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ANALYSIS OF MONITORING DATA WITH MANY MISSING VALUES: WHICH METHOD?

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ABSTRACT Large-scale monitoring of bird species becomes more and more important in many countries. In the datasets yielded by these censuses, values are often missing. This poses problems in the analysis of the data. Currently five methods are used to obtain yearly indices of abundance and trends over time: chain index, indexing according to the Mountford method, route regression, imputing of missing data and loglineair Poisson regression. Of each method the advantages and the limitations are dealt with. The loglinear Poisson regression appears to be the most promising approach.

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INTRODUCTION

Large-scale monitoring of flora and fauna is becoming increasingly important in many countries, often with birds as the main taxonomic group under investigation. The main aim of most of the projects is to reliably assess changes at a national or regional scale which can be related to changes in the environment, especially those caused by human interference (Hustings 1992). In general, the basic data are collected by censusing species on a number of sites.

The analysis of the resulting time series data is generally focused on:
1. yearly estimates of abundance,
2. between-year changes and
3. trends over a number of years.

The between-year changes can be easily assessed by means of for instance a paired t-test. Unfortunately, the yearly estimates of abundance and the trends over a certain period of time are often difficult to obtain. One reason is the huge stochastic variation in the data, resulting in a lack of power of the monitoring scheme (Van Strien *et al* 1994). Furthermore, in practice the analysis of the data is severely hampered by the occurrence of many gaps in the sites by years data matrix. When certain sites are not counted in particular years, or when new sites are added and others disappear, simple comparisons of the bird numbers between years will give misleading results. One might circumvent this problem by comparing only those sites that are covered in all years, but then the approach will be soon inappropriate in monitoring practice (Marchant *et al.* 1990).

To cope with incomplete data more properly, several methods are currently being used. They are all based on assumptions, some of which might not be valid in a particular case. Each method has advantages and disadvantages and a review of the various options is therefore appropriate. A review is relevant because of the increasing time span of the monitoring projects in some countries (such as U.S.A., U.K., The Netherlands). Thus the datasets are becoming larger and in principal more powerful for analyzing trends and their possible causes.

However, the datasets are not yet large enough to apply formal time series analysis methods as mentioned in Box & Jenkins (1976).

Efficient and reliable methods are essential. The growing interest in methodological issues concerning bird monitoring projects illustrates this (Sauer & Droege 1990). In this paper we focus on several methods used with monitoring schemes: the chain index, the Mountford index, the route regression, the imputing method and the loglinear Poisson regression (table 1).

THE OCCURRENCE OF MISSING VALUES

Collecting basic data in monitoring projects is quite expensive when using professional workers. Therefore, large-scale monitoring is only possible with the aid of skilled volunteers. Their contributions are essential to fulfil the aims of the projects. This requires relative simple, yet well standardised census methods for the collection of the data. Regarding birds these methods are available now (Bibby *et al.* 1992, Hustings *et al.* 1985). But as a consequence, the occurrence of many missing values is unavoidable. Volunteers cannot be obliged to contribute each year over many years. Furthermore, weather conditions may limit the possibilities to survey. In addition, for all sorts of reasons a site may not be surveyed from the beginning of the project or the census at that site may stop prematurely. Therefore, missing values are very likely to enter the dataset and in practice may be numerous (for an theoretical example see table 2).

To give some insight into the magnitude of the discontinuities, the number of missing values in two large-scale bird monitoring projects run by volunteers in the Netherlands were computed. The Dutch Breeding Bird Survey started in 1984 and nowadays more than 800 sites are involved, of which about 400 are sampled in recent years. From 1984—1991 the sites x years matrix contains 57% missing values,

Table 1. Characteristics of the five methods discussed.

		focus on	use of data	random walk	between-yr changes across sites	weighting factors	incorporation of covariates	zero counts	required computer power
1.	Chain index	annual indices	only of paired sites	likely	neglected	no	no	no problem	very small
2.	Mountford index	annual indices	all	possible	assumed similar	automatic	no	no problem	large
3.	Route regression	linear trends	all	absent	differences taken into account	ad hoc	possible	problematic	small
4.	Imputing	annual indices	all	absent	assumed similar	automatic	problematic	no problem	large
5.	Loglinear Poisson regression	annual indices + trends	all	absent	differences can be taken into account	automatic	possible	no problem	large

Table 2. Example of the occurrence of missing values in a dataset.
X = count
. = missing count

site \ year	1	2	3	4	5	6	7
1	X	X	X	X	X	X	.
2	X	X	X	.	.	.	.
3	X	X	.	.	X	X	X
4	.	.	X	.	X	X	.
5	.	.	X	X	X	X	X
6	.	.	X	X	X	.	.
7	.	.	.	.	X	X	X
8	.	.	.	.	X	X	X

partly caused by newly started plots in the years after the start. Those sites that have been covered from 1984 onwards contain 30% missing values. The number of missing values is even greater in the Point Transect Counts of Wintering Birds that runs from 1980: the proportion of missing values from 1980—1991 is 61%. Sites covered since 1980 contained 43% missing counts over the entire period. This is because the volunteers are less willing to watch birds in bad winter weather conditions.

CURRENT METHODS OF ANALYSIS

Chain index

Description
A common method applied to monitoring data is the chain index or ratio method (Ogilvie 1967), used for example in the analysis of the Common Bird Census data by the BTO in the U.K. (Marchant *et al.* 1990). The chain index has been proposed in order to make numbers of a species comparable from year-to-year when certain counts are missing (see Crawford 1991). For each year bird numbers are summed over all sites counted and compared with the numbers in a year preceding or succeeding year. Only sites that are counted in two successive years are involved in the calculation of the ratio of the two years:

$$\text{ratio (year}_{i+1} / \text{year}_i) = \sum \text{(count in year}_{i+1}) / \sum \text{(count in year}_i)$$

where counts are summed over all paired sites. The ratios are then chained around a reference base year, resulting in yearly indices for each species. No weighting of counts of different sites occurs, except for the total numbers of individuals.

Advantages
Sites with missing values can still be used in the calculation of indices for those years containing paired sites surveyed. Furthermore, the method of calculation is very simple and straightforward. It is clear to almost everybody how the indices are being calculated. Especially towards the volunteer bird watchers and researchers lacking a sound statistical background, this is an important advantage (O'Connor 1990). Zero counts present no serious problem.

Limitations
The chain index method however has certain serious flaws. One drawback is that the method does not use all the data available (O'Connor 1990). Only the data from sites visited in consecutive years are used, thus for site 4 in Table 2 only the counts of year *5* and 6 are compared, thereby excluding the data of year 3. Furthermore, the index ignores differences in changes between sites.

A more important objection to using chain indexing is the phenomenon known as 'random walk' which can occur in incomplete datasets. Random variations in counts of sites that only temporarily join the monitoring programme can cause spurious trends in the time series (Crawford 1991). This is especially important with small samples and with scarce species.

Geissler and Noon (1981) concluded from simulated data that random walk sometimes led to changes of more than 100% within 10—20 years. In their analysis of 25 years of Common Bird Census data Marchant *et al.* (1990) also concluded that random walk might be a serious problem generating artificial trends. Still they felt that the trends were reliable enough to draw conclusions upon, primarily because the sample sizes were large (Moss 1985*).* Yet the use of chain indexing in the CBC is in discussion at this moment (O'Connor 1990; Peach &

Baillie 1994).

Another problem with the chain index is that no test of long-term trends is available which takes into account the mutual dependence of the annual indices.

Mountford index

Description

Mountford (1982) proposed an improvement of the chain index method. Whereas the chain method uses ratios of consecutive years only, Mountford's method uses ratios of non-consecutive years as well. The Mountford index combines the ratios of all pairs of years by taking the linear combination of logratio's that has minimal variance. For this, the variance-covariance matrix of all pairwise ratios is estimated from the primary data. Mountford noticed that the counts for year k and that of year k+h are approximately linearly related, but that the scatter increased with the lag h. This increase in scatter with h is well known and is due to serial correlations in time. The variance-covariance matrix contains information on these serial correlations, although in an implicit way. The rationale of the Mountford index is based on the model:

$$\text{Count} = \text{site effect} * \text{year effect} + \text{error}$$

where count = the numbers of birds counted at a site in a particular year. This model expresses the assumption that expected changes between years are similar across all sites. Mountford provided a goodness-of-fit test for this assumption. For the error component of the model, it is assumed that the error variance is proportional to the expected value of the count and that errors of different years are correlated.

The Mountford index is calculated as a deviation from the grand mean or, if preferred, as a deviation from a base reference year. The method yields standard errors for the indices that take serial correlation into account.

The Mountford index is currently being used in the Netherlands by the CBS & SOVON and might be used in the future in the United Kingdom by the BTO (see Peach & Baillie 1994).

Advantages

The Mountford method gives more precise indices than the chain index, partly because all informative data are used (Peach & Baillie 1994). Random walk is probably less likely to occur than with the chain index. Zero counts present no serious problems and serial correlations in time are taken into account.

Limitations

The Mountford index is far more demanding computationally than the chain index. The amounts of operations and storage increases with the fourth-power of the number of years.

From an ecological point of view, the assumption of homogeneity of between-year changes across sites is questionable. Changes in bird numbers will differ between sites, especially when the sites differ in habitat or environmental pressure. Indeed, in practice the test for checking this reveals that after several years the assumption is invalid, which restricts the use of the Mountford method to only short-term time series (own observations). Using the data of some selected species from the Common Bird Census, Peach and Baillie (1994) concluded that the maximum numbers of years permitted to produce reliable indices for farmland and for woodland is 6—12 years. To produce long-term indices, they propose a 'moving-window-approach', which is effectively a less extreme form of chaining. This approach remains to be tested more thoroughly, especially whether it completely prevents random walk. Furthermore, that approach appears to be more appropriate for rather homogeneous datasets than for datasets covering a wider variety of habitats.

Mountford did not develop a test for trends in indices over a number of years, although there is nothing in the method that prevents the development of such a test. Methodologically, the Mountford index is not very satisfying. That is because the method is motivated from large-sample theory and does not follow from the model stated. Therefore, it appears extremely difficult to extend the Mountford method to include observer effects and effects of habitat differences.

Route regression

Description

Geissler & Noon (1981) proposed route regression for the statistical testing of long-term trends. Nowadays, route regression is used in Canada and in the United States, for instance in the analysis of the Breeding Bird Survey data (Geissler & Sauer 1990). Whereas the chain index and the Mountford index take pairs of years as the basis for the statistical analysis, route regression takes sites as the basis. The idea behind route regression is that local population change is controlled by site specific factors such as habitat so that each site is likely to show its own trend. This variation in local trends should therefore be used in statistical tests of trends in bird numbers. Route regression has its basis in roadside surveys, the site (sampling unit) being a route with several stops. After initial random selection, the same routes are run several years (Geissler & Sauer 1990). The route regression starts by using linear regression analysis (of logs of counts) for each individual route, adjusted for possible changes in observer. Ignoring observer effects, the model can be written as (James *et al.* 1990):

$$\text{Log(count)} = \log(\text{site effect}) + \log\,(b) * \text{ year} + \text{error}$$

whereby count means the numbers in a particular year and b is the slope term (or trend) for a particular site (or route). From this model, log (b) is estimated. An estimate for the trend b is obtained by back-transformation.

To assess a trend on a higher spatial level, for instance a region or a State, the trends per route are aggregated, using several weight factors. The weights concern the total number of birds counted per route, the number of years the routes were run and the variance of the route trend estimate (Geissler & Sauer 1990). Thus, incomplete routes are weighted less heavily than complete route surveys. The variance of the resulting trend estimate is obtained by bootstrapping the slope estimates. If routes were grouped in strata, the stratum sizes are held fixed in the bootstrap (Geissler & Sauer 1990).

In addition, Sauer & Geissler (1990) developed the 'residual method' to produce annual indices of abundance. The residual method calculates indices from the trends predicted and the average residual variation for each year. These indices can be related to a base year or to the middle year of the period under investigation.

Advantages

All available data are used and random walk is not likely to occur. Many missing values can be taken into account without great problems. The most important advantage is that differences in trends across sites are taken into account leading to valid tests for trends. To some extent, it is possible to incorporate covariates in the regression models per route, such as observer differences and the occurrence of disturbances. Furthermore, the regressions per route (without the aggregations and the calculation of annual indices) are easy to obtain, which means that observers might analyze their own data also. The full method is not difficult to compute on a personal computer.

Limitations

The back-transformation from the log of the counts may result in biased trend estimates. Zero counts present a problem, because log (0) is undefined. To incorporate zero counts a correction of 0.5 has usually been added to all counts. The choice of the correction value can influence trend estimates (Collins 1990). Another problem are the somewhat ad hoc weighting factors used (Collins 1990, James *et al.* 1990, Geissler & Sauer 1990). Therefore, the procedures followed to come to these weighting factors should be made very clear in order to be able to judge their effects in the estimates of the slope parameters.

The route regression method may provide biased results when applied to short time series. Geissler & Sauer (1990) suggest that route regression should not be applied to assess short-term (<5 year) trends. Furthermore, the method uses a linear regression model (of log-counts) which might not be appropriate for a particular species. Trends might be non-linear and counts are not necessarily lognormally distributed and may contain many zero values, especially with less common species.

The residual method appears somewhat ad hoc and does not seem to take care of missing values. As an alternative, Sauer & Geissler (1990) explored the usage of fitting an overall linear model to logged counts, but had technical difficulties fitting the linear model 'as large amounts of memory are necessary for inverting the (X'X) matrices'.

Imputation of missing values

Description

A different way of handling missing data is to impute (i.e. to fill in) missing observations into the dataset by means of a statistical model. Statistical textbooks on imputation are Little & Rubin (1987) and Rubin (1987). The method is used by Underhill & Prys-Jones (1994) to assess waterbird population index numbers. Greenwood *et al.* (1994) have used it to estimate Mute swan population levels. But its use is not restricted to the estimation of total population sizes; it could also be used for relative numbers such as estimated in the Common Bird Census.

Underhill & Prys-Jones focus on the estimation of total numbers of a population in certain years. They treat site by year tables with counts as contingency tables and impute values for missing counts on the basis of a model that is closely related to that used by Mountford (1982). The model is, if we ignore the month effects:

Expected count = site effect $*$ year effect

where count (at a site in a particular year) follows a Poisson-like distribution in which the variance is proportional to the mean. They fit this model by maximum likelihood by using the expectation-maximization (EM) algorithm of Dempster *et al.* (1977). It starts with trial values for the missing values. Given these, the table has no missing values and the usual maximum likelihood estimates of site effects and year effects are simply (proportional to) the row totals and column totals. New values for the missing values are then calculated from these totals (namely by the formula row total x column total / grand total) and the next iteration round starts. The iterations converge, although slowly, to a stable solution which is the maximum likelihood solution for the observed data.

Underhill & Prys-Jones developed a bootstrap procedure to construct confidence intervals, which they cautiously term 'consistency' intervals because of their experimental nature. An interesting aspect of their bootstrap procedure is that sites are bootstrapped, precisely as in route regression.

Advantages

In a simulated data set the imputing method produced index numbers that are close to the values based on the complete dataset (on average within 3% of the true index numbers, but the data used were fairly complete). Imputing did better than the chain method, which produced on average 16% higher numbers than the 'true' index numbers (Underhill & Prys-Jones 1994).

Zero values present no serious problem. In addition to missing values, the imputing method allows an ad hoc way of incorporating counts from incomplete surveys (Underhill & Prys-Jones 1994). Such counts could have been dealt with in a more formal way by treating them as censored values. The imputing method is computationally easy.

Limitations

A major assumption of the approach is that the between-year changes are similar across sites, which is questionable (see also Greenwood *et al* .1994). To avoid too great deviations from reality, Underhill & Prys-Jones recommend using their method 'for imputing missing counts which constitute only a small part of the total number of counts'. Their examples of the imputing method concern about 15—20% missing counts. Imputing can be used with higher amounts of missing counts, but then the assumptions of the model become even more crucial.

Underhill & Prys-Jones mention the possibility of using graphical displays such as resulting from correspondence analysis to detect model violations. The displays might suggest groups of sites for which the model would hold better. The imputing method could then be used for each group in turn. National index numbers need then to be constructed as a weighted sum of those for each group.

The method concentrates on the production of yearly indices and no tests are available for long-term trends.

The imputing method is demanding in computer-time because of the notoriously slow convergence of the EM-algorithm. This problem went unnoticed in Underhill & Prys-Jones (1994). In their example using artificial data, their index for the fourth year is 338.7, whereas after many more iterations it converges to 344.0. [1)] There is no theoretical reason why the effects of observers, disturbances, regions and habitats should not be included in the imputing method. However, the computational burden increases enormously because such additions increase the number of missing combinations of factors. Therefore, it appears problematic to incorporate observer and disturbance effects in this method.

Serial correlation in time is not explicitly taken into account but dealt with indirectly in the computer-intensive bootstrap procedure.

[1)] Corrected in the final version.

Loglinear Poisson regression

Description

Loglinear Poisson regression (a form of GLM, generalized linear modelling, see McCullagh & Nelder (1989), Dobson (1991) and Harrison & Navarro 1994) concerns linear models for the logarithm of the *expected* counts. An early application of loglinear Poisson regression to bird numbers is Opdam *et al.* (1987). Weinreich & Oude Voshaar (1992) used Poisson regression to deal with incomplete datasets of hibernating bats in marl caves. By fitting models using GLM there are no missing data; the data units are simply the combinations that are actually observed. The basic model in our context is

Expected count = site effect $*$ year effect

with count following a Poisson-like distribution in which the variance is proportional to the mean. This is the same model as that used in the imputing method. Also the estimation criterion is the same: both methods fit the model by maximizing the quasi-likelihood. The difference lies in the numerical algorithm that is used to compute the solution. Whereas imputing uses the EM-algorithm, Poisson regression uses an iteratively reweighted least-squares algorithm. After fitting the model by GLM, the model and its estimated parameters, in casu the site effects and the year effects, are used to predict the counts that were missing.

Weinreich & Oude Voshaar (1992) extended the basic model by adding factors for protection measures and for the presence or absence of mushroom culture in the caves. The effects of these factors were tested statistically by deviance tests (McCullagh & Nelder 1989). Region-specific trends were investigated by adding terms for the region. year interaction to the model. The final population indices were made (as in the imputing method) by summing the counts over each particular year, using the predicted count when the count was missing. It is a surprising property of the loglinear Poisson model (actually, of any GLM with canonical link) that the same result is obtained if the index is defined as the sum of predicted counts over all sites in each particular year.

Advantages

Standard software is available to analyze small to medium sized data sets. The numerical method used in Poisson regression converges much quicker than the EM-algorithm used in imputing. Standard errors of estimates and statistical tests are directly available. Observer effects, disturbance factors, regional effects and habitat factors can be taken into account. Extending the model in this way overcomes the assumption made in the basic model, namely that changes over years are the same across sites.

Weinreich and Oude Voshaar (1992) provide an example. Formulating the problem in terms of a GLM allows several other extensions of the basic model. For example, instead of just separate index numbers per year, GLM can also be used to fit a smooth function of year. A trend model as in route regression would look like

Expected count = site effect $* \; b^{\text{year}}$

where year is treated quantitatively (year number) and b is the slope term. Expressed as a loglinear model we obtain

Log(expected count) = log(site effect) +
log(b) $*$ year

This loglinear model comes close to route regression. There are three important differences:

1. the model is meant to be fitted to all data simultaneously instead of to each site separately;
2. the logarithm of the expected count is modelled instead of the logarithm of the count itself. So no back-transformation is needed and zero values present no serious problem;
3. the information content of high counts is assumed higher than of low counts because the variance is assumed proportional to the mean; by contrast, in route regression the standard deviation is assumed proportional to the mean, hence the information content is equal for all counts of a route.

In between the strict trend model and basic model for the index numbers, Generalized Additive Models (Hastie & Tibshirani 1990) can be formulated in which the index numbers form a smooth curve. Smooth index numbers have been explored by Taub (1990) and James *et al.* (1990) earlier in the context of route regression.

Limitations

The statistical tests used in Poisson regression are based on the assumption that counts are independent and that their variance is proportional to the mean. Serial correlation in time and random site effects are ignored. No attempts to apply the bootstrap have so far been made. If large datasets are to be analyzed, Poisson regression requires special software or skilful use of existing software. Similar technical difficulties as mentioned by Sauer & Geissler (1990) with their linear model have to be faced. One of us (ter Braak) was able to run a Poisson regression on a data set with 800 sites and 30 years on a 386 PC using GENSTAT 5 v2.2 (1987).

DISCUSSION

The five methods that have been discussed differ in several ways (table 1). The chain method, the Mountford method and the imputing method focus on yearly estimates of numbers. Trends were derived afterwards from these yearly estimates. Route regression focuses on long-term trends and annual indices are estimated more roughly afterwards. So the first three stress the importance of year-to-year changes, for instance changes due to a severe winter, whereas route regression stresses the importance of trends exceeding such short-term changes from one year to another (see also James *et al.* 1990). With the loglinear Poisson regression one is able to assess both annual indices as well as trends.

This implies that a choice of the method to use for time series data with missing values depends on the primary aim of a monitoring scheme. If the primary aim is to produce reliable annual indices, route regression seems to be less appropriate. The chain index has proved to be inferior to both the Mountford index (Peach & Baillie 1994) and the imputing approach (Underhill & Prys-Jones 1994). This means that only the Mountford index, the imputing method and loglinear Poisson regression should be considered to assess annual indices. As have been discussed already, imputing as developed by Underhill & Prys-Jones (1994) and loglinear Poisson regression use different algorithms but give identical results. The assumption of similar changes across sites underlying the Poisson regression basic model equals the assumption underlying the Mountford method and the imputing method. But with Poisson regression this assumption can be overcome by a good stratification of the sites and by adding environmental factors to the statistical model. Extension of the Mountford method to incorporate covariates appears extremely difficult. It appears possible to incorporate covariates in the imputing method, but this will suffer from computational problems.

We believe that the testing of trends over a number of years is becoming increasingly important. That is not only because time series are becoming longer so that trends can be more easily detected. It is also because monitoring schemes will be used more extensively to assess whether trends are caused by human interference, how trends differ between sites that differ in management, environmental policy etc. This means that the data need to be subdivided into strata according to environmental factors of importance and interest (see also Vos 1994). In addition, weighting procedures are necessary in order to combine the trends from different sites so as to assess the overall trend.

If the primary goal of a monitoring scheme is to examine overall trends in numbers over a number of years, then the route regression approach seems to be rather well equipped. This method can deal with a considerable amount of missing values and does not ignore the existence of different changes across sites. However, a major disadvantage of the route regression is that only linear trends (of log counts) are being examined. Very often, trends are not linear. For instance, the occurrence of three consecutive severe winters caused a significant decline of breeding numbers in many resident species and short distance migrants in the Netherlands, followed by a rapid recovery in most species affected (Van Dijk 1990, Van Strien *et al.* 1994). For a number of years the relations with time were far from linear. One way to overcome this limitation is to divide the period in smaller time spans which meet the linearity assumption (Collins 1990). Other ways are to use a smooth regression model as James *et al.* (1990) proposed or to formulate the problem as a Generalized Additive model, in combination with loglinear Poisson regression.

Poisson regression has the advantages that zero counts can be processed as well and that no ad hoc weighting is needed as with route regression. Poisson regression also allows easy development of good procedures to assess overall trends when particular strata are undersampled or oversampled.

Therefore, we consider loglinear Poisson regression as the most promising approach, both with respect to the assessment of trends as well as annual indices and effects of covariates. This conclusion differs from the one in Greenwood *et al.* (1993) who also discussed the chain index, the Mountford method, the imputing method and route regression. They stated that the Mountford method and route regression should be applied to the same datasets to discover the best method. However, they did not consider loglinear Poisson regression in their discussion.

Serial correlation in the data is often neglected, but deserves more attention. From the above discussed methods only Mountford seriously considered the problem of serial correlation. By using extensions of GLM, in casu generalized linear mixed models (GLMM, Breslow & Clayton 1993), it appears possible to take serial correlations into account as well; this needs further study.

Two sources of bias from missing values should be mentioned. The first is that the comparability of the sites is questionable when turnover of sites occurs in time, leading to changes in habitats, regions etc. (Marchant *et al.* 1990). For instance, in table 2 the index for year 7 is computed from an almost totally different sample as the index for year 2. Because the effects of, for instance, a severe winter depend on the habitats, regions etc. investigated, the same winter effects may produce unequal results. This problem can be circumvented by dividing the sites into strata concerning habitats, regions etc. and computing separate indices for each stratum.

A second potential source of bias is that missing values might be related to trends or expected trends (O'Connor 1990). Usually it is assumed that the occurrence of missing values in the data is not related to the trends in bird numbers at a particular location. This assumption will be valid when missing counts occur erratically within the time series data. But this assumption might be invalid when missing values are due to late entry into the census scheme or due to a early exit (see site 7 and 2 in table 2 respectively). For example, a volunteer bird watcher may have started the census because the bird numbers of the area censused are expected to increase due to changes in management etc. Alternatively, a census worker might lose his interest and stop because the bird numbers on the plot have declined. Both the late start as the premature stop may cause bias in the estimations of large-scale trends. According to Greenwood *et al.* (1993) this bias is limited. Nonetheless, it is necessary to examine the patterns of missing values in the dataset and to check the causes of late starts and early stops.

CONCLUSIONS

For incomplete count data, loglinear Poisson models are suitable for the construction and assessment of annual indices. Simple models of this kind can be fitted either by imputation or by loglinear Poisson regression. Loglinear Poisson regression naturally invites the user to explore more complicated models that include variables that may explain the differences in yearly changes across sites. The method of loglinear Poisson regression also allows the estimation and assessment of smooth trends over a number of years. The method needs to be developed further to allow the analysis of large data sets and of serial correlation in time.

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