



# Measuring passerine productivity using constant effort sites: the effect of missed visits

WILL MILES<sup>1</sup>\*, STEPHEN N. FREEMAN<sup>2</sup>, NANCY M. HARRISON<sup>1</sup> and DAWN E. BALMER<sup>2</sup>

<sup>1</sup>Environmental Science Research Centre, Anglia Ruskin University, East Road, Cambridge CB1 1PT

<sup>2</sup>British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU, UK

Site visits for the Constant Effort Sites (CES) ringing scheme are occasionally missed and the standard 12 scheduled annually (May–August) may not all be completed. To account for this, total annual adult and juvenile passerine catches may be adjusted for inclusion in CES productivity-indexing analyses. Adjustment methods and the inclusion of adjusted catches are thought not to generate unrepresentative measures of productivity, but we aimed to test this. Productivity-indexing analyses were carried out using CES data with and without adjusted catches, and long- and short-term changes in productivity were compared. Similarity between productivity indices (and also the precision of estimates) was consistently high between adjusted and unadjusted data, but greatest for species caught most frequently. The inclusion of data adjusted for missed visits increases the precision of measures of productivity by increasing sample sizes, although this improvement is likely to be exaggerated as no account is taken of the uncertainty in the data adjustment. We consider adjustment methods to be appropriate, despite a great potential for between-year variation in the seasonal pattern of catches on CE sites.

The aim of the Integrated Population Monitoring (IPM) programme of the British Trust for Ornithology (BTO) is to determine, and identify the natural and anthropogenic causes of, population changes affecting common breeding birds in Britain and Ireland (Baillie 1990). Long-term monitoring of breeding performance, abundance and survival rates by different projects within the programme allows stages of the life-cycle at which the most important changes are occurring to be identified (eg Greenwood *et al* 1994, Thomson *et al* 1997, Baillie *et al* 1999, Freeman *et al* 2007). Direct measures of productivity integrating all breeding events across the whole breeding season, including multi-brooding and early post-fledging mortality, are provided only by the Constant Effort Sites (CES) mist-netting scheme (Peach *et al* 1996, Robinson *et al* 2007).

The CES scheme uses total annual catches of adults and juveniles from standardised mist-netting between May and August to measure changes in abundance and productivity of common songbirds (Baillie *et al* 1986, du Feu & McMeeking 1991, Baillie *et al* 2007). An index of the annual ratio of juveniles to adults is used to measure productivity changes across the years, for each species where the data are sufficient: productivity indices were calculated for 25 species for the period 1983–2004 (Clark *et al* 2005). Twelve mist-netting visits are intended to be completed at all Constant Effort (CE) sites between May and August, each within one of 12 consecutive periods, standardised by

BTO staff in advance of the season (Peach *et al* 1996, 1998). In certain circumstances, ringers may unavoidably miss one or more site visits, but this does not necessarily mean that data from all completed visits are wasted (Peach *et al* 1996, Robinson *et al* 2007). If netting effort has reached the minimum criteria set by CES staff (see Methods), total annual catches of adults and juveniles caught at the site may be adjusted to account for missed visits and then included in productivity-indexing analyses for the year (Peach *et al* 1996, Robinson *et al* 2007).

In this paper, we present the results of an analysis of how adjustment of total annual juvenile and adult catches for missed CES visits may affect measures of productivity. For a range of species, productivity indices from data which included sites requiring adjustment to account for missed CES visits were compared with indices from data from sites which met their full complement of visits.

## METHODS

### CES ringing

Protocols for CES ringing have been set out in detail elsewhere (eg Baillie *et al* 1986, Peach *et al* 1996, 1998, Freeman *et al* 2000). CE sites are selected by the individual ringers. Each year, 12 consecutive periods of 10–11 days are predetermined by BTO staff to span the CES season (May to August). Ringers aim to mist-net at their sites once during each of these periods using the same total length

\* Correspondence author  
Email: willtsmiles@hotmail.com

and type of nets, placed in the same positions and open for a standardised duration. Precise net length, net type, positions of nets and duration of operation are decided by the individual ringer but are maintained from year to year. Data used in this study were collected by volunteer ringers for the CES scheme between 1983 and 2005.

### Missed CES visits and reduced netting effort

The extent to which it is permissible for CES ringers to miss visits, and the rules for reporting reduced effort as the result of adverse conditions, have been documented by Peach *et al* (1998) and Freeman *et al* (2000). Netting effort on any one visit may be unavoidably reduced, for example by bad weather necessitating early net closure, net inaccessibility (eg due to flooding) or net damage. If the standard netting effort per visit, in terms of total net length and time open, falls below 80% of the norm at the site (indicated by the ringer in charge) then the visit is considered to be wholly missed and its data are not included in the annual catch totals. Data from site visits where the catching effort is at least 80% are included in annual catch totals and contribute to abundance and productivity index calculations. Most CE site visits are carried out between dawn and mid-morning, with a decrease in catch rate typically occurring towards the end of the visit. It is most frequently the end of a visit which is missing, the visit having been curtailed by factors such as the weather, and this means that reductions in netting effort often incur a smaller proportional cost in catch size.

Ringers' personal circumstances or exceptionally bad weather may occasionally cause one or more CES visits per season to be missed completely; as a result the annual catch totals will be less than had all 12 visits been made successfully. Rather than waste data by excluding all sites with fewer than 12 visits from the productivity-indexing analyses, the total annual catches at sites with missed visits may be adjusted. Adjusted data include an estimate of the number of additional individual birds that would have been caught had all visits been completed. Catches are only adjusted for sites where at least eight of the 12 scheduled CES visits have been made in a given year. The index of productivity necessitates use of both adult and juvenile data from each site in each year, but adults are typically caught in greater numbers earlier in the season and juveniles later (Peach *et al* 1998). So, catches are adjusted only when at least four of the first six and at least four of the last six visits have been completed. Sites not meeting these criteria are omitted entirely from the year's productivity analyses.

For years with incomplete coverage (missed visits), the expected cumulative catches (adjusted data) are calculated using all the data at the site for the particular species from years with complete coverage (Peach *et al* 1998). It is assumed that the pattern of catching did not vary between

years. The procedure is carried out for adults and juveniles separately due to the considerable seasonal differences in catch frequency between these age classes. For sites without any years of complete, 12-visit coverage, adjustments are based on catches of the particular species made at other sites with complete visit coverage. Bias is likely to be introduced by correction methods only if atypical patterns of catching occur through the breeding season in years when visits are missed, or if large inter-annual variations occur in catching patterns (Baillie *et al* 1986). The correction methods tend to reduce the estimated size of unusually large missed catches and increase unusually small ones, and thus are conservative in their overall effect. The proportion of annual catches of any given species which are imputed is low, for example annual means of 4.3% (adults) and 5.0% (juveniles) in years to 1998 (Peach *et al* 1998). This figure, however, can vary substantially between years and both the likelihood of a visit being missed and the relative numbers of birds caught can be highly variable within the season (Cave 2006). It is also conceivable that periods of poor weather that lead to high drop-out of data might likewise have a direct effect upon productivity. All of these factors make an assessment of the method desirable.

### Productivity indexing from unadjusted and adjusted data

The data used in this analysis were the total annual CES adult and juvenile counts from all CE sites in all years of the CES scheme between 1983 and 2005 for selected species: Blackcap *Sylvia atricapilla*, Blue Tit *Cyanistes caeruleus*, Lesser Whitethroat *Sylvia curruca*, Reed Bunting *Emberiza schoeniclus*, European Robin *Erithacus rubecula*, Eurasian Treecreeper *Certhia familiaris* and Common Whitethroat *Sylvia communis*. Data files included sites with adjustment for years with missing visits. These were also filtered to produce a second data set, of unadjusted data, from only those sites not requiring adjustment for missed visits.

Indices of productivity are produced by the BTO using a Generalised Linear Model (GLM). Index values are considered to be the product of a site effect and a year effect (Robinson *et al* 2007). Thus, the logarithm of the index value ( $I_{ij}$ ) at CES site  $i$  in year  $j$  is given by the sum of a year effect ( $Y_j$ ) and a site effect ( $S_i$ ). Such an underlying framework is appropriate where sites receive different coverage from year to year, so effectively there are missing data (ter Braak *et al* 1994). In the CES scheme this happens due to frequent site turnover, for example when sites drop out of the scheme due to habitat development, changes in land ownership, or ringers' personal circumstances. The year effect accounts for change in species' productivity, which occurs between years due to different ecological or anthropogenic factors. Without the site effect, bias might occur in the annual productivity estimates, by

the model not accounting for the changing suite of CE sites through the years and for the possible influence of atypically productive sites, perhaps newly enrolled in the CES scheme.

The GLM used to derive annual indices of productivity and long-term trends from CES data is based on the annual total 'count' of individual adults and juveniles on each CE site (Freeman *et al* 2000). A binomial distribution is assumed for the number of juveniles caught at a site in a given year, with the probability of a bird that was caught being juvenile,  $p$ , and a binomial denominator,  $n$ , the total number of birds (adults + juveniles) caught at that site in that year (Robinson *et al* 2007). A logit link function is used to ensure the estimated probability lies within the valid range (zero to one). Thus, if  $p_{ij}$  is the expected proportion of juveniles at site  $i$  in year  $j$ , with year and site effects  $Y_i$  and  $S_j$ , then, in the absence of missing visits:

$$\text{Equation 1} \quad \text{logit}(p_{ij}) = \ln \left[ \frac{p_{ij}}{1 - p_{ij}} \right] = Y_i + S_j$$

Equation 1 is fitted to the annual ratio of juvenile catch ( $C_{juv}$ ) to total catch ( $C_{juv} + C_{ad}$ ) at each site (Robinson *et al* 2007). This model makes more complete use of the CES data set than just the between-year comparisons (Peach *et al* 1996), and facilitates assessment of long-term trends. On fitting the model, the resultant year effects are used as annual estimates of the productivity index for each species. The index is not an estimate of 'true' productivity, because the probabilities of catching adult and juvenile birds may differ, and the difference may vary between species. However, it relies on the satisfactory assumption that the difference in the probability of catching juvenile versus adult birds of the same species is constant between years. Catches adjusted for missed visits are implemented into the model by an offset, derived from the data-adjustment methods for missed visits (Peach *et al* 1998, Robinson *et al* 2007). This is shown by equation 2, the GLM used to produce indices of productivity in which adult and juvenile data with adjusted annual catches for missed visits ( $E_{ad}$  and  $E_{juv}$ ) are included (Robinson *et al* 2007):

$$\text{Equation 2} \quad \text{logit}(p_{ij}) = Y_i + S_j + \ln \left[ \frac{C_{juv} E_{ad}}{C_{ad} E_{juv}} \right]_{ij}$$

Species data which included adjustments for missing CE visits were analysed by fitting the GLM given in equation 2. The second data set, which included only unadjusted data from years with complete CES visits (filtered from the first data set), was analysed by fitting the GLM given in equation 1. All analyses were carried out using SAS PROC GENMOD (SAS Institute Inc 2003). The resultant year effects from analyses are plotted as indices of productivity. In the results presented, the year effects are scaled ( $Y_i = 0$  in the final year for all species), so that inverting the

logarithmic transformation sets the index to the ratio of juveniles to adults, relative to a value of unity in the final year (Robinson *et al* 2007). Productivity indices for both types of data (adjusted/unadjusted) were plotted on the same axis to allow comparison of trends between years and between data sets. The estimated asymptotic standard errors of year-effect estimates from real and adjusted data were plotted against each other for each species, to illustrate the comparative precision of the models.

## RESULTS

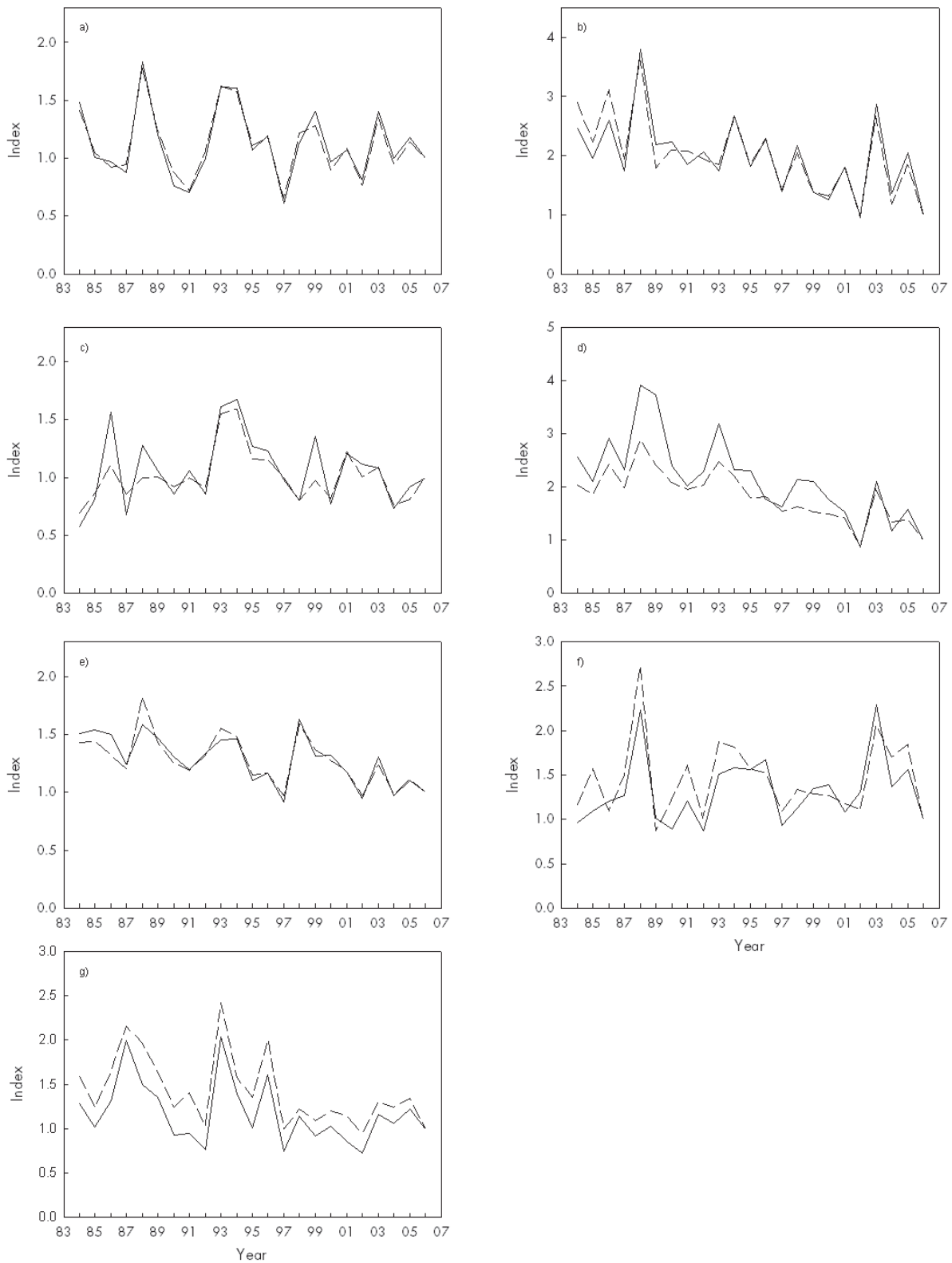
Great similarity was found between productivity indices from adjusted and unadjusted adult and juvenile total counts (Fig 1, Table 1). The pattern of productivity shown from adjusted data closely tracks the pattern shown by real (unadjusted) data for all species (Fig 1). The direction of between-year trends showed at least 80% agreement between indices for all species in the study, except Treecreeper (Table 1). Greatest similarity occurred between indices for Blackcap, Blue Tit, Robin, Reed Bunting and Common Whitethroat, for which between-year directional agreement was at least 91% (Table 1). Indices of Lesser Whitethroat and Treecreeper productivity were slightly less similar, as evidenced by the relative divergence of productivity indices for these species (Fig 1).

Estimated imprecision was greater in unadjusted data than in adjusted data for all species in this study. This is shown by all points being below the line of parity on all standard error graphs (Fig 2).

Precision differed considerably between different species' adjusted and unadjusted data sets (Fig 2). Both adjusted and unadjusted data sets for Blackcap, Blue Tit and Robin exhibited relatively high precision compared to other species in the study, shown by most SE values being below 0.12 on both axes. Precision within Reed Bunting and Common Whitethroat data sets was moderate, with SE

**Table 1.** Comparison of changes between consecutive years in productivity indices from unadjusted and adjusted data.

Species	No. of possible comparisons	Real data agree with direction of between-year change in adjusted data
Blackcap	22	95%
Common Whitethroat	22	95%
Blue Tit	22	91%
Robin	22	91%
Reed Bunting	22	91%
Lesser Whitethroat	22	86%
Treecreeper	22	64%



**Figure 1.** Comparison of trends in productivity indices from adjusted data (CES adult & juvenile annual total counts) (broken lines) and unadjusted data from a reduced number of sites (solid lines), for seven species monitored by CES ringing scheme: a) Blackcap, b) Blue Tit, c) Lesser Whitethroat, d) Reed Bunting, e) Robin, f) Treecreeper, g) Common Whitethroat.

values mostly between 0.1 and 0.25 on both axes. Highest values compared to other species were shown within Lesser Whitethroat and Treecreeper data sets, which had SE values all greater than 0.18 on both axes.

## DISCUSSION

Productivity indices calculated from CES data with and without adjustments for missed site visits were similar, for species in this study. Given their wide ecological differences, this phenomenon appears likely to hold more widely, where data are sufficient in number. Slight differences in productivity indices may have arisen from small sample sizes for certain species, rather than from effects derived from the methods of data adjustment for missed visits and the inclusion of adjusted values in indexing analyses. Species' data sets including adjusted data were obviously larger than unadjusted data sets, which were drawn exclusively from sites and years where all 12 CE visits were completed. Therefore, slight differences between productivity indices from real and adjusted data sets may not imply that inclusion of adjusted data in indexing analyses results in bias, but may arise simply from sampling variability, according to the size of each data set. SE values of year-effect estimates were greater from unadjusted data than from those including additional adjusted values for missed visits. Precision was also poorest for species caught less frequently (eg Treecreeper) and better for species caught more frequently (eg Blackcap and Blue Tit). Precision in analyses was increased by larger sample sizes, facilitated by the inclusion of adjusted values for missed visits. Standard errors were often greatest in the earlier years, when many fewer sites were active.

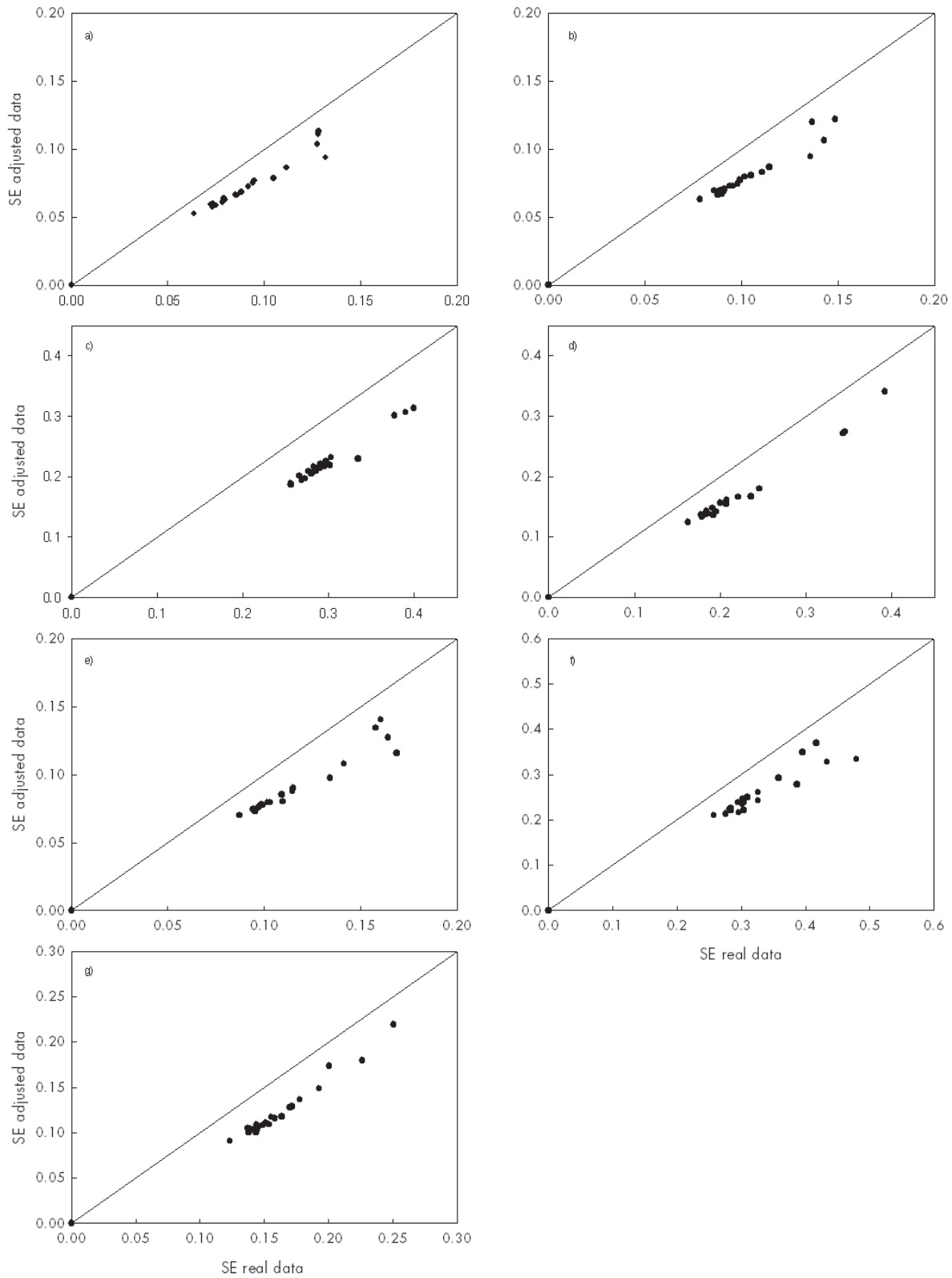
It is possible that in some cases the observed differences between index values of adjusted and unadjusted data were the result of factors other than random sampling error. The occurrence of this is perhaps most likely in years when particularly notable differences were observed between index values, in either size (indices differ particularly greatly) or pattern (abnormal disagreement in between-year trends). For example, very large differences between index values from adjusted and unadjusted data were noted for Reed Bunting in 1987 and 1988 and Treecreeper in 1987. Between-year trends differed in direction between 1985 and 1986 for Blackcap and between 1989 and 1991 for Blue Tit indices; otherwise they were in agreement throughout for these species. In these years particularly, it is conceivable that index values from data including adjustments may have misrepresented actual productivity. Unrepresentative values for missed visits would have greatest influence on productivity indexing when their inclusion incurred a large proportional increase in sample size; this would be

most likely for species caught less frequently, such as Reed Bunting and Treecreeper.

Total adult and juvenile annual catches, adjusted for missed CES visits, may also be poorly representative if the inter-annual cumulative pattern of catches is variable. The occurrence of this is likely to be species-specific, according to factors such as timing of egg-laying, clutch size, food availability or dispersal rates, and how these are affected by natural and anthropogenic factors. Habitat change (eg by natural succession to scrub and woodland, or deliberate management) can affect breeding success, and thus annual adult and juvenile catches, of many species simultaneously on a CE site (Baillie 1990, Harrison *et al* 2000). Local habitat change is perhaps unlikely to result in a widespread abnormality in catches in a given year, however, as it is not normally synchronised across a great number of CE sites. From this study, it is not possible to be certain whether differences between indices from adjusted and unadjusted data are the result of unrepresentative adjusted values, caused by (abnormal) widespread factors affecting a species' productivity in a given year.

Productivity on CE sites may be limited by weather effects and density-dependent factors. Nesting density may be constrained by local adult abundance, which may vary between years according to factors such as severe winter weather and shortages of food (Elkins 1988, Peach *et al* 1999). The nesting density of migrant birds may be limited by weather effects on adult survival during migration and by food scarcity during migration or on the wintering grounds (Baillie & Peach 1992, Burton 1992). It is certain that these migration factors are variable between species and between years (Wernham *et al* 2002). Widespread anthropogenic factors may also affect productivity as recorded by CES, in particular farming practices (Andrews & Rebane 1994). For example, earlier seasonal development and harvesting of winter-sown cereals may cause a decline in the number of breeding attempts of seed-eating species such as Reed Bunting, due to reductions in food availability for adults and young (Peach *et al* 1999, Freeman *et al* 2000).

Given the potential for inter-annual variation in catch frequency, productivity indices from adjusted and unadjusted data are remarkably similar in this study. This suggests the methodology is sound and does not commonly generate false trends in productivity indices, at least given the current rate of visits made and missed, which is unlikely to change for the foreseeable future. Precision under this method is improved; however, it does not accurately account for the uncertainty introduced by the correction factor. Further methodological developments, more accurately describing the extent of sampling variation, remain a promising area of future research. New work on developing different analytical frameworks, and simulation-



**Figure 2.** Comparison of standard error (SE) values from species' year-effect estimates from adjusted data (CES adult & juvenile annual total counts) and unadjusted (real) data from a reduced number of sites: a) Blackcap, b) Blue Tit, c) Lesser Whitethroat, d) Reed Bunting, e) Robin, f) Treecreeper, g) Common Whitethroat. Bisection lines of equality are shown as an aid to interpretation only, and are not lines of best fit.

based assessment of model performance, is currently under way at the University of Cambridge (Cave *et al* in press).

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