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**Analysis of population trends for
waterways birds: a comparison of
Waterways Bird Survey indices**

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EXECUTIVE SUMMARY

- 1 The Waterways Bird Survey (WBS), a territory-mapping census carried out by BTO volunteers, was introduced in 1974 to monitor populations of breeding waterbirds along linear waterways in the UK. Estimates of breeding territories are used to calculate estimates of population change, which in turn contribute to various conservation initiatives. The GAMs method used in this study allowed objective assessment of trends and of their confidence intervals and turning points during the period 1975-99.
- 2 Of eighteen species monitored since 1974 by the WBS, five species (Common Sandpiper, Yellow Wagtail, Grey Wagtail, Pied Wagtail and Reed Bunting) experienced a significant decline over the period 1975 to 1999. Kingfishers declined significantly during the first half of this period but recovered between 1987 and 1999. Three species (Mute Swan, Mallard and Oystercatcher) increased significantly over the period 1975 to 1999.
- 3 Analysis of the pattern of turning points in the population trajectories revealed similarities among species that reflect their ecological characteristics, in particular wintering area and preferred habitat. Turning points in the population trends were similar for Sedge Warbler, Sand Martin and Whitethroat (although Whitethroats have increased at a much higher rate). The similarity between Dipper and Grey Wagtail suggests a relationship to environmental conditions on fast-flowing riverine habitat.
- 4 Events during the winter appeared to influence trends for some species. For Mute Swan, Moorhen, Kingfisher, and Grey and Pied Wagtails, annual changes in abundance were related to mean winter temperature. The only relationship between previous spring temperature and abundance the following year was for the Reed Warbler, which may be related to higher productivity in the first year as a result of the milder climate.
- 5 Trends for two trans-Saharan migrants, Sedge Warbler and Reed Warbler, were linked to May-October rainfall in the Sahel region of West Africa in the season just prior to their arrival in winter quarters.

1 INTRODUCTION

The British Trust for Ornithology currently monitors UK bird populations through a number of different long-term censuses. The Waterways Bird Survey (WBS) was introduced in 1974 to monitor breeding birds along linear waterways (rivers and canals). Stretches of 4-5 km in length on average are chosen by volunteers, and surveyed on nine occasions during each season, using territory mapping methods (see Bibby *et al.* 1992 for further details), to produce maps of breeding territories for each species, stretch and year and an overall estimate of breeding numbers along the survey stretch. Inter-annual changes in numbers have previously been reported in *BTO News*.

Monitoring of riparian habitat on plots surveyed in consecutive years was recognised as being necessary because of the important number of breeding birds that it held, including specialists that are rarely present in other habitats and were poorly monitored by the national monitoring scheme at the time, the Common Birds Census (CBC). The Breeding Bird Survey was introduced in 1994 to take over the role of monitoring birds in the wider countryside, and provided better coverage of waterways than the CBC. It was clear, however, that the BBS was not adequate to replace the WBS, because although a BBS route may cross linear waterways, few follow them, so that species such as Common Sandpiper and Grey Wagtail that live close to water were still poorly represented. The WBS is therefore the principal national monitoring scheme for a number of bird species in the UK.

There have been previous summaries of WBS population trends (e.g. Marchant *et al.* 1990, Marchant & Balmer 1994), but none published recently. Previous summaries used analytical methods, such as the chain index, that have since been superseded by modelling techniques that are both more precise and more versatile. This study aims to:

- use Generalised Additive Models (GAMs) to model population change of riparian species on WBS plots over the first 27 years of this survey;
- objectively identify points in time at which changes in the direction of a species index series occurred; and
- provide a comparison of the similarity between species pairs in the timing of these points.

We also provide some exploratory analyses of possible factors that may be responsible for population change. The species covered are 18 waterbirds that have been monitored by WBS since 1974. WBS has also monitored Goosander, Canada Goose and Greylag Goose, but only since around the mid-1980s; trends of these three species are therefore not examined in this study.

2 METHODS

2.1 Producing GAMs of population change

Abundance indices in this paper were calculated from WBS data using generalised additive models (GAMs). The formulation of GAMs is described in detail by Hastie & Tibshirani (1990), but the following is an overview of methodological issues with particular relevance to the analyses presented here.

Unlike conventional generalised linear models (GLMs), which allow change in mean abundance over time to follow a linear form or sequence of unrelated estimates, GAMs allow mean abundance to follow any smooth function. Before the trend can be estimated, it is first necessary to set a level of smoothing that is appropriate to the objectives of the study. At one extreme, there is perfect smoothing, where abundance within each site varies linearly with time on a logarithmic scale, whilst at the other extreme annual estimates are joined with straight lines and the function is no longer smooth. In this study, the objective was to determine important features of the population trend, whilst ignoring fine-scale fluctuations. This point was estimated by calibrating a quantity known as the degrees of freedom (df). As the degrees are increased from a straight line with 1 df , the function gains in flexibility, allowing for an increased number of turning points and gradient changes. Fig. 1 illustrates the effect of increasing df on the resulting index series of Grey Wagtail.

The level of smoothing employed in studies such as ours is largely a subjective decision, although Fewster *et al.* (2000), experimenting with Common Birds Census (CBC) data, suggested that df of about one-third the number of years in the time series produced curves that were suitable in complexity and smoothness. For the present time series of 27 years, therefore, 8 df would produce an appropriate degree of smoothing, and Fig. 1 confirms this conclusion, for the Grey Wagtail at least. This is therefore the level used in this study, for all species.

To allow the significance of any change in species abundance to be assessed, we calculated 95% confidence intervals of the estimates, by randomly sampling from the raw site-specific counts, with replacement, to generate a set of 199 bootstrap replicates. The proportional changes in abundance over specific periods (1975-99, 1975-87 and 1987-99) were then calculated and the matrix of bootstrapped replicates used to provide an estimate of their precision. Note that the smoothing process in GAMs may provide less reliable estimates at the start and end years of the time series; therefore, all plots and population change estimates are restricted to the years 1975-99.

2.2 Identifying turning points in the index series

To identify objectively the point in time at which change in the direction of index series occurred, we estimated the second derivative curve of the smoothed index series, which is the rate of change of the gradient, at each time point. If the second derivative is greater than zero, there is a significant upturn, whilst a downturn is identified by a value of less than zero. It is important to note that a non-zero second derivative implies only a change of gradient, and not the nature of the gradient itself. For example, an upturn in a declining population could be a reduction in the rate of decline, rather than a change from decrease to increase.

To establish whether second derivatives were significantly different from zero, we calculated second derivatives from each of the 199 bootstrapped replicates and took the 2.5th and 97.5th percentiles from the ranked distribution to represent the lower and upper 95% confidence limits. A significant turning point was then defined as a second derivative whose confidence interval did not overlap zero. Because the calculation of turning points requires previous and subsequent years to assess the level of change at any one point, it was possible in this study to calculate turning points only for the years 1977-97.

2.3 Examining similarity in turning points

To examine whether pairs of species shared similarities in the timing and direction of their turning points, a method for scoring similarity between species pairs was devised. The theory behind this assumes that species affected by a common factor may respond by exhibiting the same turning point in the same year. There may be delay or uncertainty in the exact timing of a turning point, however, due either to a biological reason or to differences in the appropriateness of the smoothing level, set at 8 *df* for all species. Because of this, we score similarity in the following way. For two species showing the same turning point in the same year (i.e. both showing either an upward or downward turn) they have high similarity and are given a score of 1, whilst species showing opposite turning points in a given year have high dissimilarity and are given a score of -1. Species that both lack a turning point in a given year are not similar or dissimilar and are given a score of zero. However, if only one of two species shows a turning point, the other species is examined to see whether it shows a turning point in the previous or following year. A similar turning point, offset by one year, is given a score of 0.5, whilst opposite turning points (an upturn and downturn) are scored -0.5. If both previous and following years have turning points, the score is the sum of scores from both turning-point comparisons.

To help illustrate the scoring procedure, scores for all possible combination of pairings are shown in Table 1. Because this method takes into account turning points either side of the year of interest, it was not possible to produce a score for the first and last years in the series: scores are calculated for the period 1978-96, therefore, for all pairs of species. The sum of the similarity scores for each pair of species across all years is taken as a measure of their overall similarity.

2.4 Exploratory analyses of influencing factors

Exploratory analyses were carried out to examine whether there were any relationships between trends in annual abundance (non-smoothed, using GAMs with 26 *df*) and a number of possibly relevant factors. These included:

- mean temperature in Central England during the previous winter (Nov-Mar) for resident species,
- mean temperature in Central England during the previous spring (Apr-Jun) for all species,

- mean rainfall in the Sahel region of West Africa during the previous rainy season (May-Oct) for trans-Saharan migrants only (Whitethroat, Sand Martin, Sedge Warbler and Reed Warbler),
- summer diet of all species, and
- winter diet of resident species.

Classifications of summer and winter diet of species in this study were made according to Snow & Perrins (1997). All classifications for each species are shown in Table 2. Population and rainfall indices were corrected relative to the previous year to take into account autocorrelation between years, and comparisons of abundance with rainfall and temperature were made using non-parametric correlation methods. Kruskal-Wallis tests were used to compare winter and summer diet classifications against each species' change in abundance during the periods 1975-99, 1975-87 and 1987-99.

Mean temperature data for the UK were made available courtesy of the Hadley Centre, Met Office, London, via the Climatic Research Unit at the University of East Anglia on the web site www.cru.uea.ac.uk/~mikeh/datasets/uk/cet.htm. Mean rainfall data were obtained from jisao.washington.edu/data/sahel and made available by the Joint Institute for the Study of the Atmosphere and Ocean, University of Washington.

3 RESULTS

3.1 Changes in abundance

Table 3 summarises the proportional change in abundance of 18 waterways species monitored by the WBS over the years 1975-99, 1975-87 and 1987-99. This highlights a significant decline during 1975-99 in the populations of Common Sandpiper, Yellow, Grey and Pied Wagtails, and Reed Bunting. The early period 1975-87 was most important in the overall declines of Yellow, Pied and Grey Wagtails and of Reed Bunting, whilst significant declines in Common Sandpiper and Yellow Wagtail occurred during the later period 1987-99. Kingfisher also declined significantly between 1975 and 1987, although subsequent population recovery meant that the overall trend between 1975 and 1999 was non-significant.

Species showing significant population growth during the period 1975-99 included Mallard, Mute Swan and Oystercatcher. Of these, Mallard generally increased over the entire time series, whilst the increase of Mute Swan was significant only for the later period, 1987-99, and that for Oystercatcher only during the early period, 1975-87.

3.2 Turning points

The occurrence of significantly non-zero second derivatives (with 95% confidence intervals) highlighted years where a species trend had turned significantly. Of the 18 species in this study, all but the Mute Swan experienced one or more years in which the trend turned significantly. The absence of turning points in the Mute Swan is due to its slow and steady increase in abundance over the entire period. Turning points for all other species are shown in Table 4 and illustrated relative to the overall change in abundance for all species in Fig. 2. These show that species such as Sedge Warbler and Sand Martin show frequent oscillations, whereas species such as Common Sandpiper and Pied Wagtail have experienced only one or two periods during which the series turned up or down. To examine whether upturns or downturns were clumped in time, the distribution of these points (pooled across species) is plotted in Fig. 3. This shows that points where the index series turned upwards were most common during the period 1982-87, although there was no particular period during which downturns were especially common.

By scoring the level of similarity in the timing and direction of turning points in the index series (computation of which is discussed in the methods section), it was possible to begin to explore whether similar factors could be involved in driving population change across species. Similarity itself may occur by chance, however, so caution should be taken in any interpretation. In this study, pairs of species with high positive scores (up to 9) indicate high similarity in the timing and direction of turning points, whilst a highly negative score (down to -4) highlights dissimilarity between species pairs. However, it should be noted that, since a high score reflects the number of turning points in a species trend, a species pair of medium similarity is not necessarily more similar than a species with a higher score. For species with a large number of turning points, however, it is less likely that turning points coincide by chance.

Similarity scores for all pairs of species are shown in Table 5. This shows that the highest scores of similarity were between Sedge Warbler, Sand Martin and Whitethroat. A broader

grouping was also evident of these species (Sedge Warbler, Sand Martin and Whitethroat) with Kingfisher, Reed Bunting, Little Grebe and Grey Wagtail. Dipper and Grey Wagtail also gave a high score for similarity in the timing and direction of population change. The fact that Dipper trends were similar to Grey Wagtail, but not to the other species listed above, suggests that different factors may be acting upon these species' populations.

3.3 Influencing factors

Exploratory analyses were carried out to examine whether the observed changes in abundance could be related broadly to selected life-history or ecological characteristics (shown in Table 2).

Changes in abundance were correlated with UK winter temperature during the previous winter (Nov-Mar) based on data for Central England for five species (Fig. 4): Mute Swan, $r_{25} = 0.42$, $P = 0.03$; Moorhen, $r_{25} = 0.65$, $P < 0.001$; Kingfisher, $r_{25} = 0.45$, $P = 0.02$; Grey Wagtail, $r_{25} = 0.63$, $P = 0.001$; and Pied Wagtail, $r_{25} = 0.52$, $P = 0.007$. There was no significant correlation for the seven remaining resident species ($P > 0.05$). Reed Warbler was the only species in this study for there was a significant correlation between abundance and temperature during the previous spring ($r_{25} = 0.52$, $P = 0.007$; Fig. 5).

Comparing mean rainfall in the Sahel during the rainy season (May to October) with abundance the following year was appropriate for four species of trans-Saharan migrants, Whitethroat, Sedge Warbler, Sand Martin and Reed Warbler that winter in the Sahel region. Significant correlations were found for Sedge Warbler ($r_{25} = 0.45$, $P = 0.02$) and Reed Warbler ($r_{25} = 0.53$, $P = 0.006$), but the relationship was non-significant for Whitethroat ($r_{25} = 0.16$, $P = 0.158$) and Sand Martin ($r_{25} = 0.36$, $P = 0.07$); Fig 6.

No relationship was found between abundance during 1975-99 and summer or winter diet of waterway bird species (Kruskal-Wallis tests - summer diet: $H_2 = 15.86$, $P = 0.26$; winter diet $H_2 = 0.72$, $P = 0.70$). Similarly, there were no significant relationships for the periods 1975-87 (summer diet: $H_2 = 16.00$, $P = 0.45$; winter diet $H_2 = 0.41$, $P = 0.82$) and 1987-99 (summer diet: $H_2 = 16.00$, $P = 0.38$; winter diet $H_2 = 1.18$, $P = 0.56$).

Other ecological features that were initially selected for exploratory analyses included nesting habitat, phylogeny, body size, clutch size, length of dependent period and number of breeding attempts, but there was insufficient variation among the relatively small suite of riparian species monitored by WBS to test for these effects.

4 DISCUSSION

4.1 Using GAMs

Because of the flexibility of GAMs, the long-term trends of waterways bird species presented in this report are likely to be more precise than those calculated using conventional GLM analyses. The smoothing process itself provides an objective means of examining the underlying trends of populations, and the associated confidence intervals provide a quantitative assessment of their reliability. Hence, these analyses highlight those species for which conservation action is required, because there has been a steep decline in their breeding numbers, as well as identify species for which WBS has greatest or least power to detect population change. For example, indices and confidence intervals in Fig. 2 show that Reed Buntings have declined by over 50% on WBS plots between 1974 and 2000, whilst the wide confidence intervals associated with the abundance indices of Little Grebe and Tufted Duck over the same period suggest that less confidence should be placed in the observed trends of these species.

The ability in this study to identify points in time at which significant change in the direction of the index series occurred, in an objective manner, provides a step towards diagnosing the reasons behind such change. In addition, comparisons between species' turning points can assess the possibility that a single common factor or factors could be involved in driving population change. High similarity in this study between the turning points of Sedge Warbler, Sand Martin and Whitethroat may suggest a common environmental factor or factors acting upon all three species. However, correlation does not imply causation so similarities should be interpreted with caution. In addition, it is possible in theory that false similarities could result from such factors as observer and plot turnover, for example if changes in observer efficiency were to increase over time, highlighting the need for caution.

4.2 Waterways bird trends

The population trends of the 18 waterways species in this study showed a wide diversity of patterns and timing of population change. Whilst there was some indication of a higher number of upturns in species trends between 1982 and 1987, there was no obvious clumping in the timing of downturns in species trends.

Of the five species to show significant population decline between 1975 and 1999 (Common Sandpiper, Yellow, Grey and Pied Wagtails, and Reed Bunting), the timing of turning points shared little similarity. Change in Common Sandpiper abundance over time was particularly dissimilar to the other declining species, showing population growth during 1975-85 and a decline thereafter: the reasons behind this trend are not known (Baillie *et al.* 2002). It is important to note that the WBS probably provides the best coverage of Common Sandpiper of all surveys. Some similarity in the timing of a slowing-off in decline of Reed Bunting, Grey Wagtail and Pied Wagtail may suggest some common relationship, whilst the decline of Yellow Wagtail continued. The relationship between mean winter temperature and the abundance of Grey and Pied Wagtails at least suggests that these species are adversely affected by cold winters, which may partly explain the similarity between these species. A similar decline of Pied and Grey Wagtails in the mid 1970s was seen on CBC plots. The decline of Pied Wagtail on CBC plots was less severe than on WBS plots, however; Grey

Wagtail is monitored poorly by the CBC (Baillie *et al.* 2002). The reason for the decline of Yellow Wagtail is not known, although farmland drainage and the conversion of pasture to arable land have been cited as potential causes (Gibbons *et al.* 1993).

The decline of Reed Bunting occurred in the 1970s, as detected also by the CBC and by Constant Effort Sites (CES) bird ringing, and is thought to have been driven by declining survival rates during this period; more recently, population recovery may have been prevented by increased nest losses during egg-laying and incubation (Peach *et al.* 1999). Interestingly, a high similarity between the timing and direction of population change in Grey Wagtail and Dipper may suggest a relationship between environmental conditions in fast-flowing river habitat and species abundance. Studies by Ormerod & Tyler (1989, 1990) have shown that Dipper abundance is a good indicator of water acidity and other water pollution, so it may be useful to examine the effect of pollution on the abundance of Grey Wagtail.

Another species that showed a significant decline on WBS plots during the study was Kingfisher, which declined significantly during 1975-87, although population recovery in 1987-2000 meant that there was little overall change in abundance over the entire period (1975-2000). Kingfisher is known to be particularly prone to cold winters (Marchant *et al.* 1990), so the decline during 1975-87 is most likely to be attributable to the cold winters of 1978/79 and 1981/82, as is supported by a relationship between mean winter temperature and abundance in this study. The WBS is the only survey that provides adequate indices of population change for this species.

Whilst declines were observed in a number of species on WBS plots, a similar number of species increased significantly over the same period. This group includes Mallard, Mute Swan, Oystercatcher and Reed Warbler. Whilst Oystercatcher increased until the mid 1980s and remained relatively stable thereafter, all three other species increased over the entire period. Increases in Mallard are likely to have been aided by large-scale releases of this species for shooting (Marchant *et al.* 1990), and by local increases in feral Mallards of domestic origin. Increases of Mute Swan may reflect a combination of the replacement of anglers' lead shot with non-toxic alternatives and warmer winter weather (Gibbons *et al.* 1993); the role of the latter factor is supported in this study by the relationship detected between mean winter temperature and abundance.

Similar upward trends of Mute Swan and Mallard are shown by CBC, and more recently by BBS. The increase in Reed Warbler on WBS plots is not understood and conflicts with findings from CES bird ringing. CES may provide a better coverage of the national population of this species and shows a decline from 1983 until the early 1990s, followed by stability or slight recovery (Baillie *et al.* 2002). The increase in the abundance of Oystercatcher on WBS plots in the 1970s reflects colonisation of inland waterways (Marchant *et al.* 1990), which has been followed by stabilisation in the 1980s. The BBS is the only other survey that monitors breeding numbers of Oystercatcher adequately, across its breeding distribution. BBS has shown a relatively stable population trend, if slightly declining, between 1994 and 2000. The reasons why this species should suddenly take advantage of inland waterways for breeding along are not known (Baillie *et al.* 2002).

Of species showing no significant change in abundance during 1974-2000, Sedge Warbler, Sand Martin and, to a lesser extent, Whitethroat showed similar trends in abundance, with alternating upturns and downturns in abundance. Fluctuation in abundance in these species has been related to changes in annual survival, which in turn have been related to changes in

rainfall on their Sahelian (trans-Saharan) wintering grounds (Winstanley *et al.* 1974, Peach *et al.* 1991, Baillie & Peach 1992). A link between rainfall in the Sahel and species abundance is supported in this study for Sedge Warbler and Reed Warbler, at least, with some non-significant relationship found also for Sand Martin (Fig. 4). Work examining the effect of rainfall on prey abundance of these species would be required to examine this relationship further.

Additionally, for the Reed Warbler, the relationship between spring temperature in the previous year and abundance may be related to high productivity in the previous year, as a consequence of the milder weather. The WBS probably provides the most reliable trends for Sand Martin of any survey, whilst the Whitethroat and Sedge Warbler may be better monitored by the BBS and CES surveys, which are likely to provide coverage that is more representative of the UK.

Of the remaining species in this study, the WBS may provide the best estimates of population change of Coot and Moorhen, although the large number of Coot that occur on still waters may mean that the BBS provides the most reliable national trends for this species, from 1994 onwards. Some similarity between the timing and direction of turning points of Coot and Moorhen may reflect similar environmental factors acting on both species, although the overall trends are dissimilar. A significant relationship between mean winter temperature and the abundance of Moorhen may suggest that this species is adversely affected by cold winters. The decline since the 1970s in this species may be related to a decline in the number and quality of farm ponds and other standing waterbodies and has been associated with a significant decline in breeding performance, whilst the Coot has increased moderately since the 1970s (Baillie *et al.* 2002).

The Little Grebe and Tufted Duck are poorly monitored by the WBS, as shown by the wide confidence intervals associated with the indices of population change and, whilst the Little Grebe is poorly monitored by all national surveys in the UK, the Tufted Duck may now be better monitored by the BBS. In addition, the Waterways Breeding Bird Survey (WBBS) introduced in 1998 as a pilot project should greatly improve waterway monitoring, should this survey become a permanent feature.

ACKNOWLEDGEMENTS

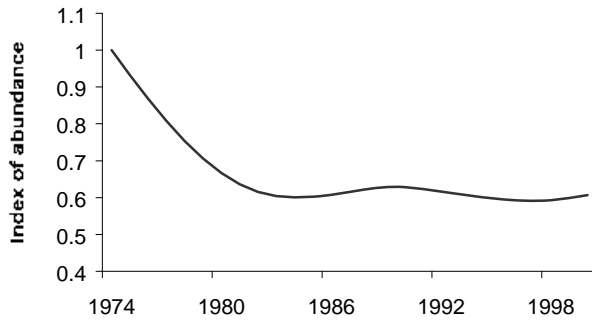
We are extremely grateful to volunteers who have contributed to the Waterways Bird Survey (WBS), which provided the data on which this study was based. Thanks also to Andrew Heaton and Geraldine Daly at the Environment Agency.

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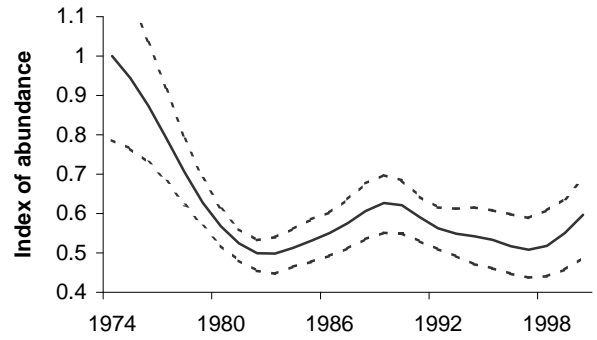
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Figure 1. Abundance indices from GAMs with various degrees of freedom fitted to WBS data for the Grey Wagtail.

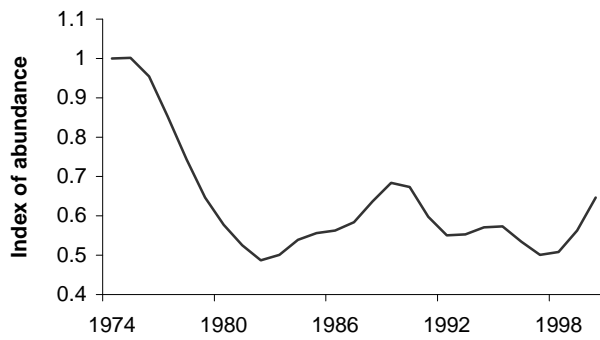
a) 4 df



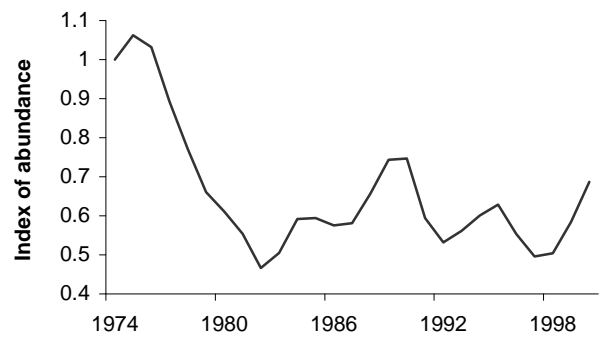
b) 8 df



c) 12 df



d) 18 df



e) 26 df

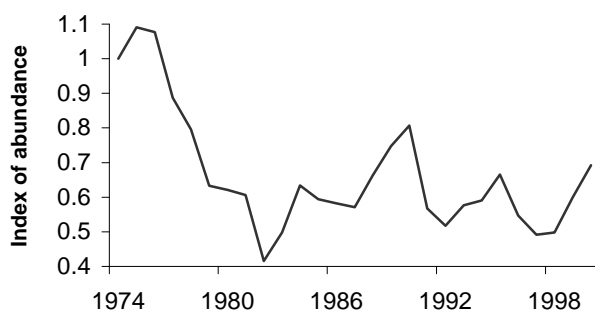
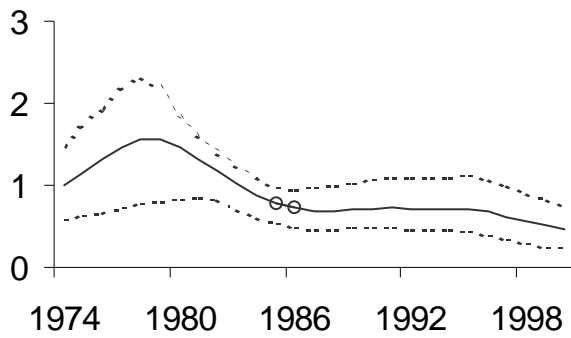
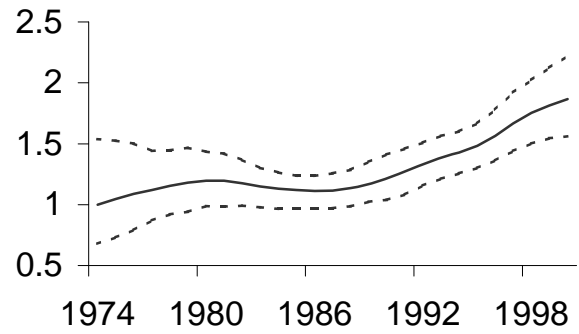


Figure 2. Waterways Bird Survey abundance indices for the period 1974-2000 shown as solid lines and bootstrapped 95% confidence limits as dashed lines. Significant change points for the period 1977-97 are shown as open and solid circles, representing up and downturns respectively.

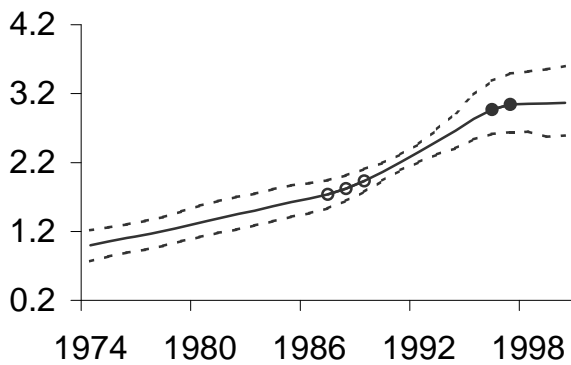
a) Little Grebe



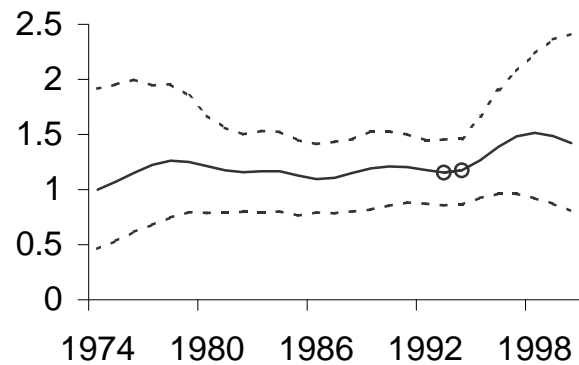
b) Mute Swan



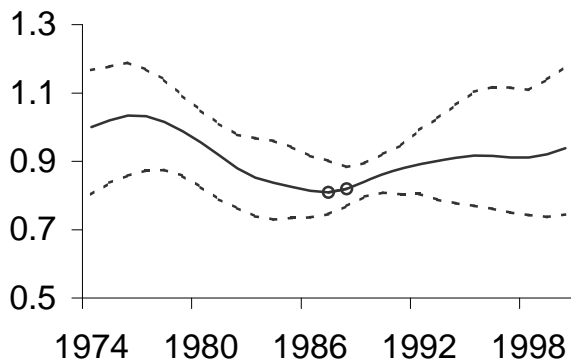
c) Mallard



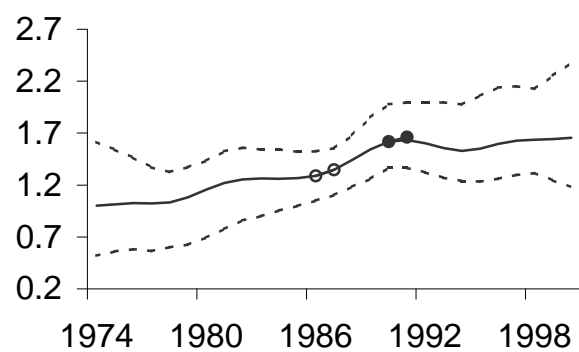
d) Tufted Duck



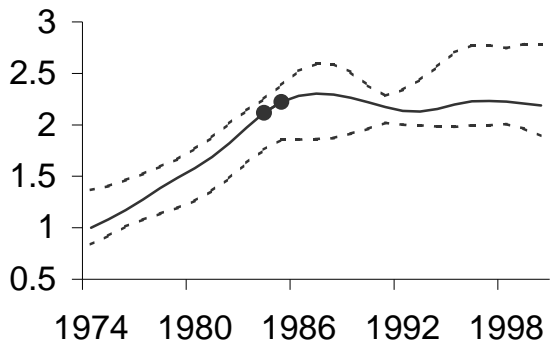
e) Moorhen



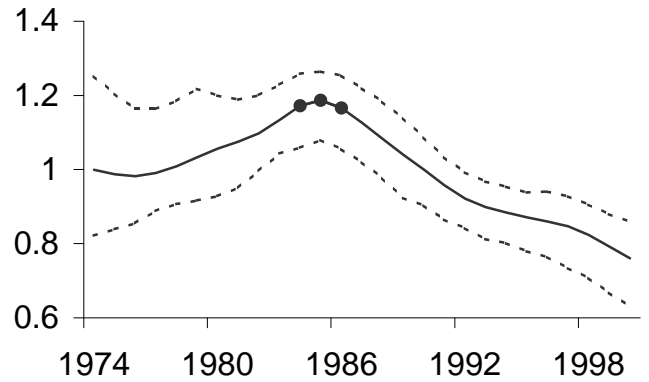
f) Coot



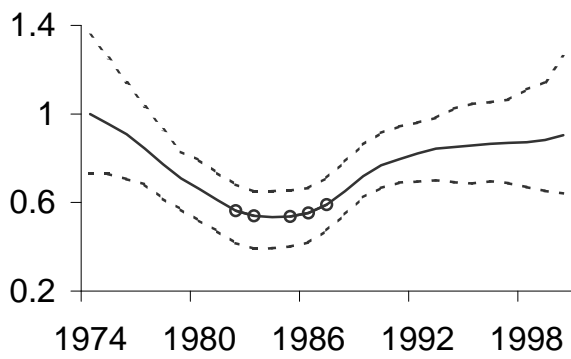
g) Oystercatcher



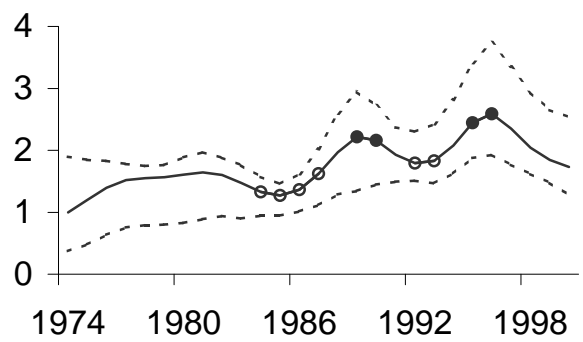
h) Common Sandpiper



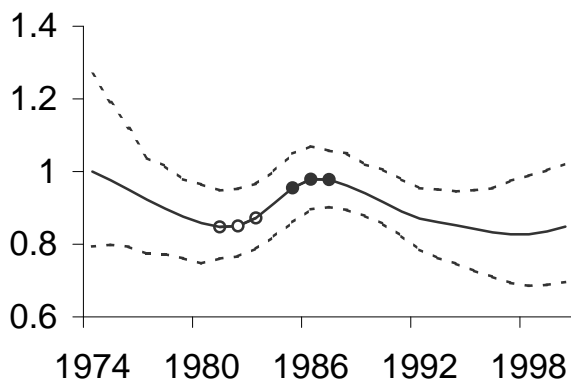
i) Kingfisher



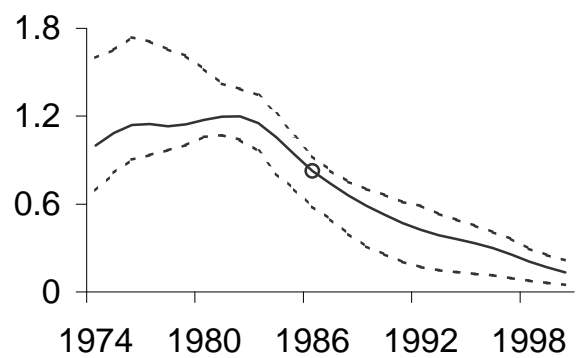
j) Sand Martin



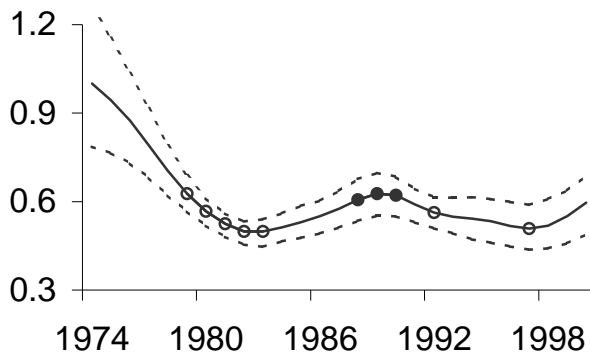
k) Dipper



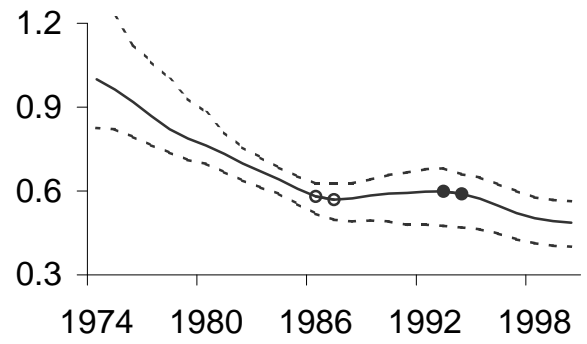
l) Yellow Wagtail



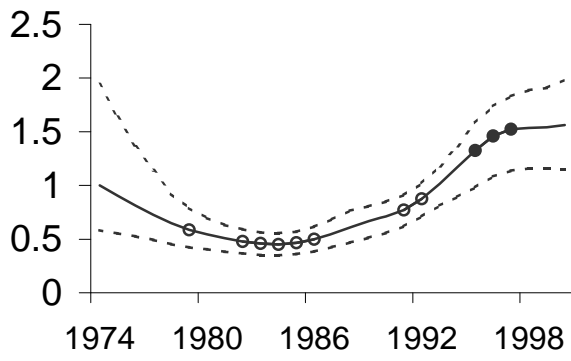
m) Grey Wagtail



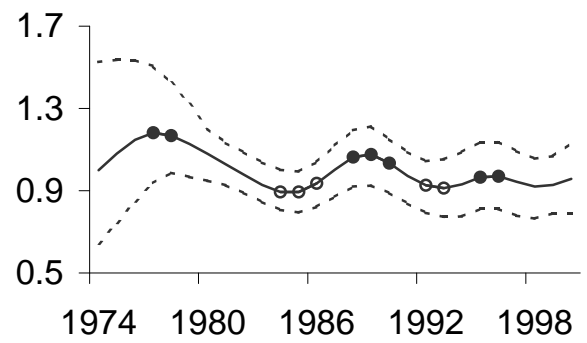
n) Pied Wagtail



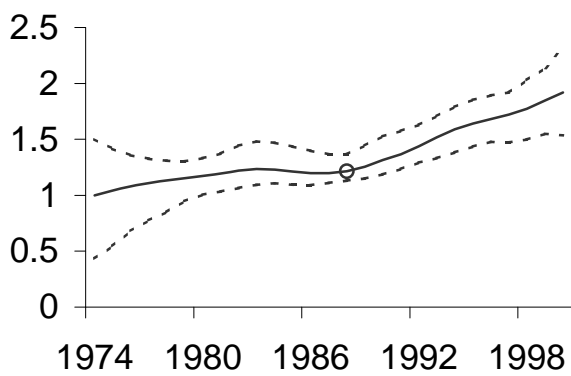
o) Whitethroat



p) Sedge Warbler



q) Reed Warbler



r) Reed Bunting

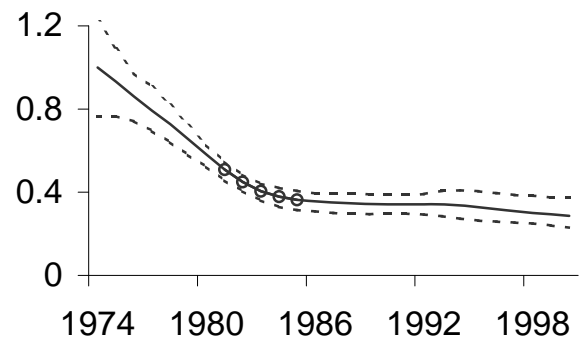


Figure 3. Annual occurrence of significantly non-zero second derivatives during 1977-97. Positive second derivatives (unfilled columns) are points where the species index series was turning up, whilst negative values (filled columns) are downturns in the index series.

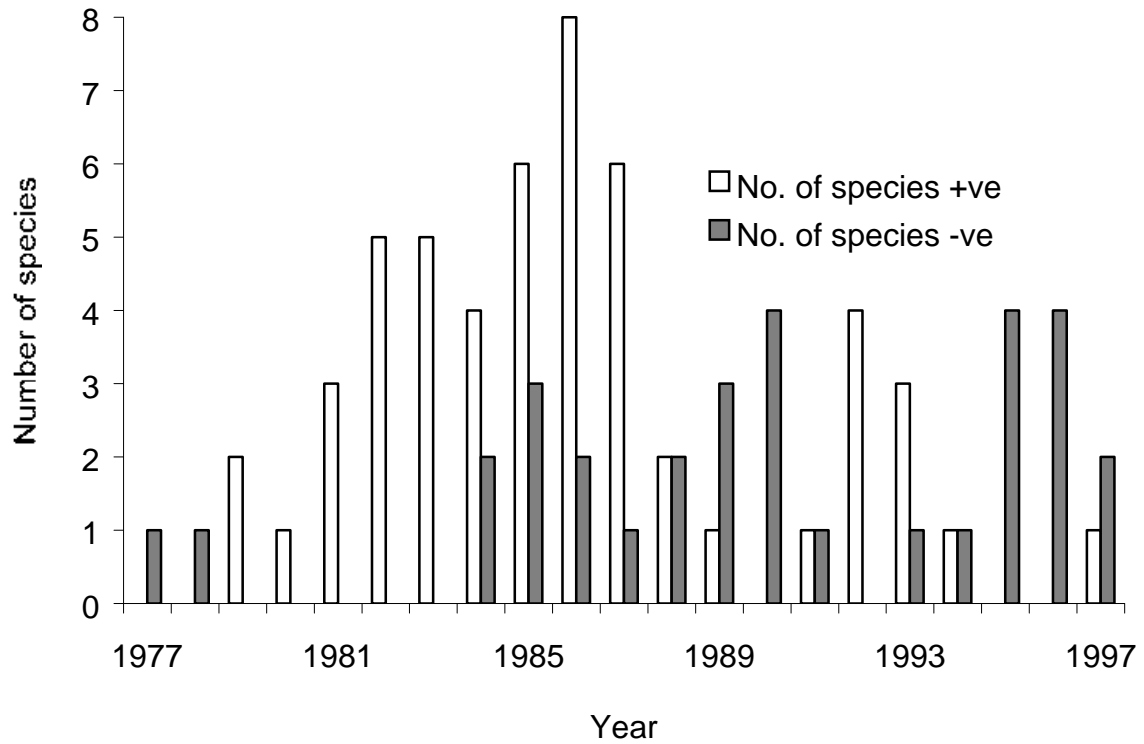
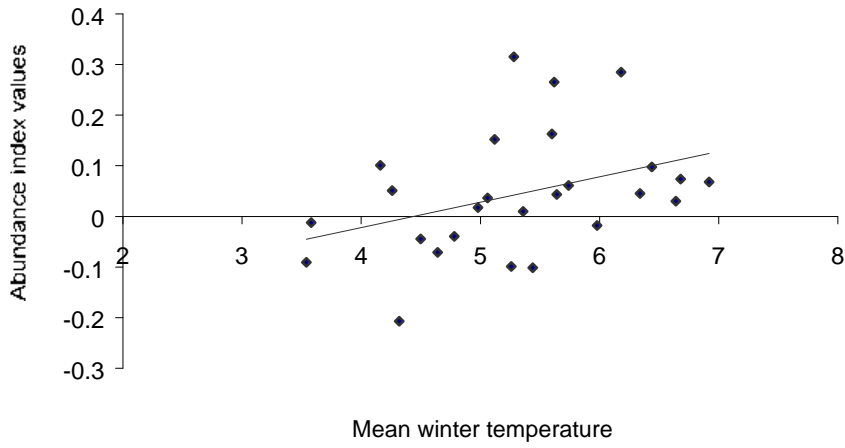
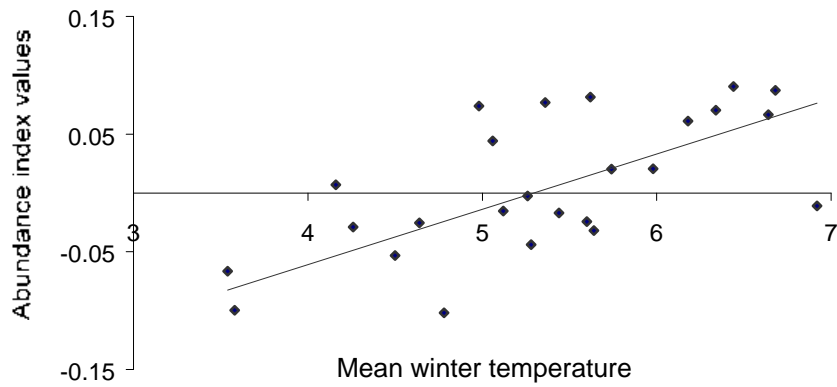


Figure 4. Comparison between WBS (1975-2000) population index values (the ratio of change between years), and mean winter temperature (Nov-Mar) in the UK for resident bird species.

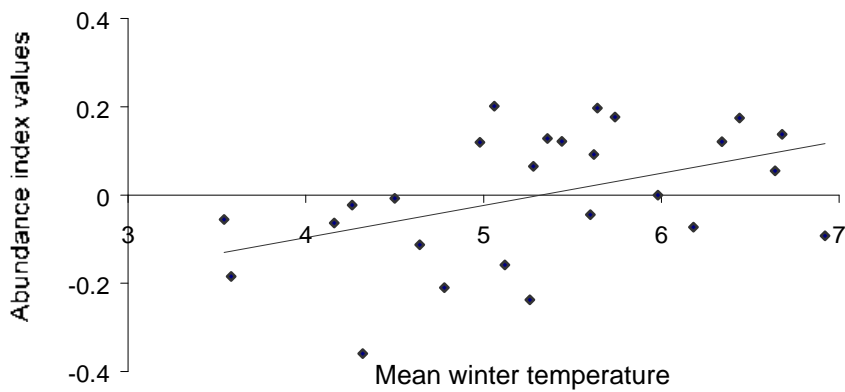
a) Mute Swan



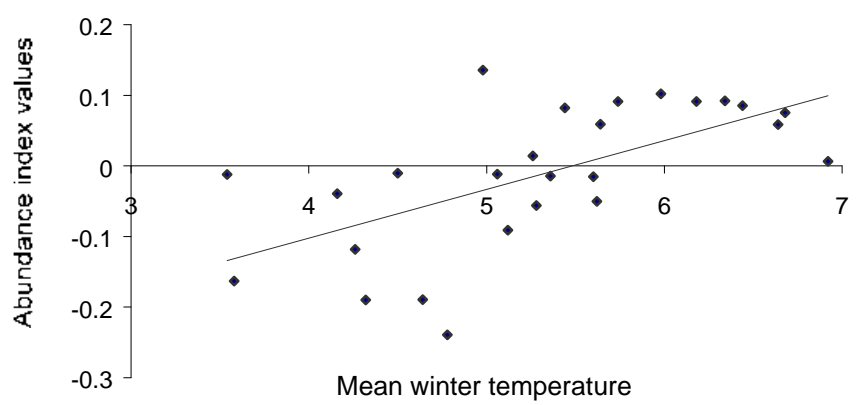
b) Moorhen



c) Kingfisher



d) Grey Wagtail



e) Pied Wagtail

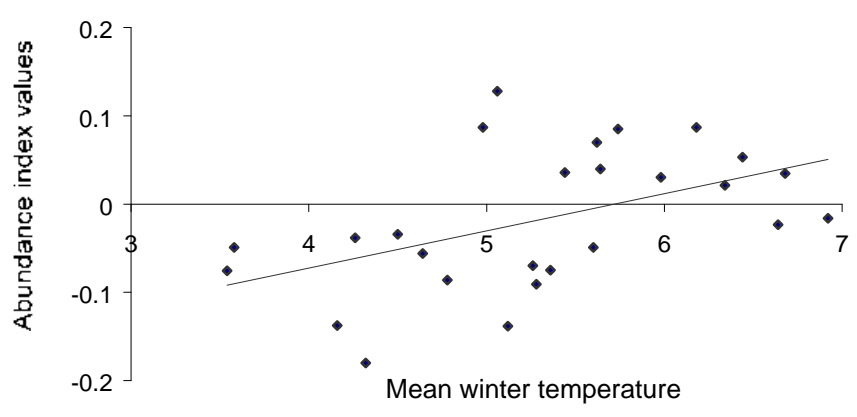


Figure 5. Comparison between WBS (1975-2000) population index values (the ratio of change between years), for the Reed Warbler, relative to the previous year, and mean spring temperature (Nov-Mar) in the UK.

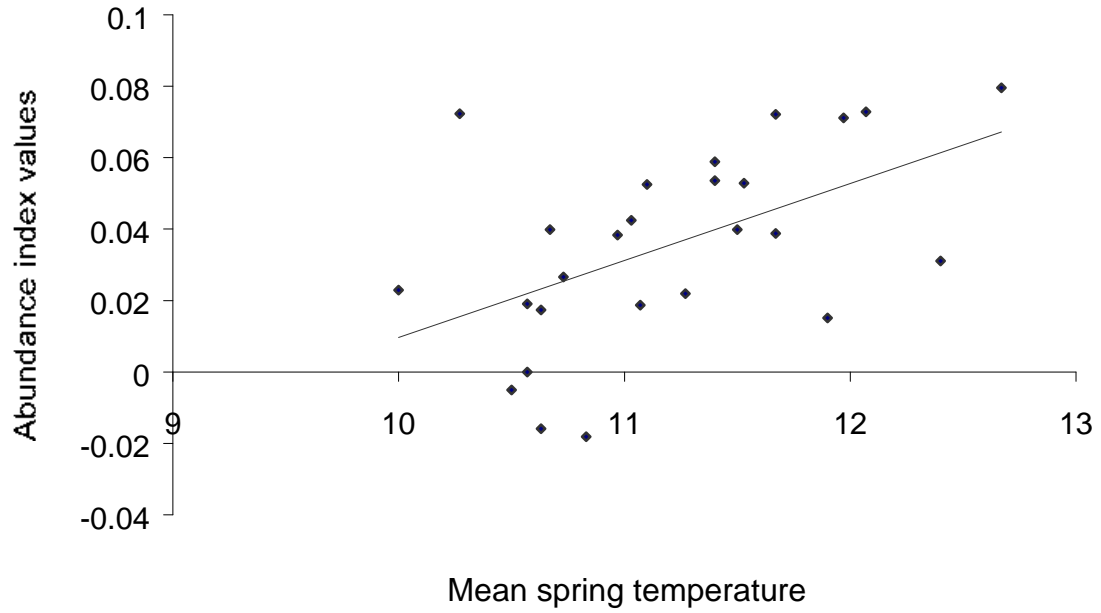
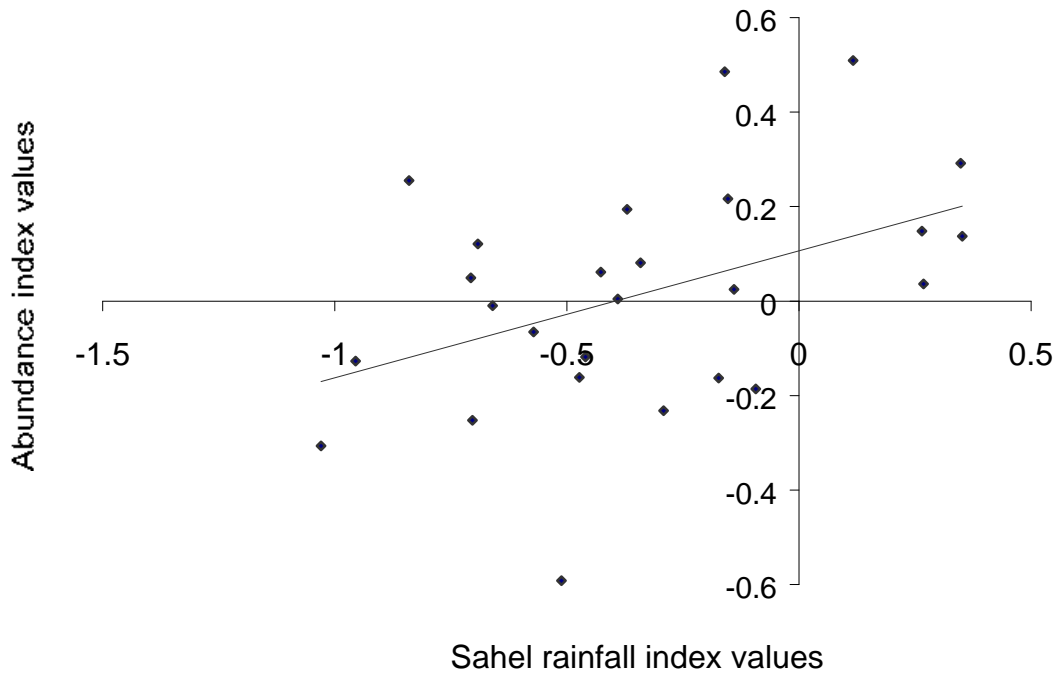
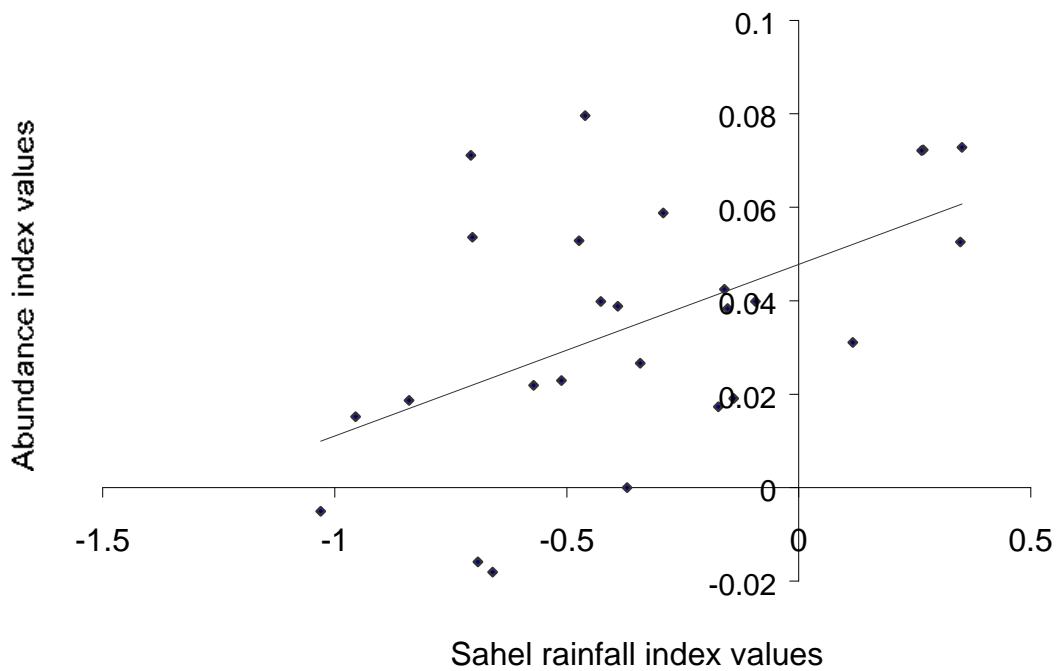


Figure 6. Comparison between WBS (1975-2000) population index values (the ratio of change between years), for four Palaearctic migrants, Whitethroat, Sand Martin, Sedge and Reed Warbler, and an index of rainfall in the Sahel region of West Africa during the rainy season (May-Oct).

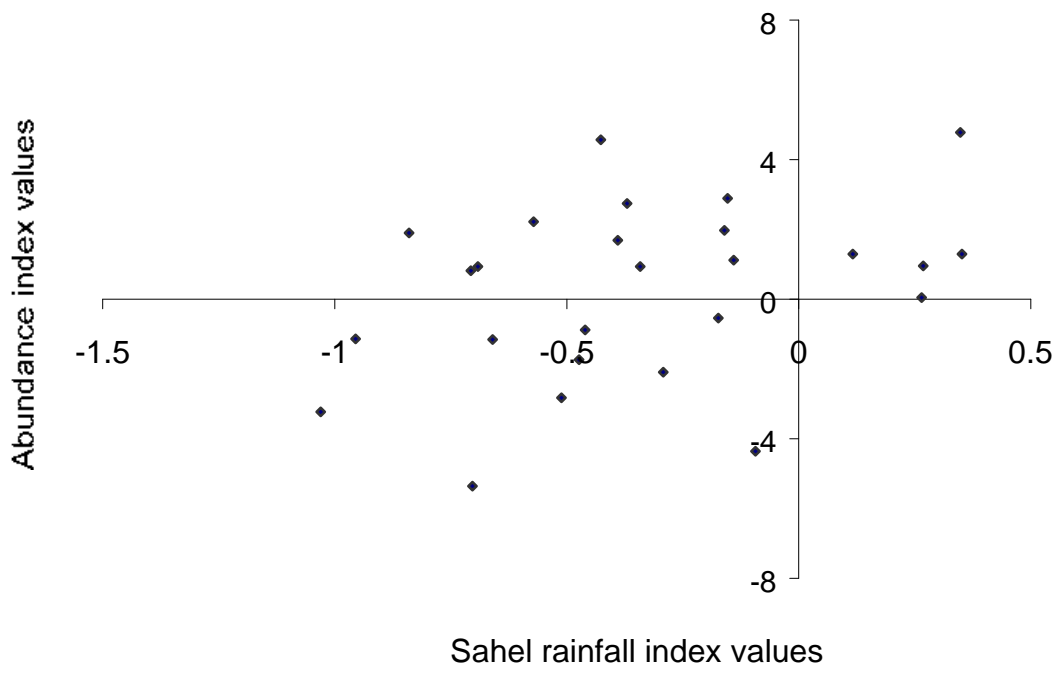
a) Sedge Warbler



b) Reed Warbler



c) Sand Martin (not significant)



d) Whitethroat (not significant)

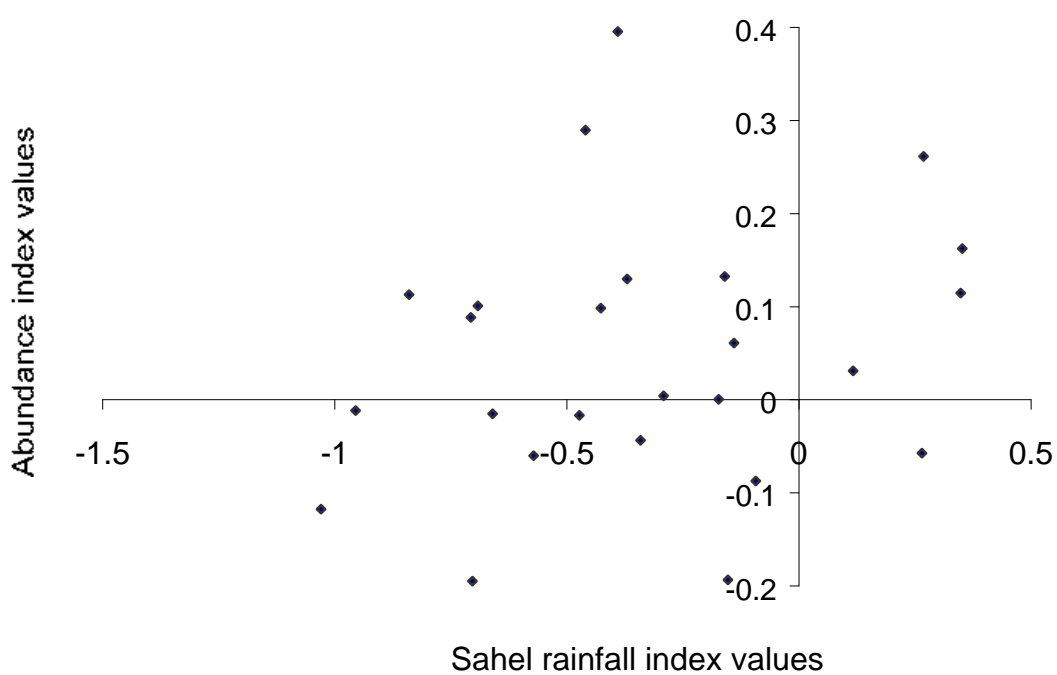


Table 1. Possible species pairings and associated similarity scores for individual years in the time series. A plus ‘+’ or minus ‘m’ in the heading sections indicate a second derivative that is significantly different from zero in that year and the direction of change.

SPECIES 1		SPECIES 2																	A+1	A	A-1			
		YEAR			m	.	+	.	m	m	.	+	+	m				+	+	m
		A-1	A	A+1	.	m	+	m	.	m	+	.	+	m				+	m	+
.	.	.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
.	.	m	0	0	0	0.5	0	-0.5	0	0.5	0.5	0	-0.5	-0.5	0	0.5	-0.5	0	0	0				
.	.	+	0	0	0	-0.5	0	0.5	0	-0.5	-0.5	0	0.5	0.5	0	-0.5	0.5	0	0	0				
.	m	.	0	0.5	-0.5	1	0.5	-1	-0.5	1	1	1	-1	-1	-1	1	-1	0	0	0				
m	.	.	0	0	0	0.5	0	-0.5	0	0.5	0.5	0	-0.5	-0.5	0	0.5	-0.5	0	0	0				
.	+	.	0	-0.5	0.5	-1	-0.5	1	0.5	-1	-1	-1	1	1		-1	1	0	0	0				
+	.	.	0	0	0	-0.5	0	0.5	0	-0.5	-0.5	0	0.5	0.5	0	-0.5	0.5	0	0	0				
.	m	m	0	0.5	-0.5	1	0.5	-1	-0.5	1	1	1	-1	-1	-1	1	-1	0	0	0				
m	m	.	0	0.5	-0.5	1	0.5	-1	-0.5	1	1	1	-1	-1	-1	1	-1	0	0	0				
m	.	m	0	0	0	1	0	-1	0	1	1	0	-1	-1	0	1	-1	0	0	0				
.	+	+	0	-0.5	0.5	-1	-0.5	1	0.5	-1	-1	-1	1	1	1	-1	1	0	0	0				
+	+	.	0	-0.5	0.5	-1	-0.5	1	0.5	-1	-1	-1	1	1	1	-1	1	0	0	0				
+	.	+	0	0	0	-1	0	1	0	-1	-1	0	1	1	0	-1	1	0	0	0				
m	m	m	0	0.5	-0.5	1	0.5	-1	-0.5	1	1	1	-1	-1	-1	1	-1	0	0	0				
+	+	+	0	-0.5	0.5	-1	0.5	1	0.5	-1	-1	-1	1	1	1	-1	1	0	0	0				
+	.	m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
m	.	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				

Table 2. Classification of species life-history and ecological characteristics as used in the exploratory analysis of factors affecting trends in species abundance. Migration strategy is classified into: migratory (M) and resident (R) species.

	Species code	Migration strategy	Winter in the Sahel (*)	Summer diet	Winter diet
Little Grebe	LG	R	-	Animal	Animal
Mute Swan	MS	R	-	Plant	Plant
Mallard	MA	R	-	Animal	Plant & animal
Tufted Duck	TU	R	-	Plant & animal	Plant & animal
Moorhen	MH	R	-	Plant & animal	Plant & animal
Coot	CO	R	-	Plant & animal	Plant & animal
Oystercatcher	OC	R	-	Animal	Animal
Common Sandpiper	CS	M	-	Animal	-
Kingfisher	KF	R	-	Animal	Animal
Sand Martin	SM	M	*	Animal	Animal
Yellow Wagtail	YW	M	-	Animal	-
Grey Wagtail	GL	R	-	Animal	Animal
Pied Wagtail	PW	R	-	Animal	Animal
Dipper	DI	R	-	Animal	Animal
Sedge Warbler	SW	M	*	Animal	-
Reed Warbler	RW	M	*	Animal	-
Whitethroat	WH	M	*	Animal	-
Reed Bunting	RB	R	-	Animal	Plant

Table 3. Proportional change in smoothed GAM indices of abundance for 18 waterways species monitored annually by the Waterways Bird Survey (WBS) during the periods 1975-99, 1975-87 and 1987-99. Species showing significant population change are highlighted in bold (confidence intervals do not include unity).

Proportional change in WBS index value (95% confidence interval)			
Species	1975-99	1975-87	1987-99
Little Grebe	0.30 (0.19-1.26)	0.43 (0.29-1.49)	0.70 (0.45-1.16)
Mute Swan	1.26 (1.09-2.76)	0.84 (0.67-1.55)	1.50 (1.33-2.05)
Mallard	3.40 (2.06-4.19)	1.56 (1.42-2.14)	2.18 (1.34-2.28)
Tufted Duck	0.70 (0.56-3.86)	0.56 (0.45-2.34)	1.25 (0.75-2.80)
Moorhen	1.26 (0.64-1.33)	0.83 (0.68-1.00)	1.51 (0.86-1.49)
Coot	2.17 (0.89-3.58)	2.06 (0.80-2.32)	1.05 (0.84-1.93)
Oystercatcher	2.11 (1.49-2.86)	1.90 (1.39-2.60)	1.11 (0.77-1.45)
Common Sandpiper	0.88 (0.58-0.96)	1.26 (0.88-1.42)	0.70 (0.59-0.80)
Kingfisher	1.42 (0.55-1.49)	0.68 (0.42-0.85)	2.07 (0.97-2.29)
Sand Martin	1.02 (0.92-5.42)	1.01 (0.73-3.62)	1.01 (0.76-2.11)
Yellow Wagtail	0.19 (0.04-0.29)	0.67 (0.29-0.95)	0.28 (0.11-0.34)
Grey Wagtail	0.41 (0.41-0.81)	0.46 (0.46-0.82)	0.89 (0.78-1.18)
Pied Wagtail	0.41 (0.34-0.68)	0.47 (0.41-0.77)	0.87 (0.71-1.06)
Dipper	0.66 (0.60-1.22)	0.71(0.80-1.29)	0.93 (0.67-1.07)
Sedge Warbler	1.02 (0.48-1.42)	0.95 (0.58-1.46)	1.07 (0.77-1.08)
Reed Warbler	1.67 (1.13-3.55)	1.07 (0.83-2.27)	1.56 (1.19-1.79)
Whitethroat	2.54 (0.76-3.35)	0.72 (0.26-1.11)	3.54 (1.98-3.95)
Reed Bunting	0.26 (0.22-0.46)	0.32 (0.28-0.50)	0.80 (0.68-1.08)

Table 4. Significant second derivative values (turning points) for species monitored by the Waterways Bird Survey (WBS). A plus or minus sign indicates that the second derivative for that species was significantly different from zero in that years, with a plus representing an upturn in the index series, and a minus a downturn.

Species	Year																					
	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	
Little Grebe	+	+	-	.	.	
Mute Swan
Mallard	+	+	+	-	-	
Tufted Duck	+	+	.	.	.	
Moorhen	+	+	
Coot	+	+	.	.	-	-	
Oystercatcher	-	-	
Common Sandpiper	-	-	-	
Kingfisher	+	+	.	+	+	+	
Sand Martin	+	+	+	+	.	-	-	.	+	+	.	-	-	.	
Yellow Wagtail	+	
Grey Wagtail	.	.	+	+	+	+	+	-	-	-	.	+	+	
Pied Wagtail	+	+	-	-	.	.	.	
Dipper	+	+	+	.	-	-	-	
Sedge Warbler	-	-	+	+	+	.	-	-	-	.	+	+	.	-	-	.	
Reed Warbler	+	
Whitethroat	.	.	+	.	.	+	+	+	+	+	+	+	.	.	-	-	-	
Reed Bunting	+	+	+	+	+	

Table 5. Similarity in timing and direction of upturns and downturns in the index series (second derivatives that are significantly different from zero) between pairs of species across years. Highly positive scores indicate a high similarity in the timing and direction of turning points, whilst a highly negative score highlights dissimilarity between species. The calculation of scoring is detailed in the methods section. Species codes are given in Table 2.

	LG																		
LG		MS																	
MS	0		MA																
MA	2	0		TU															
TU	-1	0	0		MH														
MH	1	0	2.5	0		CO													
CO	2	0	1	0	2		OC												
OC	-2	0	0	0	0	-1		CS											
CS	-2.5	0	-1	0	-1	-2	2.5		KF										
KF	2.5	0	2	0	2	2.5	-3	-4		SM									
SM	4.5	0	1.5	1	1	3.5	-2.5	-3.5	4.5		YW								
YW	1	0	0.5	0	0.5	1	-0.5	-1	1	1		GL							
GL	0	0	-3.5	1	-2	0	-1	-1	1.5	3.5	0		PW						
PW	3	0	2	-2	2	2	-1	-2	2.5	1.5	1	-2		DI					
DI	-2.5	0	-2	0	-2	-2.5	1	2	-0.5	-2.5	-1	4.5	-2.5		SW				
SW	4	0	-0.5	1	-1	2	-2.5	-3	3	9	1	4	0	-1		RW			
RW	0	0	2	0	1.5	1	0	0	1	0	0	-1.5	1	-1	-1.5		WH		
WH	4	0	2.5	0	1	0	-3	-3.5	5.5	7	1	4.5	2	0	5.5	0		RB	
RB	2	0	0	0	0	1	-2.5	-3	5	3	0.5	4	1	1.5	3	0	5		