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National and site-based alert systems for UK birds

Edited by

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Report to the Alerts Recommendations Group

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EXECUTIVE SUMMARY AND RECOMMENDATIONS

This report presents the conclusions of a working group that met in 1998 to consider alert systems for bird populations in the United Kingdom. Inputs to the working group were provided by a series of research and evaluation projects reported here, together with a workshop involving both statisticians and ecologists. The members of the working group were as follows:

David Gibbons (RSPB, Chairman), Stephen Baillie (BTO), Mark O'Connell (WWT), Stephen Freeman (BTO), Rhys Green (RSPB), Richard Gregory (BTO), Phil Grice (EN), Mark Rehfisch (BTO), Susan Davies (JNCC) and David Stroud (JNCC).

NATIONAL AND REGIONAL ALERTS

There are great advantages in having a system which has a consistent basis across both terrestrial breeding birds and wintering waterbirds and which can eventually be extended to all species with appropriate monitoring data. We have therefore presented our conclusions with this end in mind. Details will need to vary in relation to the available monitoring data and the analytical methods that can be applied to specific types of data.

Overall approach

1. Thresholds and time periods
   Alerts should flag up population declines of 25-50% and of 50% or more measured over the whole data series, 25 years, 10 years and 5 years.
   For terrestrial breeding birds the start of the maximum CBC period over which changes will be measured will be taken as 1968. This avoids problems relating to the severe winter of 1962/63 and early changes in CBC methods. When fitting GAMs it will be preferable to include data from 1966 and 1967 when fitting the GAM, but to calculate changes from 1968 so as to avoid endpoint effects (below).
   For counts of wintering waterbirds the winter of 1969/70 will be treated as the start of the index series. Note that counts of ducks and geese go back for some years before this but in the absence of major declines prior to 1969/70 it seems better to adopt a single start date for all waterbirds.

2. Measurement of population changes using smoothed population indices
   Population changes will be measured as the percentage change (on an arithmetic scale) between two points on a population index curve that has been smoothed to remove short-term environmental fluctuations.

3. Significance tests
   90% confidence intervals for population changes will be calculated. Alerts will only be flagged up when these confidence intervals do not overlap zero change (i.e. the change can be said to be statistically significant). Formal significance tests against the 25% or 50% threshold levels will not be conducted.

4. Description of data quality
   Alerts should be assessed for all data sets which are likely to produce useful information, even where these fall short of the sample sizes and representativeness that would be ideal. Use of confidence limits will largely guard against flagging spurious alerts from small samples, but they will not guard against problems of unrepresentativeness. The sources of information used to calculate alerts and known limitations on the extent to which the information may not be fully representative should be as transparent as possible. All alert reports should include the number of sites included in the analysis. Where the data may not be fully representative the known

limitations should be recorded, even if this is only possible in descriptive terms (e.g. Table 3.1). A method of assessing the likely representativeness of CBC indices using data from the 1988-91 Breeding Atlas was devised by Gibbons *et al*. (1996) as part of the Birds of Conservation Concern listing process. The ratio of mean frequency index in all Atlas squares to mean frequency index in squares with CBC plots was inspected and CBC data were then not used for species which had higher frequencies in areas without CBC plots. We propose that this ratio should be included in alert tables based on CBC data. Similar approaches could potentially be developed for other schemes where sampling is not fully representative.

For Wetland birds it may often be possible to provide an estimate of the proportion of the population that is included in the counts.

Data deficient species should be flagged separately. These will typically be species where the change measures have very wide confidence limits but where we cannot be certain that the population is not in serious decline. For example a species with change confidence limits of +5% to -60% would not flag a formal alert but is most likely to be in at least moderate decline. Such species are likely to be candidates for increased monitoring or special surveys.

5. Presentation of alert results

When considering alerts for any particular grouping (e.g. widespread UK terrestrial breeding birds) change measures for all species for which data are available should be presented. These tabulations should include summary information on data quality and representativeness, as notes against each species, with additional footnotes if necessary. They should record the population changes for all time periods of interest and which of these are statistically significant. Significant changes of 25-50% (moderate declines) and 50% or more (rapid declines) should be flagged. It would be possible to divide the alerts into many more categories based on time periods, consistency of declines, data quality and so on. However, we do not think this would aid interpretation, as such categories may be difficult to understand for those who are not familiar with the system. It would therefore be better just to describe particular alerts appropriate to any specific context, based on the information given in the alerts tables (e.g. "The Corn Bunting shows a rapid decline but the data are mainly from southern Britain"). Data deficient species should be flagged separately (above).

6. Status and dissemination of alerts information

National, country and regional alerts will be advisory and are intended to act as triggers for closer scrutiny of results and potential further investigation by interested parties. They will be released to the ornithological/conservation communities annually, at agreed times which fit into the analysis and reporting timetables of the schemes involved. The information will be made available to all interested parties and will be in the public domain. It is important that there should be close co-ordination between relevant conservation and research bodies to ensure that publicity and interpretation of the results presents a coherent picture. Details of timing of publication and of the co-ordination of publicity and interpretation are best dealt with as part of the management arrangements for the schemes and partnerships involved (i.e. WeBS, BBS and the JNCC/BTO Partnership). In addition to producing alerts for the United Kingdom there is interest in eventually producing all Ireland alerts in collaboration with colleagues from the Republic of Ireland.

7. Data to be analysed

Alerts for terrestrial breeding birds will be calculated from Common Birds Census data for the whole UK, although these have known bias towards southern Britain. Alerts will also be calculated from BBS data as they become available for particular time periods. BBS will allow separate alerts to be calculated for Scotland, England, Wales and Northern Ireland as well as for the UK as a whole. Alerts for individual countries will cover fewer species than those for the whole of the UK. Work to combine indices from CBC and BBS, where possible, is advanced but falls outside the present project.

Alerts based on WeBS data will be produced annually for the UK, Scotland, England, Wales and Northern Ireland (and also for individual designated sites - below).

Technical issues

1. Choice of statistical models
Generalized Additive Models with site and time effects provide the preferred means of calculating long-term population changes (section 2.3). They have the advantage of placing the analyses within a coherent statistical framework and yet avoiding any restrictive assumptions about the shape of the trend curves. Furthermore, models providing annual population indices (i.e. a sites x years model within log-linear Poisson regression, section 2.2 or the standard Underhill sites x years x months model, sections 4 and 5) are just special cases of a GAM. The modified Underhill index, smoothed over a 3-year moving window, provides an alternative method for waterbirds. Results will be similar to a GAM but the smoothing is less refined (section 4). We recommend that trend analyses for terrestrial birds should be carried out using GAMs. The long-term aim should be to apply these to the waterbirds data as well. However, due to computing requirements (see 11 below) the Underhill model with a 3-year moving window should be adopted as an interim solution. Where GAMs are used it is important that the precise smoothing algorithm and level of smoothing (below) should be reported.

2. Degree of smoothing
Degrees of freedom (i.e. amount of smoothing) appropriate for trend modelling using GAMs are examined in section 3.2 for terrestrial species and in section 5.4 for waterbirds. Plots showing trend curves with varying numbers of degrees of freedom are shown in figures 3.1 and 5.1. Our general recommendation for both types of data is to follow Fewster *et al.* (2000) and use 0.3 x t degrees of freedom, where t is the number of years in the time-series.

   Underhill proposes calculating changes between counts averaged over three or five years (section 4). He has not compared averaging over different numbers of years in detail. In the absence of further work we propose that the data should be averaged over three years.

   There is a special problem for a few terrestrial species, notably the Wren, where the above degrees of freedom leave fluctuations that will trigger some "false alarms" (section 3.2). In the medium term it may be possible to develop models incorporating weather co-variants in order to deal with this problem. For the time being we recommend applying the same level of smoothing to all species and dealing with such problems through interpretation of the alerts.

3. Treatment of endpoints
All methods of trend estimation are likely to give less reliable estimates for the endpoints of the series because they are based on fewer data. Problems of endpoint estimation within Generalized Additive Models are addressed for terrestrial birds in section 3.2 and for waterbirds in section 5.7. Inspection of graphs based on fitting GAMs to different numbers of years of data indicates that occasional endpoints do differ noticeably from the long-term trend. These could in principle trigger "false alarms". We therefore recommend that population changes used to evaluate alerts should be calculated from year t-1, where t is the last year of the index series. While the change is measured from t-1 all t years of data would be used to fit the GAM model on which the change estimates are based. A similar principle should be applied to calculations based on the beginning of the time series. Deviations of endpoints from the long-term trend have not been evaluated for the Underhill method. Note, however, that the use of three year means to calculate population changes from this method will result in a measure of change from t-1 as proposed above.

4. Confidence and consistency intervals
All the methods proposed calculate confidence intervals for smoothed index values and population changes using a bootstrapping technique where the data are resampled by site. This

technique does not assume that the data are described by any theoretical statistical distribution, but instead regards the distribution of the data as approximating that of the population from which they were sampled. Regional indices may sometimes necessarily be based on small numbers of sites. The statistical theory on which bootstrapping is based is only well developed in certain conditions and for "large" samples. The extent to which it is robust for small samples is unknown. It is therefore not possible to specify any particular sample size below which bootstrapping will not give reliable results, but any results for sample sizes of less than 10 should certainly be treated with particular caution (S.N. Freeman *pers comm.*) Interpretation of the confidence limits calculated in this way for many waterbirds, particularly estuarine waders, are somewhat different from conventional confidence intervals because a high proportion of the total population is counted each year. Thus Underhill has often referred to these as "consistency intervals" because they measure the extent to which changes on different sites are consistent. We believe that such consistency intervals are still helpful for interpreting alerts, particularly because counts are subject to considerable counting error even where a high proportion of the population is covered. It may be useful to distinguish those waterbirds populations where most of the population is counted from those where the counts are more like a sample survey, and for which confidence limits are therefore more appropriate. We suggest that 70% of the population being included in the counts would be a suitable threshold for this.

Terminology describing these intervals should be standardized as far as possible. We recommend that the intervals for both terrestrial birds and waterbirds should be referred to as confidence limits within alerts reports as this term is widely understood. We may wish to have a standard footnote which explains the interpretation of these confidence limits for some waterbirds.

The GAM analyses for both terrestrial breeding birds (section 3) and waterbirds (section 5) use 95% confidence limits, while Underhill has always used 90% limits. The selection of 90% or 95% limits is arbitrary but we strongly recommend that a standard approach should be adopted for both groups. We recommend that 90% confidence limits should be used on the basis that we are only testing for declines (i.e. we are doing a one-tailed test).

Ideally confidence limits would be calculated from about 1000 bootstrap replicates. In practice, however, the number of replicates is limited by computing power, particularly for GAMs. In this report GAMs for terrestrial species had 119 bootstrap replicates while GAMs for waterbirds were generally run with 199 bootstrap replicates. Analyses of Dunlin data with different numbers of bootstrap replicates (Figure 5.2) indicate that 100-200 replicates should provide adequate confidence intervals. Confidence intervals for the Underhill model were based on 500 bootstrap replicates. Normally 119 bootstrap replicates should be sufficient but if significance is marginal then more replicates should be undertaken.

5. Practicalities of computing

A large amount of computer time is needed to fit GAMs. Individual GAM models fitted to a single dataset typically take between 3 and 30 minutes of CPU time on a powerful Unix computer. While fitting individual models requiring this amount of time is not a particular problem, calculating bootstrap confidence intervals from even 119 replicates consumes a great deal of CPU time. Improvements in computer hardware and software will make it possible to run these analyses more quickly in the future, but at present it is not practical to apply GAMs with bootstrapped confidence limits to all data sets on a routine basis. We therefore propose the following approaches for the immediate future.

Analyses of CBC data for terrestrial birds will be undertaken using GAMs. However, confidence limits may only be calculated when a population change is sufficiently large to trigger an alert if it was significant. The computer resources needed to calculate confidence limits for BBS data, which include many more sites that the CBC, have yet to be evaluated.

Waterbirds analyses will be undertaken using the revised version of the Underhill method. This will be applied within a standardized alerts framework as outlined above.

SITE-BASED ALERTS

Overall approach

1. Species coverage
   Site-based alerts will only be implemented for wintering waterbirds at present, although the system outlined here may be extended to other species in the future.

2. Site coverage
   It is intended that one third of the Ramsar and Special Protection Areas classified for non-breeding waterbirds will be assessed, commented upon and reported on every year in rotation, so that all such sites are covered every three years. One sixth of SSSIs and ASSIs classified for non-breeding waterbirds will be assessed, commented upon and reported on every year in rotation, so that all such sites are covered every six years. These analyses will be based on WeBS data.

3. Change measures
   Changes on individual sites will be measured from smoothed population trends using methods similar to those outlined for national and regional trends above. Changes will be measured over the whole time series (from 1969/70), 25 years, 10 years and 5 years. Declines of 50% or more over any of these periods will be used to flag alerts. In addition, declines of 25-50% over the full time series or 25 years will be used to flag alerts.

4. Confidence limits
   Confidence limits cannot be calculated for changes on individual sites so bootstrap significance testing will not form part of the procedure for identifying site-based alerts.

5. Comparisons with national and regional trends
   Site-based alerts will be compared with national and regional trends, obtained from the national and regional alerts system outlined above, for purposes of interpretation. However, formal testing of trends or change measures from individual sites against national or regional figures will not form part of the system for flagging site-based alerts.

Technical issues

1. Measurement of population changes for individual sites
   This should probably be done using data for the site of interest only. Incorporating imputed values may bias estimates if the trend at the site of interest differs from the national or regional data set from which the imputing was carried out.

2. Endpoints
   Changes should be calculated to year t-1, where year t is the final year of the time-series. This follows the procedure outlined above for national and regional alerts.

3. Confidence limits of population changes at individual sites cannot be calculated from a bootstrap procedure because there is no replication of sites. Some large sites can be sub-divided into a number of smaller areas but there will not usually be enough of these to obtain useful confidence limits by bootstrapping. In the future it might be possible to develop suitable tests using a jack-knife procedure involving the dropping of counts for individual years from the time series but this is not a priority at present.

4. Statistical comparisons between the trends for individual sites and national or regional trends

In principle it is possible to test whether the GAM trend for a particular site or region differs from the rest of the data set (Section 5). There are two problems with this. The first is that the distributions of the deviances from GAMs may not be approximated well by the chi-square distribution. This problem may be circumvented to some extent by using an F-test approximation, which is recommended for overdispersed data, as outlined for regional CBC trends by Fewster *et al.* (2000). This F-test approach is the standard procedure for tests between Generalized Linear Models with overdispersion. It is though to be also applicable to GAMs, although further statistical validation is needed. Many of the WeBS counts show high levels of overdispersion. The second problem, however, is one of interpretation. Two smooth curves from GAMs may be highly significantly different because they have different shapes, even if their endpoints are identical. While such information may be important for interpreting alerts, it is difficult to see how it could be used to flag them up directly. We therefore recommend that such analyses should not be included within the formal alert system, although they may form a useful part of follow up investigations.

1. INTRODUCTION

1.1 Background

Population monitoring is an essential part of wildlife conservation and management. An effective monitoring programme should keep populations under surveillance and should be able to relate population changes to established threshold levels of conservation concern (Greenwood *et al.* 1995). Such an approach has been carried out in identifying “Red Data Birds” species of high conservation priority within the United Kingdom (Batten *et al*. 1990). There are a number of criteria for inclusion on such lists, including species with populations of international importance, species which have very localised breeding ranges, species with fewer than 300 breeding pairs, and species which are in a state of rapid population decline. The latter category has been set at a 50% decline over 25 years for species of high conservation concern. A recent modification of the criteria (Avery *et al*. 1995) has also recommended the identification of species of medium priority, defined as those species which have declined by 25-50% over 25 years. These criteria for rapid and moderate declines have been adopted by the statutory and voluntary conservation agencies (Anon 1995, Gibbons *et al*. 1996, JNCC 1996). Declines in widespread species have usually been identified using data from the BTO/JNCC Common Birds Census (CBC) for terrestrial birds and BTO/WWT/RSPB/JNCC Wetland Bird Survey (WeBS) for waterbirds.

Species are also considered to have undergone rapid or moderate declines if their ranges have been shown to have contracted by 50% or 25% over 25 years in terms of occupied grid squares. In this report, however, we restrict ourselves to consideration of trends in abundance of terrestrial breeding birds and waterbirds.

More recently provisional alert systems for terrestrial birds have been developed at the BTO, particularly in the context of opportunistic species (Marchant *et al*. 1997, Wilson *et al*. 1998). These alert systems consider changes over 25 years and shorter periods in relation to the 25% and 50% decline criteria outlined above. They use both absolute changes and rates of change over specified time intervals equivalent to declines of 25% or 50% over 25 years. Population changes are measured from smoothed population trends, using methods developed by the BTO in collaboration with the University of St Andrews (Siriwardena *et al*. 1998, Fewster *et al*. 2000).

1.2 Development of an alert system for UK bird populations

Here we develop standard methods for identifying national and site-based alerts for British birds. Specifically, we develop a national alert system for terrestrial birds using data from the BTO/JNCC Common Birds Census, and national and site-based alerts for waterbirds using data from the BTO/WWT/RSPB/JNCC Wetland Bird Survey. This work was prompted by a two-day workshop hosted by JNCC on October 13-14 1998. This was attended by both statisticians and ecologists from a range of GOs and NGOs. The overall objective of the workshop was to develop simple and transparent systems for alerting the statutory and voluntary conservation bodies to (i) rapid and moderate population declines among national populations of birds, and (ii) rapid and moderate population declines of bird populations at statutorily designated sites. In this report we restrict the latter to consider wintering waders and waterbirds. As part of the workshop, a recommendations group was established in order to bring together the views of those attending the workshop and define how national and site based alerts should be advanced. The recommendations group comprised: David Gibbons (RSPB, Chairman), Stephen Baillie (BTO), Mark O'Connell (WWT), Stephen Freeman (BTO), Rhys Green (RSPB), Richard Gregory (BTO), Phil Grice (EN), Mark Rehfisch (BTO), Susan Davies (JNCC) and David Stroud (JNCC). The group met on the second day of the workshop and their recommendations are presented as the executive summary of this report.

1.3 Structure of report

The Executive Summary of this report summarises proposals for the overall alert system, drawing together the work on terrestrial breeding birds and wintering waterbirds.

Methods for calculating population indices and trends (Section 2) defines the analytical approaches to indexing population trends, introduces the concepts of smoothing the data and bootstrapping confidence intervals on the trends, and deals with statistical significance. It gives particular attention to the use of Generalized Additive Models (GAMs). Section 3 presents an assessment of potential alert systems for terrestrial breeding birds, based on the application of GAMs to Common Birds Census data. Section 4 presents new developments of the Underhill method, both to address some specific deficiencies in the indexing model and also to provide features to address the issue of alerts. This is in the form of a short introductory text followed by a draft paper. Section 5 demonstrates a trial application of GAMs to WeBS data, showing many similarities with Section 3 on terrestrial birds. Section 6 provides a brief comparison of the application of the Underhill method (Section 4) and GAMs (Section 5) to waterbirds. Section 3 considers only UK/national alerts while sections 4 to 6 consider both UK/national and site-based alerts.

2. METHODS FOR CALCULATING POPULATION INDICES AND TRENDS

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2.1 Indexing populations

Long-term bird monitoring in the United Kingdom is reliant upon the efforts of a large number of skilled volunteer ornithologists. As a result of this, and the nature of some of the schemes in which they participate, abundance data are often characterised by many missing values, which cause statistical problems for the calculation of indices (ter Braak *et al*. 1994, Thomas 1996). This also means that sophisticated methods generally used for the modelling of time series data are inappropriate for most wildlife monitoring applications because the runs of data available are still too short (Bowerman and O'Connell 1987).

Traditionally, indices of abundance have been calculated from census data using simple methods such as the "chaining" together of inter-annual count ratios (see, e.g., Marchant *et al*. 1990). These methods are now generally regarded as inadequate due to inefficiency in their use of the available data and susceptibility to statistical artefacts such as "random walk" (Mountford 1982, 1985; Peach & Baillie 1994; ter Braak *et al*. 1994; Thomas 1996). A range of more sophisticated indexing methods have been suggested more recently, with particular reference to the annual monitoring of bird populations (ter Braak *et al*.1994; Thomas 1996). Of these protocols, methods in which counts are modelled as a function of the product of a site effect (allowing for variation in abundance between the plots or routes which constitute the census units) and a year effect (allowing annual fluctuations in abundance) have been used most widely in Europe.

Sites-by-years models have chiefly been formulated as the Mountford method (Mountford 1982, 1985), fitted with a "moving-windows" approach to allow long runs of years to be modelled (Peach & Baillie 1994), or in a log-linear Poisson regression framework (ter Braak *et al*. 1994). For some waterbirds analyses these models are extended by adding an additional month factor, giving a sites x years x months model (Sections 4 and 5). The number of winter months included varies between species. The addition of a month factor does not alter any of the underlying principles of the model, so in the rest of this chapter we refer only to sites x years models for simplicity. These models, however, suffer from the limitation of an assumption of linearity if trends are modelled directly: there is generally a choice between estimates incorporating annual fluctuations and a linear trend (on a log scale) (e.g. Pannekoek and van Strien 1996). While annual variation in abundance probably reflects reality most accurately, the object of long-term monitoring is often the determination of long-term trends, and these can be obscured by inter-annual fluctuations. As a result, it is often desirable to model long-term trends with some level of complexity between annual fluctuations and the over-simplification of a linear trend.

One way to reveal non-linear long-term trends beneath the "noise" of annual variation is to apply a smoothing algorithm to annual indices. Combined with confidence intervals calculated by bootstrapping, such approaches allow the significance of long-term changes to be assessed in a robust manner (Geissler & Sauer 1990, Buckland *et al*. 1992, Siriwardena *et al*. 1998). The choice of smoother (and of the amount of smoothing to be done) is subjective and *ad hoc*, however, and the analytical process involves two discrete steps: modelling counts and smoothing. Generalized Additive Models (GAMs) have the advantage that not only are they a smoothing device, but a modelling framework. With a GAM the smoothing is incorporated into the model in a single step, so that inference based on the resulting smooth index curve is made fully within the context of the model. The procedure is a generalization of log-linear Poisson regression: the same link function and error distribution are used, but a range of degrees of smoothness in the function modelled are available, ranging from a straight line, through a range of nonparametric curves of increasing complexity, to independent annual estimates. The latter are indistinguishable from the results of log-linear Poisson regression (a form of Generalized *Linear* Model (GLM)), the analytical method recommended by one recent review of those available (ter Braak *et al.* 1994). The range of smooth curves constitutes additional flexibility, allowing analyses of counts to be tailored *a priori* according to the appropriate degree of smoothing (simple linear changes, long-term trends or annual variation) for the biological question of interest.

By way of introduction to GAMs, we first review the log-linear Poisson regression model

2.2 Log-linear Poisson regression

Log-linear Poisson regression is described as a method for the analysis of survey data by ter Braak *et al.* (1994). The approach has been implemented in a specialised software package known as TRIM (*Trends and Indices for Monitoring Data*: Pannekoek & van Strien 1996), although most of the methods employed may be implemented with generalised linear modelling software such as S-PLUS (Statistical Sciences Inc. 1993), GLIM (Aitkin *et al*. 1989) or PROC GENMOD in SAS (SAS Institute Inc. 1996).

The CBC data consist of a set of N sites, monitored over T years, with counts y_{it} of the number of individuals of a species observed in site i in year t. The observation y_{it} is assumed to derive from a Poisson distribution with mean μ_{it}, and all counts are assumed to be independent. The mean μ_{it} is modelled as follows:

$$\log(\mu_{it}) = \alpha_i + b_t \qquad \text{eqn 1}$$

Here α_i and b_t are referred to as the *site effect for site i* and the *year effect for year t* respectively. In general each site is surveyed by only one observer over the time period, so that observer effects are incorporated into the site effects. The formulation of eqn 1 is equivalent to a generalised linear model (GLM: McCullagh & Nelder 1989) for the count values, with Poisson error distribution and logarithmic link function. The model is fitted by finding estimates $\hat{\alpha}_i$ and $\hat{b}_t$ for the N parameters α_i and the T parameters b_t. Once these estimates are obtained, the predicted count for site i in the year t is given by

$$\hat{\mu}_{it} = \exp(\hat{\alpha}_i + \hat{b}_t) \qquad \text{eqn 2}$$

and the total predicted count for year t is

$$\sum_{i=1}^{N} \hat{\mu}_{it} = \exp(\hat{b}_t)\sum_{i=1}^{N} \exp(\hat{\alpha}_i) \qquad \text{eqn 3}$$

We define the *abundance index for year t* to be

$$I_t = \frac{total\ predicted\ count\ for\ year\ t}{total\ predicted\ count\ for\ year\ 1} = \frac{\exp(\hat{b}_t)}{\exp(\hat{b}_1)} \qquad \text{eqn 4}$$

The index is a measure of relative abundance and has no units.

A useful feature of log-linear Poisson regression, or indeed any GLM fitted with canonical link function and including an intercept or factor, is the fact that the sum of predicted counts for year t (eqn 3) is equal to the sum of observed counts y_{it}, where they exist, added to the predicted counts for the sites where no observations exist (Nelder & Wedderburn 1972; ter Braak *et al.* 1994). This lends justification to the definition we use for the annual indices. The index for year t is also a ratio of exponentially transformed year effects, making for easy calculation.

The GLM above corresponds to the 'annual model' of the TRIM software package (Pannekoek & van Strien 1996): a separate parameter is allotted to each year, with no consideration of the sequence of years. This leads to unconstrained annual estimates, and thus trend is not modelled directly. The log-linear Poisson regression model lies at one extreme of the range of possible GAMs.

2.3 Generalized Additive Model

The generalised additive model (Hastie & Tibshirani 1990) is a flexible extension of the generalised linear model. The counts y_{it} are once again assumed to follow independent Poisson distributions with mean μ_{it} for the count in site i in year t. The linear predictor, which in the log-linear Poisson GLM above was given by eqn 1, is however replaced by a more general *additive predictor*, which allows mean abundance to vary as any smooth function of time rather than as a linear function alone. The form of the predictor function is the principal difference between the GLM and the GAM.

The additive predictor may be written as

$$\log(\mu_{it}) = \alpha_i + s(t) \qquad \text{eqn 5}$$

Here, the smooth function of time in the additive predictor is represented by $s(t)$, so that the expected count F_{it} in site i in year t is dependent on the site effect α_i, and on any number of other smoothly-varying quantities which are summarised by the value $s(t)$ in year t. The GAM is fitted by estimating the parameters α_i and the smooth function s, just as the GLM given by eqn 1 is fitted by estimating the parameters α_i and b_t.

There are two special cases of the GAM formulation (eqn 5) which fall into the category of GLMs. The first is the simple linear trend model, in which $s(t) = \gamma t$ for a single parameter γ to be estimated. In this case, the expected abundance within any site varies linearly on a logarithmic scale with time. The second case is the log-linear Poisson regression model described in the previous section, in which $s(t) = b_t$ for parameters $b_1,\ldots,b_T$ to be estimated. In this instance the function s is not smooth, but is obtained by joining the estimates b_t with straight lines.

These two cases lie at the extremes of the GAM framework: the first with maximum smoothness in the function s (a single straight line), and the second with minimum smoothness (a sequence of unconstrained estimates joined by linear segments). It is the middle ground between these extremes that is exploited by our models: a function is obtained with more flexibility to fit the observed data than a straight line, but which provides a smooth trend through the data rather than discrete annual estimates.

The output from the GAM is easily visualised. The fitted year effect curve (t) is common to all sites, so that for any two sites i_1 and i_2 the curves log (μ_{i1t}) and $\log(\mu_{i2t})$ are parallel. The intercepts of these curves are determined by the site effects, respectively α_{i1} and α_{i2}. Thus every site is subject to the same trend in the logarithm of expected count over time, although the absolute values differ between sites.

Once an estimate of the smooth function s has been obtained, the annual abundance index curve $I(t)$ is calculated as before:

$$I(t) = \frac{\textit{total predicted count for year } t}{\textit{total predicted count for year } 1} = \frac{\exp(\hat{s}_t)}{\exp(\hat{s}_1)} \qquad \text{eqn 6}$$

Note that we now write I as a smooth function of t, rather than as a set of point estimates as in equation 4.

The degrees of freedom associated with the curve *s* may be loosely interpreted as the number of parameters used in fitting *s*.

The choice of the value for d.f. is an important part of the modelling process. For clarity we shall write s_d for the curve *s* to be fitted using a smoothing spline on the variable *t* with *d* degrees of freedom, and we shall refer to the associated model as a 'GAM with *d* degrees of freedom'. Broadly speaking, *d* indicates the extent to which the smoothed curve may include changes of direction. The choice of *d* depends largely on the objectives of the analysis. For inference about long-term trends a fairly smooth index curve is required, corresponding to low d.f., while information about annual fluctuations requires unconstrained annual estimates and the maximum value of *d*. Consideration of the length of the time series is also important: the larger the number of years *T*, the higher the value of *d* must be in order to maintain a particular level of flexibility in the trend curve.

For trend estimation it is important that the value of *d* is high enough to ensure that the trend is not constrained to an unduly simplistic pattern, but low enough to remove all the roughness from the output. Previous work by Fewster *et al.* (2000) using Common Birds Census data has suggested that the choice of *d* that is roughly 0.3 times the length of the time series produces a trend curve with suitable complexity. This conclusion is re-examined in the context of indexing both terrestrial and waterland birds below.

Confidence limits on the population indices were derived using the bootstrap method (Buckland *et al*. 1992, Anganuzzi 1993, Siriwardena *et al*. 1998). The number of bootstraps was set at 119. This figure was chosen to represent a minimum acceptable level of bootstrapping given the considerable computer time required to run GAMS. At present, computer-processing time is a very considerable barrier to the bootstrapping procedure, particularly for the more abundant species, and limited the number of bootstraps to what is a relatively modest number. Population changes between two time points were treated as statistically significant if the 95% confidence limits on the change derived from bootstrapping did not overlap zero. The null hypothesis was that no change had taken place over a particular time period.

3. DEVELOPING A NATIONAL ALERTS SYSTEM FOR TERRESTRIAL BIRDS USING GENERALIZED ADDITIVE MODELS

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3.1 Data

Data for terrestrial species come from the BTO/JNCC Common Birds Census (CBC) which is a long-term monitoring programme for abundant bird species. CBC observers use the mapping method to gather information each spring and summer on the numbers and distribution of breeding bird territories on plots throughout the United Kingdom (Marchant 1983, Marchant *et al*. 1990). Observers make a series of visits to their plot through the breeding season to record all the birds seen or heard. This information is used to identify clusters of registrations which are taken to represent breeding territories.

CBC plots are classified mostly as either farmland or woodland. A smaller number of >special= plots are of other habitat types. Farmland plots reflect the general nature of farmland landscapes in that they often contain small areas of woodland. Plots of all three classes may contain or be bordered by houses and gardens. While plots are distributed throughout the United Kingdom, they are concentrated in the south-east (Marchant *et al*. 1990).

3.2 Selecting degrees of freedom in Generalized Additive Models

A series of GAMs, with differing degrees of freedom, were fitted to CBC data for 10 species showing a range of different population trends (Figure 3.1). The figure shows increasing smoothing of the data from what is equivalent to an annual model (with the number of years minus one degrees of freedom) to highly smoothed curves with a small number of degrees of freedom. When the degrees of freedom were set at around 0.3 times the length of the time series, the general trend is apparent and fluctuations around it are maintained. In the case of those time series covering 34 years this corresponds to 10 degrees of freedom.

One potential problem emerges for highly variable species such as the Wren which is sensitive to harsh winter weather (Figure 3.1). The inherent variability of the population means that even with the degrees of freedom set at 0.3 times the length of the time series, the trend is still erratic and most probably driven by winter weather conditions. For this species, and others like it, one approach would be to reduce the number of degrees of freedom further (e.g. 4 d.f.) if the overall trend, independent of short-term weather effects, is of interest (see below). If the trend is not appropriately smoothed, one is likely to raise false alarms because of the short-term influence of winter weather. The reverse side of this argument is that smoothing can remove genuine population decline which means that alarms were not raised when they should have been. This issue is discussed in more detail below.

3.3 The treatment of endpoints

The issue of endpoints in time series was examined by fitting a series of GAMs to each of 20 species, starting with 1962 to 1966 and successively adding one year=s worth of data. While the majority of the curves for different runs of years were similar, there was variation among species. Deviation is illustrated in Figure 3.2 for each species in turn, while Figures 3.3.1a to 3.3.20a show the smoothed trends fitted to different runs of years for each species in turn. The index shows deviation from the smooth for the full time-series, i.e. when all the data were included for 1962-1997, for each year in turn. So for example, the point plotted at 1966 is the difference between the index in 1966 based on data from 1962 to 1966, and the index in 1966 based on data from 1962 to 1997. A large positive or negative index indicates that the endpoints for shorter time periods are diverging considerably from the smoothed trend based on the whole time series.

In general terms, deviation was relatively modest in most species (Figure 3.2). Deviation was greatest when the direction of the trend was changing, among those species with naturally variable populations, e.g. Wren and Goldcrest, and those species with relatively sparse data, e.g. House Sparrow, Woodcock and Willow Tit (Figure 3.2). Note that the *y*-axis is scaled differently for the latter four species because of the high degree of variation.

From a statistical standpoint, one might recommend that the two or three most recent years of trend values should not be used for the calculation of population changes. The problem with this approach is it may be difficult to explain the use of only part of the data set available. There is also the complication that any alerts raised on this basis would relate to some previous time point and potentially not the current situation. The case for removing the latest time points, however, is made in Figures 3.3a to 3.22a, since at certain times the observed trend differs considerably from the pattern that has emerged. Short-term alerts raised on this basis could be misleading in some circumstances. The most serious deviation from the trend generally occurs in the last year of the series. We therefore recommend that for alerting purposes changes should be calculated to the penultimate year of the time series. Note that data for the final year of the time series are used in the calculation of the smoothed population trend from which the population change measures are calculated.

In the analyses that follow we use the entire time series available for each period of interest.

3.4 Applying an alert system to a selected group of terrestrial birds

A group of twenty species was chosen for consideration. Table 3.1 lists the species, the number of CBC plots, the CBC habitat types included, and any caveats concerning the data. Species were chosen to encompass those with large and small samples sizes within the CBC, and those showing population gains and population losses. Since the primary purpose of the alert system would be to identify population declines, the species list is dominated by those species known to have fallen in number.

Figures 3.3.1 to 3.3.20 show, on a single page for each species, indices derived from GAMs for successively longer time periods from 1962 (top graph, a), population changes based on 5, 10, 25 and all year periods (centre graph, b), and the GAM trend 1962 to 1997 with upper and lower 95% confidence intervals derived from a bootstrap procedure (lower graph, c). The centre graphs can be explained as follows: the first point on the 5-year trend line is the change in the index between 1962 and 1967, and it is plotted at 1967. The next point on the line is the change between 1963 and 1968, plotted at 1968 and so forth. The first 10-year trend compares 1962 with 1972 and the first 25-year trend 1962 with 1987. The figure described as the total change compares 1962 with latest year in the index series, so the figure plotted at 1966 is the change between 1962 and 1966 (when only these years are included in the index) and so forth. The last change in this series compares 1962 with 1997 (including all the data).

Alert levels were assessed for all species except the Chaffinch, because it has been increasing consistently over the time period we consider, and both Wren and Song Thrush because of the computer time required to complete the bootstrapping. In fact, bootstrapping was extremely demanding of computer time for most species, even though the number of bootstraps was relatively low at 119. Overall, computer time was the limiting factor in developing alert limits within this project. Future improvements in computer speed are likely to improve this situation.

3.4.1 Population trends

We will first briefly review the trends by species in taxonomic order before considering how we apply an alert system.

The Grey Partridge has declined precipitously from the 1960s and the confidence limits on the population trend are narrow indicating considerable precision in the trend (Figure 3.3.1). The 5- and 10-year change measures mostly indicate decline. Since 1980 all of the 25-year and full time series change measures show declines of greater than 50%. The 25-year and total change measures show substantial population decline. The Lapwing population has been relatively stable up to the mid 1980s with a subsequent shallow decline (Figure 3.3.2). The confidence limits on the trend are relatively large. The 25-year and total change measures show considerable long-term decline. CBC data for the Snipe are extremely sparse and this is reflected in the very broad confidence limits on the trend (Figure 3.3.3). A rapid decline is apparent from the early 1970s, although it is measured imprecisely. The change measures successively identify the decline through time and those for the shorter time periods provide an early warning as the population crashes. The overall level of decline is very large. The Woodcock shows a similar pattern to many of the other species, it increased in number in the late sixties but declined steadily from the 1970s to the 1990s, before showing a small upturn (Figure 3.3.4). The recent slight increase in numbers is reflected in the change measures for all the time periods, although most notably for 5- and 10-year changes. This indicates that the alert system is capable of detecting the improvement of populations as well as declines. The confidence limits on the overall trend are relatively wide reflecting the secretive nature of the species and the small sample sizes on CBC plots.

Turtle Dove showed a small increase in number up to the late 1970s but then a gradual decline (Figure 3.3.5). The change graph identifies the population decline but as the trend becomes less steep the 5-year changes become increasingly small, although the trends are always negative. The 25-year and total change lines show considerable population decline. Confidence limits on the trends are relatively broad. The Great Spotted Woodpecker has shown a stepped increase in numbers from the early 1960s (Figure 3.3.6). As you would expect, the change measures are almost always positive. Confidence limits on the trend are relatively narrow. The Skylark population rose towards the end of the 1970s but has declined strongly subsequently (Figure 3.3.9). The 5-, 10- and 25-year trends herald the population decline, although as the steepness of the curve declines the former two respond to the slightly improved situation. The overall trend is measured with a good degree of precision.

The number of Swallows censused within the CBC has fluctuated since the sixties and the confidence limits on the trend are fairly broad. The 5- and 10- year change measures both identify brief periods when the population begins to decline but these trends are soon reversed. The 25-year trend shows population gains. (Figure 3.3.8)

Wren numbers in the UK were greatly depleted by the cold winter of 1962-63 (Marchant *et al.* 1990). Following a rapid recovery up to the mid-1970s, abundance fell again in response to a further series of cold winters, only to return to its previous high levels as winters have become warmer. The fluctuations result in a series of 5-year alerts and 10-year alerts in the late 70s and early 80s, but the population recovered before the 25-year alerts were triggered. (Figure 3.3.9)

After a rapid increase in Song Thrush abundance following cold winters at the beginning of the 1960s, numbers declined steadily since 1967, with a rapid period of decline in the mid-1970s. There is some suggestion that the decline may have levelled off in the 1990s. Five-year alerts became apparent in the late 1970s and 10-year alerts were triggered throughout most of the 1980s. 25-year alerts became greater than 50% in the 1990s. (Figure 3.3.10)

Willow Warbler abundance increased throughout the 1960s and then showed a shallow decline in the 1970s, before showing some recovery in the early 1980s. Numbers have declined thereafter to reach their lowest level. Alerts have only been triggered in the 1990s for 5-, 10- and 25-year periods. (Figure 3.3.11)

Goldcrest numbers increased rapidly from the 1960s through to the mid 1970s and have declined in an irregular pattern since that time (Figure 3.3.12). The fluctuations within the trend are undoubtedly driven by cold winter weather which is also responsible for the low population level at the start of the time series. The change measures successively identify population decline from the mid 1970s. The 5-year alerts become less pronounced as the trend stabilises, but the 25-year trend indicates severe population decline from the highest level. Note also that the total change measure is positive throughout reflecting the very low population level at the start of the 1960s. The confidence limits of the trend are relatively narrow and we can have considerable confidence in the trend. The number of Willow Tits showed a similar increase up to the mid 1970s but has declined subsequently (Figure 3.3.13). Change measures successively highlight this downturn and the 25-year trend shows a severe decline. The confidence limits on the trend are relatively wide because the samples sizes within the CBC are quite small (Table 1). Starling populations have shown a steady decline from the 1960s with an apparent levelling of the population in the 1970s (Figure 3.3.14). The change measures rapidly identify the declines, most noticeably in the late 1960s and from 1980 onwards. The 25-year and total change measures show strong long-term decline. Confidence limits on the trend are relatively narrow.

The House Sparrow data from the CBC are quite sparse and the population trend is measured imprecisely (Figure 3.3.15). Even so, it is apparent that sparrow numbers rose briefly in the late 1970s but have since fallen. The change measures pick up population falls in the late 1960s and from 1980. The overall trend, for the 25-year period or for the entire time series, shows moderate decline. Tree Sparrows have also fallen in number although their decline has been precipitous being particularly severe from 1980 and recently levelling off (Figure 3.3.16). The 5- and 10- year changes signal the population decline and because the rate of decline is sustained they continue to do so until the population begins to plateau in the late 1980s. The overall decline is extremely severe.

The Chaffinch, in contrast with many other seed-eaters, has shown a steady but slow rate of increase (Figure 3.3.17). The 5-year change measure indicates two brief periods of decline, illustrating the sensitivity of this measure, as does the 10-year measure in the latest year, but the longer term trend is positive. Chaffinch indices are measured relatively precisely. The Goldfinch shows a complex pattern of stability with a population increase in the mid 1970s followed by a decline and recovery (Figure 3.3.18). The 5- and 10-year changes pick up the periods of decline but also show recovery. The 25-year and all change measures are predominantly negative in the second half of the time series, but become positive as the population recovery continues. Confidence limits on the trend are narrow indicating that it is measured precisely. Numbers of Yellowhammer remained stable until the late 1980s but have fallen steadily from that time (Figure 3.3.19). This downturn is heralded by the 5- and 10-year changes and both the 25-year trend and the overall trend show substantial decline. Yellowhammer indices are relatively precise. In contrast, the Corn Bunting population increased in the 1960s but declined rapidly between 1973 and 1986 before coming to a new and lesser rate of decline (Figure 3.3.20). The population crash is identified successively by the different change measures. The 25-year, and to a lesser extent the total change measures, illustrate considerable decline.

3.4.2 Identifying alerts

Using the methodologies described above we have evaluated an alert system as applied to seventeen species out of the twenty using CBC data. We have fitted a series of GAMs for different time periods and used a bootstrapping technique to assess confidence limits. Since the number of potential GAMs was very large we targeted those years where the population decline was greater than 25%.

Table 3.2 lists the species in taxonomic order, indicating the time period under consideration and the level of population change and its significance over 5, 10, 25 and over the entire time period. For all species except Willow Warbler, the results are illustrated graphically in Figures 3.4.1 to 3.4.16.

In the case of the Grey Partridge, population changes over all periods except the 5-year change have been statistically significant (Table 3.2, Figure 3.4.1). The 25-year changes show a decline of around two thirds, while the overall trend is close to 90%. Application of the proposed alert system would have provided an early warning of decline, but note that 5-year changes are sensitive to small upward fluctuations. The Lapwing trend is more complex and only in more recent years has the longer-term trend become apparent, suggesting 35-46% declines over 25 years and across the whole time series (Table 3.2, Figure 3.4.2). The number of Snipe has declined significantly by 81% over 25 years and 80% over the time series (Table 3.2, Figure 3.4.3). Partly because the trends are measured imprecisely and partly because the population has fluctuated, many of the change measures for shorter time periods are non-significant; nevertheless, they show consistent decline. Indices for the Woodcock are similarly rather imprecise and while there have been periods of significant decline, the most recent trends are non-significant, even though the 25-year trend approaches a decline of 50% (Table 3.2, Figure 3.4.4).

The decline of the Turtle Dove is quickly identified by the alert system. The overall trends are for a 72% and 65% decline over 25 years and over the entire period (Table 3.2, Figure 3.4.5). Unsurprisingly, the Great Spotted Woodpecker fails to raise significant alarms, except for one 5-year period, and is generally increasing although not significantly (Table 3.2, Figure 3.4.6). The Skylark raises significant alarms for most periods considered (Table 3.2, Figure 3.4.7). It has declined significantly by 50% over 25 years and 37% over the full time series. Swallow numbers have fluctuated according to the CBC data and few alarms are raised (Table 3.2, Figure 3.4.8). Overall the long-term trend is for around an 18% non-significant increase. Willow Warbler is another species whose numbers fluctuate through time and it has shown periods of decline (Figure 3.3.11). The 25-year trend is for a significant 30% decline, but the trend from 1962 shows no change. Even so, significant moderate declines are detected on the basis of the 5- and 10-year trends in particular years.

Goldcrest numbers fluctuate widely. The trends over 25 years and the entire time series show a 57% decline and a 228% increase respectively (Table 3.2, Figure 3.4.9). The 10-year changes also indicate significant population decline in a number of cases. The lack of consistency in the findings suggests that alerts should not be raised for this species. It also suggests that a higher degree of smoothing may have been appropriate so that the short-term effects of weather could be removed. The downward trend of the Willow Tit would have raised a number of alarms but since the trend is measured imprecisely they were not always statistically significant (Table 3.2, Figure 3.4.10). The 25-year trends illustrate severe population decline whereas the trend over the entire time period is for a non-significant increase. The exact time frame chosen will obviously influence the alert raised. The Starling raises significant alerts based on a number of different time periods (Table 3.2, Figure 3.4.11). The population has fallen by 62% over 25 years and 69% over the full time series.

Only in recent years does the House Sparrow raise significant alerts, indicating it has declined by 47% over 25 years and 65% over the time series (Table 3.2, Figure 3.4.12). Small sample sizes within the CBC mean that many of the changes assessed are non-significant, even so, significant changes are observed over all periods. The population decline for the Tree Sparrow is more consistent and raises a series of significant alerts (Table 3.2, Figure 3.4.13). The overall decline is in the region of 94%. In contrast, the fluctuating Goldfinch population raises few significant alerts and the overall trend is of stability (Table 3.2, Figure 3.4.14).

Of the years considered, only in 1997 are alerts raised for the Yellowhammer, reflecting its recent population crash (Table 3.2, Figure 3.4.15). Significant alerts are raised for all time periods in 1997; with a 54% and 47% decline over 25 years and the entire time series respectively. Significant alerts are raised for the Corn Bunting from the start of the 1980s, but as the rate of population decline slows only the longer term trends remain significant (Table 3.2, Figure3.4.16). The 25-year trend shows a decline of 84%, while the trend for the whole time series suggests a 65% decline.

In conclusion, the alert system we have developed appears to be capable of identifying population declines early on and providing a reliable signal of a worsening or improving situation. Statistical significance is important in interpreting the trends. In these cases a precautionary principle may be more advisable although this has its own drawbacks. As would be expected, alerts based on short time periods, such as 5 years, are sensitive to population fluctuation and raise the highest number of false alerts. Even so, they provide a considerable degree of sensitivity and will herald population decline. As the time period increases to 10 and 25 years we can have much greater confidence in the underlying trend. Interpretation of the alert system thus requires careful consideration of the different time periods.

Our evaluation shows, unsurprisingly, that the specific time period chosen for study has a considerable bearing on the alerts raised. In the CBC time series the extreme cold winter weather at the start of the 1960s meant that many populations were at very low levels at this time but recovered rapidly with improving conditions. One consequence of this is that the population change figures from 1962 to 1997 are often positive, giving an unrealistic picture of population gains. To assess the true situation it would seem more sensible to take the point at which populations had bounced back from the severe winter, around 1968, and compare this with the most recent year.

3.4.3 Applying an alert system to CBC data in 1997

Based on the evaluation described above, we are able to present a provisional alert table for 1997 for the 17 species listed in Table 3.2 (Table 3.3). The table merely summarises GAMs fitted to the CBC data 1962 to 1997 with bootstrap confidence limits and qualifying information. If the alert system is to be adopted we propose creating alert tables of this sort annually, thus incorporating the most recent data.

The table presents all the relevant information in order to allow users to decide what actions, if any, are to be made on the basis of the information. We have intentionally avoided a system in which birds are placed into a large number of labelled categories. The trend measures and information on data quality provided should allow users to draw their own conclusion. We do, however, flag up rapid and moderate decline categories clearly in the list.

The alert table allows the user to identify those species in steepest decline where specific action is likely to be necessary in order to reverse the downward trend. The table may also identify a group of species where there are some indications of decline, for example, a very recent drop in numbers, or a considerable decline that is measured imprecisely, where more information and/or research is required to clarify the species status. For some of the latter birds the action may simply be for vigilance in future years.

On this basis, our evaluation identifies 10 species in the Rapid decline category over 25 years (i.e. decline of greater than 50%). In all cases, the 10- or 35-year change measures show significant decline, and in three cases the 5-year changes do so.

Four species fall into the Moderate decline category over the last 25 years (i.e. decline of between 25 and 50%). In three cases the decline over this period is statistically significant. In one case the 10- and 36-year alerts also show statistically significant decline. The 5-year change measures do not indicate significant decline. Perhaps worryingly, population declines for two of these species, House Sparrow and Lapwing, are more severe when we consider the entire time series as compared with that over 25 years. Declines of 65 and 46% were identified for these two species respectively. This is indicative of a shallow but sustained decline over a very long time scale. This is arguably as important as a more severe decline over a shorter period. It emphasises the importance of including changes over the whole time series within an alert system. In contrast, the Willow Warbler shows a 3% non-significant increase from 1962 to 1997 and this implies that its moderate decline is part of a short-term fluctuation rather than a long-term trend. In this instance, the trend over the whole time period is extremely useful in understanding the overall pattern of population change.

Finally there are three species, Goldfinch, Swallow and Great Spotted Woodpecker, in which no alerts are raised. Although some of them show small, non-significant population declines over particular periods, they are generally stable or increasing. In fact, the Great Spotted Woodpecker increased significantly over 36-, 25- and 10-year periods. This illustrates the potential use of the alert system at the other end of the spectrum, among increasing 'pest' or opportunistic species. The alert system provides quantitative information on the level of population gain and its significance and will therefore be of value in identifying developing trends at an early stage.

The Recommendations Group may wish to discuss refinements and changes to the presentation of the alert results in a single table, and the supporting information required for interpretation.

Table 3.1 A list of species chosen for analysis indicating the nature of Common Birds Census data.

Species	Number of Plots (62-97)	Atlas Ratio[1]	CBC Plot Type	Comments
Grey Partridge	391	0.8084	Farmland	
Lapwing	477	1.1003	All	low densities on farmland plots
Snipe	145	-	All	small sample
Woodcock	199	-	All	small sample
Turtle Dove	383	0.5448	Woodland/Farmland	small sample on farmland and woodland
Great Spotted Woodpecker	572	0.5266	Woodland/Farmland	
Skylark	511	0.9892	Farmland	
Swallow	531	0.8913	All	
Wren	983	0.8631	Woodland/Farmland	
Song Thrush	967	0.7988	Woodland/Farmland	
Willow Warbler	913	0.8794	Woodland/Farmland	
Goldcrest	547	0.8616	Woodland/Farmland	small sample on farmland
Willow Tit	331	0.5715	All	small sample
Starling	662	0.8069	Woodland/Farmland	
House Sparrow	287	0.7791	All	small sample
Tree Sparrow	531	0.7595	All	small sample in later years
Chaffinch	986	0.8453	Woodland/Farmland	
Goldfinch	557	0.7377	Farmland/Woodland	
Yellowhammer	685	0.7454	Farmland/Woodland	
Corn Bunting	236	0.8944	All	small sample

[1] Ratio of mean Atlas frequency index for all squares to mean Atlas frequency index for squares with CBC plots. Values greater than 1.0 indicate that the species occurs at higher frequencies outside the area covered by the CBC, and that the CBC is therefore unlikely to be representative of UK population trends. Method and data from Gibbons *et al.* (1993).

Table 3.2 Population changes (%) over 5, 10, 25 years and over the whole time series for different time periods and species. * = change is statistically different. Alerts for Song Thrush, Wren and Chaffinch were not assessed.

Species	Latest Year in Time Series (beginning 1962)	5 Year Change	10 Year Change	25 Year Change	All Data
Grey Partridge	1967	-55 *	-	-	-
	1968	-49 *	-	-	-
	1971	5 n.s.	-	-	-
	1972	12 n.s.	-47 *	-	-
	1983	-63 *	-57 *	-	-
	1986	-25 *	-56 *	-	-
	1989	-29 *	-63 *	-	-
	1991	-20 n.s.	-42 *	-66 *	-
	1994	-37 *	-54 *	-77 *	-
	1997	-13 n.s.	-42 *	-75 *	-88*
Lapwing	1988	-37 *	-37 *	-	-
	1991	-24 n.s.	-35 *	-12 n.s.	-
	1994	-13 n.s.	-43 *	-39 *	-
	1997	6 n.s.	-22 n.s.	-35 *	-46*
Snipe	1975	-4 n.s.	32 n.s.	-	-
	1980	-21 n.s.	-19 n.s.	-	-
	1985	-30 *	-42 *	-	-
	1990	-20 n.s.	-43 *	-34 n.s.	-
	1997	-20 n.s.	-59 *	-81 *	-80*
Woodcock	1977	-7 n.s.	11 n.s.	-	-
	1982	-25 n.s.	-28 n.s.	-	-
	1987	-27 n.s.	-40 *	-	-
	1992	-47 *	-61 *	-65 *	-
	1997	42 n.s.	-6 n.s.	-46 n.s.	101 n.s.
Turtle Dove	1984	-34 *	-42 *	-	-
	1987	-25 *	-46 *	-	-
	1990	-33*	-55 *	-57 *	-
	1993	-30 *	-52 *	-68 *	-
	1996	-14 n.s.	-41 *	-70 *	-
	1997	-19 n.s.	-42 *	-72 *	-65*
Great Spotted Woodpecker	1983	-14 *	29 n.s.	-	-
	1987	-6 n.s.	-10 n.s.	-	-
	1997	10 n.s.	18 n.s.	64 n.s.	131 n.s.
Skylark	1982	-31 *	-26 *	-	-
	1989	-16 *	-39 *	-	-
	1995	-8 n.s.	-19 *	-45 *	-
	1997	-13*	-19 *	-50 *	-37*

Species	Latest Year in Time Series (beginning 1962)	5 Year Change	10 Year Change	25 Year Change	All Data
Swallow	1984	-20 *	13 n.s.	-	-
	1985	-24 *	6 n.s.	-	-
	1986	-22 *	-3 n.s.	-	-
	1987	-16 n.s.	-12 n.s.	-	-
	1997	-5 n.s.	2 n.s.	12 n.s.	18 n.s.
Willow Warbler	1973	-16 *	31 n.s.	-	-
	1991	-25 *	-25 *	-23 *	-
	1997	10	-28 *	-30 *	3 n.s.
Goldcrest	1979	-61 *	-1 n.s.	-	-
	1981	-30 *	-15 n.s.	-	-
	1983	1 n.s.	-43 *	-	-
	1985	-2 n.s.	-48 *	-	-
	1987	-57 *	-64 *	-	-
	1997	17 n.s.	9 n.s.	-57 *	228 *
Willow Tit	1977	-4 n.s.	37 n.s.	-	-
	1982	-30 *	-40 *	-	-
	1987	-10 n.s.	-34 *	-	-
	1992	-22 n.s.	-24 n.s.	-39 n.s.	-
	1997	-33 *	-52 *	-72 *	43 n.s.
Starling	1970	-29 *	-	-	-
	1975	-2 n.s.	-27 *	-	-
	1987	-19 *	-20 n.s.	-	-
	1990	-30 *	-38 *	-51 *	-
	1993	-21 *	-42 *	-51 *	-
	1997	-36 *	-52 *	-62 *	-69 *
House Sparrow	1969	-40 n.s.	-	-	-
	1970	-39 n.s.	-	-	-
	1971	-41 n.s.	-	-	-
	1982	-27 n.s.	43 n.s.	-	-
	1985	-35 *	-25 n.s.	-	-
	1988	-12 n.s.	-43 *	-	-
	1990	-18 n.s.	-45 *	-25 n.s.	-
	1997	-20 n.s.	-35 *	-47 *	-65 *
Tree Sparrow	1980	-27 *	-31 *	-	-
	1986	-65 *	-78 *	-	-
	1992	-35 *	-77 *	-91*	-
	1997	-32 n.s.	-59 *	-94 *	-94 *
Goldfinch	1971	-6 n.s.	-	-	-
	1979	-29 *	4 n.s.	-	-
	1984	-22 *	-38 *	-	-
	1989	8 n.s.	-25 *	-	-
	1992	33 *	4 n.s.	-10 n.s.	-
	1997	21 *	70 *	4 n.s.	10 n.s.

Species	Latest Year in Time Series (beginning 1962)	5 Year Change	10 Year Change	25 Year Change	All Data
Yellowhammer	1979	-9 n.s.	-3 n.s.	-	-
	1988	-5 n.s.	-4 n.s.	-	-
	1997	-28*	-47*	-54 *	-47 *
Corn Bunting	1977	-15 *	13 n.s.	-	-
	1980	-29 *	-26 n.s.	-	-
	1983	-34 *	-50 *	-	-
	1986	-47 *	-62 *	-	-
	1989	-41 *	-66 *	-	-
	1992	-22 n.s.	-60 *	-71 *	-
	1995	-5 n.s.	-38 n.s.	-77 *	-
	1997	-20 n.s.	-37 n.s.	-84 *	-65 *

Table 3.3 An alert table for 1997. A provisional table of alerts based on CBC data from 1962 to 1997. Population changes are presented for different time periods backwards from 1997. Those marked with asterisks are statistically different from zero based on a bootstrapping method.

	% Change[1]				Alert Status			
Species	**62-97**	**25yr**	**10yr**	**5yr**	**Decline[2]**	**Coverage[3]**	**Data quality[4]**	**Comments**
Tree Sparrow	-94*	-94*	-59*	-32	Rapid	Moderate	Moderate	Slowing decline
Corn Bunting	-65*	-84*	-37*	-20	Rapid	Moderate	Moderate	Slowing decline
Snipe	-80*	-81*	-59*	-20	Rapid	Poor	Poor	Very rapid decline
Grey Partridge	-88*	-75*	-42*	-13	Rapid	Moderate	Moderate	Slowing decline
Turtle Dove	-65*	-72*	-42*	-19	Rapid	Good	Moderate	Rapid decline
Willow Tit	+43	-72*	-52*	-33*	Rapid	Moderate	Moderate	Rapid decline
Starling	-69*	-62*	-52*	-36*	Rapid	Moderate	Moderate	Rapid decline
Goldcrest	+228*	-57*	+9	+17*	Rapid	Moderate	Good	Highly variable trend. Decline may be halting
Yellowhammer	-47*	-54*	-47*	-28	Rapid	Moderate	Good	Recent decline
Skylark	-37*	-50*	-19*	-13*	Rapid	Moderate	Good	Continuing decline
House Sparrow	-65*	-47*	-35*	-20	Moderate	Poor	Moderate	Variable decline
Woodcock	+101	-46	-6	+42	-	Poor	Poor	Probable decline but poor data
Lapwing	-46*	-35*	-22	+6	Moderate	Poor	Moderate	Variable decline
Willow Warbler	+3	-30*	-28*	+10	Moderate	Moderate	Good	Fluctuating-some periods of decline
Goldfinch	+10	+4	+70*	+21*	-	Moderate	Good	Variable. Recent increase
Swallow	+18	+12	+2	-5	-	Moderate	Moderate	Fluctuating
Great Spotted Woodpecker	+131*	+64*	+18*	+10	-	Moderate	Good	Increasing

Footnotes to Table 3.3

This table should be read in conjunction with the information on sample sizes and data representativeness given in Table 3.1.

[1] Changes with high alert status are shown in bold and underlined twice. These are declines of >50% that are statistically significant.
Changes with moderate alert status are shown in bold and underlined once. These are declines of 25-49% that are statistically significant.

Alert status

[2] Decline	Rapid	:	>50% over whole period or 25 years
	Moderate	:	>25% over whole period or 25 years
	Warning	:	heading for 50% in 25 years if current ten or five-year rate sustained, but not currently Rapid or Moderate (no examples in table)
	-	:	none of above
[3] Coverage	Good	:	adequate sampling of whole area
	Moderate	:	adequate sampling of areas and habitats of greatest importance to the population.
	Poor	:	trend may not be representative of the whole area but is the best sample available.
[4] Data quality	Good	:	large sample giving good precision. Methods very reliable and consistent.
	Moderate	:	adequate sample likely to detect major changes. May be minor methodological problems with data.
	Poor	:	small sample giving low precision and/or methodological problems with data.

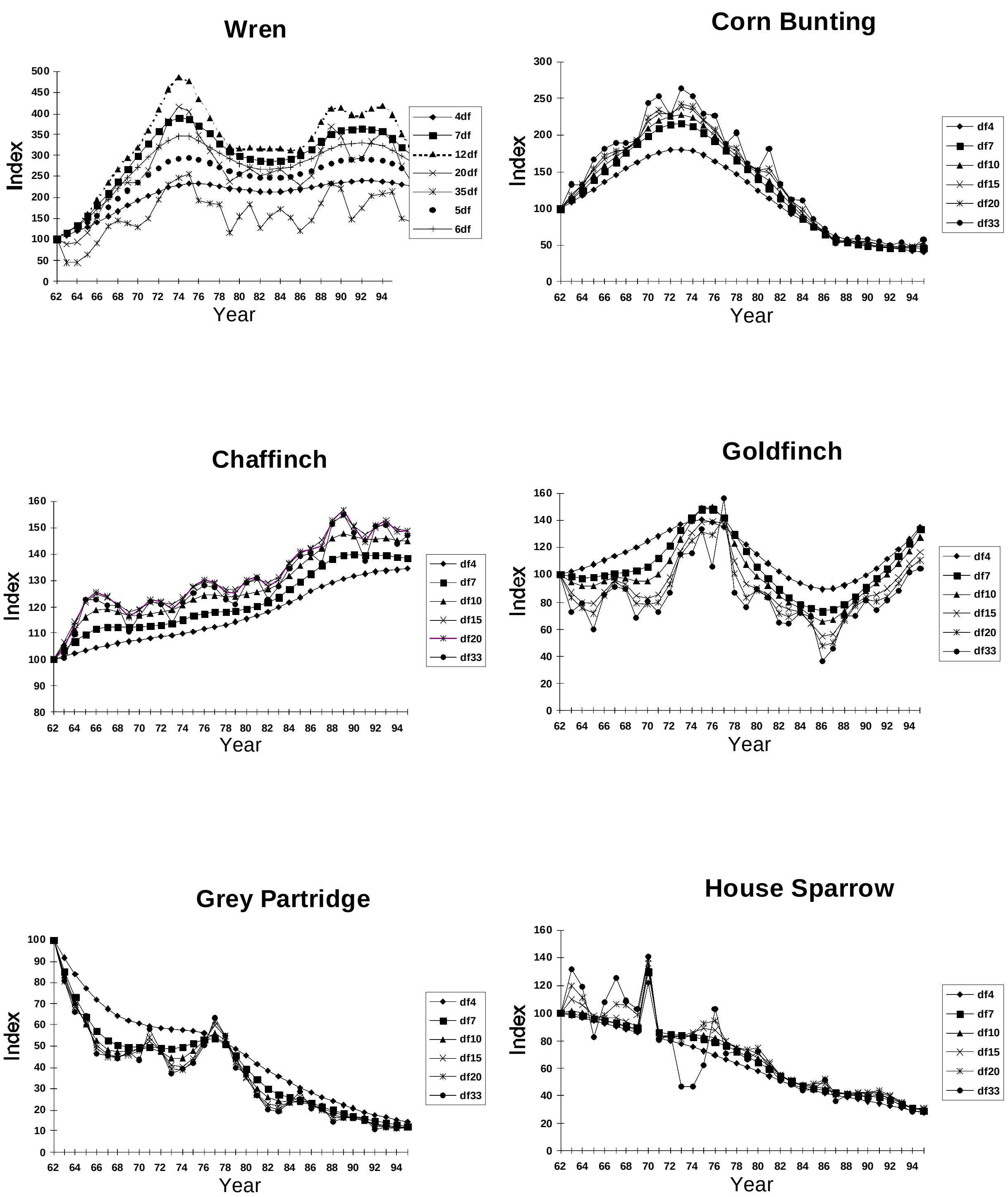


Figure 3.1 Trends from Generalized Additive Models with different amounts of smoothing (numbers of degrees of freedom) fitted to the 1962 to 1995 CBC data for 10 species. These time series cover 34 years, so 10 degrees of freedom correspond to the recommended amount of smoothing for alerts analyses (see text).

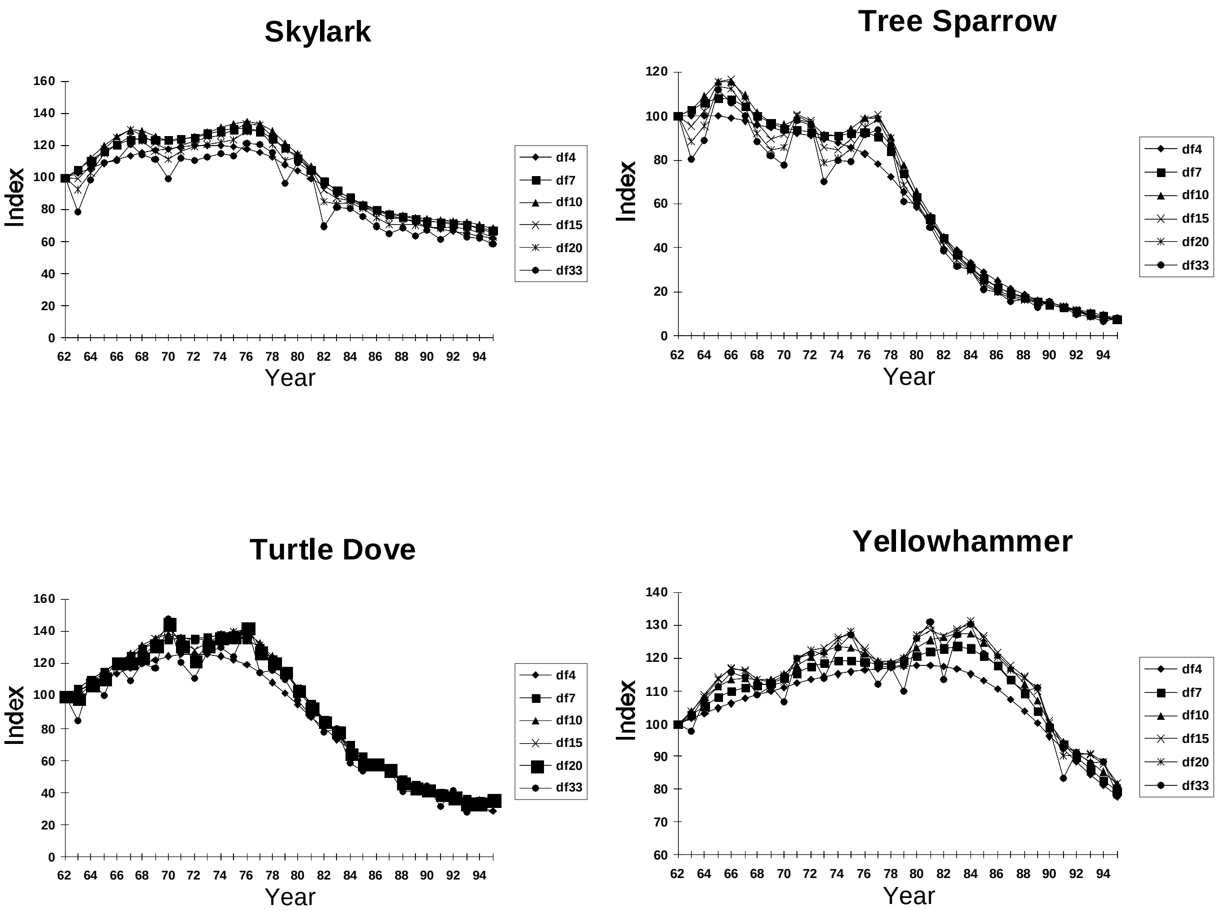


Figure 3.1 (continued) Trends from Generalized Additive Models with different amounts of smoothing (numbers of degrees of freedom) fitted to the 1962 to 1995 CBC data for 10 species. These time series cover 34 years, so 10 degrees of freedom correspond to the recommended amount of smoothing for alerts analyses (see text).

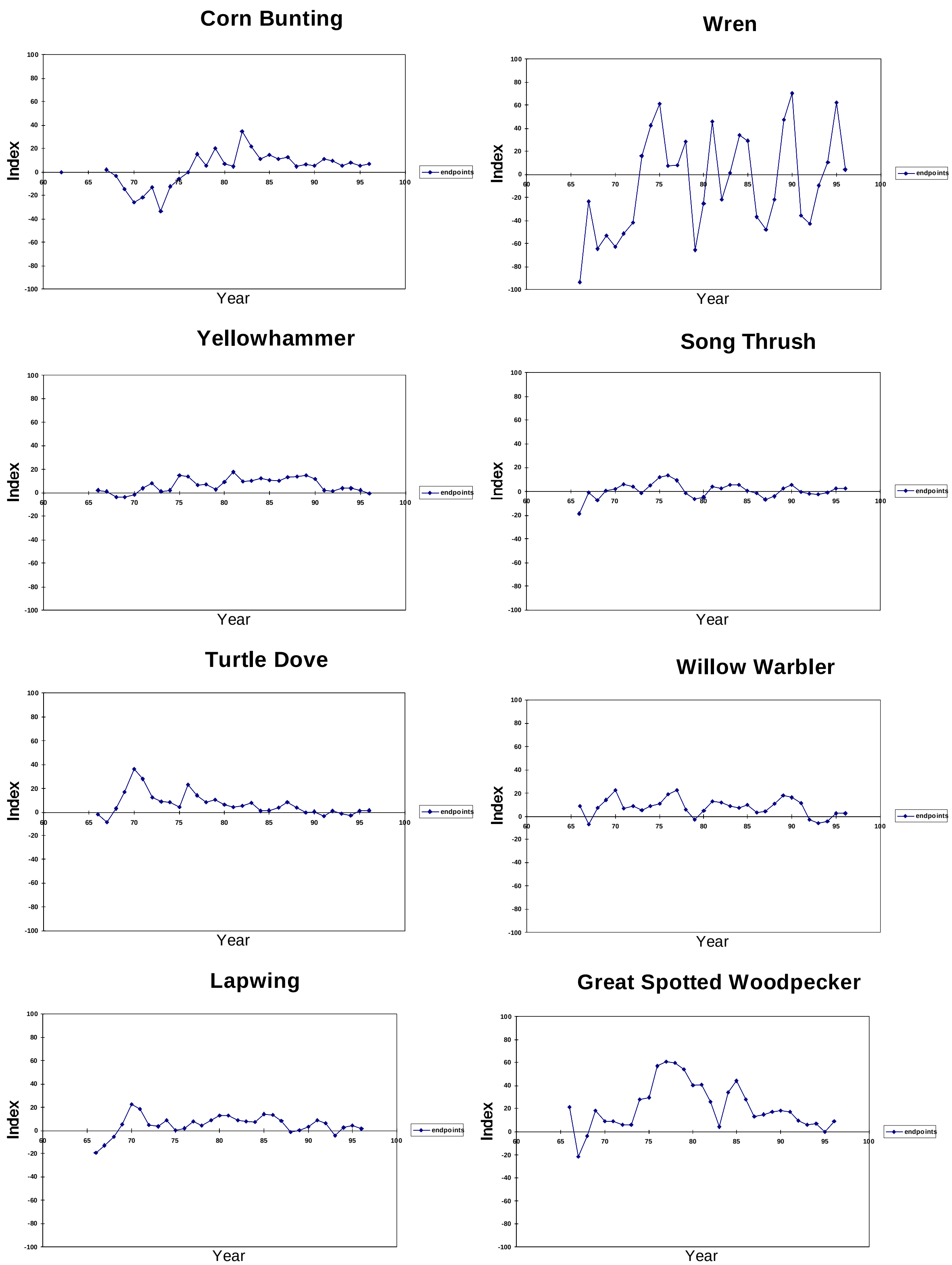


Figure 3.2 Differences between the endpoint population index for an analysis of data up to the year concerned and the population index for the same year taken from an analysis of the whole data set (1962-1997). Endpoints were estimated for data series from 1962-1966 to 1962-1996. Population indices were estimated using a Generalized Additive Model with approximately 0.3t degrees of freedom, where t is the number of years in the time series.

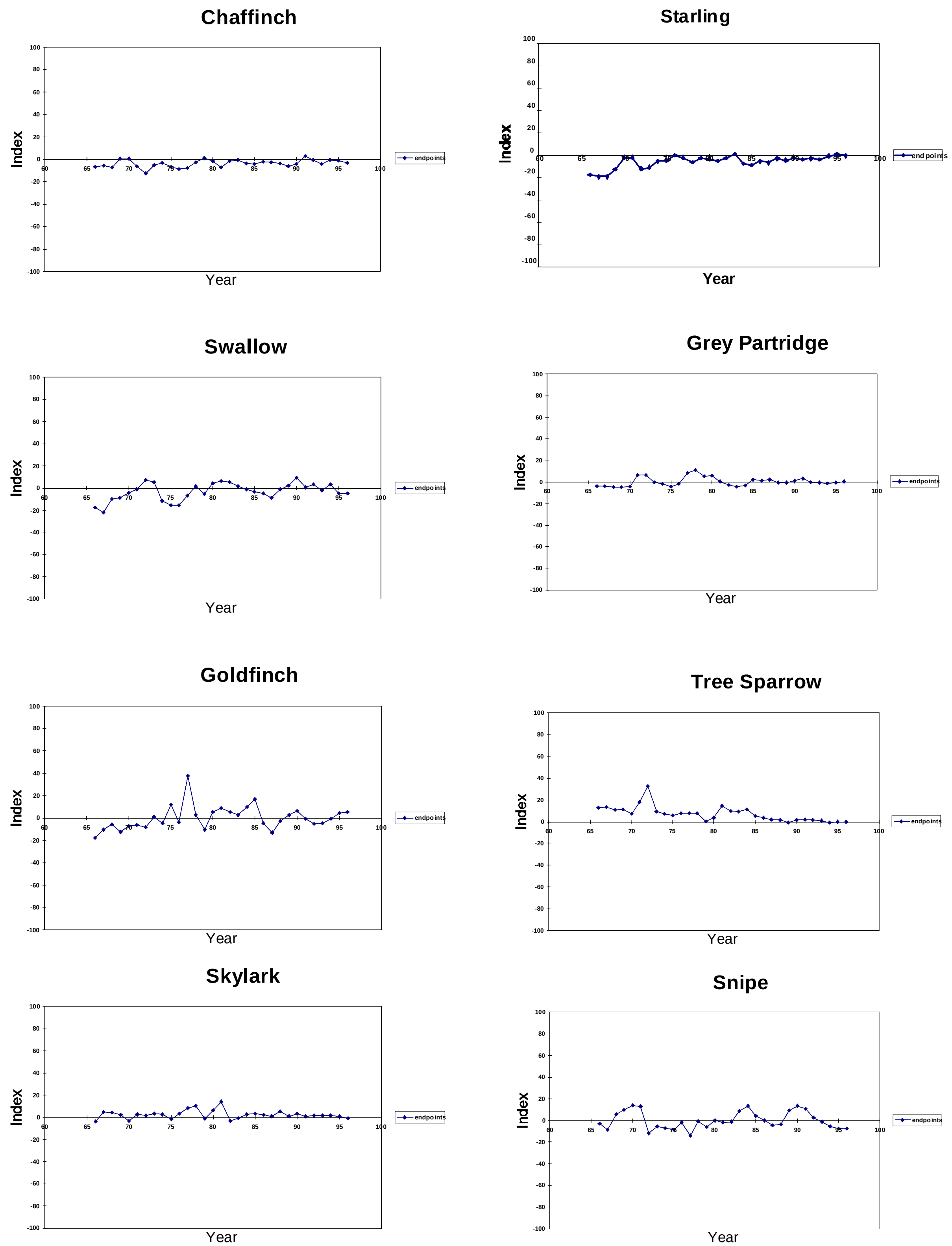


Figure 3.2 (continued) Differences between the endpoint population index for an analysis of data up to the year concerned and the population index for the same year taken from an analysis of the whole data set (1962-1997). Endpoints were estimated for data series from 1962-1966 to 1962-1996. Population indices were estimated using a Generalized Additive Model with approximately 0.3t degrees of freedom, where t is the number of years in the time series.

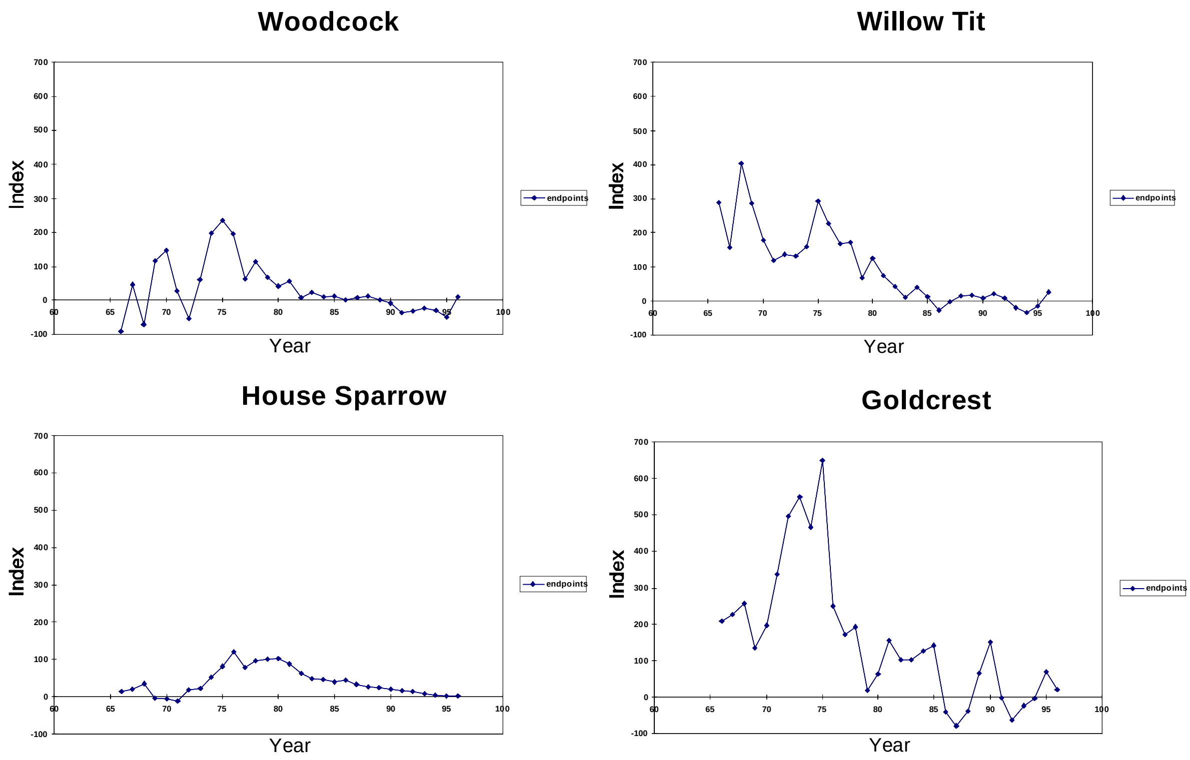
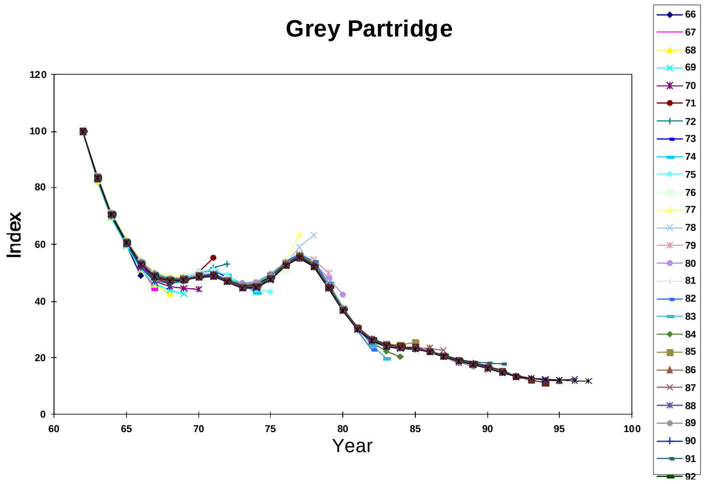
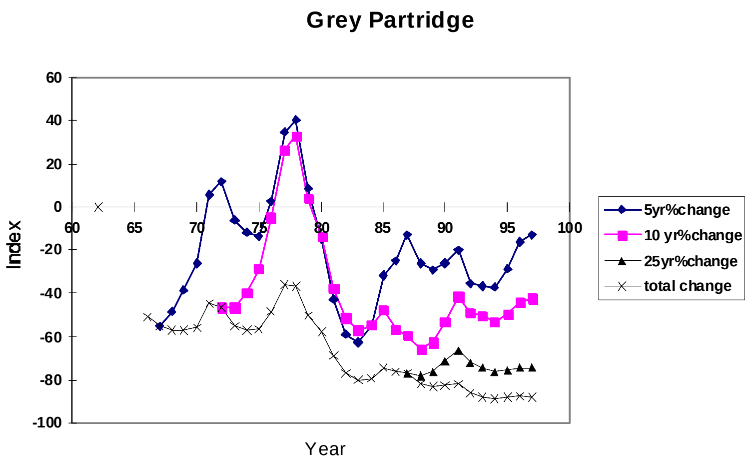


Figure 3.2 (continued) Differences between the endpoint population index for an analysis of data up to the year concerned and the population index for the same year taken from an analysis of the whole data set (1962-1997). Endpoints were estimated for data series from 1962-1966 to 1962-1996. Population indices were estimated using a Generalized Additive Model with approximately 0.3t degrees of freedom, where t is the number of years in the time series.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

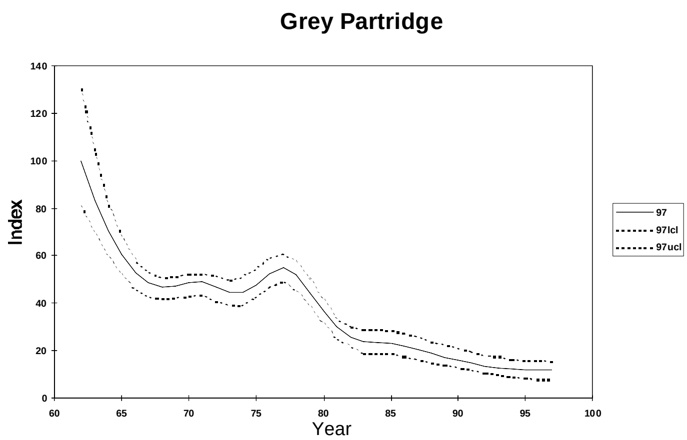
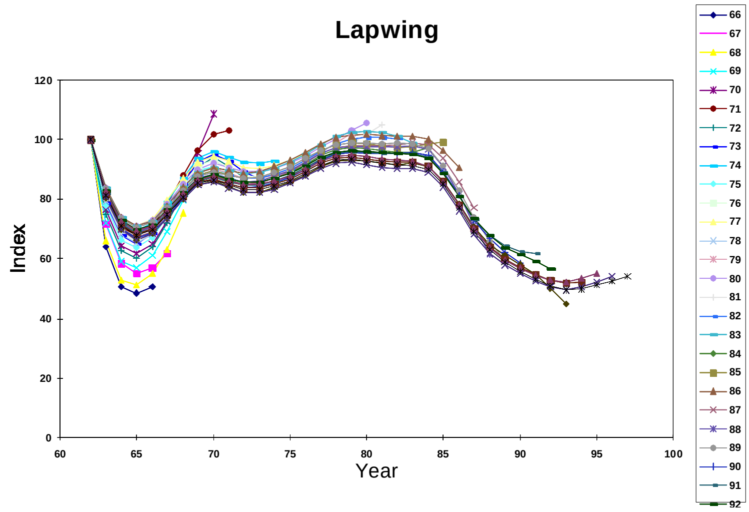
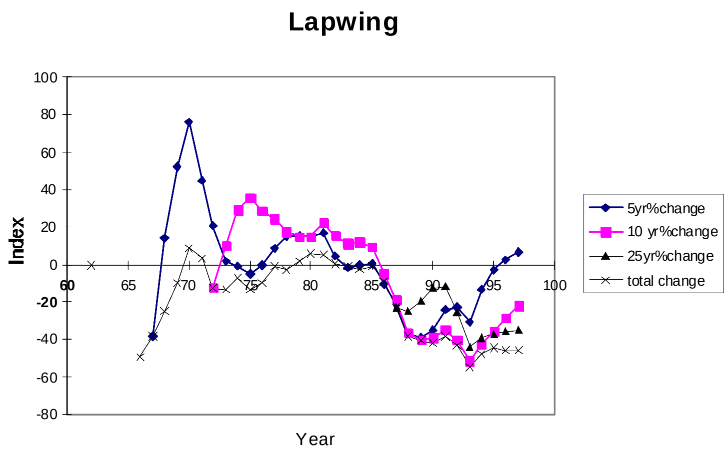


Figure 3.3.1 Long-term population trends for Grey Partridge estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

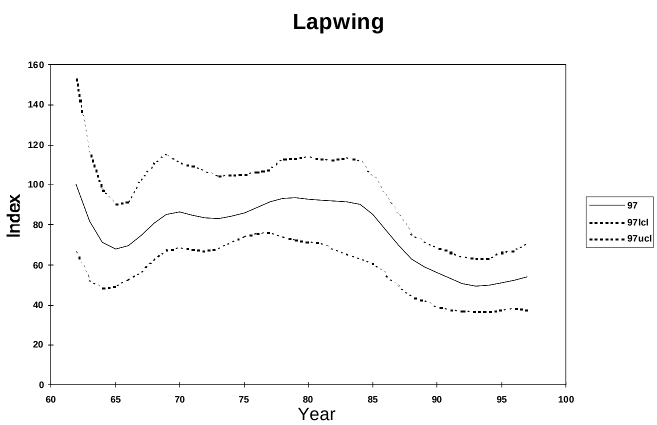
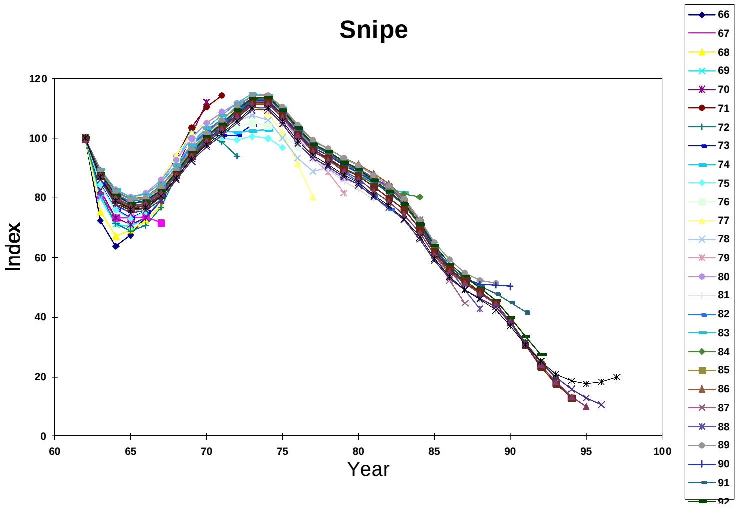
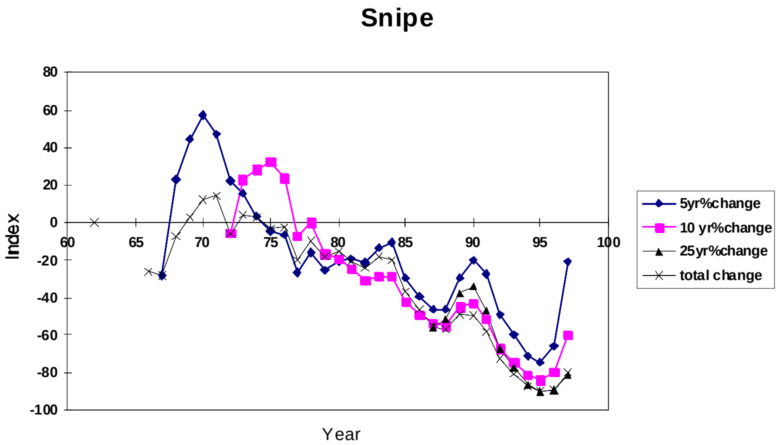


Figure 3.3.2 Long-term population trends for Lapwing estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

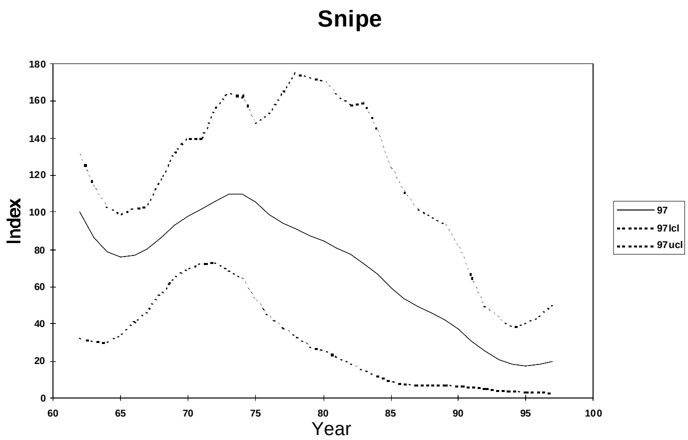
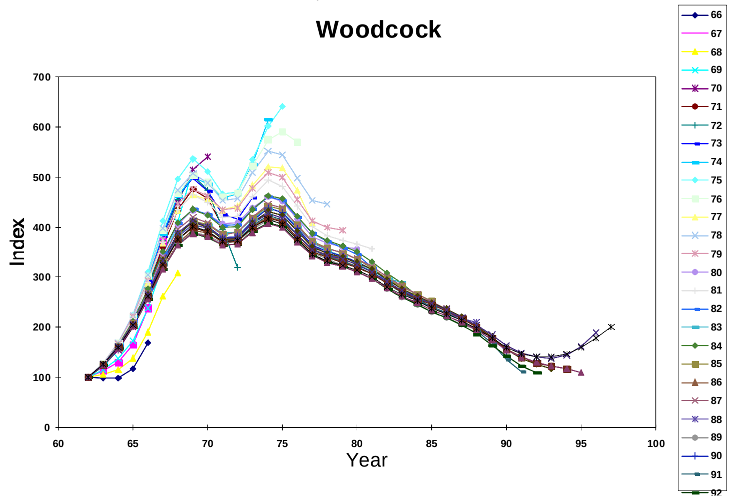
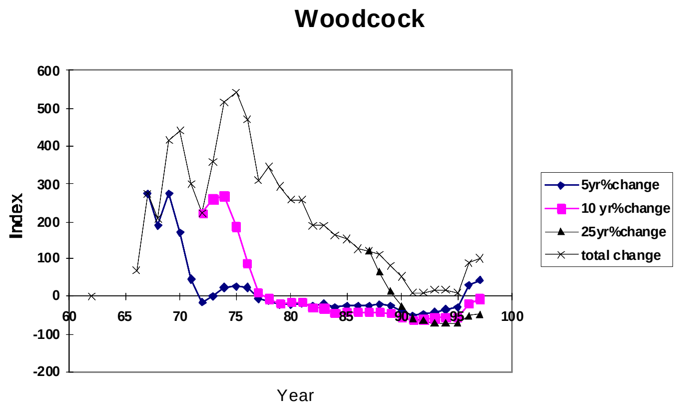


Figure 3.3.3 Long-term population trends for Snipe estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



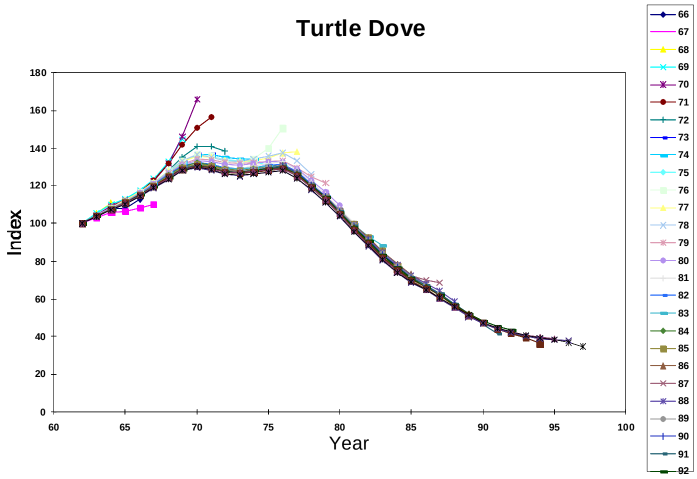
(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



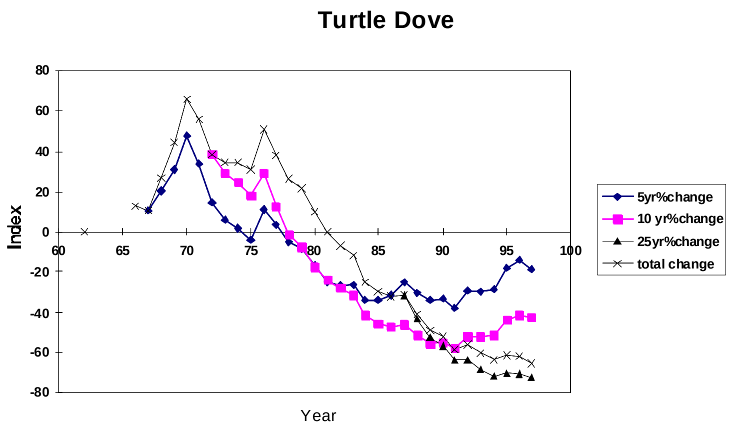
(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

Figure 3.3.4 Long-term population trends for Woodcock estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

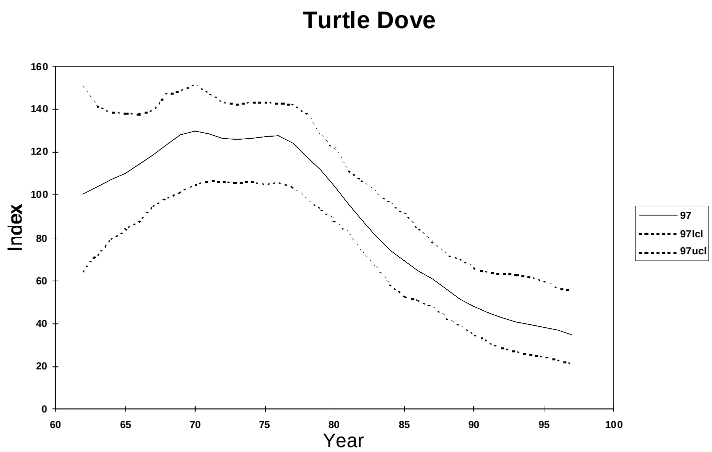
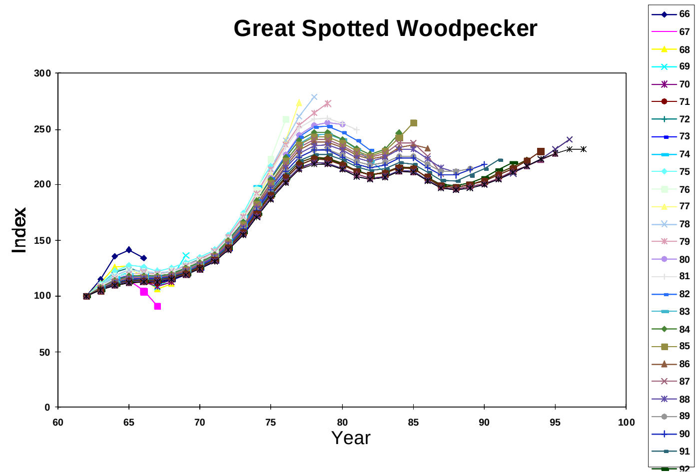
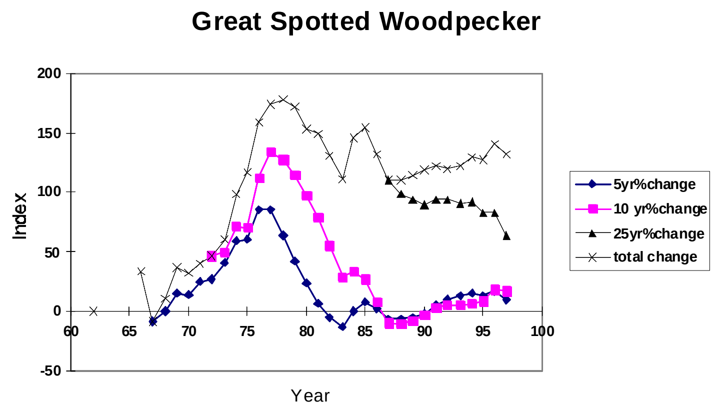


Figure 3.3.5 Long-term population trends for Turtle Dove estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

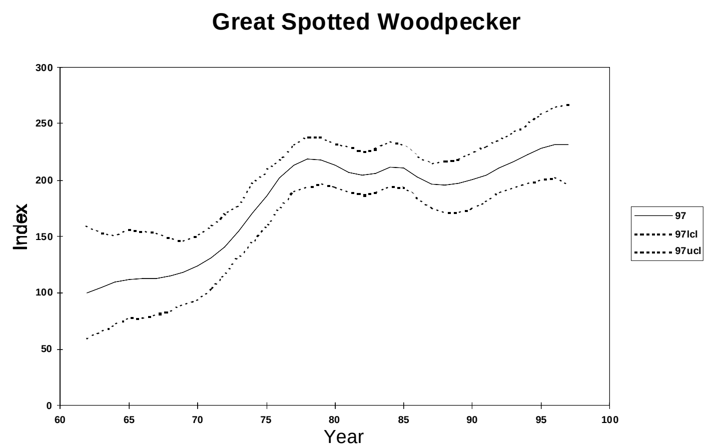
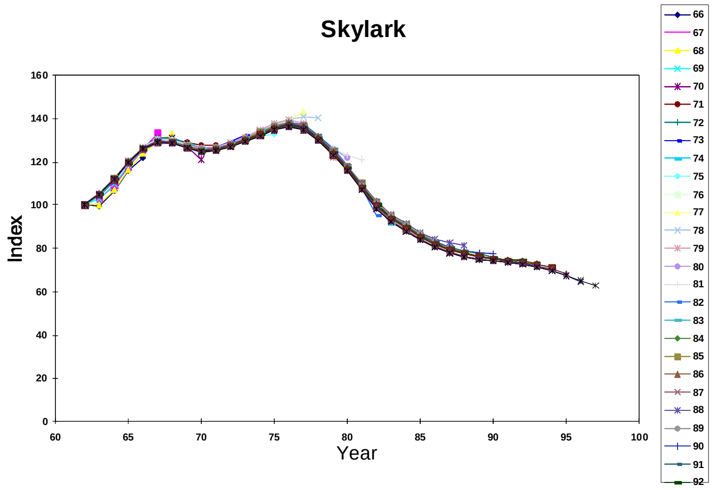
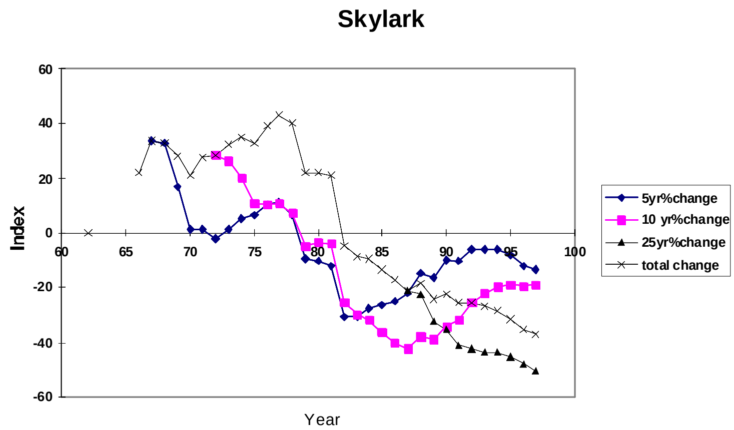


Figure 3.3.6 Long-term population trends for Great Spotted Woodpecker estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

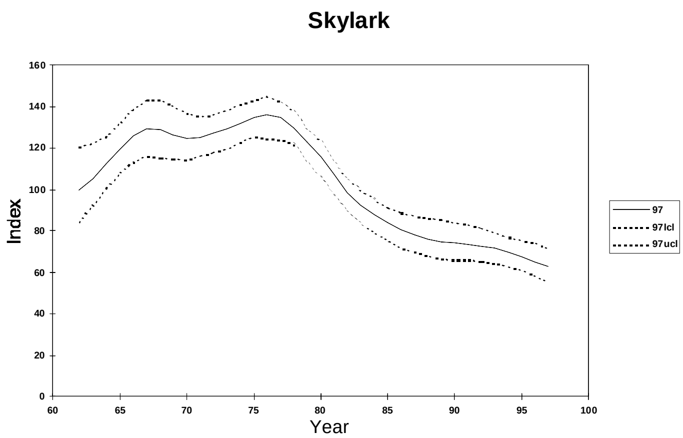
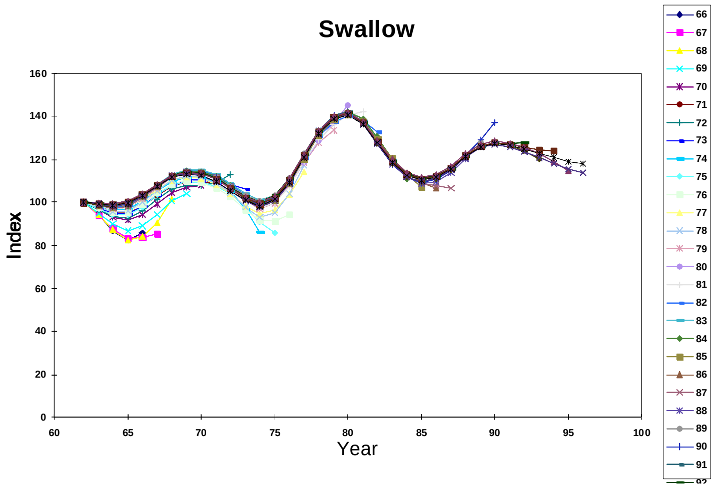
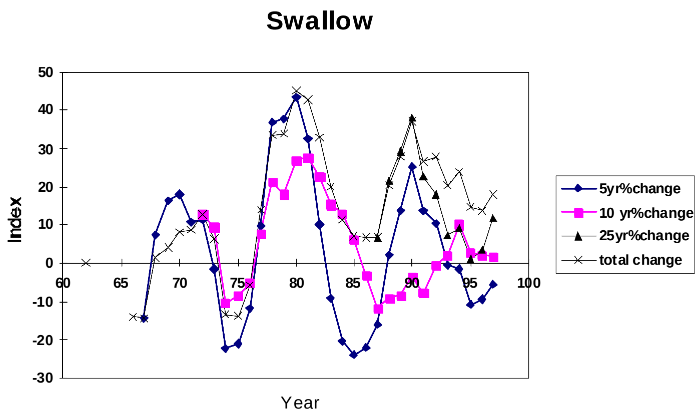


Figure 3.3.7 Long-term population trends for Skylark estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

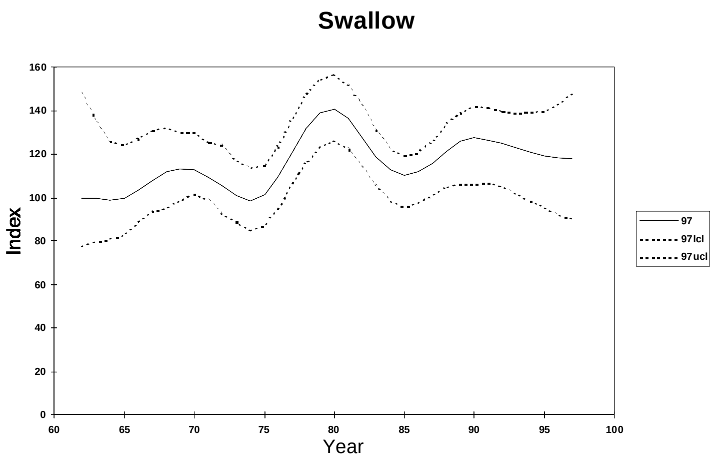
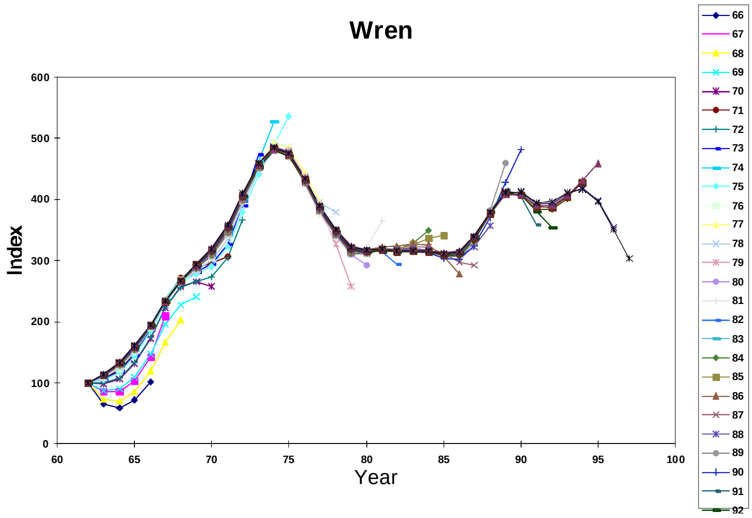


Figure 3.3.8 Long-term population trends for Swallow estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.

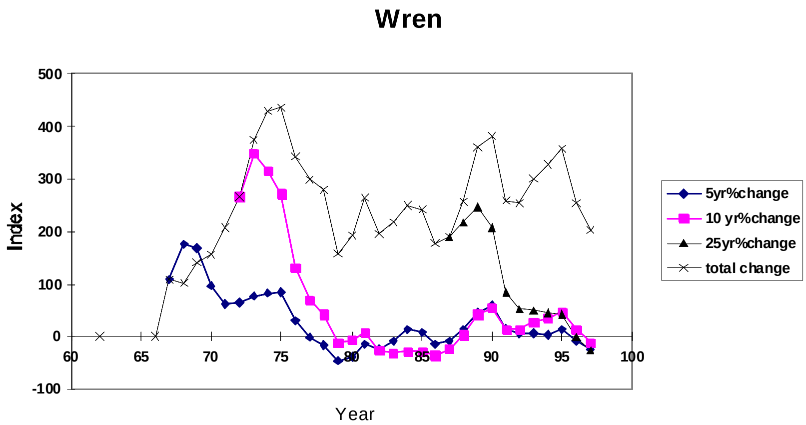
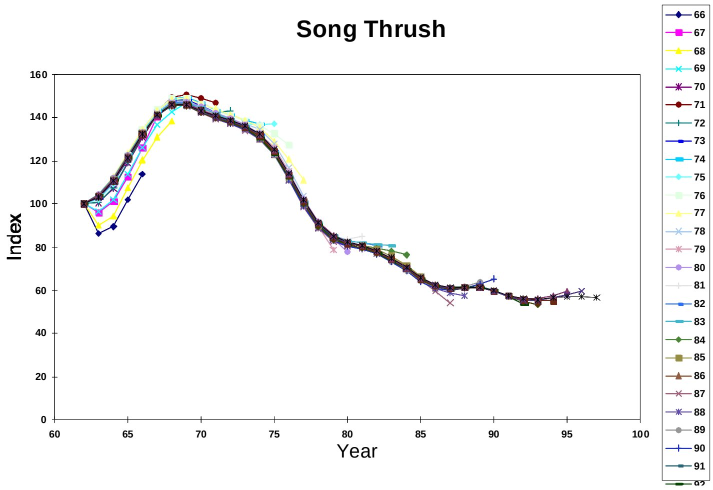


Figure 3.3.9 Long-term population trends for Wren estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.

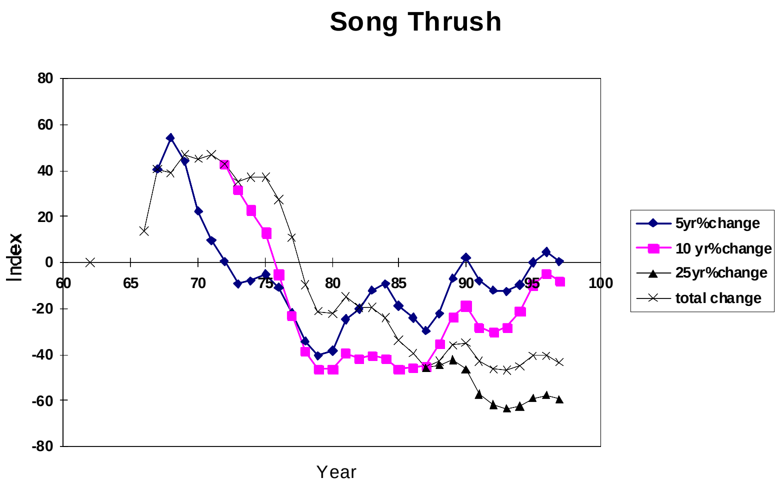
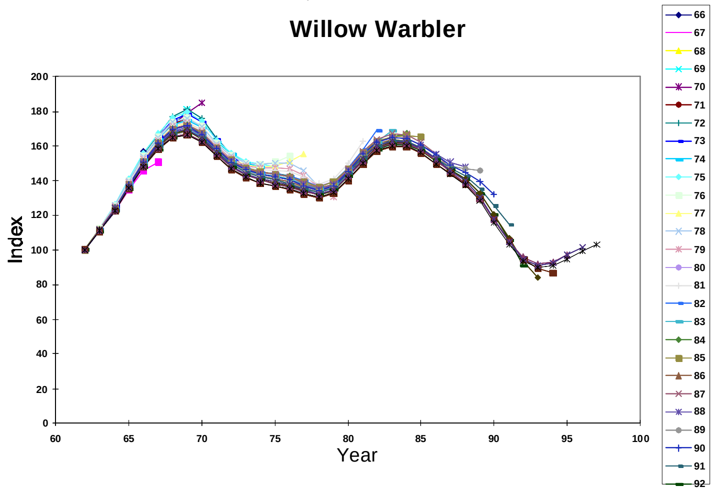
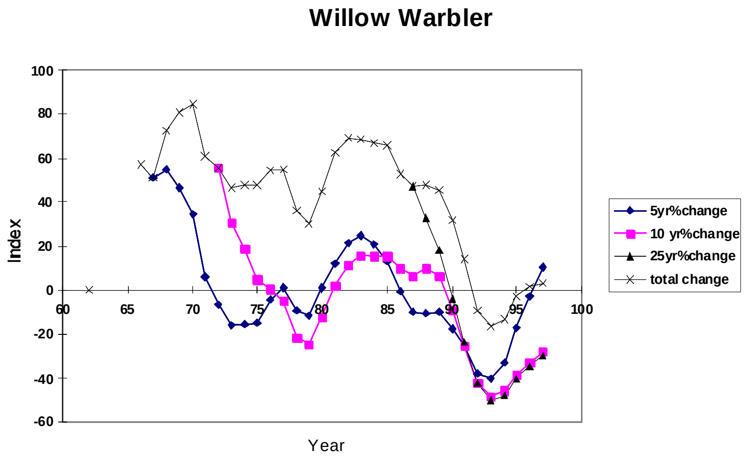


Figure 3.3.10 Long-term population trends for Song Thrush estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

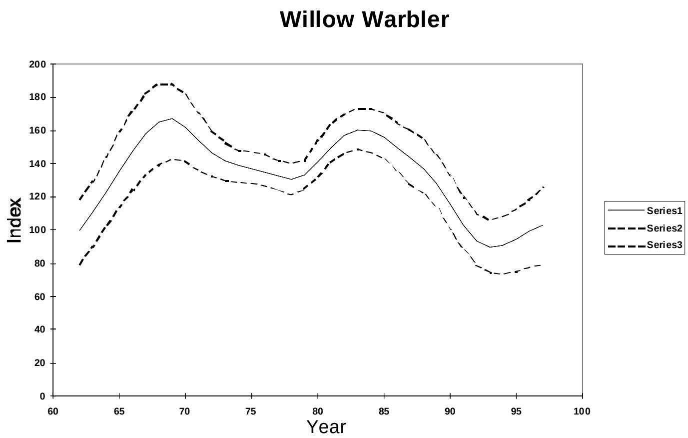
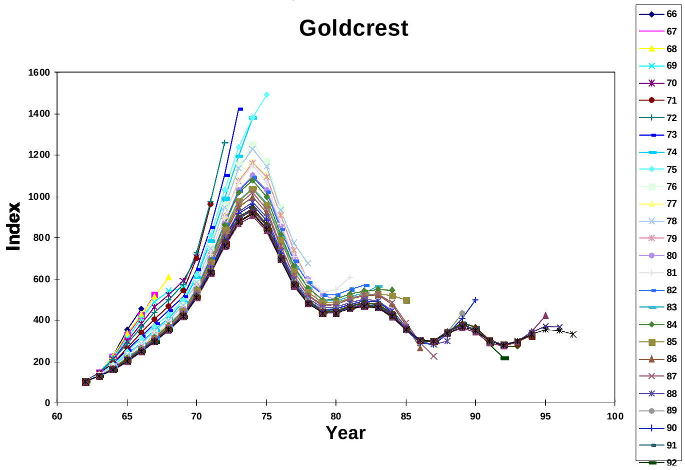
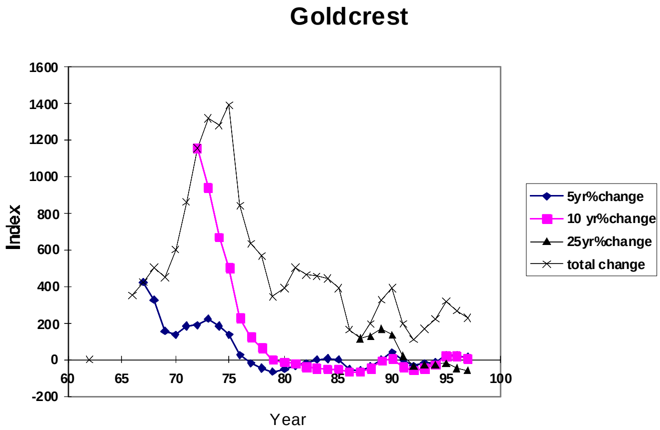


Figure 3.3.11 Long-term population trends for Willow Warbler estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

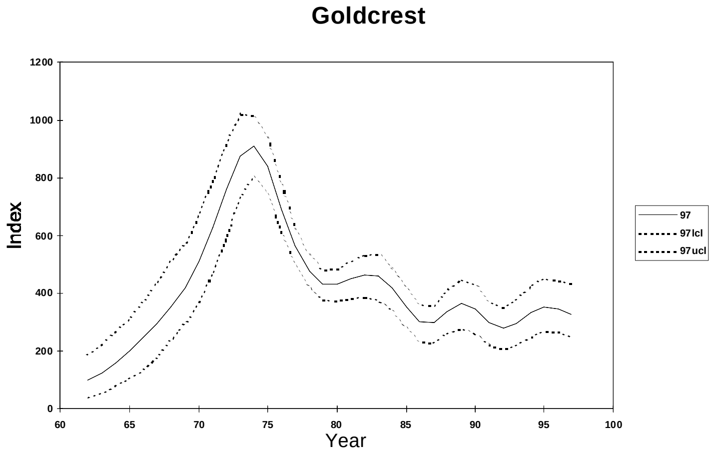
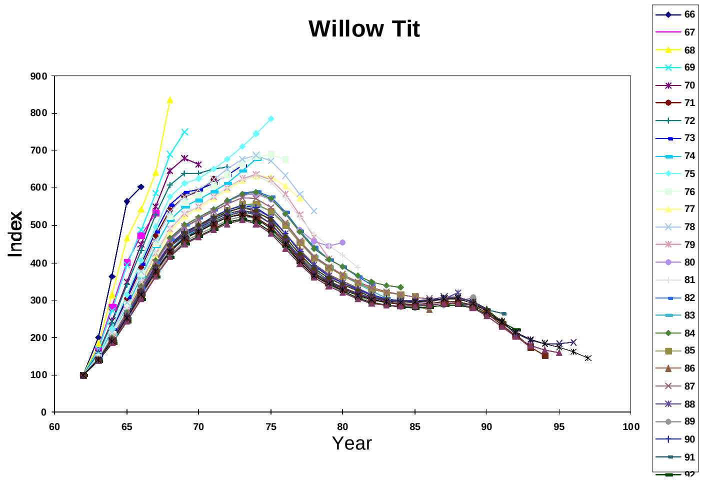
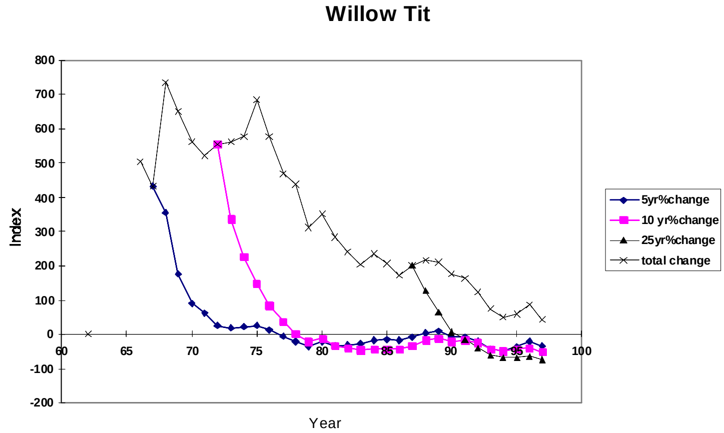


Figure 3.3.12 Long-term population trends for Goldcrest estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

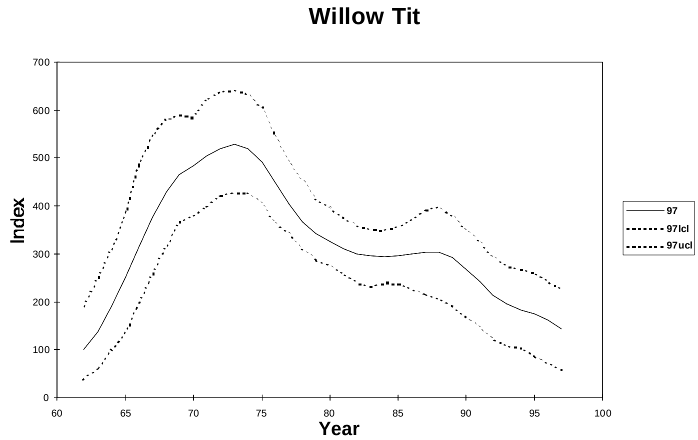
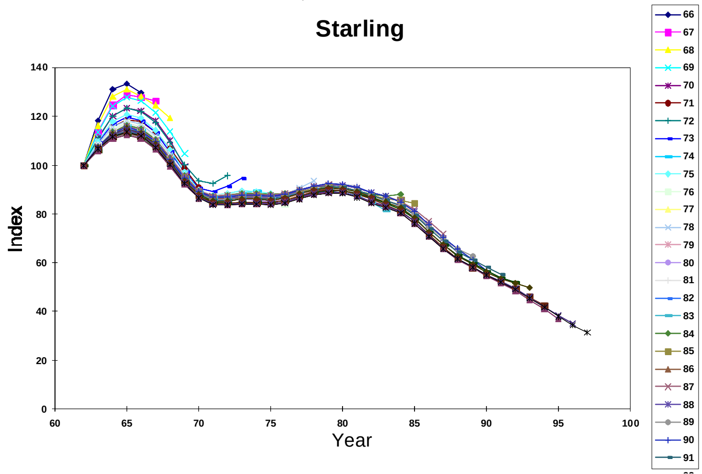
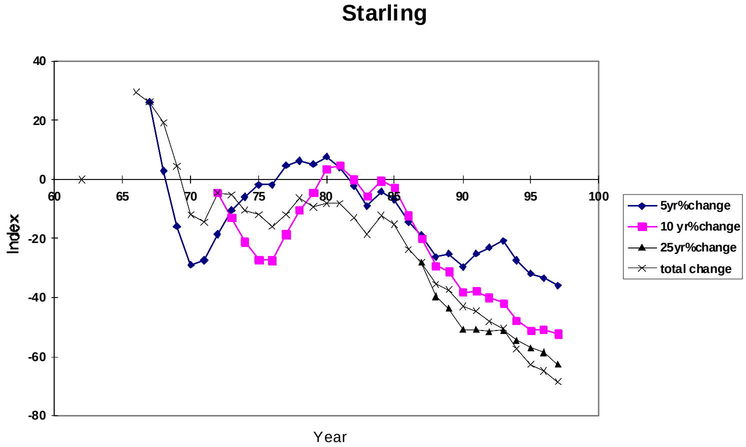


Figure 3.3.13 Long-term population trends for Willow Tit estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

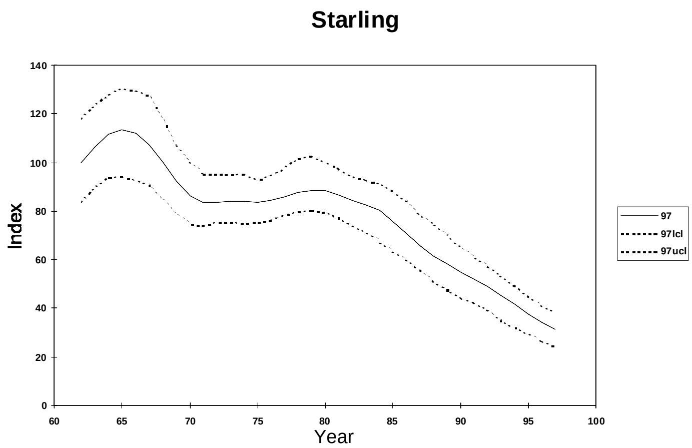
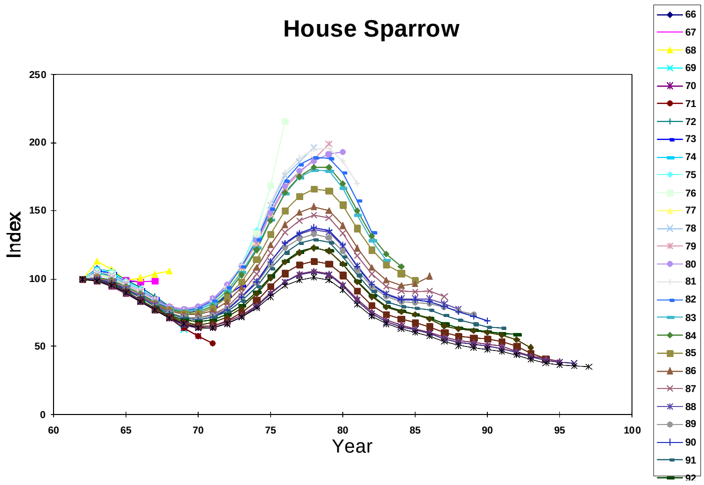
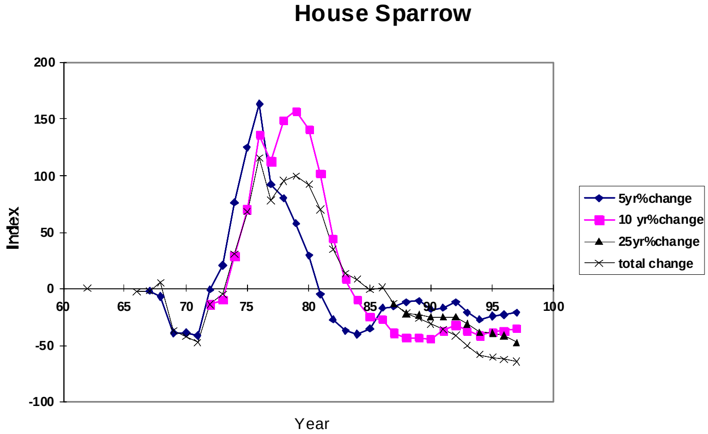


Figure 3.3.14 Long-term population trends for Starling estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

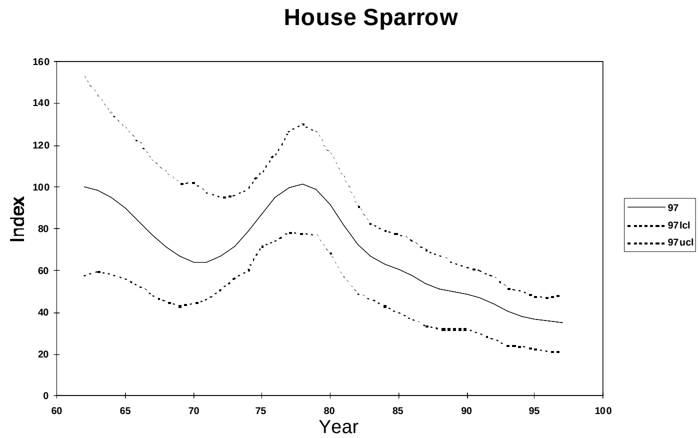
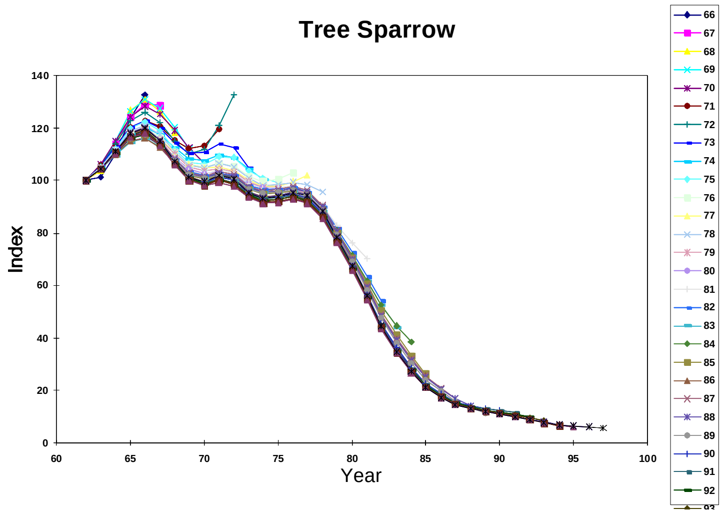
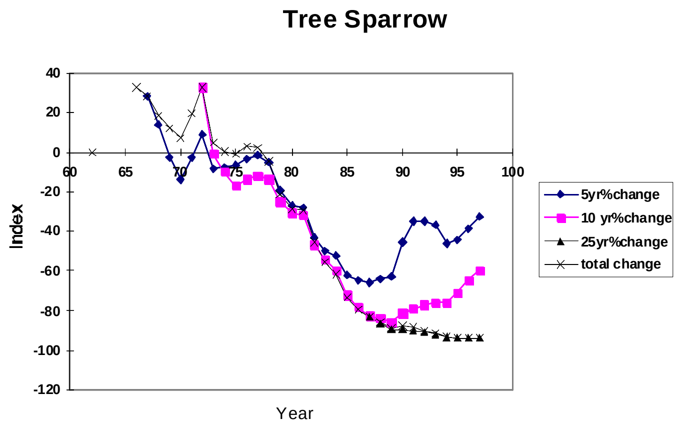


Figure 3.3.15 Long-term population trends for House Sparrow estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

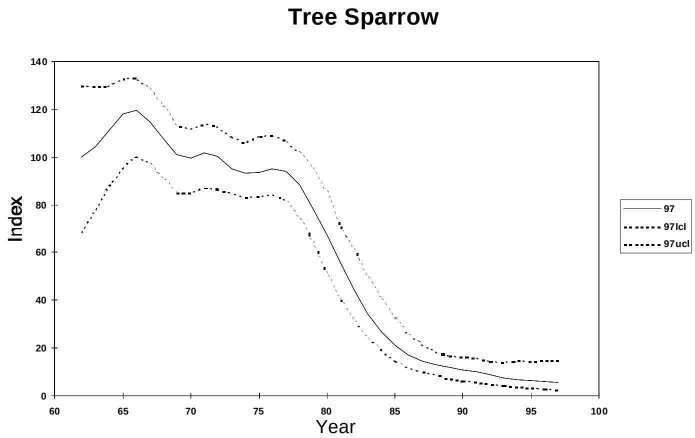
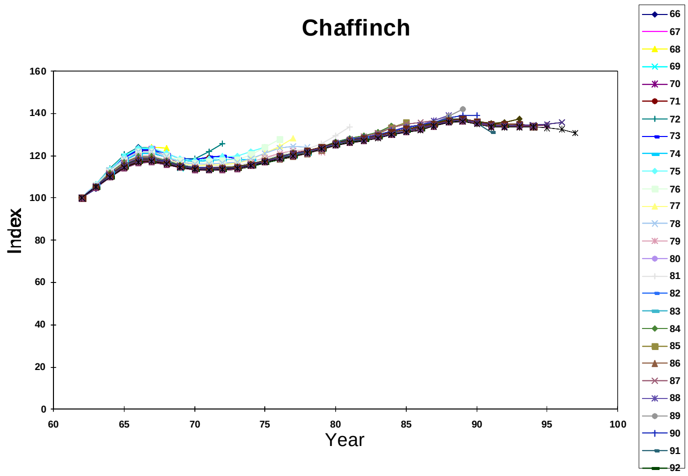


Figure 3.3.16 Long-term population trends for Tree Sparrow estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.

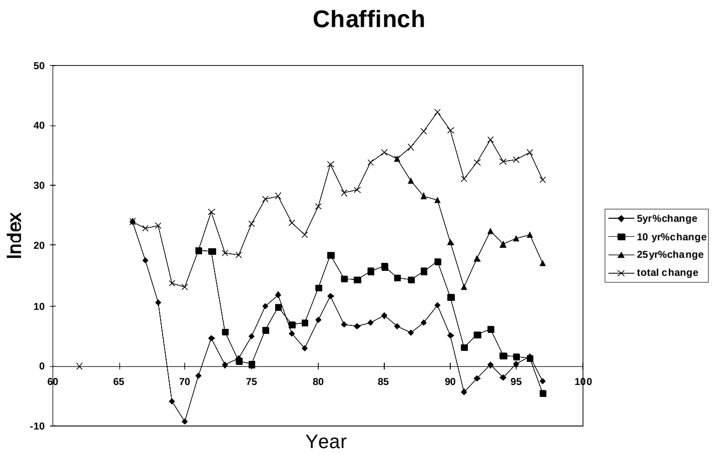
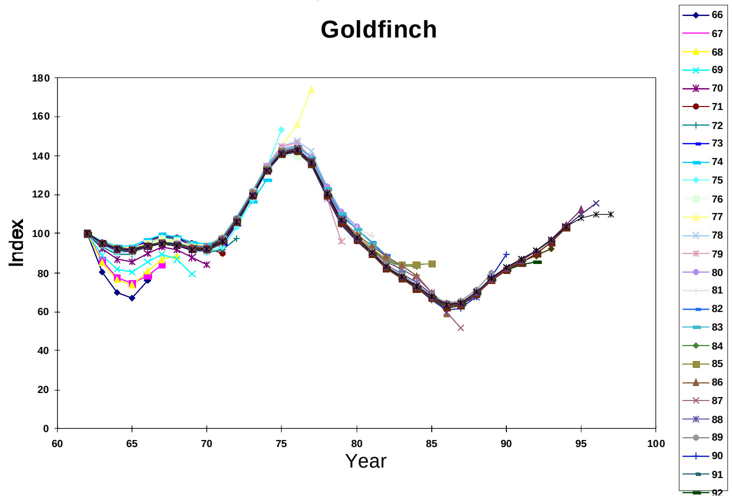
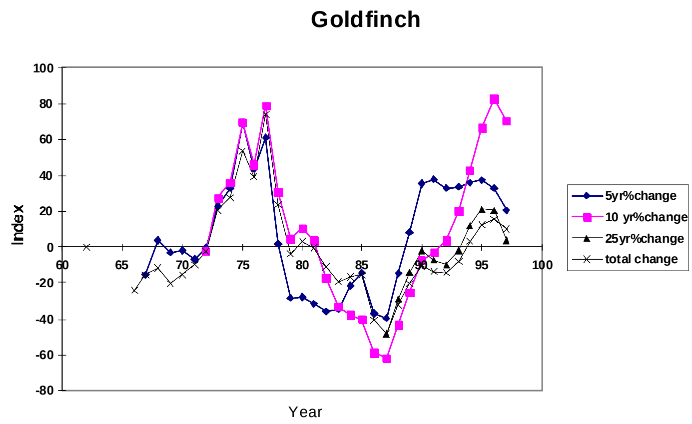


Figure 3.3.17 Long-term population trends for Chaffinch estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

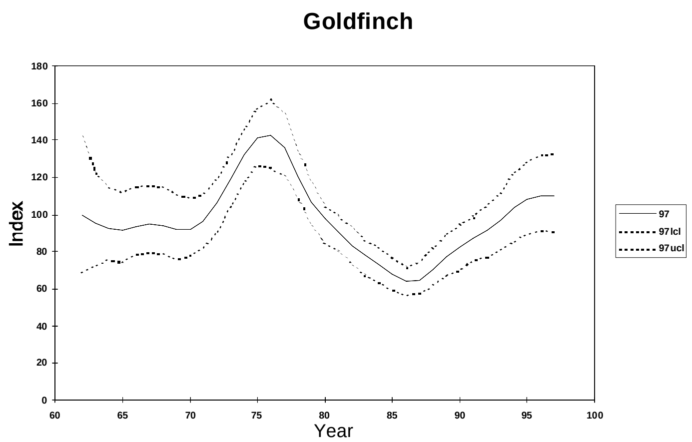
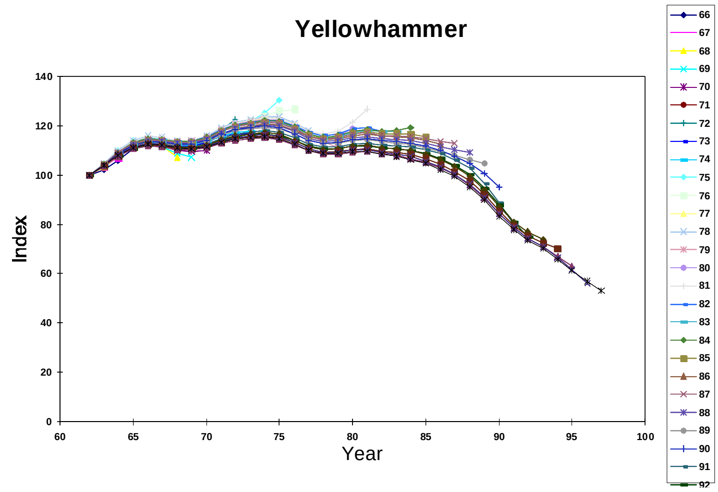
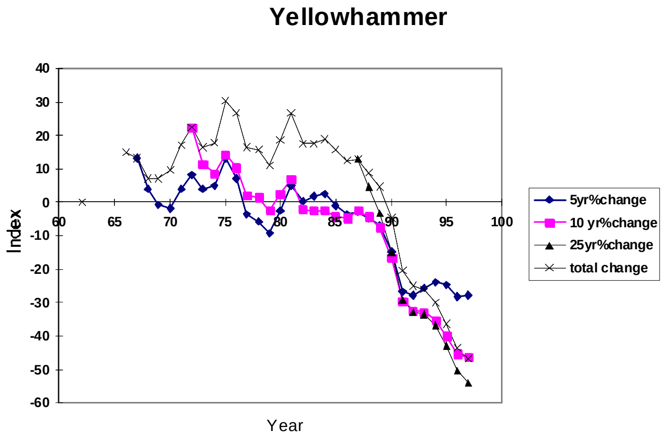


Figure 3.3.18 Long-term population trends for Goldfinch estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

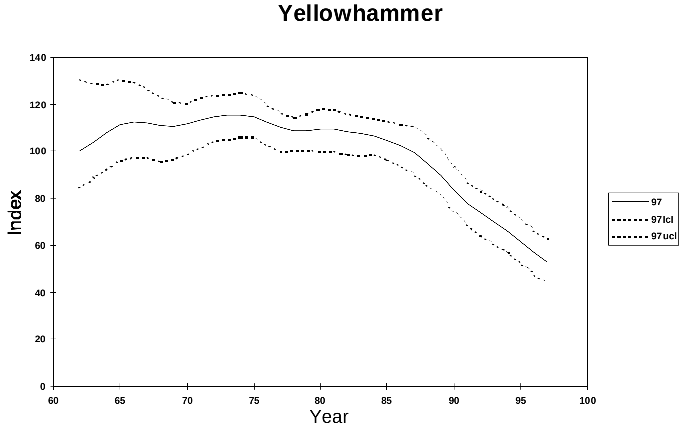
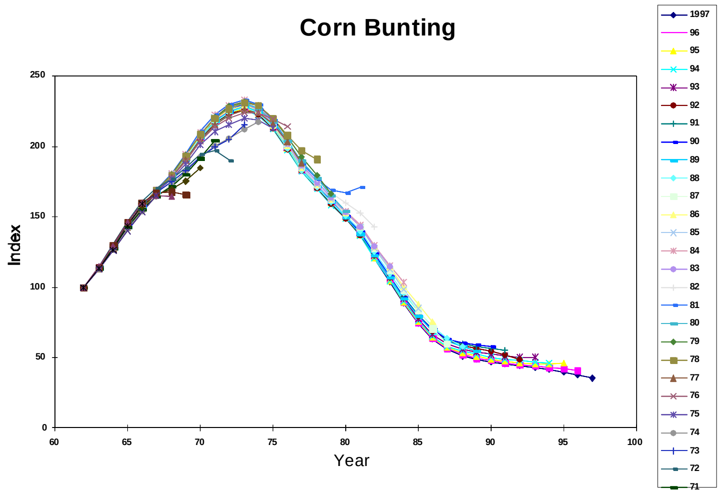
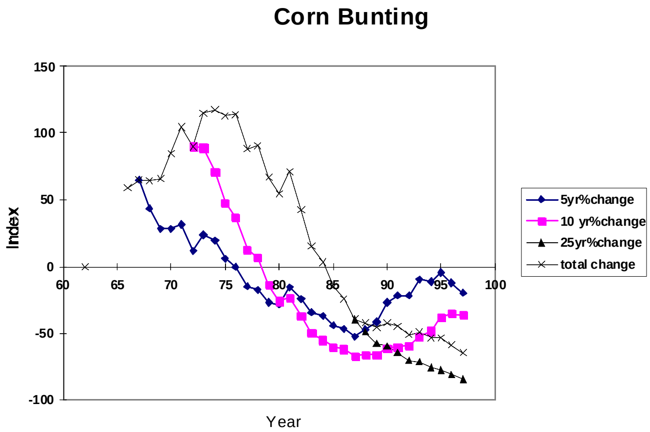


Figure 3.3.19 Long-term population trends for Yellowhammer estimated using Generalized Additive Models.

(a) Smoothed indices fitted to each run of years between 1962-1966 and 1962-1997.



(b) Changes for 5, 10 and 25 years and back to the start of the time series in 1962, plotted at the last year of the interval concerned. Changes measured from the GAM indices shown in (a) using data up to the last year of the interval of interest.



(c) Long-term trend with 95% confidence limits. The trend was fitted to the whole time series (1962-1997) using a GAM with 12 degrees of freedom. 95% confidence limits were estimated using 119 bootstraps.

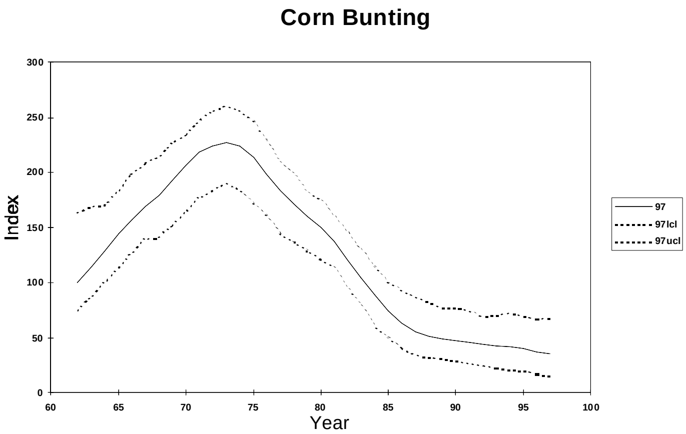
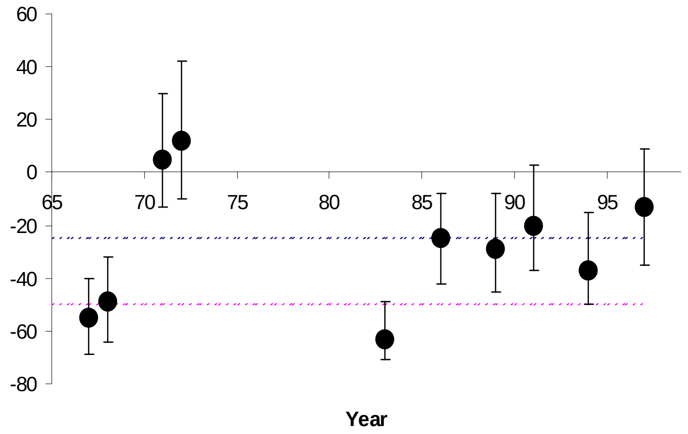
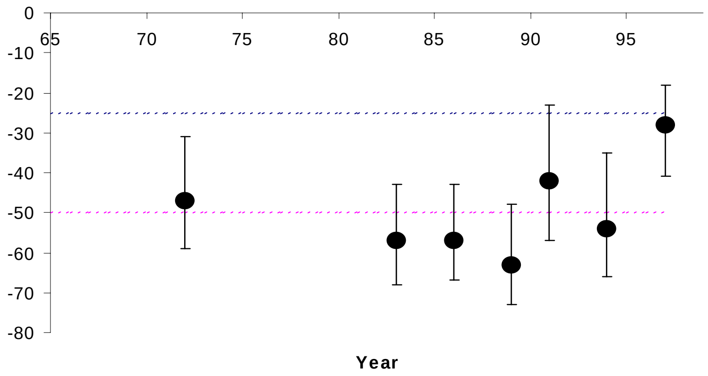


Figure 3.3.20 Long-term population trends for Corn Bunting estimated using Generalized Additive Models.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

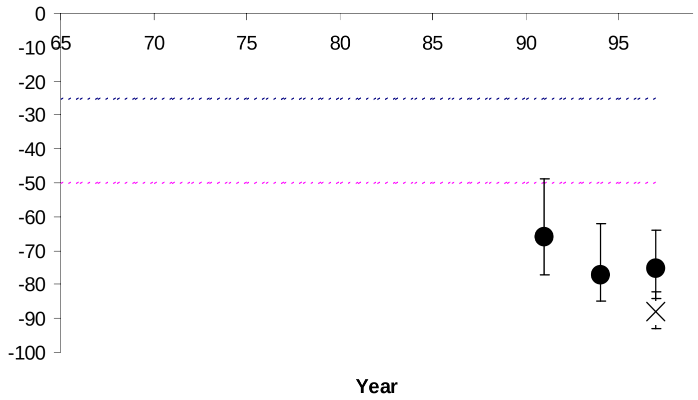
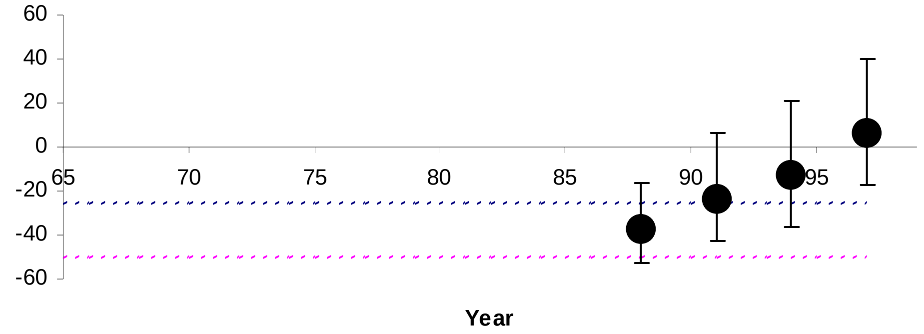
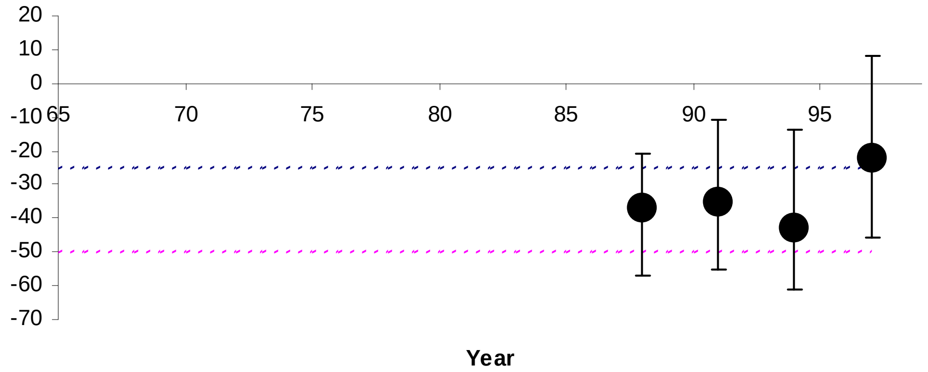


Figure 3.4.1 Population changes of Grey Partridges with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

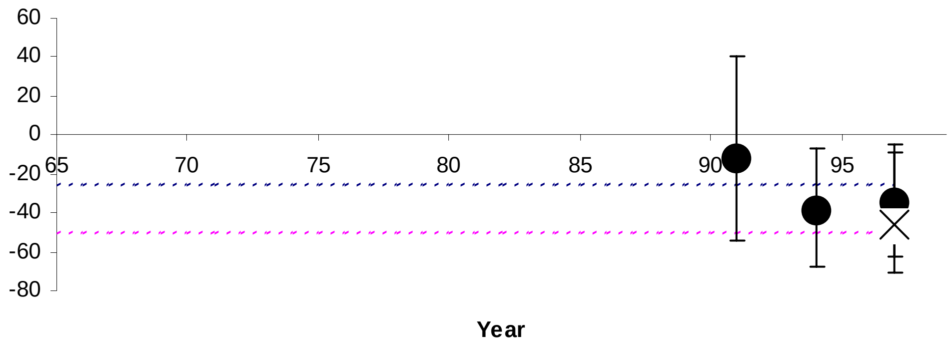
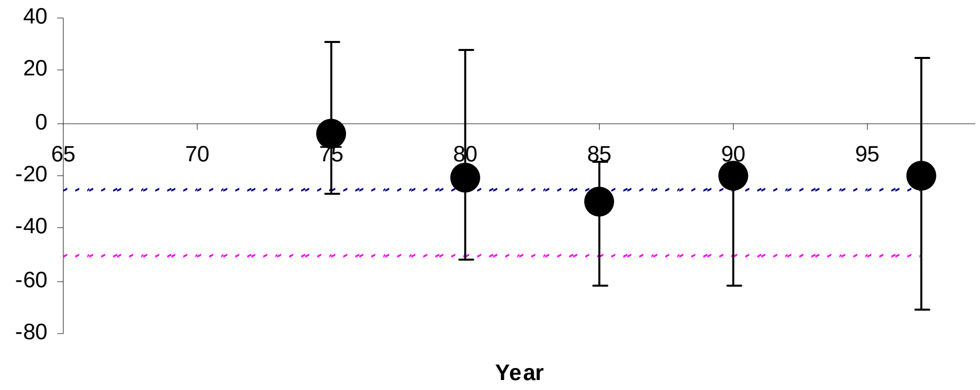
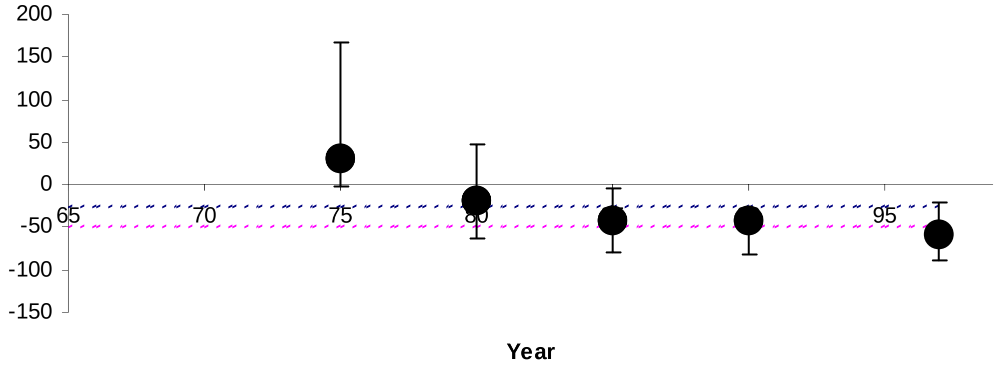


Figure 3.4.2 Population changes of Lapwings with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

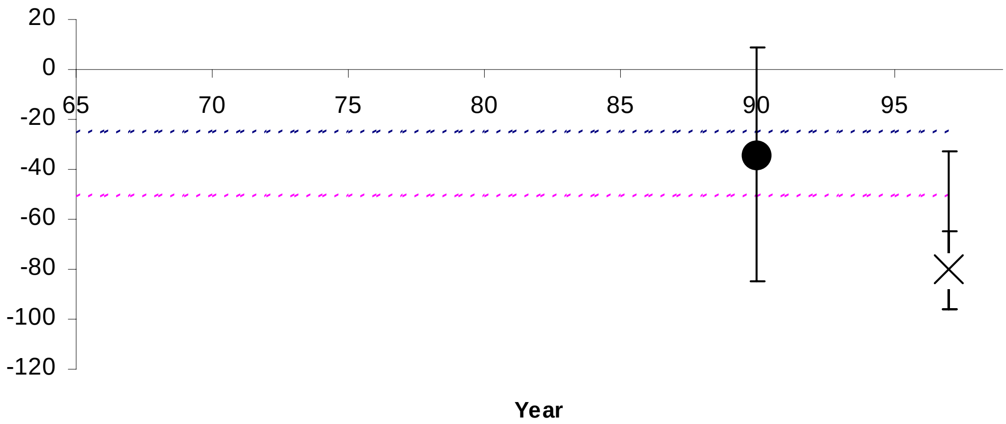
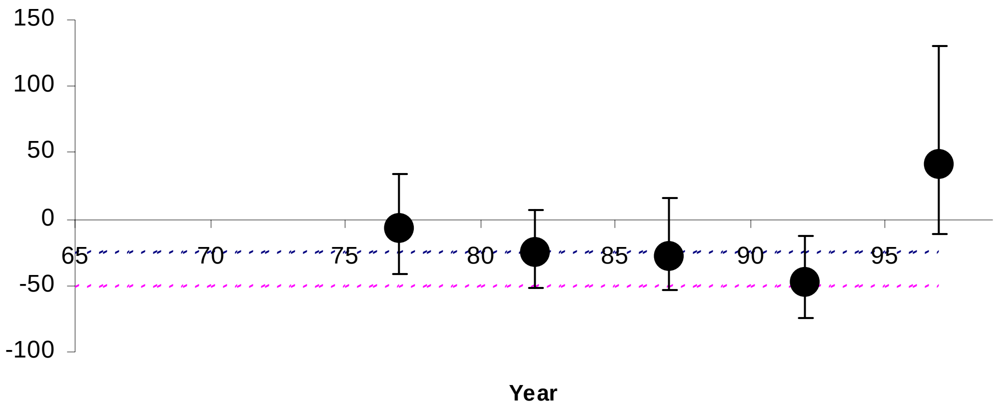
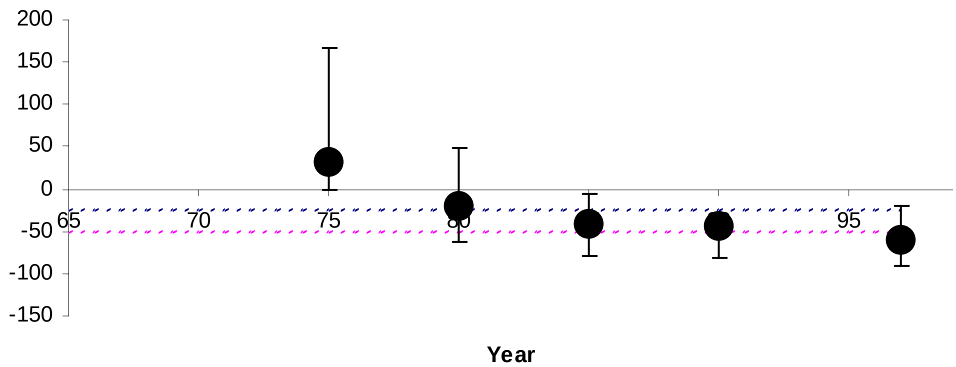


Figure 3.4.3 Population changes of Snipe with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

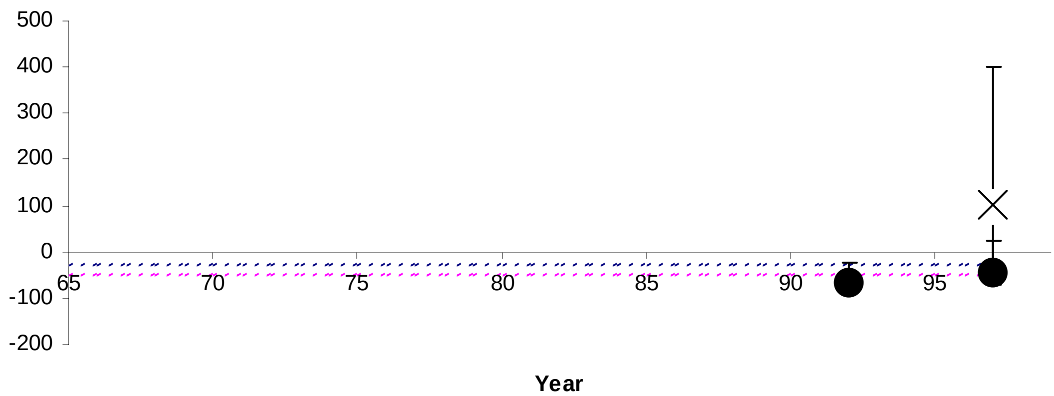
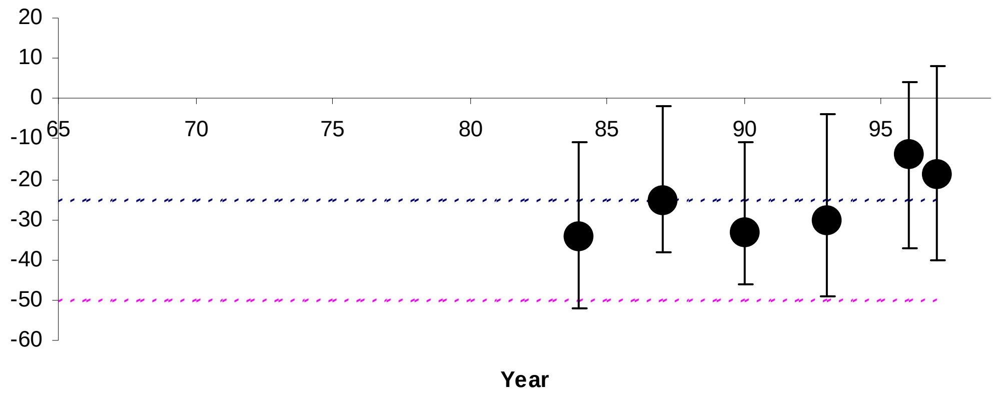
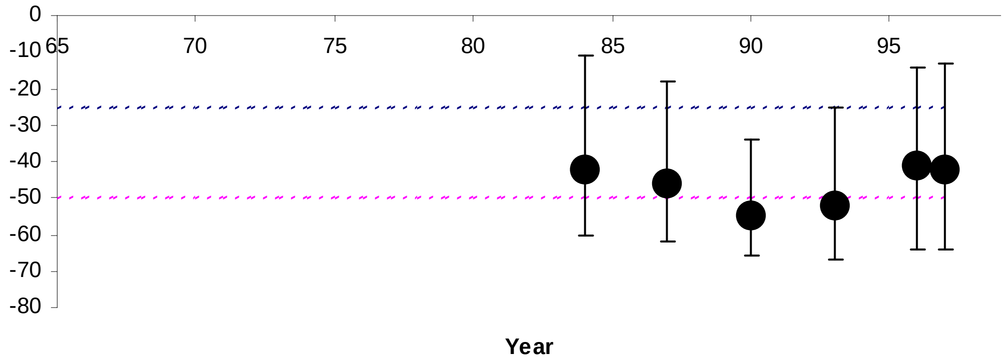


Figure 3.4.4 Population changes of Woodcock with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



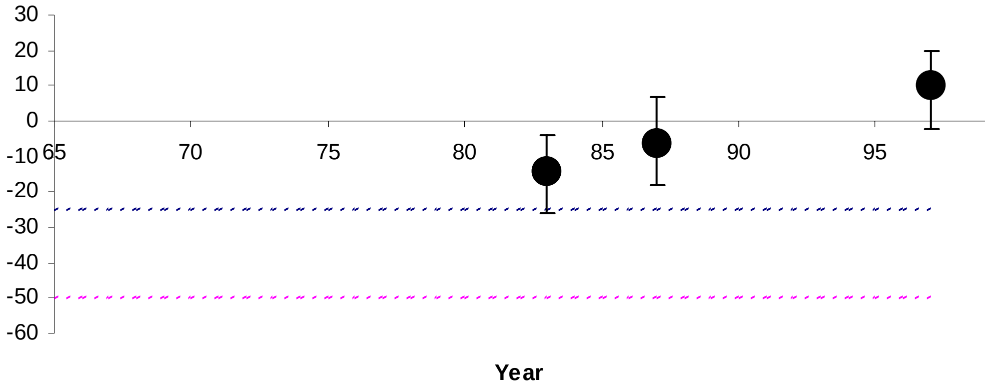
(b) Ten-year changes



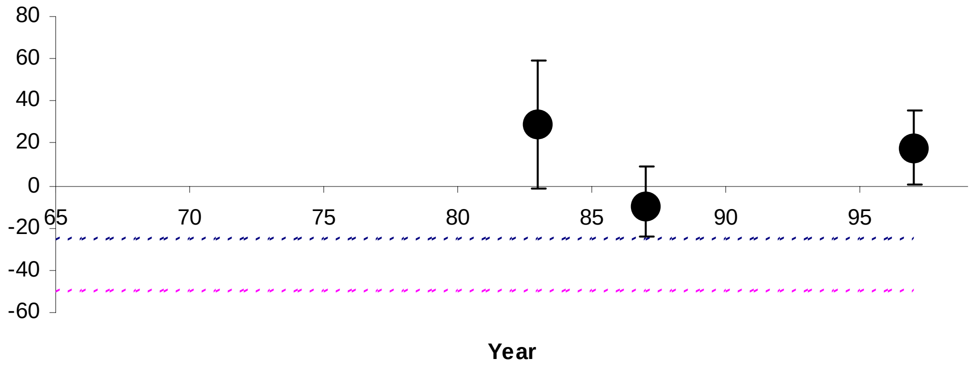
(c) Twenty-five year changes ● and overall changes X

Figure 3.4.5 Population changes of Turtle Doves with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

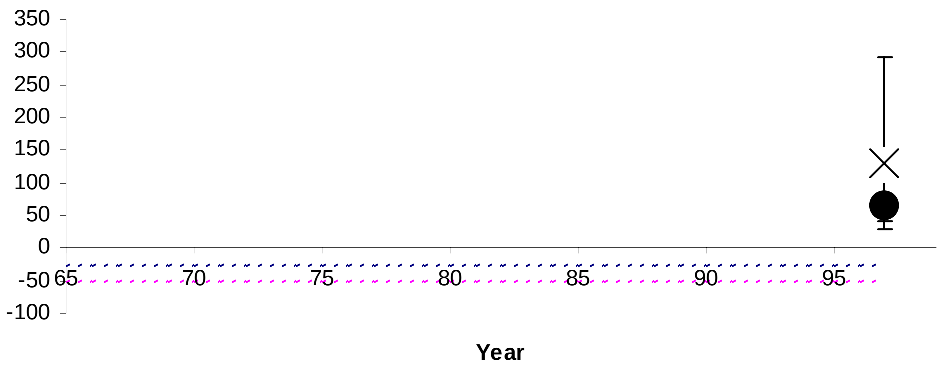
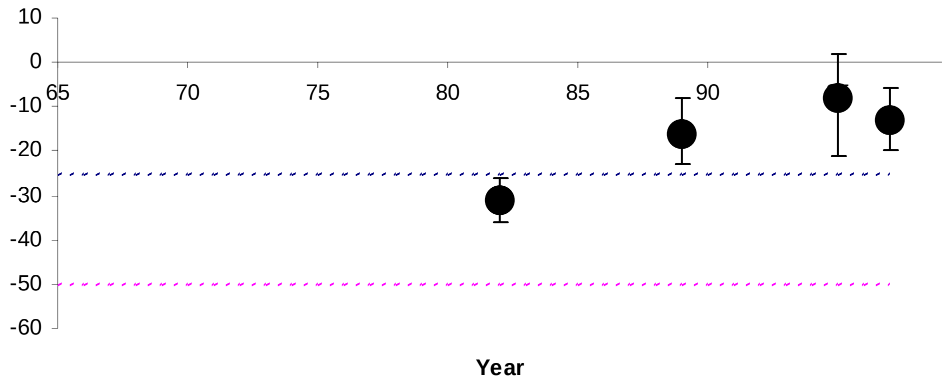
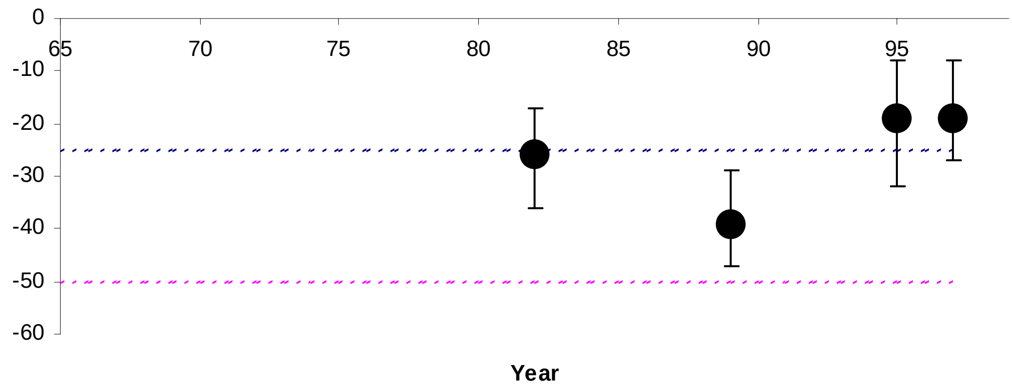


Figure 3.4.6 Population changes of Great Spotted Woodpecker with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

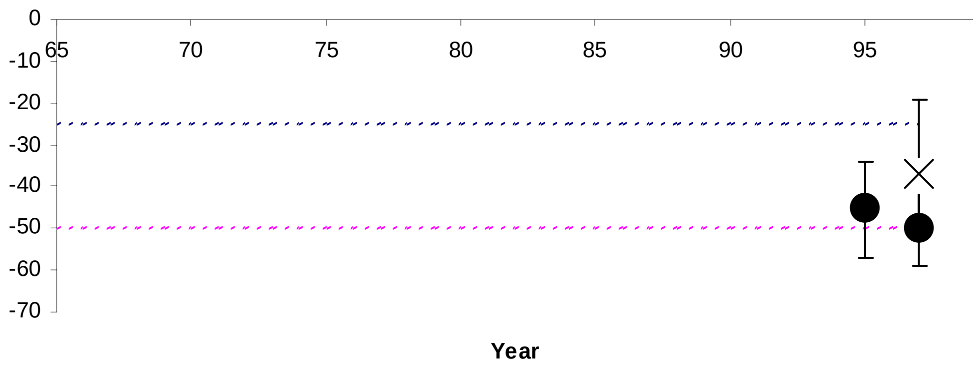
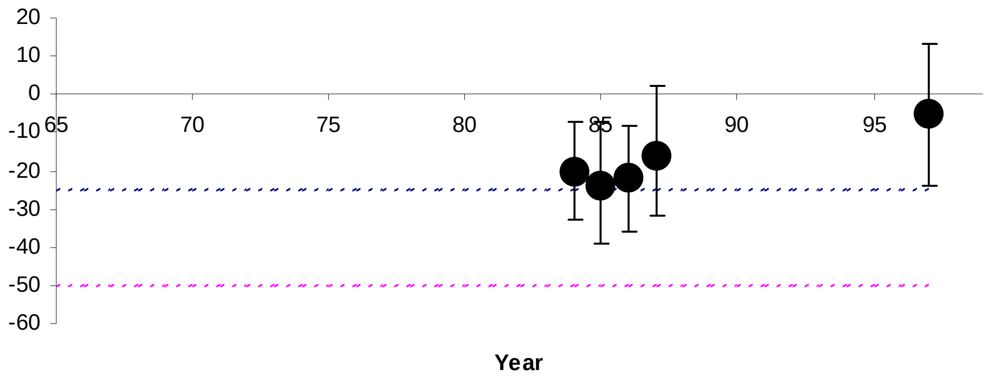
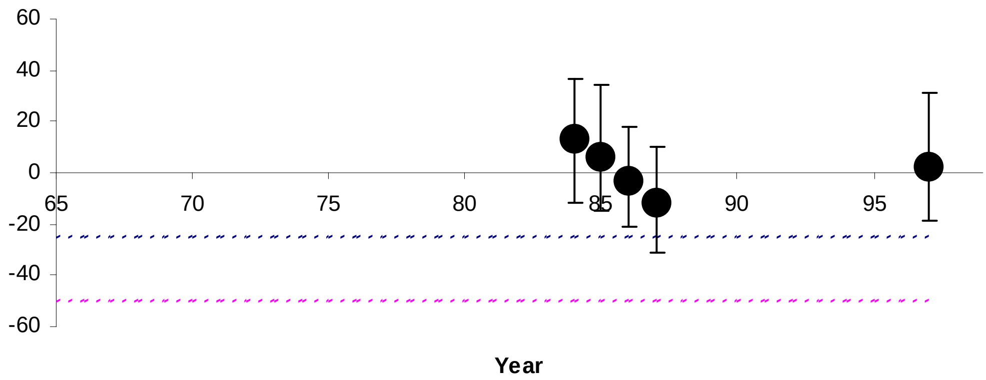


Figure 3.4.7 Population changes of Skylarks with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

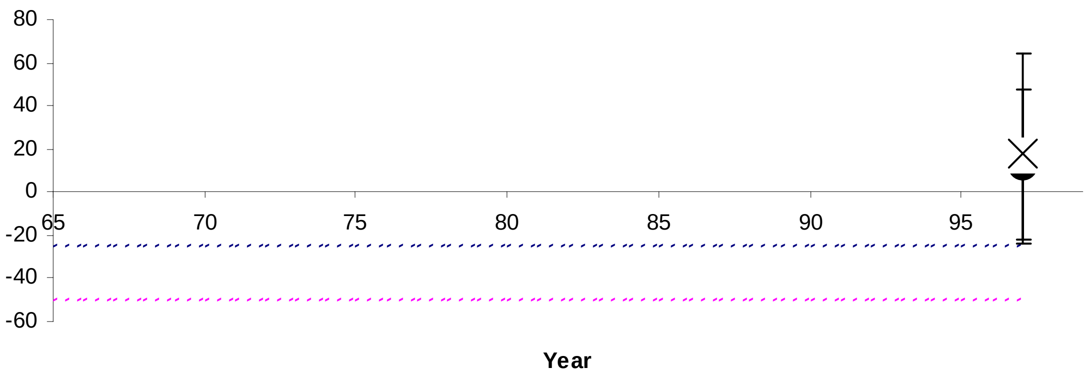
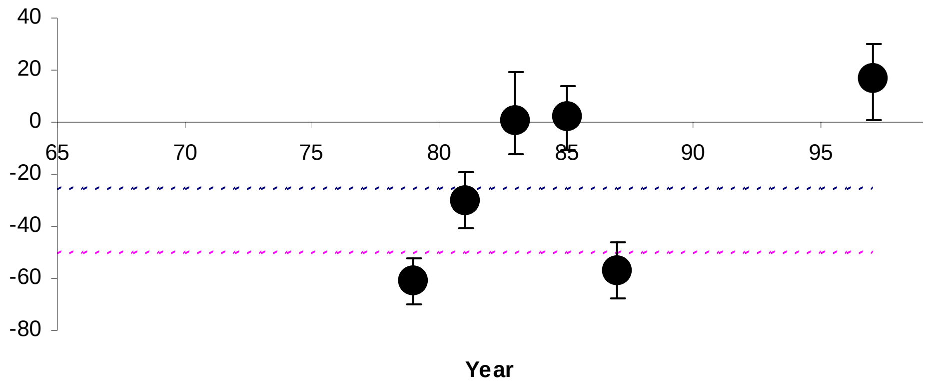
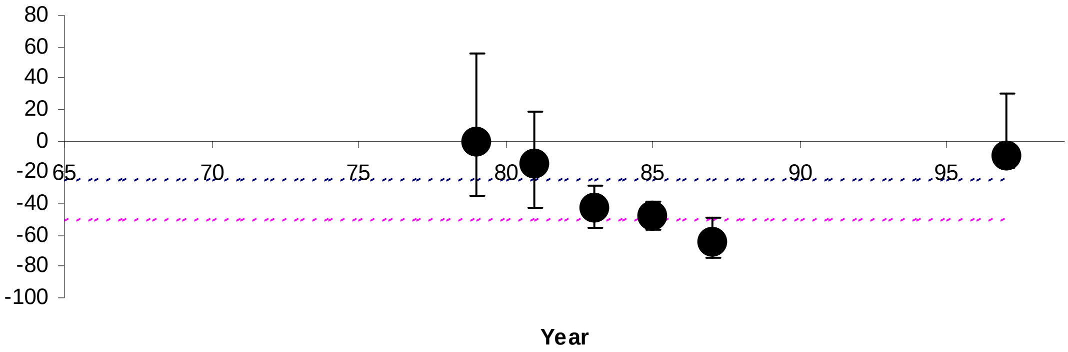


Figure 3.4.8 Population changes of Swallows with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

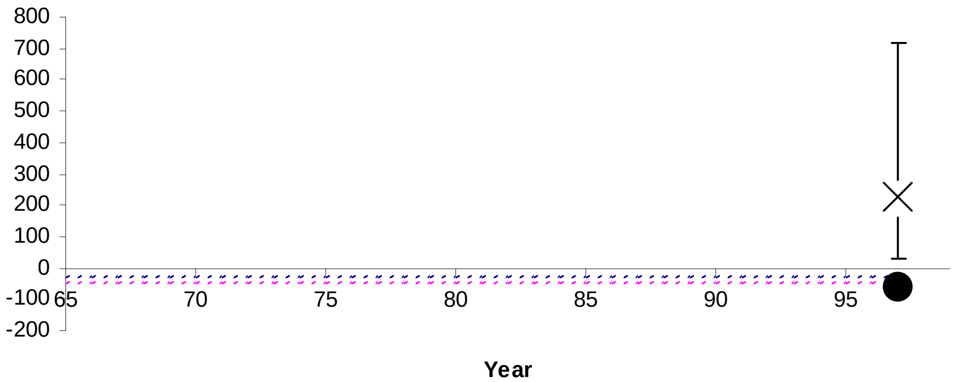
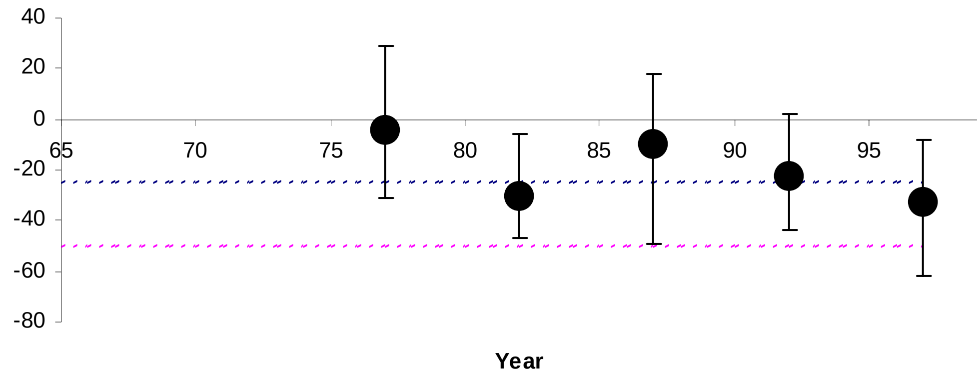
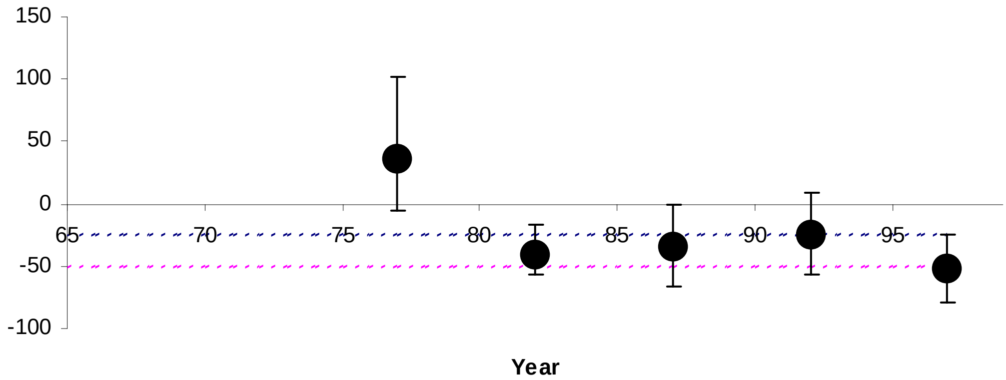


Figure 3.4.9 Population changes of Goldcrests with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

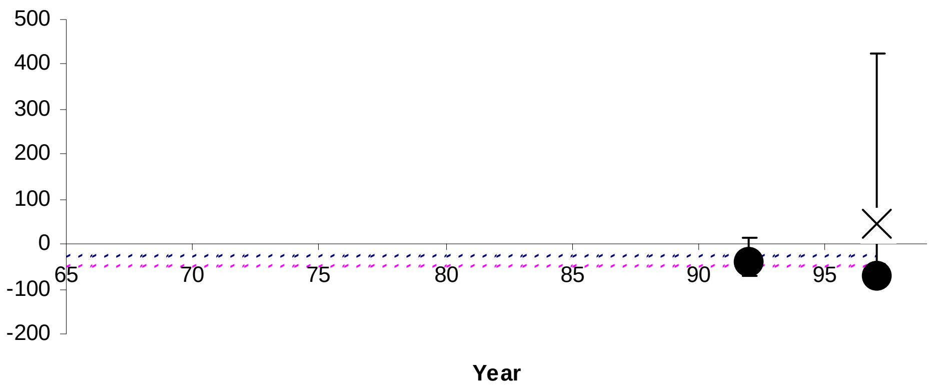
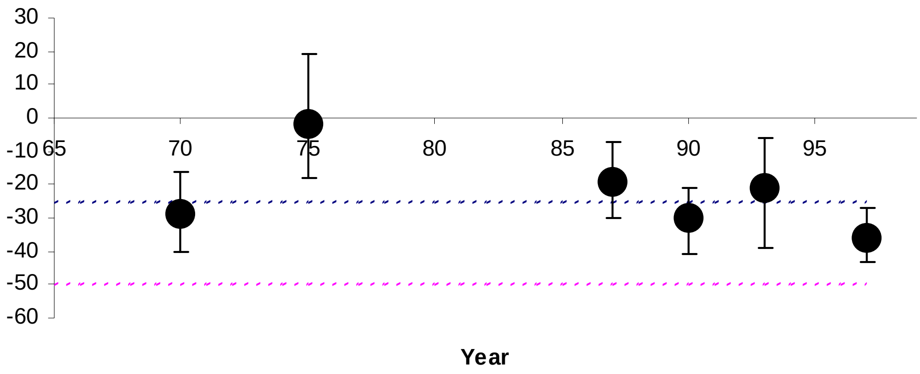
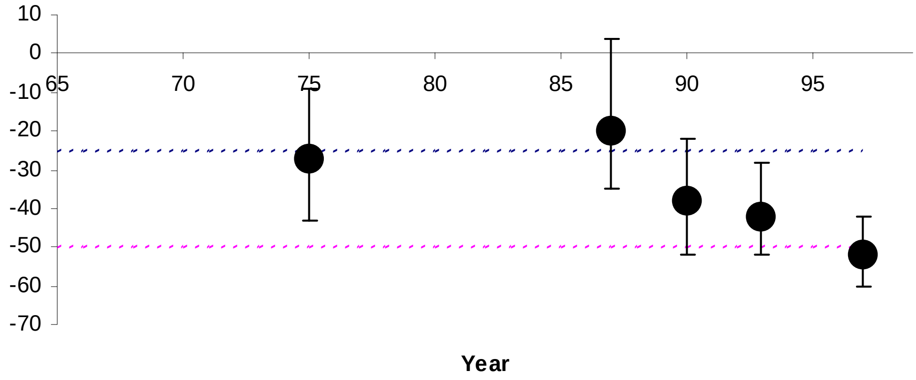


Figure 3.4.10 Population changes of Willow Tits with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

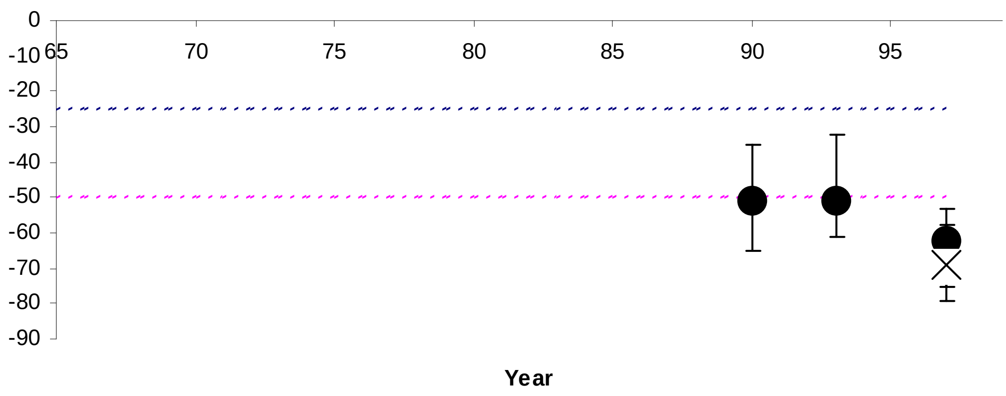
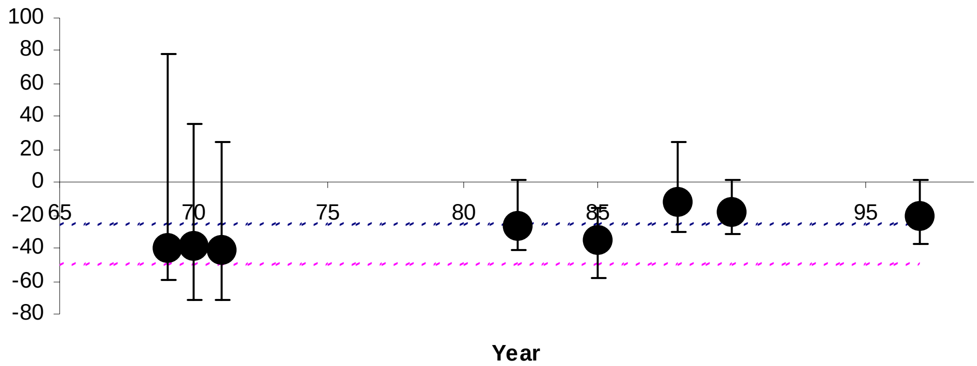
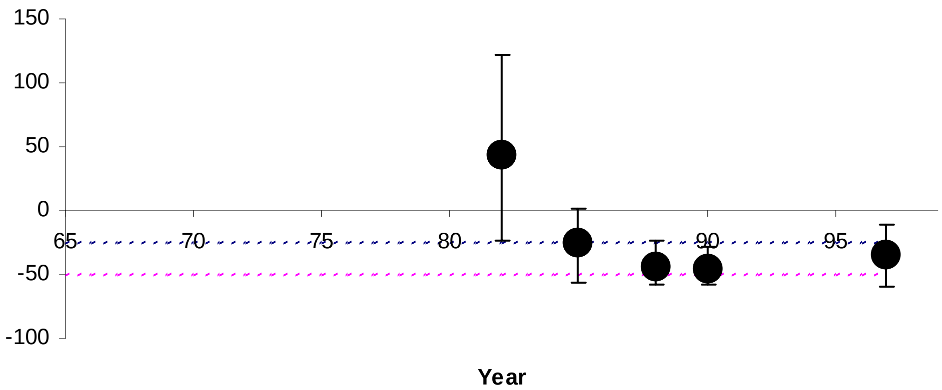


Figure 3.4.11 Population changes of Starlings with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

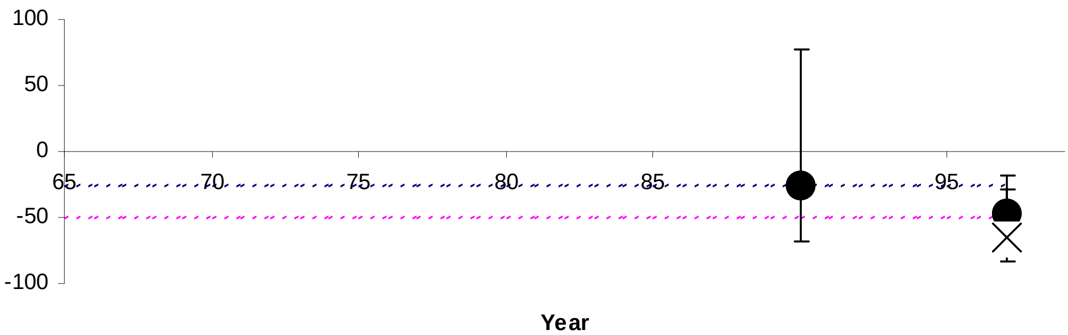
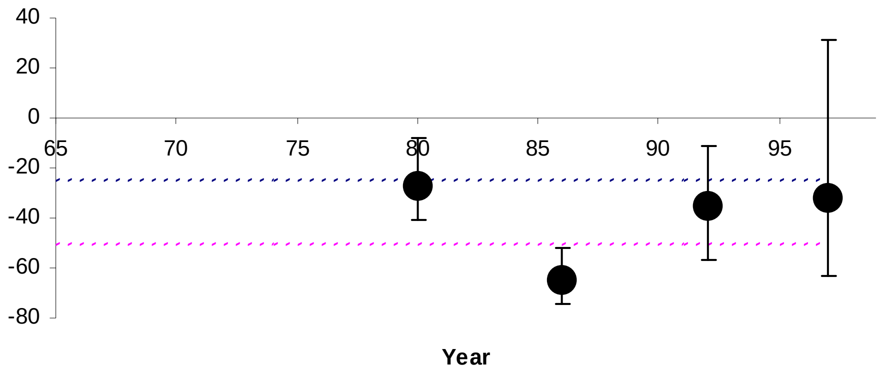
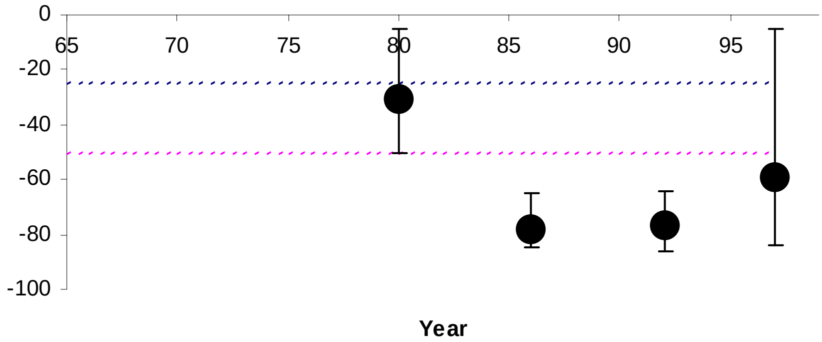


Figure 3.4.12 Population changes of House Sparrows with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

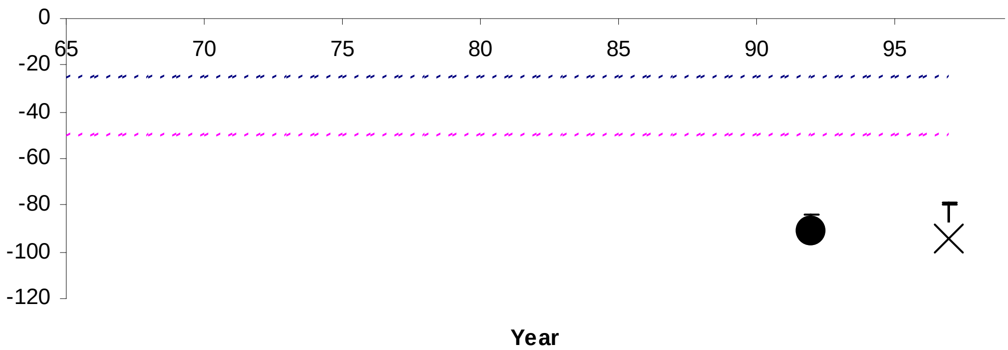
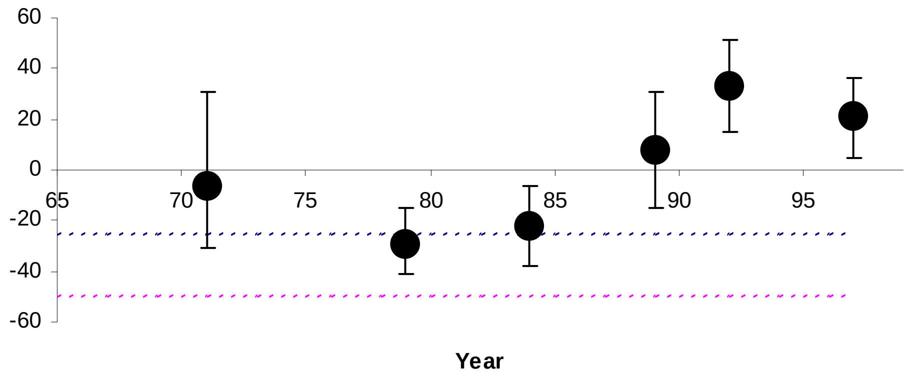
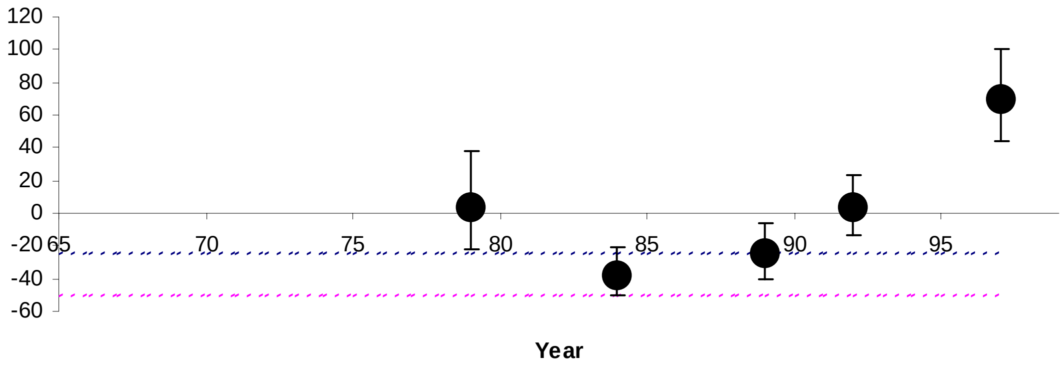


Figure 3.4.13 Population changes of Tree Sparrows with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

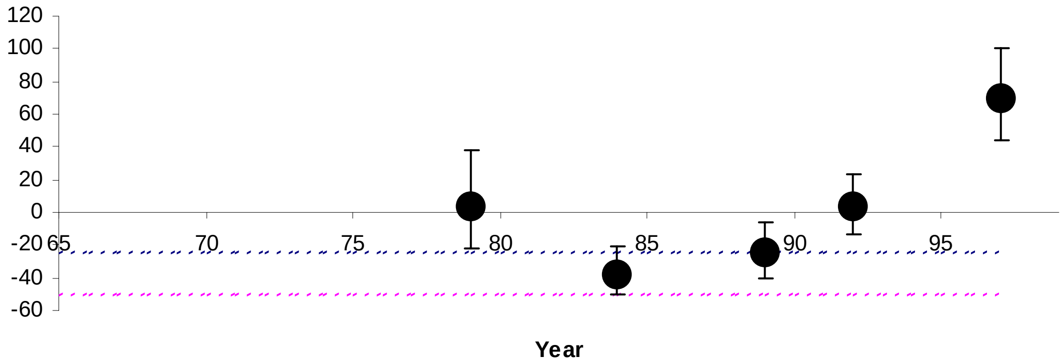
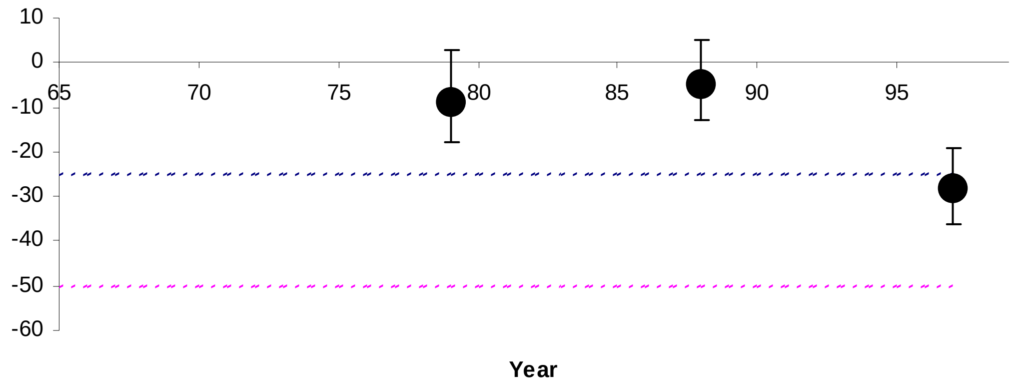
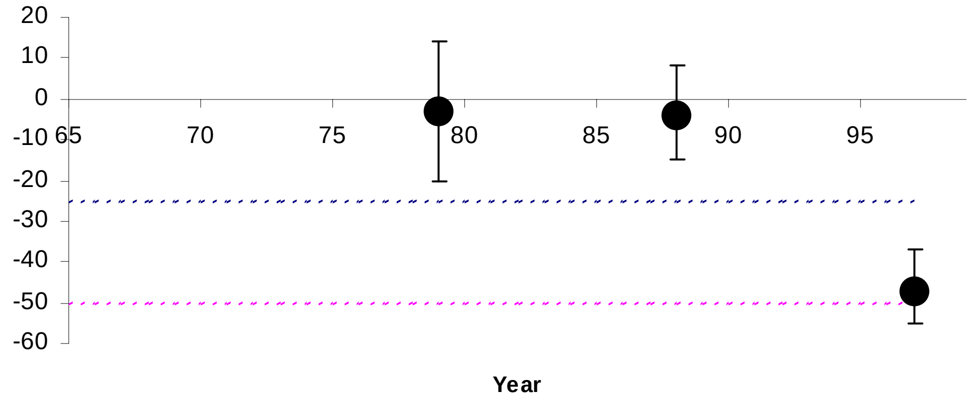


Figure 3.4.14 Population changes of Goldfinches with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

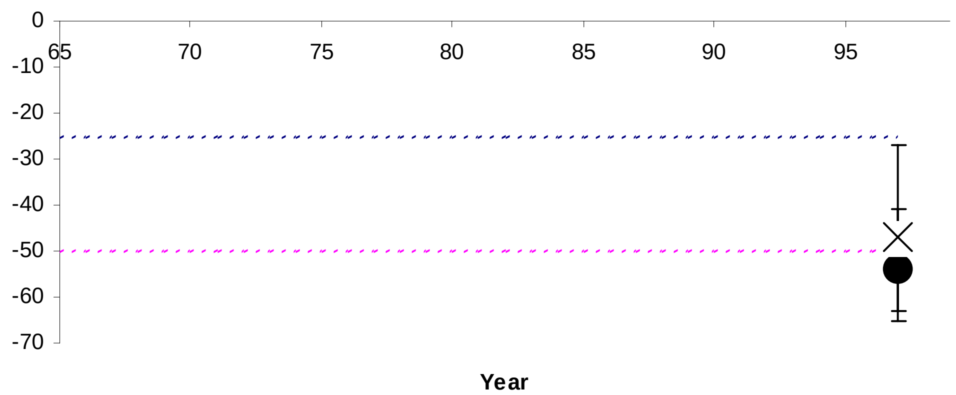
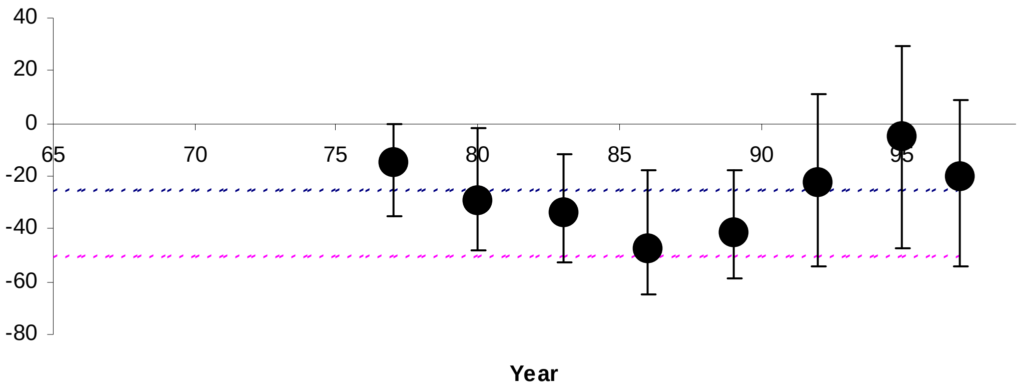
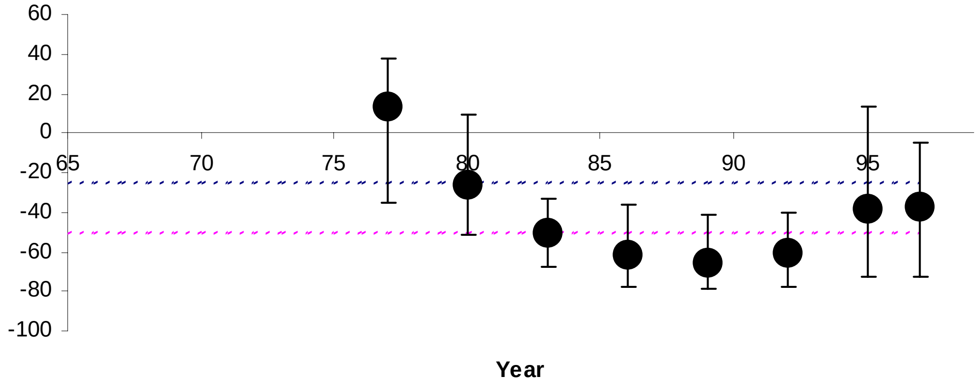


Figure 3.4.15 Population changes of Yellowhammers with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

(a) Five-year changes



(b) Ten-year changes



(c) Twenty-five year changes ● and overall changes X

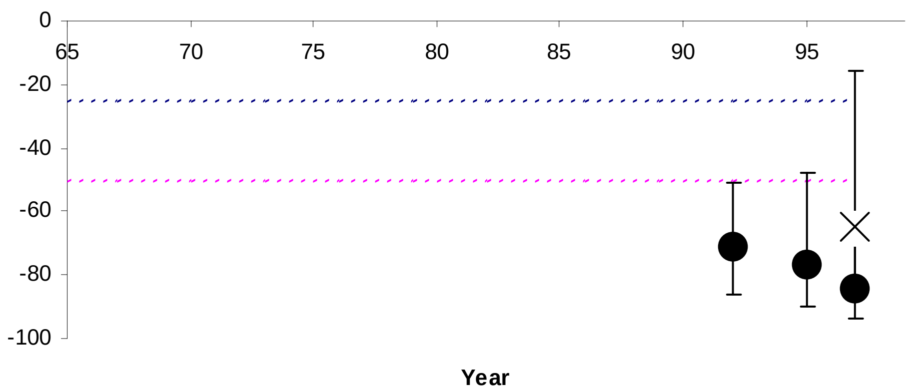


Figure 3.4.16 Population changes of Corn Buntings with 95% confidence limits. Changes are plotted against the last year of the time interval and were calculated for a sample of years for periods of five years (a), ten years (b), twenty-five years (c) and to the start of the CBC in 1962 (c). Changes were calculated using GAMs and confidence intervals were evaluated by bootstrapping with 119 replicates.

4. NATIONAL AND SITE-BASED ALERTS FOR WATERBIRDS: THE UNDERHILL METHOD

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In *National and site-based alert systems for UK birds* (eds. S.R. Baillie & M.M. Rehfisch). Research Report 226. BTO, Thetford.

In the following paper "Index numbers for waterbird populations. IV. Implementation of a modified imputing algorithm, a full bootstrap procedure, and the introduction of alert limits" Les Underhill updates the Underhill Index which is presently used to describe population change in the UK's waterbirds and proposes some original methodology for both national and site-based alerts for waterbirds.

Updating the Underhill Index

The present Underhill methodology suffered from two limitations.

- First, as a result of computers being less powerful than they are now when the Underhill methodology was first designed any missing counts for each site were imputed only once for the total set of sample wetlands. The consistency intervals around the index were then estimated from 1000 bootstrap samples generated by randomly sampling with replacement the requisite number of sites, the "restricted bootstrap algorithm". It was suspected that this would give unnaturally narrow consistency intervals. For the new "full bootstrap algorithm" a full set of sites are randomly selected with replacement and then the missing values are imputed for each bootstrap sample. This is repeated 1000 times to generate consistency intervals that are between two to three times larger than those of the original restricted algorithm. The full algorithm consistency intervals are more representative of the *real* variation in population change of species across estuaries.

- Second, presently the Underhill indexing programme uses all years of data when imputing missing values. This is a flawed concept when there have been major changes in wetland size or quality through time. For example, the Tees estuary has suffered major habitat loss in the last thirty years and the "original imputing algorithm" will include the potentially larger early counts (recorded when the estuary area was larger) when estimating by imputation the size of recent missing counts. Similarly, when a species such as Grey Plover has increased dramatically through time, counts from the early years of WeBS which will tend to be small will lead to recent missing values being underestimated. The "modified imputing algorithm" allows the user to define any odd number of years as the window length, and therefore missing values for the year *a* will be imputed using counts made *v* years either side of it. In the case of Grey Plover, the more realistic estimates imputed by the modified algorithm differed by up to 19% from the estimates imputed by the original algorithm.

Alerts

The new Underhill index methodology is adapted to the concept of generating alert limits for species and for sites. Alerts are again defined as population changes, with most emphasis being placed on decreases, of 25% or 50% over time periods of 5, 10 and 25 years.

These alerts, based on waterbird change measures, will be produced annually for the UK, England, Northern Ireland, Scotland and Wales. One third of the Ramsar and Special Protection Areas classified for non-breeding waterbirds will be assessed, commented upon and reported on every year in rotation, so that all such sites are covered every three years. One sixth of the Sites of Special Scientific Interest and

ASSI classified for non-breeding waterbirds will be assessed, commented upon and reported on every year in rotation, so that all such sites are covered every six years.

National and regional alerts

Based on the test data, the very provisional recommendations for this new methodology are that "fixed period national alert limits" use:

- Nine-year imputing windows to lessen the impact of change in habitat quality in individual wetlands, and;

- Three-year alert windows to help smooth the data while ensuring that more of the suite of data is used than if five year alert windows had been used (further testing would confirm this).

Site alerts

The results of the tests of the likely value of "fixed period site alert limits" have proved promising. As for national indices nine-year imputing windows and three-year alert windows are provisionally recommended. It may be worth further testing uneven alert windows where, for example, a shorter period is used for the current period and a longer period for the early period. This might allow the short window to be sensitive to immediate trends and the longer window to damp down noise from the earlier period. Computing consistency intervals for site alerts does not seem feasible, because any particular site does not occur in each of the bootstrap samples.

A promising approach: first draft

This paper is very much a first draft which has not yet been through the full refereeing procedure. Internal refereeing has corrected some typographical errors some inconsistencies remain that can only be checked when Prof. Les Underhill returns from his holidays. The Welsh Redshank indices are almost certainly incorrect (Table 4.11).

There has been no attempt to formally test the significance of any differences between national, regional or site-based indices or alerts. The effect of endpoints on the reliability of alerts generated using all available data has not been tested for this methodology, unlike for GAMS, but as the Underhill methodology smooths by averaging the last three or five years of data this should be less of a problem.

A major benefit of this methodology is the alert running time. Using a 360 MHz Celeron Pentium the calculation of Pintail index numbers, alert limits and consistency intervals based on 500 bootstrap samples took 17 minutes. It did not prove possible to run the full GAMs alerts for Pintail, and it took 4-6 days of computing time to run the GAMs alerts for Mallards (see later).

Index numbers for waterbird populations. IV. Implementation of a modified imputing algorithm, a full bootstrap procedure, and the introduction of alert limits

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Summary

As a prelude to developing alert limits, the original algorithm for computing index numbers for waterbirds was extended in two ways. (1) The imputing algorithm was improved by relaxing the assumption that a single multiplicative model fitted the entire period. Imputing can now be done within a window of years chosen by the user; the same multiplicative model, restricted to the window, is used to impute missing values. Even with nearly three decades of counts, the result was that use of imputing windows made unexpectedly small differences to the series of index numbers. (2) The bootstrap sampling algorithm to estimate "consistency intervals" has been made more realistic. Over the decade since the indexing method was developed in 1989, the speed of readily available computers has increased to the extent that it has become feasible to undertake imputing for each bootstrap sample. Previously, the imputing was done only once, prior to bootstrap sampling. The consistency intervals produced by this algorithm are two to three times longer than those produced by the "restricted" method.

The alert limits developed in this paper make use of the concept of ratios of moving averages of counts. Moving averages were used to reduce the influence of outlying counts in a single year. Alert limits calculated in this way have a direct interpretation. In simplest terms they represent the change in the population size averaged over recent years in comparison with the population size averaged over the same number of years, but a fixed time span earlier. These averages were computed over periods of three and five years. The preliminary recommendation is that a period of three years is long enough to reduce the impact of outliers (and avoid false alert warnings), and short enough to provide alert warnings rapidly. The alert limits were calculated over time spans of five, 10 and 25 years. These limits were calculated for Great Britain, for Wales, and for individual sites.

The concept of cumulative alert limits was tentatively explored. These are derived by calculating the alert limits over all periods up to a given time span (10 and 25 years were used), and finding the maximum and minimum of these alert limits. These upper and lower limits thus set the bounds within which the population size has varied over the given time span, and provide a historic context within which the current population size can be evaluated. This concept, which strictly lies beyond the terms of the present contract, potentially requires more elaboration and evaluation.

Introduction

A method developed by Underhill (1989) and Underhill & Prŷs-Jones (1994) has become accepted as the algorithm for generating index numbers for waterbird populations from counts of birds made at sites, which are usually discrete wetlands (Prŷs-Jones *et al.* 1994; Kirby *et al* 1995). The key element of the method was the concept of estimating missing counts by fitting a simple multiplicative model to the data, a process known within the statistical sciences as >imputing=. Various algorithms have been developed to implement essentially the same estimates of the index numbers; there has been discussion of the efficiencies of these algorithms. In this paper, we report two extensions of the Underhill & Prŷs-Jones (1994) method and develop algorithms to compute 'alert limits'.

The first extension to the original method provides a new option for imputing missing values by making use only of counts made in a subset of years; in other words, imputed values need no longer be dependent on counts made, say, 25 years earlier or later. This extension is motivated by the fact that the area or the ecological state of a wetland may have changed over the entire period for which count data are available.

The second extension represents the removal of a deficiency in the bootstrapped consistency intervals; this deficiency was recognised by Underhill & Prŷs-Jones (1994) but limitations on the computer power available to us at the time precluded dealing with it. However, improvements in the power and speed of standard personal computers enables us to implement bootstrapping in a more appropriate way. In brief, instead of taking bootstrapped samples from the set of sites after the imputing has been completed, we now select a sample of sites, and from the original count data impute the missing values for this sample, and compute the consistency intervals.

We apply the extended method to the concept of generating alert limits for species and for sites. In this context, an alert for a species is a warning signal that it has declined by a predefined percentage over a given time span; similarly an alert for a species at a site is a warning that the species has declined at the site.

Material and Methods

REVIEW

As far as possible, the same notation as in Underhill & Prŷs-Jones (1994) is used. Let x_{ijk} denote the count of the number of birds at locality i in year j and month k, where $i = 1,2,...,I$, the number of localities, $j = 1,2,...,J$, the number of years and $k = 1,2,...,K$, the number of months upon which the index will be based. In this paper, it will frequently be convenient to regard the final year J, as the current year. Designating year b as base year, 1# b#J, we define the index number for year j relative to base year b as

$$P_j = \frac{\sum_{i=1}^{I}\sum_{k=1}^{K} x_{ijk}}{\sum_{i=1}^{I}\sum_{k=1}^{K} x_{ibk}} \qquad (1)$$

For the purpose of this paper, the base year was chosen to be b = 1972/73, the base year traditionally used by WeBS. The index numbers computed will use selections of the six late autumn and winter months, October-March. To illustrate the methods, most index numbers will be computed for the midwinter months, December, January and February, denoted months 1, 2 and 3, respectively.

The critical problem in computing these index numbers is that such datasets contain missing values. Underhill & Prŷs-Jones (1994) reviewed various *ad hoc* methods that had been devised to overcome this problem. Their solution was to develop the concept of filling in missing values by a process called imputing; they estimated each missing value as the product of three factors, a site factor, a year factor and a month factor. The site factors were assumed to remain unchanged through time, the month factors were assumed the same for all years, and the year factors were assumed the same for all sites.

The assumption of multiplicity was expressed by writing the expected value of x_{ijk} as

$$\exp(x_{ijk}) = s_i \times y_j \times m_k$$

where $i = 1,2,...,I$, $j = 1,2,...,J$ and $k = 1,2,...,K$, and where s_i is the factor for locality i, y_j is the factor for year j, and m_k is the factor for month k. In order to determine s_i, y_j and m_k uniquely, it is necessary to place two constraints on these parameters (Underhill & Prŷs-Jones 1994). For continuity with the previous WeBS/BoEE index numbers, 1972/73 was chosen as the base year and January as the base month, *i.e.* $y_b = y_{1972/73} = 1$ and $m_2 = m_{\text{January}} = 1$. Then s_i may conveniently be interpreted as the expected count in the base year and month at locality i. The expected count at locality i in January of year j is then simply $s_i y_j$. The maximum likelihood estimates of s_i, y_j and m_k which minimize E, subject to the two constraints, are

$$s_i = \frac{x_{i++} x_{+b+} x_{++2}}{x_{+++}}$$

$$y_i = \frac{x_{+j+}}{x_{+b+}}$$

$$m_k = \frac{x_{++k}}{x_{++2}}$$

where the plus notation is used to denote summation over the subscripts replaced by the plus signs,

$$e.g.\ x_{i++} = \sum_{j=1}^{J} \sum_{k=1}^{K} x_{ijk}$$

Note that, as a result of the choice of constraints, $y_j = P_j$, the index number for year j, as defined above. The expressions for y_j and m_k are intuitively obvious. The expression for s_i is the total number of birds observed at site i (x_{i++}), multiplied by the proportion of the grand total observed in the base year, 1972/73, (x_{+b+} / x_{+++}) and multiplied by the proportion of the grand total observed in January, (x_{++2} / x_{+++}). Then s_i may be interpreted as the proportion of the total number of birds counted at site i that ought to have been present in January of the base year, assuming the multiplicative model to be correct.

The method for imputing values is an iterative algorithm. The Underhill & Prŷs-Jones (1994) procedure for imputing missing values is given here.

1. Replace each missing count by the mean of all available counts at the estuary. The starting value is, in fact, arbitrary, but the better the choice, the fewer iteration steps are needed.

2. Estimate the values of the parameters s_i, y_j and m_k, as described above.

3. Use these parameter estimates and the assumed model to re-estimate each missing value:

$$x_{ijk} = s_i y_j m_k$$

4. Iterate steps 2 and 3 until the successive imputed values of x_{ijk} are practically the same.

Once convergence has been achieved, the final value of y_j is the required index number P_j. It is a ratio, the numerator being the grand total of the numbers of birds actually counted plus the imputed counts at all estuaries in the chosen months, and the denominator being the similar total for the winter of the base year, 1972/73.

MODIFIED IMPUTING ALGORITHM

The Underhill & Prŷs-Jones (1994) model assumes "stationarity", *i.e.* that the relative importance of a wetland does not change through time. In the application of this assumption, all counts made at a wetland are used in imputing missing values, regardless of the time difference between an actual count and a missing value. For example, in the original imputing algorithm, a count made in 1998 influences the imputing of a missing value in 1969 and *vice versa*. This assumption was not unreasonable when the total duration of the WeBS project was relatively short, but as the project enters its fourth decade of existence, a new approach is needed.

The modified imputing algorithm uses the concept of a window. To impute the missing values for a given year a, we now use only counts made v years before and after year a, *i.e.* in the window consisting of the years a - v to $a + v$. The total window width is $w = 2v + 1$; note that w is therefore always an odd number. The choice of window width is made by the user.

The modified algorithm to impute the missing values in year a with window width w has the following steps.

1. Compute an appropriate initial value for each missing value.

2. Estimate the values of the parameters $s_{i(a)}$, $y_{j(a)}$ and $m_{k(a)}$, as described above, but restricted to the window of width m centred on year a.
3. Use these parameter estimates and the assumed model to re-estimate each missing value with the window

$$x_{ijk(a)} = s_{i(a)} y_{j(a)} m_{k(a)}$$

4. Iterate steps 2 and 3 until the successive imputed values of $x_{ijk(a)}$ are practically the same.

5. Repeat steps 2 to 4 for windows centred on year $v + 1$ to year J - v - 1.

For the first and final few years for which data are available, the algorithm needs to be modified, because the target year for which missing values need to be estimated cannot then be made the central year of the window. For years 1 to v, the window is set to the first w years of available data, so that the imputing is done within the window centred on year $v + 1$. For the final years J - v to J, the window is set to the final w years of data, so that the imputing is done within the window centred on year J - v - 1.

An invaluable by-product of the modified imputing algorithm is that the site factors and the month factors are window-dependent. Thus, if the relative importance of a site for a species changes through time, this is revealed by examining the successive values of $s_{i(a)}$, where the values of a run from $v + 1$ to J - v - 1. It also means that if the pattern of seasonality is changing through time, this will similarly be reflected in the month factors calculated for each successive window.

FULL BOOTSTRAP ALGORITHM

Underhill & Prŷs-Jones (1994) used the bootstrap algorithm to devise a procedure that generated quantities analogous to confidence limits for the annual index numbers y_j. These limits produced the endpoints of intervals which were called >consistency intervals'. These intervals measured the consistency of the change of population levels across all the estuaries included in the index number computations. If the proportional annual increases and decreases in the counts for a species were similar across all estuaries, the consistency intervals were short. On the other hand, if a species was unpredictable about the estuaries it occupied between years, the consistency intervals were long.

Statistically, it is incorrect to refer to confidence intervals in the context of WeBS. The concept of confidence interval requires random sampling from either an infinite and a finite population of objects. If the number of objects from which the random sample is taken is finite in number, a finite population correction is applied which shortens the length of the confidence interval, and reduces it to zero when sample size is equal to the number of objects available to be sampled. For WeBS, the set of objects being sampled is estuaries (not birds). In the case of WeBS, the objective is to survey the entire set of estuaries (and other major wetland sites) for a species in each month in each year. From technical statistical considerations, the length of the confidence interval on the total count, or census, is zero.

In the bootstrap algorithm used by Underhill & Prŷs-Jones (1994), described below, all missing values had already been replaced by their imputed values, and the dataset was assumed to be complete. Underhill & Prŷs-Jones (1994) pointed out that, as a consequence of this, the consistency limits it computed tended to be optimistically short. They also noted that the index number for those years in the dataset with the highest proportions of imputed values would be worst impacted by a shortening of the consistency intervals.

Step 1 has been added to Underhill & Prŷs-Jones (1994)'s original description of the algorithm, and the subsequent steps renumbered.

1. Impute all missing values in the dataset for a species, and calculate x_{ij+}, the annual totals for each of the I estuaries.

2. Draw, *with replacement,* a random sample (a bootstrap sample) of I estuaries from the population of I estuaries that have been used to compute the index numbers. Suppose that the random sample consists of the estuaries i_n, n = 1,2,...,I. Sampling with replacement means that the bootstrap sample may include some estuaries more than once and others not at all. Each element of the random sample consists of a series of J values $x_{i_nj}+$, j = 1,2,...,J, the number of birds at the i_nth estuary summed over the K months for which the index numbers have been computed.

3. Compute the proportions of birds in the bootstrap sample for each year: call these values p_j, j = 1,2,...,J:

$$P_j = \frac{\sum_{i=1}^{I} x_{i_n j+}}{\sum_{i=1}^{I}\sum_{j=1}^{J} x_{i_n j+}}$$

4. Repeat steps 1 and 2 a large number of times, say, M times, producing proportions p_{jm}, j = 1,2,...,J, m = 1,2,...,M.

5. Sort the p_{jm}'s belonging to each year j from smallest to largest.

6. Compute the required percentiles from the sorted p_{jm}'s, for each year. For, say, 90% consistency intervals, the lower and upper 5% percentiles are required; call these values $p_j(l)$ and $p_j(u)$, j = 1,2,...,J.

7. Divide the lower and upper percentiles by $p_b = (x_{+b+} / x_{+++})$ to convert them to consistency limits relative to the chosen base year. The conversion to the base year needs to done at this stage, otherwise there is no consistency interval for the base year.

This algorithm is now referred to as the restricted bootstrap algorithm.

In 1989, when the restricted bootstrap algorithm was devised (Underhill 1989), it was not feasible, with the computational resources then available, to reverse steps 1 and 2 of the algorithm. Interchanging these steps would remove the disadvantage of optimistically short consistency intervals for datasets with large numbers of missing values. Computing advances over the past decade make this interchange possible. Replacing steps 1 and 2 of the bootstrap algorithm by steps 1A and 2A below produces an improved procedure, referred to here as the full bootstrap algorithm.

1A. Draw, with replacement, a bootstrap sample of I estuaries from the population of I estuaries that have been used to compute the index numbers. Denote the sampled estuaries i_n, n = 1,2,...,I,

2A. Use the standard algorithm to impute all missing values in the bootstrap sample of I estuaries; calculate $x_{i_n j+}$, the annual totals for each of these estuaries.

The essential difference is that imputing is done with each bootstrap sample, instead of only once.

For the wader species, for which counts at approximately 130 estuaries are included in the calculations, the restricted algorithm took approximately 30 minutes to compute consistency intervals from 1,000 bootstrap samples on a '386' personal computer in 1992. The full bootstrap algorithm runs in less than 10 minutes on a standard 'pentium' PC in 1999; there is considerable variation between species, because species with generally short consistency intervals require fewer iterations at step 2A for each bootstrap sample than species with wide consistency intervals. The original restricted bootstrap algorithm runs in about 10 seconds on a pentium; the full bootstrap algorithm would have run for several days per species on a 386 in 1992.

INTRODUCTION OF ALERTS LIMITS

Fixed time span alert limits

The objective of developing a population index is to provide reliable information on the trend through time of the size of the population. On the basis of this monitoring information, management and conservation decisions need to be taken and appropriate palliative measures need to be implemented. If agreement could be reached in advance to describe what changes in population size over a specified time span are necessary before a warning is triggered, responses to such changes can be more rapid and more effective. Such warnings are known as 'alert limits'.

The aim of this section is to develop an algorithm to generate 'alert limits' based on the population index numbers of Underhill & Prŷs-Jones (1994). An alert limit needs to be generated if the population index changes by more than an agreed percentage over an agreed time span. In this paper, we consider alert limits over time spans of 5, 10 and 25 years. We abbreviate these alert limit AL|5, AL|10 and AL|25, respectively. A more general notation for this would be AL|*S*, where *S* represents the agreed time span in years over which the alert limit is calculated. In a later section, the concept of 'cumulative alert limits' is introduced.

The alert limit can refer to a single site or to a group of sites. In this paper alert limits are generated for individual British sites, and for Britain as a whole. We use SAL|*i*|*S* to denote a site alert at site *i*, and GAL|*S* to denote a general alert for a region over a time span of *S* years.

If automatically produced alert limits are to be taken seriously, the algorithm that generates them needs to be relatively robust. Clearly, an algorithm that triggers false alarms (Type I errors) is undesirable. On the other hand, if the algorithm is too robust, it will be insufficiently sensitive, and will fail to trigger alarms, or trigger them a year or more too late (Type II errors).

The simplest algorithm for generating SAL|*i*|*S* for a particular site *i* in the current year *J* is based on the ratio between the sum of the counts made in each month at the site in year *J* with the sum of the counts made in year *J* - *S*:

$$SAL\left|i\right|S_{1,1} = \frac{\sum_{k=1}^{K} x_{iJk}}{\sum_{k=1}^{K} x_{i(J-S)k}} - 1 \qquad (2)$$

A value of zero indicates that the population at the site is unchanged between years, and negative and positive values that it has decreased and increased, respectively. Likewise, a general alert over all sites may be defined as

$$GAL\left|S_{1,1}\right. = \frac{\sum_{i=1}^{I}\sum_{k=1}^{K} x_{iJk}}{\sum_{i=1}^{I}\sum_{k=1}^{K} x_{i(J-S)k}} - 1 \tag{3}$$

In these, and all other alert limit statistics proposed in this paper, missing counts are replaced by their imputed values. The subscripts 1,1 are included in SAL|i|$S_{1,1}$ and GAL|$S_{1,1}$ to indicate that they are based on one year of current and one year of earlier data. With this definition, the generation of alert limits can commence from the (S+1)th year of data collection. The weakness of this approach is that it is likely to be dependent on outlying values, especially if it either of the years included in the calculations, years J and J - S, happen to yield abnormal counts which do not fit a general trend, caused for example by exceptional weather.

Using the definition of the index numbers in equation (1) above, this definition of GAL|$S_{1,1}$ can be simplified. It is based on the ratio of the index values P_J and P_{J-S} for years J and J - S:

$$GAL\left|S_{1,1}\right. = \frac{P_J}{P_{J-S}} - 1 \tag{4}$$

Equations (2) and (4) suggest a simple interpretation of alert limits. If the alert limits SAL|i|S or GAL|S are close to zero, this means that current population sizes are similar to those S years ago, and indicates the (usually) desirable situation of no change in status. An alert warning is given when the alert limit takes on a value too far from zero. The choice of values of the alert limit at which alert warnings are triggered is a biological, rather than statistical, decision. The proposed values for triggering alerts are decreases (or increases) of 25% and 50%. This corresponds to values of the alert limit statistic of -0.5, -0.25, 0.25 and 0.5. (For presentation purposes, it is convenient to multiply the calculated alert limit values by 100, and to interpret them as percentage changes in population sizes. Calculated alert limits presented throughout this paper are expressed as percentages.)

All alert limits will be based on ratios which are of the same general form as equation (2). It is clear that alert warnings will be triggered by early counts that are large (or small) relative to the current counts. False alerts, or Type I errors, will be generated when one or more of the counts involved in the alert limit calculations were larger or smaller than they ought to have been. These incorrect counts may be due to observer error (failing to count a flock of birds, or counting a flock twice), or bird movements (a large, but transient, flock might be present during a survey, or a flock that is normally present might have temporarily moved off the site due to factors such as disturbance). The difference between the theoretically correct value and the observed value is known as the residual, and an observed value with a large residual will be referred to as an outlier.

The standard statistical technique for dealing with these residuals is to combine as many of them as is appropriate in such a way that those residuals which are positive approximately balance those that are negative. In this context, the appropriate way to combine residuals is to add them together. This leads us to consider defining an alert limit for site i based on more than one year of data; we define SAL|i|$S_{q,q}$ to be

$$SAL\left|i\right|S_{q,q} = \frac{\sum_{j=J-q+1}^{J}\sum_{k=1}^{K} x_{ijk}}{\sum_{j=J-(S+1)-q}^{J-S}\sum_{k=1}^{K} x_{ijk}} - 1 \tag{5}$$

This definition uses data from the current year J and the preceding q - 1 years, and between years J - (S + 1) - q and J - S. With SAL|$S_{q,q}$, the generation of alert limits can commence from the S + qth year of data collection. We call the value of q the >alerts window=. Note the distinction between S, the alerts time span, and q, the alerts window.

An appropriate value needs to be chosen for q. In these analyses in this paper, we have used $q = 3$ and $q = 5$. This seems satisfactory in this context because three or four monthly counts per year ($K = 3$ or 4) are used for the index numbers calculated for this paper. Thus, the number of terms in the sums in the numerator and denominator of equation (5) lies between nine and 20, which is generally likely to be appropriate to maintain the balance between the need to have a robust alert limit, which is not overly sensitive to outliers, and one that does not unduly delay the generation of alerts. The choice of q need not be universal for all species; those species which are known to be subject to survey errors can have larger values for q than the value used for species which are almost invariably counted reliably.

In the definitions above, we have considered the alerts window for both the current period and the early period to be equal to q. This equality is not necessary, and it may make sense, under certain circumstances, to use a shorter window for the current period with a longer window for the early period. An appropriate definition of the alert limit is then

$$SAL\left|i\right|S_{q,q} = \frac{\frac{1}{q_1}\sum_{j=J-q_1+1}^{J}\sum_{k=1}^{K}x_{ijk}}{\frac{1}{q_2}\sum_{j=J-(S+1)-q_2}^{J-S}\sum_{k=1}^{K}x_{ijk}} - 1 \qquad (6)$$

Alert limits constructed in this way, with say $q_1 = 3$ and $q_2 = 7$ might prove to be more sensitive than those of (3) with $q = 5$, because the short window averaged over for the current period is sensitive to immediate trends, and the longer window for the early period damps down noise from this period. However, alert limits of this form are not considered further here.

The modified algorithm for imputing missing values, described earlier in this paper, should be employed when computing SAL|i|$S_{q,q}$. The original imputing method described by Underhill & Prŷs-Jones (1994) assumed that a single multiplicative model fitted throughout the time period for which counts were available. If the importance of a site is decreasing through time, then the original algorithm will generate imputed values which tend to be underestimates for early years and overestimates for late years; the effect of this will be to reduce the likelihood that a site alert is given when one is required, and result in a Type II error.

The modified imputing algorithm requires an imputing window width w to be chosen. Consideration needs to be given to whether there is a potential interaction between the imputing window width w, the time span S over which alerts are calculated, and the period q of the alerts window. If there is an interaction, the issue of whether this could lead to incorrect alert warnings being given needs to raised. On balance, it seems that there is little likelihood of problems; currently, best recommended practice is to choose w, S and q independently so that each achieve its separate desired purposes.

By analogy with equation (6), the appropriate statistic for calculating a general alert limit, similarly based on q years of current and q years of early data, and denoted GAL|$S_{q,q}$ is

$$GAL\left|S_{q,q}\right. = \frac{\sum_{i=1}^{I}\sum_{j=J-q+1}^{J}\sum_{k=1}^{K}x_{ijk}}{\sum_{i=1}^{I}\sum_{j=J-(S+1)-q}^{J-S}\sum_{k=1}^{K}x_{ijk}} - 1 \qquad (7)$$

GAL|$S_{q,q}$ is based on the ratio of the sum of all counts (and imputed values for missing counts) made in the current year J and preceding q - 1 years, with the analogous sum of counts made J - S years ago, and the q - 1 years preceding that year. An alert warning is given when GAL|$S_{q,q}$ takes on a value too far from zero.

Clearly, GAL|$S_{q,q}$ may also be expressed as

$$GAL\left|S_{q,q}\right. = \frac{\sum_{j=J-q+1}^{J} P_j}{\sum_{j=J-(S+1)-q}^{J-S} P_j} - 1 \tag{8}$$

which is based on the ratio of the sums of index numbers P_j. This provides a simple interpretation of a general alert value.

As part of the full bootstrap algorithm defined above, it is clearly straightforward to compute consistency intervals for the point estimate of GAL|$S_{q,q}$ defined by equation (7). (Computing consistency intervals for site alert limits does not seem feasible, because any particular site does not occur in each of the bootstrap samples.) If an alert warning is triggered when, for example, there is a decrease of 25% in the population size, this means that GAL|$S_{q,q}$ is less than -0.25. If GAL|$S_{q,q}$ is less than -0.25 and the upper limit of the consistency interval is below zero, then - by analogy with the standard statistical hypothesis testing philosophy - the decrease may be considered "significant". In practical terms, this result occurs when 90% of the bootstrap samples generate negative alert limits; there is then little doubt that the species has shown a widespread and consistent decline across many sites. If both GAL|$S_{q,q}$ and the upper limit of the consistency interval are below -0.25, this may be taken as very convincing evidence for a widespread and uniform decline in the size of the population for the species.

In this paper we have used q = 3 and q = 5, although other choices can clearly be motivated and applied. These choices were based on the idea that time spans of three to five years ought to be a sufficiently long to average out any short-term effects that impact the numbers of waterbirds wintering in Britain. For example, alerts should not be triggered as a result of one-year events such as severe winters (q = 1), during which many species migrate farther south to avoid freezing conditions.

Alert limits using a cumulative time span

The alert limits defined in the previous section effectively compared average population size over the most recent q years with the average population size over an earlier period of q years. The beginning points of the two periods are separated by a time span of S years. No regard is taken of average population sizes during the time span taken as a whole.

If the time span of S years is fairly long, even as short as 10 years, the species can show an increase followed by a decline that clearly exceeds the alert warning threshold. The average population size for the earlier period may be below the maximum average population size at some stage during the time span as a whole. As a result, an alert warning may not be triggered even though the decline has been rapid. This problem can be overcome by considering

$$\text{GAL}|S_{q,q}|\text{lower} = \min_{q\#S^*\#S} \text{GAL}|S^*_{q,q} \tag{9}$$

and

$$\text{GAL}|S_{q,q}|\text{upper} = \max_{q\#S^*\#S} \text{GAL}|S^*_{q,q} \tag{10}$$

These quantities may be interpreted as comparing the average current population size with the average population size in all q-year periods starting within the S-year time span but which do not overlap with the alerts window over which the current population size is averaged. We find the smallest and largest of these comparisons. GAL|$S_{q,q}$|lower represents the current average population size in relation to the largest average population size over the time span, and GAL|$S_{q,q}$|upper represents the current average population size in relation to the smallest average population size over the time span.

If GAL|$S_{q,q}$|lower is negative and GAL|$S_{q,q}$|upper is positive, it indicates that over the past S-year time span, the average population size has been both larger and smaller, respectively, than the average current population size.

If both GAL|$S_{q,q}$|lower and GAL|$S_{q,q}$|upper are positive, it indicates that the average population size is currently larger than at any time over the past S-year time span. The population size is steadily increasing.

If both GAL|$S_{q,q}$|lower and GAL|$S_{q,q}$|upper are negative, it indicates that the average population size is currently smaller than at any time over the past S-year time span. The population size is steadily decreasing.

Results

COMPARISON OF ORIGINAL AND MODIFIED IMPUTING METHODS

The Grey Plover should provide the acid test of performance of the modified imputing algorithm. The population size of this species in Britain has increased steadily throughout the period of the surveys. It is likely that the number of Grey Plovers at individual estuaries does not follow the same pattern as the national index; in fact, Moser (1988) attempted to demonstrate that some estuaries were reaching their carrying capacity for Grey Plovers. The original imputing method is therefore unsatisfactory in using counts made in later years to impute missing values from the early years, and *vice versa*.

However, the results for Grey Plover, using a range of imputing window widths, show relatively little difference between the original and the modified methods (Table 4.1). The index numbers computed using the modified method with relatively wide window widths of 17 and 25 years are all within 3% of the values computed with the original method. This is not surprising, because the total number of years is 28, and only a small number of years are being omitted from the indexing calculations. However, even for short window widths of three and five years, the index numbers produced by the original and the modified methods are similar (Table 4.1).

The index numbers for Dunlin, obtained using the modified method with a range of imputing window widths, are also similar to the values obtained with the original method (Table 4.2). This is probably not surprising, because the Dunlin has not shown any strong pattern over the WeBS period, the index numbers having been in the range from 67 to 120 (Table 4.2).

Intuitively, imputing window widths of three and five years seem too narrow, and window widths of 17 and 25 years too wide. When computing alert limits in later sections of this paper, an imputing window width of nine years was used. However, it is clear that the indexing method is robust against the choice of imputing window width, and similar results are likely to be obtained with a wide range of imputing window widths. However, when a relatively small number of sites are included in the index, as might happen when regional index numbers are computed, outliers are likely to swamp the algorithm because they have undue influence on the calculations while they fall within the imputing window.

COMPARISON OF THE RESTRICTED AND FULL BOOTSTRAP METHODS

Both the Dunlin and the Grey Plover are examples of species that showed intermediate-sized consistency limits with the restricted bootstrap algorithm (Prŷs-Jones *et al.* 1994). A series of consistency limits were calculated for both species using the full bootstrap algorithm (Tables 4.1 & 4.2). The consistency intervals computed using the full bootstrap method are mostly two to three times longer than those computed using the restricted bootstrap method (Tables 4.1 & 4.2).

ALERT LIMITS

National alert limits over fixed periods

Fixed period alert limits, GAL|$S_{q,q}$, for Dunlin and Grey Plovers over various alert time spans S and with alert window widths q are given in Tables 4.3-4.6. The chosen values for S were 5, 10 and 25 years, so that the alert limits calculated for a given year are a comparison of a smoothed estimate of population size in the given year with smoothed estimates of the population sizes 5, 10 and 25 years earlier. The alert limits for each year in Tables 4.3-4.6 have been calculated using only the data collected from the start of the WeBS project up to that year; the alert limits are thus those that would have been calculated in those years. Data for the pilot year in winter 1968/69 were included, so that calculation of the alert limits could commence from the earliest possible year. In each case, sites with more than 50% of complete counts were included in the calculations; thus the number of included sites varied slightly for each row of these tables.

Over the five-year time span (S = 5), and with a five-year alert windows (q = 5), the calculation of general alert limits GAL|$10_{5,5}$ could commence once 10 years of count data were available; including the data from surveys in winter 1968/69, the first alert limits for Dunlin and Grey Plovers were calculated for winter 1977/78 (Tables 4.3 & 4.5). This was because the smoothed estimate of the population size for the later five-year period used the data from 1973/74-1977/78, which was compared with the smoothed estimate of the population size for the earlier five-year period 1968/69-1972/73. Over the 10-year time span (S = 10) and with q = 5, calculation of alert limits commenced at the 15th year of data collection, 1980/81. It was not possible to calculate a 25-year alert limit with q = 5, because this required 30 years of data, and only 29 were available. With a five-year alert window, calculation of the 25-year time span alerts can commence in 1997/98.

With three-year alert windows (q = 3), calculation of alert limits started two years earlier, for winter 1974/75 with S = 5, and for winter 1978/79 with S = 10, and 25-year alert limits can be calculated for 1995/96 and 1996/97 (Tables 4.4 & 4.6).

In Table 4.3, the five-year alert limit for Dunlin of GAL|$5_{5,5}$ = 17.7% in 1978 informs us that the average of the index numbers for the five-year period 1969-1973 was 17.7% above the average of the index numbers for the five-year period 1974-1978. This calculation used the values of the index numbers as they would have been computed with the data for the period 1969-1978; the index numbers shown in Table 4.3 are those computed for the full period 1969-1997. The 90% consistency interval, determined by 500 bootstrap samples, for this alert limit was (6.4, 32.3); the lower limit is above zero, indicating confidence that this represents a "significant" decrease. However, the point estimate of 17.7% is less than 25%; therefore, an alert warning of an increase is not triggered in this year.

For Dunlin, GAL|$5_{5,5}$ (five-year time span, five-year alert window) the only value relating to a decrease exceeding 25% was triggered in 1982 (*i.e.* winter 1981/82) (Table 4.3). An alert warning relating to an increase exceeding 25% was triggered in 1992 (Table 4.3). For GAL|$10_{5,5}$ (10-year time span, five-year alert window), values relating to decreases exceeding 25% were triggered for each winter between 1985 and 1988, and an increase was triggered in 1997. For each year in which an alert was triggered, the associated consistency intervals did not include the value zero, indicating that the population decrease (or increase) was widespread across all estuaries, and may informally be considered "significant".

Changing to a three-year alert window, values of GAL|$5_{3,3}$ (five-year time span, three-year alert window) for Dunlin triggered decreases exceeding 25% in 1981 and 1982 (Table 4.4). Alert warnings relating to increases exceeding 25% were triggered in 1976, 1977, 1991 and 1992 (Table 4.4). GAL|$10_{3,3}$ (10-year time span, three-year alert window) values relating to decreases exceeding 25% were triggered for each winter between 1983 and 1988, and values relating to increases in 1996 and 1997. With a three-year alert window, it was possible to compute two 25-year alerts; GAL|$25_{3,3}$ (25-year time span, three-year alert window) had a value greater than 25% in 1996 (Table 4.4). For each year in which an alert was triggered, the associated consistency intervals did not include the value zero, indicating that the population decrease (or increase) may be considered "significant".

For Grey Plovers, GAL|$5_{5,5}$ (five-year time span, five-year alert window), there were only one winter in which alert warnings relating to an increases exceeding 25% were not triggered; 1996 was marginal, at 24.7% All years from 1978 to 1997 showed "significant" increases (Table 4.5). For GAL|$10_{5,5}$ (10-year time span, five-year alert window), values relating to increases were triggered in all years, from 1983 to 1997; in all except three years (1985, 1986 and 1997), the increase exceeded 100% over the 10-year period, and in all years the lower limit of the consistency interval exceeded 50% (Table 4.5). With a three-year alert window, values of GAL|$5_{3,3}$ (five-year time span, three-year alert window) for Grey Plovers triggered increases exceeding 25% in all years except 1979, 1993 and 1997 (Table 4.6). GAL|$10_{3,3}$ (10-year time span, three-year alert window) values relating to increases exceeding 50% were triggered for each winter between 1981 and 1997 (Table 4.6). With a three-year alert window, two 25-year alerts were computed; GAL|$25_{3,3}$ (25-year time span, three-year alert window) had values of 559% and 540% in 1996 and 1997, respectively (Table 4.6). For each year in which an alert was triggered, the associated consistency intervals did not include the value zero, indicating that the increases may be considered "significant".

Comparison of the results with three- and five-year alert windows suggests that the five-year alert window is too robust to change, resulting in the triggering of alert warnings being delayed. Examination of Tables 4.3 and 4.4, shows that alert warnings are mostly triggered one year earlier with the three-year alert window than with the five-year alert window. The timings of the alert warnings with the three-year alert window also appear to be intuitively correct. Subsequent calculations in this paper are all based on a three-year alert window. This is a user-defined parameter, and more experimentation on this point might provide greater insights into the appropriate choice. Consideration needs to be given to the possibility that the choice of this parameter might need to be species specific.

Values of GAL|$5_{3,3,}$ GAL|$10_{3,3}$ and GAL|$25_{3,3}$ were also calculated for Redshanks and Turnstones (Tables 4.7 & 4.8). For Turnstones, five-year alert warnings related to increases were triggered in 1977, and from 1986 to 1989. Ten-year alert warnings of increases occurred in 1985, 1991 and 1992; there was a 10-year alert warning of a decrease in 1997. A 25-year alert warning of an increase occurred in 1996 (Table 4.7). For Redshanks, five-year alert warnings related to increases were triggered in 1976, and from 1987 to 1980. Ten-year alert warnings of increases occurred between 1992, 1993 and 1994; a 25-year alert warning of an increase occurred in 1996 (Table 4.8).

Alert limits for Pintail for the 25-year period 1970-1994 for which data were available were based on 822 sites with at least 50 counts in the four months October-January (Table 4.9). The calculation of index numbers, alert limits, and consistency intervals for the alert limits based on 500 bootstrapped samples, using the modified imputing algorithm and full bootstrap algorithm, took 17 minutes on a Pentium personal computer. For Pintails, five-year alert warnings related to increases were triggered in 1977, and from 1983 to 1985. Ten-year alert warnings of increases occurred in 1982, 1984, 1986, and from 1988 to 1990 (Table 4.9).

Regional alert limits

Regional alert limits were calculated for Turnstones and Redshanks for Wales (Tables 4.10 & 4.11). This was done by using the algorithm for the general alert limits, restricted to Welsh estuaries.

The successive calculations of these alert limits were based on index number calculations using between 12 and 16 estuaries in Wales. The number varied because in the calculations for the alert limits for each year, the number of completed counts was set to 50% of the total possible number of counts up to that year. Because the number of estuaries included in the calculations was both relatively small and variable, the successive sets of index numbers varied considerably.

Although the Welsh index numbers for both Turnstone and Redshank were superficially different from the national index numbers, there was strong coherence between them in that, for both species, the directions of the changes between successive years of the Welsh index numbers matched the direction of the changes in the national index numbers in 20 pairs of years out of 28 (Tables 4.7 & 4.8, 4.10 & 4.11). The general pattern was for the Welsh index numbers to show more volatility than the national index numbers.

For Turnstones, there were five-year alert warnings related to decreases were triggered in every year from 1991 to 1996, and 10-year alert warnings of decreases from 1995 to 1997. There were both five-year and 10-year alert warnings of increases from 1985 to 1989, and 10-year alert warnings of increases in 1981 and 1994 (Table 4.10). For Redshanks, there were five-year alert warnings related to decreases from 1994 to 1996; and to increases from 1987 to 1991. Ten-year alert warnings of increases occurred in 1981, 1982 and in every year from 1987 to 1994. Twenty-year alert warnings of increases occurred in 1996 and 1997 (Table 4.11: **the index values in this table are probably incorrect**). However, for both species, the consistency limits of the intervals were long, and many of the intervals contain zero, and the informal "significance" of the alert warnings for Wales was not consistently established.

Cumulative alert limits

Tables 4.12 and 4.13 show cumulative alert limits for Dunlin and Grey Plover, respectively, over time spans of 10 and 25 years, using three-year alert windows.

For Dunlin, cumulative alert warnings of decreases exceeding 25% over 10-year times spans were triggered every winter from 1981 to 1988 (Table 4.12). The value of -28.3% for Dunlin in 1981 informs us that the smallest of the four-year to 10-year alert limits was -28.3; this relates to the six-year alert between 1975 and 1981 (Table 4.12). The six-year alert between 1975 and 1981 is based on a three-year alert window; this means that the average of the index numbers for 1973, 1974 and 1975 was 28.3% below the average of the index numbers for 1979, 1980 and 1981 (using the values of the index numbers as they would have been computed with the data for the period 1969-1981; the index numbers shown in Table 4.7 are those computed for the period 1969-1997). The 90% consistency interval, determined by 500 bootstrap samples, for this alert limit was (-36.7, -20.6); the upper limit is below zero, indicating confidence that this represents a "significant" decrease. Because the alert limit is below -25%, an alert warning of a decrease is triggered.

Cumulative alert warnings of increases exceeding 25% over 10-year times spans were triggered every winter from 1990 to 1997, except 1994 (Table 4.12). This means that the average population in each of these years was more than 25% above the smoothed population at some stage during the previous 10 years. In each case, the smoothed population was lowest in 1987, and this was the year with which this comparison was made (Table 4.12). The smoothed population in 1987 was calculated as the average of the index numbers for 1985, 1986 and 1987.

Over the 25-year time span, the average population in 1996 was 13.8% below the maximum smoothed population for the period, which occurred in 1975, and 35.0% above the minimum smoothed population for the period, which occurred in 1987 (Table 4.12). Similar results pertain to 1997 (Table 4.12).

For Grey Plovers, the cumulative alert limits over both 10 and 25 years are all positive (Table 4.13). Between 1981 and 1990, seven of 10 of the 10-year cumulative alert limits exceeded the maximum general alert limit (equation 10) by more than 25%; between 1991 and 1997 none did. This probably indicates that the rate of increase in the Grey Plover population wintering in Great Britain is beginning to level off.

Site alert limits

Site alert limits for 1997 (winter 1996/97) were calculated for Dunlins, Grey Plovers, Turnstones and Redshanks (Tables 4.14-4.17). Tabled sites had, over a 25-year period, at least one three-year moving average which exceeded the threshold of importance for Great Britain (see Tables 4.14-4.17 for values).

In Table 4.14, the estuary with code 15 (Severn Avon) had December-February average count of 4,978 Dunlin over the three winters 1994/95, 1995/96 and 1996/97 (column headed 'Current'). The five-year site alert limit for the Severn Avon, $SAL/15/5_{(3,3)}$ calculated from equation (5), is -33.9, indicating that the 'Current' average is 33.9% below the moving average for the three winters five years earlier (*i.e.* winters 1989/90, 1990/91, 1991/92). Similarly, the 'Current' average is 38.9% below the average of 10 winters earlier (1984/85, 1985/86, 1986/87), and 41.8% below the average of 25 winters earlier (1969/70, 1970/71, 1971/72). The final six columns of Table 4.14 demonstrate that the maximum moving average for this estuary was 16,788, and that this occurred in 1976 (*i.e.* the average of counts in winters 1973/74, 1974/75, 1975/76), and that the minimum moving average was 4,847, in 1981. The 'Current' average was therefore 51.9% below the maximum moving average and 2.7% above the minimum moving average. The maximum and minimum moving averages were obtained from the period five to 25 years before the current year. We interpret this as meaning that the 'Current' average lies within the recent historical bound for the species; however the 'Current' average is close to the lower limit of this bound.

For Site 5 (Severn Gwent), the maximum and minimum three-year moving averages obtained in this way were both greater than the 'Current' moving average (Table 4.14). This indicates that the 'Current' average lies below the recent historical bound for the species, and reinforces the cause for concern. Four sites in Table 4.14 have this property: 5 (Severn Gwent), 420 (Chichester Harbour), 838 (Forth South Complex), 1,470 (Lavan Sands).

For sites 540 (Leigh/Canvey) and 1,420 (Dee Estuary), the 'Current' averages lie above the respective recent historical bounds (Table 4.14). This indicates that current Dunlin populations on these estuaries have grown.

The remaining sites in Table 4.14 have 'Current' averages that lie within their recent historical bounds. Each site can, therefore, be classified as 'within bounds', 'above bounds' (*i.e.* increasing population), or 'below bounds' (*i.e.* decreasing population). The triggering of alert warnings depends on how far the 'Current' average lies below the lower, or above the upper, bound. This approach to site alerts, based on the same philosophy as that developed for cumulative general alerts, appears to provide valuable insights into population dynamics of species at individual estuaries.

For Grey Plover, an increasing species (Table 4.2), most of the 'Current' averages lie above the historical bounds, as expected in this context (Table 4.15). Most of the tabled estuaries for Turnstone and Redshank show current populations that lie within bounds (Tables 4.16 & 4.17).

Discussion

COMPARISON OF OLD AND MODIFIED IMPUTING METHODS

A serious criticism of the imputing method devised by Underhill & Prŷs-Jones (1994) was that it assumed that a single multiplicative model fitted for the entire data collection period. The modified method restricts this assumption to a user-chosen window of years, which is centred on the year for which imputing is done, apart from the initial and final years (see Methods). It was an unexpected result that, for the Grey Plover, the original and modified imputing methods provided similar results, even for relatively short imputing window widths (Table 4.1). This result suggests that the large number of additional calculations required by the modified imputing method may be unnecessary. However, the exercise is a valuable one, because it demonstrates that the assumption of a single model does not appear to make much difference to the results, even for a species such as Grey Plover, which has increased seven-fold over the WeBS period of nearly three decades (Table 4.1). The index numbers for Dunlin, using the original and modified imputing algorithms were likewise similar (Table 4.2), although this result was less unexpected than was the case for Grey Plover.

In spite of the fact that the modified imputing method made little impact on the index numbers calculated over nearly three decades, it seems sensible to adopt this method, because the assumption of a single multiplicative model seems almost certain to break down once WeBS has run for a few more decades. The choice of imputing window width needs more exploration, and the value of nine years chosen to demonstrate alert limit calculations made in this paper should not be accepted as the final guideline; however, it does seem to be a sensible choice.

COMPARISON OF THE ORIGINAL AND FULL BOOTSTRAP METHODS

The full bootstrap algorithm, in which imputing is done for each bootstrap sample of estuaries, results in consistency intervals which are at most two to three times larger than those calculated by the method of Underhill & Prŷs-Jones (1994), in which the imputing was first done for all estuaries, and the bootstrap sampling was done from the set of "complete" estuary counts. The impact of the full bootstrap method is probably larger than anticipated.

Underhill & Prŷs-Jones (1994) were incorrect in expecting that it was mainly the years with large proportions of imputed data for which the consistency intervals would be too short. The results (Tables 4.1 & 4.2) suggest no such pattern, and the consistency intervals for years in which minimal imputing is needed are inflated by a similar ratio to the consistency intervals for years with large proportions of imputed observations.

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	Original algorithm	Modified algorithm	Imputing window width, modified algorithm					
			3	5	9	13	17	25
1970	76.4 38.3	76.4 38.3	82.1 38.1	83.1 39.6	83.7 41.5	82.7 40.3	79.0 38.4	76.0 37.5
	(64.5, 87.1)	(45.0, 111.1)	(49.3, 118.0)	(53.2, 125.3)	(51.4, 120.2)	(51.4, 121.0)	(47.1, 116.1)	(48.9, 109.8)
1971	85.4 24.1	85.4 24.1	83.4 16.2	84.5 18.4	84.6 20.4	83.6 18.9	82.9 19.3	84.0 22.4
	(73.4, 96.2)	(50.2, 119.6)	(50.2, 121.3)	(56.0, 121.5)	(53.2, 117.6)	(54.6, 117.7)	(53.3, 117.6)	(54.7, 114.5)
1972	100.0 15.9	100.0 15.9	100.0 9.3	100.0 10.4	100.0 12.6	100.0 12.0	100.0 13.1	100.0 15.4
	(87.8, 111.7)	(65.5, 134.3)	(66.8, 138.2)	(70.4, 140.1)	(67.2, 134.2)	(67.0, 137.4)	(68.1, 134.8)	(66.6, 134.1)
1973	142.2 5.2	142.2 5.2	148.9 2.5	148.1 3.1	146.9 4.6	148.1 4.8	147.5 5.6	143.1 5.3
	(118.7, 163.3)	(87.3, 199.2)	(92.6, 215.2)	(97.0, 216.7)	(93.7, 202.6)	(92.5, 209.8)	(92.8, 203.8)	(93.0, 199.2)
1974	150.8 12.0	150.8 12.0	161.0 11.2	158.1 10.7	156.3 11.8	158.5 12.5	158.2 13.4	152.0 12.2
	(125.6, 175.9)	(89.8, 220.6)	(97.0, 244.5)	(100.5, 243.3)	(97.4, 227.4)	98.1, 238.1)	(97.5, 232.6)	(91.7, 221.9)
1975	145.9 14.1	145.9 14.1	160.6 15.8	159.2 16.1	156.2 16.6	159.5 17.8	156.9 17.5	147.6 14.6
	(125.6, 167.1)	(91.1, 204.8)	(103.8, 230.0)	(104.1, 227.9)	(103.1, 216.9)	(103.0, 222.2)	(100.9, 218.7)	(91.3, 203.1)
1976	165.3 14.1	165.3 14.1	169.5 9.7	170.0 11.1	172.2 14.3	173.6 14.5	174.1 15.7	166.1 14.0
	(144.5, 191.1)	(108.7, 221.8)	(111.3, 230.6)	(123.5, 234.3)	(119.6, 230.3)	(117.0, 230.5)	(117.2, 237.5)	(112.1, 222.6)
1977	114.4 24.9	114.4 24.9	117.8 21.4	120.0 23.7	121.0 26.2	122.7 26.8	122.3 27.4	114.5 24.5
	(100.0, 133.1)	(80.1, 150.6)	(81.7, 163.3)	(88.1, 161.6)	(84.7, 156.2)	(88.7, 160.3)	(87.6, 158.4)	(80.6, 153.6)
1978	152.4 24.5	152.4 24.5	153.6 19.3	177.3 30.9	162.1 26.2	164.3 26.7	165.2 28.1	154.7 25.2
	(136.7, 170.2)	(105.9, 198.5)	(106.9, 204.6)	(128.6, 241.1)	(116.6, 210.6)	(116.1, 213.7)	(117.5, 217.6)	(110.4, 201.2)
1979	178.8 27.6	178.8 27.6	212.8 34.4	196.9 30.0	189.4 29.0	194.2 30.3	188.9 29.2	182.4 28.6
	(160.2, 197.1)	(122.8, 237.7)	(140.6, 299.5)	(139.3, 274.5)	(133.7, 249.7)	(136.1, 256.6)	(134.3, 254.2)	(126.0, 240.3)
1980	247.9 14.5	247.9 14.5	273.4 16.4	267.2 15.5	265.3 17.0	264.3 16.1	259.0 15.5	250.1 14.7
	(194.7, 289.4)	(144.9, 373.4)	(154.5, 411.5)	(162.2, 408.5)	(161.3, 387.7)	(162.6, 410.3)	(159.8, 395.5)	(153.4, 359.5)
1981	200.8 23.3	200.8 23.3	209.4 20.7	208.4 21.3	205.1 22.0	206.9 22.1	207.4 23.3	204.5 24.2
	(177.7, 225.7)	(138.6, 264.5)	(141.2, 284.9)	(149.8, 278.8)	(146.4, 272.9)	(142.6, 268.2)	(146.0, 281.5)	(140.5, 275.9)
1982	213.4 13.4	213.4 13.4	223.1 10.7	226.2 13.0	217.9 11.9	219.1 11.8	218.5 12.7	215.7 13.9
	(190.9, 234.8)	(144.7, 285.2)	(149.7, 308.8)	(156.9, 314.3)	(151.4, 292.2)	(149.7, 290.2)	(148.8, 292.8)	(146.4, 283.3)
1983	233.8 18.6	233.8 18.6	251.6 18.4	247.5 18.1	241.5 18.1	239.4 16.8	238.0 17.4	235.8 18.7
	(210.4, 257.8)	(158.7, 305.9)	(168.2, 348.9)	(175.6, 339.1)	(167.4, 321.9)	(166.4, 314.7)	(163.8, 321.5)	(162.2, 314.2)
1984	272.8 17.7	272.8 17.7	301.7 19.8	287.6 16.9	285.6 18.3	284.8 17.6	282.3 17.9	274.0 17.6
	(233.3, 306.0)	(171.5, 388.3)	(197.4, 416.9)	(189.8, 414.5)	(187.1, 397.1)	(188.0, 394.9)	(187.1, 402.3)	(179.0, 371.6)
1985	297.1 12.6	297.1 12.6	325.5 13.9	317.8 12.9	314.0 14.0	315.7 13.9	310.2 13.5	299.0 12.6
	(266.0, 327.0)	(195.7, 401.2)	(221.9, 444.6)	(226.3, 431.8)	(217.2, 411.3)	(216.1, 424.1)	(215.3, 406.7)	(205.1, 388.8)
1986	308.7 13.0	308.7 13.0	326.9 11.4	329.0 13.1	319.0 12.5	321.3 12.6	315.7 12.1	310.8 13.1
	(281.8, 342.4)	(203.0, 421.9)	(225.3, 439.8)	(224.1, 445.4)	(217.9, 419.1)	(224.8, 430.2)	(215.2, 417.8)	(205.9, 410.5)
1987	422.0 16.9	422.0 16.9	434.1 12.9	452.4 17.5	428.6 15.0	432.6 15.2	428.5 15.5	424.2 16.8
	(376.3, 458.0)	(245.7, 614.5)	(258.5, 628.8)	(269.3, 660.1)	(263.9, 604.8)	(267.3, 638.1)	(264.9, 617.2)	(253.1, 594.8)
1988	446.0 4.6	446.0 4.6	528.2 13.1	478.3 5.2	471.0 6.1	464.9 4.3	458.4 4.1	448.6 4.6
	(396.8, 492.9)	(277.4, 616.4)	(323.5, 762.2)	(314.9, 678.2)	(302.5, 646.9)	(309.3, 647.9)	(303.0, 629.4)	(286.9, 596.5)
1989	405.1 14.0	405.1 14.0	424.9 11.6	415.3 10.6	406.0 10.8	412.9 11.8	414.3 13.1	407.3 13.9
	(363.6, 444.6)	(252.3, 554.4)	(278.3, 600.7)	(266.3, 599.4)	(262.8, 556.3)	(278.1, 571.9)	(272.3, 576.3)	(259.0, 549.2)
1990	451.1 0.8	451.1 0.8	485.4 0.6	479.8 0.7	468.2 0.7	471.1 0.7	465.6 0.8	453.8 0.8
	(383.0, 519.2)	(293.4, 632.3)	(326.0, 681.8)	(320.1, 676.4)	(303.2, 640.7)	(307.1, 672.5)	(295.5, 631.2)	(300.8, 603.0)
1991	472.3 1.3	472.3 1.3	507.6 1.0	503.4 1.4	490.3 1.2	494.5 1.4	488.2 1.3	475.2 1.3
	(420.5, 517.1)	(296.7, 650.9)	(327.2, 713.9)	(332.3, 702.5)	(329.2, 662.4)	(322.4, 698.8)	(317.5, 670.7)	(301.7, 638.1)
1992	441.5 6.3	441.5 6.3	497.2 10.4	473.0 6.9	462.5 7.1	464.8 7.0	457.4 6.6	444.1 6.3
	(402.7, 490.4)	(285.3, 589.5)	(333.5, 678.8)	(335.5, 635.3)	(314.0, 616.1)	(315.6, 623.3)	(312.6, 601.4)	(299.4, 587.7)
1993	508.6 5.7	508.6 5.7	547.7 5.6	541.6 5.7	529.8 6.0	534.7 6.2	525.4 5.7	511.5 5.7
	(444.7, 598.6)	(331.6, 691.6)	(381.4, 748.1)	(366.0, 744.7)	(358.4, 710.9)	(354.9, 746.7)	(350.6, 700.0)	(334.2, 708,3)
1994	618.5 16.7	618.5 16.7	654.2 15.1	649.4 15.5	639.8 16.3	641.8 16.1	635.7 16.3	621.9 16.7
	(563.4, 668.5)	(381.2, 859.0)	(445.9, 897.4)	(433.6, 911.0)	(425.7, 878.8)	(420.3, 916.4)	(415.0, 872.1)	(401.0, 845.7)
1995	534.0 13.5	534.0 13.5	576.1 13.6	572.0 14.1	561.1 14.5	561.4 14.0	552.9 13.8	537.0 13.5
	(477.9, 617.4)	(347.6, 736.5)	(395.0, 799.8)	(389.6, 776.5)	(380.1, 740.1)	(366.9, 764.5)	(373.6, 741.3)	(345.9, 741.3)
1996	626.0 13.4	626.0 13.4	666.4 12.3	652.9 11.6	646.6 12.9	650.5 12.8	644.5 13.1	629.9 13.4
	(540.0, 734.9)	(388.5, 880.1)	(429.4, 931.8)	(423.0, 916.0)	(414.2, 895.8)	(408.9, 913.0)	(409.1, 915.0)	(387.0, 892.7)
1997	490.9 4.0	490.9 4.0	532.1 4.5	520.8 3.6	507.8 3.6	510.4 3.4	505.1 3.6	493.8 4.0
	(443.6, 545.2)	(315.0, 683.4)	(345.5, 731.1)	(357.3, 713.1)	(342.7, 691.5)	(334.2, 697.6)	(331.8, 690.2)	(318.6, 666.8)

Table 4.1 Comparison of index numbers for Grey Plovers in the United Kingdom produced by the original and the modified imputing algorithms, and by the modified imputing algorithm with

imputing window widths 3, 5, 9, 13 and 21 (see text). The figure in parentheses to the right of each index number is the percentage of birds imputed for that index number. The values in parentheses below each index number is a 90% bootstrapped consistency interval based on 500 bootstrap samples. The index is based on the three midwinter months December-February, and year 1970 in the table refers to the period December 1969-February 1970. The base year is 1972/73. The index uses 129 sites with more than 50% available counts (i.e. more than 42 out of 84 counts).

	Original algorithm	Modified algorithm	Imputing window width, modified algorithm					
			3	5	9	13	17	25
1970	74.4 32.7 (65.1, 83.3)	74.4 32.7 (49.7, 101.6)	72.6 28.4 (48.9, 101.4)	74.8 30.9 (50.2, 102.7)	72.7 30.7 (50.5, 98.6)	72.3 30.9 (49.3, 98.8)	73.2 31.7 (50.5, 101.2)	74.3 32.4 (50.1, 100.0)
1971	89.1 19.8 (79.5, 98.1)	89.1 19.8 (61.8, 119.6)	85.6 13.2 (57.5, 116.7)	88.7 16.8 (59.3, 119.1)	87.7 17.9 (59.8, 115.2)	87.4 18.4 (62.3, 116.9)	88.0 18.9 (60.9, 117.6)	88.8 19.2 (61.5, 117.6)
1972	100.0 18.1 (89.6, 110.8)	100.0 18.1 (72.5, 131.8)	100.0 14.8 (70.2, 128.3)	100.0 15.4 (70.9, 135.8)	100.0 17.5 (71.0, 130.0)	100.0 18.3 (73.1, 130.2)	100.0 18.3 (71.1, 130.8)	100.0 17.8 (70.1, 131.5)
1973	118.7 14.8 (109.0, 127.8)	118.7 14.8 (87.5, 154.7)	120.1 12.4 (82.9, 155.1)	120.4 13.2 (82.9, 158.6)	119.4 14.6 (87.1, 156.9)	118.9 15.1 (86.9, 155.4)	118.9 15.1 (84.2, 155.3)	119.0 14.7 (84.8, 156.2)
1974	113.5 15.3 (102.3, 126.3)	113.5 15.3 (84.2, 145.4)	114.6 12.7 (82.2, 151.4)	114.4 13.1 (81.7, 151.5)	113.6 14.7 (83.2, 148.2)	113.4 15.4 (81.4, 149.5)	113.7 15.6 (79.7, 152.0)	113.9 15.3 (80.5, 149.8)
1975	117.3 14.2 (106.6, 128.5)	117.3 14.2 (87.2, 150.1)	118.8 11.9 (84.4, 153.0)	117.8 11.7 (84.4, 155.1)	115.2 11.9 (85.1, 151.8)	115.8 13.2 (85.4, 151.1)	116.2 13.5 (84.9, 152.3)	117.5 14.0 (85.8, 151.9)
1976	119.6 16.6 (109.4, 128.8)	119.6 16.6 (87.5, 153.2)	117.3 11.5 (80.4, 151.2)	120.9 14.7 (87.2, 161.1)	117.4 14.3 (84.0, 153.1)	117.5 15.3 (85.3, 153.4)	118.5 16.0 (86.0, 153.2)	119.8 16.4 (87.4, 155.0
1977	89.8 27.8 (82.1, 98.7)	89.8 27.8 (67.4, 117.9)	90.0 25.1 (63.8, 119.5)	93.4 28.3 (64.5, 124.2)	91.9 28.9 (65.8, 120.3)	90.7 28.7 (66.4, 120.0)	90.2 28.3 (65.9, 118.4)	89.8 27.6 (63.8, 117.7)
1978	92.6 31.0 (85.7, 100.6)	92.6 31.0 (69.8, 117.3)	93.2 28.7 (65.1, 122.5)	97.5 32.3 (70.2, 128.2)	92.8 30.6 (68.8, 119.1)	91.7 30.5 (68.1, 120.3)	92.7 31.2 (68.1, 119.3)	93.0 31.1 (67.8, 117.9)
1979	91.8 28.7 (84.5, 100.7)	91.8 28.7 (64.3, 120.6)	94.8 28.1 (65.9, 127.7)	93.3 27.4 (63.3, 127.9)	90.0 26.6 (64.0, 119.5)	89.4 26.8 (63.2, 123.8)	89.4 26.9 (61.9, 119.7)	92.3 28.8 (64.3, 123.2
1980	89.0 21.3 (82.1, 97.8)	89.0 21.3 (62.1, 117.8)	91.1 20.0 (63.0, 121.2)	90.8 20.3 (63.4, 121.9)	89.5 21.2 (64.7, 117.3)	88.7 21.2 (63.2, 122.1)	88.3 20.9 (61.8, 116.2)	89.2 21.3 (64.0, 117.9)
1981	78.5 28.4 (72.6, 84.5)	78.5 28.4 (59.3, 98.8)	79.5 26.6 (57.4, 101.5)	80.2 27.7 (57.0, 104.2)	79.1 28.4 (57.5, 101.6)	77.4 27.6 (57.0, 99.1)	77.7 27.8 (58.1, 99.9)	79.0 28.7 (57.9, 101.6)
1982	77.2 11.9 (72.5, 82.2)	77.2 11.9 (58.8, 97.6)	79.4 10.9 (57.6, 101.2)	78.9 11.0 (57.0, 100.8)	77.3 11.3 (57.2, 96.5)	76.8 11.6 (58.1, 99.7)	76.8 11.7 (57.4, 96.6)	77.5 11.9 (58.1, 99.1)
1983	80.4 15.2 (74.4, 87.3)	80.4 15.2 (59.2, 102.8)	83.4 15.0 (58.4, 107.8)	84.0 16.2 (59.5, 109.0)	81.4 15.6 (58.7, 103.2)	80.4 15.4 (59.3, 106.4)	80.7 15.7 (57.7, 104.8)	80.3 14.8 (59.1, 103.3)
1984	73.9 9.7 (66.8, 81.1)	73.9 9.7 (52.9, 95.9)	81.1 14.3 (56.8, 104.8)	78.6 12.2 (56.7, 104.4)	76.5 12.1 (54.8, 98.3)	75.7 12.1 (55.6, 101.1)	75.2 11.4 (53.9, 98.0)	74.1 9.6 (53.7, 96.9)
1985	77.0 6.5 (70.1, 84.1)	77.0 6.5 (57.0, 98.5)	83.1 10.0 (60.5, 107.0)	83.0 10.5 (61.2, 108.1)	80.2 9.6 (59.0, 101.3)	79.1 9.3 (58.6, 103.9)	78.4 8.4 (58.5, 100.8)	77.5 6.9 (57.4, 99.9)
1986	67.1 6.7 (61.1, 73.5)	67.1 6.7 (50.9, 84.7)	72.2 9.7 (54.3, 91.9)	71.8 9.8 (53.1, 92.7)	69.1 8.6 (52.1, 86.7)	68.3 8.5 (50.3, 88.7)	68.1 8.2 (51.9, 88.1)	67.6 7.0 (50.0, 85.1)
1987	69.5 11.4 (61.9, 76.8)	69.5 11.4 (50.0, 89.6)	74.5 14.0 (51.9, 97.2)	74.2 14.2 (51.6, 98.6)	71.3 13.0 (50.6, 91.3)	70.4 12.7 (50.2, 95.0)	70.1 12.3 (50.2, 91.3)	69.9 11.5 (50.6, 90.7)
1988	87.3 2.8 (77.9, 96.8)	87.3 2.8 (63.7, 110.3)	92.1 4.2 (65.9, 121.2)	90.3 2.9 (65.9, 116.2)	88.3 3.3 (64.5, 112.1)	87.1 2.8 (63.5, 114.9)	86.9 2.5 (63.1, 112.9)	87.6 2.8 (64.5, 112.5)
1989	89.0 9.7 (78.4, 100.0)	89.0 9.7 (63.8, 116.2)	91.0 8.2 (64.2, 121.1)	90.2 8.0 (64.0, 118.6)	88.9 9.0 (64.7, 115.2)	88.2 9.1 (63.5, 118.2)	88.3 9.1 (63.5, 115.4)	89.1 9.5 (64.3, 115.4)
1990	105.2 2.0 (92.9, 116.6)	105.2 2.0 (74.4, 138.9)	109.4 2.0 (74.9, 144.9)	108.7 2.1 (75.2, 148.5)	106.1 2.1 (73.3, 138.4)	105.1 2.1 (74.4, 141.5)	105.2 2.2 (72.0, 139.8)	105.6 2.0 (73.0, 140.3)
1991	99.2 4.7 (90.5, 107.1)	99.2 4.7 (70.9, 128.3)	100.6 2.3 (69.8, 131.9)	100.1 2.4 (71.9, 133.0)	97.9 2.7 (69.5, 127.8)	97.4 3.1 (70.3, 129.9)	97.8 3.5 (69.6, 127.6)	99.7 4.8 (72.5, 129.3)
1992	86.2 7.6 (78.7, 93.5)	86.2 7.6 (62.4, 109.0)	90.7 8.6 (64.5, 117.6)	89.1 7.7 (63.6, 116.9)	86.7 7.4 (62.0, 112.3)	85.6 7.1 (62.6, 112.8)	85.3 6.9 (61.3, 109.2)	86.3 7.4 (61.9, 112.3)
1993	86.7 5.9 (80.3, 92.6)	86.7 5.9 (64.5, 108.1)	89.7 5.3 (66.1, 114.0)	88.9 5.1 (64.1, 114.3)	87.1 5.5 (63.7, 110.7)	86.5 5.8 (64.2, 111.2)	86.3 5.5 (63.3, 110.0)	87.0 5.8 (64.0, 111.0)
1994	98.2 9.0 (91.5, 103.9)	98.2 9.0 (73.0, 124.2)	102.1 9.0 (73.3, 132.3)	101.5 9.0 (74.6, 133.6)	98.9 8.9 (71.7, 124.5)	99.3 10.2 (73.4, 130.2)	99.7 10.5 (70.9, 127.8)	98.8 9.2 (72.2, 128.9)
1995	89.0 6.1 (81.6, 96.5)	89.0 6.1 (66.8, 113.4)	93.6 7.1 (69.3, 117.3)	93.1 7.3 (68.9, 120.2)	90.2 6.6 (67.5, 115.0)	89.3 6.6 (67.1, 114.2)	89.4 6.6 (65.2, 113.9)	89.5 6.3 (67.4, 113.0)
1996	114.7 12.2 (106.4, 124.4)	114.7 12.2 (83.1, 147.6)	118.9 11.9 (83.8, 150.1)	116.3 10.5 (84.4, 151.5)	114.5 11.4 (83.3, 148.6)	114.4 12.2 (84.1, 150.2)	115.1 12.7 (80.5, 151.3)	115.1 12.2 (83.3, 146.1)
1997	90.6 5.8 (81.0, 100.7)	90.6 5.8 (64.9, 119.6)	95.3 6.8 (66.9, 120.3)	93.5 5.6 (65.7, 123.5)	90.8 5.2 (65.6, 117.2)	90.0 5.4 (64.2, 120.7)	90.2 5.5 (62.2, 119.7)	90.8 5.6 (64.9, 119.9)

Table 4.2 Comparison of index numbers for Dunlin in the United Kingdom produced by the original and the modified imputing algorithms, and by the modified imputing algorithm with imputing window widths 3, 5, 9, 13 and 21 (see text). The figure in parentheses to the right of each index number is the percentage of birds imputed for that index number. The values in parentheses below each index number is a 90% bootstrapped consistency interval based on 500 bootstrap samples. The index is based on the three midwinter months December-February, and year 1970 in the table refers to the period December 1969-February 1970. The base year is 1972/73. The index uses 129 sites with more than 50% available counts (i.e. more than 42 out of 84 counts).

Year	Index	5-year		10-year	
		Alert	CI	Alert	CI
1969	72.3				
1970	72.9				
1971	87.7				
1972	100.0				
1973	119.9				
1974	113.9				
1975	115.7				
1976	117.9				
1977	92.2				
1978	92.5	17.7	(6.4, 32.3)		
1979	89.7	2.1	(-7.1, 13.6)		
1980	89.3	-10.8	(-19.1, -0.3)		
1981	78.8	-23.5	(-31.5, -15.9)		
1982	77.1	-25.4*	(-31.6, -17.6)		
1983	81.1	-24.0	(-30.8, -16.3)	-9.6	(-21.1, 2.7)
1984	76.3	-22.4	(-30.7, -11.9)	-20.5	(-30.7, -9.2)
1985	79.9	-19.3	(-31.6, -6.5)	-29.5*	(-39.2, -19.5)
1986	68.8	-13.3	(-24.9, 0.5)	-34.4*	(-44.2, -24.4)
1987	71.1	-12.2	(-22.6, -2.4)	-33.6*	(-44.9, -22.1)
1988	88.1	-7.9	(-19.1, 1.2)	-28.5*	(-39.4, -16.0)
1989	88.6	-1.0	(-9.5, 8.9)	-22.2	(-34.0, -5.9)
1990	105.7	7.9	(0.6, 15.6)	-12.5	(-25.2, 3.3)
1991	97.5	19.5	(11.5, 27.5)	3.1	(-11.6, 17.6)
1992	86.4	25.5	(17.3, 33.4)	10.9	(-1.6, 24.6)
1993	86.7	22.6	(12.7, 32.4)	13.9	(2.2, 25.6)
1994	98.5	20.2	(6.5, 34.5)	19.1	(8.8, 28.9)
1995	89.9	9.4	(-1.1, 20.2)	18.2	(6.8, 30.7)
1996	114.6	3.6	(-6.9, 15.4)	23.4	(11.7, 37.4)
1997	90.5	2.9	(-5.6, 14.3)	27.1	(13.6, 44.1)

Table 4.3 Alert limits for Dunlin, consisting of changes in population size over fixed time spans of five and 10 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at five years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the December-February index are those obtained in 1997; the calculations of the annual alert limits were however made as if only data as far as that year were available.* indicates a 25% decline.

Year	Index	5-year		10-year		25-year	
		Alert	CI	Alert	CI	Alert	CI
1969	72.3						
1970	72.9						
1971	87.7						
1972	100.0						
1973	119.9						
1974	113.9						
1975	115.7						
1976	117.9	48.7	(29.6, 72.6)				
1977	92.2	25.3	(13.4, 41.3)				
1978	92.5	-1.4	(-12.0, 11.3)				
1979	89.7	-18.4	(-27.8, -5.8)				
1980	89.3	-23.1	(-31.9, -14.1)				
1981	78.8	-28.0*	(-36.7, -18.7)	7.2	(-7.8, 26.4)		
1982	77.1	-27.0*	(-34.2, -18.2)	-9.6	(-21.5, 6.4)		
1983	81.1	-23.1	(-32.3, -12.4)	-25.9*	(-36.0, -14.1)		
1984	76.3	-14.9	(-26.2, 1.1)	-31.8*	(-42.2, -20.9)		
1985	79.9	-14.1	(-28.0, 1.2)	-35.1*	(-45.6, -23.1)		
1986	68.8	-13.1	(-24.1, 0.1)	-37.7*	(-49.0, -24.9)		
1987	71.1	-10.9	(-20.5, 0.6)	-33.6*	(-44.8, -21.1)		
1988	88.1	-3.7	(-12.5, 4.8)	-25.1*	(-37.0, -11.3)		
1989	88.6	6.8	(-3.0, 19.0)	-9.3	(-25.4, 9.7)		
1990	105.7	19.6	(11.6, 28.5)	4.3	(-11.9, 24.3)		
1991	97.5	32.1	(21.8, 41.6)	15.1	(1.1, 30.4)		
1992	86.4	33.9	(17.3, 51.7)	20.5	(5.8, 33.8)		
1993	86.7	20.6	(6.0, 36.1)	17.2	(4.7, 29.6)		
1994	98.5	-9.2	(-3.8, 34.3)	17.3	(6.0, 29.5)		
1995	89.9	-2.1	(-11.8, 10.1)	17.2	(4.0, 32.3)		
1996	114.6	1.9	(-7.6, 13.7)	33.2	(18.4, 51.1)	29.4	(8.8, 58.5)
1997	90.5	1.7	(-7.5, 13.2)	33.9	(14.8, 55.2)	13.0	(-1.6, 37.7)

Table 4.4 Alert limits for Dunlin, consisting of changes in population size over fixed time spans of five and 10 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at three years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the December-February index are those obtained in 1997; the calculations of the annual alert limits were however made as if only data as far as that year were available.* indicates a 25% decline.

Year	Index	5-year		10-year	
		Alert	CI	Alert	CI
1969	103.2				
1970	84.9				
1971	84.8				
1972	100.0				
1973	147.3				
1974	156.9				
1975	157.0				
1976	172.9				
1977	121.4				
1978	162.3	44.3	(24.9, 69.6)		
1979	189.6	36.9	(21.3, 56.7)		
1980	265.5	39.9	(25.1, 63.1)		
1981	205.3	27.4	(12.5, 47.6)		
1982	218.0	36.1	(21.6, 54.4)		
1983	241.6	39.8	(26.6, 52.6)	105.6	(81.4, 142.0)
1984	285.7	46.4	(30.0, 61.5)	103.4	(84.5, 129.0)
1985	314.1	37.8	(26.2, 49.5)	88.9	(69.2, 122.9)
1986	319.1	46.7	(36.0, 59.1)	83.0	(58.0, 117.7)
1987	428.6	58.3	(43.5, 71.4)	115.4	(84.8, 151.1)
1988	471.5	61.8	(38.2, 85.0)	134.8	(96.9, 166.4)
1989	405.9	61.5	(34.9, 87.6)	144.1	(104.5, 186.8)
1990	468.0	66.3	(41.2, 92.9)	130.7	(88.4, 175.6)
1991	490.2	64.9	(45.2, 85.8)	141.0	(99.1, 192.7)
1992	462.6	44.8	(32.1, 63.3)	121.6	(86.7, 171.6)
1993	586.7	30.3	(15.6, 47.3)	111.2	(76.1, 156.7)
1994	639.9	33.6	(17.7, 51.2)	112.6	(80.0, 155.7)
1995	561.3	28.6	(13.0, 48.9)	112.8	(80.7, 149.6)
1996	646.5	24.7	(9.2, 45.7)	104.0	(75.3, 142.7)
1997	507.7	6.3	(-12.5, 15.5)	81.6	(56.5, 112.4)

Table 4.5 Alert limits for Grey Plover, consisting of changes in population size over fixed time spans of five and 10 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at five years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the December-February index are those obtained in 1997; the calculations of the annual alert limits were however made as if only data as far as that year were available.

Year	Index	5-year		10-year		25-year	
		Alert	CI	Alert	CI	Alert	CI
1969	103.2						
1970	84.9						
1971	84.8						
1972	100.0						
1973	147.3						
1974	156.9						
1975	157.0						
1976	172.9	77.1	(38.9, 145.2)				
1977	121.4	63.5	(41.7, 96.7)				
1978	162.3	31.5	(17.5, 53.9)				
1979	189.6	13.7	(-2.5, 37.8)				
1980	265.5	32.8	(14.8, 57.6)				
1981	205.3	33.6	(17.8, 54.6)	139.2	(90.6, 214.0)		
1982	218.0	50.4	(27.3, 72.2)	151.7	(115.7, 185.8)		
1983	241.6	42.1	(24.2, 57.9)	94.1	(75.7, 122.3)		
1984	285.7	53.7	(35.1, 71.3)	76.6	(55.7, 107.5)		
1985	314.1	34.1	(25.0, 47.5)	72.3	(51.2, 109.0)		
1986	319.1	40.6	(25.1, 58.6)	83.7	(53.7, 128.4)		
1987	428.6	62.7	(44.2, 86.3)	145.4	(100.5, 192.3)		
1988	471.5	83.0	(52.4, 119.5)	166.6	(108.6, 219.1)		
1989	405.9	78.3	(49.9, 110.6)	181.0	(124.6, 238.6)		
1990	468.0	60.7	(37.6, 86.3)	119.3	(83.2, 167.2)		
1991	490.2	49.7	(30.4, 71.8)	108.3	(70.2, 159.9)		
1992	462.6	33.8	(19.4, 53.5)	106.6	(75.4, 156.3)		
1993	586.7	22.6	(7.7, 46.5)	124.3	(87.2, 166.5)		
1994	639.9	25.1	(9.3, 49.6)	117.7	(83.0, 163.5)		
1995	561.3	29.4	(10.9, 55.1)	106.6	(68.9, 148.7)		
1996	646.5	34.2	(12.8, 59.6)	98.9	(62.6, 138.0)	559.4	(391.8, 842.9)
1997	507.7	20.7	(-2.0, 49.4)	61.6	(36.4, 95.5)	539.8	(418.3, 698.6)

Table 4.6 Alert limits for Grey Plover, consisting of changes in population size over fixed time spans of five and 10 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at three years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the December-February index are those obtained in 1997; the calculations of the annual alert limits were however made as if only data as far as that year were available.

Year	Index	5-year		10-year		25-year	
		Alert	CI	Alert	CI	Alert	CI
1969	84.4						
1970	89.1						
1971	112.1						
1972	100.0						
1973	106.6						
1974	103.5						
1975	122.7						
1976	127.6	23.7	(10.1, 44.5)				
1977	123.3	25.8	(11.0, 47.5)				
1978	126.1	21.1	(6.4, 39.7)				
1979	124.2	18.1	(5.2, 31.6)				
1980	113.5	3.5	(-6.4, 14.6)				
1981	108.0	-8.3	(-17.4, 0.8)	10.3	(-7.8, 33.0)		
1982	105.7	-17.7	(-27.1, -6.5)	-1.7	(-19.1, 22.3)		
1983	131.0	-6.9	(-18.4, 5.7)	6.6	(-12.3, 26.3)		
1984	132.6	3.9	(-6.7, 15.5)	18.5	(1.9, 37.8)		
1985	157.3	24.3	(10.1, 38.3)	25.2	(9.0, 45.1)		
1986	142.9	28.3	(13.4, 45.7)	19.6	(3.8, 35.5)		
1987	169.8	48.3	(33.6, 67.7)	22.7	(7.6, 43.0)		
1988	141.3	33.6	(17.5, 59.2)	18.7	(1.6, 40.4)		
1989	149.0	25.6	(10.5, 47.7)	22.8	(5.1, 43.7)		
1990	137.7	1.8	(-9.5, 15.7)	19.5	(2.0, 41.9)		
1991	149.7	1.4	(-8.4, 12.4)	27.9	(9.7, 51.8)		
1992	131.8	-9.7	(-17.8, 0.3)	31.8	(12.9, 56.7)		
1993	129.2	-8.2	(-17.2, 2.1)	21.9	(3.4, 42.3)		
1994	131.6	-14.1	(-22.9, -0.8)	7.3	(-9.1, 25.9)		
1995	112.5	-12.2	(-21.3, 0.1)	-10.7	(-22.5, 4.2)		
1996	113.5	-18.1	(-27.0, -8.5)	-17.4	(-28.7, -4.1)	25.2	(0.9, 65.0)
1997	107.0	-20.6	(-29.7, -9.6)	-29.2*	(-37.6, -18.7)	10.5	(-10.9, 44.9)

Table 4.7 Alert limits for Turnstone, consisting of changes in population size over fixed time spans of five and 10 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at three years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the December-February index are those obtained in 1997; the calculations of the annual alert limits were however made as if only data as far as that year were available. * indicates a 25% decline.

Year	Index	5-year		10-year		25-year	
		Alert	CI	Alert	CI	Alert	CI
1969	70.2						
1970	73.8						
1971	103.9						
1972	100.0						
1973	103.6						
1974	113.2						
1975	110.9						
1976	102.3	33.1	(18.8, 52.4)				
1977	92.2	12.1	(-0.3, 24.4)				
1978	96.2	-2.7	(-13.0, 8.4)				
1979	97.2	-5.4	(-14.6, 3.7)				
1980	89.6	-11.0	(-20.8, -1.3)				
1981	79.7	-17.4	(-29.7, -4.9)	11.2	(-6.7, 30.8)		
1982	78.1	-21.2	(-34.6, -5.9)	-12.7	(-28.8, 6.7)		
1983	85.3	-14.1	(-29.0, 1.9)	-18.7	(-34.1, -3.5)		
1984	88.6	-8.0	(-20.7, 6.5)	-18.0	(-31.2, -2.8)		
1985	95.7	-5.0	(-15.2, 6.5)	-17.6	(-31.7, -3.2)		
1986	93.7	2.9	(-8.8, 16.0)	-14.4	(-29.9, 1.3)		
1987	120.9	26.6	(11.3, 43.7)	1.2	(-17.6, 23.7)		
1988	114.8	37.4	(19.7, 59.9)	15.0	(-8.2, 37.6)		
1989	113.4	41.6	(22.0, 63.6)	24.4	(0.8, 47.9)		
1990	98.1	23.3	(7.3, 39.9)	17.7	(0.8, 41.0)		
1991	106.0	16.8	(3.8, 28.1)	22.0	(3.9, 45.1)		
1992	101.2	0.2	(-8.5, 8.0)	25.9	(8.3, 46.5)		
1993	99.8	-5.3	(-12.5, 2.6)	29.8	(12.7, 50.8)		
1994	117.6	-8.7	(-16.0, -0.5)	29.0	(11.4, 46.5)		
1995	92.9	-5.2	(-12.8, 4.2)	15.9	(1.6, 31.5)		
1996	102.8	-2.2	(-10.4, 7.0)	12.9	(0.7, 26.8)	27.9	(4.2, 55.1)
1997	110.0	0.1	(-7.2, 10.7)	-1.5	(-12.0, 10.6)	10.1	(-10.1, 35.0)

Table 4.8 Alert limits for Redshank, consisting of changes in population size over fixed time spans of five and 10 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at three years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the December-February index are those obtained in 1997; the calculations of the annual alert limits were however made as if only data as far as that year were available.

Year	Index	5-year		10-year	
		Alert	CI	Alert	CI
1970	80.4				
1971	76.9				
1972	100.0				
1973	172.4				
1974	150.4				
1975	133.9				
1976	136.6				
1977	146.0	66.7	(24.9, 92.4)		
1978	100.6	9.5	(-16.0, 23.5)		
1979	138.7	-8.0	(-42.7, 10.8)		
1980	170.1	-10.0	(-45.0, 14.1)		
1981	143.1	9.3	(-42.1, 36.3)		
1982	177.6	18.0	(-17.7, 79.1)	92.8	(15.8, 204.1)
1983	162.2	25.8	(-3.4, 101.6)	23.7	(-24.7, 86.8)
1984	222.2	44.5	(17.8, 112.7)	31.4	(-21.0, 92.5)
1985	176.3	38.3	(11.3, 96.9)	23.8	(-24.9, 89.6)
1986	128.9	17.6	(-2.7, 76.5)	26.2	(-22.9, 81.1)
1987	198.0	3.5	(-22.7, 77.3)	22.0	(-23.7, 143.0)
1988	189.7	6.0	(-22.4, 97.3)	33.6	(-19.6, 172.1)
1989	190.4	2.2	(-30.8, 91.0)	49.0	(-10.1, 232.9)
1990	163.5	-3.7	(-32.0, 62.5)	31.9	(-20.8, 186.4)
1991	198.3	4.6	(-27.5, 54.8)	22.1	(-24.6, 157.9)
1992	155.9	2.9	(-18.9, 37.3)	5.5	(-38.1, 128.0)
1993	140.6	-4.2	(-25.6, 31.8)	2.4	(-32.2, 132.6)
1994	151.7	-22.5	(-41.7, 13.2)	-20.3	(-51.7, 84.2)

Table 4.9 Alert limits for Pintail, consisting of changes in population size over fixed time spans of five and 10 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at three years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the October-January index are those obtained in 1994; the calculations of the annual alert limits were however made as if only data from 1970 to as far as that year were available.

Year	Index	5-year		10-year		25-year	
		Alert	CI	Alert	CI	Alert	CI
1969	71.9						
1970	72.1						
1971	93.8						
1972	100.0						
1973	90.2						
1974	91.4						
1975	94.3						
1976	109.2	24.5	(1.8, 43.6)				
1977	90.1	12.4	(-20.9, 73.4)				
1978	119.8	7.2	(-37.3, 85.7)				
1979	145.0	17.2	(-26.0, 101.7)				
1980	98.3	15.7	(-24.0, 78.8)				
1981	78.2	5.4	(-27.6, 46.1)	28.3	(-31.2, 78.1)		
1982	95.8	-12.6	(-54.6, 51.6)	-5.8	(-56.8, 54.4)		
1983	117.6	-5.0	(-42.1, 51.7)	-4.7	(-52.1, 72.6)		
1984	123.3	2.8	(-31.3, 57.8)	13.0	(-47.9, 107.8)		
1985	230.0	43.8	(4.4, 122.7)	62.0	(-13.5, 157.6)		
1986	160.4	69.8	(0.6, 196.9)	67.9	(-4.1, 160.1)		
1987	172.9	123.4	(0.3, 474.0)	86.7	(-13.6, 256.2)		
1988	160.2	79.1	(-46.7, 584.6)	55.8	(-56.3, 292.2)		
1989	140.8	44.7	(-60.4, 418.3)	36.9	(-63.0, 248.4)		
1990	122.3	-10.5	(-73.7, 115.5)	21.7	(-66.5, 209.1)		
1991	93.2	-32.7*	(-77.9, 17.2)	10.7	(-71.1, 210.3)		
1992	85.6	-48.1*	(-78.5, -28.0)	11.3	(-72.9, 307.9)		
1993	67.2	-50.1**	(-82.2, -35.8)	-14.0	(-84.5, 209.1)		
1994	56.0	-56.0**	(-72.3, -47.2)	-36.9*	(-83.5, 97.4)		
1995	96.7	-47.9*	(-68.1, -35.0)	-53.0**	(-87.8, 5.2)		
1996	108.0	-28.3*	(-53.6, -17.7)	-49.7*	(-83.1, -13.0)	10.5	(-64.1, 111.1)
1997	112.7	5.4	(-37.3, 21.2)	-43.6*	(-80.6, -16.3)	19.4	(-73.0, 155.4)

Table 4.10 Alert limits for Turnstone in Wales, consisting of changes in population size over fixed time spans of five, 10 and 25 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at three years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the December-February index are those obtained in 1997; the calculations of the annual alert limits were however made as if only data as far as that year were available. * indicates a 25% decline, ** indicates a 50% decline.

Year	Index	5-year		10-year		25-year	
		Alert	CI	Alert	CI	Alert	CI
1969	101.4						
1970	70.9						
1971	116.1						
1972	100.0						
1973	106.1						
1974	115.2						
1975	131.0						
1976	109.1	24.2	(-6.9, 44.7)				
1977	101.9	14.5	(-24.7, 51.8)				
1978	106.6	-16.0	(-37.7, 23.9)				
1979	137.7	-4.7	(-24.5, 27.3)				
1980	140.5	-4.4	(-19.0, 13.2)				
1981	126.5	5.0	(-6.2, 20.8)	28.6	(-2.2, 47.3)		
1982	124.5	6.0	(-12.1, 37.1)	30.3	(-10.2, 60.6)		
1983	101.9	9.9	(-15.8, 44.7)	1.5	(-21.5, 43.8)		
1984	87.9	-6.0	(-23.1, 8.2)	-7.4	(-29.9, 11.6)		
1985	116.3	-16.9	(-33.2, -8.7)	-19.9	(-41.9, -1.4)		
1986	171.6	-3.6	(-42.2, 18.1)	-1.5	(-38.4, 22.7)		
1987	212.1	38.6	(-40.0, 81.6)	44.5	(-25.4, 81.0)		
1988	193.3	76.1	(-29.4, 142.5)	87.8	(-19.1, 153.4)		
1989	180.7	99.5	(-25.5, 180.9)	78.7	(-28.3, 153.1)		
1990	168.6	88.6	(-20.3, 138.6)	51.2	(-42.0, 108.7)		
1991	155.8	44.0	(-25.3, 67.2)	33.6	(-56.1, 92.5)		
1992	155.4	0.2	(-32.0, 8.7)	31.7	(-57.7, 92.4)		
1993	131.6	-18.9	(-41.2, -12.8)	35.3	(-53.8, 104.2)		
1994	138.2	-29.3*	(-44.4, -22.5)	38.1	(-37.5, 96.8)		
1995	109.0	-30.2*	(-42.4, -18.4)	23.7	(-38.0, 61.2)		
1996	139.9	-24.4	(-32.9, -13.5)	2.1	(-35.0, 22.2)	41.7	(-45.3, 112.1)
1997	137.3	-19.5	(-28.3, -11.6)	-22.7	(-48.0, -12.8)	34.6	(-60.1, 126.9)

Table 4.11 Alert limits for Redshank in Wales, consisting of changes in population size over fixed time spans of five, 10 and 25 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at three years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the December-February index are those obtained in 1997; the calculations of the annual alert limits were however made as if only data as far as that year were available. * indicates a 25% decline. **Index values likely to be incorrect in this table**.

Year	Index	10-year						25-year					
		below			above			below			above		
		Alert	Year	CI	Alert	Year	CI	Alert	Year	CI	Alert	Year	CI
1969	72.3												
1970	72.9												
1971	87.7												
1972	100.0												
1973	119.9												
1974	113.9												
1975	115.7												
1976	117.9												
1977	92.3												
1978	93.2												
1979	90.3												
1980	89.9												
1981	79.4	-28.3*	1975	(-36.7, -20.6)	7.2	1971	(-7.8, 26.4)						
1982	76.9	-32.2*	1975	(-40.4, -25.4)	-9.6	1972	(-21.5, 6.4)						
1983	81.7	-34.3*	1975	(-44.0, -24.7)	-12.7	1980	(-23.3, 2.9)						
1984	76.9	-34.7*	1975	(-44.6, -25.6)	-8.2	1981	(-20.2, 3.4)						
1985	80.5	-35.1*	1975	(-45.6, -23.7)	-5.5	1982	(-15.5, 5.4)						
1986	69.4	-37.7*	1976	(-49.1, -24.9)	-7.2	1983	(-14.8, 3.1)						
1987	71.6	-33.6*	1977	(-44.8, -21.1)	-6.8	1984	(-13.1, 2.4)						
1988	88.8	-25.1*	1978	(-37.0, -11.3)	-2.7	1984	(-9.1, 7.5)						
1989	89.3	-9. 3	1979	(-25.8, 7.2)	11.2	1986	(1.3, 21.6)						
1990	106.5	4.3	1980	(-11.9, 21.3)	28.9	1987	(22.3, 37.1)						
1991	98.3	15.1	1981	(1.1, 25.8)	35.0	1987	(25.5, 46.2)						
1992	87.0	18.1	1989	(0.4, 27.1)	33.9	1987	(21.2, 48.4)						
1993	87.4	-2.9	1990	(-13.3, 7.2)	25.6	1987	(12.1, 40.9)						
1994	99.3	-7.7	1991	(-15.6, 0.4)	22.6	1987	(10.9, 37.9)						
1995	90.5	-5.8	1991	(-14.2, 1.9)	26.2	1987	(12.8, 43.3)						
1996	115.0	1.9	1991	(-7.9, 12.0)	35.0	1987	(20.1, 55.4)	-13.8	1975	(-23.8, -4.1)	35.0	1987	(22.9, 62.0)
1997	91.1	0.9	1991	(-10.2, 10.6)	33.9	1987	(14.8, 55.2)	-15.1	1975	(-24.6, -4.9)	33.9	1987	(17.7, 56.2)

Table 4.12 Cumulative alert limits for Dunlin, consisting of changes in population size over time spans of between three and 10 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at three years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the December-February index are those obtained in 1997 for the period 1969-1997; the calculations of the annual alert limits were however made as if only data from 1969 to as far as that year were available. * indicates a 25% decline.

Year	Index	10-year						25-year					
		below			above			below			above		
		Alert	Year	CI	Alert	Year	CI	Alert	Year	CI	Alert	Year	CI
1969	103.0												
1970	84.9												
1971	84.0												
1972	100.0												
1973	147.3												
1974	157.2												
1975	157.3												
1976	173.5												
1977	121.8												
1978	163.2												
1979	190.5												
1980	266.8												
1981	206.2	33.6	1976	(15.7, 49.5)	142.8	1972	(112.8, 217.0)						
1982	219.2	39.2	1976	(19.7, 51.4)	151.7	1972	(115.5, 185.8)						
1983	242.9	8.3	1980	(-2.7, 23.1)	94.1	1973	(73.9, 123.0)						
1984	287.3	13.9	1981	(6.5, 22.8)	76.6	1974	(58.1, 107.7)						
1985	315.9	20.2	1982	(11.1, 30.9)	79.8	1977	(60.9, 115.7)						
1986	320.9	33.5	1982	(17.7, 51.7)	99.9	1977	(73.2, 139.7)						
1987	431.0	46.6	1984	(28.7, 66.0)	145.4	1977	(104.8, 193.7)						
1988	474.1	45.4	1985	(26.8, 65.9)	166.6	1978	(114.9, 223.8)						
1989	408.1	45.0	1986	(24.0, 62.9)	181.0	1979	(119.2, 232.0)						
1990	470.7	27.3	1987	(15.6, 42.6)	119.3	1980	(82.5, 172.7)						
1991	493.0	12.8	1988	(2.0, 25.6)	108.0	1981	(76.6, 156.2)						
1992	465.2	8.3	1989	(-3.6, 24.3)	113.4	1983	(80.5, 159.4)						
1993	533.3	11.1	1990	(-2.7, 28.5)	124.3	1983	(88.2, 166.0)						
1994	643.5	19.7	1991	(5.3, 34.2)	117.7	1984	(85.0, 164.1)						
1995	564.5	22.6	1992	(7.6, 40.2)	106.6	1985	(72.5, 148.6)						
1996	650.1	23.7	1993	(7.2, 41.9)	98.9	1986	(63.1, 138.2)	23.7	1993	(5.0, 42.7)	570.1	1972	(452.8, 847.8)
1997	510.6	5.1	1994	(-11.1, 22.6)	61.6	1987	(34.3, 95.9)	5.1	1994	(-10.4, 24.9)	539.7	1972	(418.3, 698.6)

Table 4.13 Cumulative alert limits for Grey Plover, consisting of changes in population size over time spans of between three and 10 years, and their 90% consistency intervals, based on 500 bootstrap samples. Alert window width was set at three years (see text). Imputing was done using a nine-year window, and the full bootstrap was used to calculate consistency intervals. The values of the December-February index are those obtained in 1997 for the period 1969-1997; the calculations of the annual alert limits were however made as if only data from 1969 to as far as that year were available.

Site Code	Current	SAL5	SAL10	SAL25	Maximum SAL	below	Year	Minimum SAL	above	Year
5	8935	-33.9	-41.2	-23.7	18578	-51.9	1981	11710	-23.7	1972
15	4978	-31.1	-38.9	-41.8	16778	-70.3	1976	4847	2.7	1981
18	10361	-23.2	48.2	-18.6	15889	-34.8	1978	6650	55.8	1985
220	3756	-11.1	2.8	-4.4	5835	-35.6	1976	3494	7.5	1988
300	3520	-3.9	28.1	-11.4	7568	-53.5	1975	2632	33.8	1986
320	3178	-10.0	-14.9	-28.4	7811	-59.3	1978	2821	12.7	1988
400	3821	-0.1	1.4	-65.8	13073	-70.8	1974	3540	8.0	1986
410	16243	-31.2	-18.1	-8.6	28000	-42.0	1989	15042	8.0	1980
420	13793	-15.6	-14.5	-28.4	25111	-45.1	1974	14246	-3.2	1988
500	11040	11.7	0.5	137.3	11579	-4.7	1980	3971	178.0	1973
510	13671	-46.3	-25.1	314.0	25444	-46.3	1992	3302	314.0	1972
520	4034	-36.1	207.6	-17.3	13068	-69.1	1978	1312	207.6	1987
530	3846	-49.0	37.3	-23.6	8136	-52.7	1991	560	586.8	1983
540	15743	74.1	93.5	120.1	9625	63.6	1975	3893	304.3	1985
545	8845	55.2	17.6	34.8	10572	-16.3	1978	5700	55.2	1992
570	4768	-19.1	35.1	121.0	6136	-22.3	1990	2158	121.0	1972
575	18256	-2.6	43.3	154.6	18751	-2.6	1992	7171	154.6	1972
590	9526	11.7	47.1	75.0	9799	-2.8	1991	2624	263.1	1977
600	7445	70.4	148.3	9.8	10295	-27.7	1975	2586	187.9	1986
610	13954	-5.6	24.9	44.0	14778	-5.6	1992	8651	61.3	1980
620	6436	5.9	5.0	150.6	8193	-21.4	1985	748	760.1	1978
710	29819	3.2	-8.4	6.3	41704	-28.5	1990	23696	25.8	1978
720	15579	12.6	38.2	0.1	23239	-33.0	1978	11274	38.2	1987
790	6596	26.2	-9.1	-28.3	29667	-77.8	1980	4734	39.3	1990
838	1778	-36.5	-26.1	-68.1	5964	-70.2	1973	1999	-11.0	1984
840	7526	104.2	213.1	40.1	8460	-11.0	1976	2403	213.1	1987
1200	1264	-7.2	76.9	-64.6	6064	-79.2	1975	633	99.8	1988
1310	7838	77.8	76.4	20.4	9028	-13.2	1975	4282	83.0	1985
1330	4649	-5.7	6.9	41.5	6558	-29.1	1975	3285	41.5	1972
1370	6783	-20.0	65.0	58.1	8735	-22.3	1977	3532	92.0	1986
1390	43549	-22.1	36.5	-7.0	55907	-22.1	1992	31904	36.5	1987
1400	26882	42.8	330.5	-13.3	47222	-43.1	1974	6058	343.8	1986
1420	41440	18.6	181.2	238.4	34940	18.6	1992	12245	238.4	1972
1430	17755	3.8	89.3	-40.4	33222	-46.6	1973	9137	94.3	1986
1470	1917	-31.6	-54.0	-74.4	8738	-78.1	1974	2505	-23.5	1991
1650	4742	56.1	92.4	54.5	5973	-20.6	1990	2226	113.1	1985
1680	2239	-20.6	29.9	-27.7	5742	-61.0	1979	1724	29.9	1987

Table 4.14 Site alerts for Dunlin in winter 1996/97 over time spans of five, 10 and 25 years. Sites included have both at least 42 counts of quality 1 or 2 in December, January and February since 1970, and have at least one three-year running average exceeding 5,300 birds over the 25-year period since winter 1971/72. The maximum and minimum three-year running averages over this 25-year period, the year in which they occurred, and the cumulative SALs are also given. The December to February average count of birds over the 1994/95, 1995/96 and 1996/97 winters is in the column headed 'Current'. See text for further details.

Site Code	Current	SAL5	SAL10	SAL25	Maximum SAL	below	Year	Minimum SAL	above	Year
5	124	-49.0	-41.2	-46.1	728	-83.0	1979	195	-36.5	1982
310	555	6.5	223.1	2244.1	521	6.5	1992	24	2244.1	1972
320	131	-40.1	-63.2	-15.5	467	-71.9	1981	155	-15.5	1972
410	1080	-4.3	32.6	433.4	1129	-4.3	1992	202	433.4	1972
420	1681	6.2	39.7	226.8	1582	6.2	1992	514	226.8	1972
430	977	59.7	49.9	732.9	720	35.6	1989	110	785.1	1973
500	1998	47.2	37.5	463.4	1526	30.9	1986	355	463.4	1972
510	1913	-34.8	-6.3	692.6	3146	-39.2	1989	241	692.6	1972
520	362	-54.5	8.6	205.4	955	-62.1	1991	119	205.4	1972
540	1630	-41.6	48.0	1001.3	2793	-41.6	1992	148	1001.3	1972
545	3322	143.3	134.3	1368.6	1796	84.9	1989	226	1368.6	1972
570	1530	7.9	118.6	250.1	1495	2.3	1981	437	250.1	1972
575	2610	66.6	190.4	810.2	1566	66.6	1992	239	992.3	1973
590	1014	24.4	94.5	645.0	924	9.7	1989	79	1185.8	1977
600	3823	207.3	633.0	982.2	1244	207.3	1992	336	1036.2	1986
610	2182	2.0	102.9	1286.9	2139	2.0	1992	157	1286.9	1972
710	6145	9.0	31.3	418.8	5803	5.9	1989	1185	418.8	1972
720	747	89.3	256.1	1799.4	436	71.4	1991	39	1799.4	1972
790	1468	35.3	22.8	1798.5	1378	6.6	1988	77	1798.5	1972
838	520	6.5	56.6	1627.2	489	6.5	1992	30	1627.2	1972
1390	1102	-17.2	11.4	704.0	1331	-17.2	1992	137	704.0	1972
1400	3140	125.2	101.5	657.4	2510	25.1	1989	366	758.7	1973
1410	947	49.9	28.7	760.3	807	17.4	1989	28	3324.1	1974
1420	371	-59.2	281.1	18466.2	909	-59.2	1992	2	18466.2	1972
1430	1080	-23.0	2.4	508.5	1403	-23.0	1992	177	508.5	1972
1650	98	-58.0	-80.9	-50.3	534	-81.7	1990	176	-44.6	1976

Table 4.15 Site alerts limits (SAL) for Grey Plover in winter 1996/97 over time spans of five, 10 and 25 years. Sites included have both at least 42 counts of quality 1 or 2 in December, January and February since 1970, and have at least one three-year running average exceeding 430 birds over the 25-year period since winter 1971/72. The maximum and minimum three-year running averages over this 25-year period, the year in which they occurred, and the cumulative SALs are also given. The December to February average count of birds over the 1994/95, 1995/96 and 1996/97 winters is in the column headed ‘Current’. See text for further details.

Site Code	Current	SAL5	SAL10	SAL25	Maximum SAL	below	Year	Minimum SAL	above	Year
710	405	-21.2	-49.8	-8.1	849	-52.3	1989	430	-6.0	1974
838	399	-21.7	-39.2	148.9	662	-39.6	1989	161	148.9	1972
1390	955	-41.6	-45.1	-43.2	1761	-45.8	1988	1159	-17.7	1983
1430	652	29.2	-1.4	268.6	732	-11.0	1989	26	2386.4	1982

Table 4.16 Site alerts for Turnstone in winter 1996/97 over time spans of five, 10 and 25 years. Sites included have both at least 42 counts of quality 1 or 2 in December, January and February since 1970, and have at least one three-year running average exceeding 640 birds over the 25-year period since winter 1971/72. The maximum and minimum three-year running averages over this 25-year period, the year in which they occurred, and the cumulative SALs are also given. The December to February average count of birds over the 1994/95, 1995/96 and 1996/97 winters is in the column headed 'Current'. See text for further details.

Code	Current	SAL5	SAL10	SAL25	Maximum SAL	below	Year	Minimum SAL	above	Year
5	743	-13.1	-30.5	261.7	1201	-38.1	1989	205	261.7	1972
420	1184	21.2	-10.9	12.5	1580	-25.1	1983	955	23.9	1976
500	971	-19.3	-55.5	10.8	2181	-55.5	1987	876	10.8	1972
510	1693	-45.7	-41.0	94.2	3762	-55.0	1989	872	94.2	1972
520	617	-29.1	-35.8	-22.6	1279	-51.8	1989	788	-21.7	1977
530	690	-43.0	-16.3	17.2	1478	-53.3	1990	350	96.9	1983
545	1367	74.5	38.0	103.4	1154	18.5	1989	672	103.4	1972
575	1322	15.7	61.5	25.5	1143	15.7	1992	685	93.1	1984
590	1220	22.1	81.0	-42.6	2260	-46.0	1973	371	229.0	1983
600	1704	116.6	164.7	59.2	1757	-3.1	1976	456	273.4	1986
610	1972	91.0	119.3	30.7	2365	-16.6	1974	607	224.7	1988
620	1224	70.2	21.6	65.7	2052	-40.3	1984	206	493.0	1978
630	1540	92.1	20.1	359.2	1366	12.8	1988	301	411.1	1979
710	1961	-0.9	-41.9	9.6	3476	-43.6	1988	1462	34.2	1977
720	2084	21.6	51.5	185.3	2496	-16.5	1976	730	185.3	1972
790	914	-37.0	-70.2	11.9	3068	-70.2	1987	778	17.5	1973
840	1857	-307	0.1	19.9	2333	-20.4	1989	1226	51.4	1985
850	416	40.6	-13.5	-70.2	1397	-70.2	1972	286	45.6	1991
870	1450	-11.4	46.1	21.1	1696	-14.5	1991	783	85.1	1986
958	1515	-23.2	7.5	42.8	2133	-29.0	1991	540	180.7	1979
980	820	-40.9	-48.6	-49.4	2142	-61.7	1976	796	3.1	1984
1200	1352	-12.9	-28.3	-74.6	6782	-80.1	1976	1553	-12.9	1992
1310	1240	-1.6	51.6	2.4	1870	-33.7	1975	481	157.8	1983
1330	365	-38.2	-28.6	-67.1	1429	-74.5	1974	506	-27.9	1986
1370	1433	29.3	26.5	14.6	1359	5.4	1973	604	137.2	1984
1390	4931	-9.6	-5.0	-26.5	7786	-36.7	1973	3382	45.8	1982
1400	1074	-9.1	-7.5	-7.1	1588	-32.4	1980	959	12.1	1986
1420	3687	7.5	59.6	498.9	3602	2.4	1991	449	720.3	1982
1430	4781	-17.3	-9.7	191.4	6634	-27.9	1989	1641	191.4	1972
1470	318	-2.4	-43.9	-72.9	1357	-76.5	1975	320	-0.5	1991
1620	549	-31.1	-47.9	-20.9	1116	-50.8	1988	669	-17.8	1977
1720	2456	22.5	10.4	116.0	2242	9.5	1988	1067	130.1	1976

Table 4.17 Site alerts for Redshank in winter 1996/97 over time spans of five, 10 and 25 years. Sites included have both at least 42 counts of quality 1 or 2 in December, January and February since 1970, and have at least one three-year running average exceeding 1,100 birds over the 25-year period since winter 1971/72. The maximum and minimum three-year running averages over this 25-year period, the year in which they occurred, and the cumulative SALs are also given.

5. DEVELOPMENT OF A NATIONAL AND REGIONAL ALERT SYSTEM FOR WATERBIRDS USING GENERALIZED ADDITIVE MODELS

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5.1 The Wetland Bird Survey (WeBS)

The Wetland Bird Survey (WeBS) is a joint scheme of the British Trust for Ornithology (BTO) the Wildfowl and Wetland Trust (WWT), the Royal Society for the Protection of Birds (RSPB), and the Joint Nature Conservation Committee (JNCC) to monitor non-breeding waterbirds in the UK. The WeBS partnership amalgamate two previous long running monitoring schemes, the Birds of Estuaries Enquiry (BoEE) and the National Waterfowl Counts (NWC). Monitoring data is available from 1969 from the BoEE scheme and from 1955 from the NWC scheme.

The principal aims of the WeBS scheme are to identify population sizes, determine trends in numbers and distribution and to identify important sites for divers, grebes, Cormorant, herons, wildfowl rails, waders, gulls, terns and Kingfisher. Core counts are made at around 2,000 wetland sites of all habitats although estuaries and large still waters predominate. Volunteers, principally from September to March with fewer observations in the summer months, carry out monthly co-ordinated counts. Approximately 250,000 records are collected annually.

Only a proportion of species, that are recorded as part of the Wetland Bird Survey, are regularly indexed. Of the 125 species recorded in the 1996-97 WeBS report (Waters *et al.* 1998), only 13 waders and 29 wildfowl species are either sufficiently common or have a sufficiently large proportion of their populations on WeBS sites to be indexed. Currently the normal method of indexing these species is by the method described by Underhill & Prys-Jones (1994) which uses a log-linear Poisson generalised linear model as its base. The counts are modelled as a function of site, year and month factors and the year factor is used as a base for the index which is set to an initial value of 100. For each species certain months are used to index the population. These are chosen to be months in which the population of that species is stable. For waders this is December through to February but varies with different species of wildfowl.

5.2 Assessment of Population Change

The overall aim of the WeBS Alert system is to devise a method whereby it is possible to flag up large changes in waterbird abundance at national, regional and site level. The coverage of the WeBS survey is an important consideration when assessing population change. For these changes to be relied on, it is essential that the survey is a representative sample of sites. For estuarine species this can be accepted as a valid assumption because over 95% of estuaries in Great Britain are counted annually. However, for some of the more widespread wildfowl such as Wigeon, much of the population occurs inland. The counting of inland sites follows no formal sampling pattern and therefore it is unclear as to whether these are a representative sample. For these species it is important that stratified sampling of estuaries, lakes and rivers of varying sizes is used for indexing. This is something that needs to be addressed in the future but, for the purposes of this report, all sites are used.

The UK holds internationally important populations of waterbirds and there is a statutory duty on government to monitor these populations. National and regional indexing using the Underhill method allows inter-annual variation in counts to be described but, due to sampling error and natural annual fluctuations, there can be a great deal of variation between counts. For statutory monitoring it is therefore essential to differentiate between these natural population fluctuations and medium to long-term population change. For this, a new way of calculating indices which smoothes the annual fluctuations is useful. Population change over various time periods can then be calculated.

The Alert system provides a framework in which medium to long-term population change in waterbird can be evaluated. If population change over a given time period exceeds a certain limit, then an alert is issued which acts as a warning as to large changes in that population. These alerts would then be issued to WeBS partners and the wider conservation community. Alerts can be set both for populations that are increasing or declining. Predetermined limits need to be set initially but would have to come under review as the scheme progresses. For waterbirds, the suggested time periods over which change could be calculated are 5, 10 and 25-year periods. Alerts would be raised if population change exceeded 25% (a 25% alert) or 50% (a 50% alert) over each given time period.

Species that show large year-to-year fluctuations may be more likely to trigger alerts. A high degree of smoothing applied to the indices will remove much of these fluctuations but it is likely that highly variable species will trigger series of 5-year alerts. Alerts should therefore be advisory and the particular species ecology and population dynamics are therefore extremely important in interpreting the alerts once they have been triggered. This is likely to be more of a problem for passerine species such as Wren *Troglodytes troglodytes*, which show much larger annual fluctuations than most wader and wildfowl species.

5.3 The Methodology Behind the Production of Alerts

The assessment of population change for waders and wildfowl needs to be carried out using smoothed indices calculated from the original count data. There are various methods to calculate smoothed indices but the use of General Additive Models (Fewster *et al.* in press) are recommended for this purpose. These explicitly incorporate the smoothing factor as part of the modelling process which is more valid than applying a smoothing process on the index itself. Details of the models and their construction can be found in Chapter 2. GAMS allow smoothed population indices to be calculated at national, regional or site level. For the purposes of this report we assess all three concepts using three wader and three wildfowl species as examples.

To test the validity of GAMs for assessing population change it is necessary to address several points which are discussed throughout this chapter:

1. The degree of smoothing applied to the models needs to be assessed. This can vary between a linear trend to a model incorporating all year effects and the degree of smoothing will inevitably affect estimates of population change.

2. Confidence limits of the estimate of population change need to be calculated to determine whether the change is significant or not. For this review percentage declines are said to be significant if the upper 95% confidence interval is less than zero.

3. Presently, bootstrapping confidence intervals is demanding of computer time making it essential to estimate the minimum number of bootstraps to obtain a sufficiently good estimate of the confidence limits.

4. As with all smoothing processes, endpoints in the data series are particularly sensitive to additional years' data. This may result in the triggering of 'false' alerts which may not have been triggered given additional years data.

In this chapter, we address each of these problems in turn and apply the provisional system to three species of wader and three species of wildfowl. These were chosen as they have showed different patterns of population change. As the majority of waders wintering in the UK are in fact increasing, and that regional alerts need to be issued, it was decided to split the wader datasets into UK and Welsh populations, as most wader populations are either stable or decreasing in Wales. Site-based alerts were also required and these have been calculated for Dunlin and presented towards the end of this chapter with the type of output that can be achieved from the Alerts procedure.

Table 5.1 Wader and wildfowl species or populations, which are regularly indexed as part of the Wetland Bird Survey and to which an alert system could be applied.

Species		Peak count in 1996/7 (nearest 500)	% of flyway/regional population (approximate)
Avocet	*Avocetta avocetta*	2,500	5
Oystercatcher	*Himantopus ostralegus*	266,000	30
Ringed Plover	*Charadrius hiaticula*	18,000	35
Grey Plover	*Pluvialis squatarola*	49,000	35
Knot	*Calidris canutus*	255,500	75
Sanderling	*Calidris alba*	10,000	10
Dunlin	*Calidris alpina*	540,500	40
Black-tailed Godwit	*Limosa limosa*	17,500	25
Bar-tailed Godwit	*Limosa lapponica*	81,500	80
Curlew	*Numenius arquata*	86,500	25
Redshank	*Tringa totanus*	77,500	50
Turnstone	*Arenaria interpres*	12,000	15
Little Grebe	*Tachybaptus ruficollis*	3,500	?
Great Crested Grebe	*Podiceps cristata*	8,500	?
Cormorant	*Phalacrocorax carbo*	13,500	10
Mute Swan	*Cygnus olor*	16,500	10
Bewick's Swan	*Cygnus columbianus*	9,500	55
Whooper Swan	*Cygnus cygnus*	4,000	25
Pink-footed Goose	*Anser brachyrhynchus*	257,500	115
European White-fronted Goose	*Anser albifrons*	7,000	1
Greenland White-fronted Goose	*Anser albifrons*	500	1
Greylag Goose - Icelandic	*Anser anser*	77,000	75
Greylag Goose - naturalised	*Anser anser*	17,500	?
Canada Goose	*Branta canadiensis*	42,000	?
Barnacle Goose - Svalbard	*Branta canadiensis*	21,000	65
Dark-bellied Brent	*Branta bernicla*	93,500	30
Light-bellied Brent	*Branta bernicla*	4,500	20
Shelduck	*Tadorna tadorna*	79,000	25
Wigeon	*Anas penelope*	405,500	30
Gadwall	*Anas strepera*	10,500	35
Teal	*Anas crecca*	12,000	30
Mallard	*Anas platyrhynchos*	146,500	5
Pintail	*Anas acuta*	27,500	45
Shoveler	*Anas clypeata*	9,000	25
Pochard	*Aytha ferrina*	34,000	10
Tufted Duck	*Aytha fuligula*	381,500	40
Goldeneye	*Bucephala clangula*	18,000	5
Red-breasted Merganser	*Mergus serrator*	4,500	5
Goosander	*Mergus merganser*	4,500	5
Ruddy Duck	*Oxyura jamaicensis*	3,500	?
Coot	*Fulica atra*	849,500	55

5.4 Degrees of Smoothing

Although the Underhill index is similar to a GAM with *n*-1 degrees of freedom it is not equivalent due to the imputing rules used by Underhill. Underhill imputes estimates for poor quality counts but uses the actual counts if larger than the estimate. The GAM models used here only consider good quality counts and estimate those which are of poor quality. However the difference between the two is negligible for the purpose of alert generation.

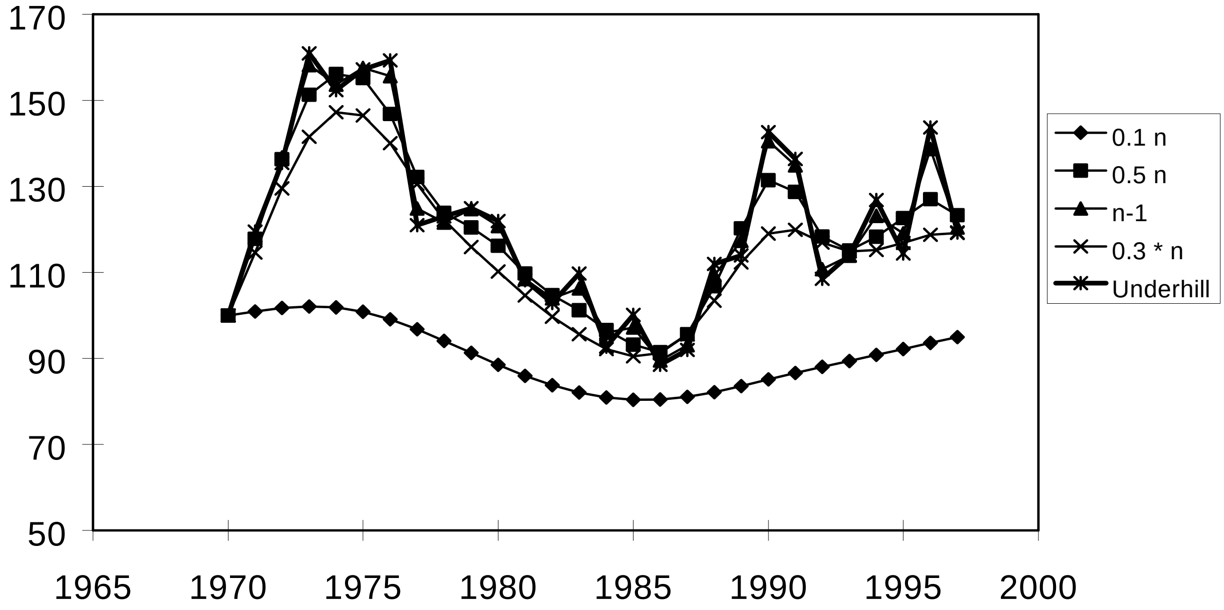
The degrees of freedom (d.f.) for the year parameter in the GAM model controls the degree of smoothing which is applied to the WeBS count data. Maximum degrees of freedom allows an unconstrained model to be run which is equivalent to a log-Poisson Generalised Linear Model with site, year and month factors. Minimum degrees of freedom constrain the fit to a linear trend.

The aim of the smoothing is to remove major year-to-year fluctuations in the Underhill index but reliably reveal the underlying trend in the index data. No exact rule can be applied to the amount of smoothing needed and the choice is necessarily somewhat arbitrary. Fewster *et al.* (in press) recommend that, for the year parameter in the GAM model, a dof equivalent to 0.3 times the number of years is suitable for CBC data.

To investigate what degree of smoothing in the GAM is desirable for WeBS data, several degrees of freedom were tested on wader data. GAMs with dofs (to the nearest integer) of 0.1n, 0.3*n*, 0.5*n* and *n*-1 where *n* = the number of years in the time series, were calculated and the resulting graphs and Underhill index are presented for UK Dunlin (1970-1997) in Figure 5.1. Only sites which were counted on over 50% of possible occasions over the time series were included in the analysis as recommended by Underhill & Prys-Jones (1994).

To infer long-term population trends, a smoothed curve is needed which requires relatively low degrees of freedom (Fewster *et al.* in press). However, if annual estimates are needed then maximum degrees of freedom are required. For small changes in the degrees of freedom, the fitted trend curve changes little (Fewster *et al.* in press) and 0.3*n* degrees of freedom produce a curve of suitable complexity and smoothness for alert purposes. Degrees of freedom substantially lower or greater than 0.3 produce curves that either lose the underlying trend or are not sufficiently smoothed for producing estimates of trends in population change respectively

Figure 5.1 Underhill index and smoothed indices using GAMS for UK Dunlin 1970-1997 with 0.1*n*, 0.3*n*, 0.5*n* and *n*-1 degrees of freedom associated with the year parameter of the model where *n* is the number of years over which the indices have been calculated. The index or trend curve has been tied to 100 in 1970 in each case and not averaged, hence the apparent discrepancy between curves.



5.5 Relationship Between the Number of Bootstraps and Confidence Intervals

It is important to know whether an alert is significant or not and bootstrapping allows confidence intervals in the change measures to be calculated. Bootstrapping the GAMs for both CBC and WeBS data is an extremely processor intensive process due to the large size of the datasets. With the current level of computing power available, it is advisable to use the smallest number of bootstraps possible to minimise computer time. Two datasets were used to test the optimum number of bootstraps needed. The national and Welsh Dunlin datasets were used and 95% confidence intervals calculated using 49, 99, 199 and 499 bootstraps (Figure 5.2). Increasing the number of bootstraps beyond 99 made little difference to the confidence intervals. Ideally, the same process would be repeated to determine optimum number of bootstraps for each species but the availability of computer time limits the number of species that can be considered, especially as the wildfowl models can take several days to run. It is likely that between 100-200 bootstraps is sufficient to obtain a realistically precise estimate of 95% confidence intervals for the smoothed index.

Figure 5.2 GAMs (bold lines) for (a) UK Dunlin 1970-1988 and (b) Welsh Dunlin 1970-1997 with confidence intervals (thin lines) calculated with 49, 99, 199 or 499 bootstraps. The numbers of bootstraps for each confidence interval are given in each figure.

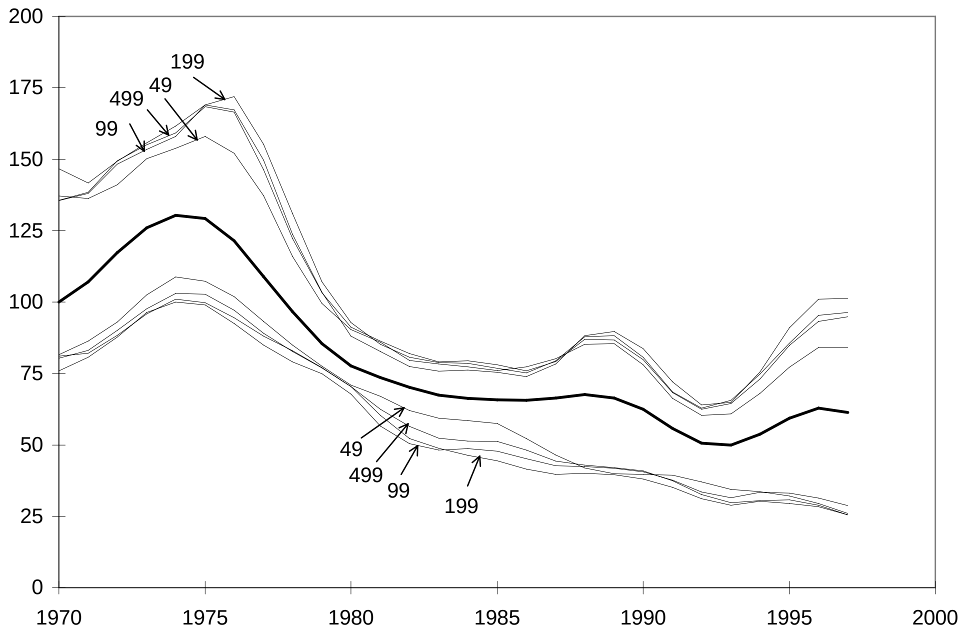
(a) UK Dunlin 1970-1988

Smoothed Index

Year

(b) Welsh Dunlin (1970-1997)

Smoothed Index



Year

5.6 Population Trends of Selected Species, Calculating Changes and Bootstrapping Confidence Intervals

5.6.1 Population trends

The Underhill index, the GAM with 0.3 times the number of years degrees of freedom with 199 bootstrapped 95% confidence intervals and 5, 10 and 25 year change measures (+/- 95% CIs) for Dunlin, Redshank, Turnstone, Wigeon and Mallard were calculated (Figures 5.3 - 5.7). The wader indices are calculated for both the UK and Wales. Nationally, over-wintering wader indices are stable or increasing but in Wales many species are declining (Austin *et al.* submitted) which makes such data particularly useful for the purposes of testing alert triggering methodology. Pintail was due to be considered as it shows large annual variations in number. However computer hardware limitations precluded the use of the Pintail data for the purposes of this report. Despite using a network computer rated at 20 SpecInts and with 2Gb of physical RAM it was not possible to run the GAM program. Whether this is a programming problem or due to reaching the limits of the hardware is unclear.

The index, change measures and confidence intervals are calculated for waders using all count data up to and including 1997. For the duck species, only data from 1970-1994 were available and confidence intervals could not be calculated due to computational limitations. As described in Chapter 2, alerts will be raised for changes in the smoothed index of between 25 and 50% (termed a '25% alert') or for changes greater than 50% (a '50% alert') over different time periods; these thresholds are shown as dotted lines on the figures. It should be noted that positive 'alerts' i.e. increases greater than a 25 or 50% increase can be described as well, although for most species the term 'alert' would be misleading.

A great deal of information is presented on these graphs as they graphically illustrate the index, the smoothing process and the change measures (+/- 95% CI) over several time periods. For routine monitoring, simplified graphs would be supplied to show just the index values and when alerts are triggered. As would be expected, confidence intervals for national data, which comprise 133 sites, tend to be smaller than data for Wales where only 14 sites were considered. For the sake of convenience, the smoothed index and the Underhill index are tied to 100 in 1970. The graph for UK Redshank (Figure 5.4a), especially, highlights a problem as the Underhill index consistently appears above the GAM fit. However, this is merely a scaling problem and associated change measures are not affected. For presentational purposes the mean of the GAM trajectory can be transformed to the mean of the index trajectory which would obviate the problem.

Confidence intervals are reasonably stable throughout the whole time series for all the UK populations, although at major turning points and at the end of the series there is a slight widening in the change measure. For the national measure of change over 5, 10 and 25 years, the confidence intervals for change are generally in the region of +/- 10 to 25% for waders. If alerts are to be triggered at population changes of 25 and 50% then these confidence intervals are realistically small to ensure that most national alerts will be significant although this will obviously depend to some extent on the degree of smoothing and the heterogeneity within the count data. This will vary between species.

Even for a small number of sites, GAMs provide a useful description of the rate of change in waterbird populations. The trajectories for the Welsh data (14 sites qualify as being counted on over 50% of available occasions) show that waders in Wales have undergone a large decline since 1970. For species which have undergone a rapid decline, such as Turnstone, the change measure is significant (i.e. the upper 95% CI is below zero) for most years since the start of the decline in 1985. Regional alerts, which could be based on Environment Agency water catchment regions following Austin & Rehfisch (1998), are therefore possible using GAMs.

5.6.2 Bootstrapping confidence (consistency) intervals and testing significance in change measures

Computation of confidence intervals (see Chapter 4 for discussion of confidence cf consistency intervals) is laborious but perfectly feasible for WeBS wader data, taking approximately 4 hours of real time (90 minutes of processor time) for 199 bootstraps on a DEC Alpha 9000/533 computer for a 30 year set of data. However, wildfowl with between 500-1,000 sites are more problematic. Bootstrap samples for Mallard, which is indexed using just one month, takes up to approximately 6 hours of real time (2.5 hours processor time) to bootstrap a 30 year sample for only 7-8 bootstraps. This time does depend on the number of users sharing processor time, but to perform 199 bootstraps could take 4-6 days for just one species. It is therefore presently not feasible to annually bootstrap confidence intervals for all widespread wildfowl species (e.g. Teal, Mallard, Wigeon, Gadwall, Shoveler, etc.). However, for species such as Red-breasted Merganser and Brent Goose which are coastal in distribution, annually bootstrapped smoothed indices are possible and would take a similar length of time to the wader data. Bootstrapping confidence intervals only for those wildfowl species that could trigger an alert may be the best way forward.

As discussed in the introduction, the problem of randomised sampling is highlighted here. At present for inland sites, a site is counted if a volunteer offers to count it and it is not clear if a representative sample of sites is being covered for each species. . This is not such a problem for purely estuarine species as over 95% of the estuaries are currently counted each year and therefore these are almost completely censused rather than sampled. If a stratified mechanism for site selection could be developed, then GAMs with 95% confidence intervals could be calculated for most, if not all, of the wildfowl species on this smaller sample of sites. This selection could be made using, for example, the region and the size and habitat type of the site.

As the majority of wildfowl are increasing, it would be feasible to annually generate GAMs just for species that show a decline of >25% or more. Computer power is continually increasing and the problem is not likely to be long-term. At present, bootstraps are being performed on the University of East Anglia High Performance Computing Centre's machines, which will be upgraded shortly.

5.6.3 Choice of time intervals over which change is calculated

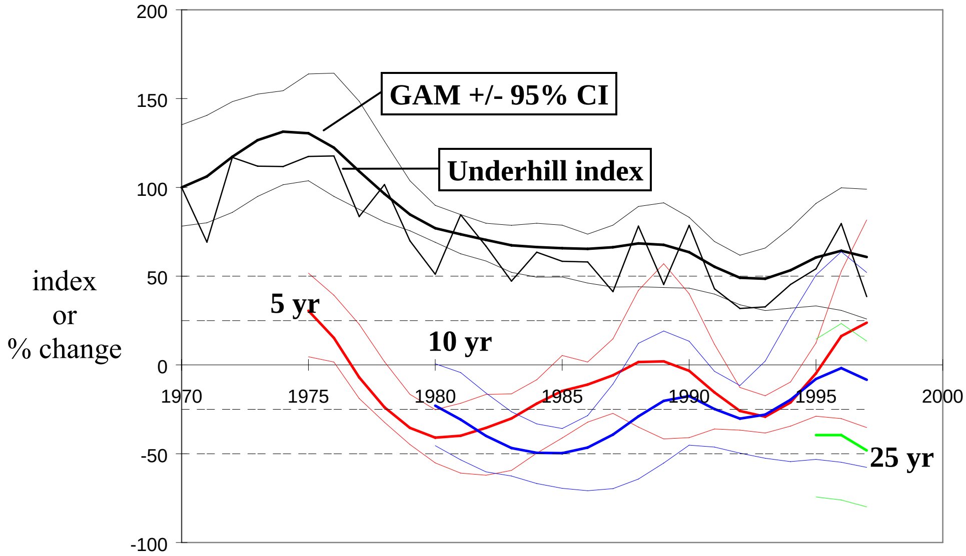
Alerts are triggered by a measure of change over a certain time exceeding a limit and do not necessarily reflect absolute abundance, i.e. if a population declines to 10% of its former level and then stabilises, alerts may be switched off. The choice of the time interval over which change is measured is therefore extremely important and interpretation of the change measures will depend on the degree to which (a) the species shows short-term fluctuations and the (b) nature of the underlying trend. Different time periods over which change is measured will trigger alerts over different time periods and it does not necessarily follow that a 25 year alert is more worthy of triggering off action by the statutory agencies than a 5-year alert.

In some instances a 25-year alert may be of much greater long-term significance than a 5-year alert. It is possible to perceive a case where, as a result of a few cold winters, a 5-year alert is triggered before a species recovers. A slow steady decline, as witnessed for Redshank in Wales, which will only trigger a 25-year alert, could have indicated a decline in habitat quality or amelioration of habitat quality elsewhere (Austin & Rehfisch submitted) which could prove difficult to reverse. Five year alerts are also likely to be turned off sooner than their 10 or 25-year equivalents if the rate of decline in the smoothed population index is reduced.

However, 5-year alerts should not be dismissed. If the population has remained at a steady, or approximately steady, level before the change (e.g. Welsh Turnstone or UK Wigeon) violent short-term change alerts are likely to be triggered by all periods of change (i.e. 5, 10, 25 years). However, if a species has undergone a long term increase and then crashed, measures of change over shorter rather than longer time periods are likely to pick this up and would be more relevant than, say, changes over a 25-year period. It is therefore imperative to measure change over a number of different time periods as the results may be indicative of quite different factors affecting the population dynamics of the species. Interpretation of each individual case is therefore extremely important when considering what action to take.

Figure 5.3 Underhill index, GAM with 0.3*n* d.f. (+/- 95% CIs) and 5, 10 and 25-year change measures (+/- 95% CIs) for Dunlin in the UK and Wales.

(a) Dunlin in Wales



(b) Dunlin in the UK

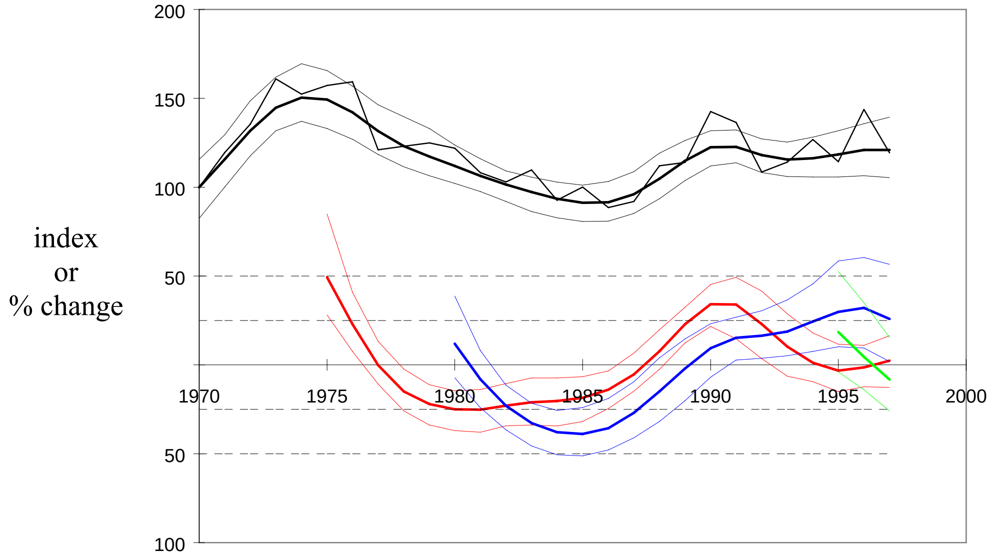
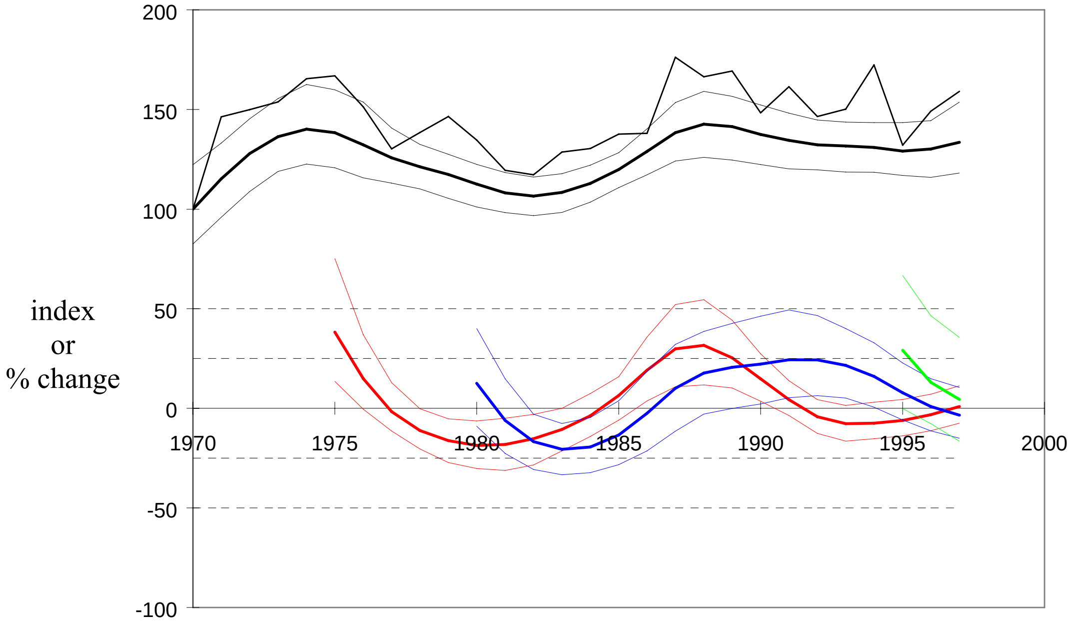


Figure 5.4 (a-b). Underhill index , GAM with 0.3*n* dof (+/- 95% CIs) and 5, 10 and 25-year change measures (+/- 95% CIs) for Redshank in the UK and Wales. Annotations are as for Figure 5.2.

(a) Redshank in the UK



(b) Redshank in Wales

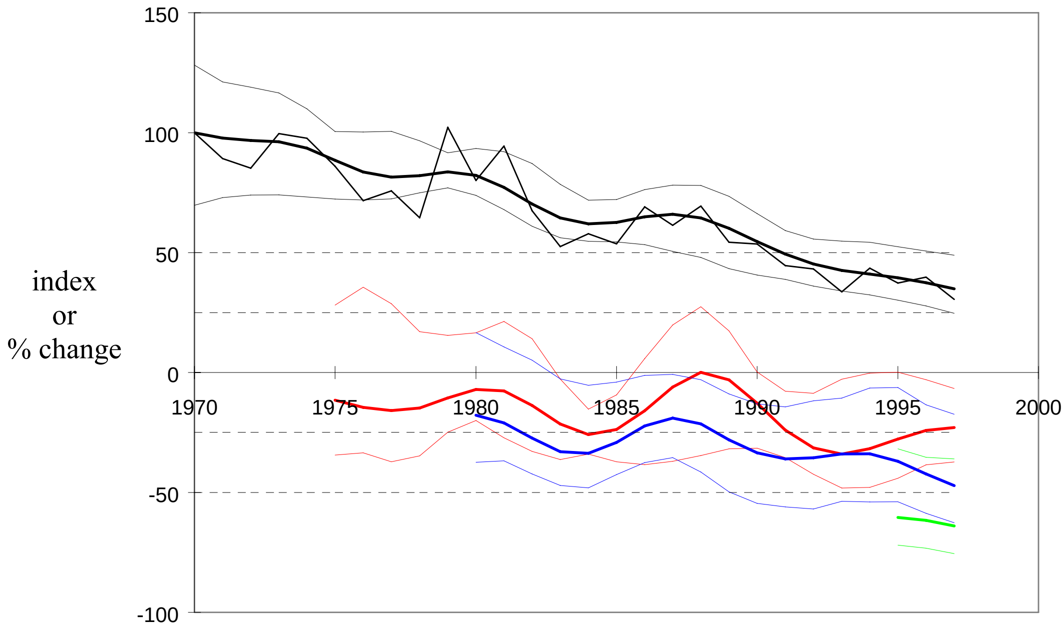
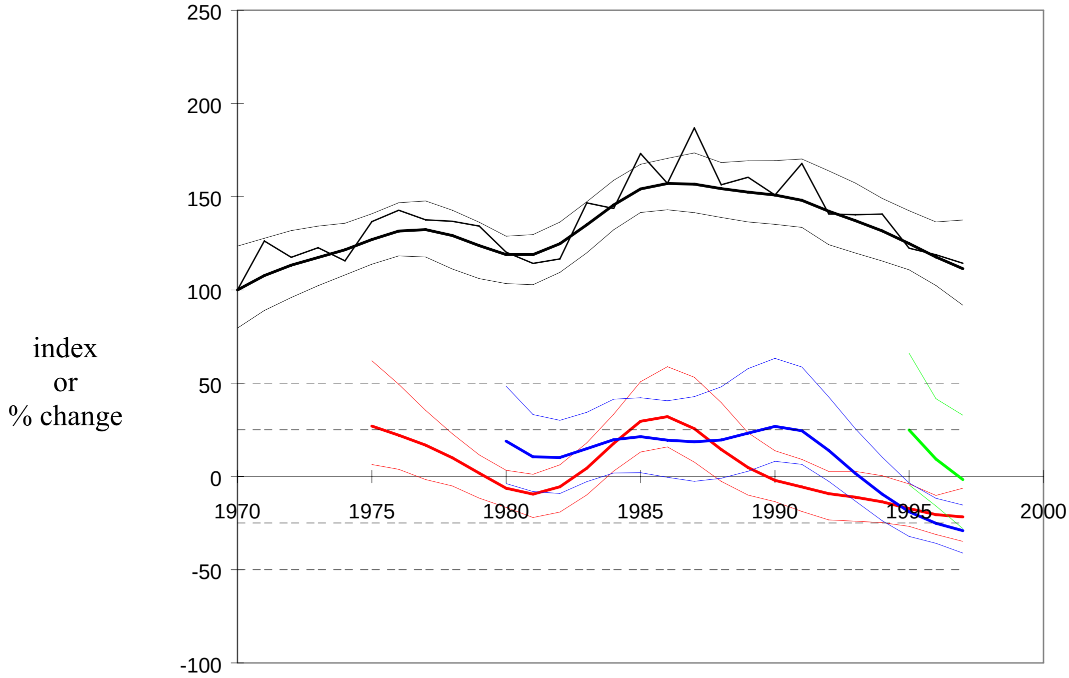


Figure 5.5 (a-b). Underhill index, GAM with 0.3*n* dof (+/- 95% CIs) and 5, 10 and 25-year change measures (+/- 95% CIs) for Turnstone in the UK and Wales. Annotations are as for Figure 5.2.

(a) Turnstone in the UK



(b) Turnstone in Wales

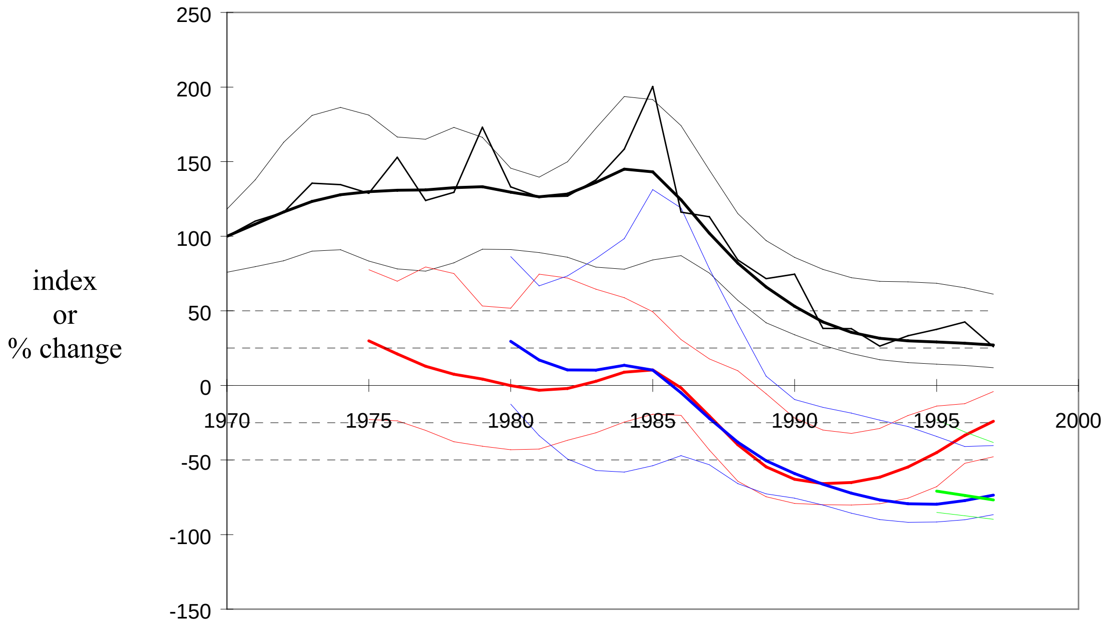


Figure 5.6 Underhill index, GAM with 0.3*n* d.f (+/- 95% CIs) and 5 and 10-year change measures for Wigeon in the UK and Wales 1970-1994. Annotations are as for Figure 5.2**. Bootstrapped confidence intervals are not included due to computational limitations**

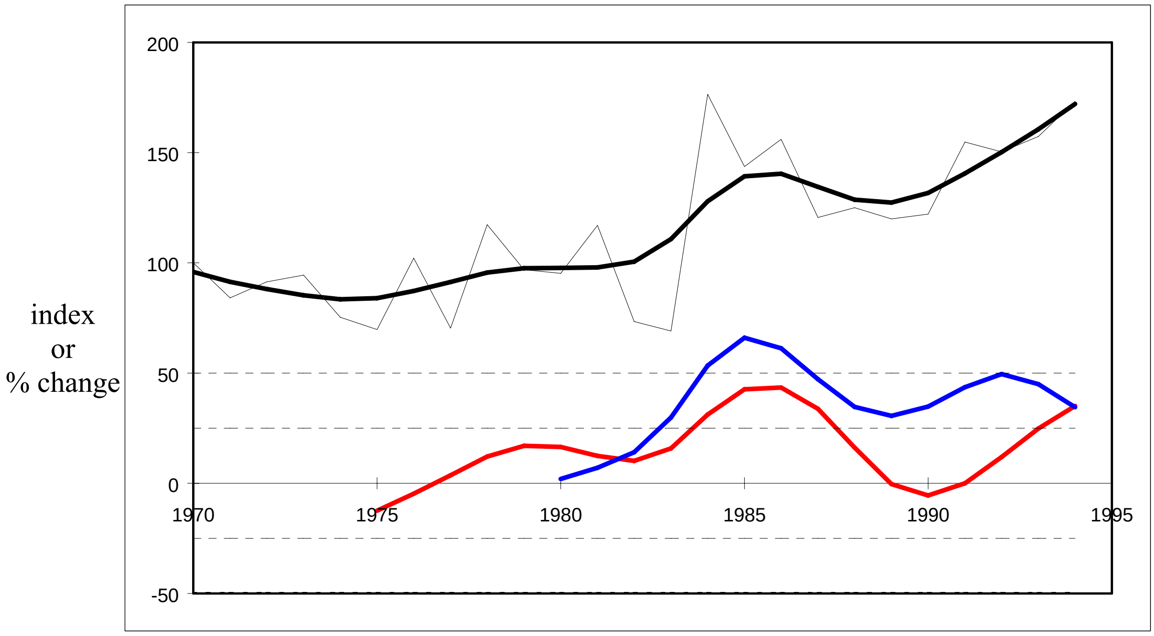
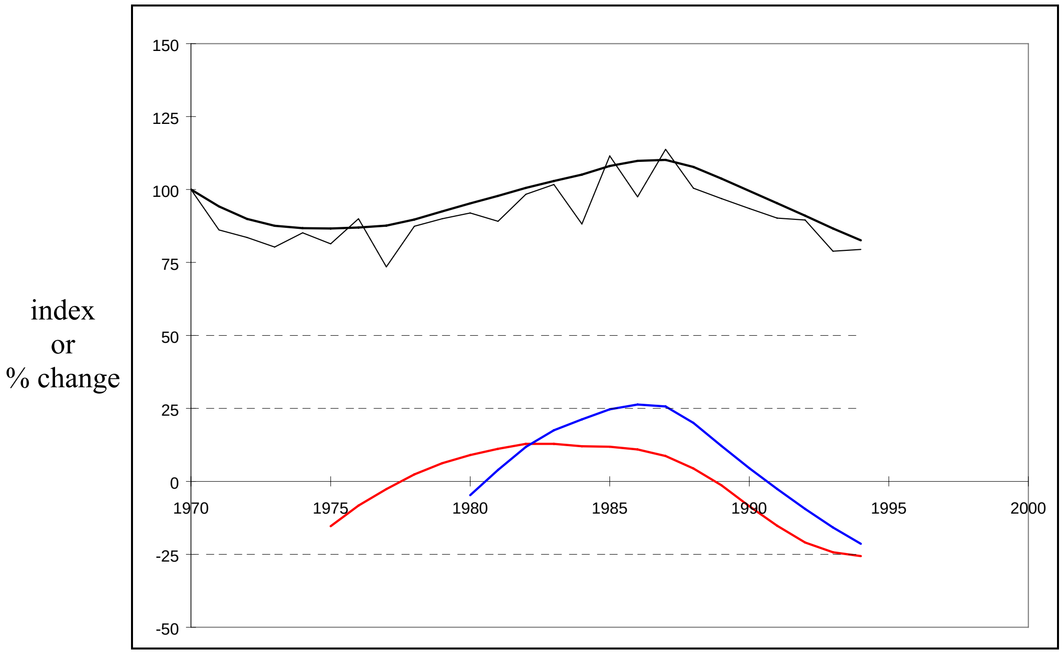


Figure 5.7 Underhill index, GAM with 0.3*n* d.f. (+/- 95% CIs) and 5 and 10-year change measures for Mallard in the UK and Wales 1970-1994. Annotations are as for Figure 5.2. **Bootstrapped confidence intervals are not included due to computational limitations**



5.7 Treatment of Endpoints

As with all smoothing functions, the current endpoint of the data series is likely to change with additional years of data, especially at turning points as the rate of change in the index changes. It is feasible that for certain species that alerts triggered in one year may be turned off for that year given additional years data. These are termed 'false' alerts.

To investigate whether this is likely to be a problem for waterbirds, GAMs were calculated annually for each year from 1975 onwards using the same site selection procedure used in the Underhill process (i.e. sites which were counted on greater than 50% of available occasions). The trajectories for the species under consideration (Figure 5.9) show a range of different scenarios such as increases followed by decreases (e.g. UK Dunlin), steady declines (Redshank in Wales), sudden declines (Turnstone in Wales) and fluctuating numbers (Wigeon).

GAMs that only consider a small number of years might be expected to show very different trajectories to ones for longer time series but this does not seem to be the case. The UK Dunlin and Redshank GAMs show very similar trajectories and are quite robust although, as expected, endpoints deviate from the overall trajectory for future years and there is significant 'fraying' of the trend at turning points although these are fairly small in most cases. The curves for UK Turnstone between 1983 and 1986 show a trajectory which is slightly above the trajectories for years prior to 1983 and post 1986. Although the indication is that the smoothed indices have undergone a fairly major change in these years, in terms of raising alerts it will be less of a problem as measures of change are calculated from one trajectory only. These relative changes are less likely to be affected than absolute changes. Now that longer sets of data exist, it would appear that the endpoints are now likely to suffer less from this problem.

It is difficult to test empirically whether these differences at endpoints are going to be a significant problem in raising alerts. There are two pragmatic solutions:

1. ignore the problem and use the endpoints for raising alerts, or
2. calculate change measures 1,2,3... years retrospectively.

There is an obvious incentive to issue alerts as soon as the data for a particular year have been processed but confidence in the change measure increases with a few years hindsight.

5.8 Applying Different Change Measures to Alerts and a Provisional Alerts System

Given the problem of endpoints, the impact of calculating changes retrospectively on the estimate of change was assessed. We assume that fits for a certain year would improve given data for additional years. The change measures tested here are:

A. **Year on year** is the change measures that would have been calculated in each year from 1975 onwards, i.e. the 5 year change in 1975 refers to the % change from 1970-1975, in 1976 it refers to the % change between 1971-1976 etc.

B. **1 year retrospectively** - changes are calculated one year retrospectively, i.e. 5 and 10-year changes for the previous year are calculated with the benefit of the current years data. For example, the change between 1970 and 1975 would be calculated in 1976 using data up to and including 1976.

C. **2 years retrospectively** - changes are calculated two years retrospectively, i.e. the 5 and 10-year changes for the previous 2 years are calculated with the benefit of an extra two years data. For example, the change between 1970 and 1975 would be calculated in 1977 using data up to and including 1977.

D. **All data** - this calculates change measures for all years using all data up to 1997 so that, for example, the change for 1975-1980 is calculated using the 1997 GAM.

It is clear that calculating change measures year-on-year produces a 'spiky' line which is due endpoint values shifting in future years (Figure 5.10). This is true for all the species that are treated here. Some of the differences between annual calculation of change measures and the retrospective measures of change can vary by 10-15% at turning points. A false 5-year 25% decline alert is almost triggered off for Turnstone in 1982 when year-on-year data are used.

To investigate these differences between the change measures, the mean annual difference between each change measure was calculated for UK populations of Dunlin and Wigeon (Table 5.2). The differences for UK Dunlin were similar in pattern and magnitude t those of UK Turnstone and Redshank which are not presented. In summary, change measures for waders calculated using the data from the current year differ by, on average, 4-6% from a more consistent estimate obtained with at least 1 years hindsight. For Wigeon, a species which shows large inter-annual variation, the mean differences can be as great as 10-15%. Change measures calculated 1or more years retrospectively or using the entire dataset vary by a similar amount of between 1-2% for Dunlin and 4-7% for Wigeon.

Although any of these different change measures could be used to trigger alerts, it is necessary to assess whether the different change measures trigger similar alerts. There are no general patterns to the number of alerts raised for UK Dunlin, Turnstone or Redshank (Tables 5.4-5.6). Year on year measures produced slightly more alerts for UK Dunlin, but slightly fewer for Welsh Turnstone compared with calculating the change retrospectively but in practical terms they produce a similar number of alerts. The timing of alerts is also similar and no change measure triggers alerts substantially earlier or later than others. However, waiting and calculating changes retrospectively will increase the chances of an alert not being raised for up to 2 years after the event.

There obviously has to be a balance between the number of additional years data collected before raising alerts and the problem of raising false alerts. There was a single instance of year on year change measures producing a false alert for the national wader data which was not raised in that year or one year either side using other retrospective change measures (1973-1978 Welsh Redshank). Practically, it appears that there are few problems associated with raising alerts in the year the data are collected, although confidence in the alerts will increase if calculated with the benefit of one year of hindsight. It should be stressed that even if 'false' alerts are raised the actual change measure (given additional years of data) is likely to be very close to a decline of 25%, probably significant (i.e. 95% CIs less than zero) at least for data encompassing the whole of the UK, and therefore should not be of too much concern. It is highly unlikely, if not impossible in the UK situation where many years of data exist, that alerts will be raised using the current years data and that in future years the trend indicates that the population was actually stable or increasing in that year. The waders and wildfowl which are indexed annually are relatively common and widespread. Therefore, unlike some CBC species (such as Woodcock) a decline of more than 25% at the national level is almost bound to be significant. A balance obviously needs to be found between raising an appropriate alert and the speed at which it is raised.

Figure 5.9 Plot of GAMs calculated from 1975 onwards with 0.3*n* degrees of freedom. National and Welsh indices of Redshank, Dunlin and Turnstone, and National indices of Wigeon and Mallard, are shown to assess the effect of endpoints. The smoothed trends have been calculated for each year from 1975 onwards (i.e. 1970-1975, 1970-1976, 1970-1977... etc), and the lines have been scaled so that the index for 1970 equals 100.

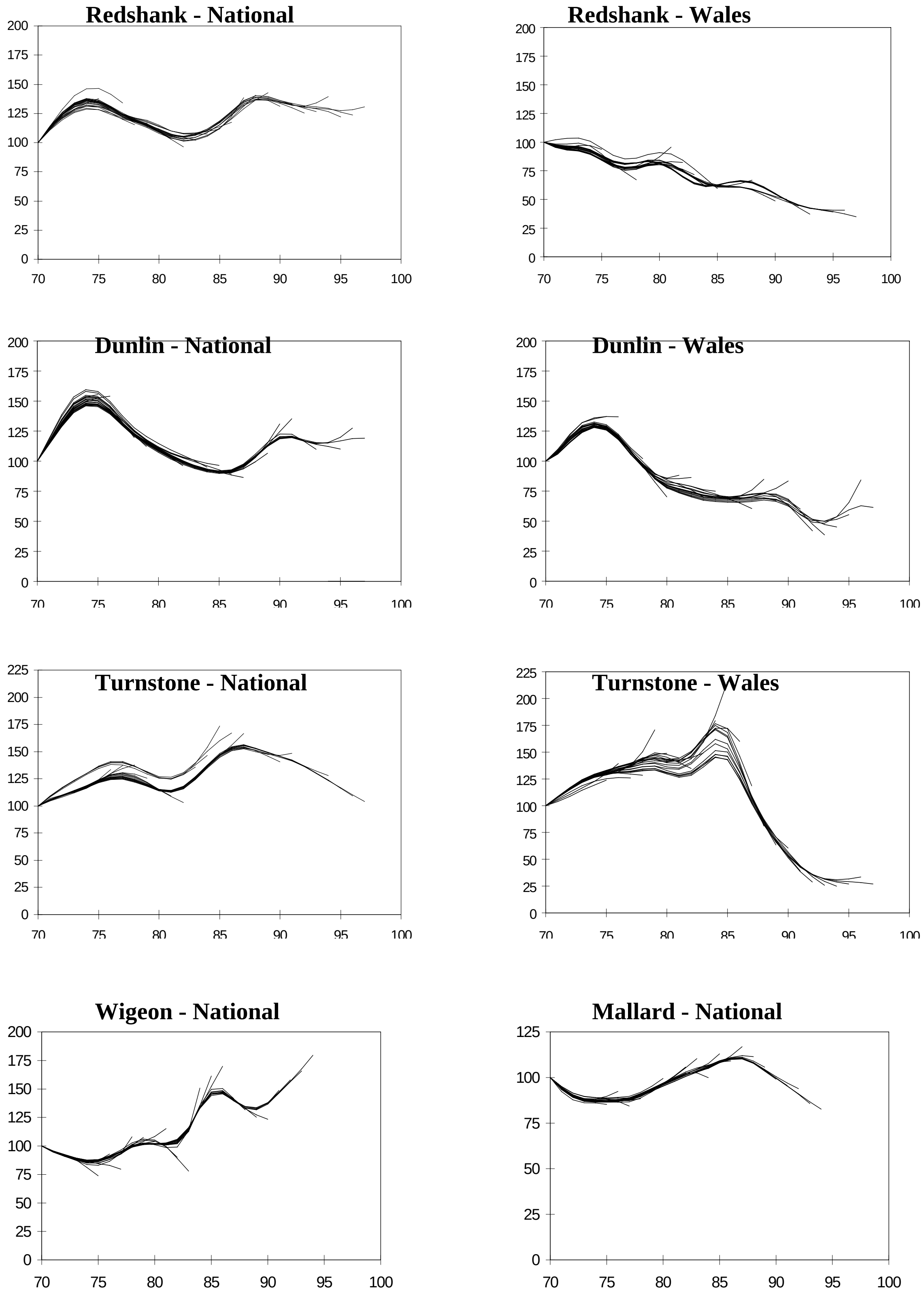
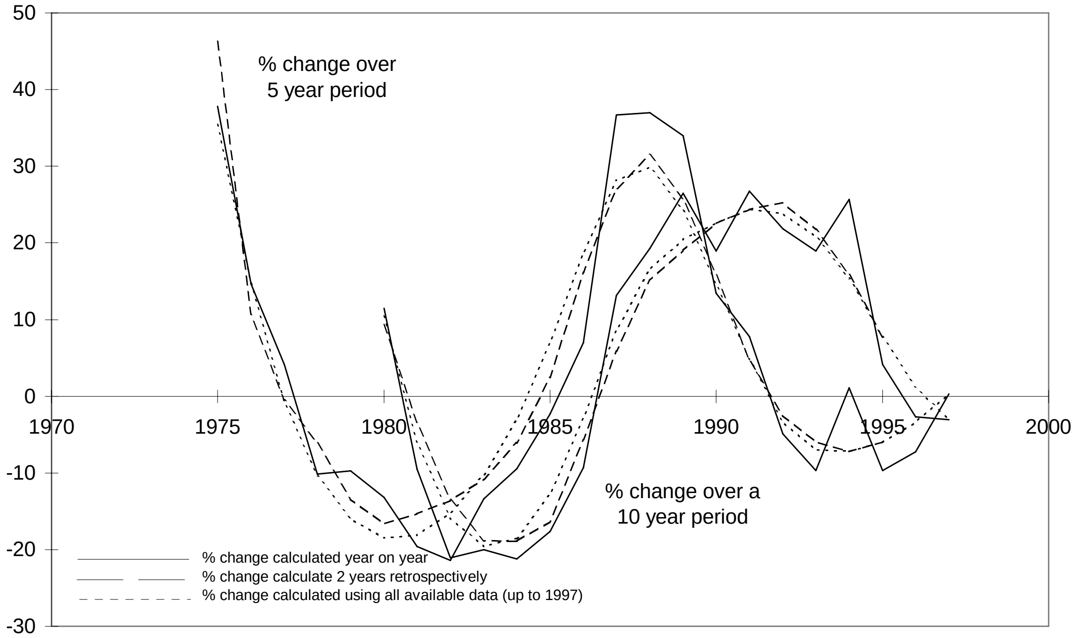
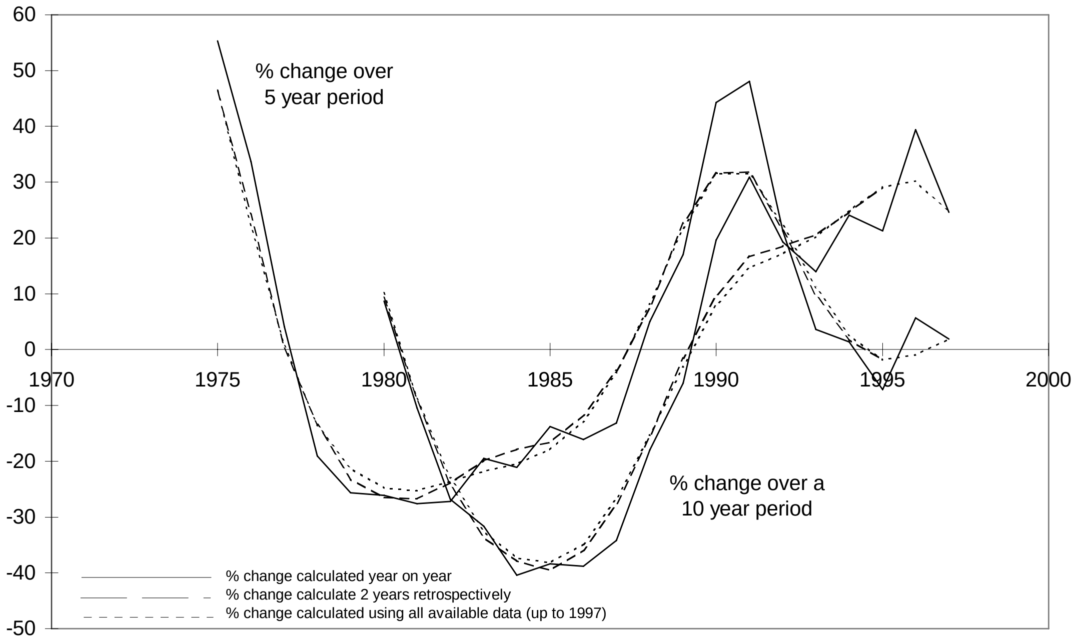


Figure 5.10 (a-e) Changes measures calculated using annually calculated change measures (year on year) and change measures calculated 2 years retrospectively and using all available data.

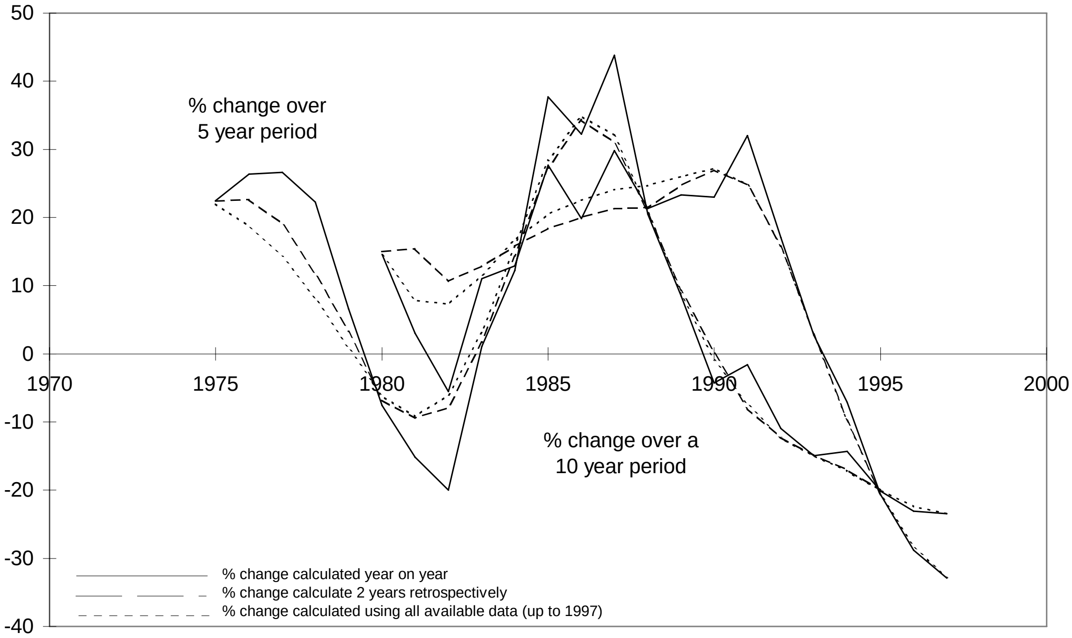
(a) UK Redshank



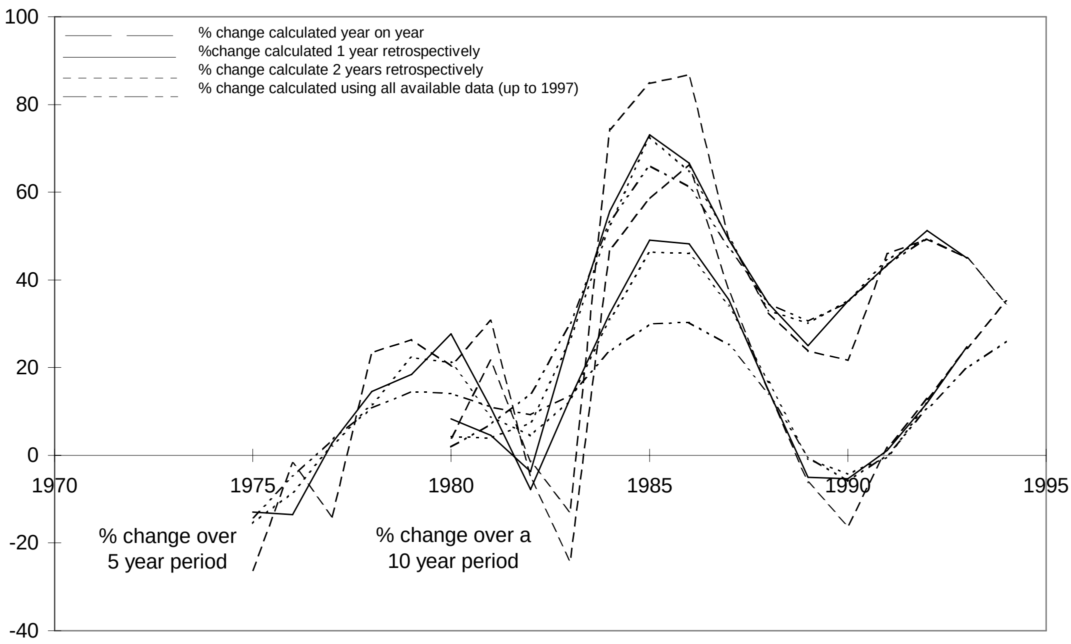
(b) UK Dunlin



(c) UK Turnstone



(d) UK Wigeon



(e) UK Mallard

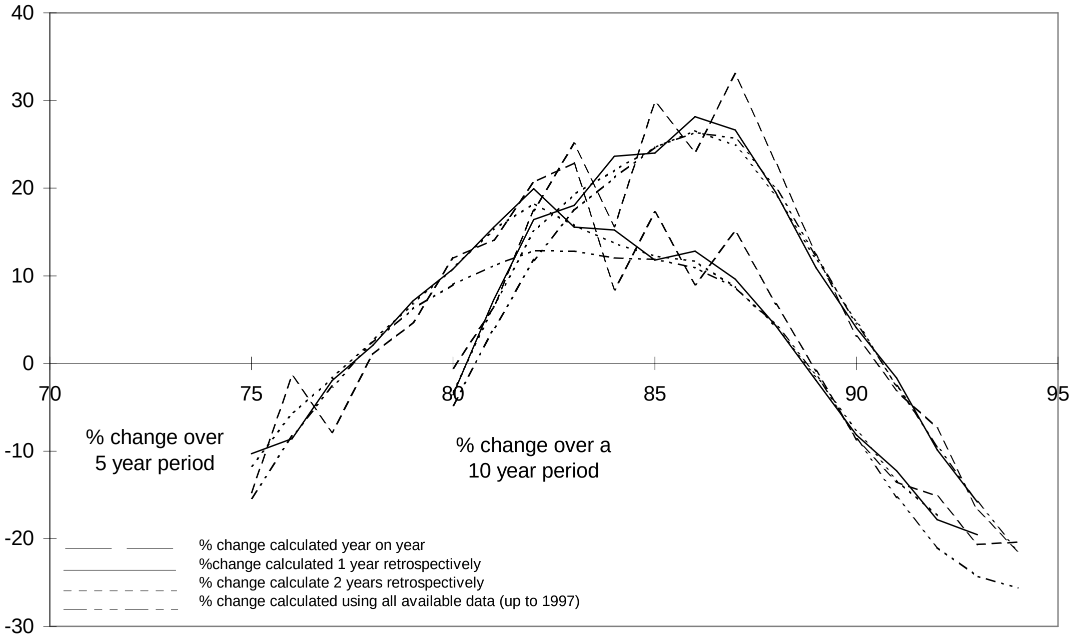

40
30
20
10
0
-10
-20
-30
70
75
80
85
90
95
% change over
5 year period
% change over a
10 year period
% change calculated year on year
%change calculated 1 year retrospectively
% change calculate 2 years retrospectively
% change calculated using all available data (up to 1997)

Table 5.2 Mean annual differences between the different types of change in the smoothed index value under consideration for the UK Dunlin datasets for 1970-1997.

UK Dunlin 5 year changes	2 years of hindsight	1 year of hindsight	1997 data
Year on Year	4.94	4.58	5.51
1 year retrospectively	1.56		1.98
2 retrospectively			1.02
1997 data			

UK Dunlin 10 year changes	2 years of hindsight	1 year of hindsight	1997 data
Year on Year	6.21	4.61	4.82
1 year retrospectively	1.5		1.97
2 retrospectively			0.95
1997 data			

Table 5.3 Mean annual differences between the different types of change in the smoothed index values under consideration for the UK Wigeon datasets for 1970-1994.

UK Wigeon 5 year changes	2 years retro	1 year retro	1994 data
Year on Year	10.7	10.94	13.48
1 year retrospectively	4.07		6.26
2 retrospectively			4.7
1994 data			

UK Wigeon 10 year changes	2 years retro	1 year retro	1994 data
Year on Year	11.12	11.36	11.13
1 year retrospectively	5.55		3.83
2 retrospectively			2.52
1994 data			

Table 5.4 Triggering of alerts using four different measures of change: year on year, 1 and 2 years retrospectively and using all available data for UK and Welsh Dunlin. * = 25% decline alert, ** = 50% decline alert.

UK Dunlin 5 yr alerts	Year on Year	Alert	1 yr retrospective	Alert	2 yr retrospective	Alert	Using all data	Alert
70-75	55.3		52.7		46.29		46.4	
71-76	33.6		24.0		24.31		22.2	
72-77	4.1		-1.1		0.27		0.8	
73-78	-19.0		-16.1		-13.47		-13.6	
74-79	-25.7	*	-22.1		-23.23		-21.3	
75-80	-26.1	*	-26.8	*	-26.48	*	-24.8	
76-81	-27.6	*	-27.7	*	-26.73	*	-25.3	*
77-82	-27.2	*	-23.5		-23.89		-23.6	
78-83	-19.5		-21.5		-19.90		-21.8	
79-84	-21.1		-16.7		-17.90		-20.4	
80-85	-13.8		-16.5		-16.58		-17.9	
81-86	-16.1		-14.7		-11.73		-12.8	
82-87	-13.1		-4.5		-3.78		-4.1	
83-88	5.1		6.1		7.42		8.1	
84-89	17.0		24.1		22.67		21.8	
85-90	44.3		37.1		31.60		31.5	
86-91	48.1		30.9		31.83		31.5	
87-92	21.2		19.5		21.36		22.3	
88-93	3.6		10.2		9.72		11.1	
89-94	1.4		-0.1		1.83		2.6	
90-95	-7.2		-0.4		-1.85		-1.8	
91-96	5.6		-1.0				-1.0	
92-97	1.9						1.9	

UK Dunlin 10 yr alerts	Year on Year	Alert	1 yr retrospective	Alert	2 yr retrospective	Alert	Using all data	Alert
70-80	8.7		-14.1		9.4		10.2	
71-81	-10.5		-21.1		-9.0		-8.7	
72-82	-26.8	*	-36.0	*	-24.3		-23.0	
73-83	-31.6	*	-40.6	*	-33.6	*	-32.5	*
74-84	-40.4	*	-44.7	*	-37.9	*	-37.4	*
75-85	-38.4	*	-44.1	*	-39.5	*	-38.2	*
76-86	-38.8	*	-45.3	*	-35.9	*	-34.9	*
77-87	-34.2	*	-28.5	*	-27.9	*	-26.8	*
78-88	-18.0		-27.4	*	-15.7		-15.4	
79-89	-6.0		-10.4		-1.5		-3.1	
80-90	19.6		-15.4		9.7		8.0	
81-91	30.9		-31.0	*	16.7		14.6	
82-92	19.3		-34.8	*	18.5		17.2	
83-93	14.0		-32.5	*	20.6		20.2	
84-94	24.1		-24.2		24.6		25.0	
85-95	21.3		-1.7		29.1		29.1	
86-96	39.4		-9.8				30.2	
87-97	24.6						24.6	

Welsh Dunlin 5 yr alerts	Year on Year	Alert	1 yr retrospective	Alert	2 yr retrospective	Alert	Using all data	Alert
70-75	37.1		37.1		25.70		29.3	
71-76	24.8		9.7		13.36		13.5	
72-77	-8.1		-7.6		-8.04		-7.1	
73-78	-21.3		-22.4		-24.17		-23.3	
74-79	-31.6	*	-36.2	*	-32.47	*	-34.4	*
75-80	-45.0	*	-33.6	*	-33.51	*	-39.9	*
76-81	-26.8	*	-28.7	*	-32.42	*	-39.4	*
77-82	-19.8		-29.6	*	-26.56	*	-35.6	*
78-83	-28.4	*	-21.1		-20.58		-30.3	*
79-84	-14.8		-16.9		-18.03		-22.5	
80-85	-16.7		-13.9		-15.07		-15.4	
81-86	-11.4		-17.8		-8.07		-10.7	
82-87	-21.4		2.2		-6.70		-5.5	
83-88	19.3		-3.8		2.72		0.3	
84-89	-4.8		10.4		1.83		0.1	
85-90	21.1		-3.8		-9.57		-5.1	
86-91	-15.1		-26.1	*	-15.49		-15.2	
87-92	-42.3	*	-32.5	*	-26.01	*	-23.8	
88-93	-47.1	*	-33.7	*	-28.34	*	-26.1	*
89-94	-35.8	*	-24.4		-20.79		-19.1	
90-95	-13.8		3.6		-4.95		-4.9	
91-96	52.8		12.9				12.9	
92-97	21.5						21.5	

Welsh Dunlin 10 yr alerts	Year on Year	Alert	1 yr retrospective	Alert	2 yr retrospective	Alert	Using all data	Alert
70-80	-29.8	*	-14.1		-14.7		-22.3	
71-81	-18.1		-21.1		-25.6	*	-31.3	*
72-82	-27.6	*	-36.0	*	-33.8	*	-40.2	*
73-83	-44.7	*	-40.6	*	-41.4	*	-46.5	*
74-84	-43.1	*	-44.7	*	-44.3	*	-49.2	*
75-85	-46.0	*	-44.1	*	-46.3	*	-49.1	*
76-86	-40.7	*	-45.3	*	-40.2	*	-45.9	*
77-87	-43.0	*	-28.5	*	-34.7	*	-39.1	*
78-88	-10.6		-27.4	*	-23.7		-30.1	*
79-89	-22.0		-10.4		-17.0		-22.4	
80-90	4.8		-15.4		-20.1		-19.7	
81-91	-21.7		-31.0	*	-22.8		-24.3	
82-92	-43.0	*	-34.8	*	-29.0	*	-28.0	*
83-93	-45.1	*	-32.5	*	-27.8	*	-25.9	*
84-94	-34.5	*	-24.2		-20.2		-19.0	
85-95	-18.1		-1.7		-9.8		-9.8	
86-96	26.9		-9.8				-4.3	
87-97	-7.4						-7.4	

Table 5.5 Triggering of alerts using three different measures of change: year on year, 1 and 2 years retrospectively and using all data for Welsh Redshank. UK Redshank have not shown declines of >25% and thus their change measures are not shown. * = 25% decline alert, ** = 50% decline alert.

Welsh Redshank 5 yr alerts	Year on Year	Alert	1 yr retrospective	Alert	2 yr retrospective	Alert	Using all data	Alert
70-75	-6.3		-10.3		-13.38		-11.5	
71-76	-18.1		-16.3		-16.37		-14.5	
72-77	-19.8		-22.2		-17.62		-15.8	
73-78	-29.6	*	-15.1		-15.83		-14.8	
74-79	-6.7		-11.1		-10.41		-10.6	
75-80	-4.2		3.1		-3.15		-7.1	
76-81	21.8		4.4		-0.16		-7.6	
77-82	7.2		-1.3		-0.85		-13.7	
78-83	-7.3		-10.6		-10.82		-21.4	
79-84	-22.7		-23.6		-19.57		-25.8	*
80-85	-34.4	*	-23.2		-25.38	*	-23.8	
81-86	-22.1		-24.0		-21.88		-15.9	
82-87	-18.9		-14.1		-19.38		-6.1	
83-88	-2.3		-16.0		-15.83		0.0	
84-89	-14.9		-16.5		-12.39		-3.1	
85-90	-21.4		-14.3		-16.32		-12.8	
86-91	-18.4		-21.9		-24.35		-24.0	
87-92	-27.3	*	-35.5	*	-31.57	*	-31.4	*
88-93	-43.3	*	-34.5	*	-34.03	*	-34.0	*
89-94	-32.4	*	-32.4	*	-31.85	*	-31.7	*
90-95	-28.5	*	-25.5	*	-27.74	*	-27.7	*
91-96	-17.3		-24.2				-24.2	
92-97	-23.0						-23.0	

Welsh Redshank 10 yr alerts	Year on Year	Alert	1 yr retrospective	Alert	2 yr retrospective	Alert	Using all data	Alert
70-80	-18.6		-12.8		-18.0		-17.8	
71-81	0.2		-13.7		-17.4		-21.0	
72-82	-12.3		-18.8		-19.2		-27.4	*
73-83	-22.3		-25.9	*	-26.0	*	-33.0	*
74-84	-31.4	*	-32.4	*	-28.2	*	-33.7	*
75-85	-37.1	*	-27.1	*	-28.3	*	-29.2	*
76-86	-23.7		-23.6		-22.2		-22.3	
77-87	-21.0		-17.3		-22.5		-19.0	
78-88	-14.4		-25.6	*	-25.8	*	-21.4	
79-89	-31.4	*	-34.3	*	-33.8	*	-28.1	*
80-90	-41.2	*	-37.5	*	-38.4	*	-33.5	*
81-91	-38.3	*	-40.6	*	-35.9	*	-36.0	*
82-92	-41.2	*	-38.1	*	-35.3	*	-35.6	*
83-93	-41.5	*	-34.1	*	-34.4	*	-34.0	*
84-94	-34.1	*	-34.7	*	-33.1	*	-33.8	*
85-95	-37.5	*	-34.6	*	-37.0	*	-37.0	*
86-96	-37.4	*	-37.0	*			-42.3	*
87-97	-47.2	*					-47.2	*

Table 5.6 Triggering of alerts using four different measures of change: year on year, 1 and 2 years retrospectively and using all available data for UK and Welsh Turnstone. * = 25% decline alert, ** = 50% decline alert.

UK Turnstone 5 yr alerts	Year on Year	Alert	1 yr retrospective	Alert	2 yr retrospective	Alert	Using all data	Alert
70-75	22.5		24.4		22.41		22.0	
71-76	26.3		23.9		22.65		18.7	
72-77	26.6		22.9		19.12		14.2	
73-78	22.3		14.0		11.63		8.1	
74-79	6.6		2.4		3.27		0.8	
75-80	-7.6		-7.0		-6.80		-6.2	
76-81	-15.2		-14.7		-9.42		-9.2	
77-82	-20.0		-6.6		-7.92		-6.0	
78-83	1.1		0.8		1.67		3.1	
79-84	12.2		17.3		14.32		15.8	
80-85	37.7		26.0		27.30		28.4	
81-86	32.3		38.2		34.29		34.9	
82-87	43.8		31.9		31.03		32.1	
83-88	20.5		20.4		20.75		20.9	
84-89	8.5		7.1		9.28		8.8	
85-90	-4.3		1.3		0.21		-1.0	
86-91	-1.6		-6.2		-8.06		-7.4	
87-92	-10.9		-12.8		-12.27		-12.3	
88-93	-15.0		-13.8		-14.89		-15.0	
89-94	-14.3		-17.3		-16.97		-17.2	
90-95	-20.1		-20.1		-19.98		-20.0	
91-96	-23.1		-22.4				-22.4	
92-97	-23.4						-23.4	

UK Turnstone 10 yr alerts	Year on Year	Alert	1 yr retrospective	Alert	2 yr retrospective	Alert	Using all data	Alert
70-80	14.6		15.3		15.0		14.5	
71-81	3.0		3.6		15.4		7.8	
72-82	-5.5		11.2		10.6		7.3	
73-83	11.0		11.5		12.9		11.5	
74-84	12.9		18.8		15.8		16.7	
75-85	27.6		18.0		18.4		20.5	
76-86	19.8		22.1		20.0		22.5	
77-87	29.8		20.9		21.3		24.1	
78-88	21.3		21.8		21.4		24.7	
79-89	23.3		22.3		24.7		26.0	
80-90	23.0		28.9		26.9		27.2	
81-91	32.0		25.1		24.8		24.8	
82-92	17.0		15.8		15.8		15.8	
83-93	2.7		4.0		2.9		2.8	
84-94	-7.1		-9.7		-9.7		-9.9	
85-95	-20.7		-21.0		-20.7		-20.7	
86-96	-28.8	*	-20.7				-28.2	*
87-97	-32.9	*					-32.9	*

Welsh Turnstone 5 yr alerts	Year on Year	Alert	1 yr retrospective	Alert	2 yr retrospective	Alert	Using all data	Alert
70-75	23.8		29.9		25.10		29.8	
71-76	32.6		18.8		20.80		21.1	
72-77	11.8		11.2		18.49		12.7	
73-78	3.7		22.5		17.66		7.5	
74-79	35.1		17.1		17.65		4.3	
75-80	14.6		14.0		11.53		-0.2	
76-81	8.9		4.8		7.30		-3.3	
77-82	-2.4		5.8		4.39		-2.1	
78-83	5.6		10.1		14.89		2.7	
79-84	22.2		31.2		19.40		8.8	
80-85	56.3		20.3		20.87		10.4	
81-86	10.9		3.1		-1.19		-1.7	
82-87	-20.6		-27.6	*	-27.57	*	-20.5	
83-88	-50.5	**	-48.8	*	-46.79	*	-39.8	*
84-89	-62.9	**	-58.9	**	-57.95	**	-54.5	**
85-90	-63.4	**	-66.7	**	-66.39	**	-63.0	**
86-91	-71.1	**	-70.7	**	-66.39	**	-65.8	**
87-92	-73.1	**	-68.7	**	-66.25	**	-65.1	**
88-93	-70.5	**	-65.4	**	-62.31	**	-61.5	**
89-94	-63.8	**	-57.1	**	-53.90	**	-54.7	**
90-95	-49.9	*	-40.8	*	-45.03	*	-45.0	
91-96	-21.7		-33.5	*			-33.5	
92-97	-24.0						-24.0	

Welsh Turnstone 10 yr alerts	Year on Year	Alert	1 yr retrospective	Alert	2 yr retrospective	Alert	Using all data	Alert
70-80	48.8		47.7		45.2		29.6	
71-81	34.0		30.4		32.8		17.0	
72-82	16.9		25.7		24.9		10.4	
73-83	22.6		28.5		29.9		10.3	
74-84	39.4		44.2		34.3		13.5	
75-85	64.6		30.1		29.3		10.3	
76-86	17.5		7.1		3.5		-4.9	
77-87	-15.2		-21.8		-21.1		-22.2	
78-88	-43.0	*	-40.9	*	-40.0	*	-38.2	*
79-89	-55.3	**	-50.7	**	-51.1	**	-50.5	**
80-90	-56.9	**	-61.4	**	-61.8	**	-59.1	**
81-91	-71.0	**	-71.2	**	-66.1	**	-66.4	**
82-92	-79.3	**	-74.5	**	-72.9	**	-72.3	**
83-93	-81.8	**	-78.9	**	-77.2	**	-76.8	**
84-94	-83.2	**	-80.2	**	-79.1	**	-79.4	**
85-95	-81.1	**	-78.3	**	-79.7	**	-79.7	**
86-96	-73.6	**	-79.7	**			-77.2	**
87-97	-73.5	**					-73.5	**

5.9 Site-based Alerts and Likely Output

GAMs can be applied to WeBS data any scale from the national to the site level. The approach to each is the same, i.e. the data are extracted and then smoothed, change measures calculated and the corresponding alert raised.

One of the prerequisites for the WeBS Alert system was the development of a procedure to produce alerts for individual sites. For sites that are nationally or internationally important for waterbirds species the data can be extracted, the smoothing procedure run (i.e. a GAM with *n* degrees of freedom; 0.3 in this case) and calculate change measures calculated. Running GAMs for individual sites is faster than for national GAMs and could therefore be applied annually to all species, including waterbirds.

We have not tested fully the problems of endpoints and degrees of freedom when running GAMS for a single site for we have assumed that the results of the national and regional tests are applicable. To illustrate the process and describe the likely output from the alerting procedure we have chosen one species, Dunlin, to test the alerting procedure.

National, regional and site-based alerts are shown in summary printouts (Figure 5.11). As would be expected there is more variation in trends and thus the number of alerts triggered counts as the geographical scale at which the population is monitored declines. This may be due to birds shifting about between seasons or due to a greater influence of environmental conditions on counts. Count error is also likely to have a greater influence at a smaller scale. This larger variation will inevitably lead to larger changes in the population and to the production of more alerts. At the site level it may be prudent to ignore the 25% alert and only consider the 50% alerts.

Nationally, there is no cause for a Dunlin alert, but 25% alerts would be triggered in several regions: 25 year alerts in the north-east, south-west and Wales and a 5 year alert in the south. Dunlin have increased by over 50% over a 10 year period in the north-west, Scotland and the Thames regions. These results coincide with what is known about wader population shifts due to climatic change and water quality (Austin & Rehfisch 1998).

The site-based alerts will tend to reflect the regional trends although individual estuaries may show very different patterns of population change within a region. Dunlin on the Severn have undergone a large decline which is ongoing and this presumably is helping drag the Welsh and south-western indices down. The increase in numbers in Poole Harbour and the Burry Inlet will partly counteract this. In the southern region, birds are declining across three of the four sites (Langstone, Chichester and the Medway) but increasing on the Swale. In the Anglian region numbers are generally increasing but going down on the Orwell. As indicated, the sites used follow the current WeBS site codes which split several large estuaries (such as the Severn) into several different sectors. It may be desired to amalgamate such sectors to reproduce as near as possible the boundaries of the SACs, SPAs or other designated units.

It is clear that when raising a site alert it is desirable to understand the change in the population on the site in the context of regional and national populations. Within the GAM framework it is theoretically possible to test whether trends in one or a group of sites differ significantly from each other by performing an analysis of deviance using models which (a) include all sites and (b) include all sites and also an interaction term for the site we wish to compare.

These differences can be tested for by using two different models and, as an example, we have compared trends in Dunlin numbers on the Wash to the Anglian region as a whole (Figure 5.12). First a GAM model is fitted on the normal set of Anglian Dunlin data. This produces a regional fit in the normal way. Next, another GAM model is fitted but with an interaction term for the test site. For all sites but the test site this is set to zero. For the test site, this term is set to the value of the year (or any other linear variable that corresponds with the year so that the model is unconstrained for this site). The GAM is then run in the same way but with the interaction term included as a predictor with a similar number of degrees of freedom associated with the year predictor already included in the model. The deviance is recalculated and the significance tested by calculating the difference in the deviance and degrees of freedom between the two models. This can be compared against the chi-squared distribution in the usual way.

To test that the GAMs were behaving as expected two further models were fitted - a Wash only model and a model with all Anglian sites except the Wash. These models should correspond to the (year + interaction) term and (year) term in the interaction model respectively. These do in fact closely match.

These regional and site comparisons were tested for a number of species and regions. For all species, sites and regions tested the change in the deviance between a (regional) model and a (regional model + test site interaction) model were enormous. The type of models we will be fitting to test site and regional differences will require a critical chi-squared value of between 50-60 at the $P < 0.001$ level. Having changes in deviance in the order of 10,000 or even 100,000 suggest that in these types of models the assumptions about the distribution of the deviance are either not correct or that the differences between trajectories are highly significant. The distribution theory for GAMs is still relatively undeveloped and although simulations have found that the chi-squared distribution is a useful approximation the deviance is not chi-squared distributed, not even asymptotically. Therefore, although deviance can be seen as a measure of similarity, formal *P* values should not be set. For alerts, formal comparisons between sites and regions should not be attempted until the distribution theory for GAMs are further explored. It may be argued that Wash Dunlin were a poor example but for all the nationally and internationally sites for Dunlin similar huge changes in deviance were found.

Figure 5.11 Example printout of site-alert program showing national, regional and site-based alerts for Dunlin. Change measures are shown to the right of the region/site and type of raised to the left alert (5 year, 10 year and 25 year). GAMs with 0.3*n* d.f. were applied for the years 1970-1997. (++/-- = change of +/- 50%, +/- = change of +/- 25%, blank - no alert raised).

(a) **NATIONAL ALERTS**. In this case none are raised.

OBS	ALERT5	ALERT10	ALERT25	SITE	5YR	10YR	25YR
1				NATIONAL DUNLIN	0.01	0.24	-0.08

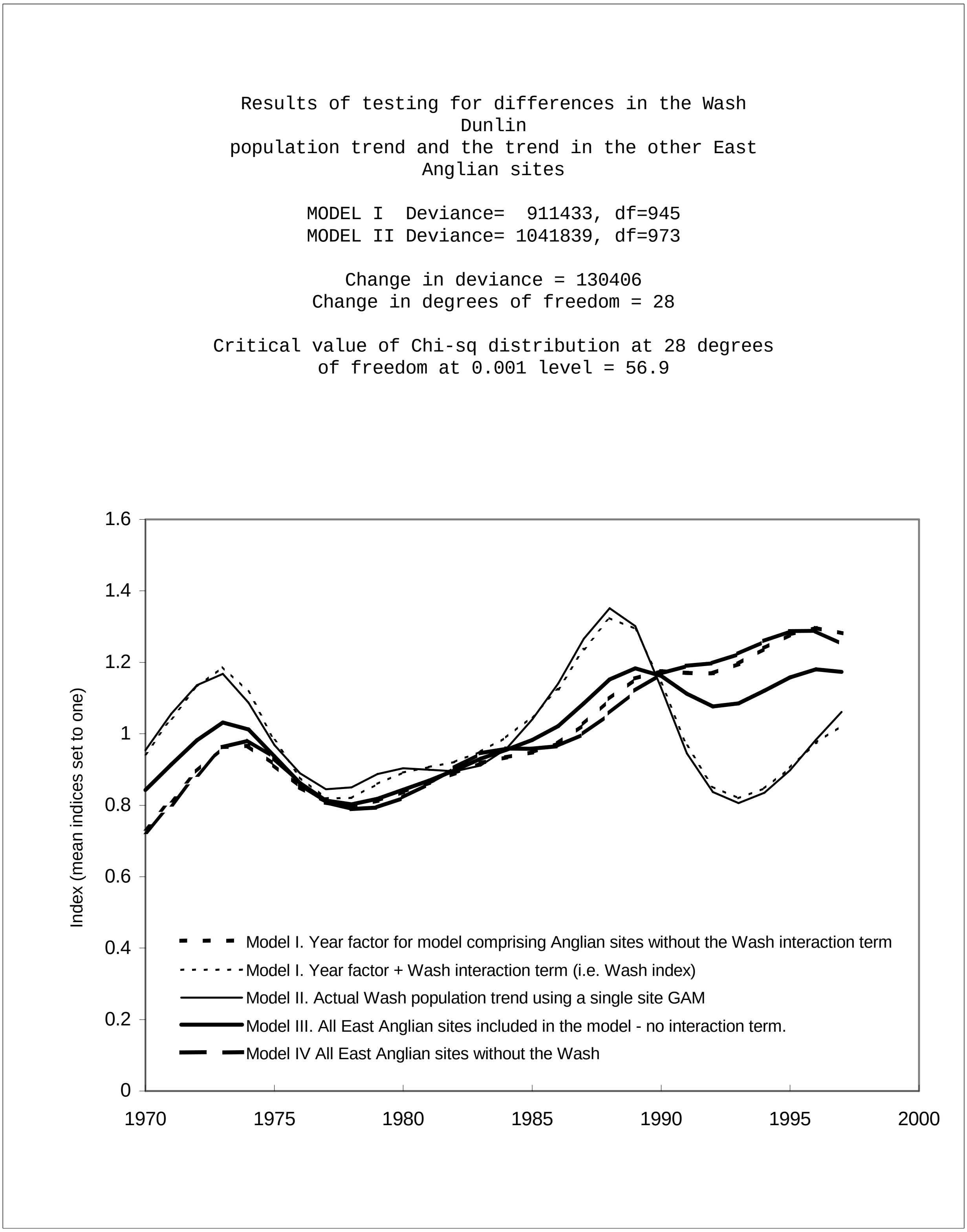
(b) **REGIONAL ALERTS**. Regions as defined in Austin & Rehfisch (1998).

OBS	ALERT5	ALERT10	ALERT25	REGION	5YR	10YR	25YR
1				ANGLIAN	0.08	0.08	0.19
2			-	NORTH-EAST	-0.11	-0.05	-0.46
3		++		NORTH-WEST	0.11	0.82	0.06
4	-			SOUTH	-0.28	-0.21	-0.24
5		++		SCOTLAND	0.15	0.61	-0.01
6			-	SOUTH-WEST	-0.21	-0.04	-0.30
7	+	++		THAMES	0.38	0.78	0.11
8			-	WALES	0.01	0.08	-0.47

(c) **SITE ALERTS.** Site code refers to the WeBS (BoEE) site code. Only sites which are of national or international importance for Dunlin are considered and that have been counted on over 50% of available occasions are included. Some comparisons may not be possible due to missing data.

OBS	ALERT5	ALERT10	ALERT25	CODE	SITE	5YR	10YR	25YR	REGION
1	--	--	n/a	5	GWENT SEVERN	-0.52	-0.63	n/a	WA
2		-	--	15	SEVERN AVON	-0.19	-0.48	-0.55	SW
3	-		-	18	SEVERN BRIDGWATER	-0.48	-0.08	-0.49	SW
4	+	++	++	280	POOLE HARBOUR (CONSOLIDATED)	0.27	0.96	1.66	SW
5	-	-	-	410	LANGSTONE HARBOUR	-0.45	-0.43	-0.38	S-
6	-	n/a	--	420	CHICHESTER HARBOUR	-0.35	n/a	-0.56	S-
7	++		++	500	SWALE ESTUARY	0.53	0.01	1.77	S-
8	--	n/a	+	510	MEDWAY ESTUARY	-0.70	n/a	0.39	S-
9	-	++	n/a	520	NORTH KENT MARSHES	-0.25	1.43	n/a	TH
10	++	++	n/a	540	LEIGH/CANVEY	0.86	1.19	n/a	TH
11	++	+	++	545	FOULNESS	0.80	0.44	1.11	TH
12		+	++	570	DENGIE FLATS	0.19	0.30	1.13	AN
13	n/a		++	575	BLACKWATER ESTUARY	n/a	0.14	0.80	AN
14			+	590	COLNE ESTUARY	-0.04	0.07	0.33	AN
15	++	n/a		600	HAMFORD WATER	0.94	n/a	0.01	AN
16			+	610	STOUR ESTUARY	-0.05	0.24	0.32	AN
17	-	-		620	ORWELL ESTUARY	-0.26	-0.31	0.09	AN
18	+			710	THE WASH	0.26	-0.16	-0.06	AN
19	+	++		720	HUMBER ESTUARY (NORTH)	0.30	0.50	0.13	NE
20			-	790	LINDISFARNE NNR	0.08	0.09	-0.47	NE
21	++	++	+	840	FORTH INNER	0.75	1.89	0.36	SC
22	+	++		1310	NORTH SOLWAY ESTUARY	0.48	0.89	0.16	SC
23	-	-	-	1330	SOUTH SOLWAY CONSOLIDATED	-0.41	-0.32	-0.32	NW
24	-		+	1370	DUDDON ESTUARY	-0.30	0.16	0.41	NW
25		+		1390	MORECAMBE BAY	0.04	0.46	0.05	NW
26		++	-	1400	RIBBLE ESTUARY	0.01	1.94	-0.43	NW
27	++	++	++	1420	MERSEY ESTUARY	0.54	1.87	1.51	NW
28		++	-	1430	DEE ESTUARY	0.21	0.80	-0.38	WA
29	++		+	1650	BURRY INLET (SOUTH SHORE)	0.56	0.24	0.27	WA

Figure 5.12 Graphical illustration of curve fitting for comparison of site and regional trends. The four models detailed in the figure legend are fitted.



5.10 Conclusions Based Purely on GAMs Analyses of Waterbird Count Data

I. GAMs are a useful way of smoothing indices for waterbird count data. Unlike other models, GAMs allow trends to be modelled as a smooth non-linear function of time and are explicitly included in the modelling framework.

II. Various degrees of smoothing can be applied to remove year to year variation from annual indices producing an underlying trend. For waterbirds, as with CBC data, we follow Fewster *et al.* (in press) and recommend using GAMs with 0.3 degrees of freedom associated with the year parameter.

III. Bootstrapping confidence intervals for (a) the smoothed trend and (b) the measures of change is possible for waders but at the limit of present computing capacity for wildfowl. We recommend two options for wildfowl. First, that the 95% CI for the change measure be calculated only in years that an alert is triggered, or second that alerts be based on a stratified sample of all possible sites. This second option will, at present, have to apply to species such as Pintail where it is not possible to run GAMs.

IV. Between 99 and 199 bootstraps are generally sufficient although these could be increased as computer processor speed improves. The 119 bootstraps used for CBC data would be sufficient. At present, it may not be possible to run models for some wildfowl species which are indexed using a large number of months. Pintail, which is indexed using four months, can only be run up to 1980 due to computational limitations thereafter. Further development of the GAM program or another smoothing system may be required for producing confidence intervals for such species. This is likely to be a problem for Cormorant, Mute Swan, Gadwall, Tufted Duck, Ruddy Duck and Coot, all of which are indexed using four or more months.

V. As with all smoothing processes, values for endpoints of time series tend to be less reliable as their values may change with additional years of data, especially at turning points in the trend. For national waterbird data, these changes are relatively small but their magnitude will vary as a result of inter-annual variation in the smoothed index and changes in the number of sites being indexed.

VI. Change measures can be calculated in a number of different ways - annually or with *n* years hindsight. Due to endpoints changing, alerts raised using changes calculated using the current year's data may not have been raised for that year with the benefit of an additional *n* years of data. Changes for a particular year will be slightly more consistent when calculated using additional years of data but, in practice, these differences have very little impact on the alerting procedure. A balance needs to be struck between raising alerts in a timely fashion and having sufficient confidence in the estimate of change but our evidence indicates that there are no clear problems associated with raising alerts based on the last year of available data.

VII. For waterbirds, change measures should be calculated at 5, 10 and 25-year periods and alerts raised if the change exceeds 25% over the time period (a 25% alert) or 50% (a 50% alert). Alerts can be raised for populations that are both increasing or decreasing but perhaps a new term rather than 'alert' should be introduced for increasing populations.

VIII. Using GAMs, alerts can be raised and their significance tested for national and regional populations of waterbirds. Comparisons between site and regional trends are possible but testing the significance of these differences is currently uncertain.

IX. The use of GAMs is developing rapidly and if they are to be used to trigger alerts possible expansion of their capabilities should be kept under review in future years.

6. NATIONAL, REGIONAL AND SITE-BASED ALERTS FOR WATERBIRDS: UNDERHILL AND GAMS

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Chapter 4 assessed the value of using a development of the Underhill Index to generate national and site-based alerts for waterbirds. Chapter 5 assessed the value of GAMs for generating national and site-based alerts for waterbirds. Both methods have proved suitable for the generation of national and site-based alerts but each has costs and benefits. In this chapter the relative benefits of the two methods are briefly contrasted.

Overall approach

6.1 Nations, Regions and Sites

The alerts, based on waterbird change measures, will be produced annually for the UK, England, Northern Ireland, Scotland and Wales. One third of the Ramsar and Special Protection Areas classified for non-breeding waterbirds will be assessed, commented upon and reported on every year in rotation, so that all such sites are covered every three years. One sixth of the Sites of Special Scientific Interest and ASSI classified for non-breeding waterbirds will be assessed, commented upon and reported on every year in rotation, so that all such sites are covered every six years.

6.2 Thresholds and time periods

Following the protocol set in place for the generation of alerts from CBC data, waterbird change measures should flag up population changes of 25-49% and 50% or more over the whole time series, 25, 10 and 5 years. For wintering waterbirds the start of the WeBS index series has been taken to be 1969/70, the start of the Birds of Estuaries Enquiry monitoring. Earlier National Waterfowl Counts data exist for wildfowl but in the absence of major declines prior to 1969/70, 1969/70 was selected as it matched the start date used for the wildfowl indices in the Wetland Bird Survey Annual Reports. These three time periods allow both rapid and slow declines to be detected. The time period over which change is measured is important in that it may describe different types of population change. Five-year alerts will be triggered by rapid declines, 25-year alerts may be triggered by slower, steady decreases through time. Both are equally important.

6.2 Measurement of Population Changes

The Underhill model and GAMs measure population change as the percentage change on an arithmetic scale between two points on a population index. In both instances the index values have been smoothed to remove short-term environmental fluctuations.

6.3 Significance Testing

Confidence intervals require random sampling from either an infinite or a finite population of objects. If the number of objects from which the random sample is taken is finite, a finite population correction is applied which shortens the length of the confidence interval, and reduces it to zero when the sample size is equal to the number of objects available to be sampled. In the case of WeBS alerts, the objects being sampled are estuaries (not birds). WeBS aims to survey the entire set of estuaries (and other major wetland sites) for a species in each month in each year. From technical statistical considerations, the length of the confidence interval on the total count, or census, is zero.

Therefore the intervals produced by both the Underhill model and GAMs, quantities analogous to confidence limits, are more suitably called ‘consistency intervals’. (This could be argued to depend on the proportion of the sites that are covered, and that for the primarily wildfowl species that are present on the less completely covered inland wetlands therefore the consistency intervals start tending towards confidence intervals.) These intervals measure the consistency of the change of population levels across all the estuaries included in the index number computations. If the proportional annual increases and decreases in the counts for a species were similar across all estuaries, the consistency intervals would be short.

Consistency intervals around the population changes have been calculated for the GAM and the Underhill model. An alert is only flagged up as statistically significant if the consistency intervals do not overlap no change. Significance tests against the 25% and 50% threshold levels have not been calculated.

6.4 Presentation of Alert Results

The results for each species may be presented in a tabular form, starting with the national alert status of the species, followed by its regional and designated site alert status (see Figure 5.11).

6.5 Terminology

Alerts can be raised for populations that are both increasing or decreasing but a new term rather than 'alert' should be introduced for increasing populations.

Technical issues

6.6 Degree of Smoothing

GAMs are a useful way of smoothing indices for waterbird count data which unlike other models allow trends to be modelled as a smooth nonlinear function of time which is explicitly included in the modelling framework. For waterbirds, as with CBC data, GAMs with 0.3 degrees of freedom associated with the year parameter are recommended. Similarly, a three-year alert window smoothed the Underhill index. Thus in both instances unnecessary annual variation that could be due to such relatively transient factors as cold winters and poor breeding seasons can be removed to produce an underlying trend. The underlying trend produced by the GAMs is a smooth function of time rather than the linear function of time produced by the Underhill method.

6.7 Endpoints

Endpoints had a relatively small effect on the alerts generated by GAMs, but their magnitude did vary as a result of inter-annual variation in the smoothed index and changes in the number of sites being indexed. As the Underhill methodology smooths by averaging the last three or five years of data there is no endpoint as such.

6.8 The Effect of Calculating Alerts Retrospectively

Change measures can be calculated in a number of different ways - annually or with a few years of hindsight. Due to endpoints changing, occasionally GAMs-based alerts raised using changes calculated using the current year's data would not have been raised for that year with the benefit of a few years extra data. In practice, these differences have very little impact on the alerting procedure. Occasionally year on year alerts raise alerts a year earlier than retrospective alerts (which could be argued to be valuable), but the opposite is also true. From the test data, there are no obvious problems associated with raising alerts based on the last year of available data. The effect of calculating change measures retrospectively was not assessed for the Underhill methodology.

Following the precautionary principle, it is recommended that alerts be assessed one year retrospectively to lessen the likely effect of any endpoints (Figure 5.9).

6.9 Confidence and Consistency Intervals

The GAMs have been run with 95% consistency intervals but the Underhill model with 90% consistency intervals. To ensure comparability with the terrestrial alerts it is recommended that in future the Underhill model be adapted to run with 95% consistency intervals.

Between 99 and 199 bootstraps are generally sufficient for GAMS. Such a number may be sufficient for the Underhill method but this was not tested. The 500 bootstraps used throughout the Underhill testing did not prove to be time limiting.

6.10 Testing the Significance of National, Regional and Site Alerts

Using GAMs, alerts can be raised and the significance of the change in a regional population of waterbirds can be tested against the change in the national population of waterbirds. Comparisons between site and regional trends are in theory possible but testing the significance of these differences is currently uncertain. The tests carried out so far have generated enormous change in deviance values which suggests that in these models the assumption that the deviance values are χ^2 distributed is possibly incorrect or that the test is overly sensitive to small changes. The distribution theory of GAMs for small samples is still relatively underdeveloped and until it has been further explored formal comparisons between sites and regions should not be attempted. The use of GAMs is developing rapidly and if they are to be used to trigger alerts possible expansion of their capabilities should be kept under review in future years. At present it may be wise to rely on largely visual comparisons when assessing if the alerts triggered off at a particular spatial scale are reflecting population changes at another spatial scale.

The Underhill model allows any change in the relative importance of a site for a species to be assessed by examining the successive values of the site factor. This will help interpret the data. Otherwise, no comparisons between site and regional trends have been carried out within the Underhill model.

6.11 Number of Alerts Raised by Both Models

Based on the National Alerts for Dunlin (Table 4 in Chapter 4 and Table 5.4 in Chapter 5) there is a mean annual difference of 8.6 ± 7.4 (S.D.) index points between the Underhill and GAMs methods. The differences are not systematically in one direction and do not appear to obviously affect the results.

Table 6.1 Comparison of the number of year on year alerts raised by Underhill (U.) and GAMs methodology. The Underhill method based on a three-year alert window width and nine-year imputing window. GAMs with 0.3n d.f.

Species	National				Welsh			
	5-year alerts		10-year alerts		5-year alerts		10-year alerts	
	GAM	U.	GAM	U.	GAM	U.	GAM	U.
Dunlin	4	2	6	6	7	-	10	-
Redshank	0	0	0	0	6	*	11	*
Turnstone	0	0	2	1	8	6	10	4

* Error in analyses.

Based on a small sample of comparisons, the Underhill methodology appears to generate slightly fewer alerts than the GAMs (Table 6.1).

6.12 Present Computing Limitations

Using a combination of the Underhill model and a 360 MHz Celeron Pentium, the calculation of Pintail index numbers, alert limits and consistency intervals based on 500 bootstrap samples took 17 minutes. It did not prove possible to run the GAM program for Pintail despite using a powerful mainframe rated at 20 SpecInts and with 2Gb RAM. It has been estimated, based on the time taken to run 7-8 bootstraps, that to perform 199 bootstraps on a widespread species of wildfowl such as Mallard would take some 4-6 days of computing time. Further development of the GAM program or another smoothing system may be required for producing confidence intervals for such wildfowl as Cormorant, Mute Swan, Gadwall, Tufted Duck, Ruddy Duck and Coot which are indexed using four or more months and are present on a large number of sites. At present it does not appear feasible to generate all required UK alerts using GAMs for these species. The number of alerts that will need to be generated for the approximately 45 common species of waterbirds on all designated sites would require too many computer resources.

6.13 Recommendations

At least for wildfowl, the Underhill model should be used to generate alerts until more powerful computers allow faster running of GAMs.

Following the precautionary principle, alerts should be assessed one year retrospectively.

The Underhill model should be run with a three-year alert window width, the GAMs with $0.3n$ degrees of freedom. The Underhill model should be adapted to run with 95% consistency intervals to be consistent with the GAM output. 199 bootstraps should be used for GAMS and 500 bootstraps for the Underhill method.

Until the distribution theory of GAMs for small samples is more advanced, visual comparisons should be used to determine if alerts triggered off at a particular spatial scale are reflecting population changes at another spatial scale.

7. RECENT DEVELOPMENTS IN ALERTING METHODOLOGY

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In *National and site-based alert systems for UK birds* (eds. S.R. Baillie & M.M. Rehfisch). Research Report 226. BTO, Thetford.

7.1 Methodological developments

As new mathematical approaches are developed, their value for solving alerting problems is considered. A Doctoral Thesis by Chiara Mazzetta of Cambridge University will assess the value of Bayesian/MCMC techniques for generating alerts. Probabilities are assigned to quantify the likelihood of a species' decline meriting Red or Amber status, based on site counts either in isolation or in tandem with demographic data. The resulting population trends have a biological underpinning, rather than an arbitrary degree of smoothing, and have been found to compare favourably with GAM-based alternatives in terms of precision.

Some recent methodological developments are already being applied to the generation of alerts.

7.1.1 Waterbird Alert Developments

The detail of the waterbird alerting methodology is updated annually and can be downloaded from the BTO web site. For access information see Maclean *et al*. (2005) in Section 7.2 of this report. The two main recent developments, the application of "biological" and "conservation concern" filters are summarised below.

The "biological filter" is applied to the alerts before they are triggered; it comprises four components.

The "mean absolute percentage change between subsequent winters" addresses the fact that the populations of some species have been historically stable whereas others have shown a history of wide fluctuations between years. Short-term declines in the size of previously stable populations or in those previously showing a steady increase are more likely to be indicative of real declines than short term drops in historically fluctuating species.

The "median longevity of birds", calculated from ringed waterbirds, addresses the issue that relatively larger annual fluctuations are expected in short-lived birds than in long-lived birds.

The "median between winter movements of birds", also calculated from ringed waterbirds, addresses the issue of between-winter site faithfulness. Changes in a site-faithful species are more likely to be due to a local problem than those of a mobile species.

The "median within winter movements of birds", also calculated from ringed waterbirds, addresses the issue of within-winter site faithfulness. False alerts are more likely to be triggered for species that have a higher proportion of individuals that shift between sites within a given winter for some individuals may be missed by the WeBS counts.

The biological filter score is based on the summation of the four contributing scores. The filter scores are set so that species that are short-lived and / or fluctuating and/or highly mobile have a lower score than those that are long-lived and / or stable and / or site faithful. Thus, the lower the score for a species the more restricted the suite of alerts issued without caution.

The "conservation concern filter" aims to restrict the species discussed in the site alerts to those for which the site is important and thus for which decreases in numbers give cause for particular concern to conservationists. The conservation concern filter applies principally to SPAs.

7.1.2 Breeding Bird Alert Developments

There have been no recent major changes in the alerting methodology used for terrestrial birds. For access to details of the methodology used to generate breeding bird population alerts, see Baillie *et al*. (2006) in Section 7.2 of this report.

However, in addition to the population alerts, each year the BTO produces the Nest Record Scheme *Concern List* incorporating those species that are currently demonstrating statistically significant declines in both breeding performance and abundance. Species are placed on the list if a) they demonstrate significant declines in some aspect of breeding performance (clutch and brood size, daily nest failure rates during the egg and nestling stages) over at least the last 15 years and b) they are on the Red or Amber Birds of Conservation Concern list or there is some uncertainty over their population status. The list is intended to act as an early-warning system, focusing attention on those species that may be in greatest need of conservation action in the future and is sent to the UK government's conservation advisors.

7.2 Key recent publications

Atkinson, P.W., Austin, G.E., Rehfisch, M.M., Baker, H., Cranswick, P., Kershaw, M., Robinson, J., Langston, R.H.W., Stroud, D.A., Van Turnhout, C. & Maclean, I.M.D. (2006) Identifying declines in waterbirds: the effects of missing data, population variability and count period on the interpretation of long-term survey data. *Biological Conservation*, 130, 549-559.

To manage and conserve wildlife populations effectively it is necessary to use methods that identify the often non-linear trends in populations, have an inbuilt assessment of trend quality and can analyse count data from a range of spatial scales. A method of trend analysis using generalised additive models is described that produces smoothed indices of abundance that can be used to assess population change from one or more sites or time periods, with any number of estimates of abundance per index period. In the paper the method is applied to count data collected under the Wetland Bird Survey. To highlight declining populations, "alerts" were raised if the population decline was equal to or greater than 50%. Significance was determined using bootstrapped confidence intervals for analyses that included many sites, or a novel Monte-Carlo method for single site analyses. The impact of missing data, species count variability and the number of months used to calculate the population change was greater at individual sites than for national datasets, which were relatively insensitive to changes in the above parameters. For single sites it is essential that three or more counts be made per index period if reliable estimates of population change are required. We propose that the method presented could be applied to a wide range of national or other monitoring schemes for a variety of taxa.

Austin, G.E., Maclean, I.M.D., Atkinson, P.W. & Rehfisch, M.M. (in press) The UK Waterbirds Alerts System. *Proceedings of the Waterbirds Around the World.* Wetlands International, The Netherlands, JNCC, UK, and Ministry for Agriculture, Nature and Food Quality, the Netherlands.

The UK hosts internationally important numbers of waterbirds and to conserve and manage these populations effective monitoring protocols are needed. The Alerts-system, by adopting a standardised method for identifying the direction and magnitude of changes in waterbird numbers at a range of spatial and temporal-scales, provides an effective means of doing so. The system makes use of generalised additive models to produce smoothed indices of abundance and is applied to assess trends at several spatial and temporal-scales. To flag population changes alerts are issued if population declines exceed 25%. Several of the key findings from recent Alerts analyses are presented.

Baillie, S.R., Marchant, J.H., Crick, H.Q.P., Noble, D.G., Balmer, D.E., Coombes, R.H., Downie, I.S., Freeman, S.N., Joys, A.C., Leech, D.I., Raven, M.J., Robinson, R.A. & Thewlis, R.M. (2006) *Breeding Birds in the Wider Countryside: their conservation status 2005*. BTO Research Report No. 435. BTO, Thetford.

The report, that is updated annually (www.bto.org/birdtrends), provides a species-by-species overview of the trends in breeding population size and reproductive success of birds covered by BTO monitoring schemes since the 1960s, at the UK or UK-country scale. It also provides warning alerts to JNCC and Country Agencies and other conservation bodies concerning worrying declines in population size or reproductive success, with special reference to species on the UK red and amber lists. The alerting methodology is described in detail in Section 2.8 of the 2005 report that can be downloaded from www.bto.org/birdtrends2005/index.htm.

Maclean, I.M.D., Austin, G.E., Mellan, H.J. & Girling, T. (2005) *WeBS Alerts 2003/2004: Changes in numbers of wintering waterbirds in the United Kingdom, its Constituent Countries, Special Protection Areas (SPAs) and Sites of Special Scientific Interest (SSSIs)*. BTO Research Report No. 416 to the WeBS partnership. BTO, Thetford.

The report, that is updated annually, provides interpretation of the Wetland Bird Survey (WeBS) trends in over-wintering numbers of common and widespread waterbird species that occur in the constituent countries of the United Kingdom. It is based on the "Alerts System" which provides a standardised technique with which to monitor changes in the numbers of wintering waterbirds in the UK over a range of spatial scales and time periods using WeBS data collected from some 2000 wetlands. The report is divided into four sections: the National Account, an account for the suite of SPAs in Great Britain and Ireland, a section with maps showing the location of upward and downward trends, and a section which details the accounts for each site. The National Account reports on the trends for all species included in the WeBS Alerts System for the UK, Great Britain, and the constituent countries. The SPA suite accounts compares counted numbers and trends on the SPAs in Great Britain and Northern Ireland with those for the relevant countries as a whole. The section with maps indicates, for every species, all locations counted as part of WeBS, at which increases or decreases have occurred. The Site Account section deals with the wetland sites of national importance for non-breeding waterbirds that form part of the SPA and SSSI/ASSI networks. Each site account lists the species for which that site is important and gives details of alerts that have been triggered. The alerting methodology is described in detail in Section 2 of the report that can be downloaded from blx1.bto.org/webs/alerts/index.htm.

8. ACKNOWLEDGEMENTS

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