Delivering robust population trends for Scotland's widespread breeding birds

B. DARVILL, S.J. HARRIS, B. MARTAY, M. WILSON & S. GILLINGS

Introduction

Our understanding of the changing fortunes of the UK's commoner terrestrial breeding birds is, to a large extent, based on the combined efforts of many dedicated and skilled volunteers who take part in the Breeding Bird Survey (BBS) each year. This survey, coordinated by the British Trust for Ornithology in partnership with JNCC and RSPB, was launched in 1994 and is based on standardised annual bird counts undertaken by volunteers in randomly located 1-km squares (Box 1, Harris *et al.* 2019). Data from the BBS and its predecessor, the Common Birds Census, are combined to give long-term bird population trends, running from the 1960s to the present (Massimino *et al.* 2019). These trends inform our general understanding of the status of the c.117 commonest terrestrial breeding birds and have many applied and research uses. It is due to these schemes, for example, that we have robust quantitative information about ongoing declines in many farmland birds (Massimino *et al.* 2019) and a growing understanding of the problems facing breeding waders (Franks *et al.* 2017). This information has helped to prioritise, shape and then subsequently monitor the effects of conservation management in both the lowlands (e.g. Baker *et al.* 2012) and the uplands (Calladine *et al.* 2014).

The BBS has been designed to provide robust information at relevant spatial scales (Box 1), with country-level trends of critical importance to the quality of devolved decision-making. In addition to the applied and political relevance of reporting at this scale, there are also real geographical differences in some species' population trends (e.g. Willow Warbler *Phylloscopus trochilus* and Cuckoo *Cuculus canorus*; Balmer *et al.* 2013) which might otherwise be overlooked. However, the breadth and robustness of the trend information that can be provided by the BBS is closely linked to the level and geographical spread of survey coverage achieved by volunteers. For example, in 2018, surveys in 3918 1-km squares contributed to the reporting of UK trends for 117 species (Harris *et al.* 2017), all but four of which are regular breeders in Scotland. In the same period, surveys in 557 squares in Scotland (equivalent to about 0.7% of Scotland's land area) enabled Scottish trends to be produced for 69 species. Bird Atlas data (Balmer *et al.* 2013) show c.200 species bred in Scotland during 2008–11 but that includes c.25 largely coastal species such as seabirds, Eider *Somateria mollissima* and Rock Pipit *Anthus petrosus* which BBS is not designed to cover. The Scottish avifauna also includes a number of very rare and localised species such as Green Sandpiper *Tringa ochropus* and Slavonian Grebe *Podiceps auritius* which a random survey cannot hope to monitor. Forty-four species occurred (probable & confirmed breeding) in fewer than 30 10-km squares, leaving 130 species that one might consider reasonable widespread, and BBS produces long-term Scottish trends for approximately half. The key prerequisite for production of Scottish trends is for a species to have been recorded in an average of at least 30 BBS squares each year since the start of the survey. Hence as things stand we cannot use BBS data to produce Scottish trends for a range of high-interest species such as Whinchat *Saxicola rubetra* (25 squares on average per year since 1994), Dipper *Cinclus cinclus* (22), Greenshank *Tringa nebularia* (10) and Ring Ouzel *Turdus torquatus* (7), as well as more widespread species such as Mute Swan *Cygnus olor* (21) and Jay *Garrulus glandarius* (26).

Box 1. Design of the Breeding Bird Survey and unintended consequences.

The BBS employs a stratified random sampling approach. This entails randomly selecting 1-km squares within BBS regions, most of which follow similar boundaries to traditional counties. The number of 1-km squares initially allocated in each region was determined relative to the number of BTO members in the region to reflect the likely size of the volunteer base.

Superficially, this appears to bias the set of squares towards lowland areas where more people live. However, when done in a predetermined way this can be handled in the production of trends by down-weighting data from regions with a high number of squares relative to their area and up-weighting squares from regions with a low number of squares.

Crucially, this approach requires that the squares covered *within* a region be representative of the region. For this reason, BBS squares in a region should be assigned to volunteers in a random order but this is rarely practical and it is much harder to find long-term volunteers for remote squares. Over time, this can lead to bias in the set of squares surveyed, particularly in areas of Scotland with very large regions and low population densities.

In some regions new volunteers are unable to take on a nearby square because only inaccessible remote squares remain from the original list. New BBS squares are typically only released in regions when coverage exceeds 75% of the original list, but this threshold is often not met in regions with many inaccessible remote squares.

Although these rules were designed with the best intentions of maintaining a gold-standard monitoring scheme, in some parts of Scotland, biases may already exist and the rules may be preventing further increases in coverage and constraining our ability to monitor certain species.

An increase in the overall number of squares surveyed annually in Scotland would increase the likelihood that trends could be produced for these and other species, as well as enhancing our ability to produce finer-scale, regional trends. Despite ongoing efforts to recruit new volunteers in Scotland, there are severe constraints that limit further growth of the BBS in Scotland (Box 1). Some of these constraints may be leading to biases in the squares actually covered, with the consequence that some trends may not be as representative of Scotland's landscapes and avifauna as we would like. In this study, we examine the historical pattern of coverage of Scottish BBS squares and assess biases in coverage. We assess the relative importance of geographical factors in determining coverage of squares by volunteers, using the results to evaluate options for improving coverage and reducing biases.

Methods

To assess the representativeness of existing surveyed BBS squares we collated the history of coverage of all BBS squares in Scotland. The BBS has been running since 1994 but during 1994–98 paid surveyors conducted surveys in some remote areas. Unfortunately, we cannot identify the affected squares, and as the focus is on coverage achieved by volunteers, we focus on the period 1999–2016. We discounted coverage in 2001 due to the Foot and Mouth outbreak which significantly restricted access. We also excluded the following squares from the analysis:

- squares which had been permanently marked as 'uncoverable' due to access restrictions (e.g. military land), particularly dangerous terrain, or their being mostly water (so containing too little land to undertake a bird survey);
- an extra sample of woodland-dominated squares that were surveyed by professional field-workers during 2007–09;
- 'upland adjacent' squares. These are paired with 'core' BBS squares and are surveyed by the same volunteer on the same day, hence are not independent;
- squares on the island of Rum. In this unique case the island contains five BBS squares but no public roads. Analyses involving distance to or ascent from the nearest public road would therefore have been confounded if these squares had been retained.

For each of the remaining 958 BBS squares in Scotland, coverage was expressed as the proportion of visits undertaken out of the total number of possible visits (two visits per year, in each year since the square was made available for coverage). For an overview of coverage we summarised patterns of coverage by 200m elevation classes. Next we assessed whether geographical factors were associated with coverage of individual 1-km squares. A number of explanatory variables were derived using geographical information system software for each BBS square (Table 1). Where appropriate, variables were log-transformed and then tested for their degree of inter-correlation. To assess the importance of the different variables in determining square coverage a logistic regression model was produced using all variables. All variables were included as continuous variables except for BTO Region which was included as a random effect. The model assumed binomial error structure and was fitted using the statistical software package R (www.r-project.org). The best-fitting model was selected from the full model (containing all variables) using backwards selection based on AIC (Akaike Information Criterion).

Table 1. The variables used in models to explain variation in coverage among BBS squares.

Variable name and expected direction of effect	Variable definition and source
Human (+)	human population size within the 10-km square in which each BBS square occurred. Derived from Scotland's Census 2011
Elevation (-)	mean elevation of the BBS square. Derived from a digital elevation model (UK 90m Shuttle Radar Topography Mission DEM).
Medium (-)	the proportion of the land surface of the BBS square which had a medium slope, defined as 5–20% in gradient. Derived from the digital elevation model.
Steep (-)	the proportion of the land surface of the BBS square which was steeply sloping, defined as 20% or greater in gradient. Derived from the digital elevation model.
ForestBL (+)	the proportion of the land surface area of the BBS square which was covered by broad-leaved forest. Derived from the Corine Land Cover map
ForestCon (-)	the proportion of the land surface area of the BBS square which was covered by coniferous forest. Derived from the Corine Land Cover map
Remoteness (-)	the distance from the centre of the square to the nearest public road, based on the Ordnance Survey 'Open Roads' GIS layer (https://www.ordnancesurvey.co.uk/opendatadownload/products.html#OPROAD)
Ascent (-)	the absolute difference in elevation between the square's centre and the nearest public road (crudely approximating to required ascent/descent when walking to and from the square).
BTO Region (no hypothesised direction of effect)	these are areas used by the BTO to administer surveys and approximate to the Scottish counties in many cases. This variable was included because some determinants of square coverage may be region specific, such as differences in the aggregation of people, the quality of the road network, and the willingness of the local population to engage in voluntary activities.

Results

Patterns of BBS coverage in Scotland

Of the 958 Scottish BBS squares analysed, 740 have been surveyed by a volunteer at least once and 218 were never surveyed during 1999–2016. Forty-one percent of BBS squares have been surveyed on at least half of available visits. A total of 10,925 survey visits were completed, relative to a total of 25,870 available visits, equating to 42% coverage overall. Mapping the pattern of coverage revealed coarse geographical differences, such as high coverage in the central belt (Figure 1), but also that patches of low and high coverage were dotted throughout Scotland.

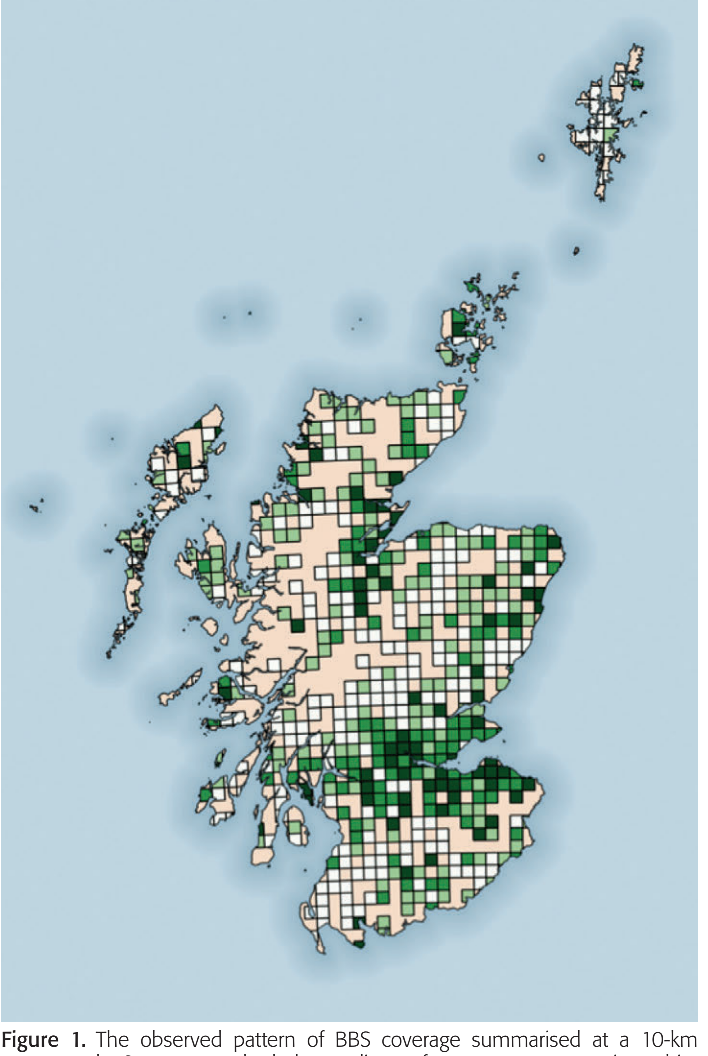

Figure 1. The observed pattern of BBS coverage summarised at a 10-km square scale. Squares are shaded according to four coverage categories: white (0–25% average coverage) through to dark green (75–100% average coverage). The remaining areas contain no BBS squares, partly due to the randomised way in which squares were originally selected, but gaps are also more likely to occur in regions with low population density because fewer squares overall were selected there.

In low lying areas of Scotland (0–200 m elevation) there are 565 BBS squares which have been surveyed, on average, on 44% of available visits (Figure 2). This contrasts markedly with squares above 600 m which have been surveyed on c.20% of visits (Figure 2).

Correlates of coverage

The model including the eight environmental variables plus BTO Region explained 20% of the variation in the proportion of visits completed to a BBS square. Six of the eight environmental variables made a statistically significant contribution to the model (Table 2) while Remoteness and Medium Slope did not make any contribution to explaining coverage. Human population density had a strong positive effect on coverage, as can be seen from the shape of the curve in Figure 3. Cover of coniferous woodland had a negative effect on coverage, with negative effects of similar magnitude for the amount of steeply sloping ground, elevation of the square and ascent from the nearest road to the square (Table 2, Figure 3). After accounting for these square attributes, the BTO region in which the square fell also had a very strong effect on coverage.

Discussion and solutions

The stratified random sampling design of the BBS aims to avoid bias in site selection to ensure that robust and representative information can be provided on the commoner breeding birds in the UK and constituent countries. However, although the squares selected for coverage were randomly chosen, we demonstrate that their historical coverage in Scotland is non-random, being systematically lower where there are few people and where land is remote, steep or at high elevation.

Two factors affect how many BBS squares are available for coverage at different elevations. Firstly, there is considerably less land above 800 m (775 1-km squares) than below 200 m (46,582 1-km squares) so purely randomly generated squares will rarely fall in high altitude areas. This effect is

Table 2. The direction and statistical significance of retained environmental variables in explaining variation in coverage of BBS squares. The Z statistic and P value test whether the parameter estimate was significantly different from zero. BTO Region was also a statistically significant variable in the model.

Variable	Parameter estimate (± SE)	Z	P
Human	1.31 ± 0.09	14.23	<0.001
Steep	-0.06 ± 0.01	-4.55	<0.001
ForestBL	0.30 ± 0.13	2.34	<0.05
ForestCon	-0.50 ± 0.06	-9.05	<0.001
Ascent	-0.06 ± 0.02	-3.48	<0.001
Elevation	-0.12 ± 0.02	-44.8	<0.001

compounded by the stratified design of the BBS which originally made more squares available in regions with high human populations, which are more often in the lowlands. The consequent differences in the number of squares between regions is analytically accounted for during trend production, but non-random coverage within a region is not, meaning that differences in trends between upland and lowland areas may not be adequately reflected in Scottish BBS trends.

Squares in some regions are much more likely to have been regularly surveyed than in other regions, even once other explanatory variables are taken into account. These inter-region differences are likely caused by multiple and inter-related factors, such as the activities of individual participants and organisers, aspects of human demographic variation not included in our analysis (e.g. distribution, average age, interest in birds), differences in the availability, connectivity and quality of roads, required driving distance/time and other factors related to accessibility. Inter-region differences in overall coverage are taken into account by 'regional weighting' during the production of BBS trends. However, while this ensures that each region contributes information in proportion to its area, it cannot correct for within-region biases due to non-random uptake of allocated survey squares. It would be valuable to further analyse differences in uptake in lowland areas.

Evaluation of possible solutions

Identifying acceptable interventions to reduce biases and increase coverage in

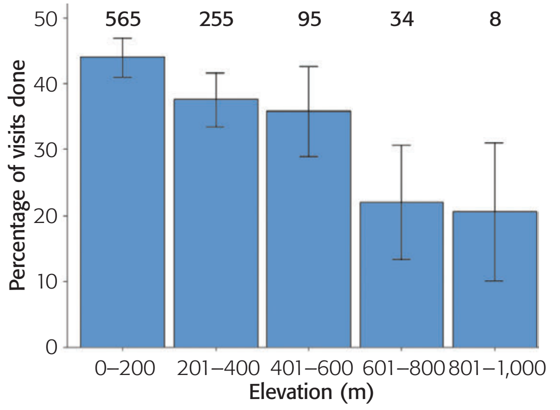

Figure 2. The average percentage of possible visits undertaken to BBS squares in different elevation bands. Numbers above bars show the total number of BBS squares present in each elevation band. Error bars show 95% confidence intervals.

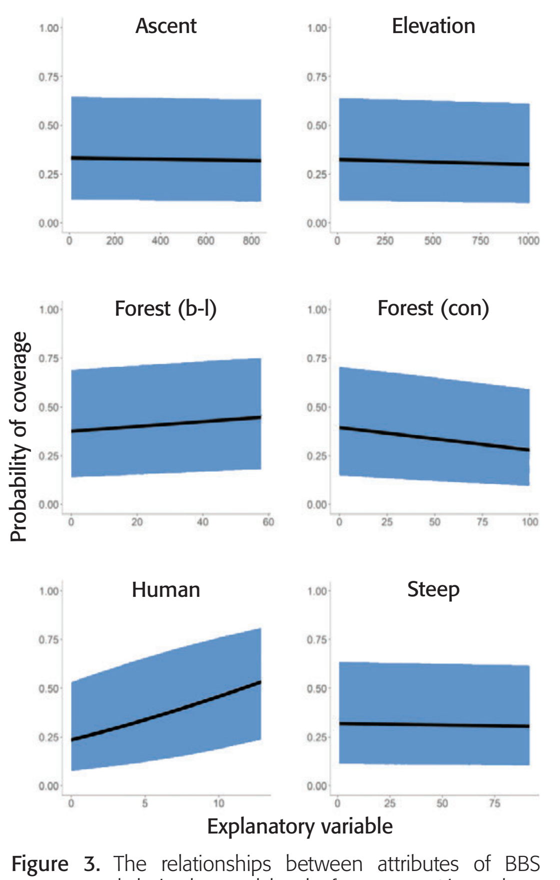

Figure 3. The relationships between attributes of BBS squares and their observed level of coverage. Lines show the fitted relationship from statistical models, shading shows the confidence limit around the relationship.

Scotland requires careful balancing of multiple costs and benefits. The value of BBS trends depends on the robust nature of the survey they are based on. Whilst accepting that the biases we identify here need to be addressed, it is critical that we do not make changes that have unintended negative consequences. Table 3 lists a number of possible changes that have been proposed at various times and considers likelihood of success and unintended consequences, such as possible effects on 'noise' (increased uncertainty) in the reported trends. The possible solutions are ordered by the degree of intervention required on the basis that we should first consider solutions that require the least modification to existing protocols. It should be noted that these interventions are mostly targeted at upland and remote areas, as these are the areas where under-sampling is most severe, and where increasing coverage would be likely to resolve obstacles limiting coverage at a wider scale (see Box 1).

Improved promotion and associated engagement and training require no methodological intervention but it is our view that they will have limited success in isolation. In some instances, promotion identifies new people keen to take part in lowland areas where there are no available squares. Instead we think that substantial reductions in bias will be best achieved by using public engagement to support and build upon the implementation of one or more of the other structural changes to the survey design which in the long term should also increase availability of new squares in upland and lowland areas. Of the changes highlighted, allowing visiting observers to make single visits without a commitment to take on the square long term seems to offer the best compromise of high return for limited methodological intervention. Single visits to remote squares are already permitted in extreme cases, but relaxing the rules could allow a potentially large pool of visiting surveyors (e.g. holidaying birders) to contribute to the survey.

This approach, promoted as Upland Rovers, was trialled mid-way through the 2017 field season. The analyses described above were used to identify a set of 301 remote and rarely visited squares across the UK. Of these, about half were already allocated to BBS volunteers in 2017; the remaining 156 were publicised as being eligible for visits by Upland Rovers, the majority of these squares being located in Scotland. In that first trial 49 squares were taken on, which was impressive considering the late date the option was promoted, and gave us confidence this was worth extending in 2018. Subsequently, Upland Rovers has proven very popular with 99 squares surveyed in 2018 and 125 in 2019 (all but five of which were in Scotland). The benefits of this increased upland coverage can already be seen, with 125 squares surveyed in 2019 providing data on Meadow Pipits *Anthus pratensis*, giving a 12% increase in sample size over what would likely have been achieved without the Upland Rover approach. Similarly, Golden Plovers *Pluvialis apricaria* were detected in an extra 39 squares giving a 33% increase in sample size in 2019. If maintained, these increased sample sizes and better geographical spread of data will improve the robustness of published trends for such species. For species where a Scottish trend is not currently calculated, Upland Rovers yielded an additional seven Scottish squares with Greenshank, six with Ring Ouzel and seven with Whinchat. These are valuable increases and help to bring sample sizes closer to the critical 30-square threshold.

At present, the total number of BBS squares allocated to a region is only increased when BBS coverage in that region reaches 75% of existing BBS squares. In addition to providing much-needed data on upland species, the additional coverage resulting from Upland Rovers will bring regional coverage totals closer to or past the 75% threshold, thereby resulting in more squares being released into a region and enabling more people to participate in this key survey. This will have a positive impact on sample size in lowland areas and will likely increase the sample size for species such as Mute Swan. However, it is important to emphasise that Upland Rovers is not intended to replace the traditional model of BBS survey, even in the remote upland areas where it is likely to make the biggest difference. Squares where dedicated BBS volunteers commit to carrying out two surveys per year to specific squares are still the 'gold standard' for this survey. Having a single observer carry

Table 3. Possible solutions to the upland coverage issue and an assessment of the degree of change needed to core BBS methods and any costs or unintended consequences.

Proposal	Changes to methods	Likelihood of success, costs and possible consequences
Better promotion, engagement and training: highlight value of upland squares, species and habitats.	None	Increased awareness and skills are great in their own right but if they are not the factors limiting BBS coverage in the uplands, this could be a costly exercise.
Roving Observers: for selected squares, allow visiting birdwatchers to undertake one-off surveys.	Low	More squares with single visits. More year-to-year turnover in volunteers of remote squares. Need to understand how visit timing impacts apparent trends.
Mark more squares as "uncoverable": squares never visited could be marked as uncoverable.	Low	Ill-advised as would lead to dilution of the random nature of the set of surveyed squares. Whilst this would help reach the 75% allocation target to trigger release of more squares, there is no guarantee that the new random squares would be in the uplands, and even if they are, they may be equally remote and "uncoverable" leading to greater upland:lowland bias.
Modify weightings: during analysis adjust weights given to squares within a region to reflect habitat coverage.	Modest	There is a risk that up-weighting the contribution of a small number of upland squares could increase margins of uncertainty in the trends.
Re-stratify uplands into accessible and inaccessible.	Significant	Accessible squares may not be considered representative of inaccessible areas, with the risk this effectively excludes parts of the landscape from the BBS design.
Replacement squares: for long-term uncovered squares identify a set (e.g. 10) of nearby accessible alternatives from which one is selected to replace the original.	Significant	Reliant on our ability to identify squares that are similar in every characteristic except their inaccessibility to observers.
Allocate more upland squares: release new randomly selected upland squares.	Significant	No guarantee that new squares will be accessible and covered. Significantly complicates weighting and disrupts randomised design.
Spatial modelling to produce trends: produce population trends using models that account for square characteristics (e.g. location, habitat, elevation).	Significant	Trends should be less affected by coverage biases but may be noisier due to still small sample size in large upland areas. Increased time taken to run trends.

out surveys in a BBS square over an extended period of time is likely to improve data quality, both by eliminating variation between years due to different observers, and by enabling the surveyor to get to know their square, and how best to survey it (Eglington *et al.* 2010).

Conclusions

Information on the changing populations of Scotland's commoner breeding birds is of enormous value to birdwatchers, land managers and decision-makers. To meet the needs of end-users such trends should include as many species as possible, be robust and unbiased, and should be available at relevant spatial resolutions. This analysis has identified imbalances in the current sampling of Scotland by the BBS owing to low levels of coverage of remote or inaccessible squares, and has highlighted some ways in which these might be addressed. One of these solutions is already helping to reduce the lowland-upland coverage imbalance and is generating valuable data on under-recorded species. It is too early to say if the increased upland coverage is sustainable (or whether the pool of holidaying surveyors is too small).

Without the volunteers who participate throughout the UK the BBS would obviously be unable to function. The geography of Scotland is challenging, both for the volunteers undertaking surveys and for scientists trying to design them. After more than 20 years of implementing the BBS methods in Scotland, this review illustrates some of the constraints and opportunities. We hope that future developments will be effective in building upon existing foundations and that volunteers throughout Scotland will continue to help us provide high-quality information on Scotland's changing bird populations.

Acknowledgements

We would like to thank all the BBS Regional Organisers who work hard to get surveyors to often difficult places, and to the many hundreds of volunteers who have contributed to BBS in Scotland over the years. Particular thanks to those who have battled steep slopes and long walks through coniferous plantations to provide crucial data on bird populations in upland and remote areas. The BTO/JNCC/RSPB Breeding Bird Survey is a partnership jointly funded by the BTO, RSPB and JNCC with fieldwork conducted by volunteers.

References

Baker, D.J., Freeman, S.N., Grice, P.V. & Siriwardena, G.M. 2012. Landscape-scale responses of birds to agri-environment management: a test of the English Environmental Stewardship scheme. *Journal of Applied Ecology* 49: 871–882.

Balmer, D.E., Gillings, S., Caffrey, B.J, Swann, R.L., Downie, I.S. & Fuller, R.J. 2013. *Bird Atlas 2007–11: the breeding and wintering birds of Britain and Ireland*. BTO Books, Thetford.

Calladine, J., Critchley, C.N.R., Baker, D., Towers, J. & Thiel, A. 2014. Conservation management of moorland: a case study of the effectiveness of a combined suite of management prescriptions which aim to enhance breeding bird populations. *Bird Study* 61: 56–72.

Eglington, S.M., Davis, S.E., Joys, A.C., Chamberlain, D.E. & Noble, D.G. 2010. The effect of observer experience on English Breeding Bird Survey population trends. *Bird Study* 57: 129–141.

Franks, S.E., Douglas, D.J.T., Gillings, S. & Pearce-Higgins, J.W. 2017. Environmental correlates of breeding abundance and population change of Eurasian Curlew *Numenius arquata* in Britain. *Bird Study* 64(3): 393–409.

Fuller, R.M., Smith, G.M., Sanderson, J.M., Hill, R.A. & Thomson, A.G. 2002. The UK Land Cover Map 2000: construction of a parcel-based vector map from satellite images. *The Cartographic Journal* 39(1): 15–25.

Harris, S.J., Massimino, D., Eaton, M.A., Gillings, S., Noble, D.G., Balmer, D.E., Pearce Higgins, J.W. & Woodcock, P. 2019. *The Breeding Bird Survey 2018*. BTO Research Report 717. BTO, Thetford.

Massimino, D., Woodward, I.D., Hammond, M.J., Harris, S.J., Leech, D.I., Noble, D.G., Walker, R.H., Barimore, C., Dadam, D., Eglington, S.M., Marchant, J.H., Sullivan, M.J.P., Baillie, S.R. & Robinson, R.A. 2019. *BirdTrends 2019: trends in numbers, breeding success and survival for UK breeding birds*. Research Report 722. BTO, Thetford. www.bto.org/birdtrends.

Ben Darvill, Blaise Martay & Mark Wilson, BTO Scotland, Unit 15, Beta Centre, Innovation Park, University of Stirling FK9 4NF.
Email: ben.darvill@bto.org, blaise.martay@bto.org & mark.wilson@bto.org

Sarah Harris & Simon Gillings, BTO, The Nunnery, Thetford, Norfolk IP24 2PU.
Email: sarah.harris@bto.org & simon.gillings@bto.org

Revised ms accepted April 2020