07	-0.11
REBFL	-0.08	-0.07	0.57**	0.52**	-0.20	-0.03	-0.29	0.10
ROCST	0.19	0.19	0.28	0.20	-0.01	0.07	-0.05	0.00
SCARO	-0.29	0.07	0.79***	0.49*	-0.11	-0.08	-0.15	-0.07
RSUBU	-0.03	-0.12	0.37*	0.32	-0.23	0.17	-0.34	0.30
LITBU	-0.18	0.04	0.62***	0.37*	-0.17	0.02	-0.19	0.02
YEBBU	-0.12	0.07	0.36*	0.40*	-0.21	-0.28	-0.15	-0.21
Total +	2	11	16	16	8	7	5	7
Total -	14	5	0	0	8	9	11	9

Table 3.3.6 Pearson correlation coefficients between annual numbers of autumn passage migrants (wintering outside Europe or Africa) on weather in two time periods. (Levels of significance shown by * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$.) The total numbers of positive and negative associations are also shown for each species. Bird numbers were log-transformed prior to the analyses. The weather variables and time periods are defined in the text.

Species Code	Temperature					Frosts					Precipitation					Total R^2
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
WHBDI							0.32								0.08**	0.40
KINEI							0.32**	0.09								0.41
GYRFA				0.16*									0.21**			0.37
CRANE							0.27*			0.08				0.11*		0.46
NUTCR†																
ARCRE									0.06	0.21**	-0.10	-0.06				0.44
SERIN	0.12**						0.38***				0.10*					0.61
PARCR							0.10		0.18*							0.28
Total +	1	0	0	1	0	0	5	1	2	2	1	0	0	1	1	
Total -	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	

Table 3.3.7 Results of multiple regressions of annual numbers of spring passage migrants (wintering in Europe) on weather in five time periods. (See text for definitions of weather and time periods.) Figures are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$), using the 'stepwise' method. Signs indicate the direction of the association. The total numbers of positive and negative associations are given for each variable and the total R^2 values for each species. Bird numbers were log-transformed prior to the analyses. Species marked † were too infrequent in spring to be included.

Species Code	Temperature				Frosts				Precipitation				Total R^2
	4	5	6	7	4	5	6	7	4	5	6	7	
WHBDI							0.31**						0.31
KINEI								0.45***					0.45
GYRFA		0.15***			0.06*				-0.12*		-0.35***	0.05	0.73
CRANE			0.06*		0.37**			0.05		0.07			0.55
NUTCR								-0.08			0.15*		0.22
ARCRE	0.18**		0.08*		0.07								0.33
SERIN		0.04***		-0.05**	0.07**	0.06***		0.41*	0.15**		0.08***	0.02	0.89
PARCR			0.10*			0.12*		0.23***					0.45
Total +	1	2	3	0	4	2	1	4	1	1	2	2	
Total -	0	0	0	1	0	0	0	1	1	0	1	0	

Table 3.3.8 Results of multiple regressions of annual numbers of autumn passage migrants (wintering in Europe) on weather in four time periods. (See text for definitions of weather and time periods.) Figures are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$), using the 'stepwise' method. Signs indicate the direction of the association. The total numbers of positive and negative associations are given for each variable and the total R^2 values for each species. Bird numbers were log-transformed prior to the analyses.

Species Code	Temperature		Frosts		Precipitation		Wet Days		Sahel		Total R^2
	2	3	2	3	2	3	2	3	A	B	
LITBI						-0.12*			0.08		0.20
NIGHE			0.09								0.09
LITEG		0.18**		0.13**						-0.07	0.38
PURHE			0.37***							-0.16**	0.53
WHIST			0.15								0.15
BLAKI	0.09**	-0.06	0.33***							-0.13***	0.61
REFFA									-0.18*		0.18
BLWST				0.11							0.11
TEMST			0.54***	0.08*							0.63
BRBSA									-0.55***	-0.05	0.60
GUBTE			-0.08								0.08
CASTE	0.10*		0.08*	0.05						-0.21**	0.44
WWBTE		0.10									0.10
ALPSW									-0.26**		0.26
BEEEA									-0.27**		0.27
HOOPO											—
SHTLA		0.05	0.17**		0.12*						0.34
RERSW			0.19*								0.19
TAWPI			0.42***								0.42
RETPI			0.08	0.25**							0.34
BLUTH			0.55***								0.55
AQUWA†											
GRRWA				-0.08	-0.12*		0.08				0.28
ICTWA									-0.18**	-0.23**	0.41
MELWA			0.15								0.15
SUBWA		0.05*	0.26**	0.04*				0.13**		-0.09*	0.61
BARWA				-0.16**	0.07	-0.14**	-0.09			-0.08*	0.55
LEGSH		0.10*		0.07	0.08				0.09*		0.34
WOOSH											—
ORTBU	0.05*		0.34***	-0.05	0.08**						0.60
Total +	3	5	14	7	4	0	1	1	2	0	
Total -	0	1	1	3	1	2	1	0	5	8	

Table 3.3.9 Results of multiple regressions of annual numbers of spring passage migrants (wintering in Africa) on weather in two time periods. (See text for definitions of weather and time periods.) Figures are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$), using the 'stepwise' method. Signs indicate the direction of the association. The total numbers of positive and negative associations are given for each variable and the total R^2 values for each species (— indicates that no variables entered the regression for that species). Bird numbers were log-transformed prior to the analyses. Species marked † were too infrequent in spring to be included.

Species Code	Temperature		Frosts		Precipitation		Wet Days		Sahel		Total R^2
	6	7	6	7	6	7	6	7	A	B	
LITBI				0.11*					0.21**		0.32
NIGHE			0.11								0.11
LITEG						0.08*	0.07		-0.10		0.26
PURHE		0.06	0.36**								0.42
WHIST			0.24**		-0.07*	-0.11	0.11*				0.53
BLAKI					-0.07			0.13	-0.17**		0.37
REFFA											—
BLWST	0.08				0.14**					-0.09	0.32
TEMST			0.54***						-0.05		0.59
BRBSA				0.10		0.11*		-0.08			0.28
GUBTE			-0.10			-0.10					0.20
CASTE		-0.09*				-0.09					0.18
WWBTE			0.15							-0.06	0.22
ALPSW											—
BEEEA					0.28**				-0.07*	-0.07	0.42
HOOPO											
SHTLA			0.56***		0.06*	0.05					0.67
RERSW									-0.11		0.11
TAWPI			0.37***		0.11*						0.48
RETPI			0.17**						0.07		0.24
BLUTH					0.16**			0.11*	0.28**		0.54
AQUWA			0.38***				-0.07			0.12*	0.57
GRRWA	0.13										0.13
ICTWA			0.41**	0.16*							0.56
MELWA			0.27**								0.27
SUBWA									-0.08		0.08
BARWA			0.33**	0.06	0.09						0.47
LEGSH											—
WOOSH	-0.13										0.13
ORTBU				0.35**							0.35
Total +	2	1	12	5	6	3	2	2	3	1	
Total -	1	1	1	0	2	3	1	1	6	3	

Table 3.3.10 Results of multiple regressions of annual numbers of autumn passage migrants (wintering in Africa) on weather in two time periods. (See text for definitions of weather and time periods.) Figures are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$), using the 'stepwise' method. Signs indicate the direction of the association. The total numbers of positive and negative associations are given for each variable and the total R^2 values for each species (— indicates that no variables entered the regression for that species). Bird numbers were log-transformed prior to the analyses.

Species Code	Temperature		Frosts		Precipitation		Wet Days		Total R^2
	2	3	2	3	2	3	2	3	
WHRSA									—
BAISA									—
LOBDO			0.17*						0.17
LOTSK			0.39***						0.39
SABGU			0.28**						0.28
RICPI			0.25**						0.25
GSHWA									—
ARCWA†									
PALWA†									
YEBWA	0.09	-0.08	0.10*						0.27
REBFL					-0.15				0.15
ROCST			0.14*						0.14
SCARO			0.44***						0.44
RSUBU			0.36**	0.14**	0.06		-0.06*		0.62
LITBU		0.09		0.15**	-0.08				0.32
YEBBU†									
Total +	1	1	8	2	1	0	0	0	
Total -	0	1	0	0	2	0	1	0	

Table 3.3.11 Results of multiple regressions of annual numbers of spring passage migrants (wintering outside Europe and Africa) on weather in two time periods. (See text for definitions of weather and time periods.) Figures are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$), using the 'stepwise' method. Signs indicate the direction of the association. The total numbers of positive and negative associations are given for each variable and the total R^2 values for each species (— indicates that no variables entered the regression for that species). Bird numbers were log-transformed prior to the analyses. Species marked † were too infrequent to be included.

Species Code	Temperature		Frosts		Precipitation		Wet Days		Total R^2
	6	7	6	7	6	7	6	7	
WHRSA			0.11						0.11
BAISA				0.21*					0.21
LOBDO			0.31**	0.08					0.39
LOTSK	0.14*		0.37***	0.08					0.60
SABGU			0.37**	0.07					0.44
RICPI			0.24**		0.27**				0.50
GSHWA			0.06	0.38***		0.05			0.50
ARCWA			0.27**						0.27
PALWA			0.11*	0.29**					0.40
YEBWA	0.04		0.58***	0.05	0.05*				0.73
REBFL			0.33**	0.15*					0.48
ROCST	0.13**		0.08***				0.18**		0.39
SCARO			0.62***	0.09*					0.71
RSUBU			0.14*			-0.09		0.12*	0.35
LITBU			0.38***	0.05					0.43
YEBBU			0.07	0.16					0.24
Total +	3	0	15	11	2	1	1	1	
Total -	0	0	0	0	0	1	0	0	

Table 3.3.12 Results of multiple regressions of annual numbers of autumn passage migrants (wintering outside Europe and Africa) on weather in two time periods. (See text for definitions of weather and time periods.) Figures are partial R^2 values for all variables remaining in the multiple regressions at the criterion $P<0.15$ (with * for $P<0.05$, ** for $P<0.01$, *** for $P<0.001$), using the 'stepwise' method. Signs indicate the direction of the association. The total numbers of positive and negative associations are given for each variable and the total R^2 values for each species. Bird numbers were log-transformed prior to the analyses.

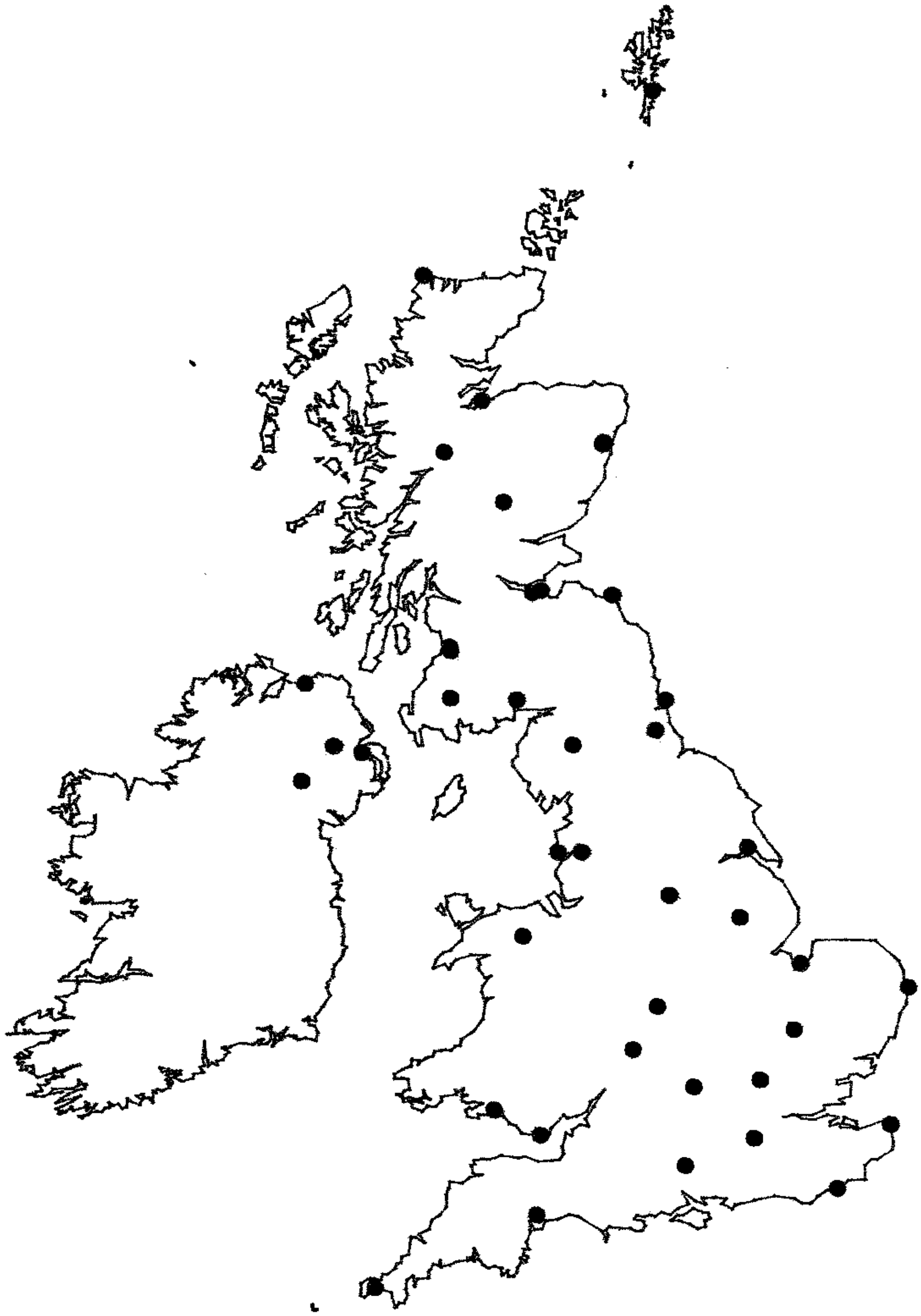

Figure 2.2.1.1 Distribution of British weather stations providing data for this analysis.

APPENDIX 1 - LIST OF COUNTY CODES

Avon	AV	Grampian Region	GR	Orkney	OR
Bedford	BD	Gwent	GT	Oxford	OX
Berkshire	BK	Hampshire	HA	Salop	SA
Breconshire	BS	Hebrides	HE	Shetland	SH
Buckingham	BC	Hereford & Worcs.	HF	Staffordshire	ST
Caithness	CT	Hertfordshire	HT	Strathclyde Region	SC
Cambridge & Huntingdon	CA	Highland Region (excl. Caithness & Sutherland)	HI	Somerset	SO
Central Region	CR	Kent	KE	Suffolk	SK
Cornwall	CO	Leicester & Rutland	LE	Surrey	SR
Derby	DB	Lincolnshire	LI	Sussex (W. & E.)	SX
Devon	DV	London (Greater)	LO	Sutherland	SU
Dorset	DO	Norfolk	NK	Tayside Region	TR
Dumfries & Galloway Region	DR	Northamptonshire	NH	West Midlands	WM
Essex	ES	Nottinghamshire	NT	Warwickshire	WK
Glamorgan	GM			Wiltshire	WT
Gloucester	GL			Worcestershire	WC