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Using simple species lists to monitor trends in animal populations: new methods and a comparison with independent data

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Abstract

There is an urgent need to develop simple and inexpensive methods for monitoring wildlife populations in resource-poor countries. List-based methods have been advocated as simple yet potentially useful biodiversity monitoring tools, and systems have recently been launched in a number of countries to collect species lists. We attempt to advance the use of systematic list-based monitoring by (1) suggesting improvements to the way in which list reporting rates are calculated; (2) assessing the extent to which degrading effort-corrected measures of abundance into simple species lists results in loss of information on population trends; (3) comparing long-term trends in list reporting rates with population trends from a wholly independent monitoring scheme. Daily species lists of birds were derived from regular trapping at a nature reserve in southern England. Most species showed a strong correlation across years between the proportion of lists on which they occurred, adjusted for list length (adjusted list reporting rate; ALRR), and an effort-corrected measure of abundance (captures per unit effort; CPUE). ALRR revealed almost as much about annual variation in abundance as CPUE for all but the most frequently captured species. Long-term (>20 years) trends in ALRRs at the nature reserve were positively correlated with UK national population trends recorded over the same period by an independent, labour-intensive monitoring scheme that counted birds at a large number of widely spread sites. Our results support previous claims that simple species lists could generate data useful for monitoring long-term population trends, particularly where such lists are collected systematically. However, further research on the efficiency of list reporting rates relative to more sophisticated methods is necessary, before list-based methods can be advocated for dedicated monitoring schemes in resource-poor regions.

Introduction

Monitoring trends in the abundance and distribution of species has become an essential pillar of conservation, and represents a more sensitive and informative way of tracking anthropogenic impacts on the global environment than the estimation of extinction rates (Balmford, Green & Jenkins, 2003). Monitoring is used to identify and set conservation priorities (e.g. BirdLife International, 2001; Gregory *et al*., 2003), assess the drivers of population change (e.g. Chamberlain *et al*., 2000; Donald, Green & Heath, 2001) and determine the effectiveness of conservation actions (e.g. Peach *et al*., 2001). Most of the world's countries are now Parties to the Convention on Biological Diversity (CBD), and have an obligation under Article 7 of that agreement to monitor biodiversity. However, limited progress has been made towards developing systems by which to measure the CBD's 2010 target to reduce biodiversity loss (Green *et al*., 2005), conforming to a general pattern for monitoring of conservation effort to lag far behind that in other policy areas (Ferraro & Pattanayak, 2006). At present, most monitoring of biodiversity involves the use of relatively complex and standardized methods in dedicated schemes (Danielsen, Burgess & Balmford, 2005). Monitoring could therefore require considerable resources, but alternatives such as rule-based predictive modelling are no more cost-effective (Chamberlain *et al*., 2004). In most countries, and particularly those with the highest biodiversity, a lack of resources means that the overwhelming majority of taxa are not monitored systematically (Balmford *et al*., 2003). There is therefore a pressing need to identify new protocols for monitoring biodiversity that require fewer resources than existing methods (Chamberlain *et al*., 2004; Danielsen *et al*., 2005).

Simple lists document the presence of species at a particular site, although they are rarely complete. Where lists are

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collected repeatedly at the same site, it becomes possible to calculate a list reporting rate (LRR, also termed frequency of occurrence) for each species at that site (i.e. the proportion of lists it is recorded on). A species' LRR tends to be strongly positively correlated with its abundance (e.g. Bart & Klosiewski, 1989; Harrison *et al*., 1997; Kemp *et al*., 2001; Royle & Nichols, 2003), and is a commonly used method of describing spatial variation in abundance in biological atlases (Gibbons *et al*., in press). This relationship arises from two general ecological principles (Lawton, 1996; Gaston *et al*., 2000): (1) there is a positive correlation between range size and population size, and so an observer is less likely to be within the range of an uncommon species than a common one; (2) even where their ranges overlap, uncommon species tend to occur at lower densities than common species and hence are less likely to be recorded. The relationship between LRR and abundance is sufficiently close and general that a number of methods for estimating relative abundance from presence/absence data have been developed (e.g. Bibby *et al*., 2000). As spatial variation in LRR is correlated with abundance, it is reasonable to expect that changes in LRR are related to changes in abundance (Bart & Klosiewski, 1989; Harrison *et al*., 1997). Lists, particularly when collected repeatedly at well-defined sites, may be an under-valued method for monitoring biodiversity (Droege, Cyr & Larivée, 1998) that may be more efficient than abundance-based methods (Joseph *et al*., 2006). When the abundance of a species declines, it is likely to be recorded on a smaller proportion of lists made at a given site within its geographical range. In addition, because changes in population size are correlated with changes in geographical distribution, the proportion of sites where lists are compiled that lie within the range will also decrease – although range may contract at a slower rate than population (e.g. Donald & Fuller, 1998).

If changes in LRR adequately reflect changes in species abundance, list-based monitoring would have considerable benefits in countries low in resources but high in biodiversity, as lists are easy to collect and can be derived from many different types of activity, such as quadrat sampling, line transects, point counts, atlas studies, trapping for ringing and casual observation. Each activity produces lists that may vary systematically, within and between locations, in the proportion and component of the bird community they record. For example, line transects might record a higher proportion of the species present in open habitats than does netting (Whitman, Hagan & Brokaw, 1997), but the opposite may be true in dense forest. However, if repeated at a single site, each method will produce a number of lists that are directly comparable within, and combinable between, sites. A number of web-based schemes now exist to collect geo-referenced lists of species for conservation purposes (e.g. Roberts, Donald & Fisher, 2005). Comparisons of list-based and count-based indices of long-term population change derived from independent data are few, but usually demonstrate a strong positive correlation between the two (Temple & Cary, 1990; Dunn, Larivée & Cyr, 1996, 2001; Cannon *et al*., 2005). Recent studies suggest that list-based indices of population change can be less or more powerful than count-based indices, depending on the variation in the number of biological or logistical constraints (Strayer, 1999; Joseph *et al*., 2006; Pollock, 2006). Huge numbers of lists have already been collected by observers visiting countries high in biodiversity to observe charismatic fauna (particularly birds) recreationally, and internet-based systems for capturing such data are being developed (Roberts *et al*., 2005). Some of these data span many years, allowing an assessment of long-term trends from existing data sources (e.g. Greenberg & Droege, 1999; Castelletta, Sodhi & Subaraj, 2000; Parody, Cuthbert & Decker, 2001).

List-based monitoring schemes would be easier to establish and more attractive to potential participants in countries with few trained observers than schemes using more advanced field methods, and any loss in precision might be compensated by increased sample sizes (Bart & Klosiewski, 1989). Furthermore, such schemes could include lists collected from a wide range of sources. Seasonal and annual population trends of birds inhabiting British gardens have been estimated from list data with good accuracy and precision, the simplicity of the methods encouraging very large numbers of observers to contribute records (Cannon *et al*., 2005). Low-level monitoring of a wide range of taxa using simple presence/absence data is a robust alternative to intensive monitoring of a small number of taxa (Manley *et al*., 2004). The use of simple presence/absence data may avoid some of the problems of count-based methods, because while both methods share the problem of observer bias in species detection and identification, the latter have the additional problem of observer bias in the accuracy of counting and distance estimation (M. Shaffer, in Bart & Klosiewski, 1989); a bias that has been demonstrated empirically (e.g. Cunningham *et al*., 1999).

In this paper, we attempt to advance the use of species lists in monitoring by assessing the extent to which information is lost when an effort-corrected quantitative estimate of abundance is degraded into a simple list. We are unaware of any long-term list-based datasets that could be compared directly with a systematic monitoring scheme, and so we derived lists from a bird mist-netting project carried out at Wicken Fen, Cambridgeshire, southern England. This dataset is unusual in that, over a long period (1968–2001), mist netting was carried out regularly at a number of discrete sites, and at each visit records were kept of trapping effort (length of nets set and time they were set for). We focus on the extent to which changes in LRR reflect changes in abundance, the proportion of species that show such a relationship and the correlation between long-term trends in LRR and trends derived from wholly independent census data.

Materials and methods

Study area

Wicken Fen (305 ha) is one of the oldest (established in 1899) and most intensively studied nature reserves in the

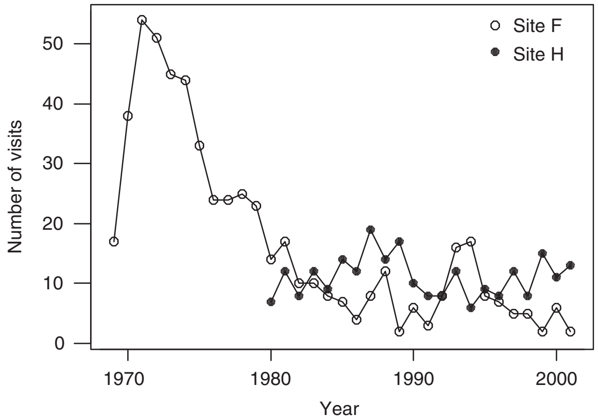

Figure 1 Number of visits made annually to each Wicken Fen ringing site, 1969–2001. This equates to the number of derived lists available in each year.

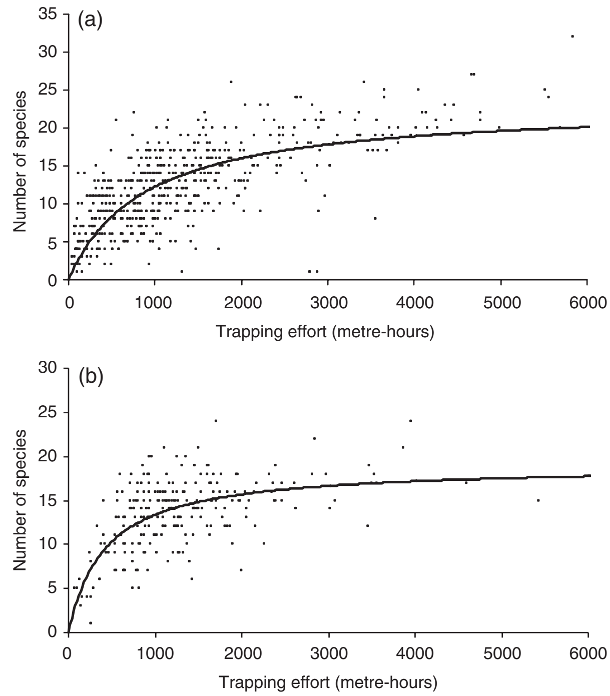

Figure 2 Number of species captured during mist-netting sessions at Wicken Fen in May–August in relation to the effort expended in metre-hours of net. Each point represents one ringing session. Results are shown separately for (a) site F and (b) site H. The curves are Clench functions (Soberón & Llorente, 1993) fitted by non-linear least squares; (a) $y=(0.02615\ x)/(1+0.001133\ x)$, (b) $y=(0.04519\ x)/(1+0.002381\ x)$.

UK. An isolated remnant of fen habitats, it includes woodland, scrub, reed *Phragmites australis* and sedge *Cladium mariscus* beds and open water (Friday & Harley, 2000). We use data collected at two sites within the reserve: Adventurers' Fen (site F; 52°18.1′N, 0°16.5′E) and St Edmund's Fen (site H; 52°18.4′N, 0°17.7′E). Site F is a wetland that includes a reed bed used for commercial harvesting of reeds for thatching; site H consists mainly of fen carr (scrub with some large trees).

Data collection

The Wicken Fen Group, operating under the national ringing scheme run by the British Trust for Ornithology (BTO), has been trapping birds in mist nets for ringing since 1968. Two sites where mist netting has been carried out annually for the longest period (since 1969 for site F and since 1980 for site H) were selected. We restricted analysis to data collected from May to August inclusive, when resident species and summer visitors were both present. The number of days on which mist netting was carried out during these months is shown for each year in Fig. 1. The number of individuals of each species captured, the number of metres of nets set and the length of time for which they were set were recorded at each visit. All birds were marked individually with numbered rings on first capture, and recaptures on the same day were excluded. Birds ringed as nestlings were also excluded. For each visit, the number of individuals of each species captured and the total number of metre-hours of net (the product of length of net and time, taken as a measure of capture effort) were calculated.

Data analysis

Estimating adjusted list reporting rates (ALRR)

We degraded the data from each visit into a list of species captured. To estimate LRR (the proportion of lists on which a particular species was recorded), it was necessary first to account for the effects of capture effort and time of year. Logistic regression analysis was used to model the presence or absence of a species on a list as a dependent binary variable. The objective was to develop methods of analysis that could be used when the only data available are lists, and so we used the total number of species on the list as a proxy for variation in capture effort. Plots of list length against metre-hours of mist netting (Fig. 2) demonstrated a clear relationship between proxy and real estimates of effort. To allow for seasonal effects (caused, e.g. by the appearance of juveniles in the populations of different species at different times), calendar month was entered into models as an independent four-level categorical variable. Two logistic regression models were used to estimate ALRR for each species: one with year and month as categorical variables and list length as a covariate, and another with month as a categorical variable and year and list length as covariates. Species captured on fewer than five occasions were excluded. Analyses were carried out separately for the two sites F and H.

Our method for calculating trends based upon ALLR allowed for variation in recording effort (in the assumed absence of any other information on effort), by including the total number of species recorded on the list as a covariate in a logistic regression with presence or absence on the list as the binary dependent variable. This approach is similar to that of Franklin (1999), who used log-linear models rather than logistic regression. In our view, logistic regression is more generally applicable because it more accurately models the probability of occurrence of common species, which will approach 1 when they are abundant. Clearly, it would be preferable to use a direct measure of effort where possible, such as fieldwork time.

Estimating catch per unit effort (CPUE)

As a different measure of annual variation in abundance, Poisson's regression analysis was used to estimate the number of individuals of a particular species captured per day with annual and month categorical terms added as covariates as in the calculation of ALRR. A log link was specified and the logarithm of the number of metre-hours of mist netting was added as an offset variable. This estimate of CPUE is equivalent to modelling the number of birds caught per metre-hour.

Comparing ALRR and CPUE

For each species, Pearson's correlation was used to describe the relationship between the year-effect coefficients from models of ALRR and CPUE in which year was fitted as a categorical variable. These coefficients were not back-transformed because doing so made the relationships markedly curvilinear. Correlations were weighted by the total number of metre-hours of mist netting per year to allow for the considerable variation in effort between years. Significance levels of the resulting correlation coefficients were not of interest, because the two variables were derived from the same data and so were not independent. However, the correlation coefficients represent an estimate of the extent to which information on changes in abundance was retained when an effort-corrected estimate of abundance was degraded into a simple list-based method. Correlation coefficients for all species were then regressed against the proportion of lists each species was recorded on, to examine the extent to which this retention of information varied with abundance. This relationship was linearized using the inverse hyperbolic tangent transformation of the correlation coefficient and least squares linear regression models were fitted.

Comparing list-based trends with independent data

To determine whether the ALRR-based trends at Wicken Fen reflected any wider patterns, and to compare ALRR trends with trends in numbers from an independent dataset, we used correlation to compare them with trends over the same period from the Common Birds Census (CBC – a dedicated national monitoring scheme operated by the BTO). The CBC used volunteers to map the distribution of birds within well-defined study areas. It collected data from more than 100 farmland and woodland study plots widely scattered across the UK during the breeding season and analysed them using standard methods to estimate the number of territories present on each plot in each year (Marchant *et al.*, 1990). To allow for plot turnover, an annual index of population size from log-linear Poisson's regression models with plot and year main effects were fitted and the year effects used to calculate annual abundances of abundance (Pannekoek & van Streijn, 1996). We carried out least squares regression analyses of $\log_{10}$ transformed CBC population indices on year for each species from pooled data from farmland and woodland plots. These regressions covered the periods for which we had both LRR from Wicken Fen and CBC data (1969–2000 at site F and 1980–2000 at site H). Collection of CBC data ceased after 2000. The number of species analysed was restricted to 40 at site F and 36 at site H because CBC trend data were not available for all species (Supplementary Material Appendix S1). The ALRR-based trends from Wicken Fen with which the UK national trends were compared, were those estimated from models in which year was fitted as a covariate.

Results

The number of lists available each year varied, but was always <20 at site H and declined from up to 50 at site F in the 1970s to about 10 after 1980 (Fig. 1). The mean number of species recorded on a list was 12.3. List length was strongly influenced by ringing effort (Fig. 2). The numbers of each species and the number of days on which they were captured are given in Supplementary Material Appendix S1.

Comparing ALRR and CPUE

For the majority of species, the Pearson correlation coefficient r between year-specific coefficients from the ALRR and CPUE methods exceeded 0.5, but the correlation was markedly weaker for species occurring on a high proportion of lists (Fig. 3, Supplementary Material Appendix S1). At both sites there was a highly significant relationship between transformed values of r and the overall proportion of lists each species was recorded on ($P<0.001$), but analysis of covariance showed that the parameters of the regression model should not be regarded as the same for the two sites ($F_{(2,83)} = 5.39$, $P<0.01$). While the regression slopes for the two sites were not significantly different ($F_{(1,83)} = 2.52$, $P>0.1$), the intercept for site H was significantly greater than for site F ($F_{(1,83)} = 9.87$, $P<0.005$).

Comparing list-based trends with independent data

There was a significant positive correlation across species between long-term trends in ALRR at the two Wicken Fen sites and trends in their national populations over the same period (Fig. 4). At site F, the data were also broken down into three 10-year periods and the regression coefficients were recalculated for each period. Significant positive

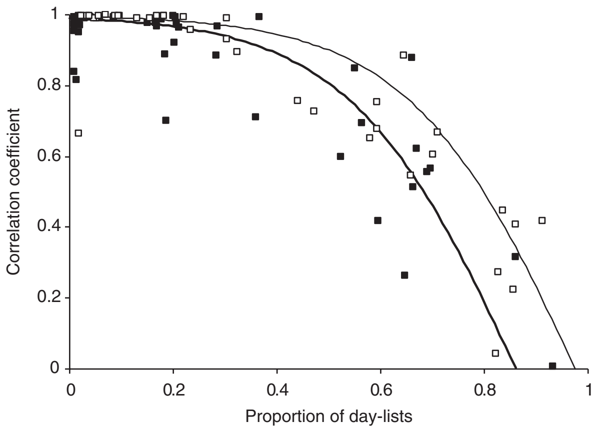

Figure 3 Correlation coefficient between annual fluctuations in adjusted list reporting rate and birds captured per metre-hour of mist netting (see text) in relation to the proportion of all lists on which a species occurred. Each point represents one species at one of the two sites (F, filled squares; H, open squares). Curves show models fitted by least squares linear regression analysis, with the inverse hyperbolic tangent of the correlation coefficient as the dependent variable. The results shown are from the most parsimonious model with site-specific intercepts and a common slope (see text). The thick curve represents site F and the thin curve represents site H.

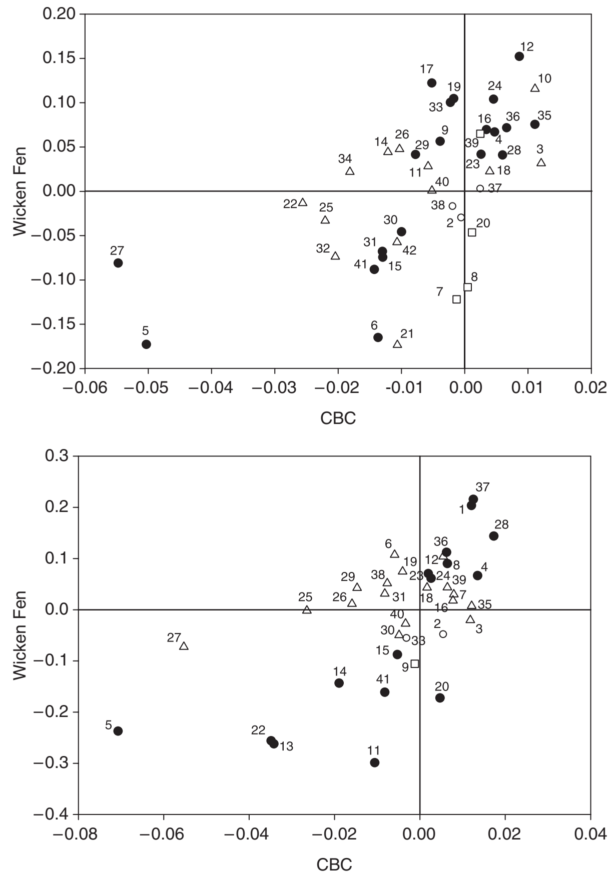

Figure 4 Plots of coefficients of regression of UK National Common Birds Census (CBC) index and Wicken Fen adjusted list reporting rate on year for sites F (upper; 1969–2000) and H (lower; 1980–2000). Correlations were significant in both cases (F: $r_{38}=0.581$, $P<0.001$, H: $r_{34}=0.617$, $P<0.001$). The correlation for site F retained significance after removal of the two points in the lower left quadrant ($r_{36}=0.523$, $P=0.001$). Open circles – neither trend significant; triangles – CBC trend significant; squares – Wicken Fen trend significant; filled circles – both CBC and Wicken Fen trends significant. Significance in this case is accepted when the slope of the regression on year differs from zero at $\alpha=0.05$. Numbers identify the species (see Supplementary Material Appendix S1).

correlations between changes in ALRR and changes in national population remained in the first two of these periods (1970–1979: $r_{38}=0.43$, $P<0.01$; 1980–1989: $r_{38}=0.36$, $P<0.02$) but not in the third decade (1990–1999: $r_{38}=-0.12$, $P>0.05$), when the number of visits made to site F was generally <10 per year (Fig. 1). In order to assess whether the strength of this relationship differed according to the abundance of species at Wicken Fen, as suggested by Fig. 3, we compared a least squares linear regression model (with CBC trend as the dependent variable and Wicken Fen trend as the independent variable) with a more elaborate model in which the slope of this relationship was taken to be a quadratic function of the proportion of all lists for the Wicken Fen site on which each species appeared. An *F*-test was carried out of the combined effect of all the terms in the model that included the proportion of lists a species was recorded on. There was no effect of the proportion of lists terms for either site ($P>0.20$ in both cases). Because the choice of which trend to make the dependent variable is arbitrary, the analysis was repeated with CBC trend as the dependent variable with similar results. Hence, the data provide no evidence for a systematic effect of relative abundance at Wicken Fen on the strength of the correlation between ALRRs and national population trends.

The national CBC detected a significantly higher proportion of population trends that were significantly different from zero at $P<0.05$ than the ALRR analysis at Wicken Fen ($\chi^2_{(1)}=19.73$, $P<0.0005$). Combining data for Wicken Fen sites F and H gives 76 species–site combinations covered by both methods. The CBC analyses detected a significant trend in 87% of these cases (39 declines, 27 increases), compared with 53% for the Wicken Fen ALRR analyses (19 declines, 22 increases). The difference between the two methods in the proportions of increases and decreases was not significant ($\chi^2_{(1)}=1.66$, $P=0.20$). Of the 66 cases in which the CBC indicated a significant population trend, in 36 there was also a significant trend in ALRR at Wicken Fen. For 83% of these (30/36), the trend was in the same direction for the two methods (sign test, two-tailed; $P<0.001$).

Discussion

Our results support previous assertions (e.g. Droege *et al.*, 1998; Pollock, 2006) that list-based methods have considerable capacity to monitor changes in the abundance of species, particularly scarcer species (Joseph *et al.*, 2006).

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For most of the species recorded at Wicken Fen, degrading an effort-corrected measure of abundance to simple presence or absence entailed only a minor loss of information on annual fluctuations in population size. Only for the most frequently recorded species, which occurred on most lists even in the years when they were at their least abundant, were the correlations between the two measures weak. Comparable results were obtained by Bart & Klosiewski (1989), who recorded an average correlation coefficient between LRR and abundance (rather than our measure of occurrence) of >0.95.

The strong correlations between ALRR at Wicken Fen and national population trends recorded by the CBC were unexpected for several reasons. First, they were correlations between results from a single site and those from a national scheme with more than 100 study sites in a typical year, and the correlations were apparent even over periods as short as 10 years. Second, Wicken Fen is an atypical site (being a nature reserve) where birds might be buffered against the effects of changes in land management that have affected populations in the wider British countryside (Chamberlain *et al*., 2000). This might explain why there were significant increases at Wicken Fen for a number of species that declined significantly at the national level. Finally, the ALRRs from Wicken Fen were calculated from a small number (usually <20) of lists each year. Similar correlations between LRR and independently derived abundance data have been described for neotropical migrants in Canada (Dunn *et al*., 1996) and garden birds in the UK (Cannon *et al*., 2005). Our results suggest that useful information could be collected by systematically compiling relatively small numbers of lists, at a relatively small number of sites.

Practical applications of the ALRR method must recognize its underlying assumptions and attempt to avoid or minimize violations of them. We assume that, when the fieldwork used to produce the species list is repeated at a given site, the distribution of recording effort within the site is similar on each occasion. If this is not the case, misleading results would arise if the amount of time spent in different habitats varied among visits. This problem could be avoided by ensuring that the observers follow the same route on each visit and by selecting the boundaries of study areas so that they include one or a few habitat types. Another important assumption is that the observer's probability of detecting and recording each species does not vary. Neglect of the recording of the presence of common species, which might be regarded as of no interest by some observers, would invalidate the method. Changes over time in fieldwork skill and methods might also invalidate the method if they affect the probability of detection of species differently.

Our method quantifies changes in abundance of each species relative to an aggregate of the others in the community, rather than the change in its absolute abundance. If the abundance of all species at a site changed to the same extent over time so that their abundances relative to one another remained the same, then our method would produce little or no evidence of change for any of them. In this event, the adjustment for list length would work against the accuracy of the method. For a given level of effort, list length would decline, and so the use of list length as a surrogate for effort would tend to cancel out the real decline in ALRRs. Furthermore, a decline in the ALRR for a particular species could result either from a decrease in its abundance, or an increase in the abundance of other species in the community. One way in which these problems could be overcome would be to monitor the abundance of a few of the most common species in ways that provide at least an index of their absolute density, and combine this with the ALRR approach to quantify changes in the relative abundance of the scarcer species.

The change in ALRR arising from a given change in the absolute abundance of a species seems unlikely to be linearly related to the magnitude of that change. We expected that changes in ALRR would be less clearly related to change in abundance for common species. Although our comparison of annual estimates of ALRRs and numbers of captures per metre of mist net supported this idea, we found no evidence that the strength of the correlation across species between trends in ALRRs at Wicken Fen and national trends in absolute abundance varied systematically with average abundance.

In spite of the various caveats we have identified, ALRRs calculated from small sample sizes at a single atypical site matched the results from a well-replicated and costly national monitoring scheme well. Further development and validation of list-based methods would pay dividends in extending the taxonomic and geographic scope of biodiversity monitoring. In particular, an assessment of the relative efficiency of list-based methods compared with more sophisticated count methods is required. Analyses of existing monitoring scheme data, such as the Breeding Bird Survey (BBS) in the UK, could further investigate the relationship between LRR and population change, and the relationship between the number of sites at which lists are collected, the number of lists collected at each and their relative effects on the precision of the resulting trend estimates. The BBS dataset is large enough that the survey squares could be divided into two equal sets at random and trends derived from existing methods calculated for one set and the ALRR-based trends derived from the other set. Previous assessments suggest that list-based methods are efficient relative to other methods (Temple & Cary, 1990; Pollock, 2006), but in any new monitoring scheme, the method chosen will inevitably depend upon a trade-off between reliability on the one hand and requirement for resources on the other. List-based methods are likely to fall at the lower end of the scale in terms of reliability and precision, but are likely to score well in terms of resources and sample sizes. Furthermore, list-based monitoring schemes might incorporate many sources of data that are currently collected outside dedicated monitoring schemes.

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Supplementary material

The following material is available for this article online:

Appendix S1. List of species caught at the two ringing sites at Wicken Fen, the number of lists each was recorded on, the total number of individuals caught and Pearson correlation coefficient between ALRR and CPUE. Species lacking CBC trend data comparable to other species, and therefore excluded from some analyses, are marked with an asterisk. Species are numbered to allow data on Fig. 4 to be identified.

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