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Importance of geographical location and local habitat features for species abundance: analyses using Breeding Bird Survey data

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1.2 BBS data routinely provide valuable information on temporal trends in abundance. We consider here the extent to which their conservation value may be increased by the development of spatial models for bird distributions and numbers, based on the habitat data.

1.3 One of the three data sets is gathered by the BBS observers themselves, and therefore most closely reflects the spatial distribution and resolution of the bird count data. The other two sources, 'landclass' and 'landcover', are taken from CEH databases and are available on a national scale. Habitat-based models based on the latter sources of information therefore permit prediction of bird distributions a national scale.

1.4 Predictably, most species showed pronounced differences in abundance between sites of different habitats and landscapes. Reflecting large-scale differences in range, a modelling approach showed relationships with latitude, longitude and altitude for most species. Habitat-based models were then considered in detail for seven species of widely differing ecology (Buzzard, Skylark, Meadow Pipit, Dunnock, Sedge Warbler, Nuthatch, and House Sparrow).

1.5 After adjusting for Northing, Easting and altitude, similar distributions were predicted whether habitat was represented by data from the BBS (at the scale of the 200m. transect section) or data from the CEH databases (at the scale of the 1 km square).

1.6 We split the data for species of interest into two random halves, and employed a model fitted to one half to predict the numbers of birds in squares of the other half. A comparison of residuals suggests that the BBS-based habitat data, due to their more direct equivalence in scale to the bird data, are marginally superior to the coarser CEH data. The latter, however, permit the mapping of predicted numbers on a national scale.

1.7 Predictions based upon the two CEH datasets were also similar. Of the two, landclass (a single category, to which a square is assigned) proved more likely to produce predicted values close to zero although a species may have been present. As the landcover data set assigns to each square the proportion of the land surface of a number of land cover types, these models were less prone to this severe underestimation.

1.8 Areas for future research into the spatial distributions of birds, and their relationships with habitat, including the utilisation of Neural Network models, are discussed.

2. INTRODUCTION

The study of geographic patterns of species abundance at a large spatial scale has long been of interest to ecologists (Bolger *et al*. 1997, Beard *et al*. 1999, Pearce & Ferrier 2001). From a conservation viewpoint, knowledge of species abundance at a regional level is crucial for managing biodiversity and protecting declining or endangered species effectively (Noss 1983). However, the reliability and accuracy of this knowledge is dependent on the quality of the surveys collecting the data.

The last Breeding Atlas of 1988-91 (Gibbons *et al*. 1993) used data collected through the Common Bird Census (CBC) in 1989 to interpolate maps of species abundance for all common and widespread bird species in Britain and Ireland. Interpolations were based on the assumption that survey sites that are close to one another are more alike than those further apart, with no regard to the habitat or other requirements of the species in the predictions. We also know that coverage provided by the CBC is biased to the south and east of Britain and to farmland and woodland habitat. With the similar aim of producing abundance maps, Newson & Noble (2003), explored the potential of integrated geostatistical/GIS software for improving the precision of abundance maps using data from the BTO/JNCC/RSPB Breeding Bird Survey (BBS), although predictions were again based on geographical location only (see Noble *et al*. submitted for a discussion of BBS survey design and methodology).

Because it is clear that many bird species are distributed with respect to habitat, several multi-species bird studies on UK birds have examined using information on habitat to try and predict abundance or distribution for a range of species. These include work by Fuller *et al*. (2001), who examined associations of birds commonly found on farmland with hedgerows and woodland, whilst Henderson *et al*. (2000) modeled the effect on bird density of a number of independent fine-scale habitat and geographic characteristics. Species-specific studies also include work to derive habitat preference indices for the Skylark (Browne *et al*. 2000) and using habitat and climate information to predict the distribution of Nightingale in the UK (Wilson *et al*. 2000). Using a different approach and with ultimately different aims, distance sampling has been used to calculate habitat-specific densities and abundance using BBS data for a range of species (Gregory & Baillie 1998, Gregory 1999, Newson *et al*. submitted), and research is currently developing this approach to produce spatial dynamic models, although much of this methodology is still under development (Buckland in litt.).

The BBS is now the main source of continuous monitoring data for common and widespread species in the UK and as such biologists are increasingly relying on this data to guide management actions. However good the survey, data of this type will always be patchy and incomplete and it is important for us to understand how this data reflects the real distribution and abundance of the species surveyed. Because many bird species are distributed with respect to habitat (or altitude or climate or space), it is important to examine whether geospatial data at this scale can be used to improve our predictions. In addition, a understanding of the relationships between bird distribution and abundance and habitat and other environmental factors, would allow us the potential to explore and predict the effect of say land-use or climate change on bird species, and is therefore of substantial interest to understand these relationships from a conservation viewpoint.

In this study, we use stochastic models to quantify and compare the effectiveness of habitat data from three sources to predict bird abundance for 73 species routinely monitored by the BBS. We examine the prediction of bird counts from fine scale data collected by BBS recorders themselves and two independent datasets of different resolution obtained from the Centre for Ecology and Hydrology (CEH) and cover the entire UK to see how well these compare. In addition all models include altitude, latitude and longitude as predictor variables to account for restricted distributions of many species.

3. METHODS

Using stochastic models, we consider the prediction of bird counts recorded by the BBS from habitat data from three main sources. BBS recorders themselves record the two main brood habitat types (primary and secondary) either during the counting or on a prior reconnaissance visit. This recording assigns each 200-m transect section to one of nine broad habitat types (a tenth, 'miscellaneous' category is rarely adopted in practice, and is not considered further here).

Two further sources of data, independent of the carrying out of the BBS, were obtained from databases of the Centre for Ecology and Hydrology (CEH), referred to here as 'landcover' and 'landclass' data, and described in Appendix 2 at the back of this report. Basically, 'landcover' records the percentage of each 1-km square covered by each of 25 land types. One of these types records the area of coastal squares covered by sea, which is ignored here and remaining percentages adjusted accordingly, to record the percentage of terrestrial landcover represented by each habitat. The other data source ('landclass') is considered here on a 1x1 km basis; each 1x1 square is assigned to one of 32 mutually exclusive categories. Due to the nature of these two data sources, landcover is modeled as 24 continuous variables, the percentage of the 1-km square covered by each landcover type and landclass modeled as a factor (with 32 levels). Comparison of the predictive capability of the various habitat data sources is of interest because the CEH data, though seemingly at a disadvantage being recorded on a scale coarser than the level of the transect, are available for the whole country, enabling potential useful approximation of bird numbers for squares not visited, and allow for predictions relating to spatial and temporal changes in British bird population to be examined. The time and costs involved in mapping the national distributions of large numbers of species via direct observation are so great that they have only been attempted in the two BTO Breeding Atlases, some twenty years apart. The ability to track distributional changes by means of a sampling scheme such as the BBS, and habitat/occupancy relationships, therefore has considerable appeal. A successful approach increases the conservation value of the BBS to beyond that already provided by the construction of temporal trends in abundance on the national, or large-scale regional, level (Raven *et al.* 2002).

Statistical models used are from the Generalized Linear Model (GLM) family (Nelder & Wedderburn, 1972, McCullagh & Nelder 1989). For many species, especially when considered at the transect level, the data will often amount either to detection of a single individual, or failure to detect the species at all. Beyond that, counts will generally be small and models based on assumptions of normality inappropriate. Clearly models for simple 'presence' or 'absence' provide one analytical option, though clearly the absence of a species from the record at a site does not necessarily equate to its not occurring. Genuine absence, and non-detection when present, are confounded at the level of a single visit to a site. We assume in this report a Poisson distribution for the bird counts and a logarithmic link function, to ensure that fitted values for the counts are non-negative. The Poisson distribution, which is restricted to non-negative integers, is appealling as a model for counts of birds. Though it is possible to adjust models to account for any over-dispersion in some species, relative to the Poisson distribution, we have not done this here as parameter estimates, and hence the estimated counts which are the main interest of this report, remain unaffected. The intention of this report is less to assess the significance of differences in occupancy between different habitats, and more to test the adoption of predictive models that can be used to explore the consequences of land-use change for birds. These models assume a monotonic, and linear (on the logarithmic scale) relationship between abundance and the predictor of interest. We return to this point in the discussion.

All models described include altitude, latitude and longitude as predictor variables to account for the restricted regional distributions of many species, along with the relevant habitat variables. We employ data gathered by BBS volunteers in the year 2000 for 73 species routinely monitored by the BBS (see Appendix 1); data for 2001 were much reduced in number and regionally skewed due to the outbreak of foot-and-mouth in that year which prohibited surveys in many parts of the country. We further restrict detailed analyses to include up to 7 example species of differing abundance, distribution and ecology including Buzzard, Skylark, Meadow Pipit, Dunnock, Sedge Warbler, Nuthatch and House Sparrow.

Contributors to the BBS record birds seen along 2 1km. transects, on two visits ('early' and 'late' in the season) and in three distance bands (0-25m., 25-100m. and > 100m). In this report, to obtain a single count value for each transect, we sum the birds counted in the two nearest distance bands, to obtain all the birds seen within 100m either side of the transect. We then take the greater of the resulting 'early' and 'late' totals as the observation for the transect in question. Birds seen at > 100m., or birds overflying the square, are ignored. This data extraction scheme is consistent with that routinely employed in the production of annual abundance trends from BBS data, though it is clearly but one of a number of alternatives.

4. RESULTS

4.1 Relationship between bird counts and habitat, as recorded by the observer

Before we proceed to model-fitting, Table 1.1 shows the simple mean number of birds recorded on each 200-m transect section, in each of the nine primary habitat types, across the country. Inevitably, most species show a degree of preference for one or more of these habitats. By employing as predictor variables, primary habitat type and, to control for variation in range on a national scale, altitude, easting and northing, the relative preference for each habitat was calculated by fitting the log-linear GLM to the counts of each species on each 200-m transect section. It should be noted, however, that to regard transect sections within the same BBS square as independent replicates may be highly questionable, and these results may overstate the strength of inter-habitat differences. Nonetheless, given the simplicity of the null hypothesis, that all habitats are equally favoured, and the scale of the differences between mean values in Table 1.1, for example, it seems inconceivable that this difference should not be real, and the results are retained here for completion. More importantly for the purposes of this report, however, the model permits us to calculate expected values of the BBS counts, which can be used to investigate spatial and habitat relationships across the country, and to compare with similar fitted values predicted using data independent of the BBS. Later in the report, we consider models based on counts pooled over each 1km square (rather than counts within individual 200-m transect sections), and the relationships between these counts and habitat data at the 1-km square level.

Whilst model fitting failed to converge for two species (Shelduck and Reed Warbler), which may be because these species occurred in very few habitats, the inclusion of primary habitat in this model significantly improved the fit for all species except Sparrowhawk (Table 1.2). A comparison between the relative abundances in various habitats predicted by the models (at an arbitrarily chosen latitude and longitude), with the simple mean counts for selected species in Figure 1.1 show that these are broadly comparable. Note that the additive nature of these models implies that numbers predicted, per habitat, at any real site will differ due to the relationships with other variables included in the model, but are directly proportional to the fitted values of Figure 1.1 – it is only their magnitudes *relative to one another* that are of interest here. Simple plots of predicted against observed counts are of limited value because of the sheer numbers of observations, the predominance of low fitted and observed values and the considerable variation about the line of equality that represents a perfect match. However, plotting bird counts against their estimated values from a model based on habitat recorded by the observer (Figure 1.2), it is gratifying that there are so few cases in which the largest observed values are grossly high compared to their predictions.

Variation in mean count on each 200m transect section by secondary brood habitat is shown in Table 1.3. As with the primary habitat, the inclusion of secondary habitat revealed a highly significant relationship differing only in that the test was significant for Sparrowhawk, but was now no longer significant for the Willow Tit.

4.2 Relationship between bird counts and habitat, as recorded by CEH

Because of the different resolution of the CEH data considered here, compared with BBS habitat data, bird counts are modeled as a function of habitat at the 1-km square level for landcover data or landclass data. Whilst it is not possible to present mean counts of species per transect section by landcover, because landcover was available only as a percentage over the square, it is informative to show the mean number of birds per transect section classified into each landclass category (Table 2.1). All models based on habitat data hereafter also include Northing, Easting and altitude as predictor variables, to account for any large-scale gaps in the species' range attributable more to climatic suitability than local habitat. Added to a base model incorporating Northing, Easting and altitude, landclass type significantly improved the predictions of bird counts for all species apart from

Sparrowhawk and Little Owl (Table 2.2), although there were again problems of model convergence for Shelduck and Reed Warbler.

For landcover data, we restrict our analyses to a limited number of species including Buzzard, Skylark, Meadow Pipit, Dunnock, Sedge Warbler, Nuthatch and House Sparrow. Plotting bird counts against their estimated values from a model based on landcover data (Figure 2.1), it is gratifying that there are so few cases in which the largest observed values are grossly high compared to their predictions. The Sedge Warbler is perhaps to some extent an exception to this; the five highest observations each exceed expectation by more than ten-fold. This species is especially particular in its habitat requirements, and can breed at a very high density where conditions are suitable. It may be that these very high observations are taken at squares in which a small area is very suitable, but the rest of the square entirely unsuitable.

To investigate further the precision of the predicted values, we examined the geographical distribution of the raw residuals (observed-expected count values). Residuals from the landclass model for selected species are plotted against Easting in Figure 2.2 and Northing in Figure 2.3. Corresponding values based on the landcover data are shown in Figures 2.4 and 2.5. Any heteroscedascity shown here is largely explained by the species' large-scale distribution: thus residuals are minute in the North for the Nuthatch, as the model controls for latitude and the species is largely absent from Scotland. Thus the zero counts at high latitude tend to be associated with very small predicted values due to the presence of latitude (and altitude) in the GLM, along with large areas of unsuitable habitat type. Likewise there are no large residuals for Buzzard in the east of the country. Although this species has recently begun to expand eastwards (Clements, 2002), it is still rarely recorded in the BBS outside its Western strongholds. These figures suggest that with controls for latitude and longitude, the models perform adequately in restricting substantial predicted numbers to the species' known breeding range in Britain. A more direct comparison between landclass and landcover data is provided by plotting the residuals against one another in Figure 2.6, where the obvious correlation is encouraging. It should be noted however, that this comparison merely compares the predictive ability of one data set against that of another – such correlation would be expected from two, similarly poor predictive models. However, all plots also show a predominance of small residuals, indicating squares accurately predicted, and a few major outliers – squares with a pronounced difference between observed and expected values.

We can look in more detail at the geographical nature of the fitted model by plotting the BBS sites on a map of Great Britain, with sites producing positive and negatively residuals separately identified. In the maps shown in Figure 2.7, the filled circles represent sites with positive residuals (more birds observed than predicted by the model) and the open circles those with negative residuals (more birds predicted by the model than observed). Apart from the longitudinal and latitudinal gradients in abundance discussed above, the geographical distributions of positive and negative residuals over the species' main ranges appear roughly random, without large areas devoid of residuals of one sign, whereas the absence of Nuthatches in the North and Buzzards in the East is reflected in a predominance of negative residuals in these areas. The use of the log link function ensures that fitted values can only ever be > 0, albeit perhaps by a negligible amount, hence squares lacking birds can only be over-predicted. This accounts for the residual patterns seen outside a species' natural range. Furthermore, in all cases the patterns derived from the landcover data and the landclass data are remarkably similar, for all the differences in habitat definition and scale of recording.

4.3 Using CEH data to predict species abundance at squares not surveyed

An appealing feature of a good habitat-based model is the possibility of using the estimated species:habitat relationships to predict bird densities at squares that were not surveyed, using the recorded habitat data. The previous analyses derive predicted values for each square visited based on counts from all squares, but it would also be of interest to assess how well the counts at unvisited squares can be predicted.

To examine this, we randomly split the squares surveyed into two approximately equal groups, such that each square has an equal probability of being in either group. We then fitted landclass and landcover models to one of the groups only; this model was then used to predict the count at the squares in the other group. Counts in the latter group, although known in practice, were therefore effectively treated as missing values. The difference between the predicted and the true (but ignored) values were then computed as residuals as before. Residuals under the two models are compared for three species in Figure 2.8, and it again found that both landclass and landcover models produce similar residual patterns.

However, more subtle differences are revealed by closer analysis. For a fitted model, Pearson X^2 statistics can formally be derived from observed values and their expectations, in the standard manner:

$$X^2 = \sum \frac{(0-E)^2}{E}$$

A Pearson-type statistic can then be calculated as above as a crude representation of the quality of the predictions under a model, reduced to a single statistic. As both types of habitat data were used to model the same subset of the data, and then predict the same set of (assumed) unvisited squares, this statistic provides a rough comparison of the utility of the two data sources, landclass and landcover data.

For the Dunnock, the two data sources produce similar statistics, with a slight favouring of the landcover data (X^2 = 2967.94) over the landclass data (X^2=3073.43). Predicted values are plotted against the observations in Figure 2.9. A similar result is found for the Skylark (X^2 =10314.16, as opposed to 12863.19), and examination of the fitted values (Figure 2.9) shows that of many sites recording over 12 birds, only one is given a predicted value greater than twelve under the landclass model. Considerably more produce such predictions from the landcover data. For some species (Buzzard, Sedge Warbler and Meadow pipit) the value of X^2 based on landclass data was grossly exaggerated compared to that from landcover, though it is strongly influenced by a small number of sites at which the bird was seen, yet the predicted value was scarcely higher than zero. These sites are most clearly visible for the Meadow Pipit in Figure 2.9. It is perhaps not surprising that landcover should be a good predictor of bird numbers, as the 1x1 km scale is identical to that employed by the BBS and, further, each square is assigned proportions of various landtypes, rather than defined by a single category. These results appear to suggest that this is the case, though similar analyses for additional species would be required to confirm whether this is a general rule. It appears too that the difference is predominantly a consequence of a relatively small number of sites at which birds were observed on squares in a landclass category that produces an expected number of birds very close to zero – that is a category for which the majority of squares were indeed devoid of the species.

4.4 A comparison of the utility of BBS and CEH habitat data as predictors of bird counts

It is now of interest to consider a comparison of predicted bird counts on the basis of habitat data from the CEH databases and from the data gathered by BBS volunteers. Residuals from BBS-based primary habitats are plotted against those from models based on CEH landclass and landcover for selected species in Figures 2.10 and 2.11. Again the general consistency between all three sources is gratifying.

The mean square residual from the BBS habitat-based model provides a simple summary of the predictive effectiveness of the BBS habitat data, when considered relative to that from a model fitting the same bird count data to either of the two CEH data sets. For the species considered here this ratio is, in general, slightly less than unity. The range of ratio values spans 0.81 (Meadow Pipit) to 0.96

(Buzzard) for the BBS and landclass comparison, and 0.87 (Dunnock) to 1.05 (Meadow Pipit) for a similar comparison with landcover data.

It should be noted that the GLM framework readily permits the adoption of two or more habitat variables in the model simultaneously. BBS habitat data are recorded using a hierarchical system common to many BTO schemes (Crick 1992) potentially allowing further desegregation of BBS habitat types, but we have not explored this issue here.

5. DISCUSSION

For many species, there is a longitudinal and latitudinal gradient (probably associated in part with altitude) in species abundance, so including these in a model predicting counts at unsurveyed squares can only improve the precision of resulting predictions. Examining the distribution of positive and negative residuals for a sample of species on a map of Great Britain for models of predicted counts from landclass and cover data, it is encouraging that patterns of occurence for these species are expected based on what we know of the distribution of these species and that there are not large areas devoid of residuals of one sign or other. It is also interesting to see that predictions based on landclass and landcover data are remarkable similar, considering the differences in habitat definition and scale of recording. By performing a crude formal test between the quality of predictions from landclass and landcover data for number of species, it was shown that landcover (percentage in each 1km square of 25 landcover types) produced slightly better predictions that landclass data. However, this finding is probably not surprising considering the greater resolution of landcover data and perhaps one might have expected a larger difference that this. It is also gratifying that there is pretty good consistency between residuals from BBS-based primary habitat models plotted separately against CEH landcover and landclass data for the example species in these analyses.

Clearly uncertainties in the bird and habitat data and model assumptions influence the patterns of predicted abundance of species and the amount of errors (Conroy & Noon 1996). The errors in our predictions are due to both cartographic errors and generalisation as well as to the imperfect relationship between species and these different variables. Although we have quantified the error generated by this approach, we did not attempt to identify the error sources. It is possible that further refinements of the habitat data and including climatic information could improve the performance of the model we developed. However, it is well known that vegetation and climate are related to each other as well as to factors such as altitude, latitude, and topography (Begon *et al*. 1990, Woodward 1987), so it is uncertain as to how much the addition of climate into a model would improve predictions. There are also reasons to expect both climate and vegetation to be spatially autocorrelated (Legendre 1993, Brown 1995). Such changes could potentially affect our conclusions about the comparability of different datasets.

There is much potential for further modelling work on presence/absence or abundance/habitat relationships. We alluded earlier to the complications caused by the confounding of ‘non-detection’ and ‘genuine absence’. In principle, the practice of repeated visits within a survey permits the estimation of these two different probabilities, separating the (useful) probability of absence from the probability of non-detection of a species where present, which is largely a nuisance parameter. Further, the parameters can readily be made habitat-dependent and hence provide inference about species/habitat relationships. Statistical theory is provided by MacKenzie *et al*. (2002, 2003), in a manner similar to the Robust Design for survival analysis of Pollock (1982) and Pollock *et al*. (1990). With only two visits per year on BBS, however, potential may be restricted, especially for more elusive species. Consideration of greater numbers of visits, to some sites at least, may prove beneficial in this respect.

For the investigations into abundance and habitat of this report we have employed Generalized Linear Models of the form used in the regular publication of temporal trends. It is very easy to produce software to carry out these analyses for multiple species. These methods are long established and have provided a useful initial exploration of habitat relationships. In particular, an examination by eye of the geographical distributions of positive and negative residuals suggests that each species’ major population centres can be reliably identified via these models. We have not here attempted a formal assessment of the predicted geographical distributions, compared to those observed. A natural extension to the work would be a rigorous comparison of the various sources of habitat data, and their success as predictors of either a species’ range or abundance. Numerous similarity measures exist for comparing maps this way. Given the mobility of birds, relative to the scale on which they are recorded, and the fact that some birds are inevitably overlooked, the preferred approach should identify those models which most accurately predict distribution or numbers on a scale greater than

the 1 km. square, rather than placing great importance on more local discrepancies with the observed data. A statistical means of comparison, with just this emphasis, is described by Fewster & Buckland (2001).

Other approaches that could be used to predict species abundance include the modelling of spatial autocorrelation to effectively "fill in the blanks" in survey data. Newson & Noble (2003) used kriging to produce interpolated maps of species abundance for a number of species from BBS data. This methodology could be developed using co-kriging to include habitat and other environmental data as predictive variable to improve these predictions further. The GLMs are based on simple assumptions (about the form of the error distribution, and the linearity of relationships) that may be too restrictive in practice. Consideration should also be given to the utilisation of Neural Network models (Cheng & Titterington, 1994), which relax these assumptions, to provide more sophisticated predictive potential for the spatial distributions of birds. Analyses of Breeding Atlas data (Berry *et al*, 2001) and our own preliminary analyses of BBS data, incomplete at the time of writing, suggest great potential in this approach.

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APPENDIX

CEH habitat categories used in the models of this report

24 (terrestrial) landcover types recognised in the CEH landcover database:

Inland Waters
Beach/ Flats
Saltmarsh/seaweed
Lowland grass heaths
Pasture / amenity turf
Meadows, verges and seminatural cropped swards
Marsh / rough grassland
Montane / hill grass
Dwarf shrub / grass moorland
Upland dwarf shrub moorland
Bracken
Lowland heath
Scrub / orchard
Deciduous wood
Evergreen wood
Upland bog
Arable land
Ruderal weeds
Suburban / farms
Urban / industrial
Bare ground
Felled forest
Lowland bog
Dwarf shrub / grass heath

32 landclass types recognised in the CEH landclass database are as discussed in Bunce *et al.* (1996).

Table 1.1 Mean bird count (per 200-m transect section) by primary BBS habitat type.

Species	Wood	Scrub	Grass	Heath	Farm	Human	Water	Coast	Rock
Little Grebe	0	0	0.01	0	0	0	0.07	0.01	0
Mute Swan	0.01	0.03	0.06	0	0.01	0.01	0.35	10.96	0
Shelduck	0	0	0.04	0	0.01	0	0.09	0.59	0
Mallard	0.13	0.26	0.24	0.01	0.17	0.2	2.08	2.54	0.03
Tufted Duck	0.01	0.02	0.03	0	0.02	0.02	0.39	0.04	0
Sparrowhawk	0.01	0	0	0	0	0	0	0	0
Buzzard	0.03	0.04	0.03	0	0.02	0	0.02	0	0.09
Kestrel	0.01	0.01	0.03	0.01	0.02	0.01	0.02	0	0.06
Red-legged Partridge	0.02	0.01	0.03	0.02	0.1	0.01	0.02	0.04	0
Partridge	0.01	0.01	0.02	0	0.03	0	0.03	0	0.01
Pheasant	0.28	0.16	0.11	0.03	0.28	0.06	0.16	0.01	0.04
Moorhen	0.04	0.05	0.06	0	0.05	0.05	0.45	0.04	0.01
Coot	0.04	0.07	0.07	0.01	0.01	0.02	0.75	0.25	0
Lapwing	0.01	0.02	0.27	0.09	0.11	0.02	0.12	0.03	0.18
Curlew	0	0.02	0.14	0.12	0.03	0	0.03	0.09	0.04
Stock Dove	0.04	0.03	0.03	0.01	0.07	0.03	0.06	0	0
Wood Pigeon	1.75	1.04	0.31	0.09	1.39	1.56	1.63	0.19	0.23
Turtle Dove	0.02	0.02	0.01	0	0.02	0.01	0.03	0	0.01
Collared Dove	0.05	0.09	0.02	0	0.13	0.97	0.25	0.02	0.06
Cuckoo	0.02	0.01	0.02	0.02	0.02	0	0.03	0.02	0
Little Owl	0	0	0	0	0.01	0	0	0	0
Tawny Owl	0.01	0	0	0	0	0	0.01	0	0
Green Woodpecker	0.06	0.06	0.03	0.01	0.03	0.03	0.03	0	0
Great S. Woodpecker	0.13	0.04	0.01	0.01	0.04	0.04	0.04	0	0.01
Skylark	0.06	0.16	0.88	0.77	0.46	0.06	0.19	0.12	0.26
Swallow	0.06	0.04	0.06	0.02	0.21	0.18	0.22	0.1	0.04
House Martin	0.02	0.01	0.07	0	0.07	0.17	0.04	0	0
Carrion Crow	0.41	0.33	0.32	0.13	0.54	0.58	0.49	0.42	0.29
Jackdaw	0.3	0.12	0.28	0.02	0.44	0.64	0.34	0.29	0.16
Magpie	0.21	0.39	0.16	0.04	0.28	0.68	0.44	0.11	0.1
Jay	0.11	0.07	0.01	0.01	0.02	0.04	0.05	0	0
Great Tit	0.77	0.47	0.17	0.05	0.42	0.56	0.56	0.06	0.13
Blue Tit	1.29	0.83	0.26	0.08	0.7	1.25	1.16	0.15	0.34
Coal Tit	0.43	0.18	0.03	0.02	0.04	0.05	0.07	0	0.03
Marsh Tit	0.06	0.01	0.01	0	0.01	0	0.01	0	0
Willow Tit	0.01	0.01	0	0	0	0	0.01	0	0
Long-tailed Tit	0.23	0.21	0.08	0.01	0.11	0.13	0.24	0.02	0
Nuthatch	0.11	0.03	0.01	0	0.02	0.02	0.03	0.01	0
Treecreeper	0.09	0.02	0.01	0	0.01	0.01	0.04	0	0.03
Wren	1.78	1.66	0.44	0.31	0.86	0.94	1.43	0.27	0.95
Robin	1.41	1	0.25	0.12	0.67	0.88	0.72	0.07	0.4
Redstart	0.02	0.01	0.03	0.01	0.02	0	0.02	0	0
Blackbird	1.12	1.05	0.37	0.08	0.98	2.38	1.35	0.44	0.34
Song Thrush	0.45	0.38	0.09	0.03	0.18	0.33	0.34	0.04	0.1
Mistle Thrush	0.12	0.11	0.05	0.03	0.08	0.12	0.13	0	0.04
Reed Warbler	0	0.03	0.1	0	0.02	0.01	0.11	0.05	0
Sedge Warbler	0.01	0.13	0.18	0.02	0.04	0.02	0.34	0.13	0.01
Blackcap	0.51	0.4	0.08	0.02	0.15	0.18	0.39	0.04	0.12
Garden Warbler	0.08	0.1	0.02	0	0.03	0.01	0.1	0	0.01
Whitethroat	0.07	0.36	0.08	0.02	0.26	0.09	0.25	0.25	0.05
Lesser Whitethroat	0	0.01	0	0	0.02	0.01	0.03	0.01	0
Willow Warbler	0.57	1.21	0.29	0.23	0.21	0.12	0.52	0.11	0.36
Chiffchaff	0.4	0.38	0.07	0.01	0.11	0.11	0.21	0.05	0.12
Goldcrest	0.58	0.27	0.04	0.01	0.04	0.07	0.13	0.03	0.01
Spotted Flycatcher	0.03	0.01	0.01	0	0.01	0.01	0	0	0
Dunnock	0.21	0.43	0.1	0.02	0.4	0.54	0.44	0.2	0.19

Meadow Pipit	0.05	0.29	1.94	2.6	0.15	0.02	0.15	0.33	1.43
Tree Pipit	0.03	0.08	0.04	0.04	0.01	0	0.01	0	0
Pied Wagtail	0.04	0.04	0.08	0.03	0.11	0.11	0.12	0.03	0.1
Grey Wagtail	0.01	0.02	0.02	0.01	0.01	0.01	0.07	0	0.03
Yellow Wagtail	0	0	0.02	0	0.03	0	0.03	0.02	0
Starling	0.19	0.36	0.5	0.17	0.99	3.54	0.75	1.79	0.05
House Sparrow	0.16	0.21	0.07	0.04	0.6	3.48	0.58	0.3	0.06
Tree Sparrow	0	0.02	0	0	0.03	0.02	0	0.05	0
Greenfinch	0.16	0.21	0.08	0.01	0.39	1.01	0.39	0.24	0.16
Goldfinch	0.08	0.15	0.1	0.01	0.21	0.29	0.23	0.08	0.1
Linnet	0.04	0.2	0.17	0.1	0.32	0.17	0.13	0.24	0.08
Lesser Redpoll	0.03	0.05	0.02	0.01	0	0.01	0	0.01	0
Bullfinch	0.07	0.09	0.02	0.01	0.03	0.03	0.05	0.03	0.03
Chaffinch	1.74	1.3	0.53	0.19	1.18	0.89	1.26	0.07	0.17
Corn Bunting	0	0	0	0	0.03	0	0	0.01	0
Yellowhammer	0.07	0.18	0.08	0.01	0.35	0.04	0.15	0.01	0.06
Reed Bunting	0.01	0.07	0.14	0.03	0.04	0.01	0.12	0.14	0

Table 1.2 Significance of relationship between birds recorded per 200-m transect section and BBS primary habitat (per 1-km square), controlling for latitude, longitude and altitude. Note that quoted *P* values will be affected by any lack of independence between adjacent transect section (see text).

Species	χ^2	*P*	Species	χ^2	*P*
Little Grebe	172.11	<.0001	Nuthatch	421.58	<.0001
Mute Swan	9543.53	<.0001	Treecreeper	473.59	<.0001
Shelduck	****	****	Wren	3026.17	<.0001
Mallard	3909.06	<.0001	Robin	2580.28	<.0001
Tufted Duck	778.16	<.0001	Redstart	223.08	<.0001
Sparrowhawk	6.99	0.6378	Blackbird	5104.21	<.0001
Buzzard	136.11	<.0001	Song Thrush	1201.36	<.0001
Kestrel	65	<.0001	Mistle Thrush	137.78	<.0001
Red-legged Partridge	710.98	<.0001	Reed Warbler	****	****
Partridge	218.88	<.0001	Sedge Warbler	927.03	<.0001
Pheasant	1316.26	<.0001	Blackcap	1498.43	<.0001
Moorhen	573.76	<.0001	Garden Warbler	381.79	<.0001
Coot	1886.38	<.0001	Whitethroat	1128.63	<.0001
Lapwing	1082.72	<.0001	Lesser Whitethroat	77.18	<.0001
Curlew	399.68	<.0001	Willow Warbler	2270.83	<.0001
Stock Dove	223.3	<.0001	Chiffchaff	1314.12	<.0001
Wood Pigeon	1963.78	<.0001	Goldcrest	3643.67	<.0001
Turtle Dove	61.99	<.0001	Spotted Flycatcher	82.37	<.0001
Collared Dove	6003.04	<.0001	Dunnock	888.46	<.0001
Cuckoo	75.77	<.0001	Meadow Pipit	6339.46	<.0001
Little Owl	53.53	<.0001	Tree Pipit	245.94	<.0001
Tawny Owl	98.36	<.0001	Pied Wagtail	377.09	<.0001
Green Woodpecker	115.05	<.0001	Grey Wagtail	82.71	<.0001
Great S. Woodpecker	396.93	<.0001	Yellow Wagtail	317.75	<.0001
Skylark	4080.51	<.0001	Starling	16374.9	<.0001
Swallow	1118.36	<.0001	House Sparrow	20687.2	<.0001
House Martin	772.22	<.0001	Tree Sparrow	268.64	<.0001
Carrion Crow	484.66	<.0001	Greenfinch	2890.16	<.0001
Jackdaw	1555.64	<.0001	Goldfinch	630.27	<.0001
Magpie	1516.31	<.0001	Linnet	1187.3	<.0001
Jay	370.12	<.0001	Lesser Redpoll	189.44	<.0001
Great Tit	1074.01	<.0001	Bullfinch	135.33	<.0001
Blue Tit	2493.74	<.0001	Chaffinch	2856.75	<.0001
Coal Tit	2739.15	<.0001	Corn Bunting	326.13	<.0001
Marsh Tit	320.51	<.0001	Yellowhammer	2597.24	<.0001
Willow Tit	30.09	0.0004	Reed Bunting	505.39	<0.001
Long-tailed Tit	413.88	<.0001			

Table 1.3 Means bird count (per 200-m transect section) by secondary BBS habitat type.

Species	Wood	Scrub	Grass	Heath	Farm	Human	Water	Coast	Rock
Little Grebe	0	0	0.01	0	0	0	0.02	0.03	0
Mute Swan	0.01	0.01	0.05	0	0.02	0.02	0.09	0.03	0.01
Shelduck	0	0.01	0.04	0	0.02	0	0.04	0.36	0
Mallard	0.15	0.17	0.28	0.06	0.18	0.24	0.85	0.81	0.02
Tufted Duck	0.02	0.04	0.02	0	0.02	0.01	0.15	0.02	0.01
Sparrowhawk	0.01	0.01	0	0.01	0	0	0	0	0.01
Buzzard	0.04	0.03	0.04	0.03	0.02	0.01	0.02	0	0.03
Kestrel	0.02	0.02	0.01	0	0.01	0.01	0.03	0.03	0.02
Red-legged Partridge	0.06	0.04	0.01	0.01	0.09	0.04	0.05	0.03	0.01
Partridge	0.02	0.02	0.01	0	0.03	0.01	0.02	0.02	0
Pheasant	0.38	0.23	0.11	0.07	0.3	0.15	0.2	0.01	0.05
Moorhen	0.04	0.05	0.04	0	0.05	0.07	0.23	0.04	0
Coot	0.03	0.05	0.05	0.01	0.03	0.04	0.17	0.08	0
Lapwing	0.03	0.04	0.17	0.14	0.11	0.05	0.16	0.18	0.07
Curlew	0.03	0.03	0.07	0.13	0.03	0.01	0.05	0.26	0.07
Stock Dove	0.07	0.03	0.02	0	0.07	0.05	0.06	0.13	0.02
Wood Pigeon	1.78	1.52	0.61	0.26	1.71	1.65	1.19	0.36	0.26
Turtle Dove	0.01	0.02	0.01	0	0.02	0.01	0.02	0	0
Collared Dove	0.1	0.12	0.09	0.01	0.2	0.59	0.14	0.11	0.01
Cuckoo	0.02	0.04	0.02	0.02	0.02	0.01	0.02	0.01	0
Little Owl	0	0	0	0.01	0.01	0.01	0.01	0	0
Tawny Owl	0.01	0.01	0	0	0	0	0	0	0.01
Green Woodpecker	0.06	0.06	0.02	0.01	0.03	0.03	0.04	0	0.02
Great S. Woodpecker	0.09	0.08	0.04	0.01	0.05	0.05	0.05	0	0.01
Skylark	0.17	0.22	0.61	0.39	0.42	0.16	0.35	0.62	0.34
Swallow	0.09	0.09	0.1	0.04	0.21	0.29	0.16	0.2	0.01
House Martin	0.05	0.01	0.06	0	0.09	0.12	0.05	0.09	0
Carrion Crow	0.57	0.31	0.57	0.13	0.53	0.58	0.48	0.36	0.17
Jackdaw	0.42	0.28	0.25	0.03	0.46	0.6	0.35	0.01	0.2
Magpie	0.27	0.31	0.29	0.14	0.31	0.58	0.3	0.16	0.06
Jay	0.08	0.06	0.03	0.04	0.04	0.04	0.04	0	0.01
Great Tit	0.72	0.53	0.29	0.12	0.5	0.62	0.48	0.15	0.2
Blue Tit	1.14	0.82	0.54	0.2	0.88	1.17	0.85	0.12	0.35
Coal Tit	0.22	0.23	0.16	0.24	0.07	0.05	0.07	0.02	0.03
Marsh Tit	0.03	0.03	0.01	0	0.01	0	0.01	0	0
Willow Tit	0	0.01	0.01	0	0	0	0.01	0	0
Long-tailed Tit	0.2	0.18	0.18	0.05	0.14	0.13	0.16	0.02	0.06
Nuthatch	0.08	0.04	0.01	0	0.03	0.02	0.03	0	0.01
Treecreeper	0.05	0.03	0.03	0.01	0.02	0.02	0.04	0	0.02
Wren	1.38	1.49	0.87	0.78	0.98	1.14	1.19	0.47	0.51
Robin	1.1	1.02	0.48	0.6	0.79	0.97	0.74	0.2	0.33
Redstart	0.04	0.02	0.03	0.01	0.02	0	0.02	0	0.02
Blackbird	1.1	1.04	0.79	0.3	1.2	1.97	1.07	0.58	0.48
Song Thrush	0.37	0.33	0.22	0.12	0.25	0.31	0.23	0.14	0.09
Mistle Thrush	0.13	0.1	0.04	0.06	0.09	0.13	0.1	0	0.01
Reed Warbler	0	0.02	0.06	0	0.02	0.01	0.08	0.06	0
Sedge Warbler	0.02	0.1	0.15	0.08	0.06	0.03	0.14	0.03	0.01
Blackcap	0.39	0.39	0.12	0.08	0.22	0.23	0.25	0.01	0.09
Garden Warbler	0.07	0.07	0.03	0.04	0.03	0.02	0.06	0	0
Whitethroat	0.11	0.27	0.24	0.05	0.25	0.19	0.23	0.35	0.03
Lesser Whitethroat	0.01	0.03	0	0	0.02	0.01	0.02	0.02	0.01
Willow Warbler	0.46	0.86	0.48	0.87	0.24	0.2	0.39	0.11	0.28
Chiffchaff	0.32	0.32	0.12	0.04	0.15	0.15	0.16	0.03	0.07
Goldcrest	0.27	0.33	0.17	0.39	0.09	0.07	0.11	0	0.06
Spotted Flycatcher	0.03	0.01	0.01	0.01	0.01	0.03	0.03	0	0.01
Dunnock	0.34	0.37	0.23	0.13	0.43	0.56	0.31	0.25	0.16

Meadow Pipit	0.12	0.27	1.15	1.65	0.14	0.07	0.41	0.96	1.5
Tree Pipit	0.02	0.08	0.05	0.05	0	0	0.01	0	0.01
Pied Wagtail	0.07	0.06	0.06	0.04	0.11	0.15	0.12	0.18	0.07
Grey Wagtail	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0	0.01
Yellow Wagtail	0	0	0.01	0	0.02	0.01	0.04	0.01	0
Starling	0.5	0.7	0.67	0.21	0.99	2.63	0.95	2.42	0.12
House Sparrow	0.22	0.39	0.46	0.04	0.84	2.36	0.4	0.6	0.15
Tree Sparrow	0.01	0.02	0.01	0	0.02	0.03	0.02	0.08	0
Greenfinch	0.26	0.23	0.17	0.01	0.48	0.93	0.33	0.31	0.22
Goldfinch	0.15	0.14	0.13	0.01	0.25	0.33	0.19	0.14	0.09
Linnet	0.09	0.32	0.2	0.06	0.3	0.25	0.2	0.86	0.24
Lesser Redpoll	0.01	0.02	0.03	0.1	0.01	0	0.01	0.02	0
Bullfinch	0.05	0.07	0.01	0.02	0.04	0.04	0.05	0.06	0
Chaffinch	1.58	1.26	0.95	0.89	1.33	1.19	1.18	0.23	0.41
Corn Bunting	0	0.01	0	0	0.02	0.01	0.02	0.14	0
Yellowhammer	0.16	0.18	0.11	0.03	0.35	0.16	0.21	0.11	0.09
Reed Bunting	0.01	0.04	0.11	0.07	0.03	0.02	0.1	0.12	0.01

Table 2.1 Mean bird count (per 200-m transect section) by landclass variable. Figures are number of birds recorded per transect in squares of each of 32 landclass categories.

	CEH LANDCLASS TYPE															
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Little Grebe	0	0.01	0	0.01	0	0	0	0	0	0.01	0	0	0	0	0.01	0
Mute Swan	0.02	0.04	0.01	0.05	0	0.01	0	0.02	0.02	0.02	0.03	0.04	0.03	0.04	0.03	0.02
Shelduck	0.01	0	0.04	0.06	0.04	0	0.22	0.05	0.01	0.01	0	0	0.04	0	0	0
Mallard	0.22	0.23	0.2	0.31	0.35	0.07	0.09	0.19	0.24	0.25	0.38	0.22	0.21	0.22	0.25	0.34
Tufted Duck	0.02	0.04	0.04	0.03	0	0.02	0	0	0.02	0.04	0.03	0.09	0.04	0.02	0.01	0.02
Sparrowhawk	0	0	0.01	0	0	0.01	0	0	0.01	0.01	0	0.01	0	0	0.01	0
Buzzard	0.02	0.02	0	0	0.08	0.04	0.03	0.01	0.01	0.01	0	0	0.02	0	0.08	0
Kestrel	0.02	0.01	0.02	0.01	0	0	0	0.03	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.03
Red-legged Partridge	0.05	0.05	0.15	0.13	0.03	0.01	0	0.03	0.06	0.05	0.12	0.28	0.02	0.04	0	0.03
Partridge	0.01	0.02	0.03	0.04	0	0	0	0.02	0.02	0.03	0.03	0.07	0.02	0.02	0.02	0.04
Pheasant	0.23	0.25	0.33	0.27	0.26	0.11	0.21	0.25	0.23	0.15	0.27	0.38	0.18	0.28	0.12	0.12
Moorhen	0.04	0.07	0.07	0.11	0.03	0.02	0.04	0.08	0.07	0.08	0.08	0.09	0.09	0.06	0.05	0.07
Coot	0.02	0.08	0.03	0.06	0	0.02	0	0.04	0.05	0.07	0.08	0.08	0.03	0.02	0.04	0.07
Lapwing	0.03	0.03	0.06	0.11	0.04	0	0	0.06	0.05	0.15	0.06	0.03	0.1	0	0.15	0.2
Curlew	0.01	0	0.01	0	0.01	0.02	0	0	0.01	0.05	0	0.01	0.11	0.02	0.06	0.02
Stock Dove	0.07	0.06	0.05	0.09	0.14	0.04	0	0.07	0.07	0.05	0.08	0.06	0.02	0.04	0.02	0.02
Wood Pigeon	1.54	1.71	2.11	2.15	0.85	0.64	1.82	1.37	1.3	1.2	1.99	2.77	1.25	0.84	0.72	0.53
Turtle Dove	0.01	0.01	0.05	0.04	0	0	0	0.02	0	0.01	0.01	0.04	0	0	0	0
Collared Dove	0.3	0.36	0.32	0.41	0.26	0.11	0.15	0.21	0.27	0.37	0.34	0.26	0.46	0.1	0.16	0.22
Cuckoo	0.01	0.02	0.02	0.02	0.04	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0	0.03	0.01
Little Owl	0.01	0.01	0	0	0	0	0	0.01	0.01	0.01	0.01	0	0.01	0	0	0.01
Tawny Owl	0	0.01	0	0	0.01	0	0	0	0	0.01	0	0	0	0.06	0.01	0.01
Green Woodpecker	0.05	0.08	0.05	0.05	0.04	0.04	0.05	0.05	0.02	0	0.03	0.02	0	0	0.01	0
Great S. Woodpecker	0.09	0.08	0.06	0.04	0.04	0.02	0.04	0.03	0.04	0.03	0.04	0.05	0.04	0.04	0.04	0.02
Skylark	0.24	0.24	0.5	0.51	0.2	0.32	0.23	0.44	0.33	0.25	0.48	0.65	0.24	0.4	0.14	0.37
Swallow	0.12	0.11	0.09	0.1	0.27	0.13	0.16	0.11	0.2	0.21	0.1	0.1	0.34	0.14	0.36	0.35
House Martin	0.08	0.08	0.06	0.06	0.31	0.01	0.2	0.05	0.05	0.09	0.07	0.06	0.15	0.04	0.08	0.05
Carrion Crow	0.62	0.68	0.43	0.51	0.81	0.46	0.5	0.4	0.46	0.46	0.37	0.36	0.62	0.7	0.72	0.21
Jackdaw	0.54	0.46	0.23	0.56	0.46	0.46	0.39	0.32	0.38	0.44	0.33	0.22	0.42	0.66	0.74	0.11
Magpie	0.38	0.45	0.31	0.36	0.45	0.35	0.37	0.38	0.29	0.45	0.32	0.38	0.43	0.08	0.5	0.4
Jay	0.06	0.05	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.04	0.03	0.02	0.05	0	0.03	0.05

	CEH LANDCLASS TYPE															
Species	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Little Grebe	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0
Mute Swan	0.01	0	0.02	0.03	0.01	0.01	0	0	0	0	0	0	0	0	0	0
Shelduck	0.01	0	0.02	0	0.04	0	0.01	0	0	0.01	0	0	0	0.1	0	0
Mallard	0.08	0.23	0.13	0.39	0.09	0.13	0.2	0.03	0.06	0.08	0.18	0.07	0	0.2	0.2	0
Tufted Duck	0.01	0	0	0.01	0	0.01	0	0	0.01	0	0	0.01	0	0	0	0
Sparrowhawk	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buzzard	0.04	0.01	0.01	0.04	0.03	0.03	0.02	0.01	0.04	0.02	0	0.02	0	0	0	0
Kestrel	0.01	0	0.02	0.01	0.01	0.02	0	0	0.03	0	0.02	0	0	0	0	0
Red-legged Partridge	0.02	0.01	0.01	0.04	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0
Partridge	0.01	0.01	0.02	0.01	0	0.03	0.01	0	0.05	0	0.01	0	0	0	0	0
Pheasant	0.13	0.07	0.08	0.09	0.03	0.08	0.06	0.01	0.24	0.11	0.14	0.21	0	0	0	0
Moorhen	0.01	0.02	0.02	0.08	0	0.01	0.01	0	0.01	0.01	0	0.01	0	0	0	0
Coot	0	0	0.02	0.07	0	0.02	0	0	0.01	0	0	0	0	0	0	0
Lapwing	0.06	0.22	0.38	0.11	0.19	0.21	0.33	0.18	0.19	0.06	0.04	0.13	0.13	0	0.3	0
Curlew	0.05	0.09	0.16	0.01	0.16	0.14	0.07	0.02	0.1	0.07	0.1	0.1	0.03	0.05	0.1	0
Stock Dove	0.03	0.02	0	0.04	0	0.06	0.01	0.03	0.05	0.01	0.02	0	0	0	0	0
Wood Pigeon	0.52	0.35	0.66	0.29	0.08	0.64	0.31	0.17	1.16	0.46	0.68	0.25	0	0	0	0
Turtle Dove	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Collared Dove	0.1	0.07	0.06	0.09	0.01	0.05	0.04	0.05	0.05	0.09	0.03	0.05	0	0	0	0
Cuckoo	0.01	0.01	0.03	0	0.04	0.01	0	0.01	0	0	0	0.02	0.03	0	0	0
Little Owl	0	0.02	0.01	0	0	0	0	0	0.01	0	0	0	0	0	0	0
Tawny Owl	0	0.01	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0
Green Woodpecker	0.02	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
Great S. Woodpecker	0.03	0.02	0.03	0.03	0.01	0.01	0	0.01	0.03	0.03	0	0.04	0	0	0	0
Skylark	0.32	0.16	0.34	0.74	0.22	0.42	0.46	0.09	0.45	0.43	0.51	0.29	0.43	0.9	0.1	0
Swallow	0.14	0.25	0.22	0.06	0.06	0.2	0.21	0.34	0.19	0.1	0.09	0.08	0	0	0	0
House Martin	0.06	0.07	0.01	0	0.09	0.02	0.1	0.22	0.01	0.03	0.09	0.03	0	0	0	0
Carrion Crow	0.51	0.52	0.53	0.31	0.11	0.53	0.24	0.61	0.49	0.37	0.34	0.32	0	0	0	0
Jackdaw	0.3	0.58	0.38	0.21	0.14	0.32	0.2	0.24	0.34	0.29	0.25	0.21	0	0	0	0
Magpie	0.26	0.3	0.34	0.16	0.03	0.15	0.05	0.01	0.06	0.07	0.02	0.07	0	0	0	0
Jay	0.04	0.01	0	0.03	0	0.02	0	0.01	0.01	0	0	0	0	0	0	0

	CEH LANDCLASS TYPE															
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Great Tit	0.61	0.71	0.53	0.53	0.48	0.32	0.43	0.47	0.4	0.44	0.45	0.42	0.49	0.72	0.46	0.42
Blue Tit	1.03	1.25	0.87	0.95	0.89	0.71	0.87	0.75	0.78	0.9	0.87	0.83	0.95	1.12	0.97	0.83
Coal Tit	0.08	0.09	0.09	0.02	0.08	0.11	0.09	0.03	0.06	0.05	0.04	0.01	0.05	0.16	0.09	0.13
Marsh Tit	0.02	0.02	0.02	0.01	0.03	0.01	0	0.01	0.01	0.01	0.02	0.01	0	0	0.02	0.05
Willow Tit	0.01	0	0	0	0	0	0	0	0	0.01	0.01	0	0.01	0.06	0	0
Long-tailed Tit	0.16	0.2	0.14	0.13	0.07	0.09	0.26	0.08	0.15	0.14	0.16	0.14	0.12	0.36	0.11	0.1
Nuthatch	0.05	0.06	0.02	0.02	0.04	0.07	0.03	0.03	0.01	0.02	0.01	0.01	0.02	0	0.06	0.03
Treecreeper	0.03	0.02	0.02	0.02	0.02	0.03	0.04	0.02	0.02	0.01	0.02	0.01	0.01	0.06	0.11	0.02
Wren	1.06	1.09	0.83	0.89	1.32	1.12	1.04	0.8	0.92	0.92	0.85	0.96	0.9	1.1	1.05	0.97
Robin	0.96	0.96	0.75	0.69	0.99	0.78	0.68	0.56	0.66	0.68	0.66	0.63	0.7	0.5	0.93	0.75
Redstart	0.01	0	0.01	0	0.01	0.02	0	0	0.02	0	0	0	0.04	0.02	0.08	0
Blackbird	1.38	1.51	1.2	1.33	1.46	0.96	0.9	0.98	1.19	1.38	1.35	1.24	1.52	1.38	1.14	1.03
Song Thrush	0.3	0.28	0.2	0.25	0.29	0.22	0.21	0.21	0.2	0.18	0.19	0.14	0.23	0.56	0.28	0.29
Mistle Thrush	0.08	0.1	0.09	0.11	0.1	0.05	0.06	0.07	0.08	0.1	0.09	0.1	0.11	0.06	0.12	0.09
Reed Warbler	0.01	0.02	0.04	0.13	0.01	0	0	0.09	0.01	0	0.01	0.04	0	0	0	0.02
Sedge Warbler	0.01	0.03	0.06	0.12	0.03	0.05	0.02	0.09	0.03	0.02	0.03	0.12	0.08	0.5	0.02	0.07
Blackcap	0.29	0.27	0.27	0.24	0.27	0.17	0.26	0.17	0.18	0.18	0.21	0.32	0.15	0.4	0.23	0.18
Garden Warbler	0.03	0.04	0.04	0.03	0.01	0.03	0.02	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.06	0.02
Whitethroat	0.14	0.17	0.35	0.25	0.25	0.12	0.41	0.24	0.19	0.21	0.25	0.43	0.19	0.46	0.14	0.31
Lesser Whitethroat	0.01	0.01	0.02	0.03	0.02	0	0.01	0.02	0.02	0.01	0.04	0.06	0.01	0.04	0.01	0.01
Willow Warbler	0.12	0.11	0.15	0.08	0.25	0.44	0.18	0.11	0.22	0.27	0.1	0.18	0.26	0.72	0.48	0.39
Chiffchaff	0.22	0.2	0.14	0.13	0.24	0.28	0.21	0.15	0.14	0.11	0.1	0.12	0.12	0.14	0.19	0.08
Goldcrest	0.11	0.11	0.07	0.05	0.16	0.22	0.06	0.08	0.07	0.05	0.05	0.01	0.05	0.24	0.13	0.14
Spotted Flycatcher	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0	0.01	0.01	0.01	0.01	0.02	0.06	0.04	0.02
Dunnock	0.44	0.43	0.34	0.37	0.45	0.27	0.41	0.39	0.37	0.45	0.4	0.5	0.38	0.66	0.31	0.36
Meadow Pipit	0.01	0.03	0.05	0.13	0.18	0.23	0.36	0.23	0.15	0.22	0.03	0.03	0.04	0.7	0.2	0.1
Tree Pipit	0	0.01	0.01	0	0.03	0.03	0.01	0.01	0.01	0.01	0	0	0.01	0	0.02	0
Pied Wagtail	0.08	0.09	0.07	0.09	0.11	0.06	0.12	0.13	0.1	0.11	0.08	0.09	0.12	0.22	0.12	0.1
Grey Wagtail	0.01	0.01	0	0.01	0.02	0.02	0	0	0.01	0.01	0.01	0	0.02	0.1	0.02	0
Yellow Wagtail	0.01	0.01	0.04	0.05	0	0	0	0.08	0.03	0.03	0.03	0.07	0.03	0	0	0.02
Starling	1.16	1.6	1.49	1.53	0.87	0.61	0.55	0.98	1.07	1.38	1.52	1.07	1.81	0.96	1.11	1.08
House Sparrow	0.9	1.03	1.17	1.4	1.21	1.04	0.61	1.16	0.96	1.24	1.08	0.82	1.43	1.48	0.88	0.87
Tree Sparrow	0.01	0	0.01	0.01	0.01	0	0	0.03	0.04	0.05	0.04	0.03	0.04	0.04	0.04	0
Greenfinch	0.5	0.58	0.45	0.57	0.53	0.36	0.61	0.45	0.45	0.48	0.54	0.46	0.45	0.72	0.48	0.32
Goldfinch	0.18	0.2	0.21	0.22	0.19	0.26	0.29	0.18	0.19	0.16	0.15	0.12	0.28	0.22	0.22	0.08

	CEH LANDCLASS TYPE															
Species	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Great Tit	0.32	0.18	0.25	0.32	0.15	0.18	0.14	0.13	0.23	0.14	0.13	0.21	0	0.05	0	0
Blue Tit	0.62	0.41	0.46	0.69	0.11	0.41	0.29	0.28	0.38	0.5	0.42	0.47	0	0	0	0
Coal Tit	0.08	0.05	0.05	0.11	0.14	0.18	0.13	0.12	0.07	0.22	0.18	0.27	0	0	0	0
Marsh Tit	0.02	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0
Willow Tit	0	0	0	0.02	0	0	0	0	0	0	0.01	0	0	0	0	0
Long-tailed Tit	0.07	0.07	0.04	0.06	0	0.02	0.03	0.05	0.17	0.05	0.05	0.06	0	0	0	0
Nuthatch	0.04	0.03	0	0.02	0	0	0.01	0	0	0	0	0.01	0	0	0	0
Treecreeper	0.03	0.02	0.01	0.04	0.03	0.01	0	0.02	0.01	0	0.03	0	0	0	0	0
Wren	0.76	0.47	0.63	0.84	0.4	0.67	0.32	0.68	0.42	0.83	0.52	0.86	0	0.15	0	0.13
Robin	0.67	0.37	0.44	0.65	0.24	0.43	0.25	0.53	0.31	0.38	0.25	0.48	0.03	0	0	0.13
Redstart	0.14	0.08	0.03	0.04	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.06	0	0	0	0
Blackbird	0.8	0.53	0.67	0.79	0.19	0.6	0.28	0.43	0.61	0.65	0.66	0.36	0.03	0.1	0.4	0.07
Song Thrush	0.21	0.11	0.09	0.23	0.14	0.23	0.1	0.25	0.16	0.17	0.2	0.18	0.03	0	0	0.07
Mistle Thrush	0.09	0.08	0.06	0.06	0.08	0.07	0.06	0.02	0.07	0.04	0.05	0.06	0	0	0	0.1
Reed Warbler	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sedge Warbler	0.01	0.02	0.03	0.06	0.03	0.06	0.04	0.02	0.08	0.03	0.06	0.01	0	0	0	0
Blackcap	0.13	0.1	0.04	0.22	0.02	0.05	0.01	0.04	0.05	0.07	0.03	0.08	0	0	0	0
Garden Warbler	0.08	0.02	0.01	0.04	0	0.01	0.01	0	0.03	0.03	0.01	0.01	0	0	0	0
Whitethroat	0.06	0.04	0.05	0.09	0.07	0.07	0.03	0.03	0.06	0.07	0.08	0.04	0	0	0	0
Lesser Whitethroat	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0
Willow Warbler	0.45	0.41	0.37	0.39	0.54	0.46	0.34	0.65	0.39	0.6	0.38	0.85	0	0.45	0	0.7
Chiffchaff	0.1	0.04	0.02	0.09	0.03	0.02	0	0.01	0.16	0.04	0.02	0.04	0	0	0	0
Goldcrest	0.17	0.08	0.16	0.09	0.08	0.18	0.12	0.14	0.08	0.2	0.26	0.31	0	0	0	0
Spotted Flycatcher	0.02	0.01	0	0.02	0.05	0.01	0.01	0.01	0.02	0.03	0.02	0.02	0	0	0	0
Dunnock	0.24	0.15	0.18	0.27	0.08	0.19	0.1	0.12	0.18	0.27	0.14	0.14	0	0	0	0.07
Meadow Pipit	0.79	1.08	0.93	1.94	1.62	0.81	1.26	0.61	0.87	0.37	1.38	0.86	2.08	1.8	0.3	0.67
Tree Pipit	0.07	0.02	0.01	0.05	0.06	0.02	0.03	0.06	0.03	0.03	0.02	0.07	0	0	0	0
Pied Wagtail	0.12	0.1	0.11	0.09	0.07	0.1	0.11	0.07	0.16	0.13	0.08	0.11	0	0.25	0	0.17
Grey Wagtail	0.01	0.03	0.01	0.01	0.01	0.02	0.01	0.04	0.01	0.02	0.02	0.07	0	0	0	0
Yellow Wagtail	0	0	0.01	0	0	0	0	0	0	0.02	0	0	0	0	0	0
Starling	0.45	1.1	1.49	0.24	0.56	1.72	0.88	0.34	1.14	0.86	0.92	0.29	0	0	3.1	0
House Sparrow	0.47	0.98	0.65	1.02	0.25	0.41	0.17	0.53	0.36	0.8	0.68	0.15	0.15	0	0.4	0
Tree Sparrow	0.02	0.01	0.15	0	0.01	0.04	0	0.01	0.03	0.02	0.01	0	0	0	0	0
Greenfinch	0.21	0.13	0.16	0.15	0.06	0.18	0.09	0.27	0.24	0.24	0.13	0.24	0	0	0	0
Goldfinch	0.16	0.09	0.27	0.21	0.05	0.09	0.09	0	0.16	0.14	0.06	0.1	0	0	0	0

	CEH LANDCLASS TYPE															
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Linnet	0.19	0.19	0.26	0.21	0.25	0.43	0.29	0.24	0.19	0.19	0.31	0.34	0.25	0.46	0.13	0.3
Lesser Redpoll	0.01	0	0	0	0	0.02	0.01	0	0	0	0.01	0	0	0	0.02	0
Bullfinch	0.06	0.04	0.04	0.03	0.04	0.05	0.04	0.03	0.02	0.04	0.05	0.03	0.04	0.12	0.05	0.05
Chaffinch	1.19	1.26	1.05	1.08	1.17	0.85	0.8	0.92	1.13	1.02	1.12	1.2	1.08	1.4	0.95	0.79
Corn Bunting	0	0.01	0.03	0.04	0	0	0	0.04	0.02	0.01	0.02	0.11	0.02	0	0	0.02
Yellowhammer	0.27	0.21	0.29	0.21	0.12	0.08	0.09	0.19	0.28	0.24	0.43	0.51	0.2	0.44	0.07	0.2
Reed Bunting	0.01	0.02	0.03	0.1	0.01	0.04	0.01	0.04	0.04	0.02	0.05	0.06	0.04	0.2	0.05	0.08

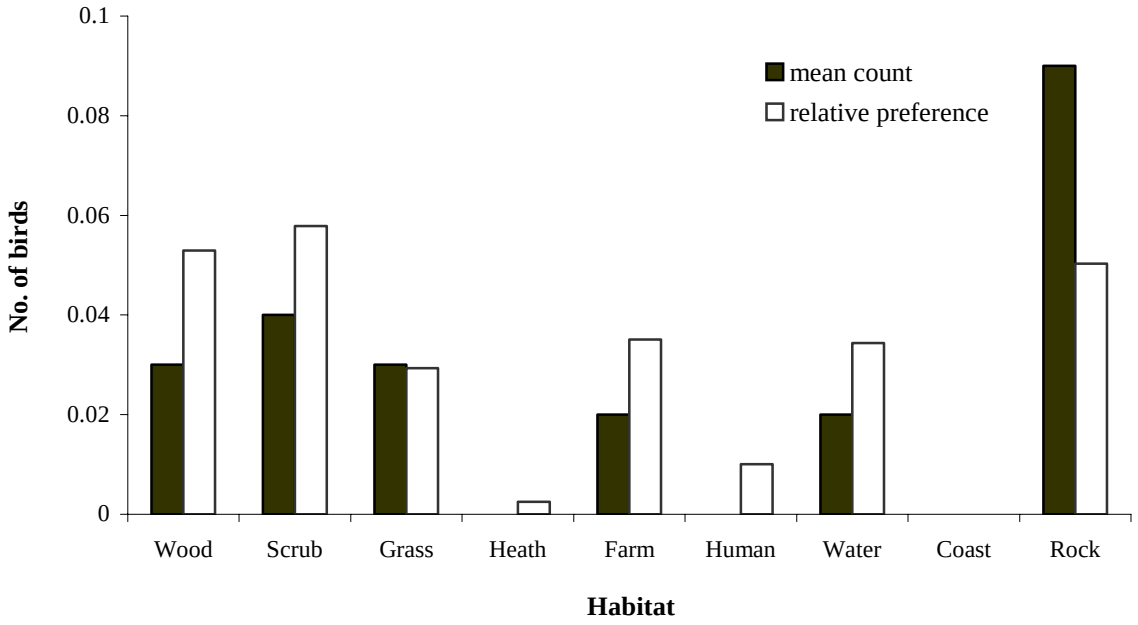
	CEH LANDCLASS TYPE															
Species	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Linnet	0.18	0.08	0.11	0.06	0.06	0.14	0.09	0.02	0.29	0.24	0.13	0.08	0	0	0	0
Lesser Redpoll	0.02	0.02	0	0	0.18	0.01	0.01	0.07	0.02	0.02	0.01	0	0	0.4	0	0
Bullfinch	0.03	0.02	0.01	0.08	0.06	0.01	0	0.01	0.01	0.03	0.02	0.02	0	0.2	0	0
Chaffinch	0.99	0.59	0.87	0.64	0.66	0.89	0.68	1.32	1.01	1.1	0.92	1.11	0.03	0.05	0	0.37
Corn Bunting	0.01	0	0	0	0	0	0	0	0.04	0	0.01	0	0	0	0	0
Yellowhammer	0.08	0.04	0.12	0.06	0.08	0.18	0.08	0.05	0.34	0.19	0.12	0.14	0	0	0	0
Reed Bunting	0.04	0.04	0.04	0.08	0.01	0.03	0.02	0.01	0.04	0.03	0.02	0.03	0	0	0	0.07

Table 2.2 The effect of CEH landclass on bird counts per square.

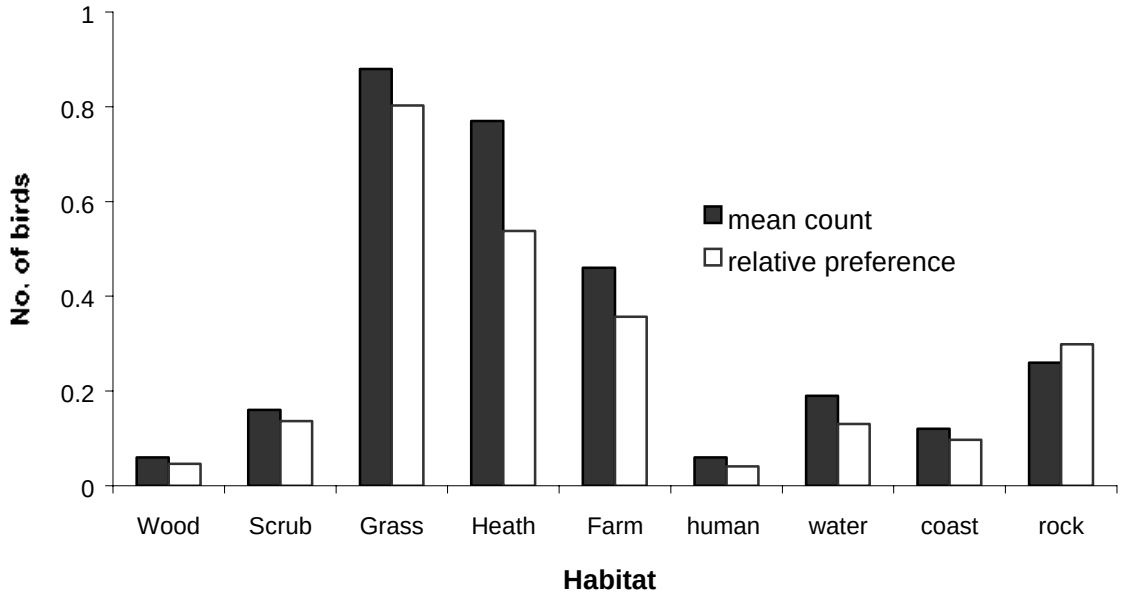
Species	χ^2	*P*	Species	χ^2	*P*
Little Grebe	50.95	0.0099	Nuthatch	89.53	<.0001
Mute Swan	262.32	<.0001	Treecreeper	87.88	<.0001
Shelduck	****	****	Wren	292.51	<.0001
Mallard	604.86	<.0001	Robin	276.63	<.0001
Tufted Duck	365.35	<.0001	Redstart	265.87	<.0001
Sparrowhawk	28.48	0.5449	Blackbird	533.2	<.0001
Buzzard	156.41	<.0001	Song Thrush	207.63	<.0001
Kestrel	45.38	0.0356	Mistle Thrush	101.63	<.0001
Red-legged Partridge	324.42	<.0001	Reed Warbler	****	****
Partridge	101.68	<.0001	Sedge Warbler	374.07	<.0001
Pheasant	4497.27	<.0001	Blackcap	168.75	<.0001
Moorhen	144.3	<.0001	Garden Warbler	82.58	<.0001
Coot	262.21	<.0001	Whitethroat	284.07	<.0001
Lapwing	1003.36	<.0001	Lesser Whitethroat	79.45	<.0001
Curlew	979.08	<.0001	Willow Warbler	629.95	<.0001
Stock Dove	206.09	<.0001	Chiffchaff	172.25	<.0001
Wood Pigeon	1543.8	<.0001	Goldcrest	274.89	<.0001
Turtle Dove	62.59	0.0004	Spotted Flycatcher	75.32	<.0001
Collared Dove	440.56	<.0001	Dunnock	210.8	<.0001
Cuckoo	106.54	<.0001	Meadow Pipit	2476.7	<.0001
Little Owl	42.88	0.06	Tree Pipit	122.41	<.0001
Tawny Owl	53.01	0.0059	Pied Wagtail	94.01	<.0001
Green Woodpecker	44.59	0.0421	Grey Wagtail	80.32	<.0001
Great S. Woodpecker	105.03	<.0001	Yellow Wagtail	119.4	<.0001
Skylark	536.49	<.0001	Starling	3380.15	<.0001
Swallow	696.13	<.0001	House Sparrow	1278.52	<.0001
House Martin	558.66	<.0001	Tree Sparrow	295.65	<.0001
Carrion Crow	1157.58	<.0001	Greenfinch	309.84	<.0001
Jackdaw	758.85	<.0001	Goldfinch	180.28	<.0001
Magpie	592.24	<.0001	Linnet	492.7	<.0001
Jay	97.59	<.0001	Lesser Redpoll	392.98	<.0001
Great Tit	239.87	<.0001	Bullfinch	90.92	<.0001
Blue Tit	489.88	<.0001	Chaffinch	325.33	<.0001
Coal Tit	297.78	<.0001	Corn Bunting	150.88	<.0001
Marsh Tit	109.69	<.0001	Yellowhammer	479.76	<.0001
Willow Tit	70.78	<.0001	Reed Bunting	202.47	<.0001
Long-tailed Tit	261.93	<.0001			

Figure 1.1 Mean counts per 200-m transect section and relative habitat preference for 7 selected species from a GLM controlling for geographical variation (latitude, longitude and altitude). Habitat preference is the predicted count at a hypothetical site at Easting = 300, Northing = 500, Altitude = 200-m. Predicted numbers at any other square are in direct proportion to these figures.

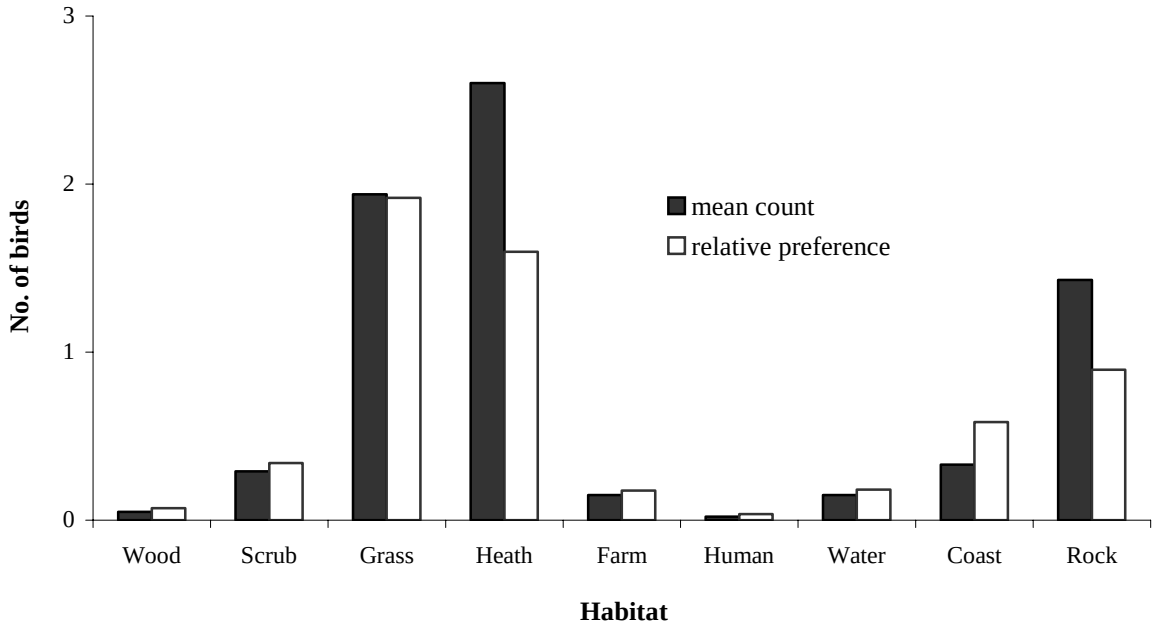
a) Buzzard



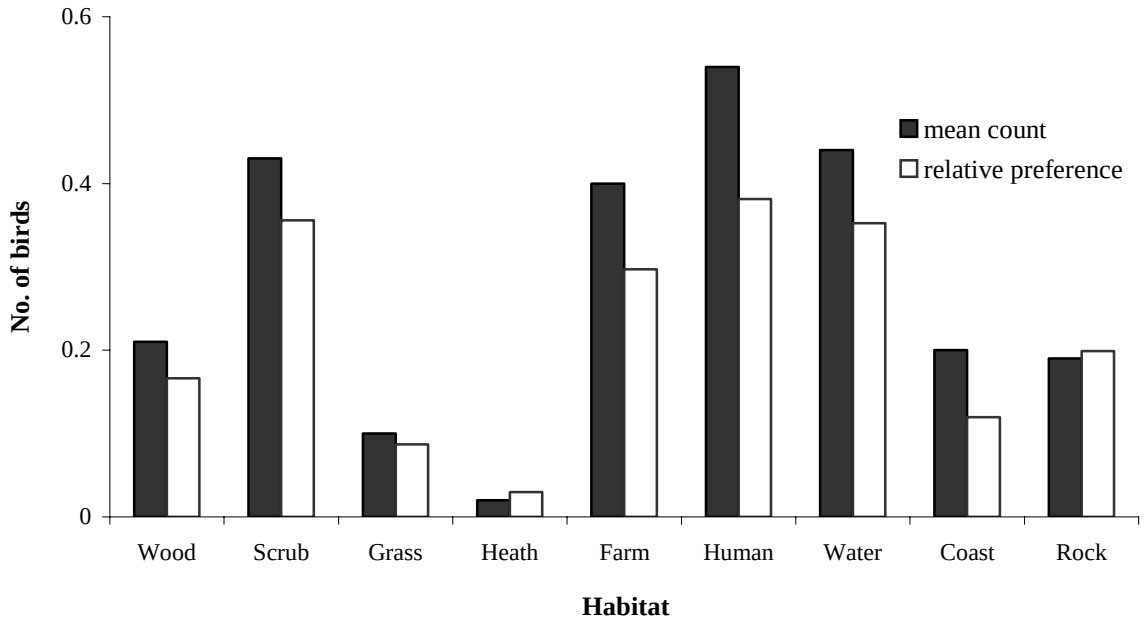
b) Skylark



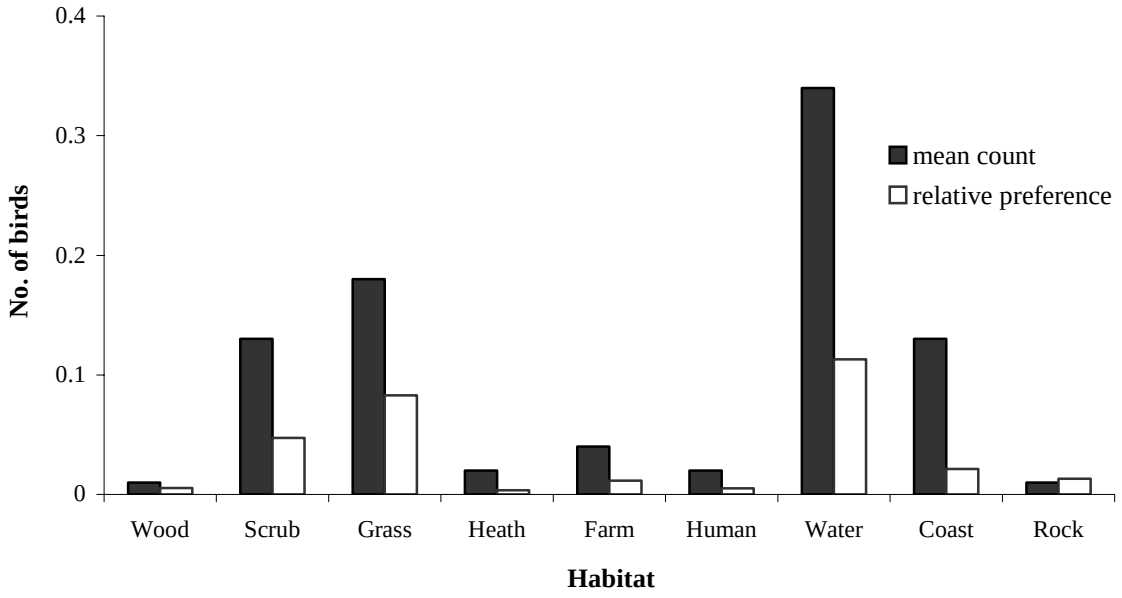
c) Meadow Pipit



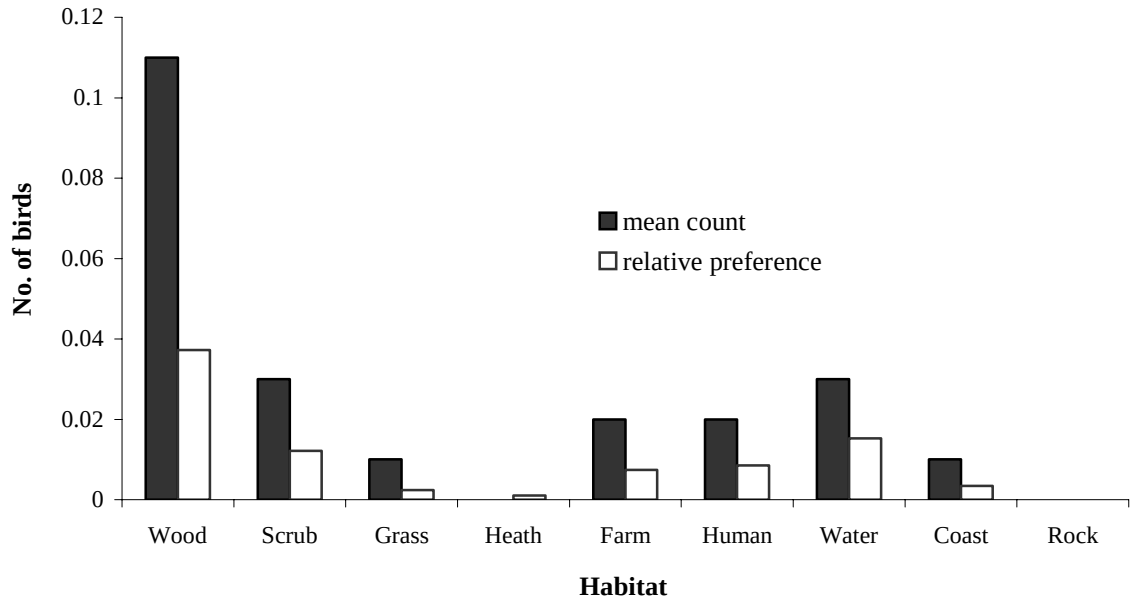
d) Dunnock



e) Sedge Warbler



f) Nuthatch



g) House Sparrow

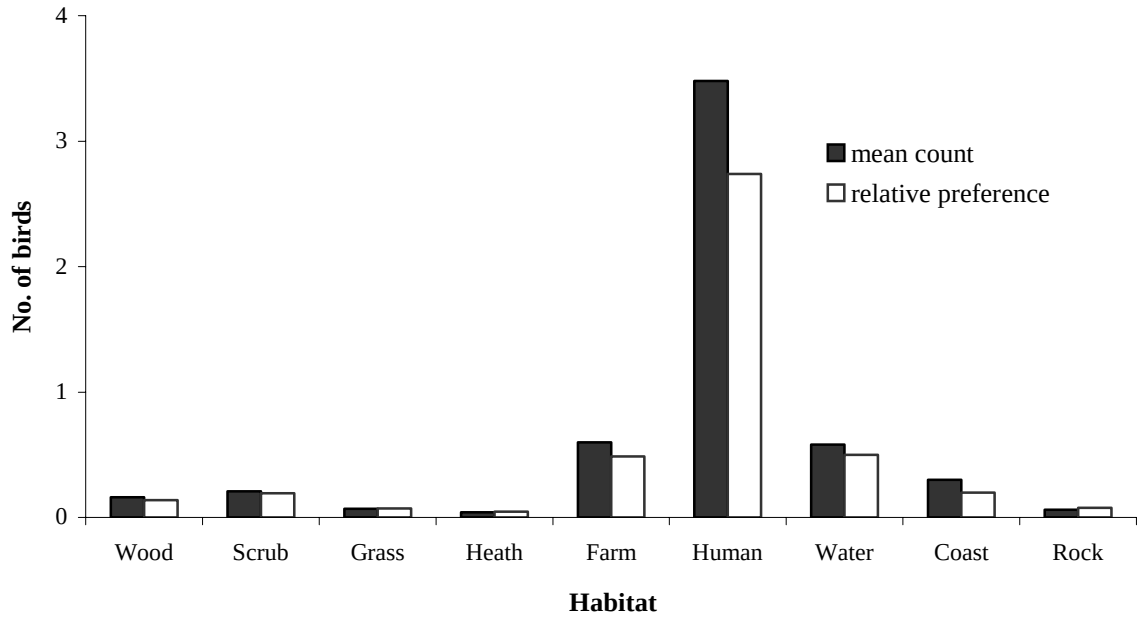
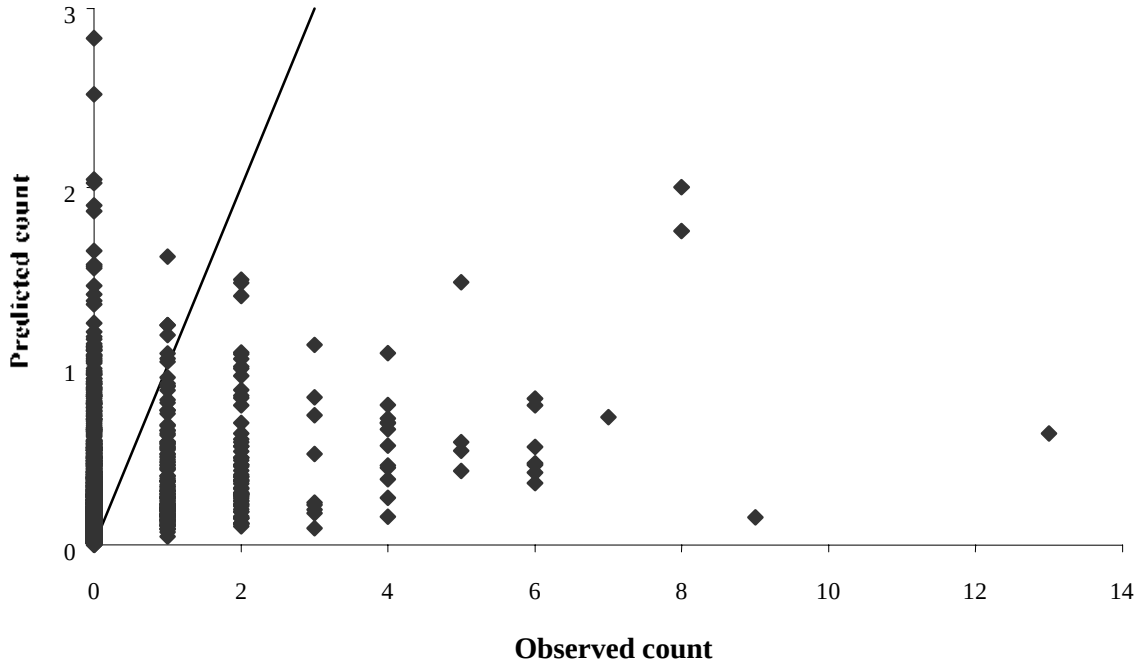
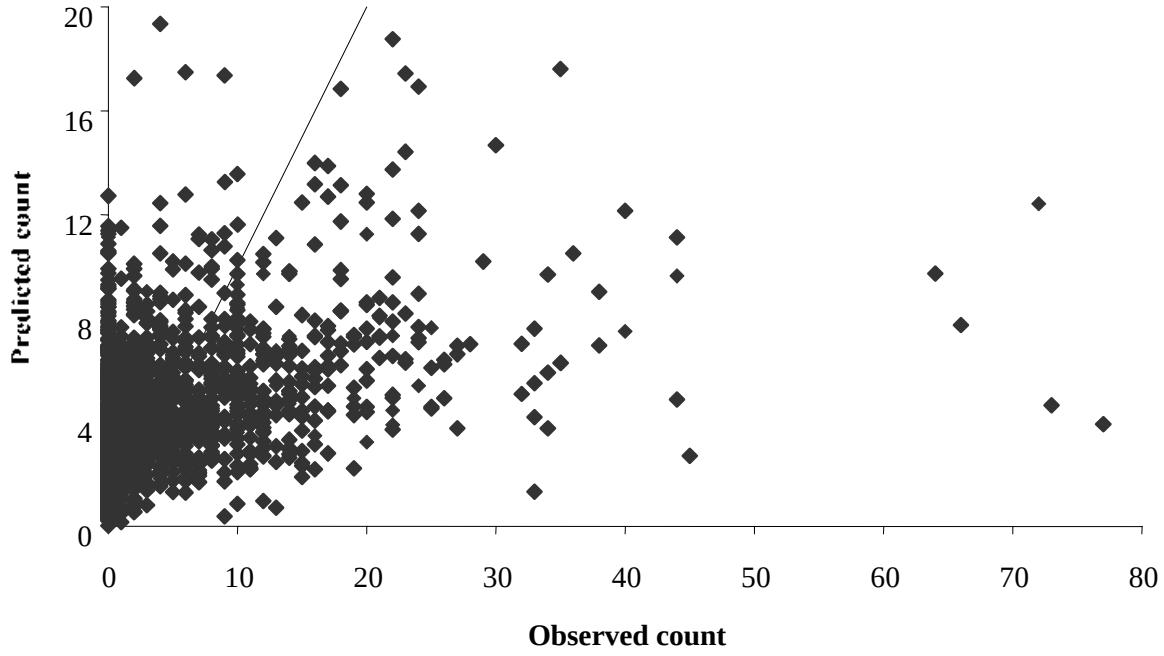


Figure 1.2 Counts per 1-km square for 7 selected species as predicted from BBS primary habitat data, plotted against the observed count. The diagonal line represents the line of equality, observed = expected.

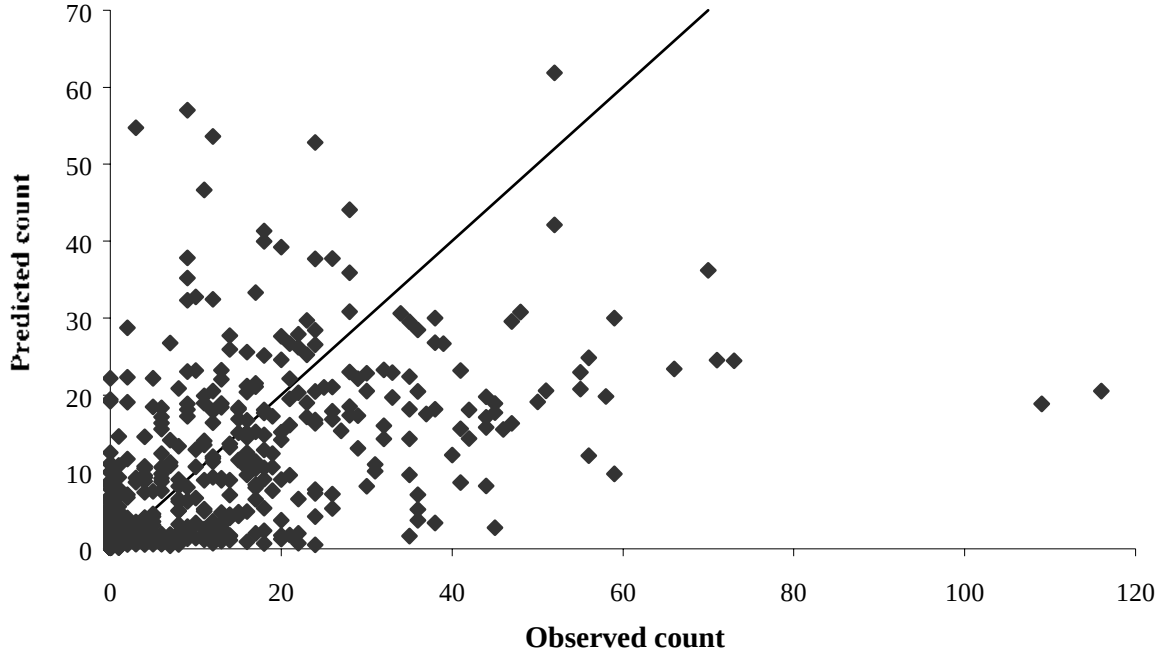
a) Buzzard



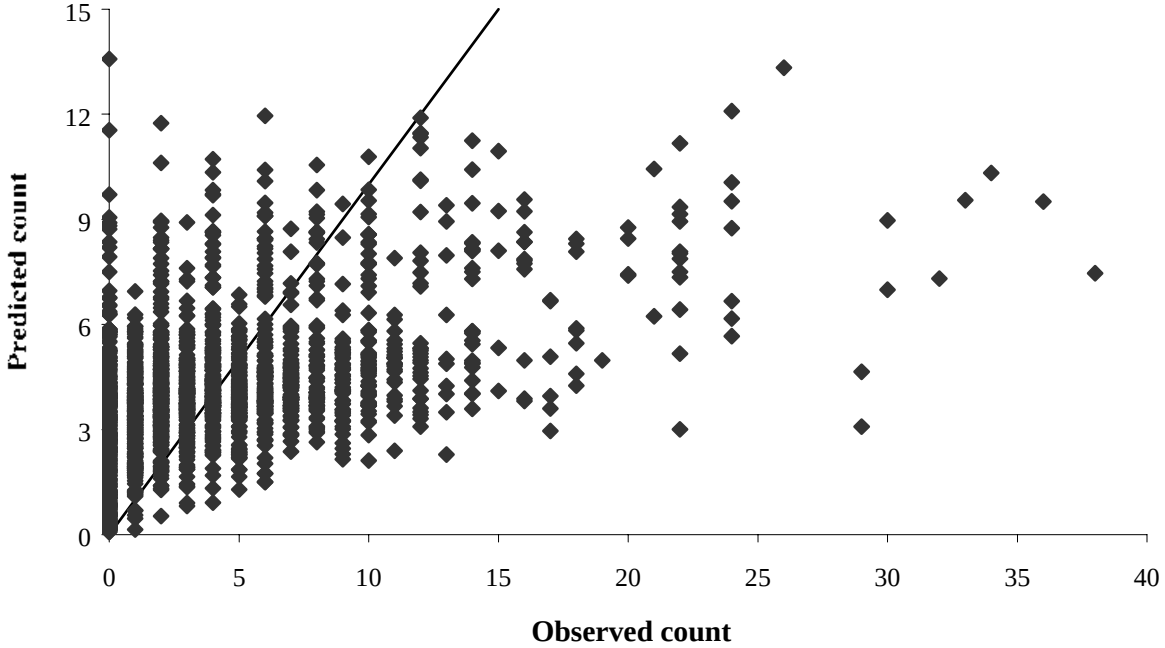
b) Skylark



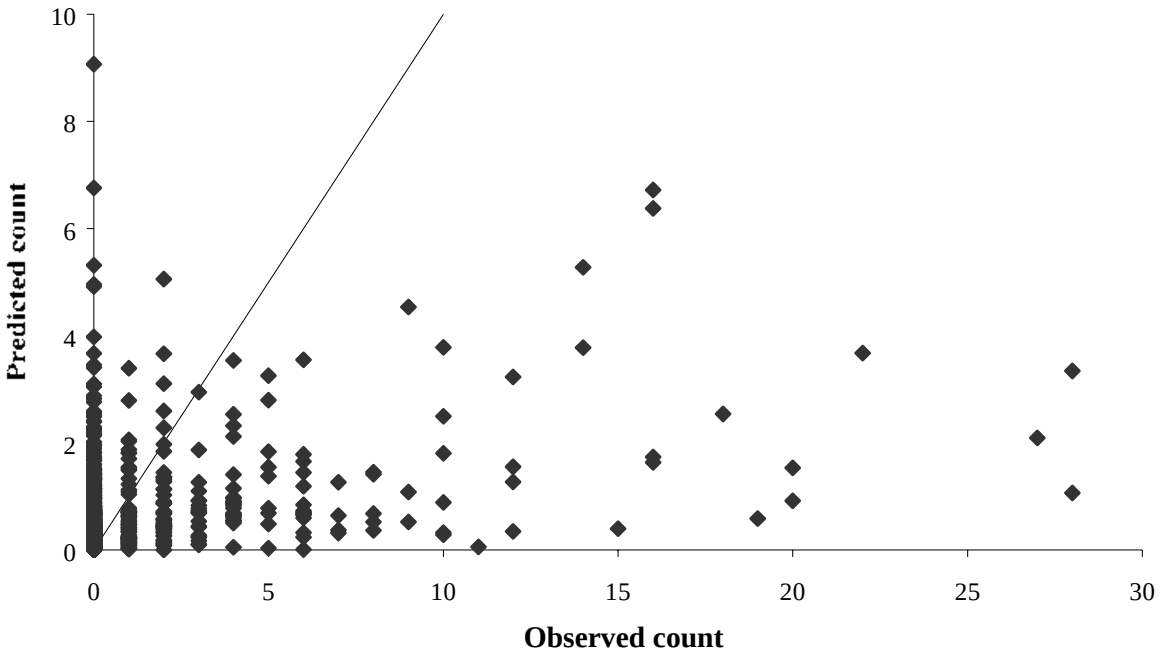
c) Meadow Pipit



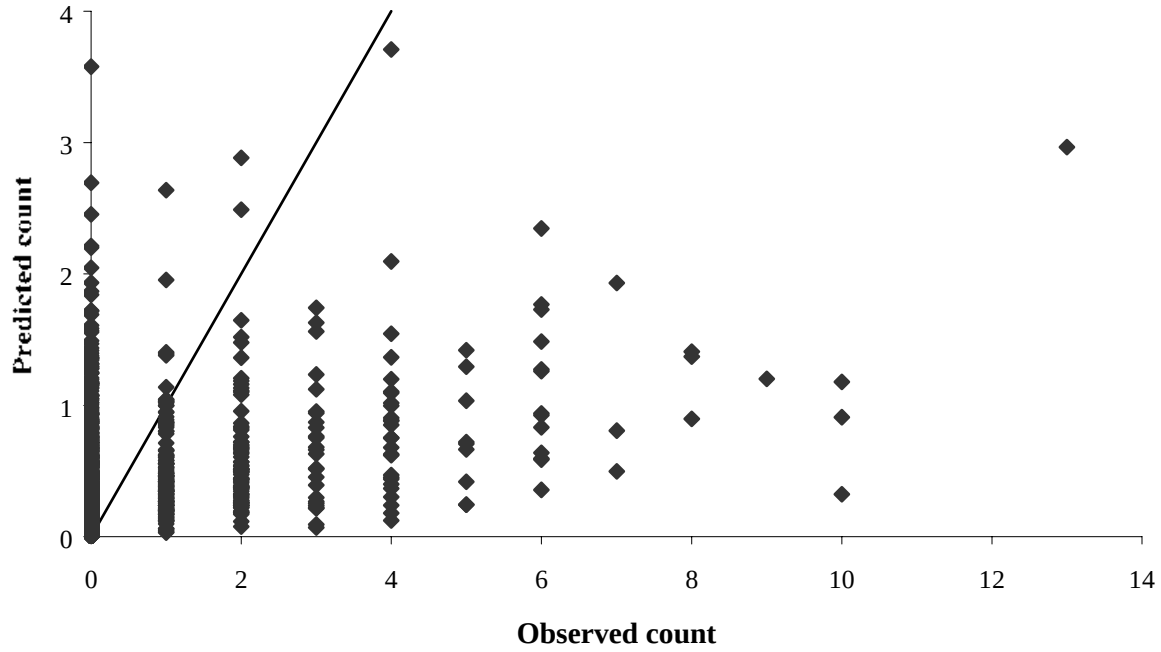
d) Dunnock



e) Sedge Warbler



f) Nuthatch



g) House Sparrow

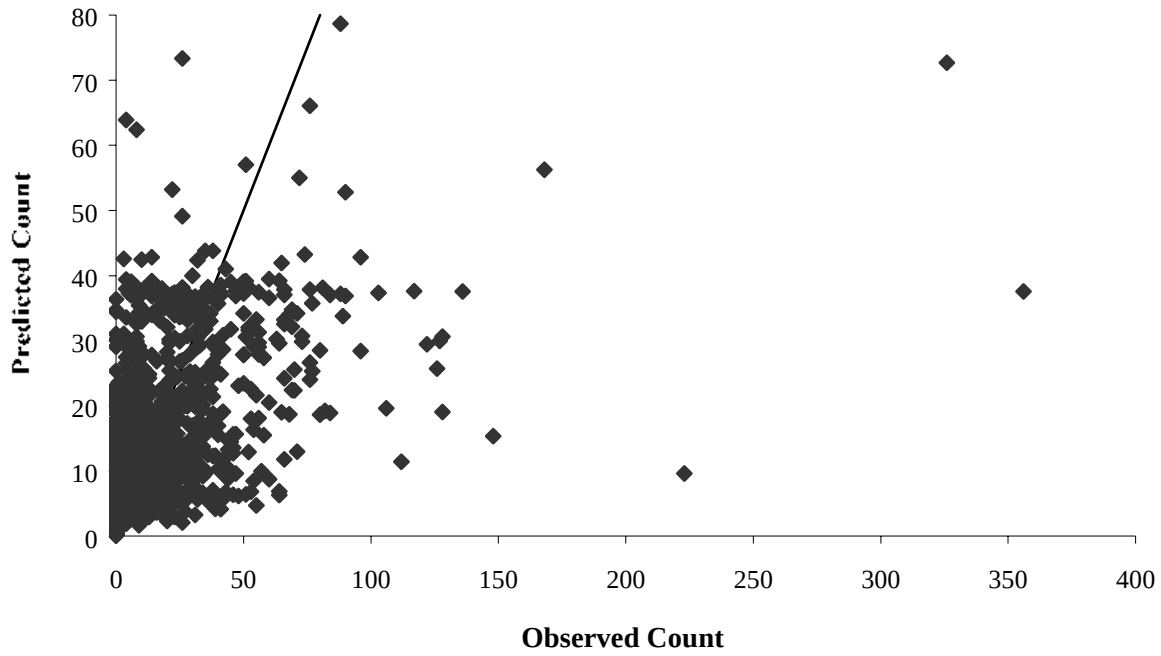
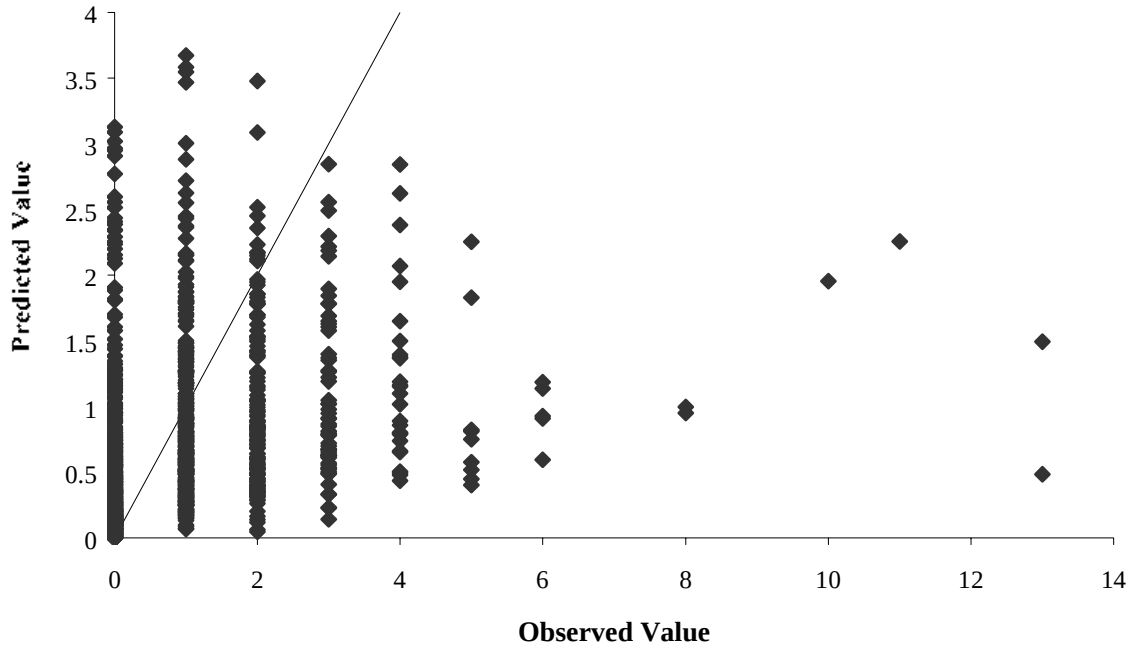
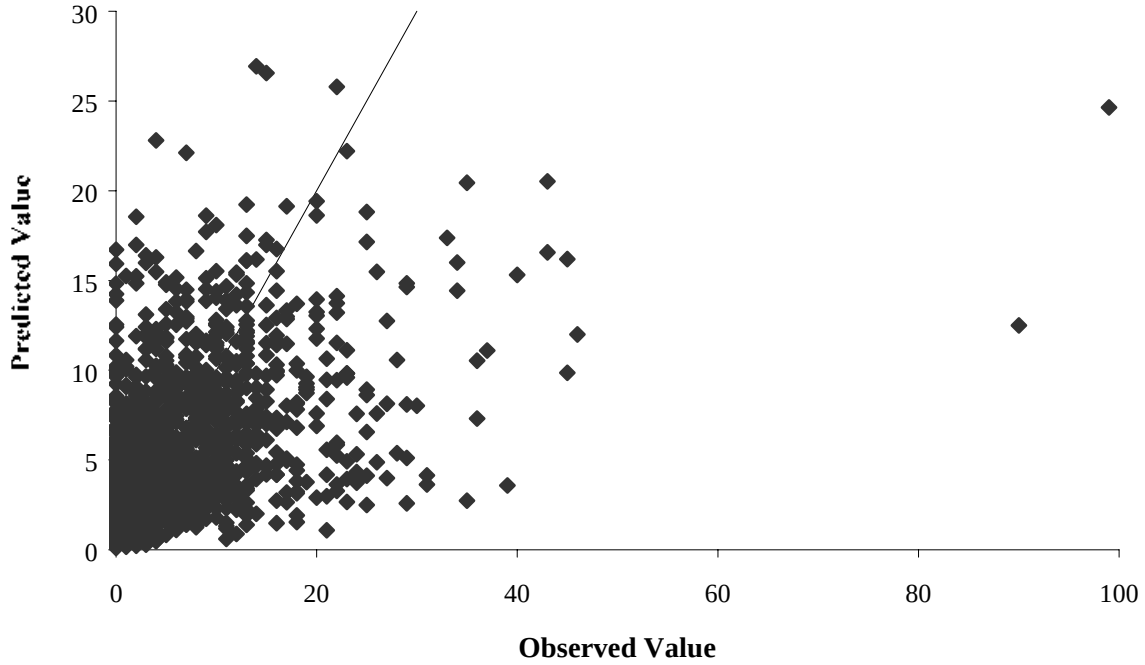


Figure 2.1 Counts for selected species per 1-km square as predicted from CEH landcover data, plotted against the observed count. The diagonal line represents the line of quality, observed = expected.

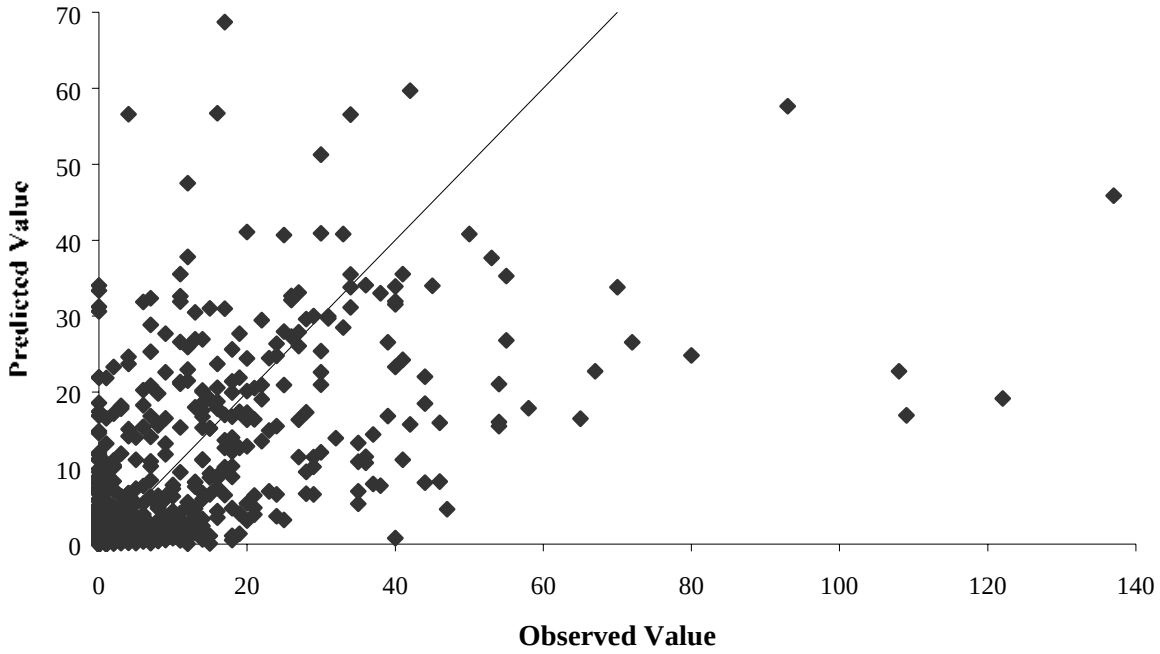
a) Buzzard



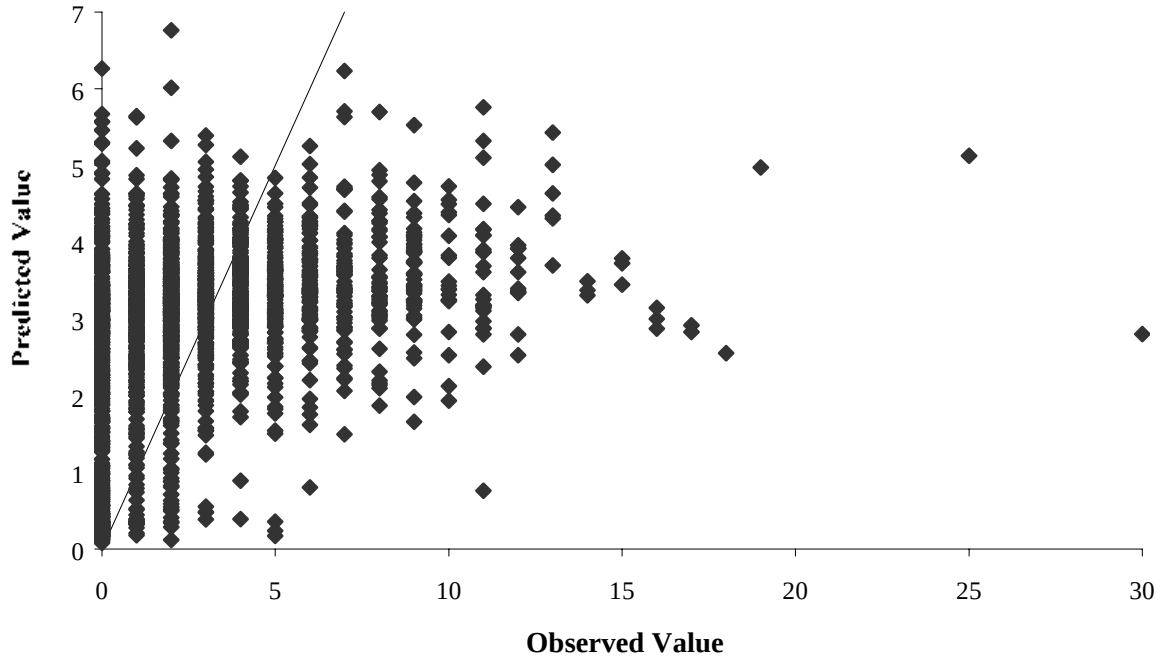
b) Skylark



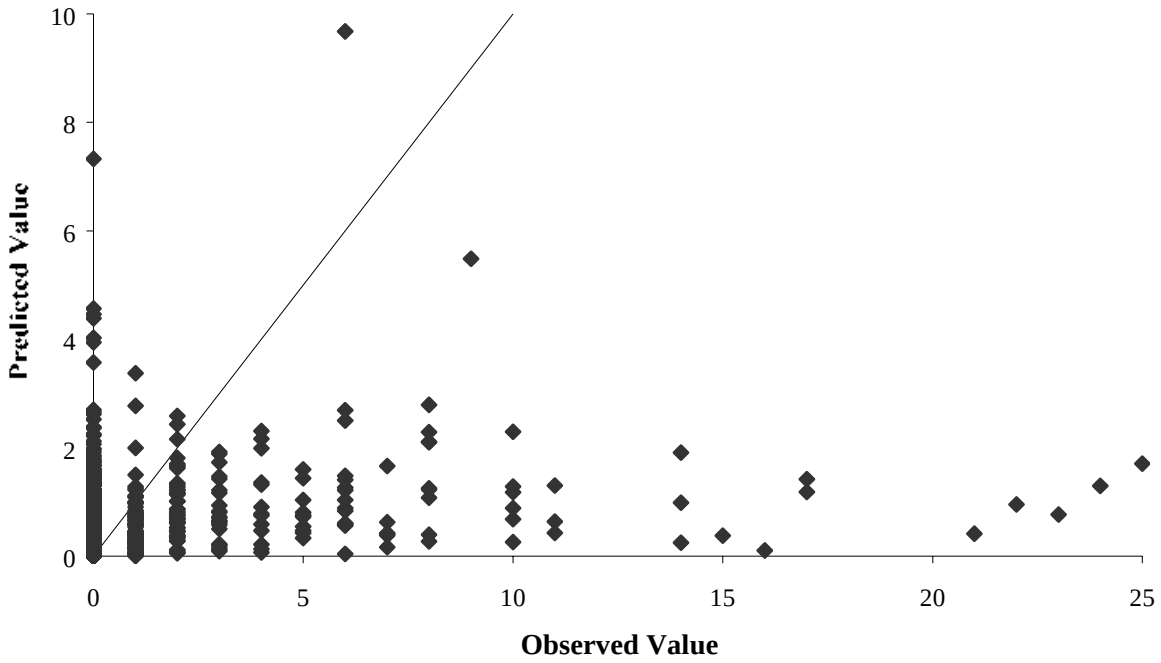
c) Meadow Pipit



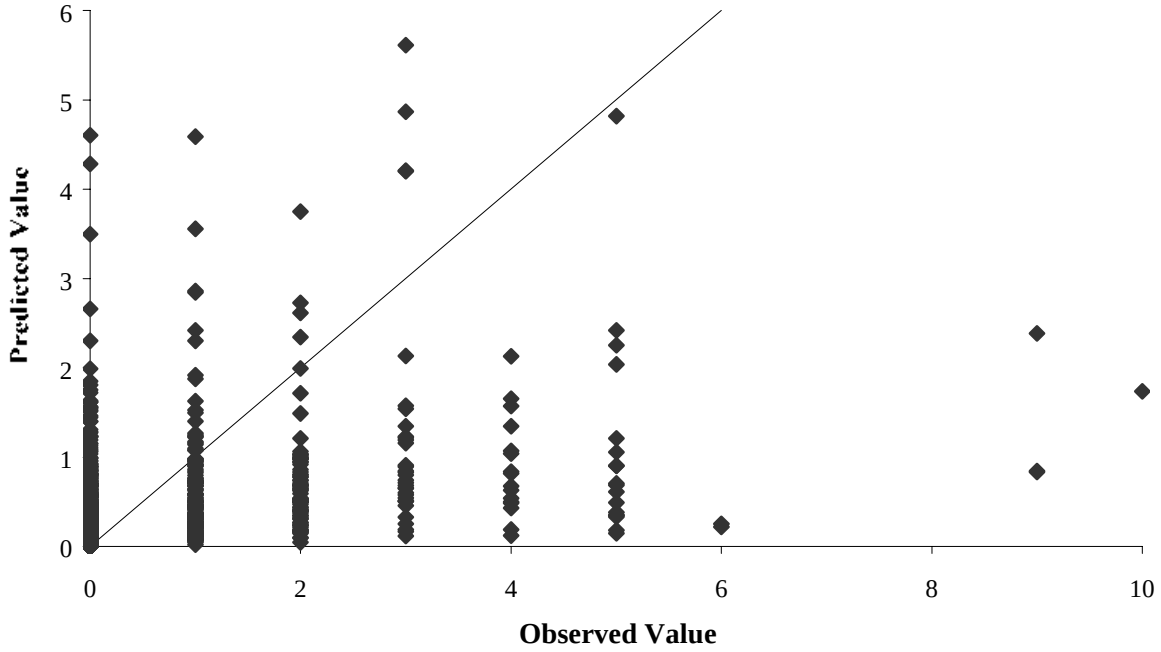
d) Dunnock



e) Sedge Warbler



f) Nuthatch



g) House Sparrow

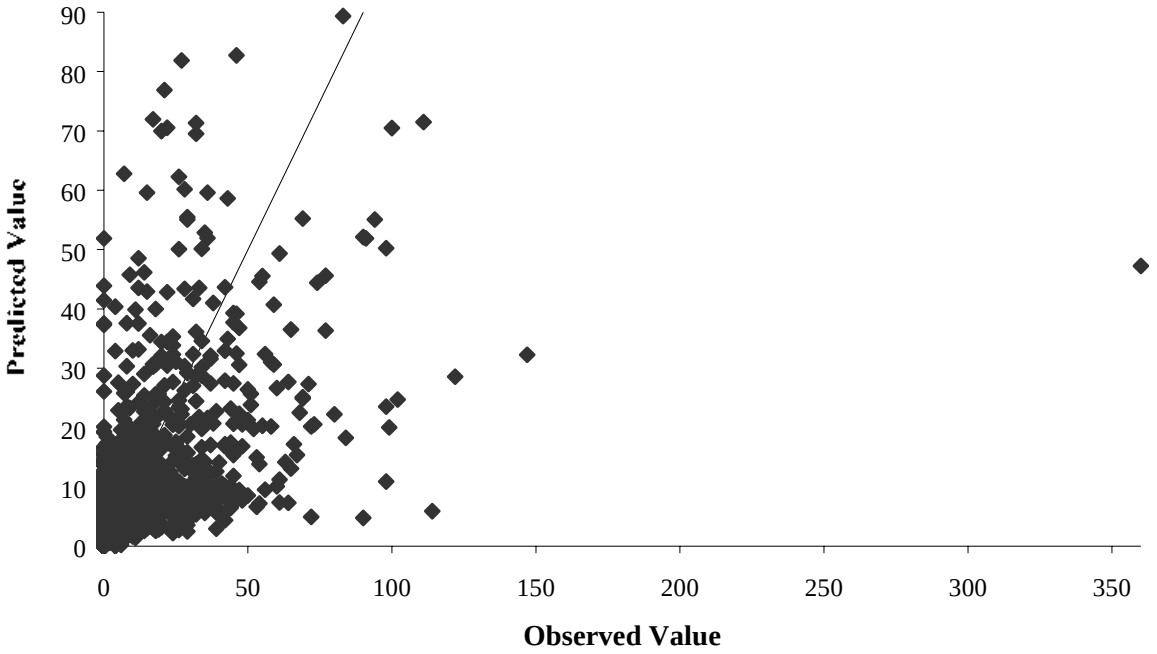
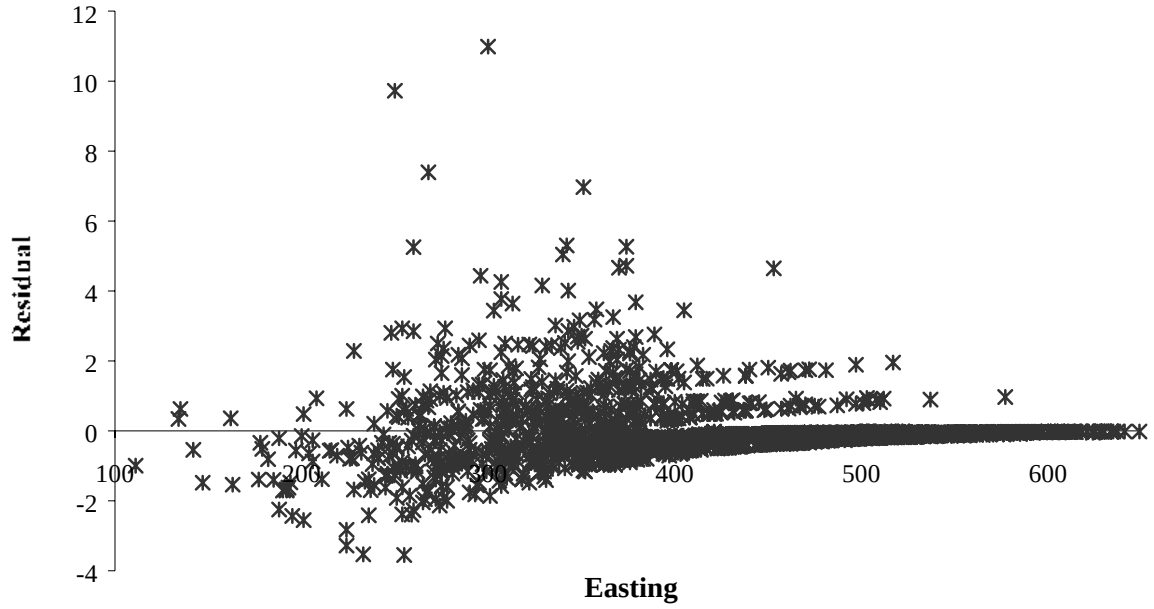
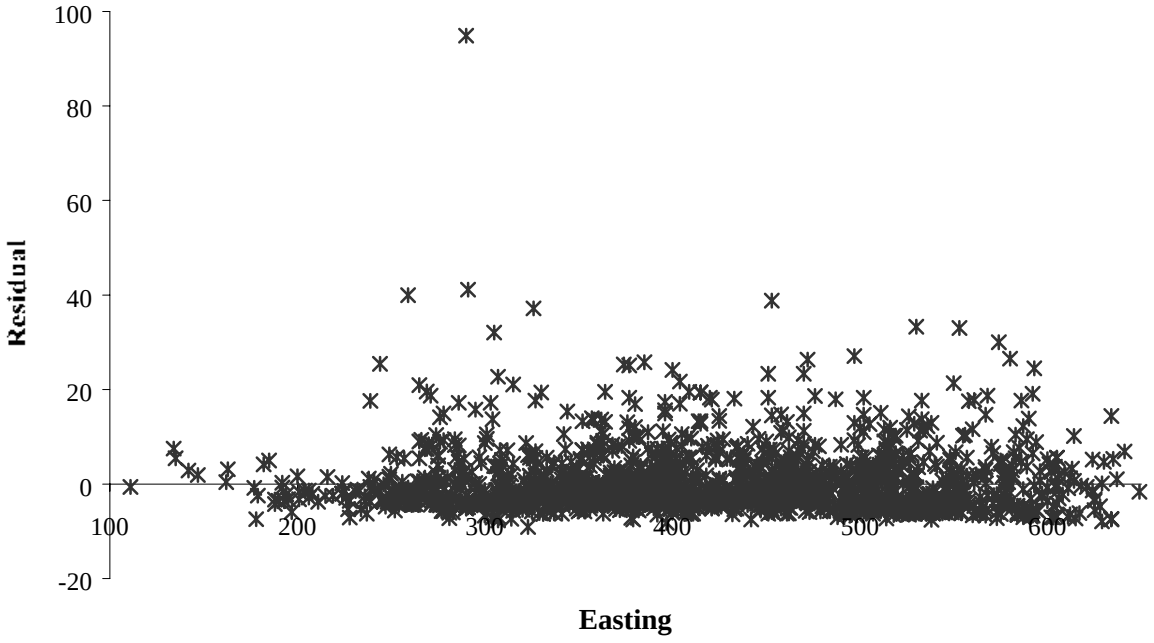


Figure 2.2 Residuals from a model relating counts for selected species to CEH landclass, versus Easting.

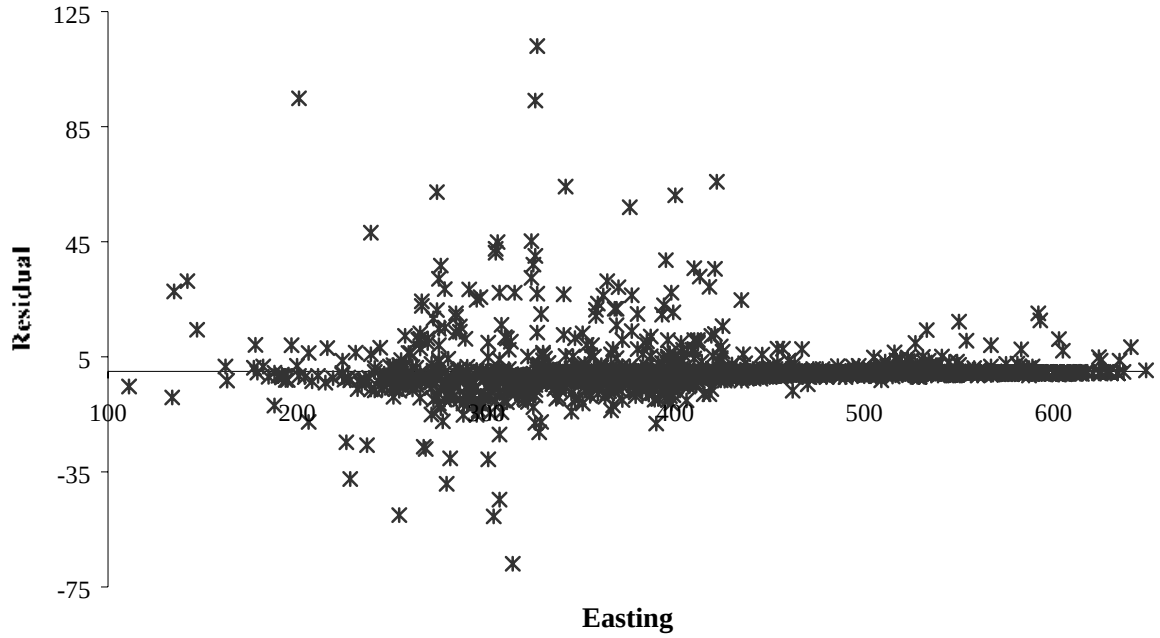
a) Buzzard



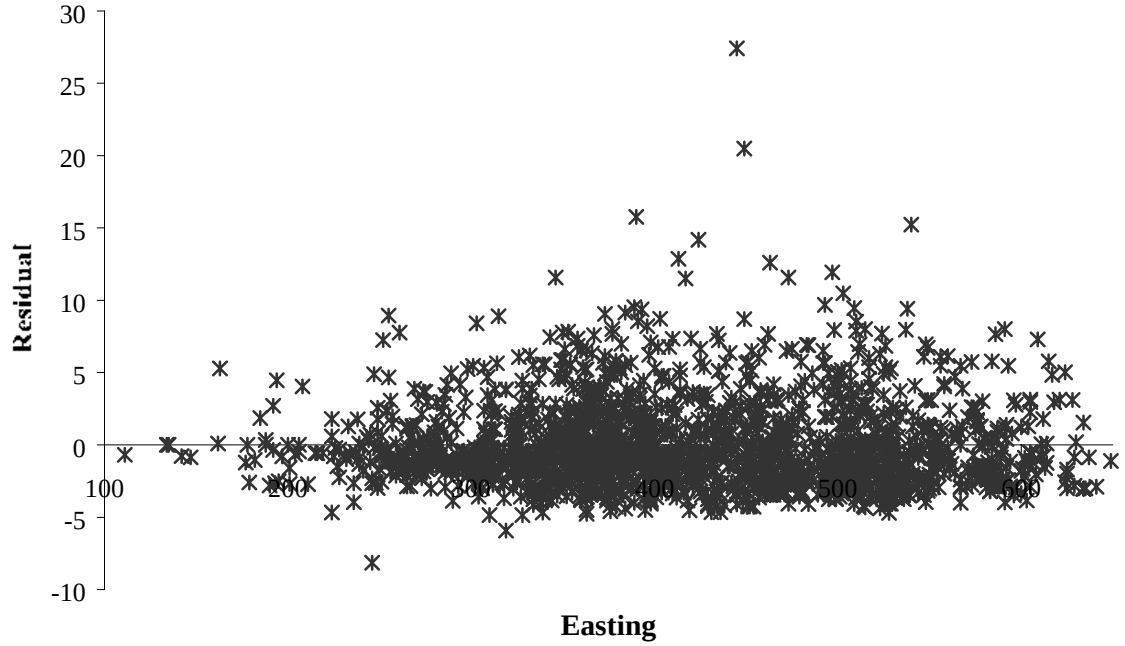
b) Skylark



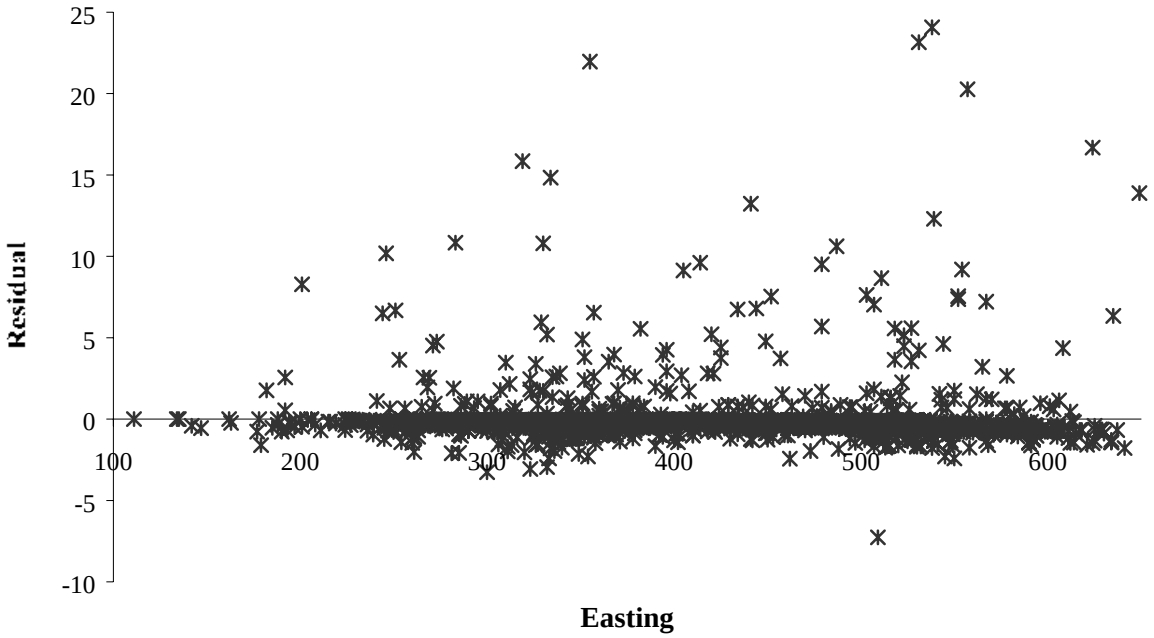
c) Meadow Pipit



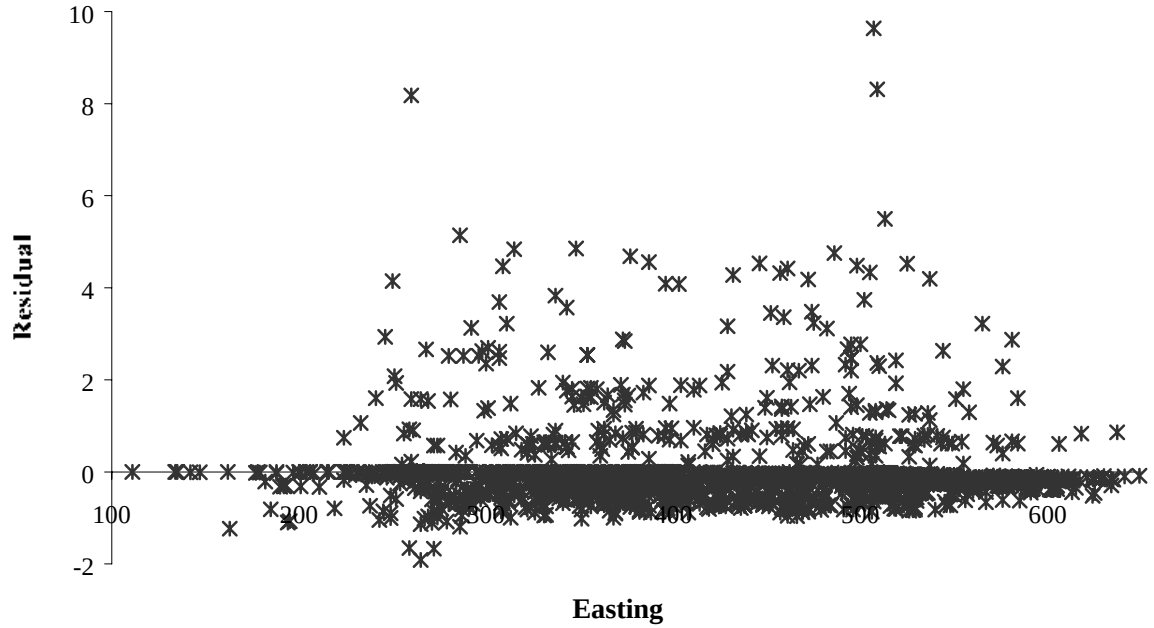
d) Dunnock



e) Sedge Warbler



f) Nuthatch



g) House Sparrow

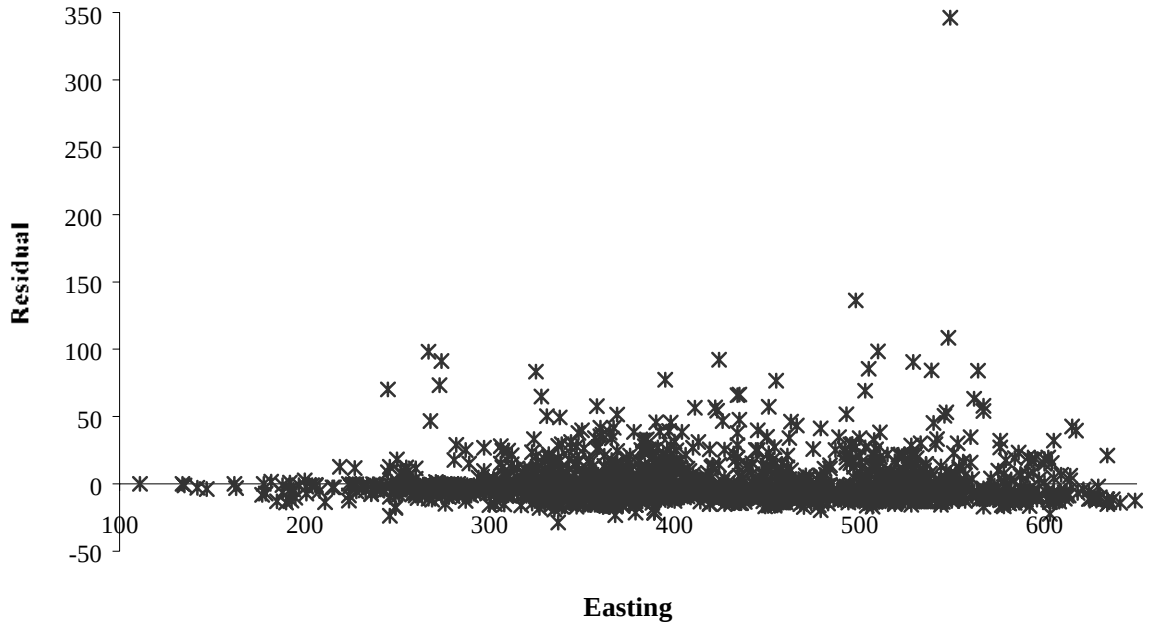
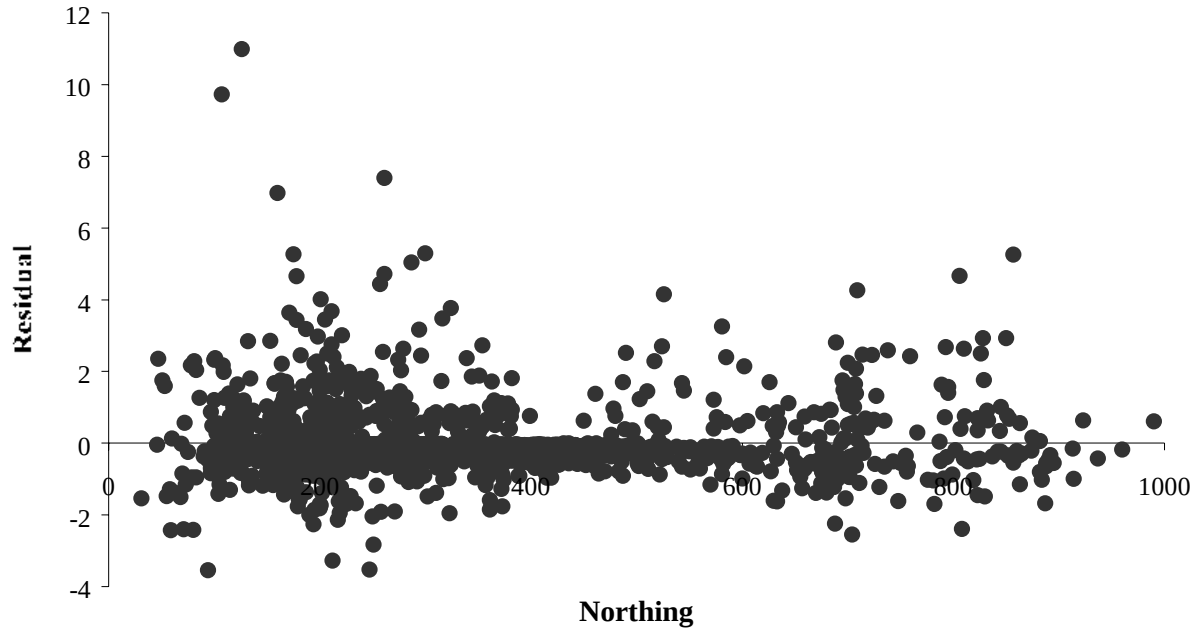
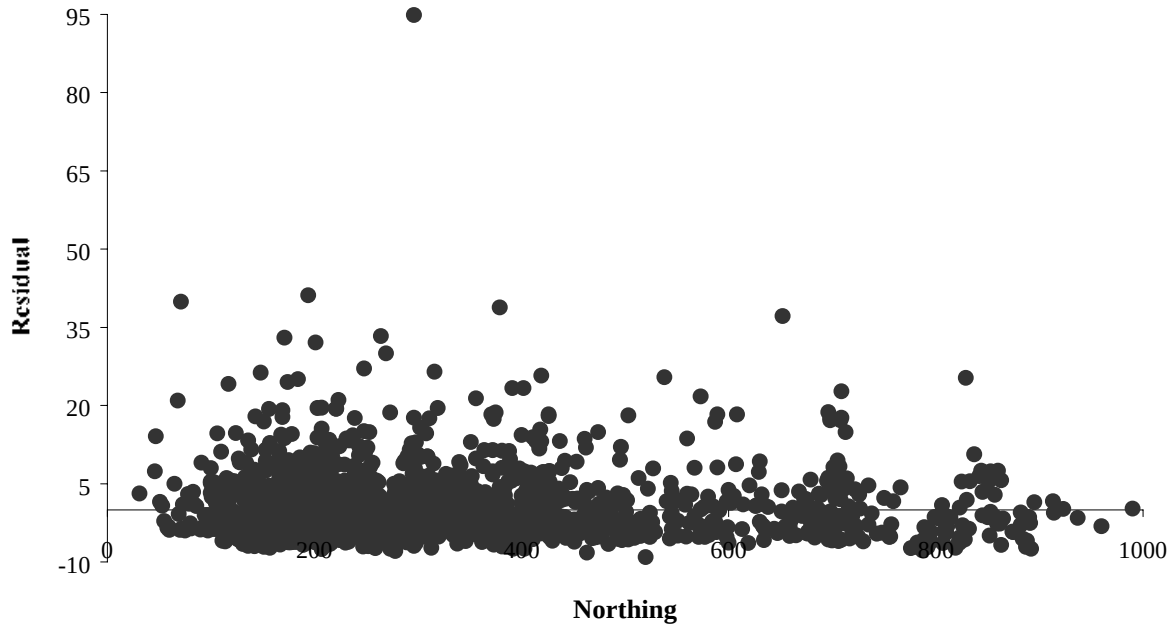


Figure 2.3 Residuals from a model relating counts for selected species to CEH landclass, versus Easting.

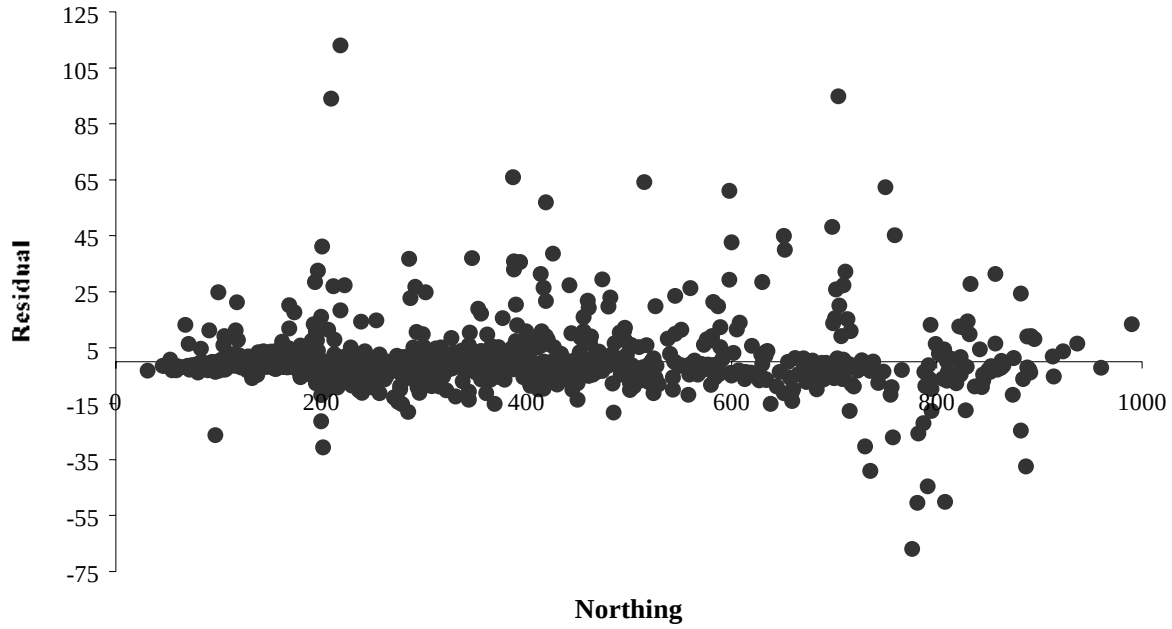
a) Buzzard



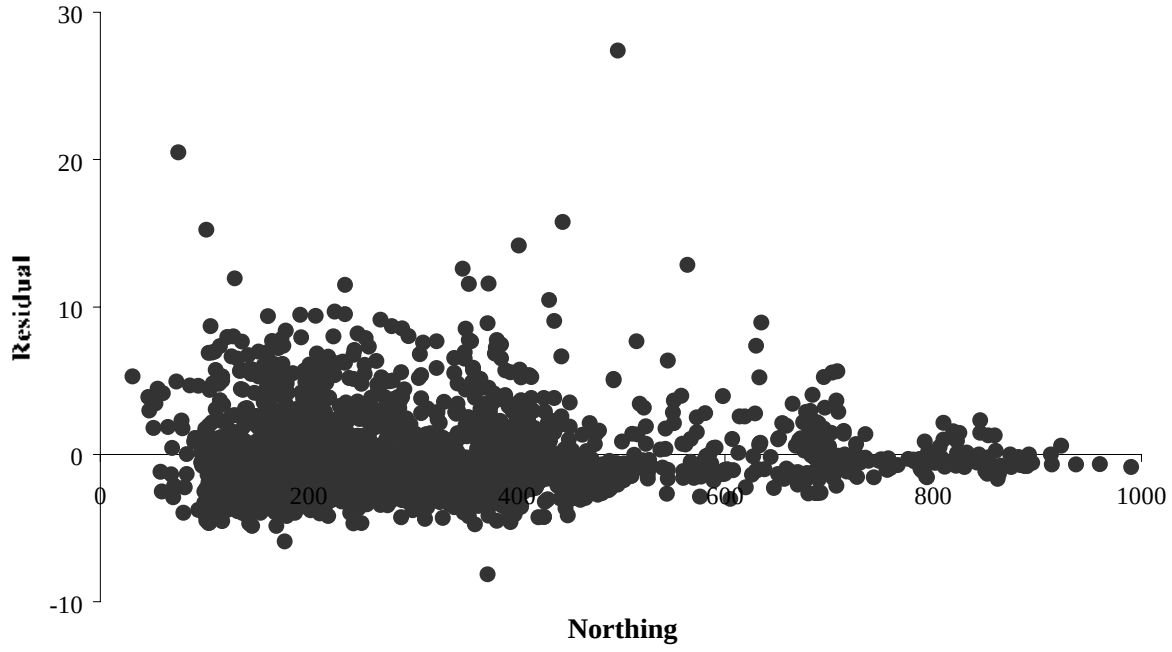
b) Skylark



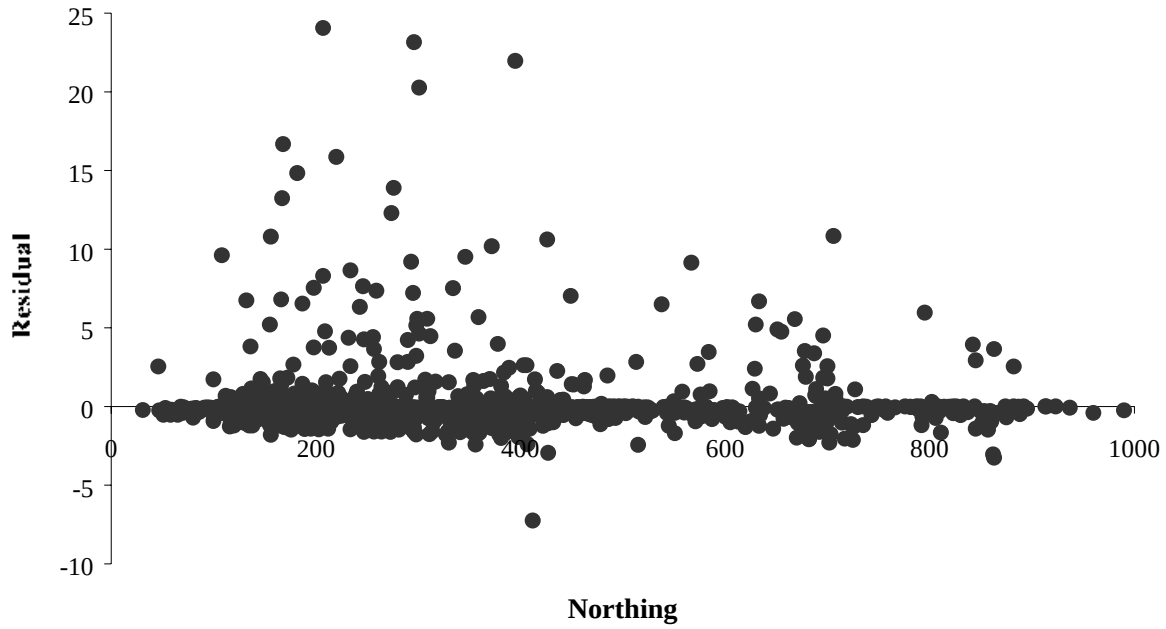
c) Meadow Pipit



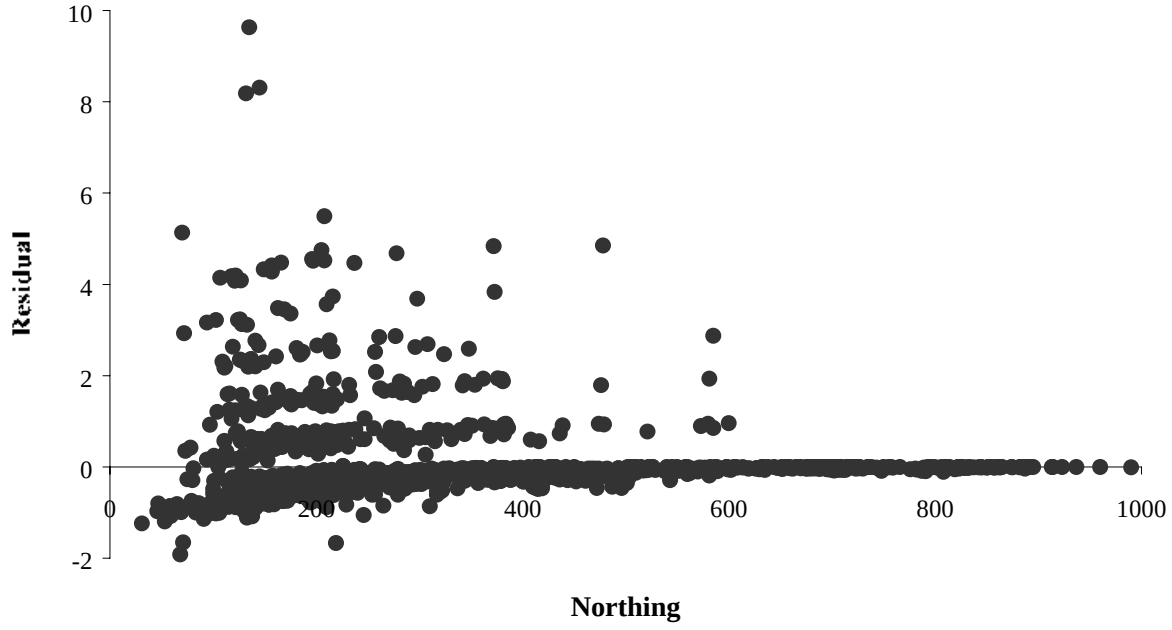
d) Dunnock



e) Sedge Warbler



f) Nuthatch



g) House Sparrow

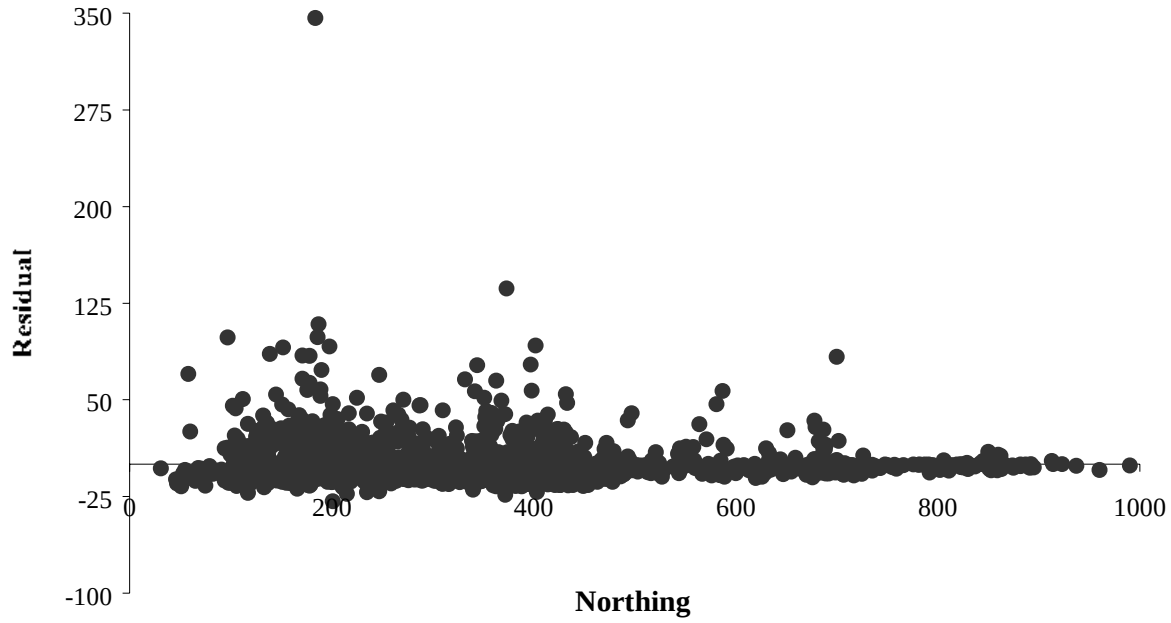
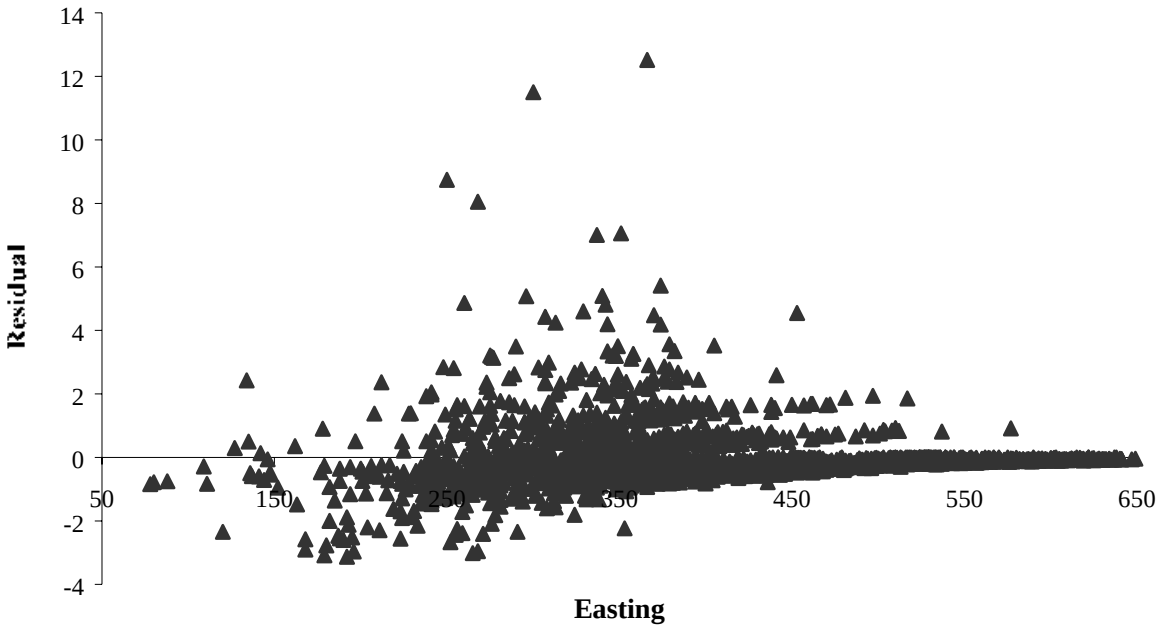
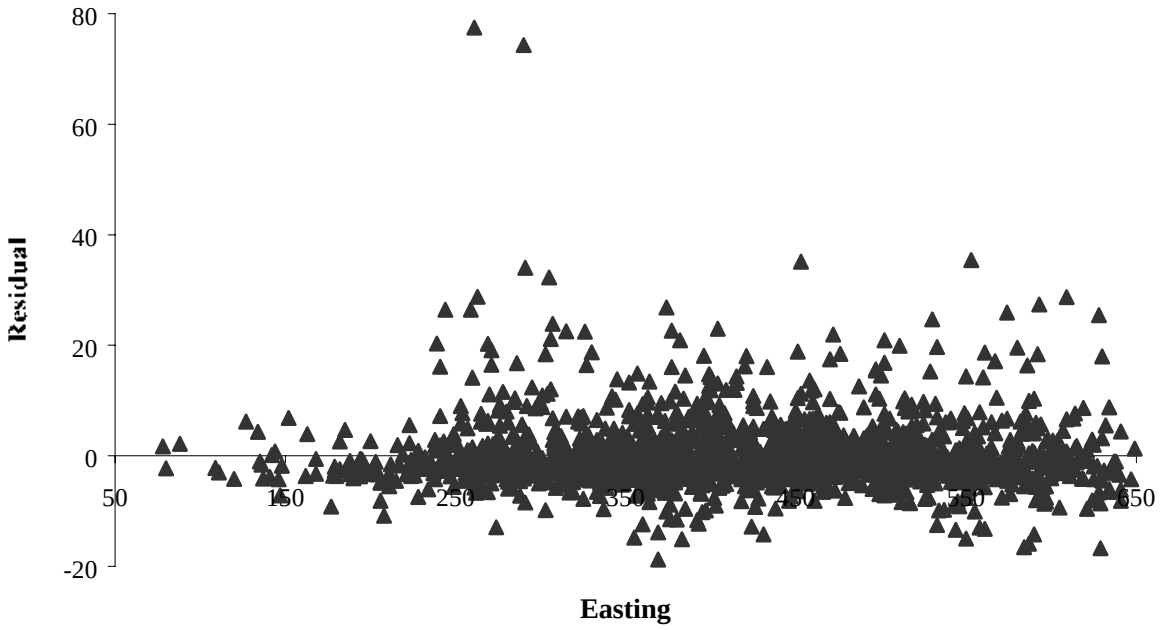


Figure 2.4 Residuals from a model relating counts for selected species to CEH landcover, versus Easting.

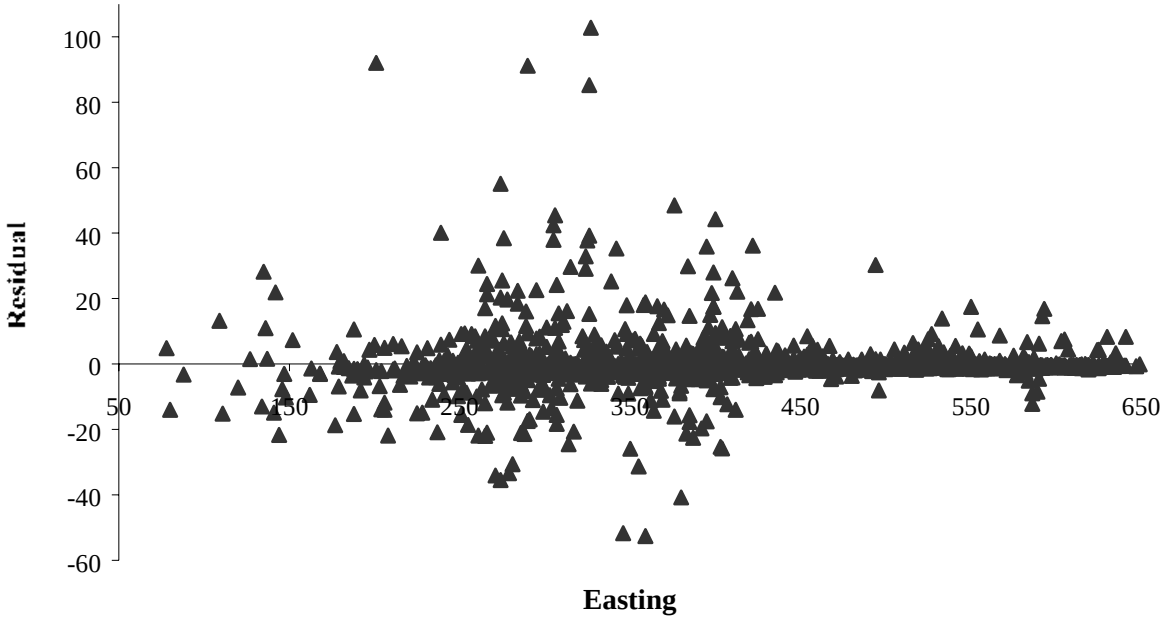
a) Buzzard



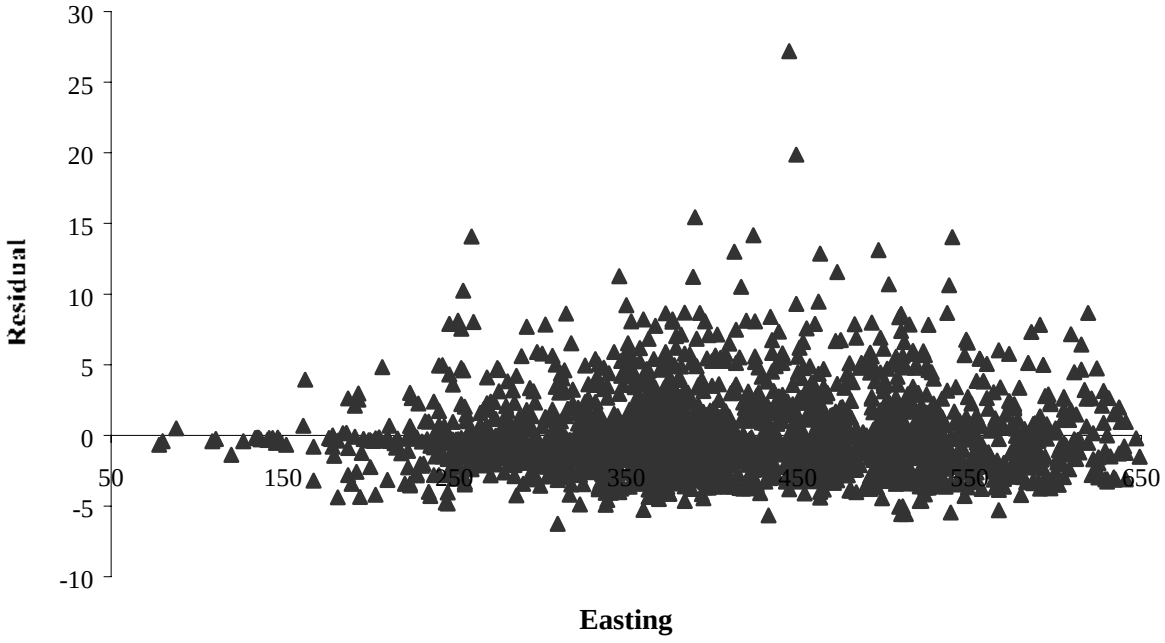
b) Skylark



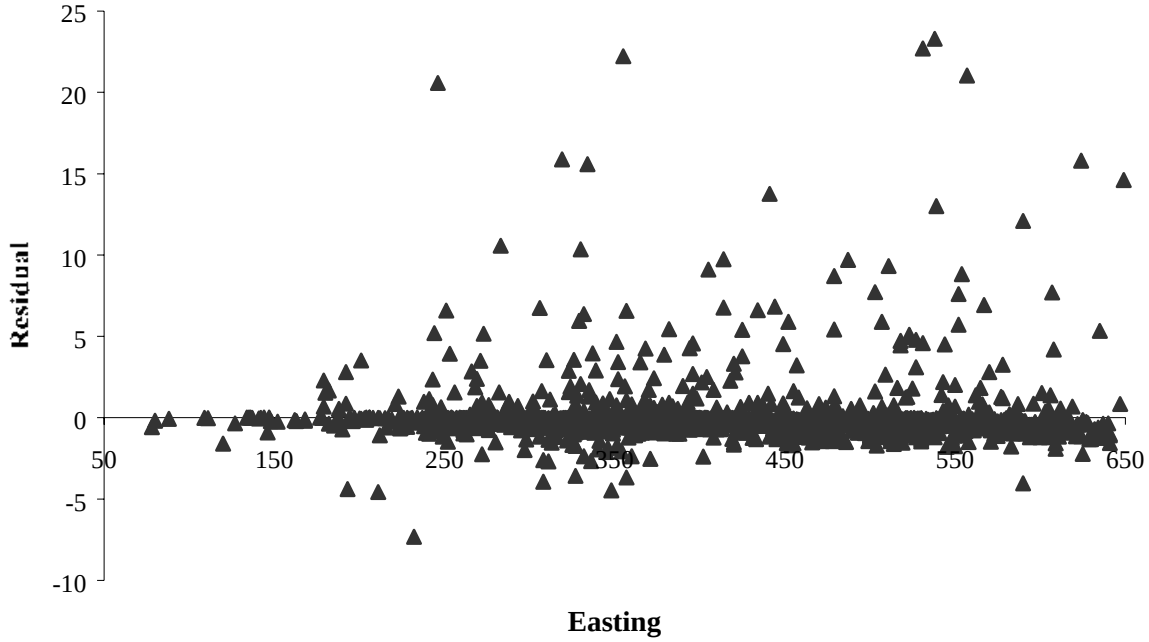
c) Meadow Pipit.



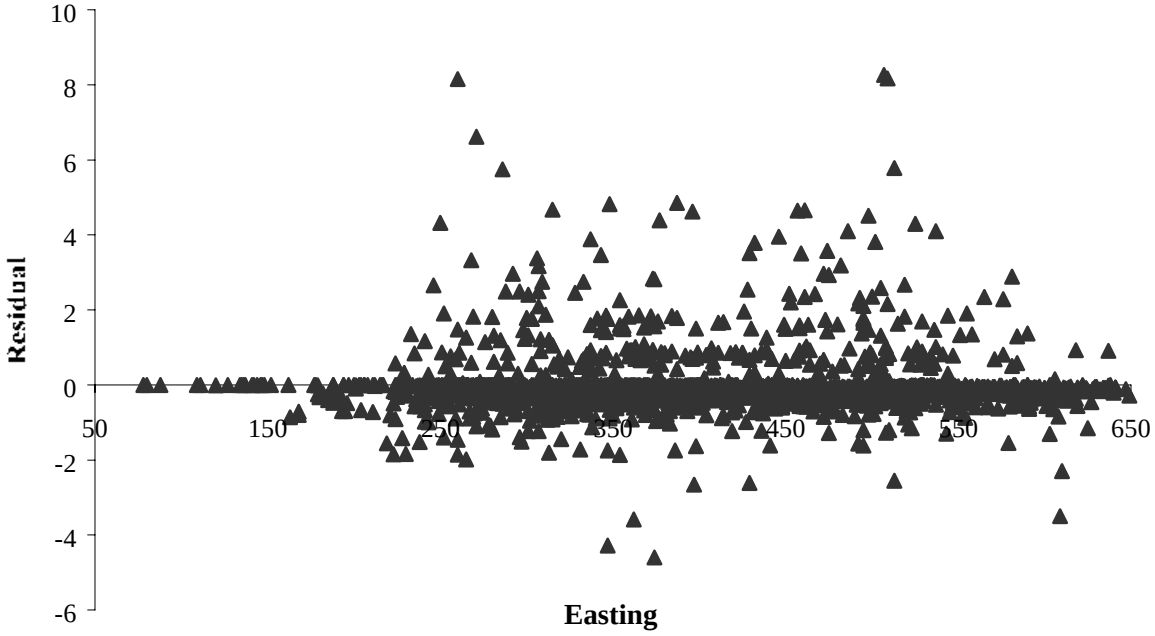
d) Dunnock



e) Sedge Warbler



f) Nuthatch



g) House Sparrow

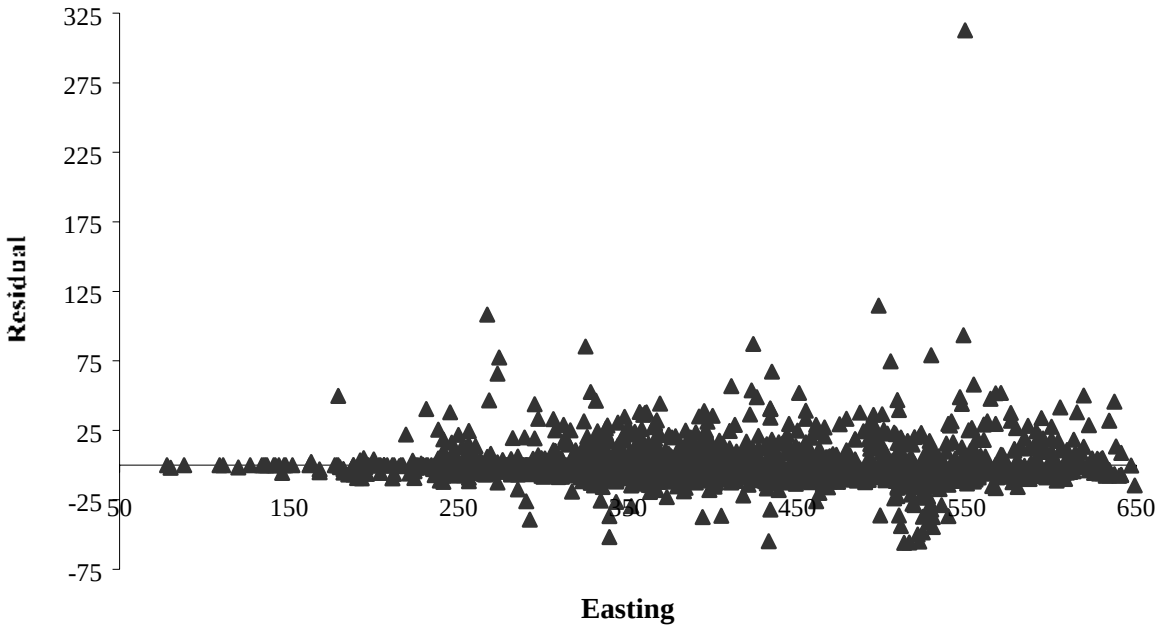
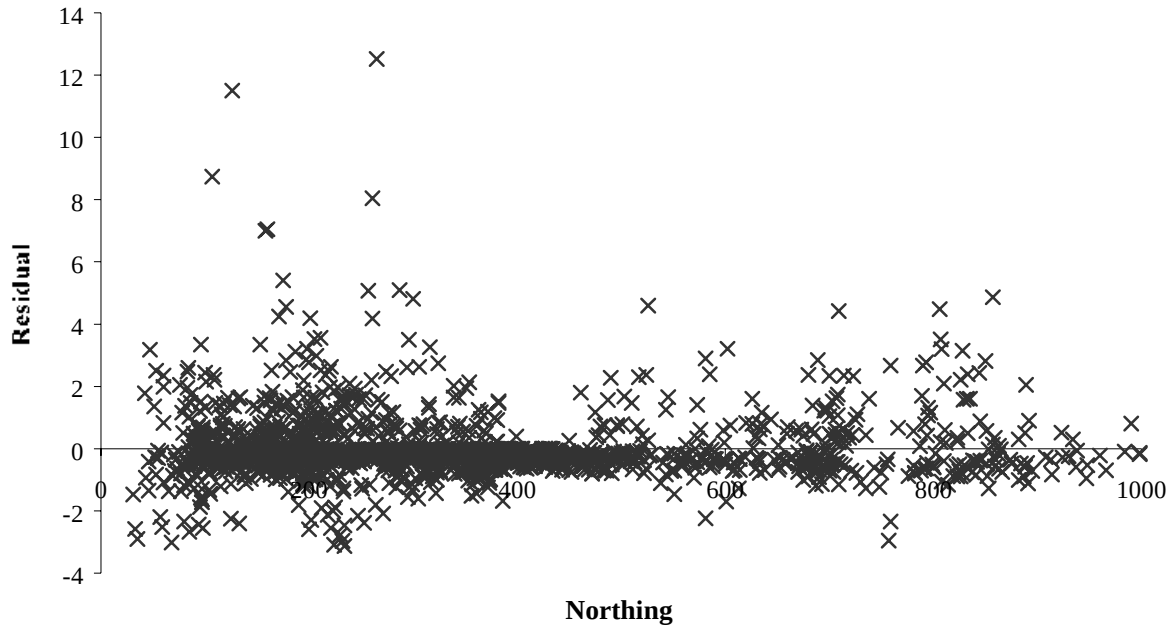
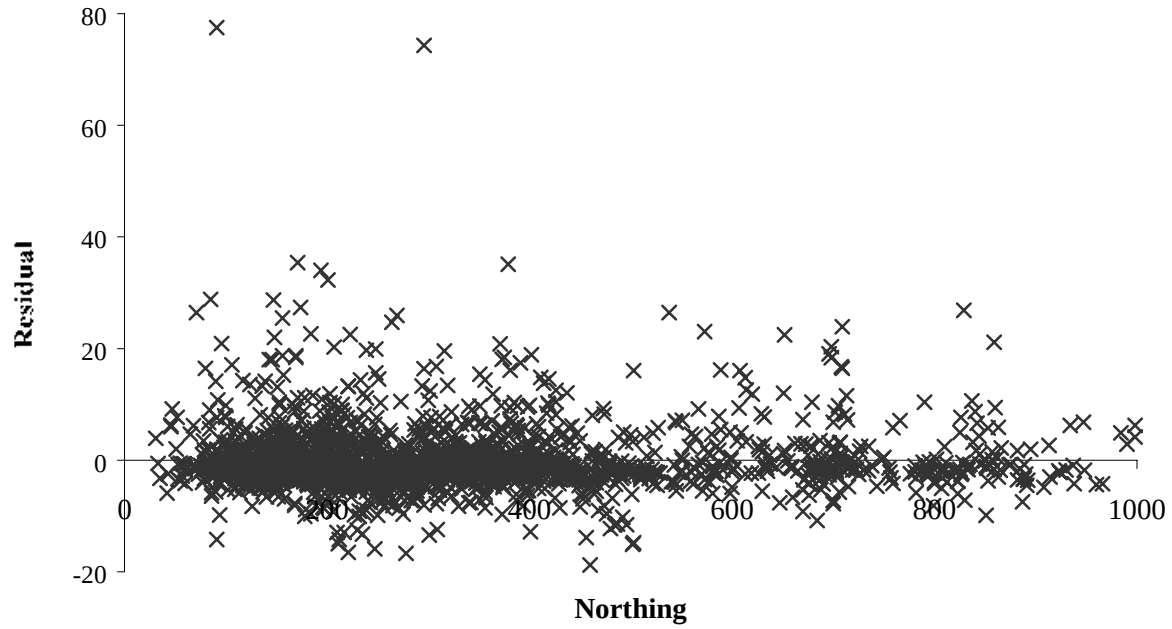


Figure 2.5 Residuals from a model relating counts for selected species to CEH landcover, versus Northing.

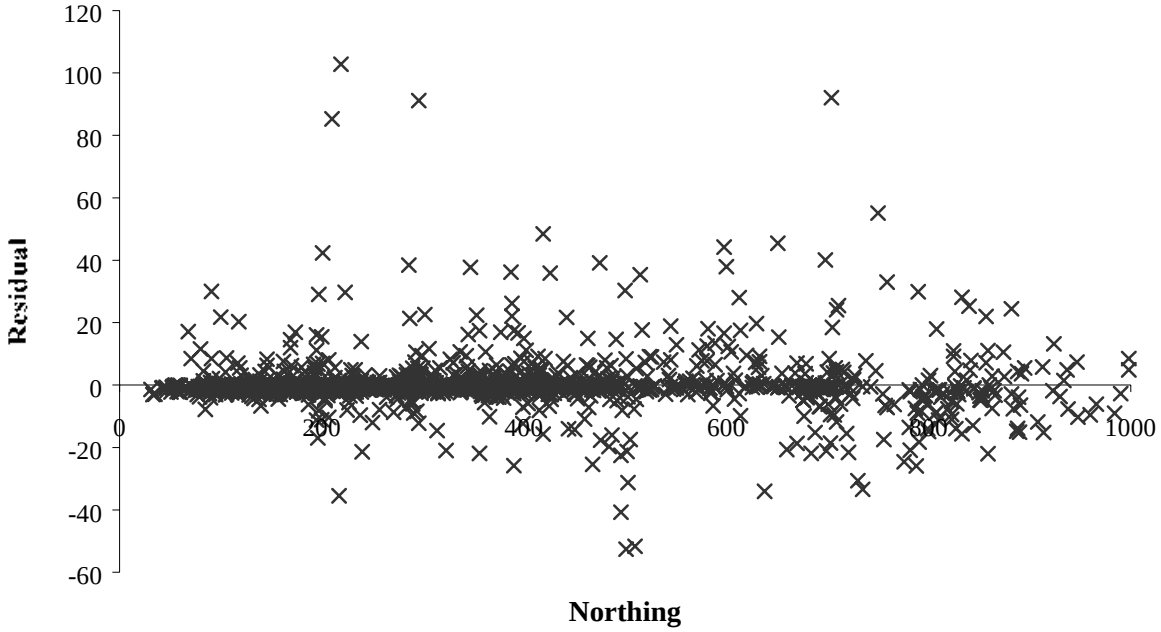
a) Buzzard



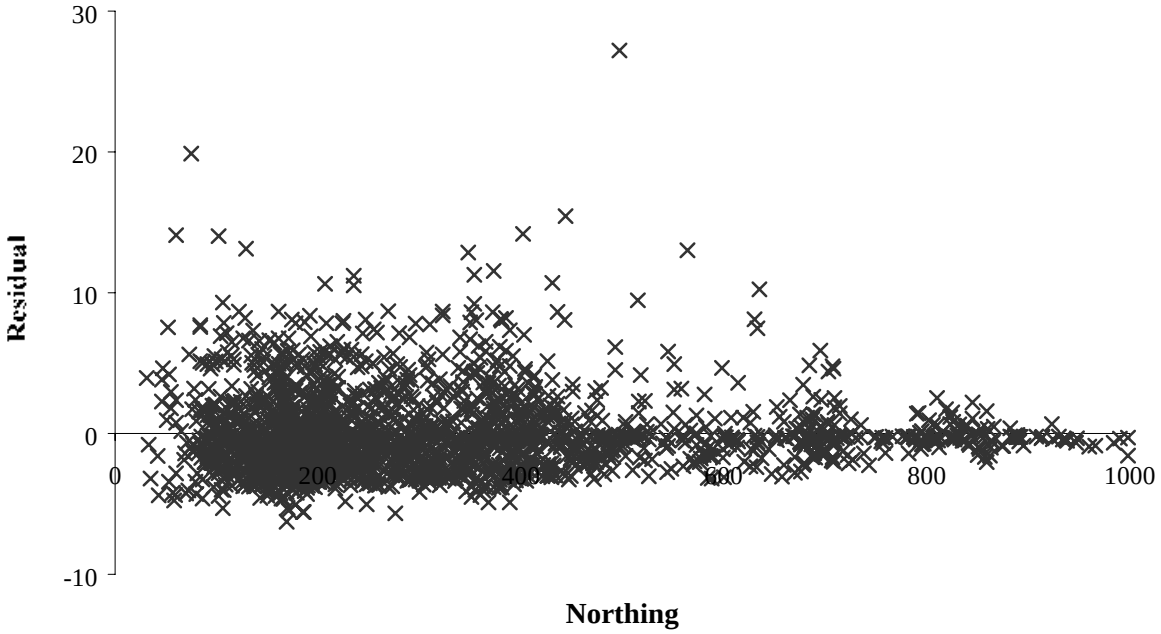
b) Skylark



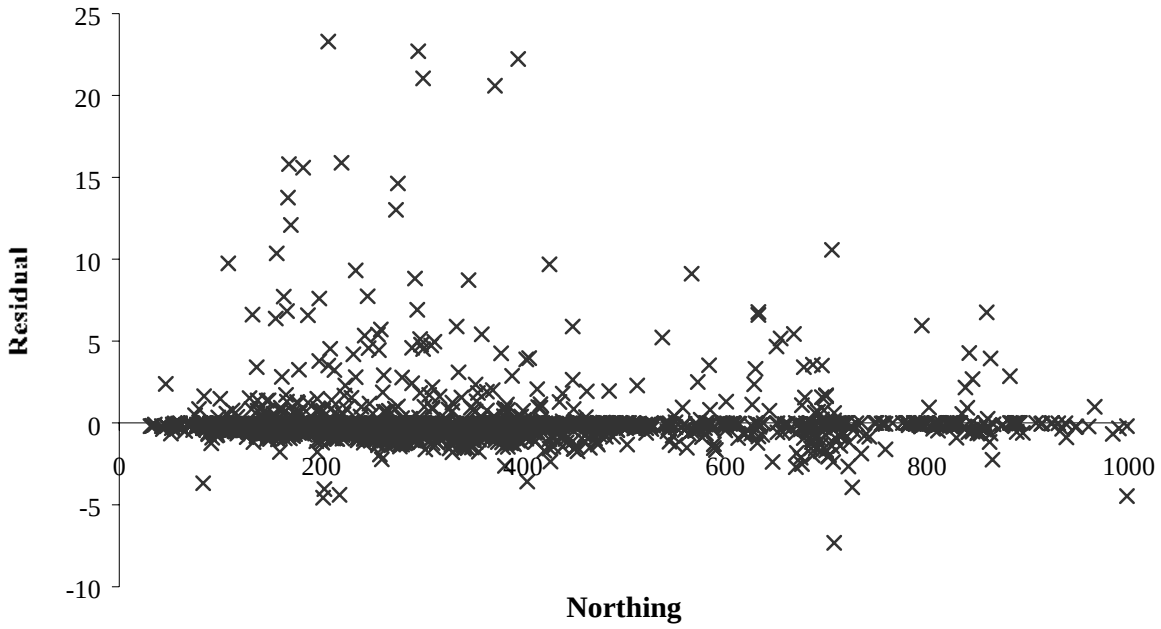
c) Meadow Pipit



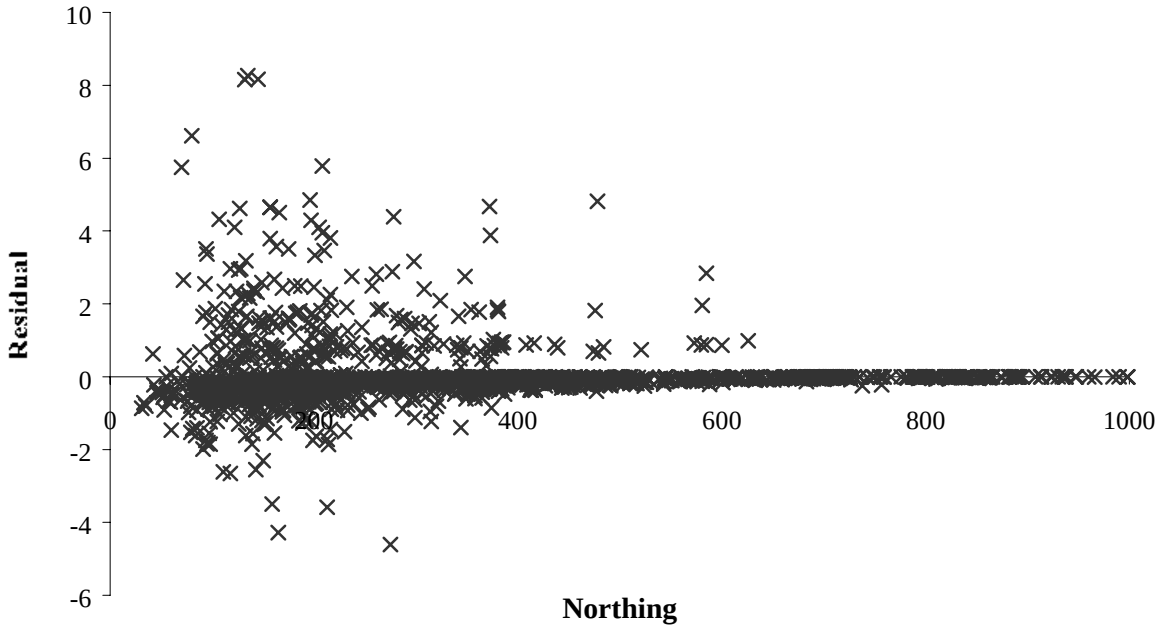
d) Dunnock



e) Sedge Warbler



f) Nuthatch



g) House Sparrow

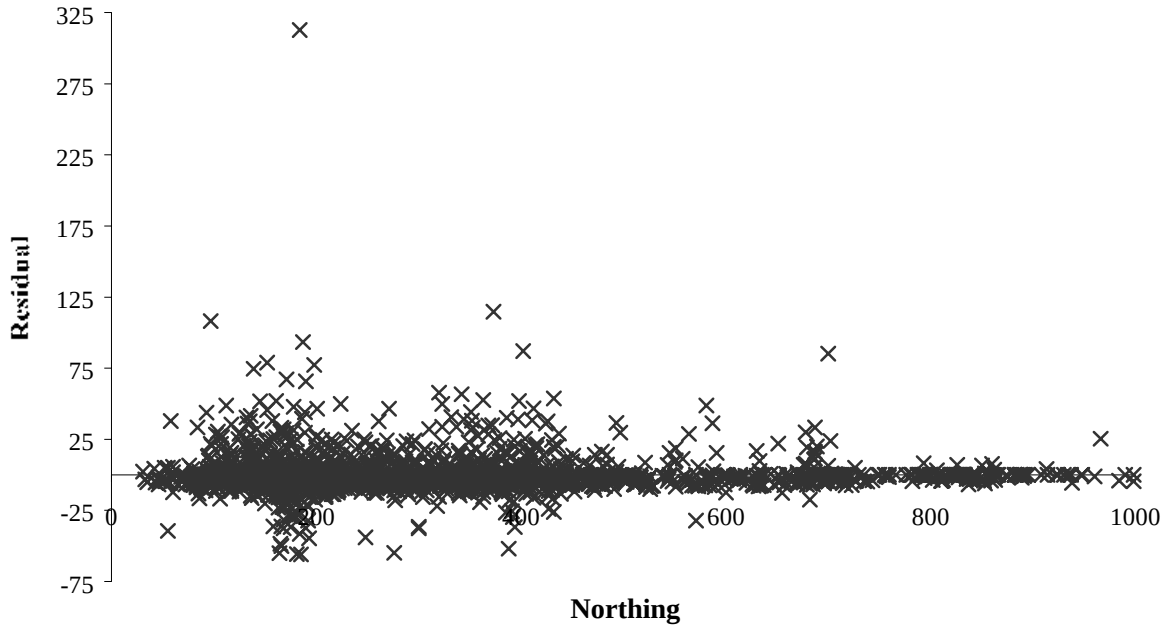
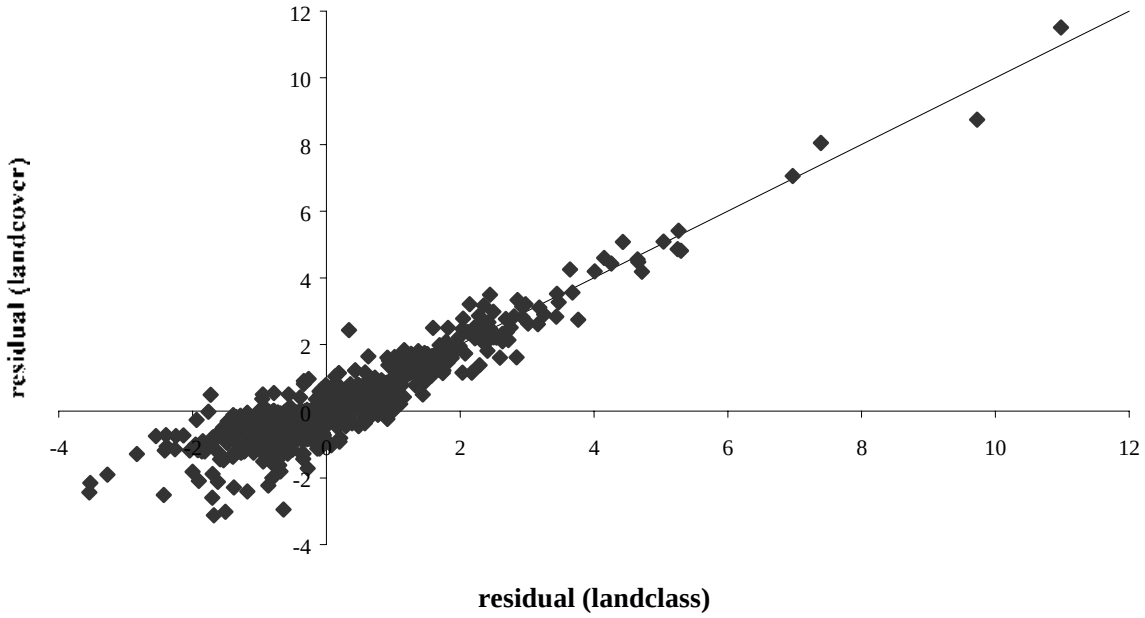
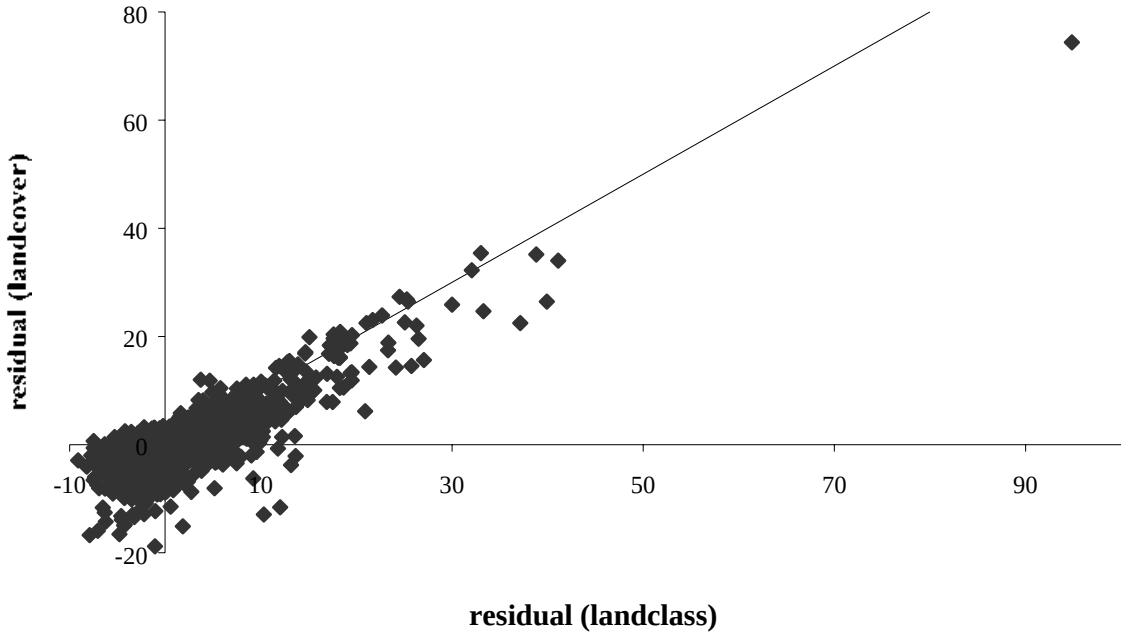


Figure 2.6 Residuals from a model relating counts for selected species to landcover, versus those from a model based on landclass. The diagonal line represents equal residuals under each model.

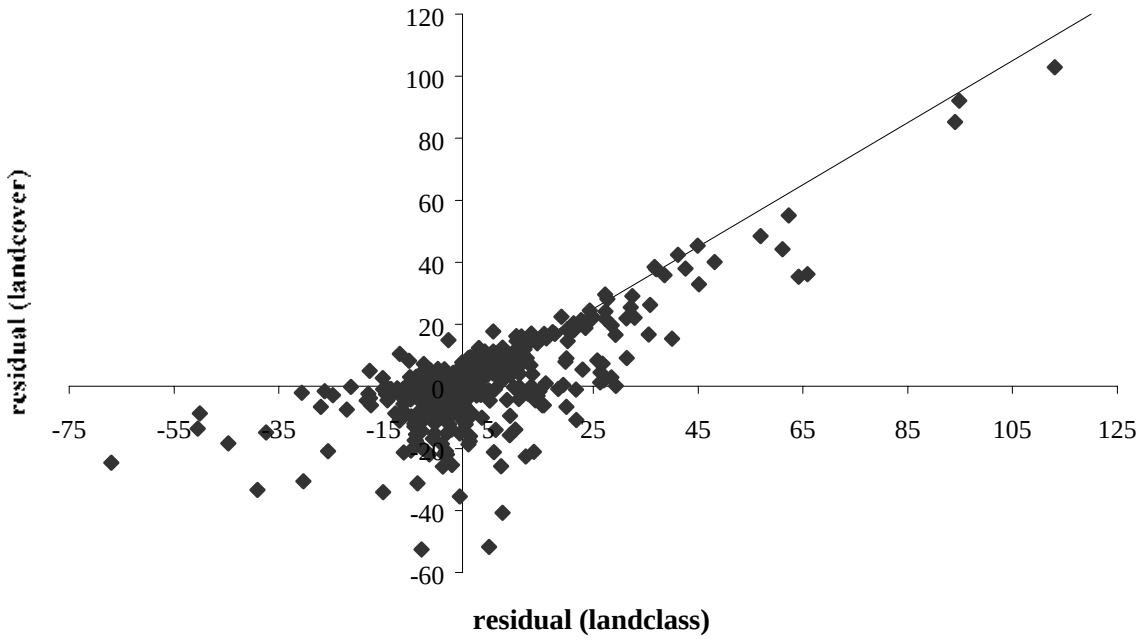
a) Buzzard



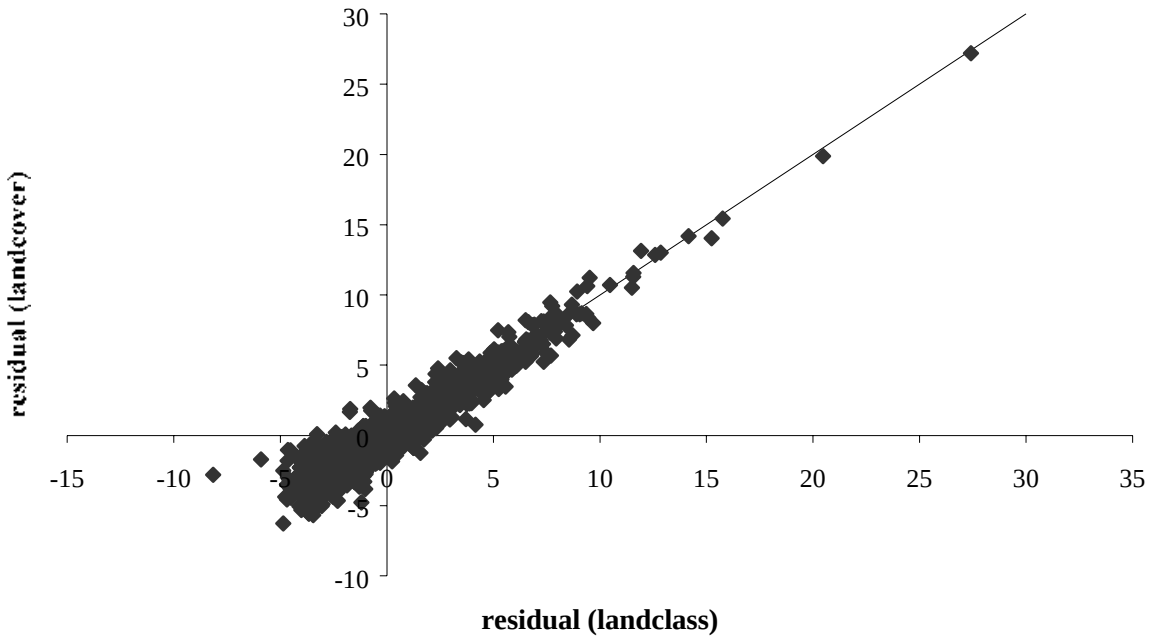
b) Skylark



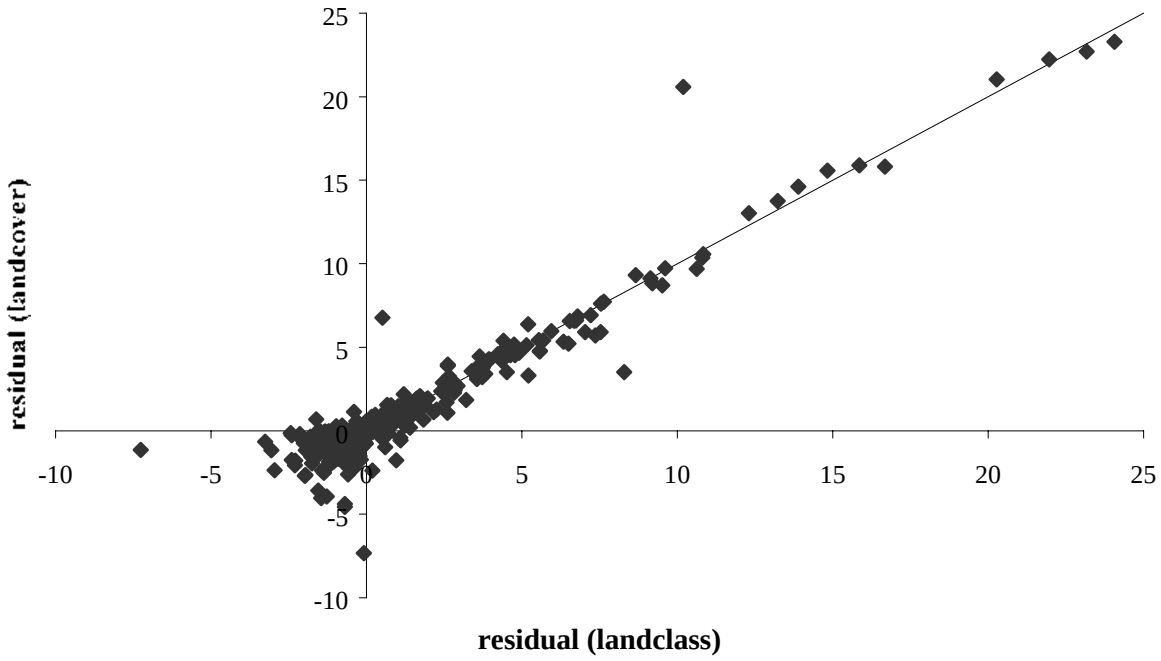
c) Meadow Pipit



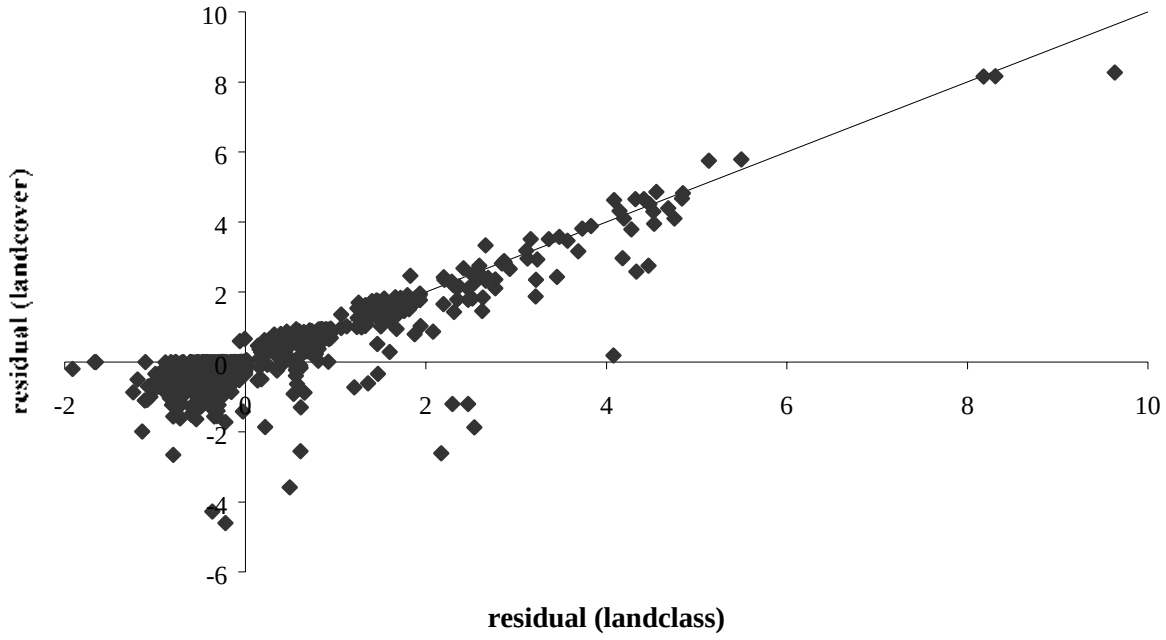
d) Dunnock



e) Sedge Warbler



f) Nuthatch



g) House Sparrow

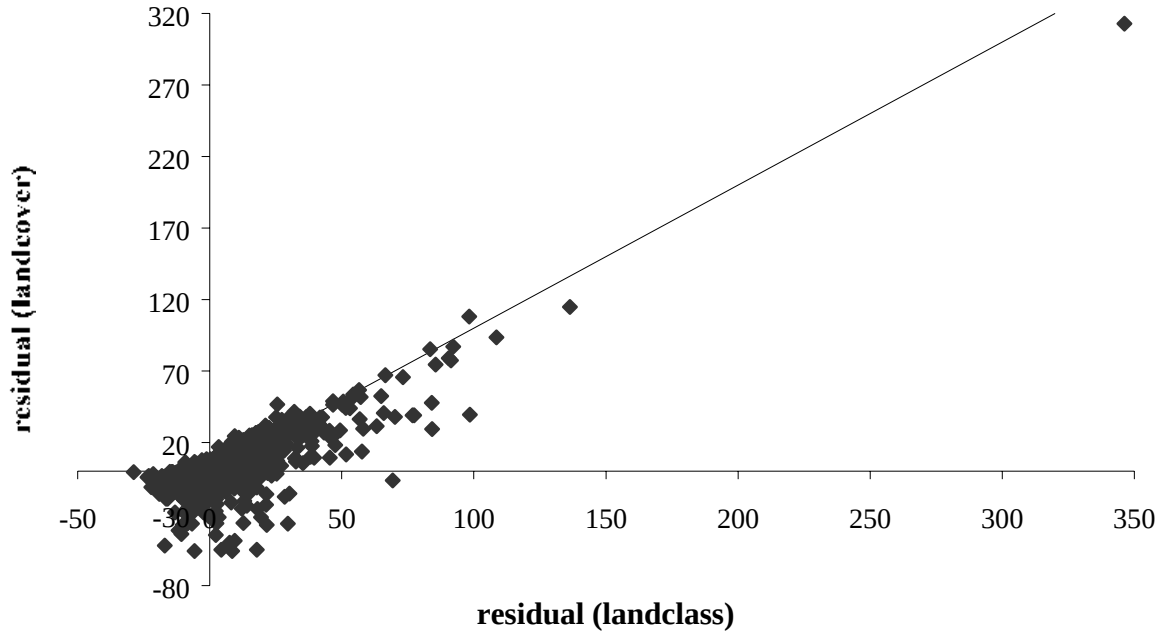
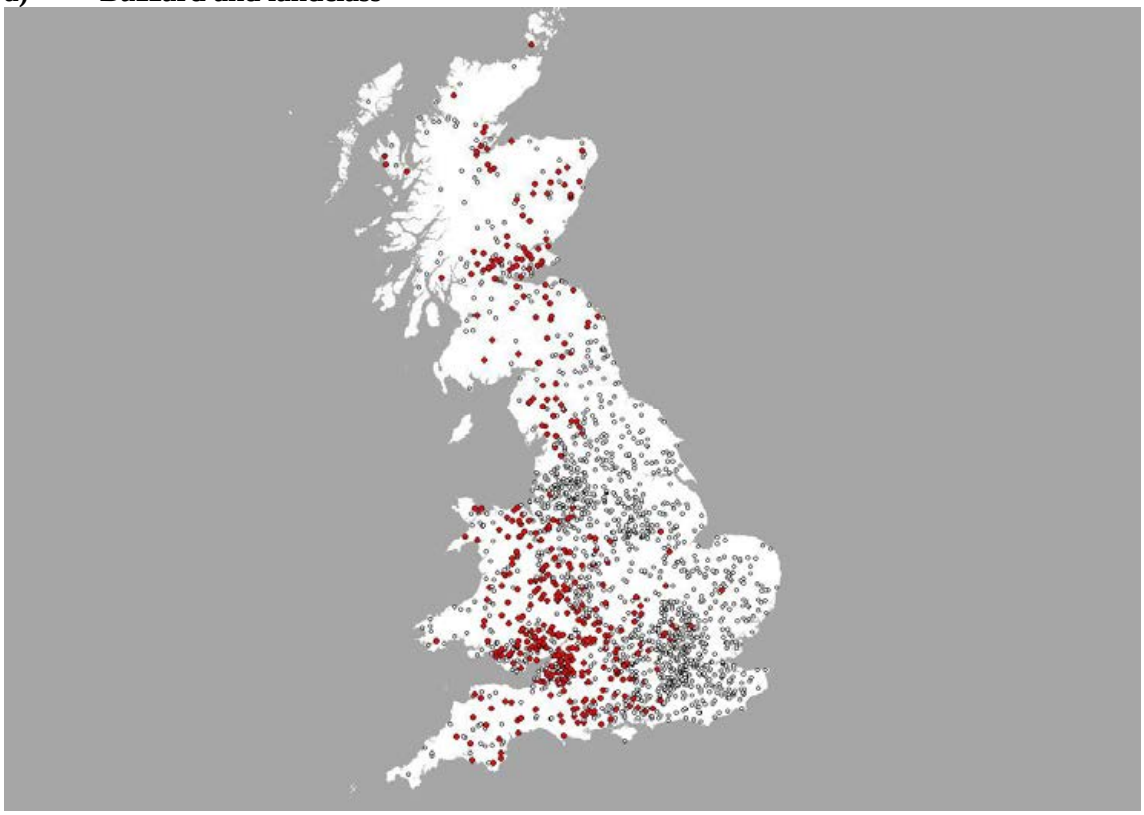
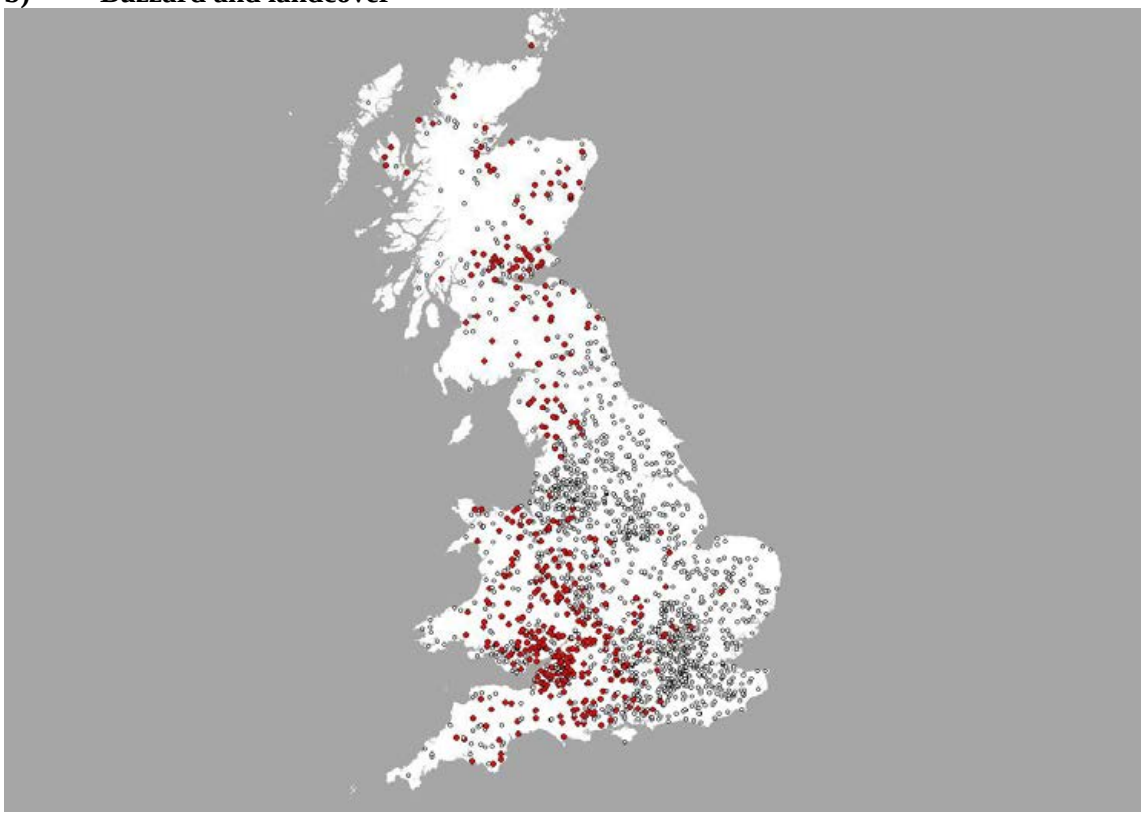


Figure 2.7 Geographical Distribution of positive residuals (filled circles) and negative residuals (open circles) from models relating counts for selected species to landclass and landcover

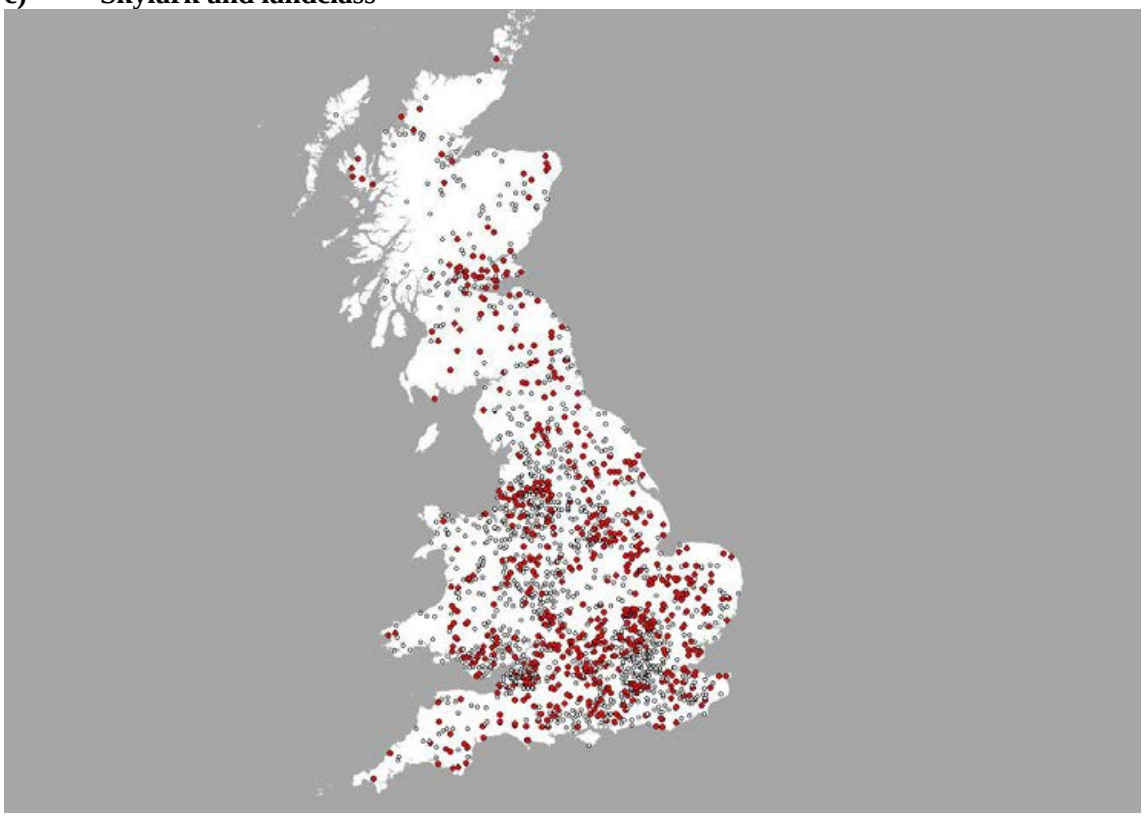
a) Buzzard and landclass



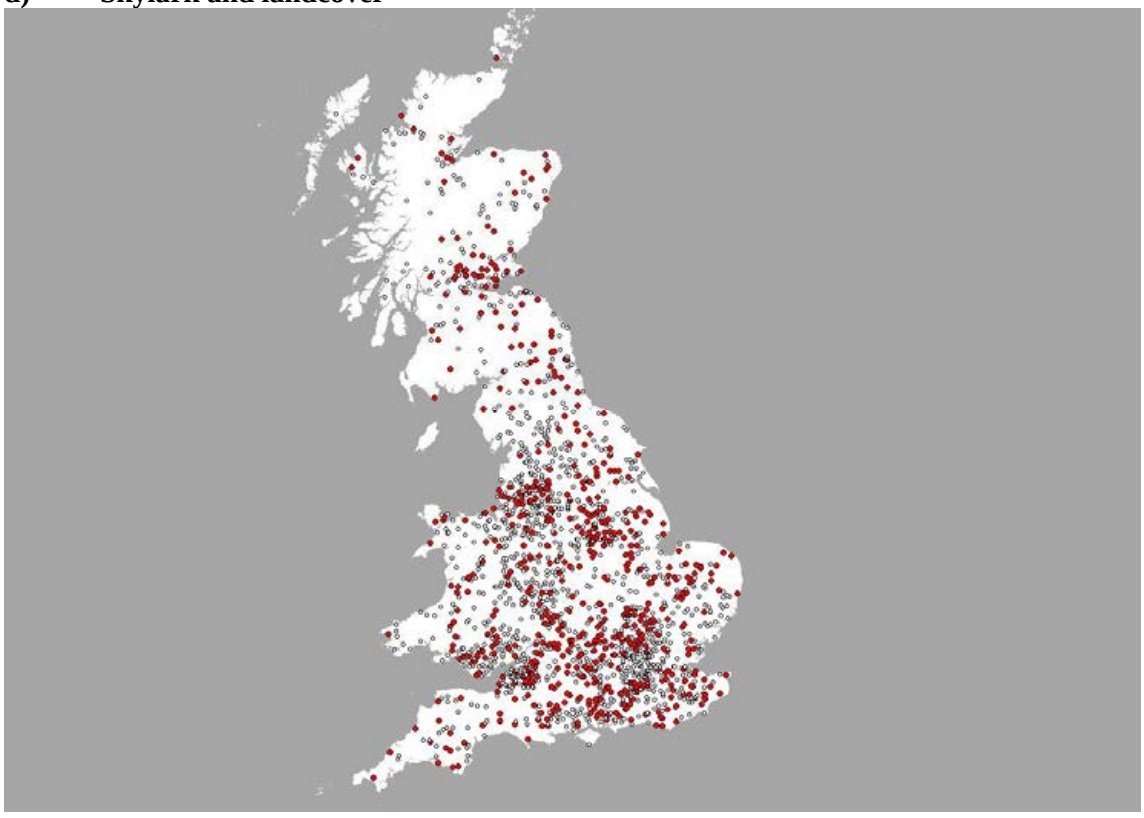
b) Buzzard and landcover



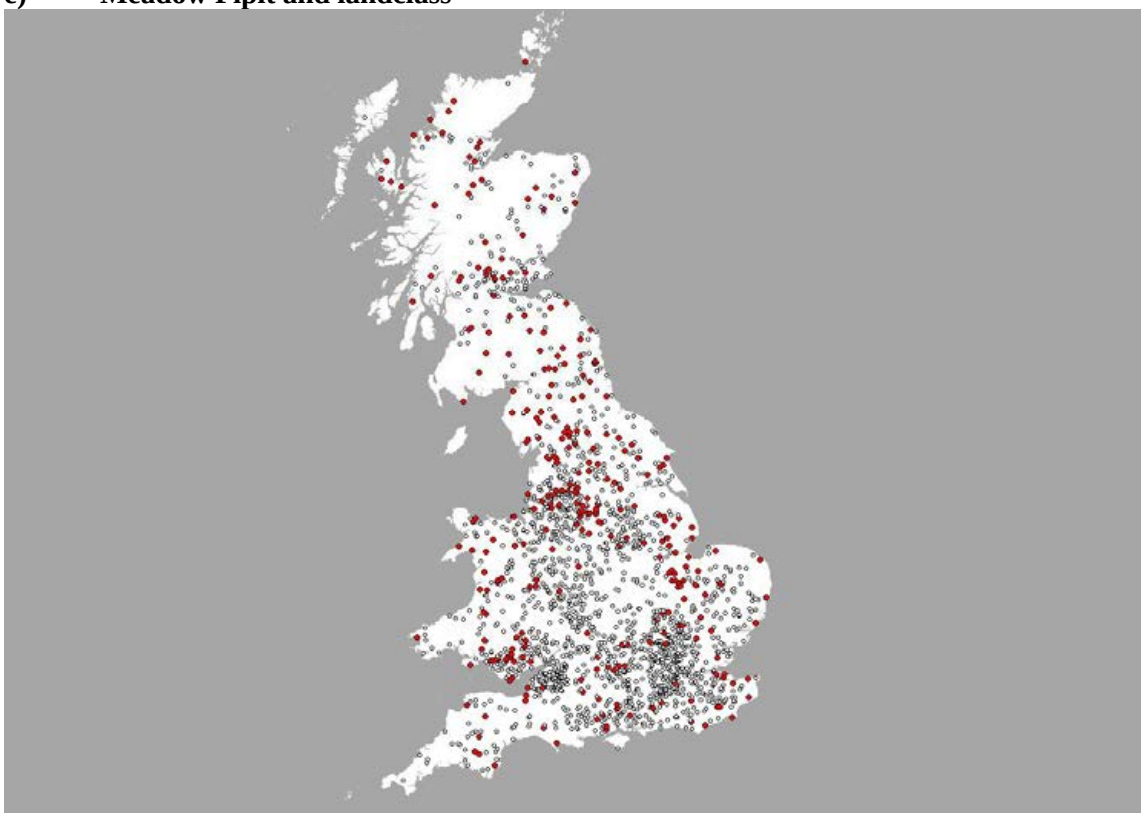
c) Skylark and landclass



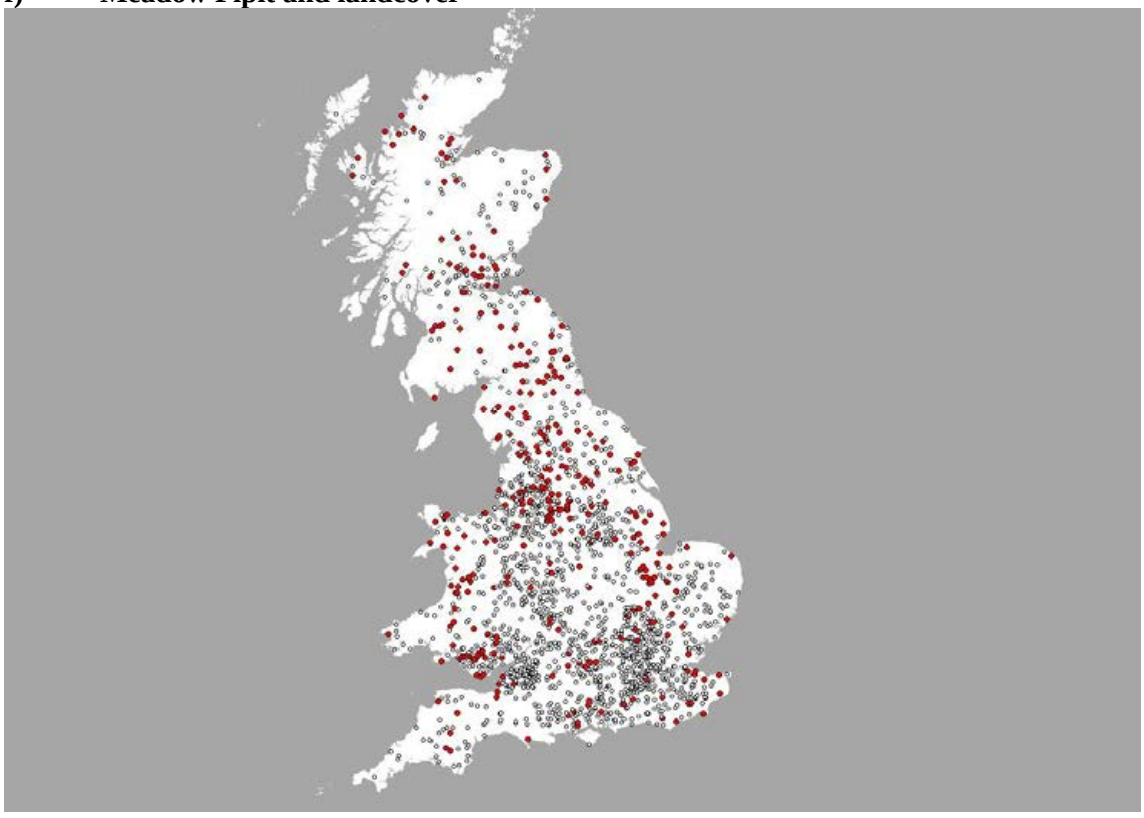
d) Skylark and landcover



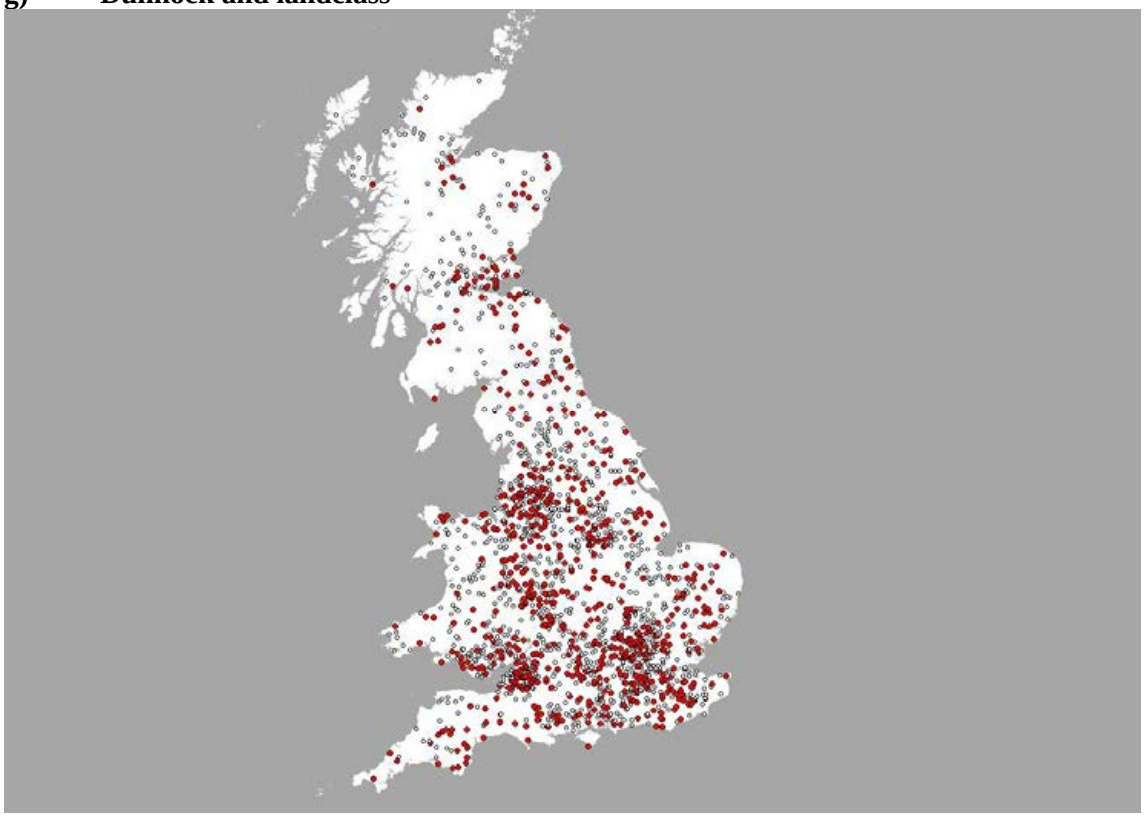
e) Meadow Pipit and landclass



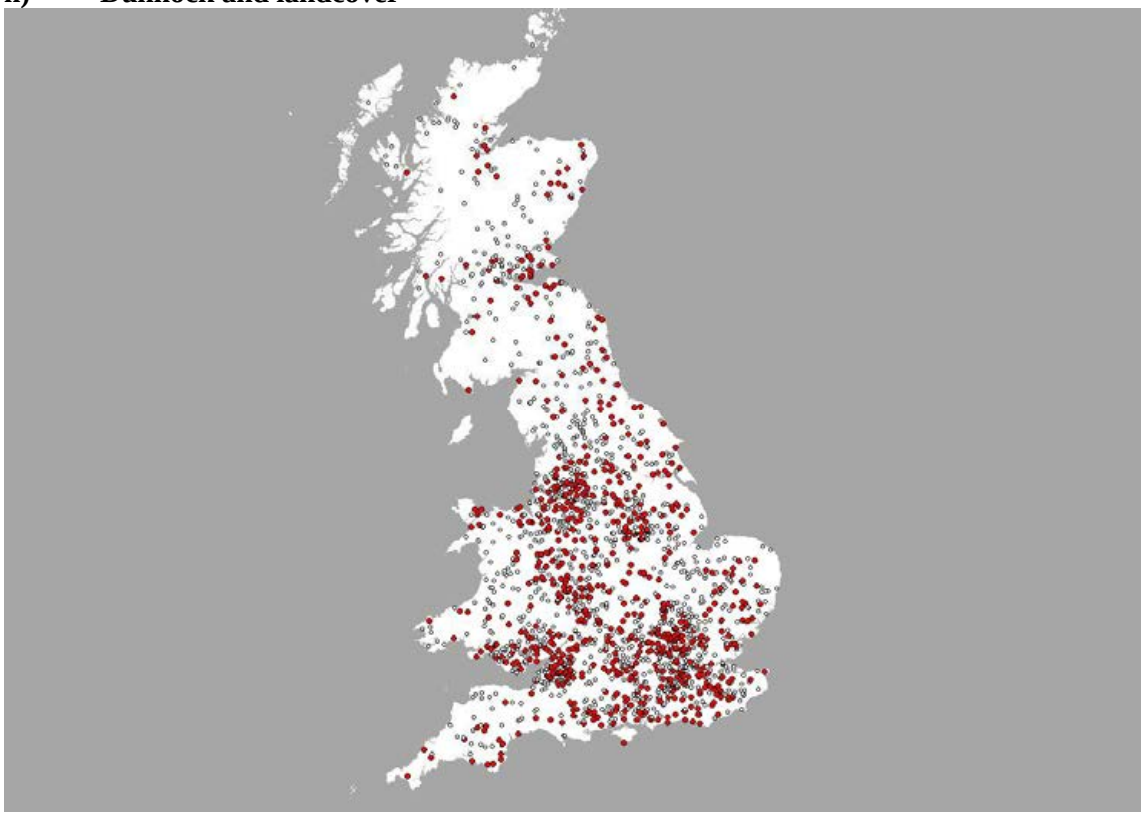
f) Meadow Pipit and landcover



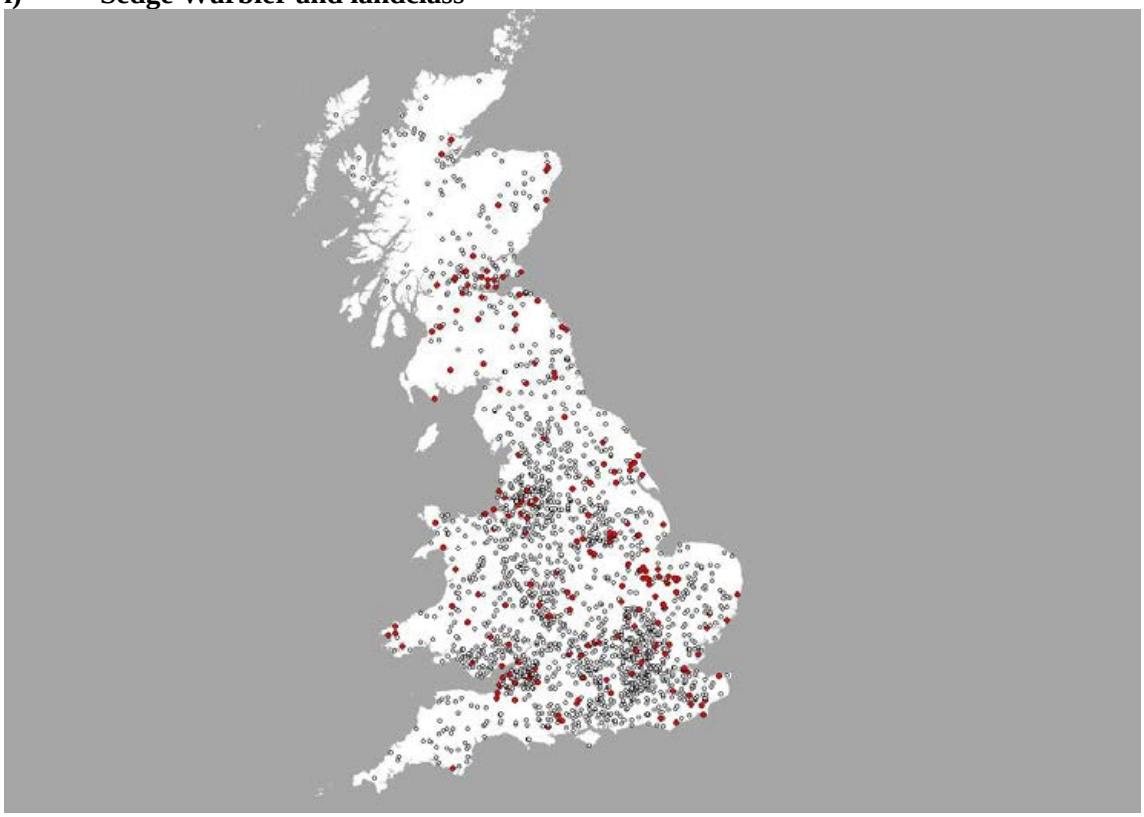
g) Dunnock and landclass



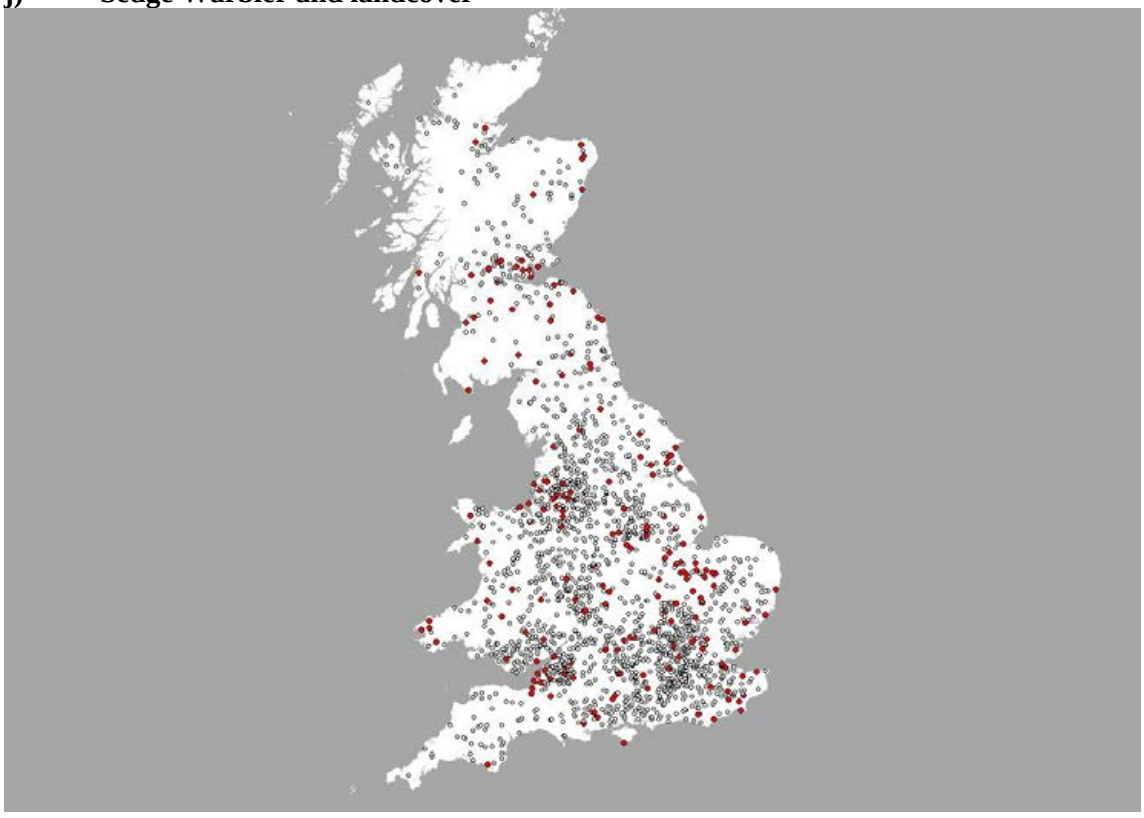
h) Dunnock and landcover



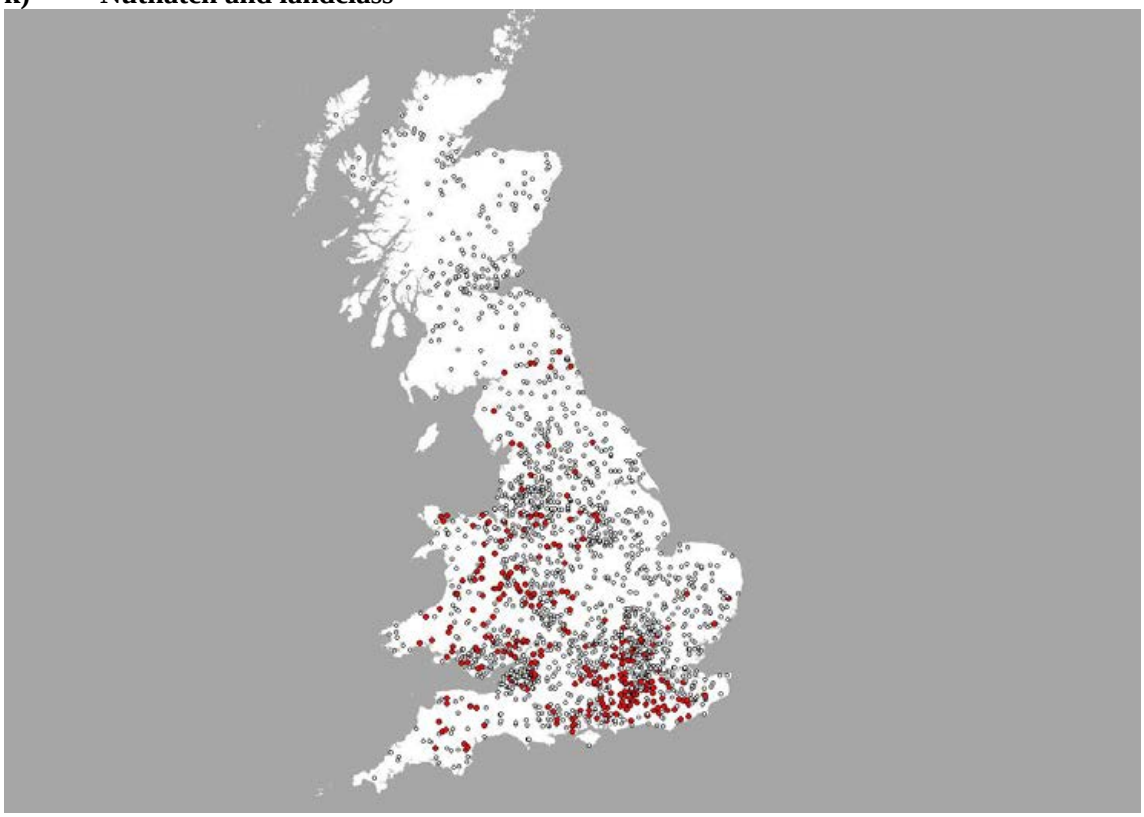
i) Sedge Warbler and landclass



j) Sedge Warbler and landcover



k) Nuthatch and landclass



l) Nuthatch and landcover

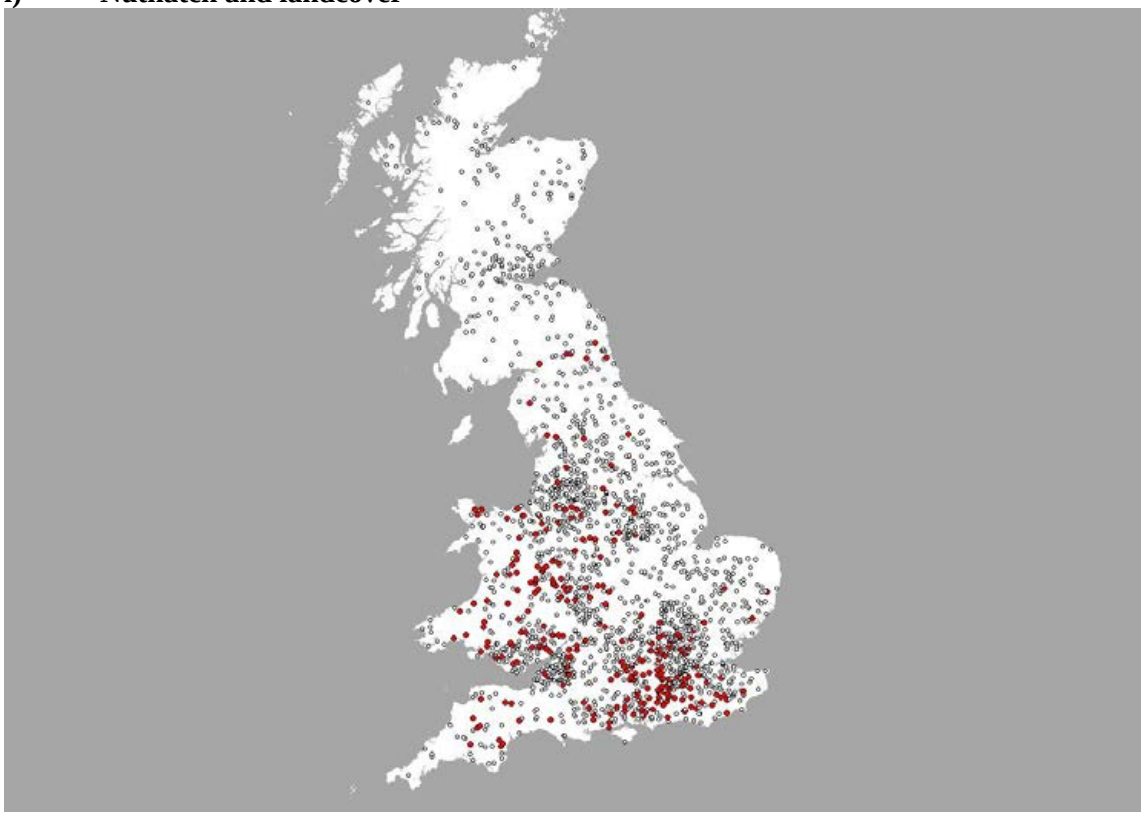
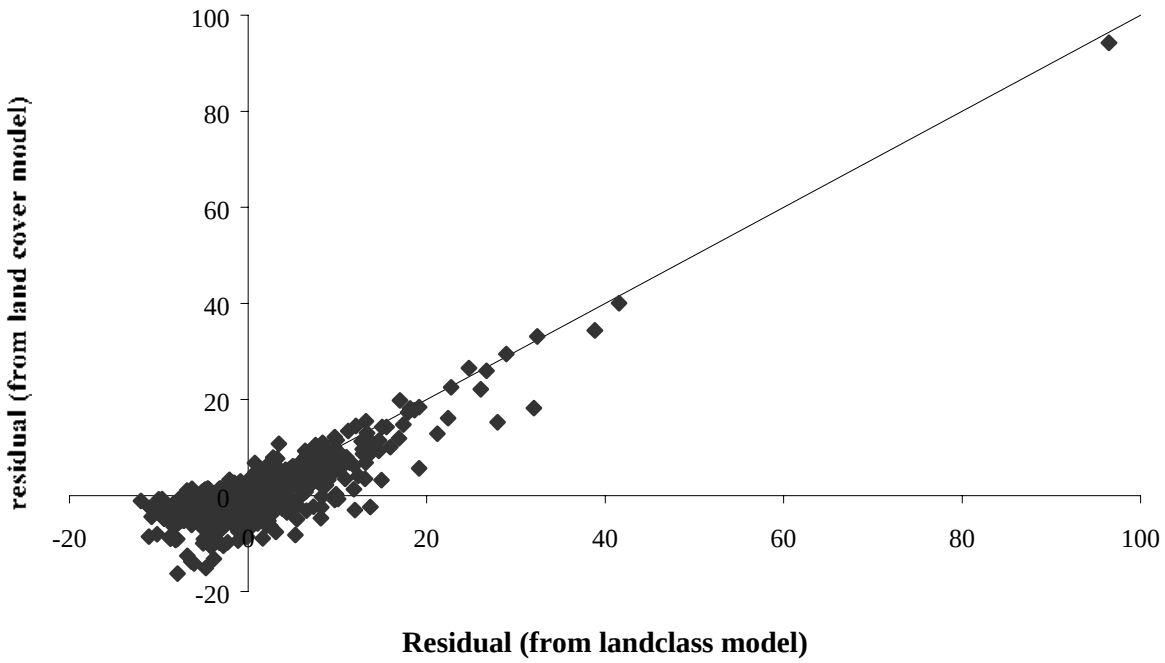
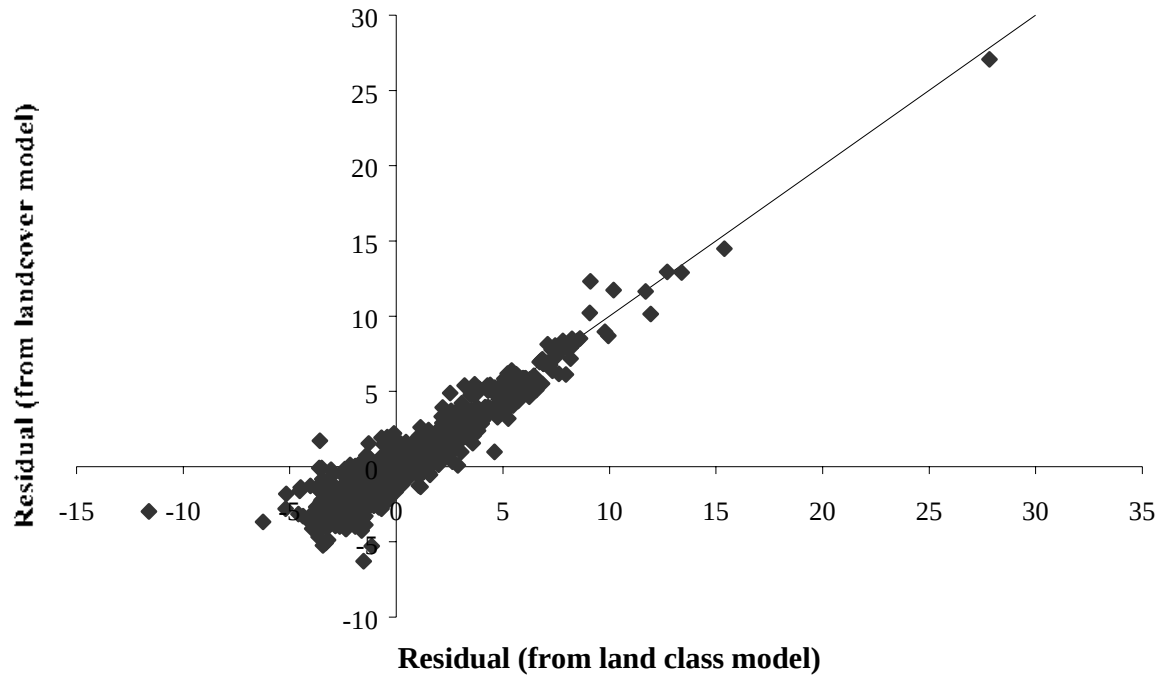


Figure 2.8 Results of a cross-validation exercise for selected species; residuals for sites regarded as 'missing counts' from two models, based on landclass and landcover data. The diagonal line represents equality of residuals under each model.

a) Skylark



b) Dunnock



c) Sedge Warbler

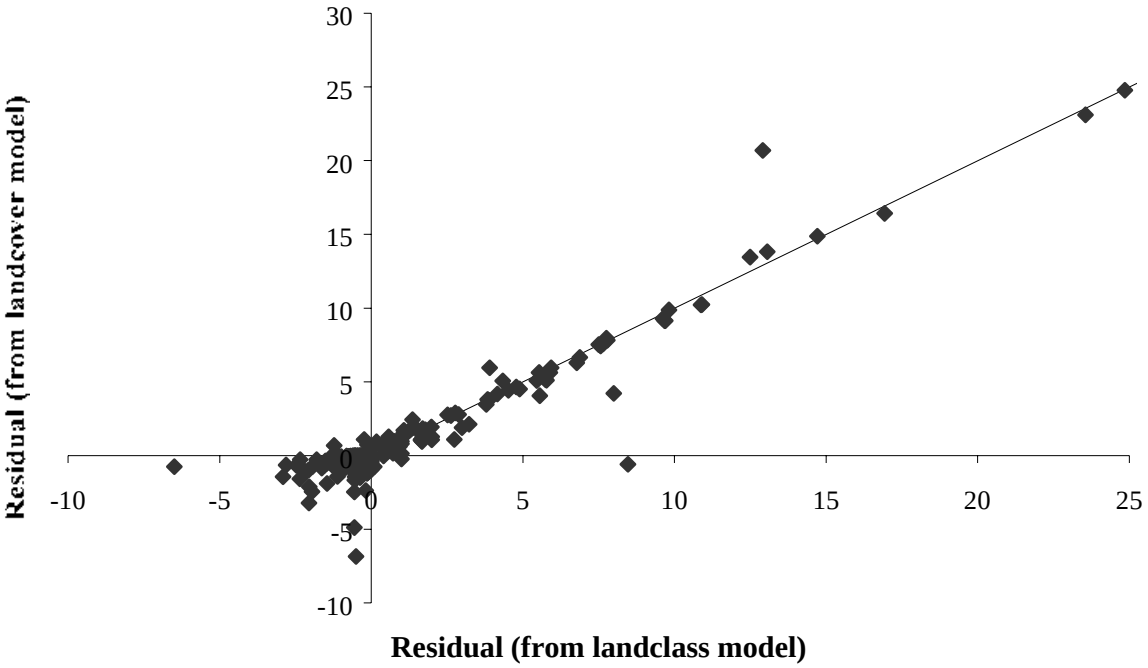
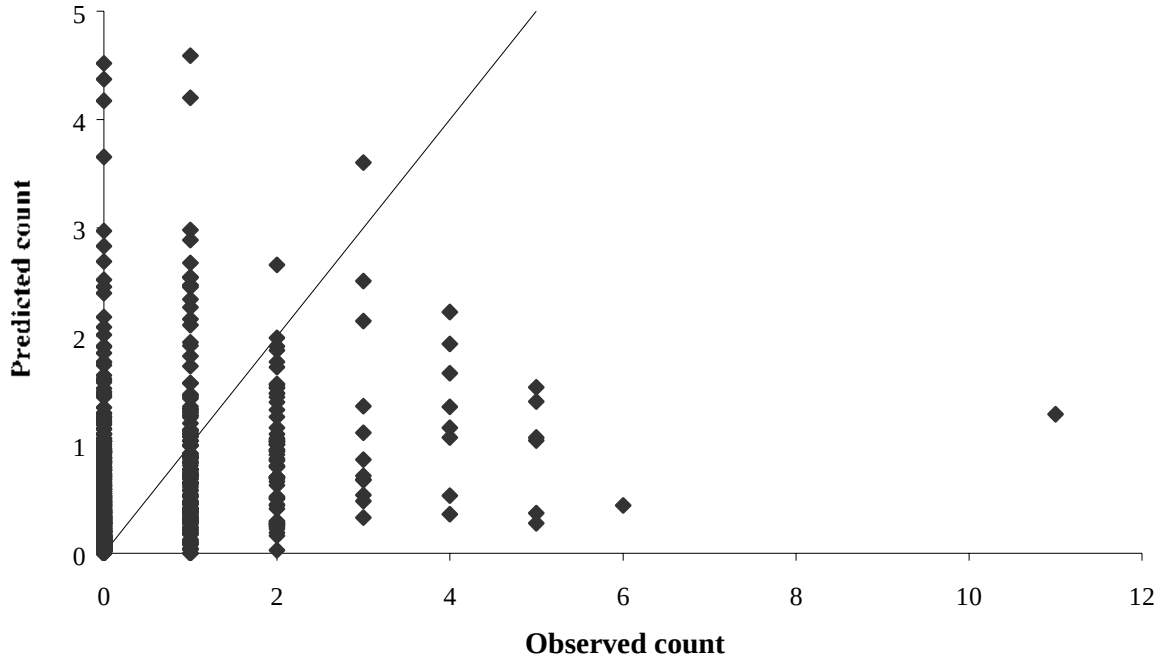
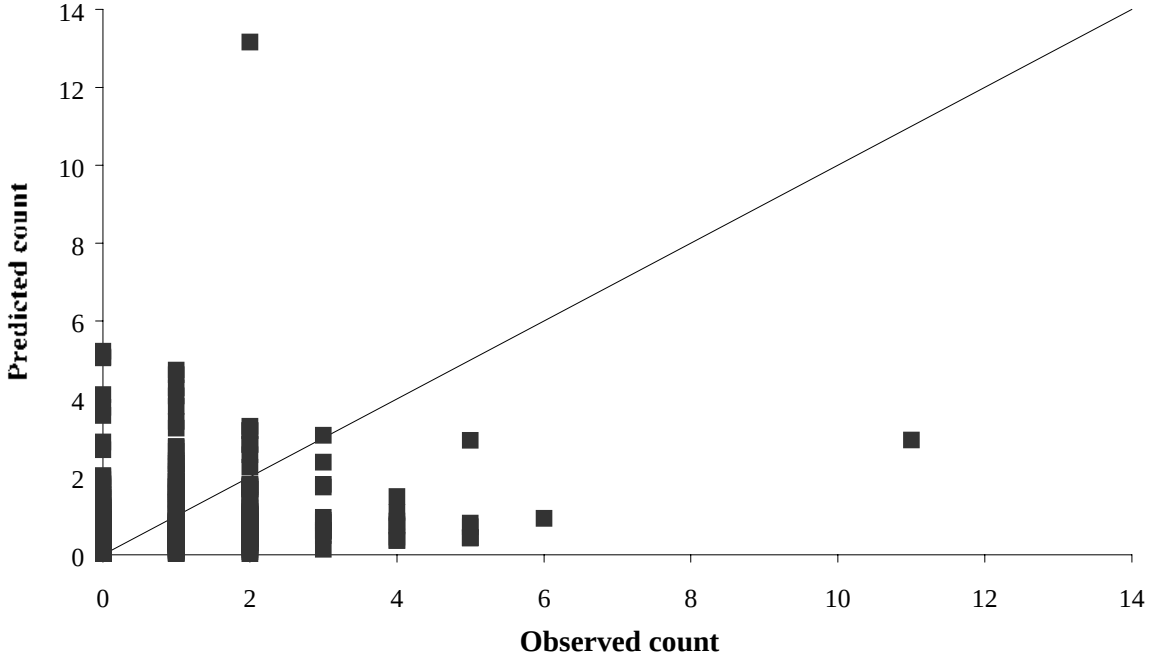


Figure 2.9a Observed and expected counts of selected species for sites treated as 'missing counts', based on models employing landclass and landcover data. The diagonal line represents the line of equality, observed = expected.

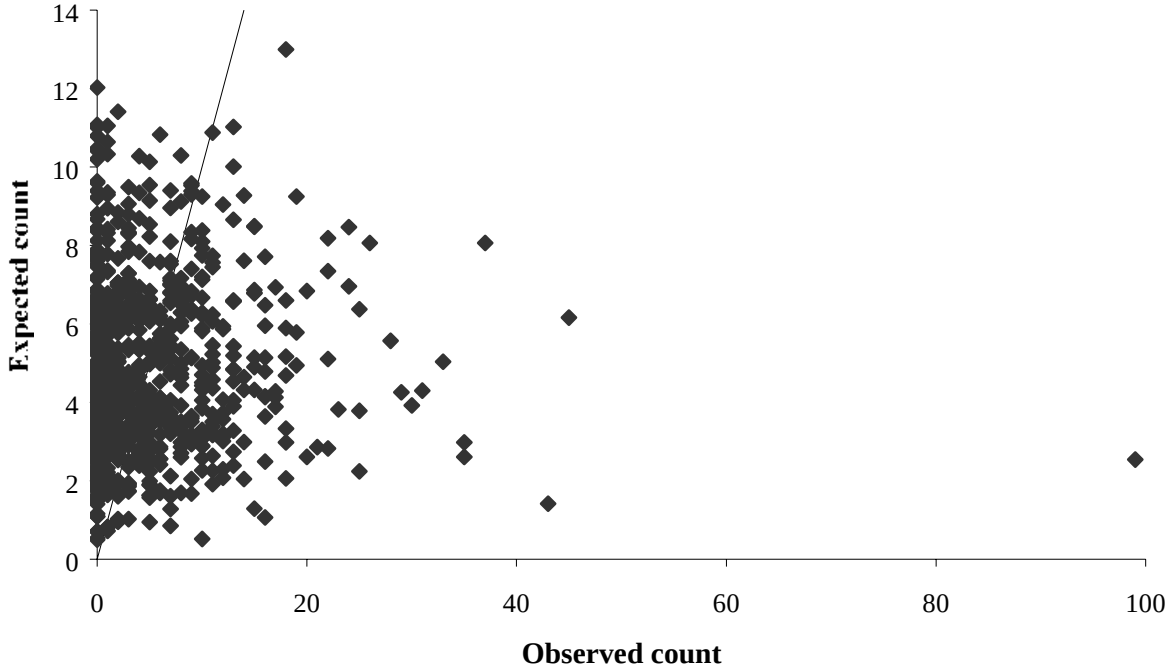
a) Buzzard and landclass



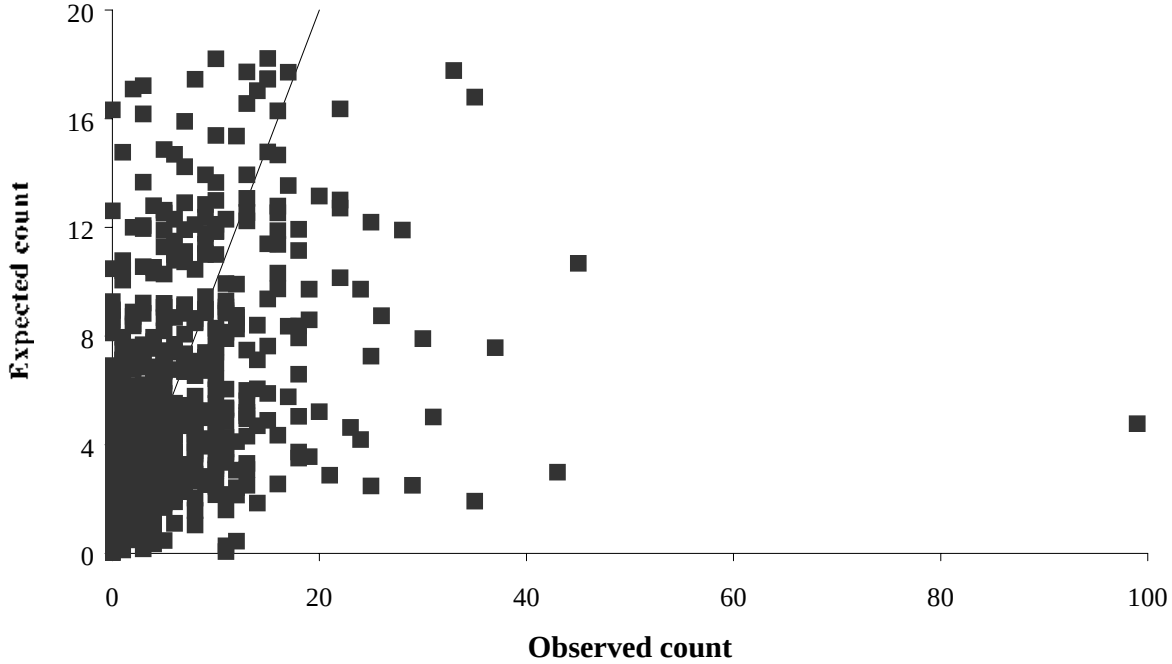
b) Buzzard and landcover



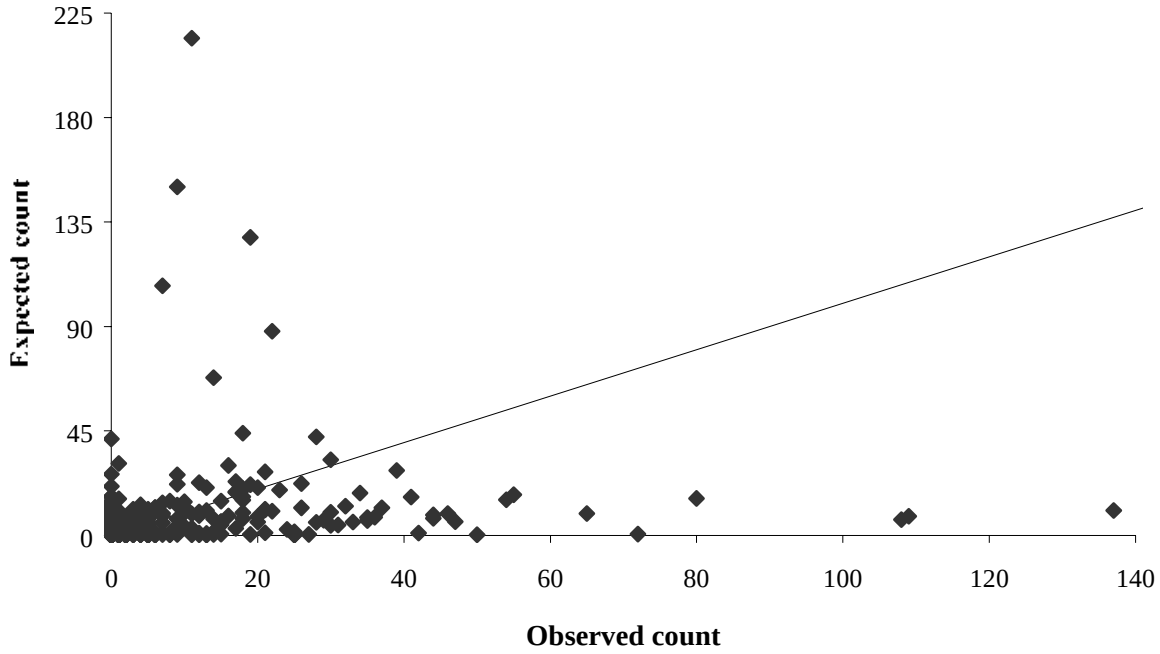
c) Skylark and landclass



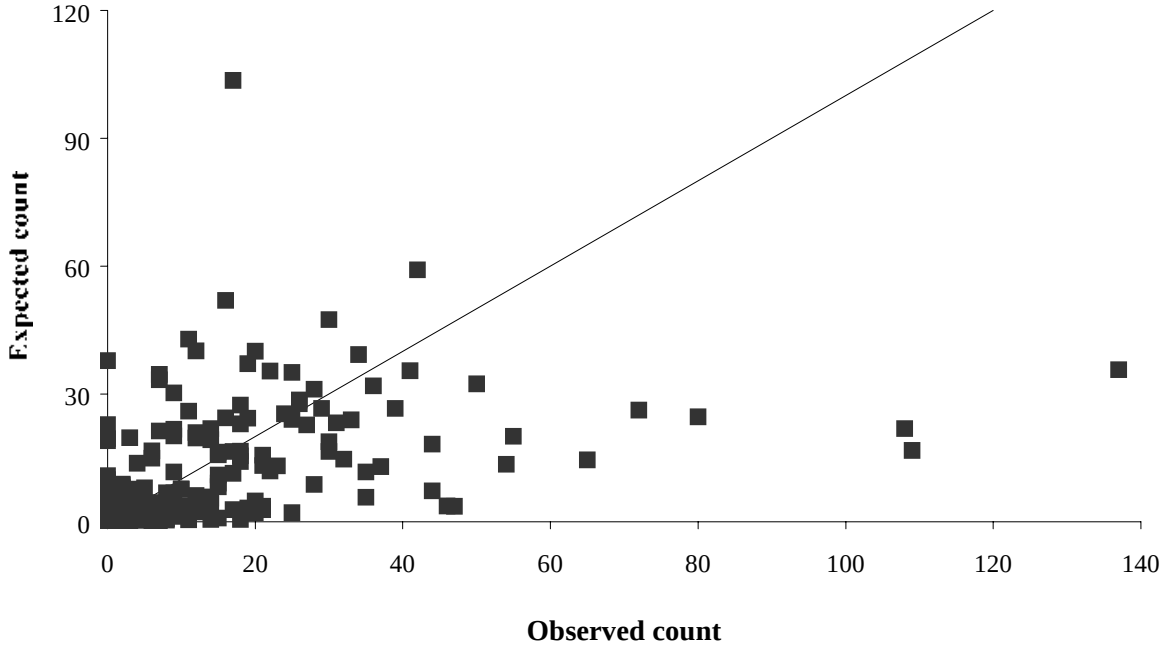
d) Skylark and landcover



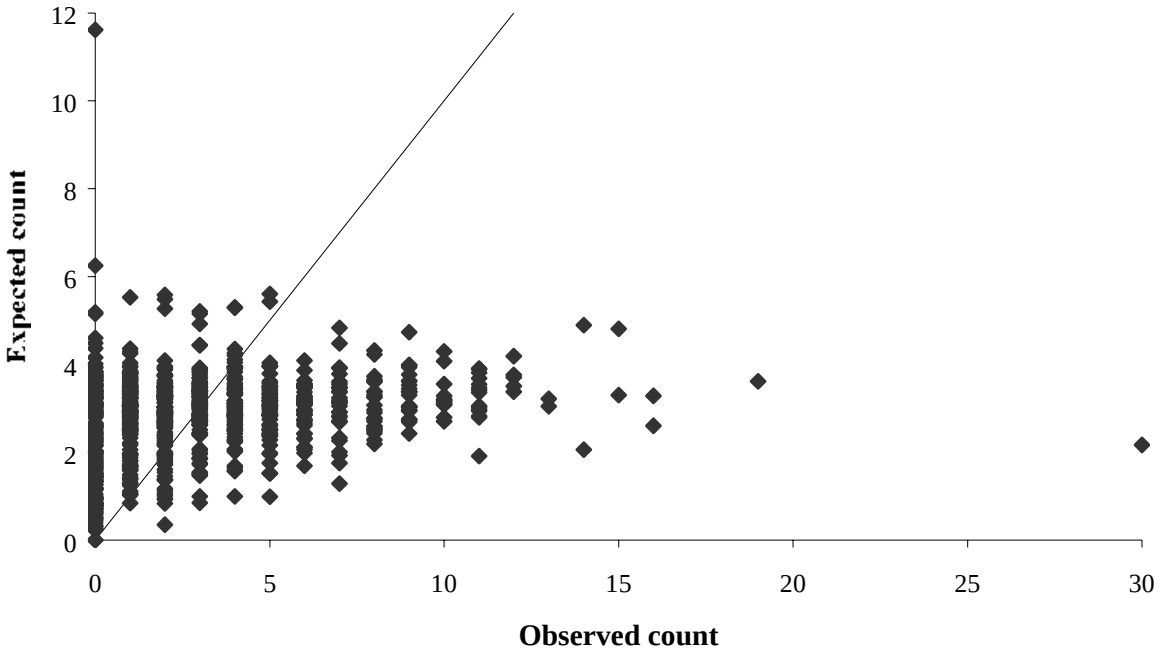
e) Meadow Pipit and landclass



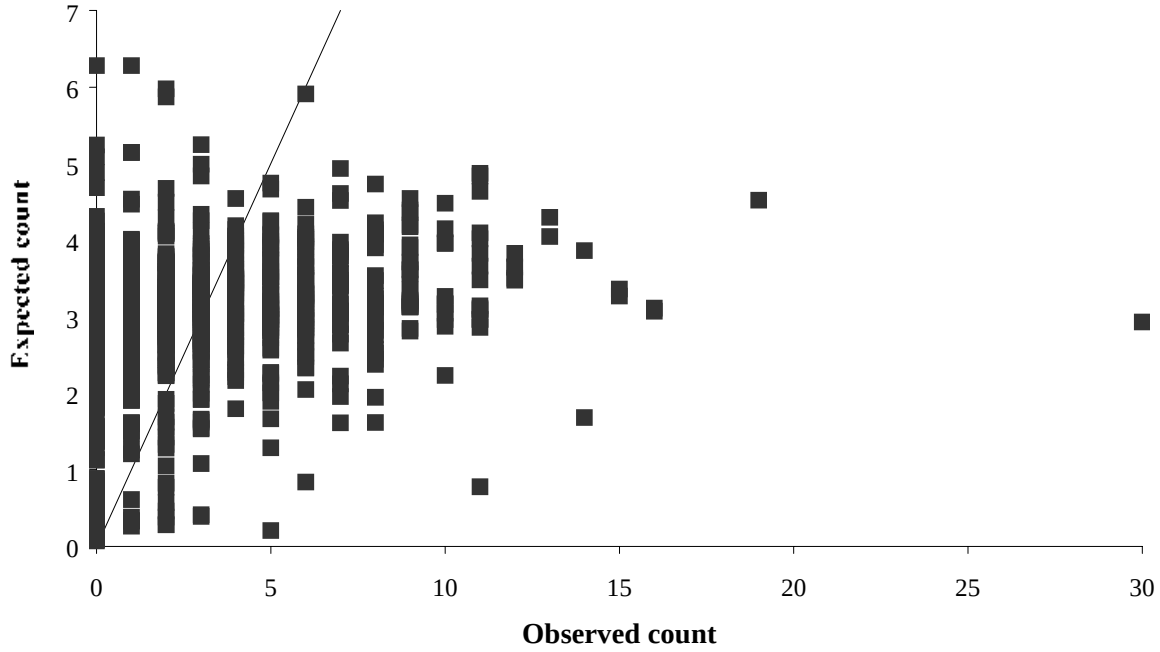
f) Meadow Pipit and landcover



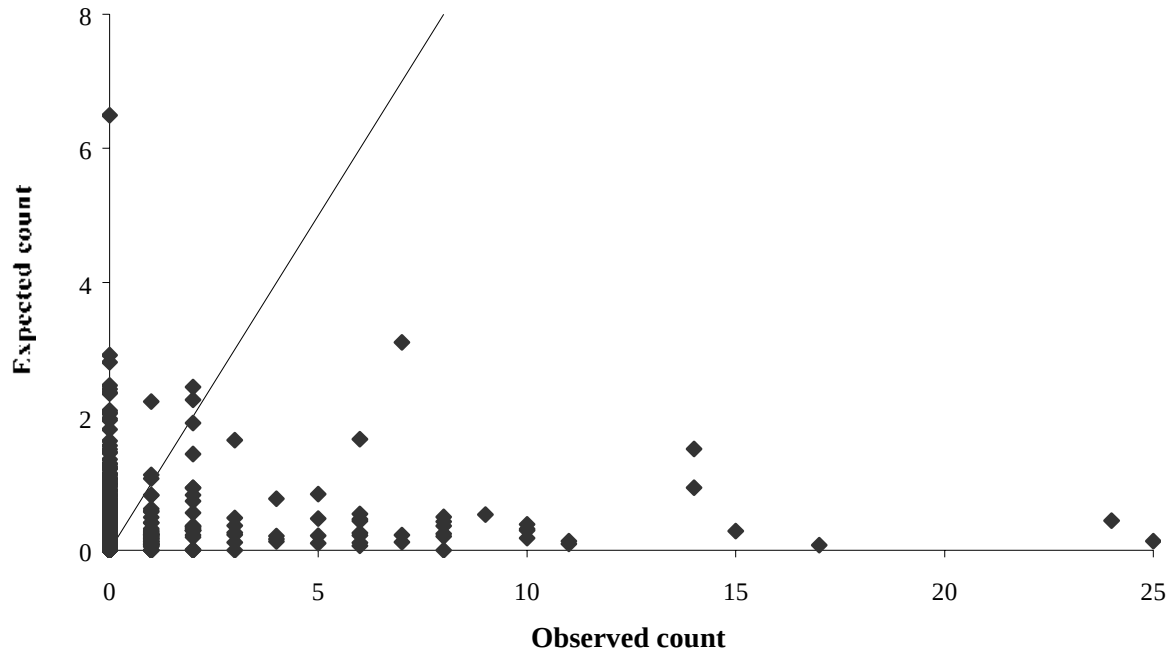
g) Dunnock and landclass



h) Dunnock and landcover



i) Sedge Warbler and landclass data



j) Sedge Warbler and landcover