Trends in breeding bird populations of the Peak District Moorlands from 1990 and 2004/5 to 2018

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1. Executive summary

- We report on changes in breeding bird populations in the Peak District Moors SPA based on three moorland breeding bird surveys (MBS) undertaken in 1990, 2004/5 (the 2004 survey was supplemented by additional surveys in 2005 to cover some gaps in the 2004 coverage) and 2018, whilst accounting for variation in survey effort and coverage.

- The Brown & Shepherd methodology adopted is a widely used general-purpose method for surveying large areas of extensive moorland. Developed for surveys of breeding waders, it is less suited for estimating the breeding abundance for some other species, such as raptors and many passerines. Reported changes in such species are best regarded as changes in the frequency of sightings rather than necessarily directly reflecting changes in breeding numbers.

- In 2018, Meadow Pipit and Red Grouse were estimated to be the most numerous bird species across the moors of the Peak District National Park, followed by Skylark, Curlew, Golden Plover and Wren. We discuss the uncertainties associated with these estimates and the challenges of estimating 'true' abundance from bird surveys.

- Of 29 species surveyed in both 1990 and 2018, 20 increased in number, of which fourteen species showed statistically significant increases (Canada Goose, Red Grouse, Buzzard, Peregrine, Kestrel, Lapwing, Golden Plover, Curlew, Snipe, Cuckoo, Short-eared Owl, Carrion Crow, Dipper and Grey Wagtail) and five increased from zero in 1990 (Mallard, Pheasant, Oystercatcher, Raven and Stonechat). Of the apparently declining species, trends in reported numbers of Skylark, Ring Ouzel, Wheatear, Meadow Pipit and Twite were statistically significant.

- A total of 37 species were surveyed in both 2004/5 and 2018, of which 25 species increased in number, and 19 significantly so. These were the Canada Goose, Mallard, Buzzard, Kestrel, Lapwing, Golden Plover, Curlew, Snipe, Short-eared Owl, Cuckoo, Carrion Crow, Raven, Willow Warbler, Grasshopper Warbler, Whitethroat, Ring Ouzel, Grey Wagtail and Linnet. Statistically significant declines over this period were apparent for five species: Red Grouse, Skylark, Wren, Whinchat and Tree Pipit.

- We used BTO/JNCC/RSPB Breeding Bird Survey (BBS) squares surveyed annually in the Peak District from 1994 to 2018 to produce separate annual estimates of population change. There were strong correlations between population changes estimated separately from both BBS and MBS data for both 1990 to 2018 and 2004/5 to 2018 and for many species a good concordance in the form of these trends. This provides independent support for the general trends reported by the MBS, although some of the changes derived from the MBS data appeared greater in magnitude than those estimated from the BBS.

- Positive population trajectories of breeding waders (Lapwing, Golden Plover, Curlew and Snipe) across the Peak District Moors SPA detected from the MBS contrast with national declines in wader populations. Given statistically significant positive trends from both MBS and BBS data sources, we can be reasonably confident that Curlew and Lapwing have increased in abundance since 2004/5, even though the precise magnitude of estimated increase differs between surveys. Limited BBS sample sizes reduce our ability to test for equivalent concordance in Snipe and Golden Plover trends.

- BBS trends for the Peak District correlate well with BBS trends for England for the same species. For 16 species the Peak District trends were more positive than the English trends, and significantly so for Buzzard, Cuckoo, Curlew, Lapwing, Pheasant, Snipe, Willow Warbler and Wren. For nine species, the reverse was true, with significantly more negative trends in the Peak District than nationally for England for Wheatear, Tree Pipit, Red Grouse, Pied Wagtail, Meadow Pipit and Linnet.

- This is an updated report following additional analysis undertaken in 2021 (see Section 3.1 and Waterman Infrastructure & Environment Limited 2021).

2. Introduction

The moors of the Peak District National Park support nationally and internationally important populations of a range of breeding waders and other moorland birds. The Peak District Moors are located within the South Pennines Moors Phase I SPA (also termed Peak District Moors SPA), designated for Merlin, Golden Plover and Short-eared Owl. The South Pennines Moors Phase II SPA is located immediately north of the Peak District National Park and designated for Merlin, Golden Plover and its breeding bird assemblage. The South Pennines Moors as a whole are also a SAC, and include five SSSIs, of which four are located within the Peak District (Dark Peak, Leek Moors, Goyt Valley and Eastern Peak District Moors).

Three moorland breeding bird surveys (MBS) of the Peak District Moors have been carried out over more than 500 km² contiguous area. The first was undertaken in 1990 (Stillman & Brown 1994), and underpinned the original designation. Analyses of these were used to assess the habitat associations of different moorland species. The second survey was undertaken in 2004, and documented declines in Dunlin, Twite and Wheatear populations, and increases in Curlew, Lapwing, Snipe and Whinchats (Carr & Middleton 2004). Due to limited coverage of some moorland areas as a result of access restrictions in 2004, supplementary data were collected from those areas in 2005. Changes observed from these surveys were largely supported by RSPB-led analyses of regional upland bird population trends from 1990 to 2002 (Sim *et al.* 2005), which suggested that the South Pennines as a whole had more favourable changes in the abundance of many species than other UK mainland regions, although still with significant declines in Dunlin, Meadow Pipit, Wheatear, Ring Ouzel and Twite populations. The third survey of the Peak District Moors took place in 2018 (Waterman Infrastructure & Environment Limited 2021), to support the condition assessment of the SSSI and SPA, to inform future conservation prioritisation in the area, and as a resource for assessing and documenting the impacts of a range of potential drivers upon the moorland bird populations.

In combination, these surveys provide not just a vital health-check of the status of breeding birds across the Peak District moorlands, but can also be used to help understand why changes are occurring and thus inform future policy and management changes. Although the same approach to surveying moorland breeding birds was adopted in each year (Brown & Shepherd 1993), given the different surveyors employed, the potential impact of visit timing upon the numbers of birds encountered, and the potential for variation to occur in how encounters are translated into estimates of breeding territories (e.g. Pearce-Higgins & Yalden 2005, Calladine et al. 2009), it is important to independently assess the robustness of these single-year surveys using independent data. To do so, we compared the changes described by the three moorland bird surveys against long-term trends produced independently by bespoke analyses of BTO/JNCC/RSPB Breeding Bird Surveys (BBS) for the Peak District study area and across the South Pennines as a whole, covering both SPAs (Phase I and II). Note that although we report on BTO/JNCC/RSPB Breeding Bird Surveys (BBS) from across both of the South Pennines Moors SPAs, we do not report on the results of the moorland breeding bird surveys of the South Pennines Moors Phase II SPA undertaken in 1990, 2005 and 2014. Finally, we identified other moorland bird survey data for the area that could also be used to provide further information about changes in specific areas and years.

In summary, the aim of this report is threefold:

1) To document moorland breeding bird population changes within the Peak District Moors study area using the Moorland Bird Survey (MBS) data from 1990, 2004/5 and 2018, whilst accounting for variation in survey effort and coverage.
2) To compare changes in moorland breeding bird populations from MBS with the annual trends estimated from BTO/JNCC/RSPB BBS data.
3) To scope other moorland breeding bird survey data from within the study area.

3. Methods

3.1. Moorland Breeding Bird Surveys (MBS)

The Brown & Shepherd (1993) methodology was originally designed to support the 1990 bird survey as a means for covering large areas rapidly, and was subsequently used in 2004/5 and 2018. In short, two visits are made to each 1-km square; the first between 1 April – mid-May, and the second from mid- May to the end of June. During each visit, all areas of moorland are approached to within a distance of approximately 125 m, and the locations of breeding birds and their behaviour mapped on 1:25,000 maps. In 1990 and 2018 this was achieved by dividing the survey area into 500m x 500m squares with observers aiming to spend a minimum of 20-25 minutes in each square (see Waterman Infrastructure & Environment Limited 2021). A more flexible approach without dividing each area into 500 m squares was adopted in 2004 to achieve the same coverage. Surveys were conducted between 08:30 – 18:00 during suitable weather conditions without obscured visibility, heavy precipitation or strong winds (above Beaufort Scale 4). Although a methodology primarily designed to survey breeding wader populations, sightings of most other bird species were recorded in the same way, although in 1990 a more restricted list of species was recorded. Red Grouse, Skylark and Meadow Pipit numbers were too frequent to map individual sightings. Instead abundances were tallied per 1-km square during the first visit only.

Individuals were regarded as breeding if: 1) they were observed displaying or singing; 2) nests, eggs or young were located; 3) adults repeatedly alarm called; 4) distraction displays were seen; or 5) territorial disputes were seen. Sightings of territorial birds were then interpreted using the following guidance taken directly from Brown & Shepherd (1993) in order to map and count the location of breeding territories.

> '*A single registration in which territorial behaviour was recorded (singing, displaying or alarming, or the finding of nests or dependent young) was assumed to identify an occupied territory or pair of breeding birds. Where it was possible, simultaneous registrations of birds were used to identify different territories. Where this was not possible, we assumed a separation distance between registrations of 500 m or more on the same survey visit and 1000 m or more on different survey visits to define birds as occupying different territories. For passerines, which generally have smaller breeding territories, we adopted a smaller*

separation and similarly arbitrary distances of 200 m on both the same and different survey visits to identify separate breeding territories.'

This method was developed for application to breeding waders, but also applies to waterfowl (e.g. Canada goose and Mallard) and moorland passerines (e.g. Wheatear, Stonechat and Whinchat). Individuals without breeding evidence were also recorded, and contributed to the population estimates of a subset of species, such as raptors and corvids. Due to uncertainties in the original interpretation of the 2004 surveys, the 2004 raw data were re-interpreted by Moors for the Future Partnership (MFFP) staff to ensure that individuals that did not exhibit evidence of breeding behaviour were not recorded as breeding, in line with 1990 and 2018 surveys.

After the publication of the 2018 survey report in November 2019, MFFP became aware that the data had not been processed in an identical way to the previous surveys of 1990 and 2004. Through a series of collaborative discussions with the consultants and partners, two areas which required attention were identified and updated. Firstly, the final stage of the application of distance thresholds using the Brown & Shepherd methodology was applied to the data, reducing potential double-counting of individuals when seen in similar areas on the two visits, and secondly, further explanation of this data processing between the field maps and digitised dataset was documented. More information can be found in Waterman Infrastructure & Environment Limited 2021.

Although designed for large-scale surveys of breeding waders, for at least some species, such as Golden Plover, this interpretation of breeding behaviour will probably result in an under-estimate of true breeding abundance (Pearce-Higgins & Yalden 2005). The Brown & Shepherd methodology is also not ideally suited for estimating the breeding abundance for some other species, such as raptors and many passerines; it is a widely used general-purpose bird survey method for large areas of extensive moorland. Estimates of breeding abundance will not properly account for imperfect occupancy (whether a breeding bird was present during the survey) or detectability (whether a breeding bird was present but not detected); issues which are particularly challenging for estimating the true abundance of species. However, as long as all surveys underestimate counts to approximately the same extent, this should not be a problem when considering trends. For consistency across the three surveys, we conducted our analysis based on the number of identified breeding territories in each 1-km square, as extracted from GIS layers for each survey period created by the surveyors or MFFP staff, using the criteria outlined above, accepting that 2/3rds of territorial pairs or fewer might be detected using this approach for some species. This was also the only resolution of data available for all three time-periods.

It should be noted that there were slight differences in survey coverage between the survey periods. In 1990, a wider area was surveyed than subsequently. In 2004, access to a large area of moors in the eastern areas of the Peak District, and some other estates, was not granted to the surveyors. These areas were surveyed in 2005 to fill that gap. In 2018, the survey area again differed slightly from the 2004 survey area: twenty eight survey squares to the north east of the Goyt Valley around Combs Moss were excluded as this area was not part of the Peak District Moors SPA. In addition, a late start due to adverse weather in 2018 meant that seventy nine, 1-km squares received only a late visit, and 19 squares were part-surveyed with incomplete coverage. Given this variable coverage, the total counts cannot be robustly used to infer population changes, which must be inferred analytically (see below).

3.2. Breeding Bird Surveys (BBS)

The BTO/JNCC/RSPB Breeding Bird Survey (BBS) is an extensive volunteer survey used to monitor breeding bird populations in the UK every year since 1994. The BBS is undertaken on a stratified random sample of 1-km squares, where squares are stratified regionally by human population density in order to make the most of volunteer resources (Newson et al. 2013). BBS surveyors make two early-morning visits to their square, the first between April and mid-May and the second between mid-May and the end of June. All birds are recorded while walking two 1 km transects across the square.

3.3. Species selection

Given the focus of these surveys is on moorland birds, we have selected the following species for this report. Firstly, we identify a number of upland species as defined by Pearce-Higgins et al. (2009) and for which uplands hold a substantial part of breeding population (Grant & Pearce-Higgins 2012), and for which the Moorland Bird Survey method provides a reliable approach for estimating breeding abundance (i.e. not raptors). These 'core' species include Red Grouse, Golden Plover, Dunlin, Snipe, Curlew, Skylark, Meadow Pipit, Whinchat, Stonechat, Wheatear, Ring Ouzel and Twite. We then have considered a wider range of additional species of interest for which moorlands are regarded as being of moderate or low importance (Grant & Pearce-Higgins 2012) but for which the moorland bird surveys produced sufficient data. These were Canada Goose, Mallard, Buzzard, Kestrel, Lapwing, Oystercatcher, Common Sandpiper, Cuckoo, Grey Wagtail, Linnet, Pheasant, Tree Pipit, Pied Wagtail, Willow Warbler, Whitethroat, Wren, Carrion Crow and Raven. Teal, Merlin, Peregrine, Redshank, Short-eared owl, Dipper and Grasshopper Warbler were also recorded by the moorland bird surveys and their abundance and trends were estimated accordingly, although they were not sufficiently covered by the BTO/JNCC/RSPB BBS for independent trends to be produced for the Peak District. Hen Harrier and Black Grouse were too rare to be recorded properly using either method, and gulls were not surveyed in 1990 or 2004/5. Species and their scientific names are listed in Appendix 1.

3.4. Data analysis

Population trends were modelled for the surveyed 1-km squares located within the Peak District Moors SPA (South Pennines Moors Phase I) (Figure 1). Trends were modelled separately for 37 species. For most, the bird surveys recorded the number of breeding pairs per 1-km square, although for raptors (Buzzard, Kestrel, Merlin, Peregrine, Short-eared Owl), Pheasant and a range of passerines (e.g. Cuckoo, Carrion Crow, Twite) for which breeding is difficult to confirm, individual sightings were recorded and used as a measure of abundance. For raptors in particular, it is important to note that our estimates of numbers of sightings do not relate to likely numbers of breeding pairs in the Peak District, which are better monitored by local study groups (South Peak Raptor Study Group & Peak District

Raptor Monitoring Group 2018, Bird of Prey Initiative 2018). To avoid the risk of under-estimating abundance from partially surveyed squares, we removed records from years where a 1-km square was not fully surveyed in that year. This removed 480 individual records across 16 square and year combinations.

Breeding bird abundances were modelled using a mixed model approach which is described in detail in Appendix 2. Total breeding bird abundances within the Peak District Moors SPA survey area for each year were produced by summing all square-level abundances using two different methods: method 1 consisted of using model-based estimates of abundance for all squares, whilst method 2 consisted of using the actual counts (detected abundances) where available, and model-based estimates only for squares that had not been surveyed in a given year. As a result, the predictions for method 1 are associated with greater uncertainty because they are based on predicted mean densities across the whole Peak District, and do not directly incorporate counts of the number of birds actually recorded in individual squares, which are used in method 2. Method 1 therefore better captures the uncertainty associated with the recorded counts but without more detailed modelling in relation to the environment, we are unable to distinguish between such variation due to habitat differences between squares, and variation due to the survey. The larger error margins associated with method 1 are therefore best regarded as indicating the potential range of estimates that could be achieved if the bird survey were independently repeated for that year, whereas in method 2, the observed counts are treated as 'true' and modelled counts are only applied to unsurveyed squares. The true error is probably somewhere between these two approaches.

Population trends from BTO/JNCC/RSPB BBS data are routinely calculated every year for the UK as a whole, for the four constituent countries, and for nine regions of England. The maximum count across the two visits over each BBS square is used. For the present work, we replicated this to produce bespoke BBS trends for the Peak District moorland area. Given the density of BBS squares across the study area, in order to produce robust trends, we produce two versions of the BBS trend. The first is for the Peak District Moors (South Pennines Moors Phase I) SPA and the second for both South Pennines Moors SPAs (Phases I and II combined), allowing a greater sample size. To increase statistical power, we also made use of BBS squares that are within a 3km buffer of the moorland edge. Although these are outside of the habitat surveyed by the MBS, for many species the individuals surveyed in these enclosed habitats will be part of the same meta-population as those breeding on moorland (Dallimer et al. 2010), or even the same individuals given that individuals of species such as Golden Plover, Snipe and Curlew breeding on moorland habitats also forage on neighbouring enclosed fields (Robson et al. 2002, Pearce-Higgins & Yalden 2003, Hoodless et al. 2007). A map showing all BBS squares used in this analysis is given in Figure 2. BBS population trends were calculated for each species that had been detected across an average of at least five squares per year – far below the usual threshold of 30 applied to such trends and therefore potentially associated with significant uncertainty, but enabling us to produce trends for a wide-range of species.

Given the uncertainties associated with estimating species' trends, we use the strength of the correlation between BBS and MBS trends at the species level to infer the confidence we have in the reporting of trends for the Peak District Moors. Full details of the analytical methods used for calculating BBS trends are given in Appendix 2.

3.5. Scoping of other moorland bird survey data

Correspondence with Natural England, Moors for the Future Partnership (MFFP), The National Trust and RSPB identified historical moorland bird surveys undertaken across the Peak District Moors. These are summarised and mapped, along with summary meta-data of the surveys undertaken, and the location and ownership of data, in Appendix 3.

4. Results

4.1. Estimated moorland bird abundances in 1990, 2004/5 and 2018

Estimated abundances for all species are displayed in Table 1. Although the estimates are likely to have a variable relationship between true abundance due to species-specific variation in detectability (e.g. Buchanan et al. 2006, Johnston et al. 2014) and variation in the suitability of the MBS survey to assessing the abundance of each species, they do indicate that in 2018, Meadow Pipit and Red Grouse were the two most abundance bird species across the moors of the Peak District National Park, followed by Skylark, Curlew, Golden Plover and Wren, although in 2004/5 Wrens were more common than either Curlew or Golden Plover. It is noteworthy that our estimates of abundance are generally inflated compared to the raw numbers counted. This is a result of the modelling approach used which averages counts across squares and accounts for incomplete surveys or squares which were not surveyed in that year. Note that the confidence intervals for Ring Ouzel could not be robustly calculated as the Generalised Linear Mixed Model (GLMM) for this species failed to converge.

4.2. Changes in moorland breeding birds from 1990 to 2018

Of the 29 species surveyed in both the 1990 and 2018 MBS, 20 have increased in abundance, of which fourteen were statistically significant increases with 95% confidence intervals that were non-overlapping with zero (Canada Goose, Red Grouse, Buzzard, Peregrine, Kestrel, Lapwing, Golden Plover, Curlew, Snipe, Cuckoo, Short-eared Owl, Carrion Crow, Dipper and Grey Wagtail). Of the 20 increasing species, five (Mallard, Pheasant, Oystercatcher, Raven and Stonechat) increased from zero in 1990. Of the declining species, losses of Skylark, Ring Ouzel, Wheatear, Meadow Pipit and Twite were statistically significant. Additionally, Black Grouse became extinct as a breeding species after 1990 (Table 2, 4).

4.3. Changes in moorland breeding birds from 2004/5 to 2018

A total of 37 species were surveyed in both 2004/5 and 2018 (Table 3, 4). Of these, 25 species increased in abundance, nineteen significantly (Canada Goose, Mallard, Teal, Buzzard, Kestrel, Lapwing, Golden Plover, Curlew, Snipe, Short-eared Owl, Cuckoo, Carrion Crow, Raven, Willow Warbler, Grasshopper Warbler, Whitethroat, Ring Ouzel, Grey Wagtail and Linnet). Statistically significant declines were apparent for five species: Red Grouse, Skylark, Wren, Whinchat and Tree Pipit.

4.4. Comparison of population changes derived from MBS and BBS

By way of comparison, BBS trends could be produced for many of the species covered by the MBS. There was a statistically highly significant positive correlation between both sets of long-term trends, irrespective of whether assessed using the Peak District BBS squares only (1990 to 2018 $r = 0.83$, $P < 0.001$, $y = 1.42x + 0.45$), or BBS squares from across both South Pennines Moors SPAs (Phases I and II) (1990 to 2018 $r = 0.88$, $P < 0.001$, $y = 1.59x + 0.50$); the correlation was weaker if considering 2004/5 to 2018 trends, but still highly significant for the wider area, or marginally significant using the Peak District BBS squares only ($r = 0.38$, $P = 0.08$, $y = 0.57x + 0.52$, and $r = 0.63$, $P = 0.001$, $y = 0.82x + 0.52$, respectively). Buzzard was excluded from these comparisons because its large increase recorded by both surveys disproportionally influenced the regression slope. Scatter plots of the MBS and Peak District BTO/JNCC/RSPB BBS trends (Figure 3) show the strong correlation between MBS trends from 1990 to 2018 and BBS trends from 1994 to 2018, accounting for almost 70% of the variation between species, and a weaker correlation from 2004/5 to 2018. The MBS indicated notably greater population increases than the BBS survey for some species.

The individual trends for the Peak District are shown species-by-species in Figure 4. For most species, the direction of change between the BBS trend and the MBS trends was similar. Although the temporal changes are similar with overlapping confidence intervals across the time-series for some species (e.g. Lapwing, Pheasant, Snipe), for thirteen of twenty-three species the estimated changes from one method are outside the confidence intervals predicted by the second method. More extreme increases were apparently detected in the MBS for a number of species (e.g. Buzzard, Curlew, , Golden Plover), whilst for a small number of species, the trends differed between the two method (e.g. Cuckoo, Kestrel, Wren). Over the period from 1994 to 2018, four species showed significant increases across the Peak District BTO/JNCC/RSPB BBS squares (Canada Goose, Pheasant, Buzzard, Carrion Crow), and two declined (Meadow Pipit and Tree Pipit; Table 2). Over the shorter time-frame from 2004, Buzzard and Curlew also showed significant population increases in the Peak District, and Willow Warbler, Meadow Pipit and Tree Pipit significant declines (Table 3). Across both South Pennines SPAs (Phase I and Phase II combined), four species showed statistically significant increases from 1994 to 2018 and six from 2004 to 2018, compared to one and two declining species respectively (Tables 2 and 3).

4.5. Comparison of Peak District moorland and English trends

There was a good correlation between Peak District and English trends for the BTO/JNCC/RSPB BBS from 1994 to 2018 ($r = 0.63$, $P = 0.002$, $y = 0.40x - 0.11$), and a weaker correlation for the period of 2004 to 2018 ($r = 0.41$, $P = 0.06$, $y = 0.18x – 0.17$; Figure 5), again excluding Buzzard from the statistics as above due to the disproportionally large population increases observed relative to the other species. The individual trends are shown for each species (Figure 6) and indicate that for 16 species, the trends were more positive in the Peak District than nationally and, based on confidence intervals non-overlapping the mean values, probably significantly so for Buzzard, Cuckoo, Curlew, Lapwing, Pheasant, Snipe, Willow Warbler and Wren. Conversely, for nine species, the trends were more negative in the Peak District than across England, and apparently significantly so for Wheatear, Tree Pipit, Red Grouse, Pied Wagtail, Meadow Pipit and Linnet.

5. Discussion

In this report we have estimated changes in moorland breeding bird populations across the Peak District Moors, and compared those to independent estimates derived from the BTO/JNCC/RSPB BBS surveys of the Peak District Moors, and across both of the South Pennines Moors SPAs. Given variation in surveyed effort and coverage across surveys, we have used two different modelling approaches to predict abundances across partially surveyed or un-surveyed squares in any particular year, which are associated with different assumptions and can be compared against previous assessments of abundance based purely on total count (e.g. Stillman & Brown 1994). For example, Brown (1993) estimated a population of 456 pairs of Golden Plovers in the Peak District in 1990, very similar to our method 2 estimate. However, our modelled estimate using method 1 suggests there were 406 breeding pairs, with a 95% probability that this was between 350 to 472 pairs, a much greater range of uncertainty. Given the potential for the Brown and Shepherd two-visit survey to significantly under-estimate the abundance of species such as Golden Plover (Pearce-Higgins & Yalden 2005), it is worth noting though, that each of these probably under-estimates the true figure. It is also worth noting that for species with an over-dispersed distribution (i.e. lots of zeros and a few high counts), the method 1 modelled estimates are likely to be associated with additional bias due to violated assumptions around the Poisson model, and the fact they are based upon averages across logged values.

As noted earlier, these estimates are based on statistical extrapolation across all squares for each year as a function of survey effort only. They do not consider any impact of habitat, topography or other environmental covariates that would account for variation in the likelihood of squares supporting particular species. If the partially surveyed or un-surveyed squares from a particular year are a non-random subset of all squares, which is likely to be the case in some instances due, for example, to a greater tendency for some landowners to refuse access in 2004 than others, then this will result in biased estimates. Further modelling as a function of additional environmental covariates may produce more robust estimates in such circumstances. All of this highlights the challenges of estimating true abundance from bird surveys that do not account for detectability. For the purpose of this report, the method 2 estimate will be closest to what would be estimated from a full survey, but under-estimates the uncertainty associated with the bird survey methods treating each count as 'true', whilst method 1 probably over-estimates the survey uncertainty which cannot be separated from the effects of variation in habitat that are not being formally accounted for and may also be biased downwards for some species with highly over-dispersed distributions.

Despite these caveats associated with estimating abundance, our analysis has identified two key messages, particularly associated with estimates of population trend. Firstly, that most of the moorland bird population trends derived from the moorland breeding bird surveys across the Peak District Moors were positive. Twenty of 29 species showed positive increases from 1990, and 25 of 37 from 2004/5. Given the general pattern of decline in upland species that has been a characteristic of the UK avifauna over recent decades (e.g. Sim et al. 2005, Balmer et al. 2013), this positive assessment is noteworthy. Most obviously, increases in breeding waders over this time period (Lapwing, Golden Plover, Curlew, Snipe and Dunlin), generally buck the national trend, as do increases in Cuckoo, Kestrel, Linnet and Willow Warbler, although more positive trends in both Cuckoo and Willow Warbler in northern and upland habitats have previously been documented (Morrison et al. 2010, Hewson et al. 2016), and form part of a general pattern of more positive trends for many previously widespread species in such areas (Massimino et al. 2015).

Secondly, the trends produced from the moorland bird surveys correlate significantly with the independently collected annual BTO/JNCC/RSPB BBS data. These correlations were strongest over the longer 28 year period. This may suggest that the 2004/5 data, where there were more difficulties with access, and some reinterpretation of the raw data by MFFP staff for the purposes of this analysis, may be slightly less reliable than data from the other two years. Whether this was due to the survey difficulties or *post-hoc* interpretation, or both, is difficult to assess, but indicates the value of being able to validate the more comprehensive but periodic MBS snapshots, with the annual BBS survey, despite the latter suffering from lower coverage. These correlations are particularly noteworthy because they are based upon a relatively small sample of BBS squares that would not normally be used to estimate region-specific trends, where an arbitrary threshold of 30 squares is normally used for trend estimation (Harris et al. 2019). This small sample for many moorland species accounts for the relatively small number of the species trends produced by BBS that were regarded as statistically significant.

Although there were significant correlations in trend between both surveys, it is worth noting that the precise magnitude of the observed trend differed for many species. Accurately estimating species' trends is a difficult task. There could be legitimate differences in population trends between the MBS and BBS surveys, particularly due to variation in trend between habitat (Sullivan et al. 2015a). Trends of non-moorland specialists, such as Mallard and Canada Goose were much greater in the MBS data, potentially because such population increases have particularly favoured the expansion of populations into less suitable moorland habitats (Sullivan et al. 2015b). The BBS trends included data from adjacent non-moorland habitats to boost sample size which may have contributed to this difference, whilst any potential variation in habitat coverage between the MBS and BBS surveys, for example due to the specific locations of transects and survey routes across the landscape being more- or less-likely to traverse particular moorland habitats, or due to variable access or uptake in squares in different habitats relative to those available, could also result in variations in trends due to habitat differentially affecting the trends across the two surveys.

There will be particular interest in the positive population trajectories of breeding waders (Lapwing, Golden Plover, Curlew and Snipe) detected from the MBS from both 1990 and 2004/5 to 2018. Although the BBS surveys did not detect significant increases for these species from 1994, there is evidence for a significant population increase in Curlew from 2004 in the Peak District Moors (South Pennine Moors Phase I SPA) when sample sizes for the other three species were less than 30, and a significant increase for both Lapwing and Golden Plover across both South Pennines Moors SPAs (Phases I and II). However, variation in the magnitude of some of the differences, such as the apparent more than doubling of Curlew populations on moorland compared to a more gradual increase across the BBS data highlights uncertainty over the magnitude of increase. Given the statistically significant trends for both MBS and BBS data sources, we can be reasonably confident that Curlew and Lapwing have increased in abundance since 2004/5. Given the limited BBS sample size for both Snipe and Golden Plover, we have less power to test for similar concordance in the significance of their population increases between surveys, and more generally, the lower coverage of the BBS compared to the relatively comprehensive MBS may at least partially explain the differences in results between the two surveys. Working to increase annual BBS coverage across the Peak District Moors through time, so that as many species of interest are recorded in an average of at least 30 squares per annum, would help address this and provide more confidence in the long-term trends across species.

In addition to this comparison of trends, our analyses of the MBS data has provided updated population estimates for a range of species, which can be compared with UK-wide population estimates (Woodward et al. 2020). Of the grouse, waders and passerines covered, for which the MBS is best-suited, these figures suggest that the Peak District Moors SPA hold in excess of 1% of the UK population of Red Grouse, Golden Plover, Curlew and Ring Ouzel, although as noted earlier, estimating true population size is challenging and the MBS is associated with variable detection of these species groups. It is therefore likely that numbers of Red Grouse, Golden Plover and Ring Ouzel in particular are likely to be under-estimates, relative to true abundance.

To conclude, combined analyses of the Peak District Moors SPA moorland breeding bird survey, and annually surveyed BTO/JNCC/RSPB BBS squares, provide a robust assessment of changes in a suite of moorland breeding birds across the Peak District Moors, and put those changes in a wider context. Bird population trends in the Peak District Moors are generally positive. For breeding waders, this is in contrast to wide declines elsewhere (Balmer et al. 2013, Harris et al. 2019). Populations of nationally declining migrants such as Cuckoos and Willow Warblers are also more positive than the English average, although some other passerines, such as Meadow Pipits and Wheatears appear to have declined, and by more than apparent across England. Most raptors, such as Buzzards, and corvids, such as Carrion Crows and Ravens, also have generally positive population trajectories in the Peak District, with populations that are recovering nationally from historical persecution and poisoning, with the possible exception of Merlin. Trends in raptor abundance are better captured by the annual monitoring undertaken by local raptor study groups whose results broadly match the trends in sightings reported here (South Peak Raptor Study Group & Peak District Raptor Monitoring Group 2018, Bird of Prey Initiative 2018), noting that for long-lived species like raptors, trends in productivity can be as or more important indicators of environmental quality than trends in breeding populations. Finally, a number of other species expanding into upland areas such as Mallard, Canada Goose and Pheasant are also increasing rapidly, the latter of which is probably assisted by release on shooting estates (Pringle et al. 2019). Given the multiple uses that the Peak District National Park is put to, whether for farming, game management, recreation or water supply, and the long history of multiple environmental challenges such as high levels of grazing intensity (Anderson & Yalden 1981), visitor disturbance (Pearce-Higgins & Yalden 1997 Finney et al. 2005) and climate change (Pearce-Higgins et al. 2010), these generally positive trends in many bird populations are particularly noteworthy. Whether they reflect the outcome of the extensive conservation effort to restore degraded moorland and blanket bog across the moors of the Peak District undertaken by MFFP, partners and a range of other landowners, or are a consequence of other processes, are the subject of further analyses. This provides a valuable opportunity to assess the impact of peatland restoration programmes alongside associations with other land-uses.

6. Acknowledgements

This analysis was of data from bird surveys undertaken in 2018 by Waterman Infrastructure & Environment Limited, and included comparing these data with those of previous surveys. The 2018 surveys and this analysis was funded by Natural England, Moorland Association, National Trust, RSPB, Severn Trent Water, Yorkshire Water and United Utilities. The British Trust for Ornithology also supported this analysis. We are grateful to Mollie Hunt from the Moors for the Future Partnership who managed this project for her support and advice throughout, and to Mollie, David Chandler, Amanda Anderson, Allan Drewitt, Richard Pollitt, Dan Richmond-Watson, Jon Stewart and Geoff Williams for comments on this report. Allan Drewitt and Richard Pollitt (Natural England) also provided advice in relation to previous moorland bird surveys. Tessa Coldale (RSPB) provided access to RSPB survey meta-data from the Peak District and South Pennines. And Steve Davies (Peak District Raptor Monitoring Group) provided access to recent raptor monitoring reports. The Breeding Bird Survey is a partnership jointly funded by the BTO, RSPB and JNCC, with fieldwork conducted by volunteers.

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8. Figures and tables

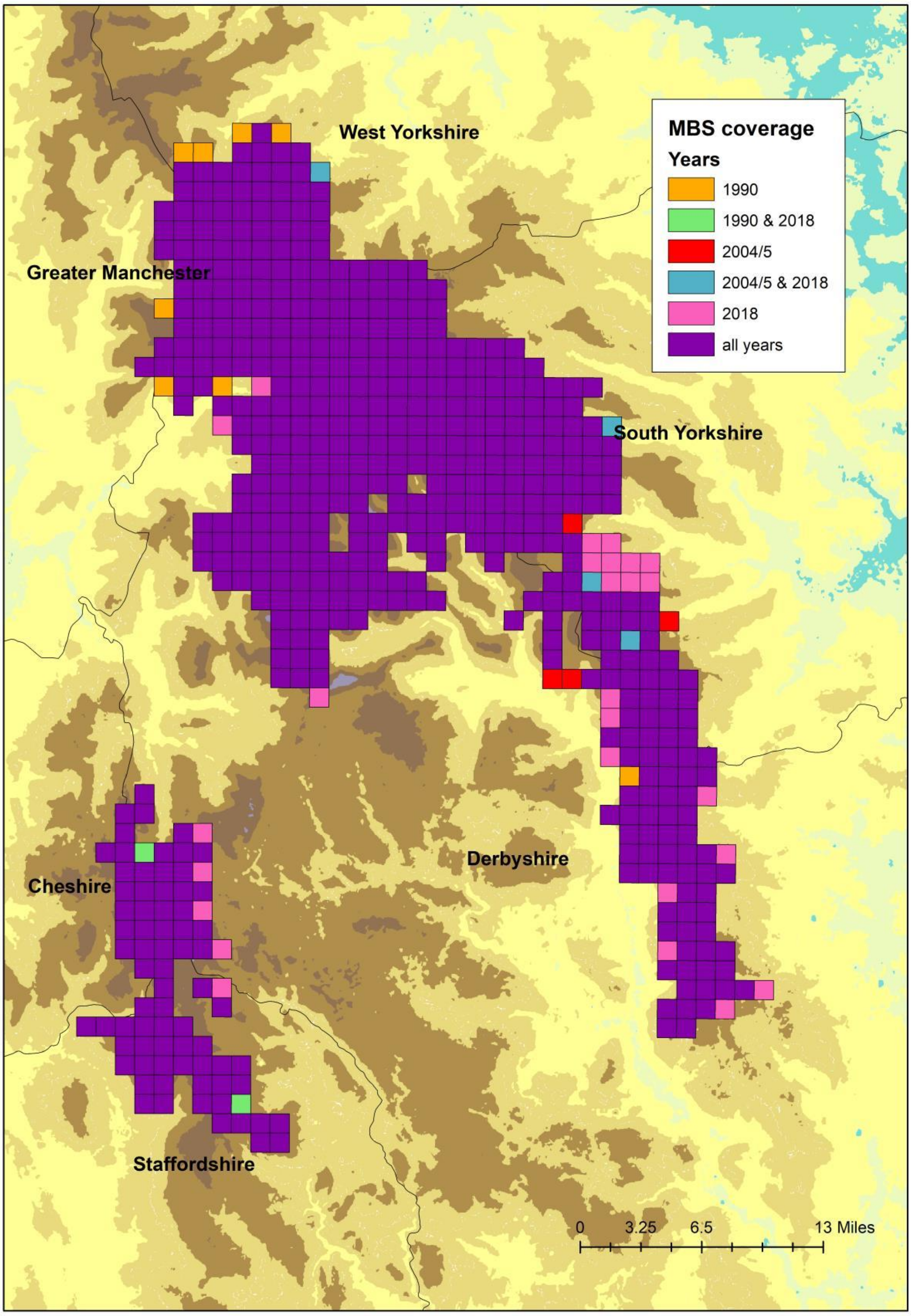


Figure 1. Variation in coverage across the three moorland bird surveys of the Peak District Moors, identifying for each 1km square which combination of years it was surveyed in.

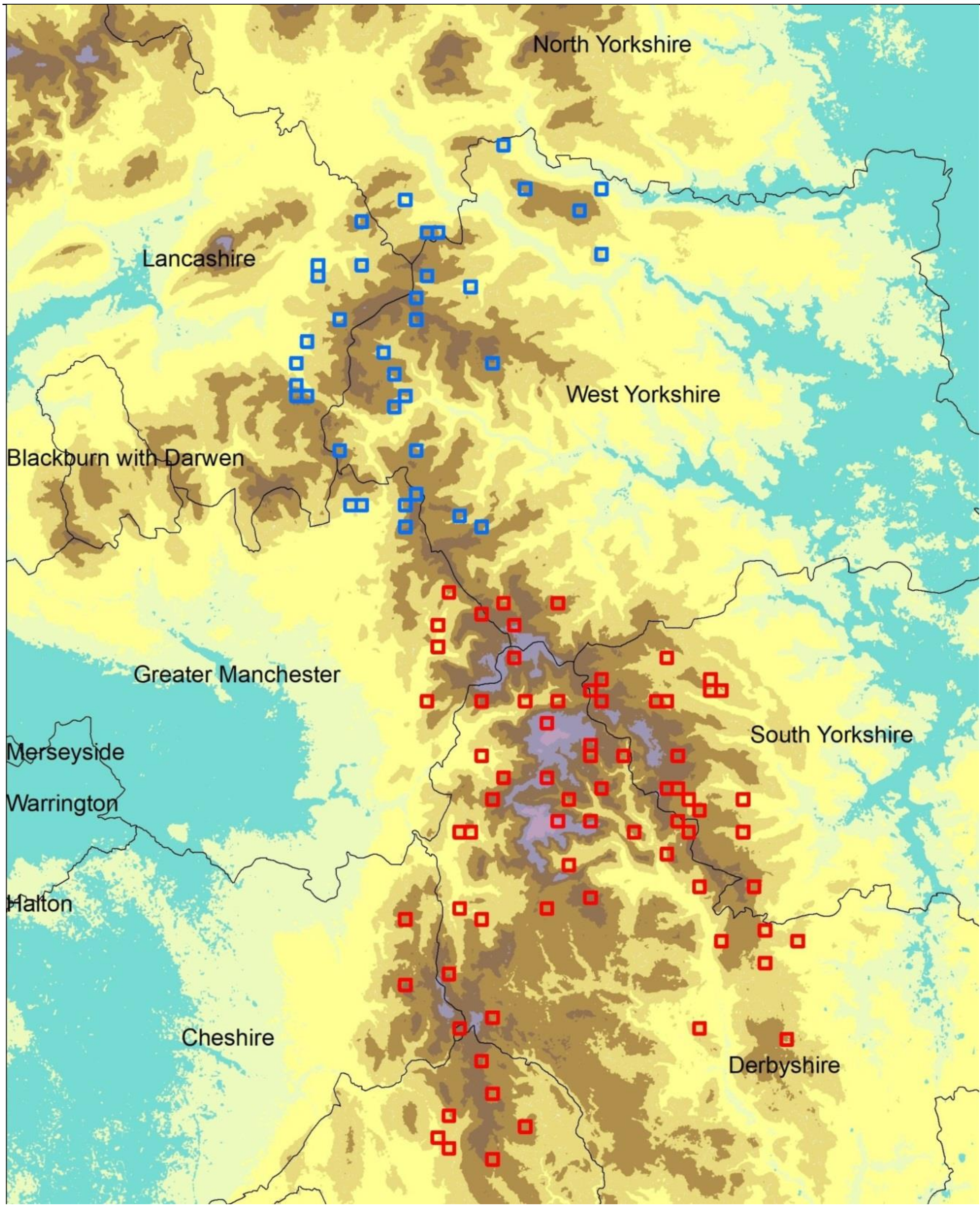


Figure 2. Map of the BBS squares that were used to estimate population trends from BTO/JNCC/RSPB BBS data. The red squares belong to the Peak District area (Phase I) and its 3km buffer, and were used to calculate the first version of the BBS trends for the Peak District Moors only (South Pennine Moors Phase I). Both red and blue squares belong to the entire SPA (Phase I and II) and its 3km buffer and were used to calculate the second version of the BBS trends for the entire South Pennine Moors SPA (Phases I and II combined).

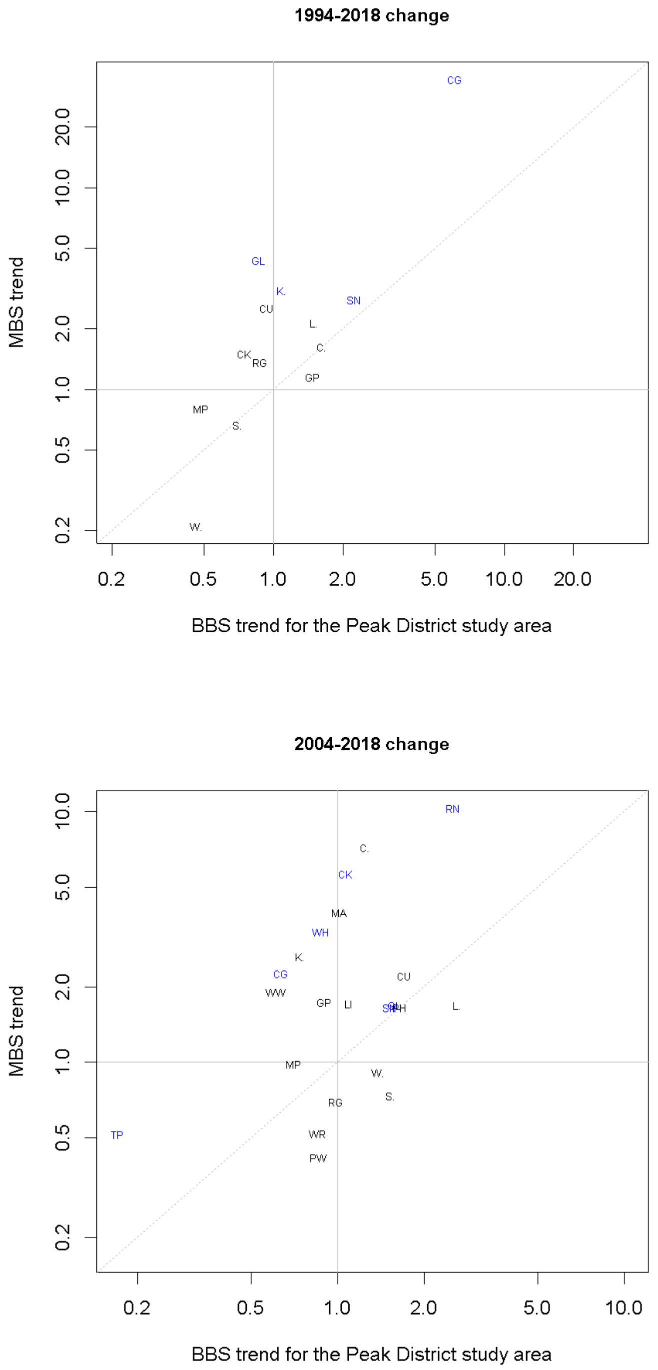
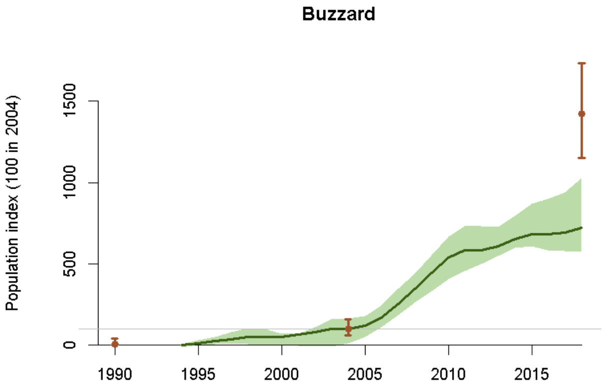


Figure 3. Scatterplot of BTO/JNCC/RSPB BBS trends compared to MBS trends for 1994 to 2018 (top; r = 0.83) and 2004/5 to 2018 (bottom; r = 0.38) for the Peak District Moors SPA. Species 2-letter codes are reported in Appendix 1. Colours denote whether confidence intervals around the estimates were narrow (confidence interval narrower than 4 times point estimate) or large (confidence interval wider than 4 times point estimate), as follows. Black: narrow confidence intervals along both axes. Blue: narrow confidence interval around the MBS trend but large confidence interval around the BBS trend. No MBS trend had large confidence interval as defined above.


Buzzard
Population index (100 in 2004)
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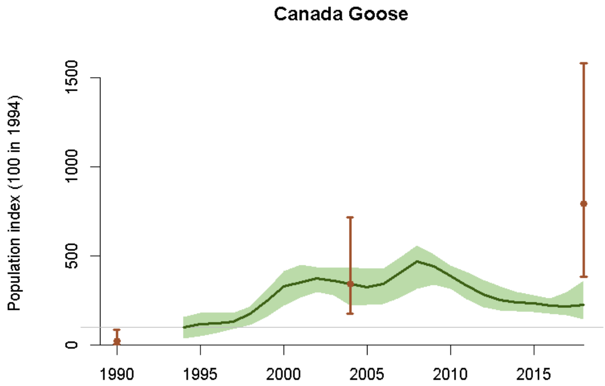
Canada Goose
Population index (100 in 1994)
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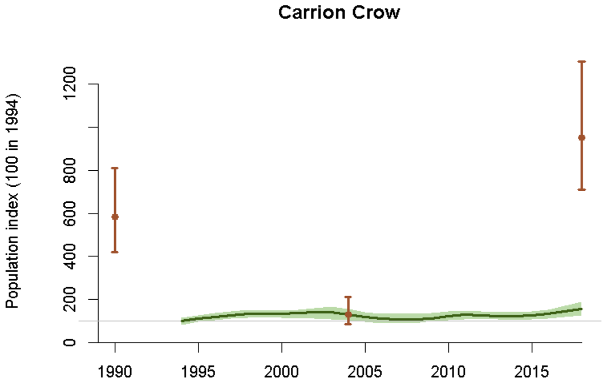
Carrion Crow
Population index (100 in 1994)
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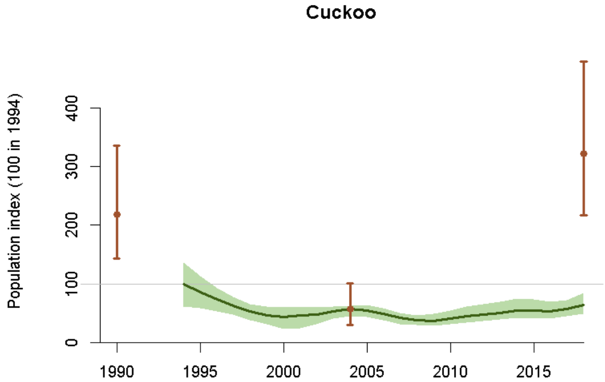
Cuckoo
Population index (100 in 1994)
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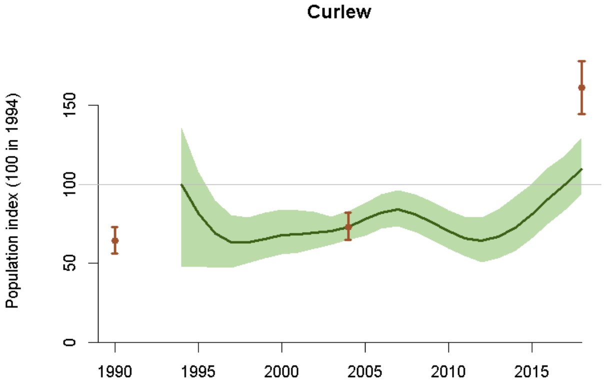
Curlew
Population index (100 in 1994)
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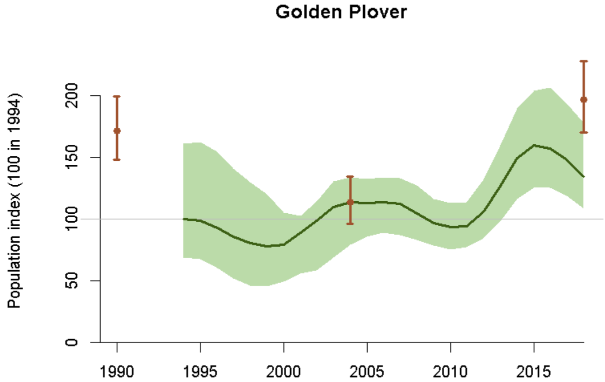
Golden Plover
Population index (100 in 1994)
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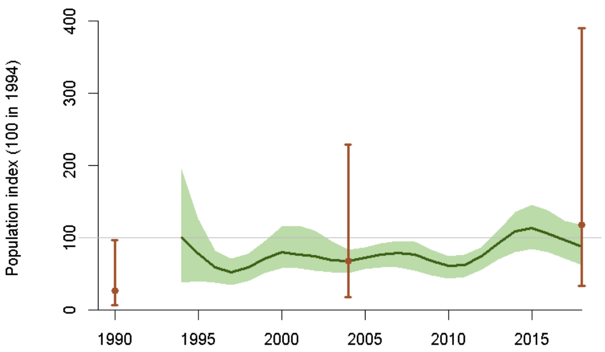
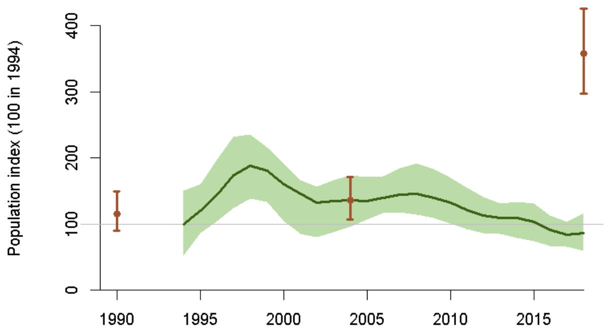
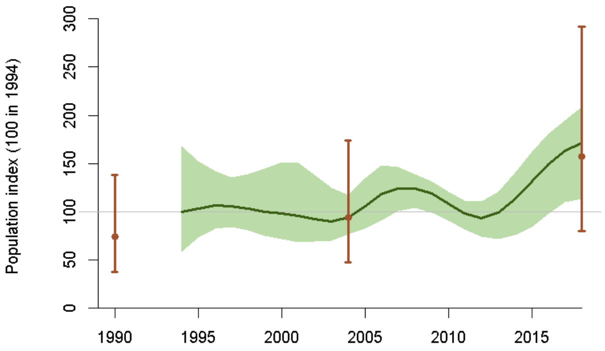
Grey Wagtail



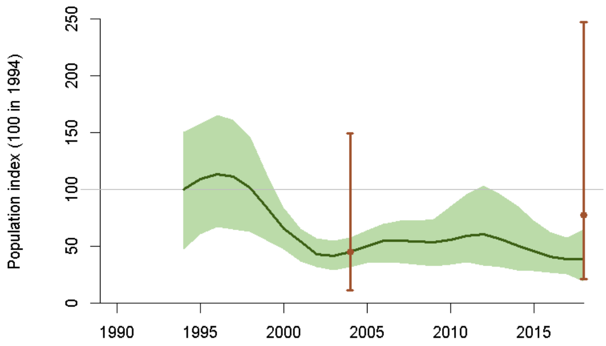
Kestrel



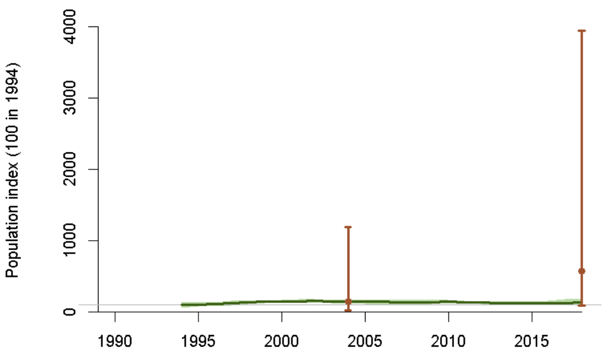
Lapwing



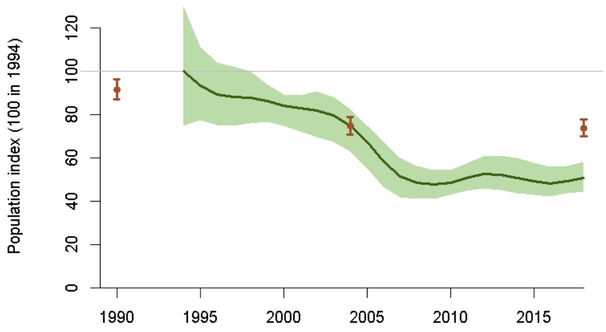
Linnet

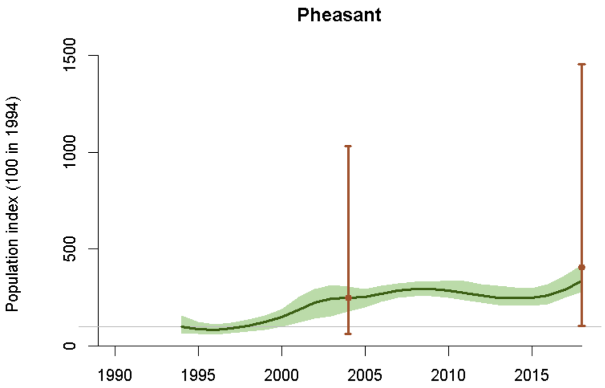


Mallard



Meadow Pipit




Pheasant
Population index (100 in 1994)
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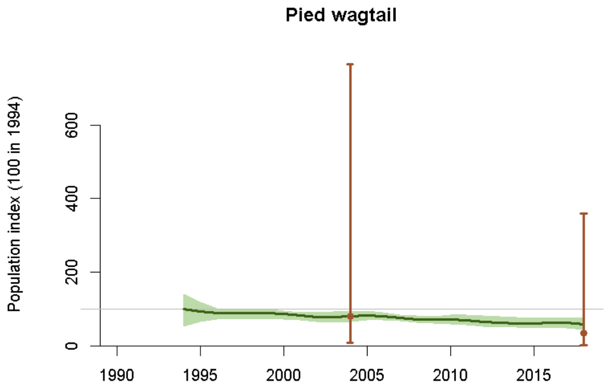
Pied wagtail
Population index (100 in 1994)
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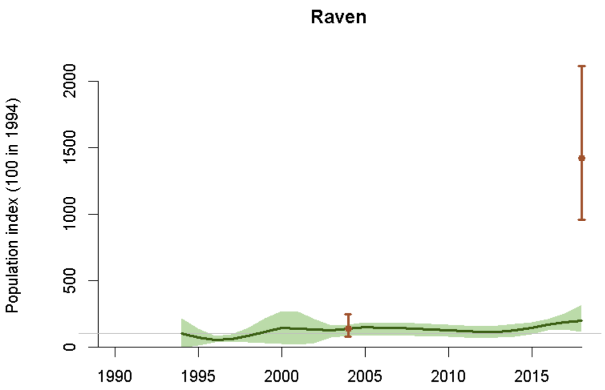
Raven
Population index (100 in 1994)
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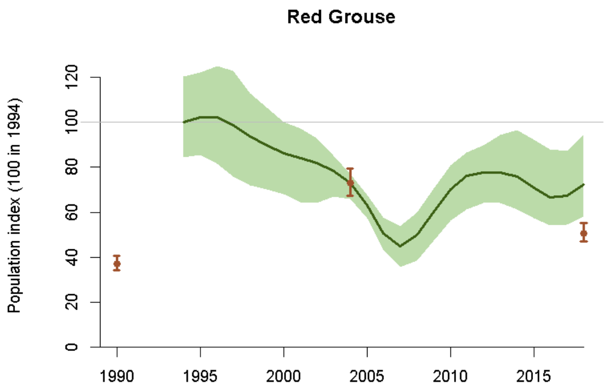
Red Grouse
Population index (100 in 1994)
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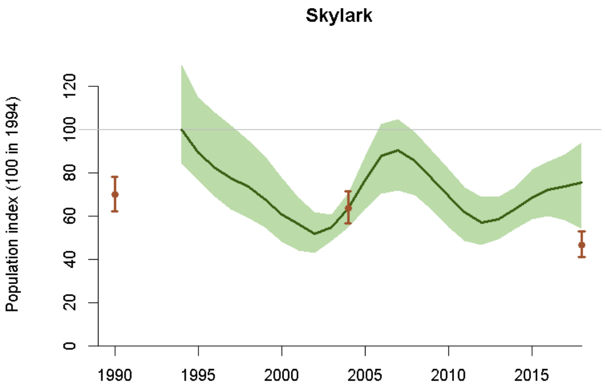
Skylark
Population index (100 in 1994)
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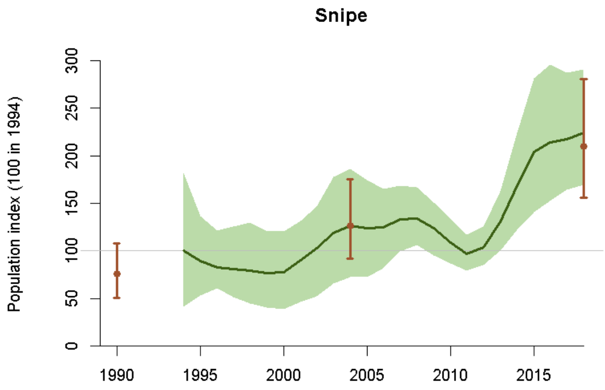
Snipe
Population index (100 in 1994)
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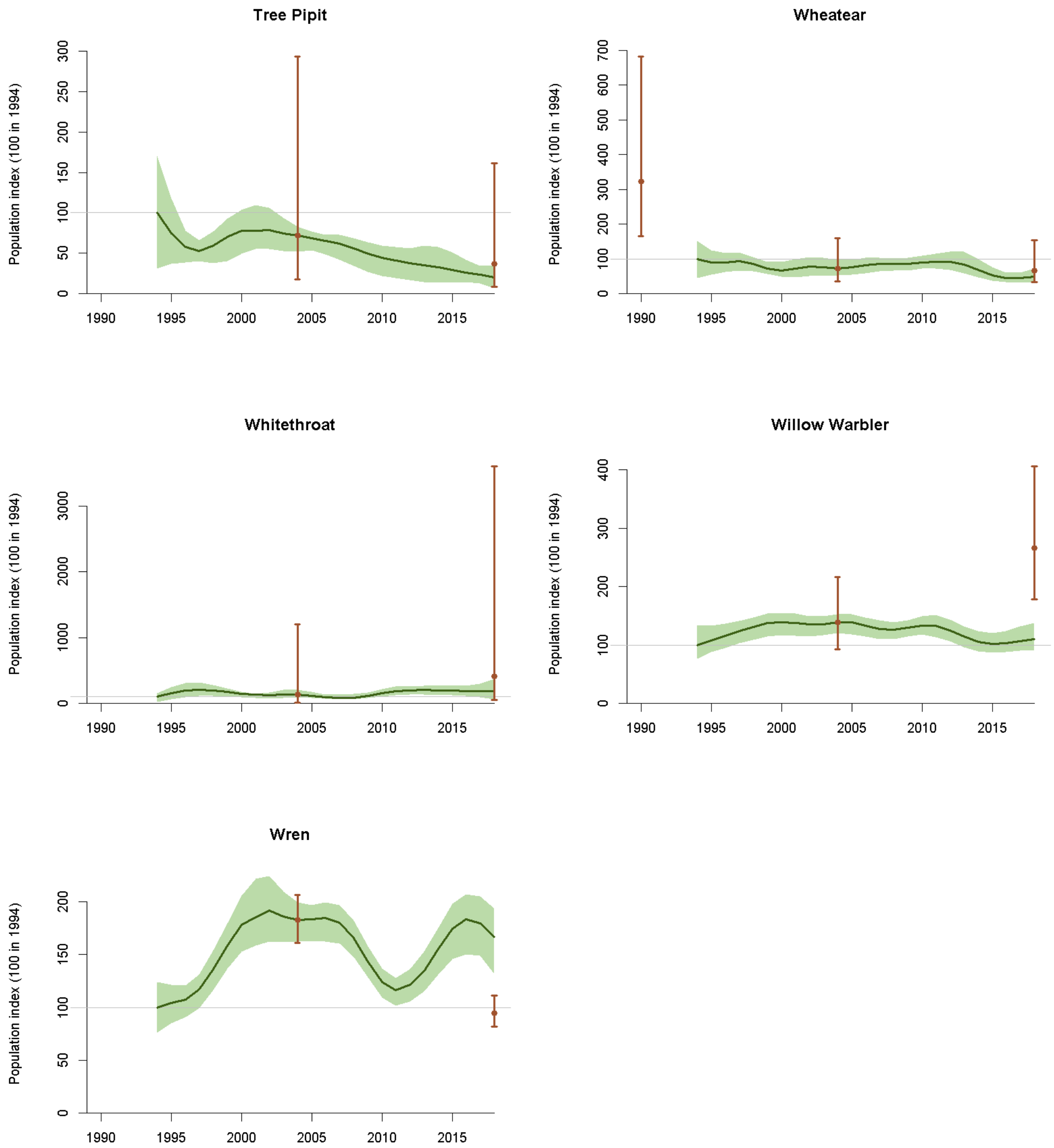
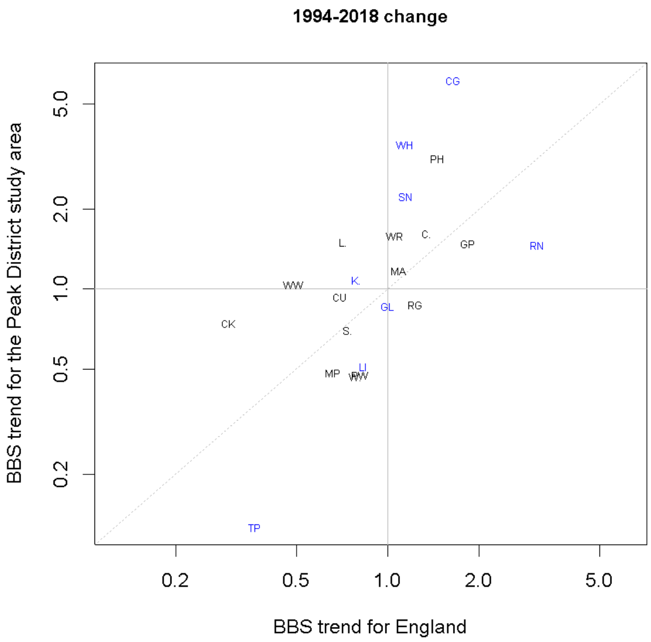


Figure 4. Annual population trends estimated from the BTO/JNCC/RSPB Breeding Bird Survey (BBS) for the Peak District Moors SPA compared against the point survey estimates for 1990, 2004/5 and 2018 derived from the Moorland Breeding Bird Survey (MBS). The dark green line shows the smoothed population index estimated using BBS data for the Peak District study area and the shaded green area shows the 95% confidence band around the index. The brown dots with 95% confidence intervals show the population indices estimated using MBS data. All indices show relative abundance and are set to 100 in 1994, with the exception of Buzzard whose index is set to 100 in 2004 as no Buzzards were detected during the 1994 BBS.



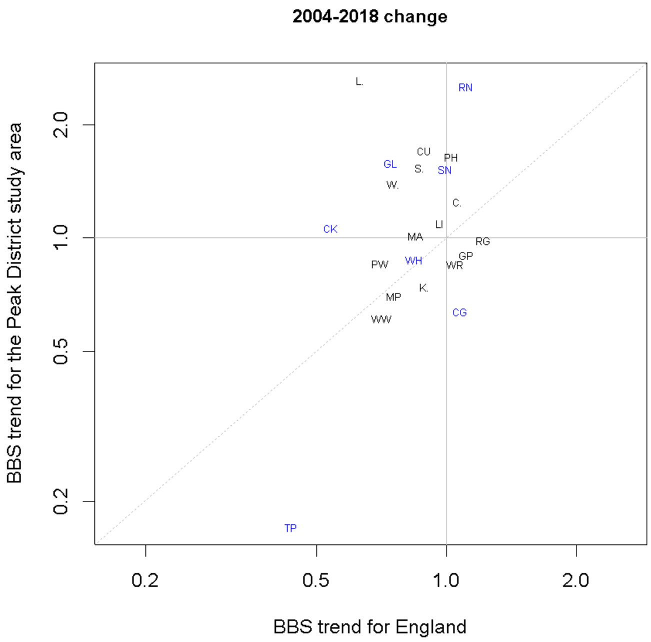
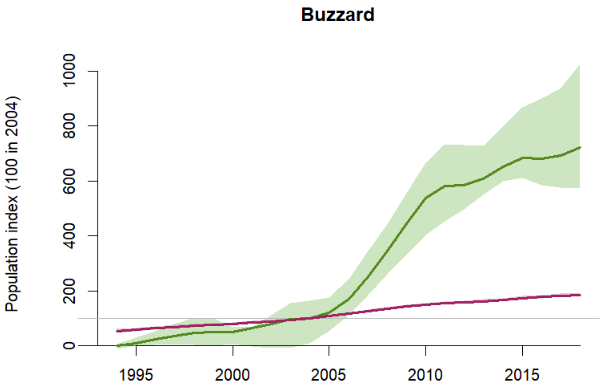


Figure 5. Scatterplot of population changes derived for the whole of England for BBS (x axis) against population changes estimated for the Peak District Moors SPA from BBS data for the same period (y axis) for the period 1994 to 2018 (top; r = 0.63) and 2004 to 2018 (bottom; r = 0.41). Changes are expressed as ratio of population index for year 2018 to population year for year 1994. Species 2-letter codes are reported in Appendix 1. Colours denote whether confidence intervals around the estimates are narrow (confidence interval narrower than 4 times the point estimate) or large (confidence interval larger than 4 times point estimate), as follows. Black: narrow confidence intervals along both axes. Blue: narrow confidence interval around the England trend but large confidence interval around the Peak District trend.


Buzzard
Population index (100 in 2004)
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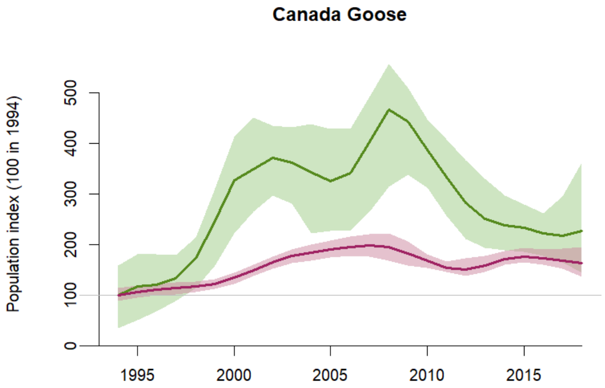
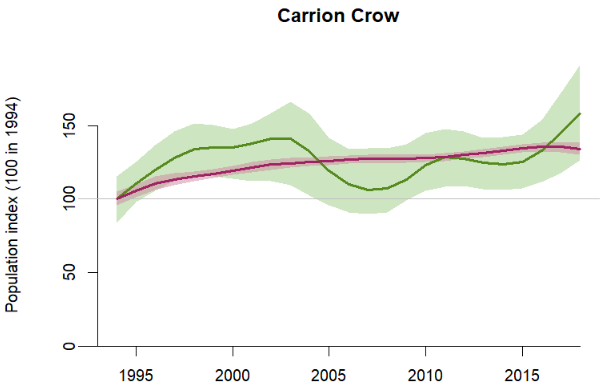
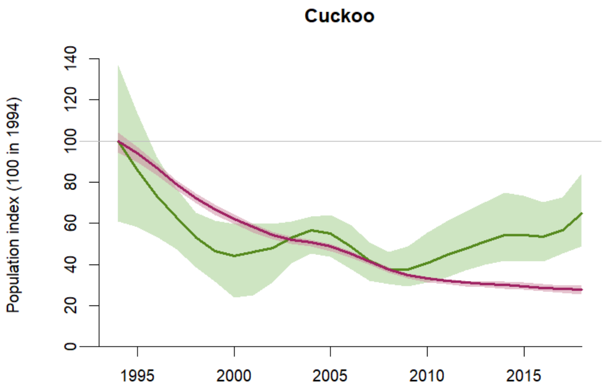
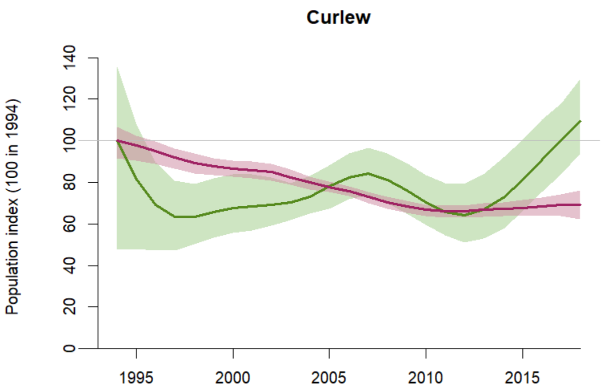
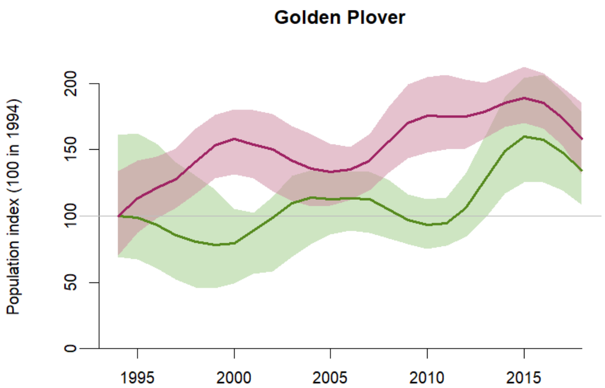
2010
2015

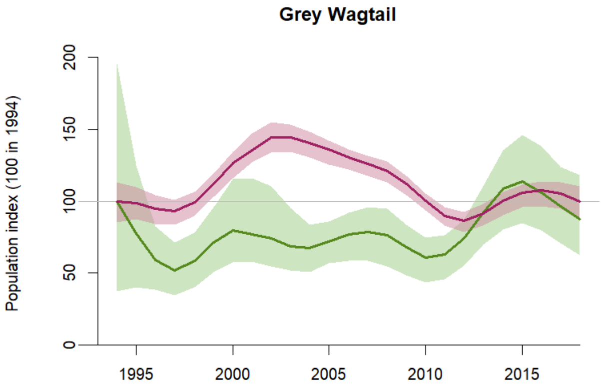

Canada Goose
Population index (100 in 1994)
0
100
200
300
400
500
1995
2000
2005
2010
2015

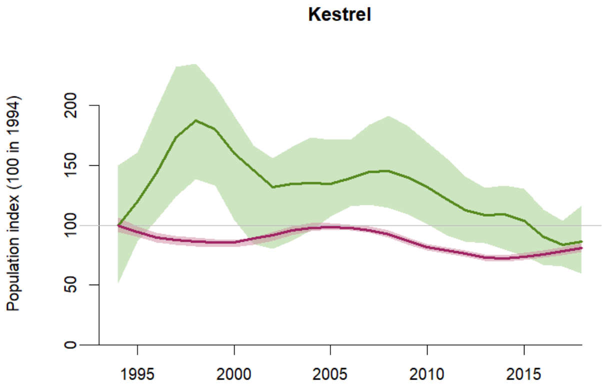

Carrion Crow
Population index (100 in 1994)
0
50
100
150
1995
2000
2005
2010
2015

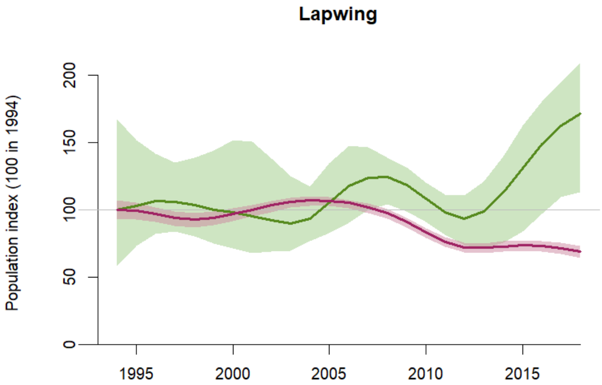

Cuckoo
Population index (100 in 1994)
0
20
40
60
80
100
120
140
1995
2000
2005
2010
2015

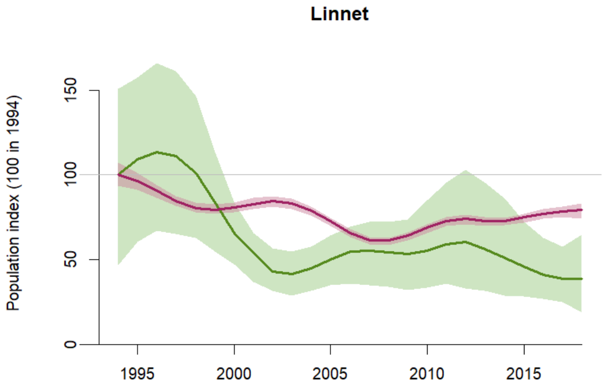

Curlew
Population index (100 in 1994)
0
20
40
60
80
100
120
140
1995
2000
2005
2010
2015

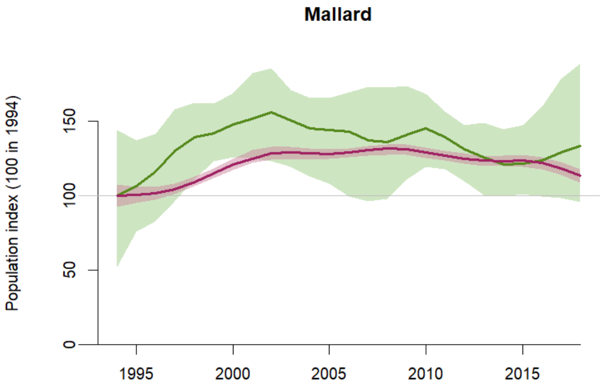

Golden Plover
Population index (100 in 1994)
0
50
100
150
200
1995
2000
2005
2010
2015

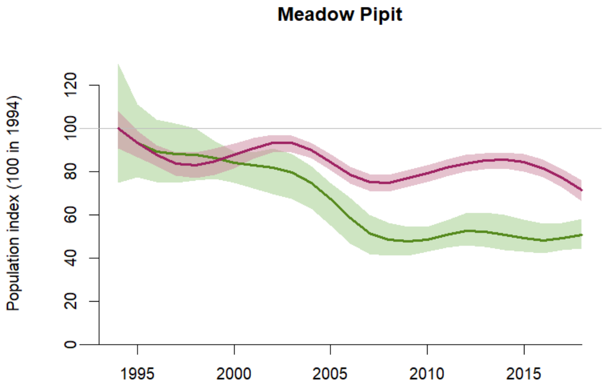

Grey Wagtail
Population index (100 in 1994)
0
50
100
150
200
1995
2000
2005
2010
2015


Kestrel
Population index (100 in 1994)
0
50
100
150
200
1995
2000
2005
2010
2015

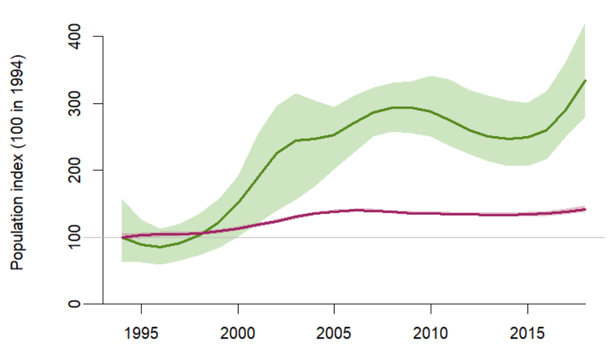

Lapwing
Population index (100 in 1994)
0
50
100
150
200
1995
2000
2005
2010
2015


Linnet
Population index (100 in 1994)
0
50
100
150
1995
2000
2005
2010
2015

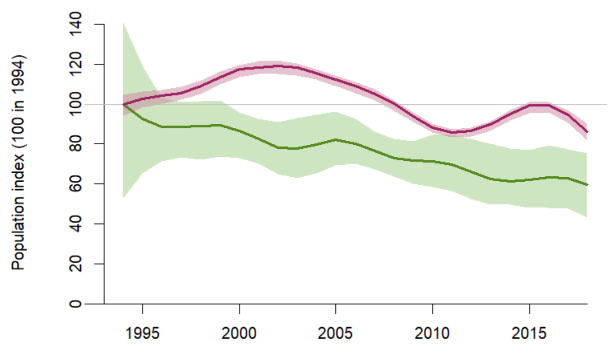

Mallard
Population index (100 in 1994)
0
50
100
150
1995
2000
2005
2010
2015


Meadow Pipit
Population index (100 in 1994)
0
20
40
60
80
100
120
1995
2000
2005
2010
2015

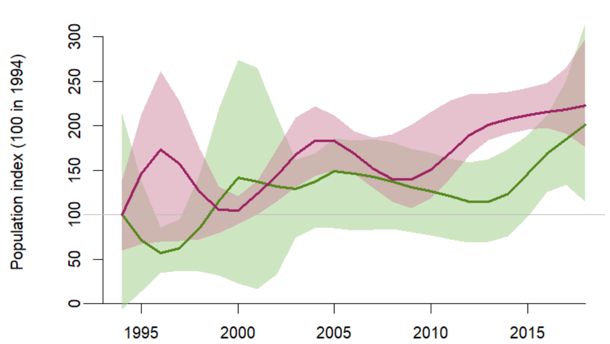
Pheasant



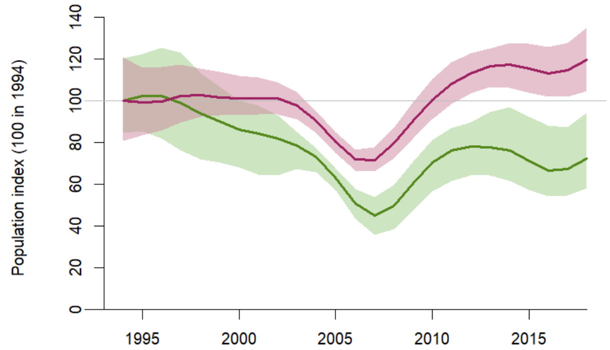
Pied wagtail



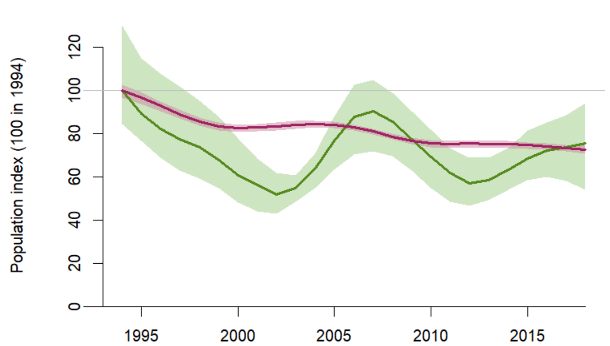
Raven



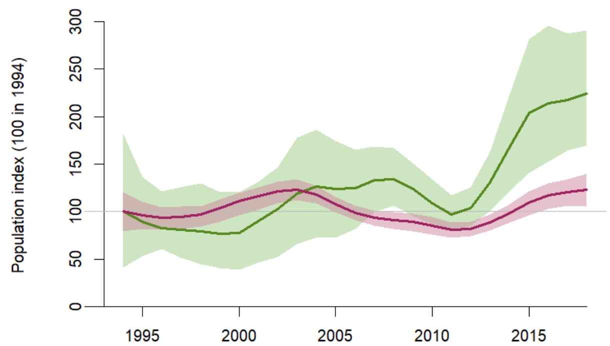
Red Grouse



Skylark



Snipe



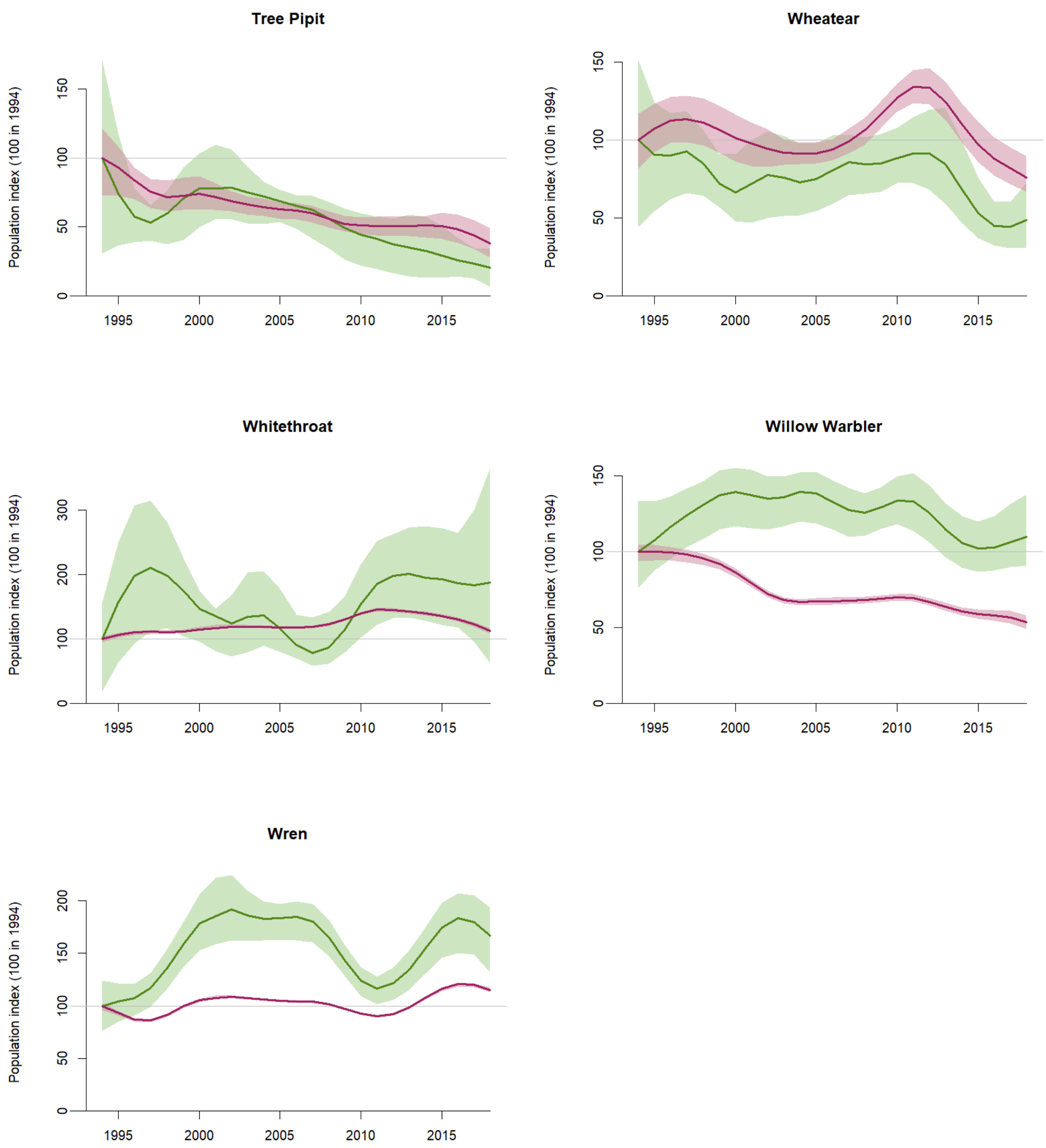


Figure 6. A comparison of population trends estimated from the BTO/JNCC/RSPB Breeding Bird Survey (BBS) for the Peak District Moors SPA and for England. The lines show the smoothed population indices estimated using BBS data for the Peak District area (dark green line) or for England (dark pink line). The shaded areas indicate the confidence band around the indices. All indices show relative abundance and are set to 100 in 1994, with the exception of Buzzard whose index is set to 100 in 2004 as no Buzzards were detected in the Peak District area during the 1994 BBS.

Table 1. Predicted breeding bird abundances within the Peak District Moors SPA survey area for each year, using method 1 (model-based predictions are used for all squares) and method 2 (detected abundances are used for surveyed squares, while model-based predictions are used for missing surveys) . 95% confidence intervals are shown in brackets next to the predictions. Note that, for method 2, uncertainty is only ascribed to the small proportion of squares that were missed, therefore the confidence intervals are narrow. Blanks indicate years when surveyors did not record species. Species are given in order of the estimated populations in 2018.

Species	1990		2004/5		2018	
	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2
Meadow Pipit	12820 (12143–13521)	11176 (11167–11186)	10479 (9923–11035)	9819 (9812–9827)	10355 (9795–10924)	8966 (8943–8990)
Red Grouse	2693 (2482–2958)	2719 (2718–2720)	5302 (4888–5799)	5963 (5961–5966)	3694 (3378–4030)	3784 (3766–3805)
Skylark	1442 (1288–1614)	1286 (1284–1289)	1316 (1166–1472)	1252 (1251–1254)	967 (853–1085)	859 (853–865)
Curlew	264 (233–301)	284 (283–284)	302 (263–342)	358 (358–359)	666 (604–734)	716 (712–720)
Golden Plover	406 (350–472)	448 (447–448)	270 (227–319)	341 (341–341)	468 (400–541)	521 (519–525)
Wren	-	-	889 (776–1021)	1000 (999–1001)	463 (400–537)	478 (475–483)
Willow Warbler	-	-	154 (102–242)	168 (164–173)	296 (195–455)	331 (322–343)
Buzzard	1 (0–6)	1 (1–1)	15 (10–24)	21 (21–21)	215 (174–263)	248 (246–251)
Kestrel	68 (52–88)	78 (78–78)	80 (62–98)	102 (102–102)	211 (177–256)	242 (240–244)

Species	1990		2004/5		2018	
	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2
Lapwing[a]	92 (47–174)	83 (82–83)	117 (60–218)	125 (125–126)	196 (105–375)	175 (171–183)
Crow	101 (73–140)	124 (123–125)	23 (15–36)	32 (31–32)	164 (122–222)	190 (189–192)
Linnet	-	-	81 (24–289)	73 (71–79)	141 (43–471)	104 (103–107)
Snipe	40 (27–57)	52 (52–52)	67 (49–93)	99 (99–99)	110 (80–151)	142 (140–144)
Raven	-	-	11 (6–19)	19 (19–19)	110 (75–155)	157 (155–160)
Canada Goose	2 (1–7)	3 (3–3)	31 (15–63)	53 (53–53)	69 (34–140)	104 (102–108)
Cuckoo	40 (26–61)	56 (55–56)	10 (5–17)	16 (16–16)	59 (40–85)	80 (79–81)
Ring Ouzel[a]	80	103	51	73 (73–73)	58	75
Dunlin	79 (27–223)	92 (92–92)	43 (15–122)	52 (52–52)	59 (19–172)	70 (69–72)
Grasshopper Warbler	-	-	14 (14–14)	4 (4–4)	56 (20–143)	13 (13–14)
Short-eared Owl	14 (8–25)	2 (20–20)	15 (9–27)	26 (26–26)	54 (34–88)	79 (77–82)
Stonechat	-	-	47 (31–71)	76 (75–76)	49 (32–76)	73 (71–75)

Species	1990 Method 1	1990 Method 2	2004/5 Method 1	2004/5 Method 2	2018 Method 1	2018 Method 2
Pheasant	-	-	24 (6–92)	28 (28–29)	40 (10–154)	36 (33–48)
Whinchat	47 (23–98)	62 (62–63)	64 (30–132)	95 (95–96)	36 (18–75)	48 (47–49)
Grey Wagtail	8 (2–28)	11 (11–11)	21 (6–69)	31 (31–32)	34 (10–104)	46 (45–49)
Mallard	-	-	7 (1–51)	8 (8–8)	29 (5–159)	19 (19–19)
Peregrine	4 (1–14)	7 (7–7)	18 (7–44)	3 (33–33)	22 (9–54)	37 (36–37)
Merlin	18 (11–31)	28 (28–28)	22 (13–37)	38 (38–38)	19 (11–33)	28 (28–29)
Tree Pipit	-	-	33 (8–127)	40 (38–45)	17 (4–72)	19 (19–20)
Common Sandpiper	19 (4–85)	17 (17–17)	20 (4–95)	22 (21–26)	18 (4–87)	17 (16–23)
Wheatear	82 (40–177)	117 (116–117)	19 (8–42)	29 (29–29)	17 (8–39)	23 (23–24)
Whitethroat	-	-	5 (0–54)	6 (5–14)	16 (2–155)	14 (14–14)
Dipper	1 (0–13)	1 (1–1)	8 (1–62)	10 (10–10)	9 (1–58)	10 (10–12)
Teal	-	-	1 (0–17)	2 (2–3)	7 (1–93)	13 (13–13)

Species	1990		2004/5		2018	
	Method 1	**Method 2**	**Method 1**	**Method 2**	**Method 1**	**Method 2**
Pied Wagtail	-	-	9 (1–82)	11 (11–11)	4 (0–40)	4 (4–4)
Redshank	9 (1–158)	10 (10–10)	2 (0–52)	3 (3–3)	2 (0–35)	2 (2–2)
Twite	113 (36–365)	130 (129–131)	5 (1–23)	7 (7–7)	2 (0–11)	2 (2–2)

[a] Model failed to converge so confidence intervals could not be robustly estimated.

Table 2. Estimated change in relative abundance (% Change) of 30 bird species in the Peak District Moors SPA according to analysis of Moorland Bird Survey data between 1990 and 2018. This is presented alongside change in relative abundance estimated for the same species where there is data from Breeding Bird Survey for the closest comparable period of 1994-2018 for both the Peak District Moors and for both South Pennine Moors SPAs (Phase I and Phase II combined). For the Breeding Bird Survey, we include 1-km squares which fall within a 3-km buffer of the focal area. For Moorland Bird Survey, the sample size is the number of sites which recorded the species in 1990 and 2018, whilst for the Breeding Bird Survey we present the mean number of 1-km squares reporting the species each year over the whole period, 1994-2018. Species in bold show statistically significant trends.

	Moorland Bird Survey				**Breeding Bird Survey**					
					Peak District Moors SPA (South Pennines Moors Phase I)			**South Pennines Moors SPAs (Phase I and II)**		
Species	**Sample 1990**	**Sample 2018**	**Index in 2018 relative to 1990 (% Change)**	**95% CI**	**Mean sample**	**Index in 2018 relative to 1994 (% Change)**	**95% CI**	**Mean sample**	**Index in 2018 relative to 1994 (% Change)**	**95% CI**
Canada Goose	**2**	**64**	**3,162**	**937 – 10,211**	**13**	**514**	**227 - >100,000**	**21**	**507**	**217 - 2,567**
Mallard	0	16	-	-	17	18	-41 - 275	30	22	-25 - 163
Red Grouse	**401**	**381**	**37**	**30 – 44**	17	-12	-51 - 70	25	-1	-47 - 80
Pheasant	0	25	-	-	**21**	**211**	**85 - 641**	**34**	**232**	**88 - 729**

Buzzard	**1**	**188**	**25,089**	**3,213 – >100,000**	**7**	**>10,000**	**>10,000 - >100,000**	**9**	**>10,000**	**>10,000 - >100,000**
Oystercatcher	0	9	-	-	0	-	-	**7**	**>10,000**	**>10,000 - >100,000**
Lapwing	**59**	**87**	**113**	**61 – 179**	16	51	-55 - 280	27	11	-51 - 114
Golden Plover	**229**	**229**	**15**	**2 – 30**	9	48	-41 - 343	15	23	-51 - 255
Curlew	**200**	**342**	**154**	**119 – 190**	27	-7	-46 - 238	44	-7	-46 - 102
Snipe	**41**	**103**	**178**	**103 – 295**	8	123	-0.04 - 1,019	12	56	-33 - 657
Dunlin	55	40	-25	-43 – 4	0	-	-	0	-	-
Common sandpiper	12	16	-2	-50 – 97	0	-	-	5	18	-75 - >10,000
Cuckoo	**53**	**67**	**47**	**1 – 107**	9	-26	-61 - 52	12	-34	-65 - 52
Kestrel	**77**	**180**	**208**	**143 – 303**	12	9	-53 - 411	20	13	-36 - 248
Carrion Crow	**70**	**126**	**63**	**27 – 104**	**26**	**62**	**9 - 159**	44	36	-10 - 99
Raven	0	110	-	-	6	47	-68 - >10,000	8	90	-25 - >10,000
Skylark	**333**	**254**	**-33**	**-39 – -26**	21	-30	-66 - 18	**37**	**-35**	**-59 - -7**

Willow Warbler	0[a]	136	-	-	24	4	-33 - 77	38	4	-26 - 71
Whitethroat	0[a]	12	-	-	5	252	-58 - >10,000	6	303	-26 - >10,000
Wren	0[a]	197	-	-	29	59	-21 - 186	45	47	-2 - 144
Ring Ouzel	**72**	**60**	**-27**	**-27 – -27**	0	-	-	0	-	-
Whinchat	39	32	-22	-49 – 13	0	-	-	0	-	-
Stonechat	0	58			0	-	-	0		-
Wheatear	**71**	**22**	**-79**	**-87 – -68**	10	-53	-82 - 53	**18**	**-61**	**-83 - -1**
Grey Wagtail	**10**	**38**	**340**	**131 – 749**	6	-14	-79 - >10,000	9	-6	-72 - 371
Pied Wagtail	0[a]	3	-	-	16	-53	-81 - 66	28	-38	-64 - 55
Meadow Pipit	**511**	**480**	**-19**	**-21 – -17**	**29**	**-52**	**-73 - -8**	**48**	**-46**	**-66 - -17**
Tree Pipit	0[a]	15	-	-	**6**	**-87**	**-100 - -36**	**6**	**-88**	**-100 - -22**
Linnet	0[a]	59	-	-	13	-49	-91 - 296	21	-30	-78 - 180
Twite	**87**	**2**	**-98**	**-100 – -94**	0	-	-	0	-	-

[a] missing data assumed to be because that species was not surveyed for in 1990, even if present.

Table 3. Estimated change in relative abundance (% Change) of 30 bird species in the Peak District Moors SPA according to analysis of Moorland Bird Survey data between 2004 and 2018. This is presented alongside change in relative abundance estimated for the same species where there is data from BTO/JNCC/RSPB Breeding Bird Survey for both the Peak District Moors and for both South Pennine Moors SPAs (Phase I and Phase II combined). For the Moorland Bird Survey, the sample size is the number of sites recorded for the species in 2004/5 and 2018, whilst for the Breeding Bird Survey we present the mean number of 1-km squares reporting the species each year over the period, 2004-2018. Species in bold show statistically significant trends.

	Moorland Bird Survey				**Breeding Bird Survey**					
					Peak District Moors SPA (South Pennines Moors Phase I)			**South Pennines Moors SPAs (Phase I and II)**		
Species	**Sample 2004/5**	**Sample 2018**	**Index in 2018 relative to 2004** (% Change)	**95% CI**	**Mean sample**	**Index in 2018 relative to 2004** (% Change)	**95% CI**	**Mean sample**	**Index in 2018 relative to 2004** (% Change)	**95% CI**
Canada Goose	**20**	**64**	**123**	**62 – 213**	18	-36	-73 – 1209	28	-45	-73 – 37
Mallard	**4**	16	**299**	**53 – 896**	22	1	-44 – 102	39	-4	-36 – 71
Red Grouse	**446**	**381**	**-30**	**-33 – -28**	23	-2	-36 – 103	33	12	-22 – 94
Pheasant	4	25	68	-4 – 184	29	64	-3.2 – 186	**48**	**81**	**19 – 168**

Buzzard	**18**	**188**	**1,317**	**790 – 2,113**	**12**	**>10,000**	**>10,000 - > 10,000**	**14**	**898**	**171 - >10,000**
Oystercatcher	1	9	-	-	0	-	-	**11**	**483**	**73.59 - >10,000**
Lapwing	**58**	**87**	**69**	**33 – 116**	19	162	-12 – 605	**34**	**72**	**1 - 320**
Golden Plover	**151**	**229**	**72**	**49 – 97**	12	-10	-40 – 261	19	-0.4	-40 – 77
Curlew	**217**	**342**	**122**	**94 – 153**	**34**	**70**	**17 – 184**	**57**	**49**	**11 - 100**
Snipe	**55**	**103**	**65**	**26 – 115**	10	52	-49 – 1047	16	12	-43 – 184
Dunlin	22	40	41	0 – 103	0	-	-	0		-
Common sandpiper	12	16	-9	-54 – 70	0	-	-	7	-20	-80 - >10,000
Cuckoo	**10**	**67**	**481**	**231 – 905**	11	7	-43 – 563	15	6	-41 - 195
Kestrel	**79**	**180**	**166**	**110 – 233**	15	-26	-63 – 99	26	-10	-48 – 66
Carrion Crow	**3**	**126**	**605**	**400 – 934**	32	25	-28 – 142	55	8	-28 - 62
Raven	**10**	110	**931**	**532 – 1556**	9	152	-44 - > 10,000	**12**	**300**	**8 - >10,000**
Skylark	**345**	**254**	**-27**	**-33 – -19**	26	53	-15 – 185	46	7	-33 - 69

Willow Warbler	**77**	136	**91**	**57 – 129**	**31**	**-39**	**-56 - -7**	49	-30	-50 – 6
Whitethroat	**3**	12	**239**	**15 – 916**	6	-13	-98 – 402	7	12	-87 - >10,000
Wren	**310**	197	**-48**	**-54 – -42**	37	-15	-47 – 30	58	-16	-42 - 22
Ring Ouzel	**47**	**60**	**14**	**14 – 15**	0	-	-	0	-	-
Whinchat	**59**	32	**-43**	**-61 – -20**	0	-	-	0	-	-
Stonechat	53	58	5	-24 – 47	0	-	-	0	-	-
Wheatear	21	**22**	-9	-48 – 58	14	39	-46 – 415	12	18	-40 – 179
Grey Wagtail	**29**	**38**	**68**	**8 – 163**	8	58	-28.19 - >10,000	12	-1	-72 – 350
Pied Wagtail	10	3	-59	-87 – 41	19	-14	-67 – 143	34	-1	-40 – 94
Meadow Pipit	531	480	-1	-4 – 2	**36**	**-30**	**-45 - -4.2**	**60**	**-25**	**-42 - -7**
Tree Pipit	**32**	**15**	**-48**	**-71 – -6**	**6**	**-83**	**-100 - -12**	**6**	**-83**	**-100 - -18**
Linnet	**36**	59	**71**	**28 – 132**	15	9	-75 – 214	25	22	-44 - 134
Twite	2	2	-65	-93 – 48	-	-	-	0	-45.22	-

Table 4. Estimated change in relative abundance (% Change) of 7 bird species in the Peak District Moors SPA between 2004 and 2018 (top) and 1990 and 2018 (bottom) based on analyses of Moorland Bird Survey. The sample size is the number of squares each species was recorded from in each year. Species with statistically significant population changes are given in bold.

	Moorland Bird Survey			
Species	**Sample 2004**	**Sample 2018**	**Index in 2018 relative to 2004** (% Change)	**95% CI**
Merlin	31	28	-13	-47 – 39
Peregrine	25	34	21	--20 – 90
Redshank	3	2	-24	-86 – 365
Short-eared Owl	**24**	**60**	**260**	**135 – 455**
Dipper	10	9	9	-54 – 153
Teal	**2**	**10**	**583**	**59 – 2971**
Grasshopper Warbler	**4**	**12**	**290**	**50 – 986**

	Moorland Bird Survey			
Species	**Sample 1990**	**Sample 2018**	**Index in 2018 relative to 1990** (% Change)	**95% CI**
Merlin	28	28	4	-38 – 77
Peregrine	**7**	**34**	**428**	**131 – 1117**
Redshank	8	2	-8	-96 – 5
Short-eared Owl	**20**	**60**	**288**	**129 – 549**
Dipper	**1**	**9**	**925**	**37 – 7,700**

9. Appendices

9.1. Appendix 1. List of species

List of species scientific names and 2-letter codes used in this report. Those in bold are regarded as core upland birds with a substantial proportion of their breeding population restricted to peatland and moorland habitats.

Code	English name	Scientific name
BZ	Buzzard	*Buteo buteo*
C.	Carrion Crow	*Corvus corone*
CG	Canada Goose	*Branta Canadensis*
CS	Common Sandpipier	Actitis hypoleuca
CK	Cuckoo	*Cuculus canorus*
CU	**Curlew**	***Numenius arquata***
DN	**Dunlin**	***Calidris alpine***
GL	Grey Wagtail	*Motacilla cinerea*
GP	**Golden Plover**	***Pluvialis apricaria***
K.	Kestrel	*Falco tinnunculus*
L.	Lapwing	*Vanellus vanellus*
LI	Linnet	*Carduelis cannabina*
MA	Mallard	*Anas platyrhynchos*
MP	**Meadow Pipit**	***Anthus pratensis***
OC	Oystercatcher	*Ostralegus haemotopus*
PH	Pheasant	*Phasianus colchicus*
PW	Pied wagtail	*Motacilla alba*
RG	**Red Grouse**	***Lagopus lagopus***
RN	Raven	*Corvus corax*

RZ	**Ring ouzel**	***Turdus torquatus***
S.	**Skylark**	***Alauda arvensis***
SN	**Snipe**	***Gallinago gallinago***
SC	**Stonechat**	***Saxicola torquata***
TP	Tree Pipit	*Anthus trivialis*
TW	**Twite**	***Carduelis flavirostris***
W.	**Wheatear**	***Oenanthe oenanthe***
WC	**Whinchat**	**Saxicola rubetra**
WH	Whitethroat	*Sylvia communis*
WR	Wren	*Troglodytes troglodytes*
WW	Willow Warbler	*Phylloscopus trochilus*

9.2. Appendix 2. Detailed data analysis methods

9.2.1. Analysis of Moorland Bird Survey (MBS) data

Trends were modelled using a Generalised Linear Mixed Model (GLMM) with a Poisson error distribution and log-link function. Year was included as a fixed effect and the identity of each 1-km square was included as a random effect. We amalgamated the data from 2004 and 2005 and modelled them as a single year. This was because the 2005 surveys were conducted to fill coverage gaps from access issues in 2004, but there were too few squares surveyed in 2005 to come up with a robust estimate of abundance in that year alone. To account for variation in survey effort across squares we weighted the contribution of each square x year combination by an ordinal variable describing survey effort, under the assumption that survey effort was affecting the precision of the estimates rather than introducing a negative bias. The values of this ordinal variable were based on whether a square was fully surveyed in one visit only (1), partially surveyed in one visit and fully in another visit (1.5) or fully surveyed in both visits (2). These values were then normalised by dividing them by their mean to ensure proper estimation of the model parameters and their standard errors. Unfortunately, as we did not have information on the extent of partial surveys, we were unable to use a more precise approach and had to exclude squares that were not fully surveyed (and therefore most likely to be under-estimates) on at least one visit to avoid systematic under-estimation of abundance. Reassuringly, using the weights had little impact on the final estimates, as assessed by fitting the same models without weights. As the survey only covered unenclosed moorland SPA habitat within each 1-km square, the natural log of the area of such habitat was included as an offset term, in order to generate breeding densities. The model for each species was used to predict species abundance in each surveyed 1-km square in each survey year (1990, 2004/5 and 2018).

Total breeding bird numbers within the Peak District Moors SPA survey area were estimated by summing all square-level predictions using two different methods: method 1 consisted of using the model-based estimates of abundance for all squares, regardless of whether the squares had been surveyed; conversely, method 2 consisted of using the actual counts (detected abundance) where available, while the model-based estimates of abundance were only used for squares that had not been surveyed in a given year. Before summing any square-level model-based estimates, we multiplied these by the fraction of area, in the 1-km square, that was covered by the survey (the same quantity used as a model offset), to avoid them being inflated by extrapolation across unsurveyed non-moorland areas. For the estimates of change in relative abundance (Table 2), we used the method 1, whose estimates are likely to be more robust against missing data.

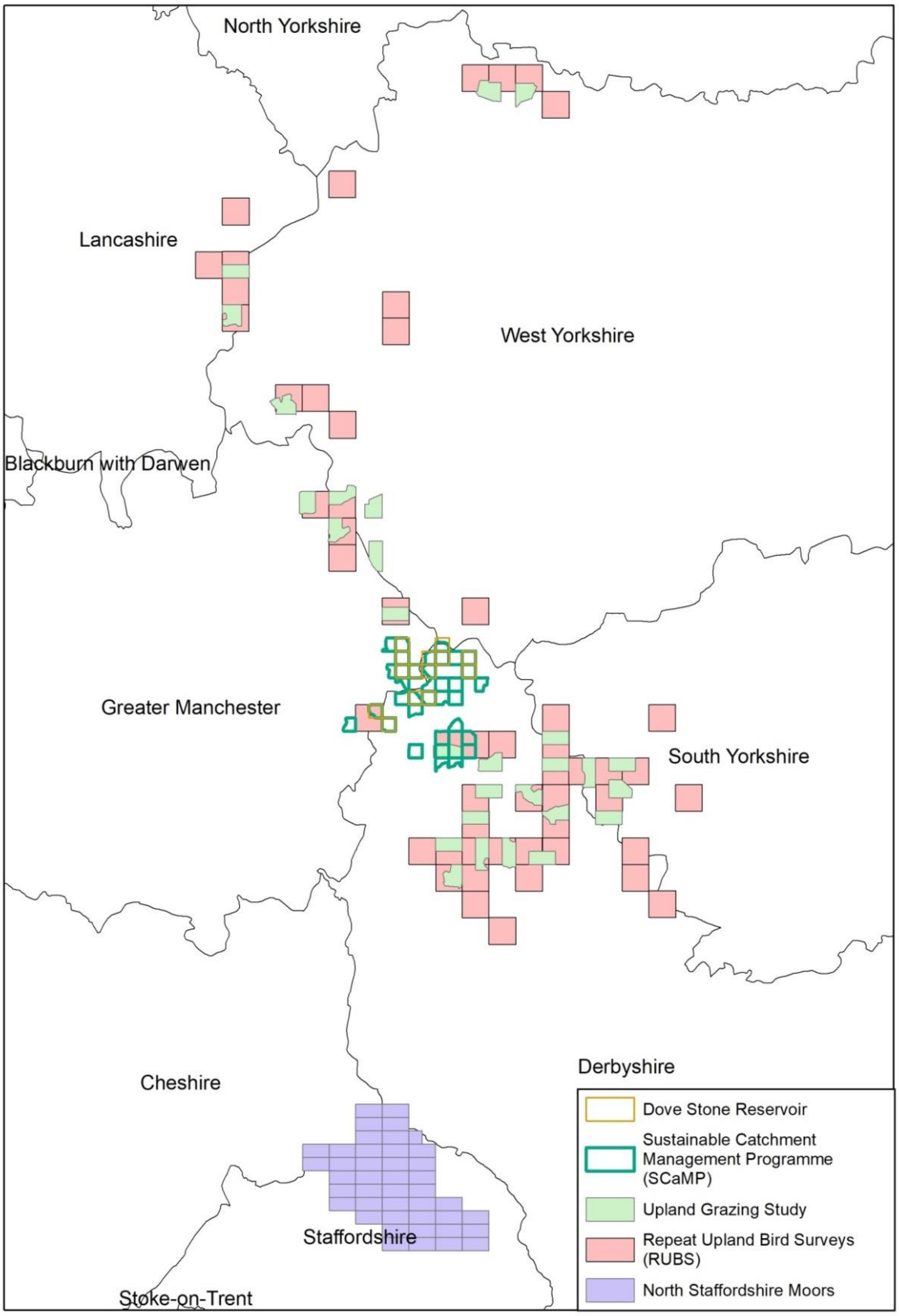
Predicted values and 95% confidence intervals were approximated by simulation following Krinsky & Robb (1986, 1990). Briefly, 1000 sets of year coefficients were drawn from a multivariate normal distribution, parameterized with means of the estimate of the year coefficient for each year and the variance-covariance matrix of the GLMM model. Next square-level predictions were calculated for each of these 1000 sets of resamples for the three main survey years (1990, 2004/5 and 2018) adding the random effect intercept for each 1-km square. These were summed across all squares and we took the 2.5th, 50th and 97.5th quantiles across the sets of simulations to obtain the lower confidence interval, median, and upper confidence interval.

A number of different analytical approaches to estimating abundance and trends are possible. We therefore also tested two variations on this method. Firstly, all squares which had zero counts in all four survey years were removed from the dataset before undertaking the modelling. Secondly, instead of using a GLMM, we used a Generalised Linear Model (GLM) in which 1 km-square identity was specified as a fixed rather than a random effect. This produces specific estimates of abundance for each square, again, excluding all squares with zero counts in all four years, for which such estimates are not possible. The first approach, using a GLMM without zero counts, gave very similar results to the GLMM with zero counts which are presented in this report. The second approach, using a GLM with year as a fixed effect, resulted in much higher predicted counts than the other two models and with much wider confidence intervals, due to the uncertainty and abundance inflation associated with the square-specific estimates of abundance based on only a small number of survey years. As a result, we simply present the results from the GLMM model with all zeros included as this was judged to be the most statistically sound approach.

9.2.2. Analysis of BBS data

An annual population index was calculated by fitting a log-linear model with Poisson error terms where count was modelled as a function of site (BBS square) and year (Harris et al. 2019). The model was weighted to account for the regional stratification. As annual population indices reflect annual fluctuations in abundance as well as long-term trends, a thin-plate smoothing spline was used to assess long-term population changes (Newson et al. 2013). The number of degrees of freedom was set to 0.3 times the number of years in the time series (Fewster et al. 2000). Confidence intervals for all measures of population change were estimated by bootstrapping (n=200) over all BBS squares.

9.3. Appendix 3. Location and coverage of other moorland bird surveys undertaken across the South Pennines SPA (Phase I and Phase II) during the same period.



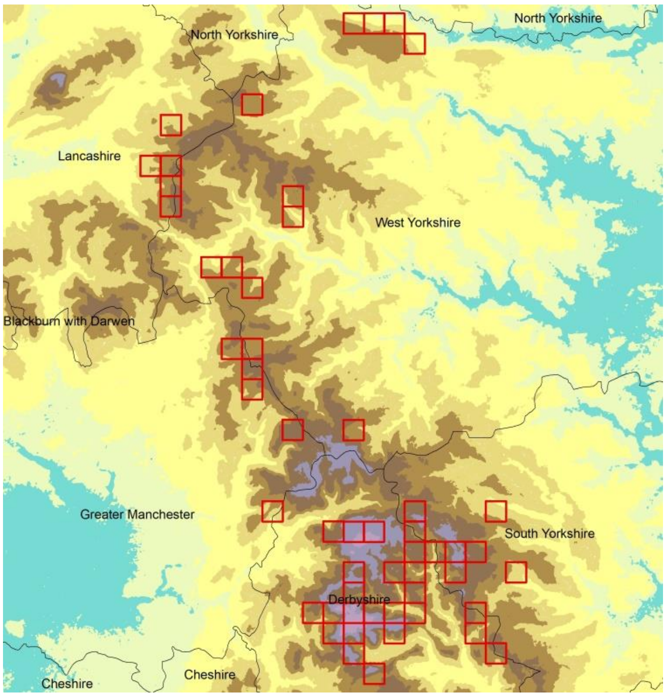
9.3.1. Breeding Bird Survey of the Eastern Moors

This survey covers the Eastern Moors and Burbage Moors. It was carried out in 2010 and 2015 by the Eastern Moors Partnership. Numbers of breeding pairs of 22 key species were estimated and mapped over 48 (in 2015) 1km squares.

No GIS layer was provided but a map with the location of the squares is shown in the report (Leyland 2015).

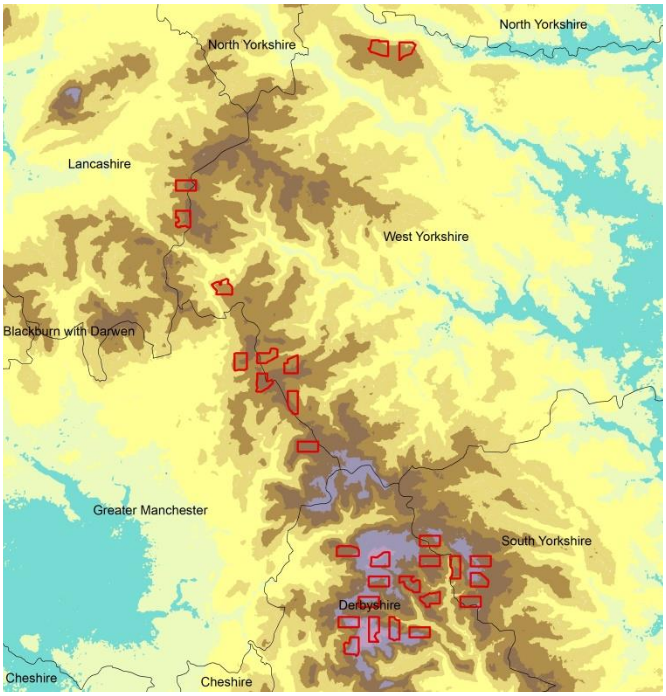
9.3.2. Repeat Upland Bird Surveys (RUBS)

This is essentially a repeat of surveys that had already been carried out in the past, with the aim of estimating abundance medium-term (10-20 years) changes in upland breeding birds throughout Britain. All 1km squares in the South Pennine Moors SPA (Phases I and II) were first surveyed in 1990 by English Nature and were re-surveyed in 2000 by RSPB, using the Brown & Shepherd (1993) constant effort method. Analyses were carried out by Sim et al (2005) and showed widespread population declines in Lapwing, Dunlin and Curlew.



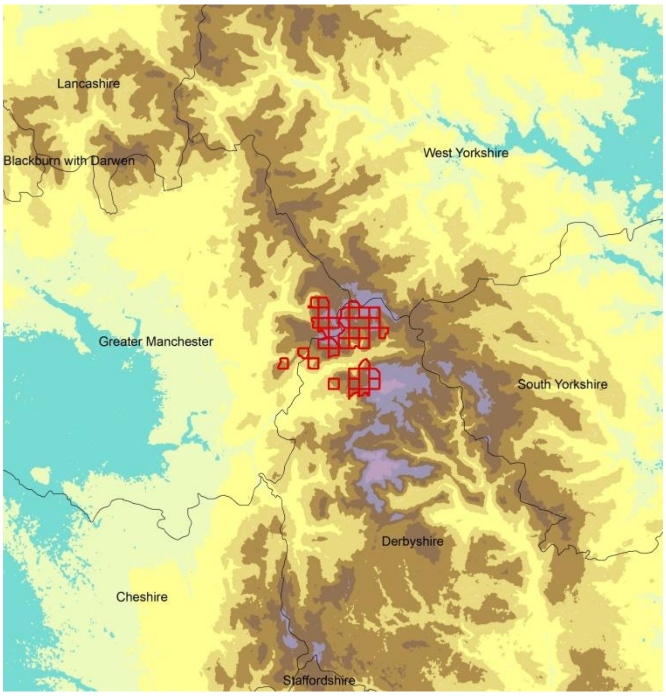
9.3.3. Upland Grazing Study

This survey covers 37, $2km^2$ across South Pennine Moors SPA in 2002, 36 of which were then resurveyed in 2010 specifically to look at changes in breeding Curlew abundance. Breeding waders, Red Grouse and moorland passerines were surveyed using a three-visit census method, whilst detailed vegetation data were also collected in the field, recording composition and structure (Pearce-Higgins & Grant 2006). The results of this survey were published by Buchanan et al. (2017) alongside equivalent data from Wales, North Pennines and South Scotland, whilst changes in Curlew populations were documented by Douglas et al. (2014).



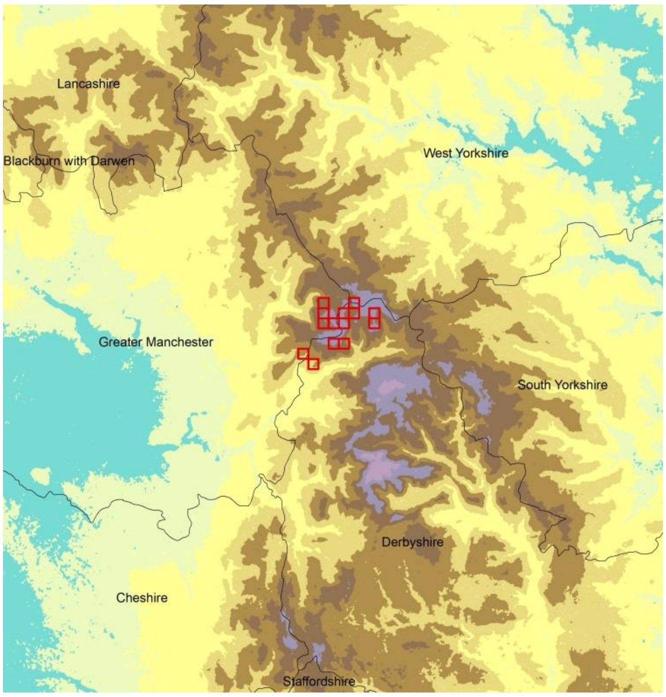
9.3.4. Sustainable Catchment Management Programme (SCaMP)

This program was aimed at improving biodiversity and water quality on the Bowland and Peak District. As part of a project, breeding bird surveys were carried out in 2005, 2007, 2008 and 2014. Two methods were used to measure bird abundance: a three-visit 'breeding wader' census method, where the surveyor covers all parts of the plot to within 100 m (Brown & Shepherd 1993, Pearce-Higgins & Grant 2006) and transect surveys for Meadow Pipit and Skylark (Thirgood *et al.* 1995, Buchanan *et al*. 2006).



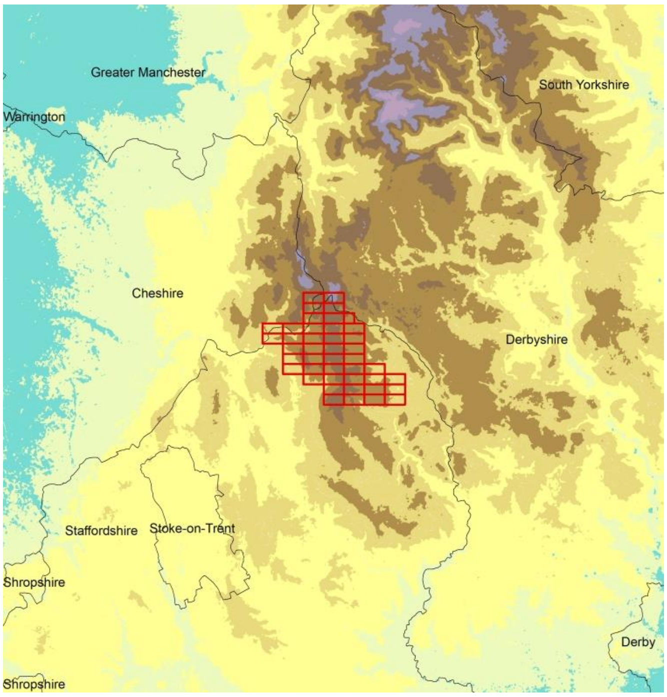
9.3.5. Dove Stone Reservoir

Data seem to have been collected following the Brown and Shepherd method modified by Grant, but information on the survey itself is not provided.



9.3.6. North Staffordshire Moors

Two different surveys were undertaken in 2004: The North Staffordshire Moorland Survey and the Moors for the Future Breeding Bird Survey. The North Staffordshire Moorland Survey was aimed at surveying the in-bye land using the O'Brien and Smith (1992) methodology. The Moors for the Future Breeding Bird Survey was aimed at surveying moorland using the Brown and Shepherd (1993) methodology. The GIS layer shows 2x1km rectangles, which were used in previous surveys undertaken in 1985, 1992 and 1996, while in the 2004 survey 1km squares were used.



9.3.7. National Trust Breeding Bird Survey

The National Trust have undertaken annual breeding bird surveys following the line-transect methodology of the BTO/JNCC/RSPB Breeding Bird Survey across 39 1km^2 in the High Peak Estate since 2016.