

# Nesting dates of Moorland Birds in the English, Welsh and Scottish Uplands

Wilson, M.W., Fletcher, K., Ludwig, S.C. & Leech, D.I



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# Nesting dates of Moorland Birds in the English, Welsh and Scottish Uplands

A BTO Report to Natural England

Wilson, M.W., Fletcher, K., Ludwig, S.C. & Leech, D.I.

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For further information on this report please contact:

Allan Drewitt,  
Mail Hub, Natural England,  
County Hall, Spetchley Road,  
Worcester  
WR5 2NP  
E-mail: [allan.drewitt@naturalengland.org.uk](mailto:allan.drewitt@naturalengland.org.uk)

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BTO, The Nunnery, Thetford, Norfolk IP24 2PU  
Tel: +44 (0)1842 750050 Email: [info@bto.org](mailto:info@bto.org)  
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## 1. EXECUTIVE SUMMARY

1. Rotational burning of vegetation is a common form of land management in UK upland habitats, and is restricted to the colder half of the year, with the time period during which burning may be carried out in upland areas varying between countries. In England and Scotland, this period runs from the 1st October to 15th April, but in the latter jurisdiction, permission can be granted to extend the burning season to 30th April. In Wales, this period runs from 1st October to 31st March.
2. This report sets out timing of breeding information for upland birds in England, Scotland and Wales, to assess whether rotational burning poses a threat to populations of these species, and if any such threat varies in space and time.

### Datasets and modelling

3. First-egg dates were estimated from Nest Record Scheme (NRS) records for 17 species of moorland and moorland-edge habitats. General Linear Models related laying date to species, year, latitude, longitude, elevation, habitat, rainfall, temperature, proximity of roads and occurrence of moorland burning.
4. Laying date models for individual species were also constructed, based on first-egg dates derived from NRS and Ringing Scheme records, and including year, latitude and longitude as explanatory variables.
5. Independent datasets for species poorly represented in the NRS dataset were obtained from existing studies of these species in upland areas. These were used to validate the results of models based on NRS and Ringing Scheme records.
6. Timing of breeding information from studies of Red Grouse in Strathspey (1992–2016) and Langholm (2008–2016) was analysed in relation to overlap with burning seasons, relationship with elevation, and (for Strathspey only) trends over time.
7. Importance of landscapes where moorland burning is practised was explored, to better understand the impact of burning at a population level. Using the RSPB/JHI moorland burning dataset, three categories of tetrads were distinguished: those with burned moorland; those with moorland but no evidence of burning; and all other tetrads. Count data from the Bird Atlas were used to assess the relative abundance of different species in each category and, for England, Scotland and Wales, the proportion of each species' population in tetrads with burned moorland.
8. The potential for pre-breeding impacts of heather burning was assessed by comparing data on timing of migrant arrival from BirdTrack reporting rates with the relevant burning seasons. National reporting rates were used to estimate peaks of arrival for long-distance migrants, while reporting rates in 1 km squares containing burned moorland were used to estimate timing of arrival for a broader suite of species, including many short-distance and partial migrants.

### Importance of laying phenology

9. Mean laying date varied considerably between species. Standardised values predicted for different species by the all-species model for the year 2019 spanned a two-month period between late March and late May.
10. Over the four-decade period from which the modelled data were drawn, mean laying date across all species in the model advanced by about one day every eight years. Other variables significantly related to laying date in this model are easting, northing, cover of conifer woodland and semi-natural grassland, rainfall and temperature.
11. Predictions of laying date from individual species models agreed well with estimates from the global model based on data from all species. There is, however, considerable variation among these models in whether, and at what rate, laying dates appear to have advanced.
12. Mean laying dates from individual datasets also fit well with the predictions generated from BTO datasets, suggesting that these models are suitable for evaluating the effect of timing of breeding on the risk posed by moorland burning to upland birds.
13. Across the available time series, 3% of Red Grouse clutches in Strathspey and 4% of Red Grouse clutches at Langholm were initiated before 15th April. The proportions of clutches started before the end of April were considerably higher, being 72% in Strathspey, and 93% at Langholm.
14. Between 1992 and 2016, mean clutch initiation date for Red Grouse in Strathspey advanced by 0.46 days per year. Clutch initiation date between 2009 and 2016 did not differ significantly between Strathspey and Langholm. Strathspey nests at higher altitudes were initiated later (by 1.1 days per 100 m) than those at lower altitude.

## Importance of distribution and arrival phenology

15. Many moorland species were more abundant in tetrads with burned moorland than in tetrads with unburned moorland, or in the wider countryside. In England, tetrads with burned moorland accounted for 61% to 78% of the populations of Black and Red Grouse, Golden Plover and Ring Ouzel. Negative effects of burning on these species could have larger consequences for their populations, particularly in England.
16. Some long-distance migrants (such as Wheatear and Ring Ouzel) arrive back in their upland breeding areas several weeks before the main burning season closes in mid-April. Most short-distance and partial migrants that breed in these areas return well before the end of any of the earliest of the upland burning periods.

## Main conclusions

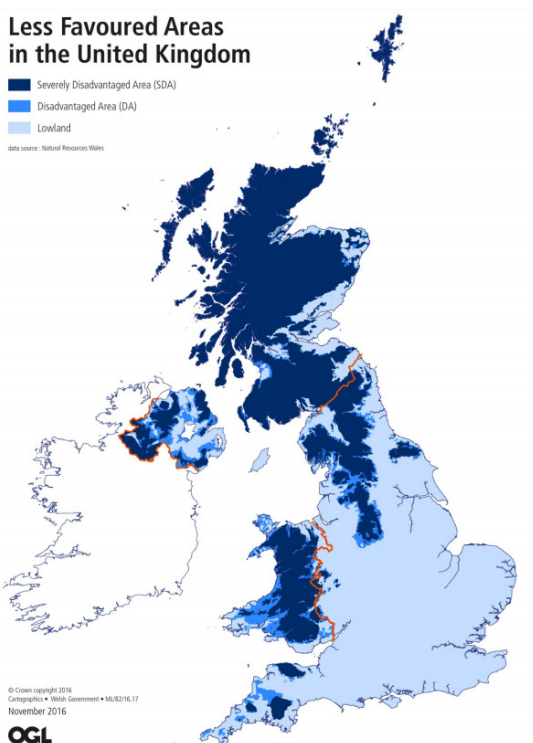
17. Changes in timing of breeding over the past several decades have been modest. These vary between species, with laying dates typically advancing by 1–2 days per decade.
18. Overlap for most species between burning season and laying dates remains small. Even among early breeding birds in moorland areas, the risk presented by burning is low for many species. Early breeders include species such as Golden Plover and Lapwing that typically breed in short vegetation unlikely to be targeted for burning, and species such as Golden Eagle and Peregrine that breed on crags, most of which are unlikely to be included in rotational burns.
19. The overall risk to populations posed by burning depends on several factors. Some of these, such as timing of breeding, nesting ecology, and the proportion of each population that nests in areas of rotationally burned moorland, are species-specific. Others, like the area of moorland burned each year, and the proportion of burning done in the spring, are dependent on management practices and will affect risk in a similar way for many species.
20. Taking all of these factors into account, the species for which burning poses the greatest population level risk are not the earliest breeding species. Stonechat breeding attempts are probably among the most frequently destroyed by burning. However, this species is a habitat generalist which also breeds in lowland areas, so no more than 0.3–0.5% of all Stonechat nests are likely to be destroyed by burning.
21. Conversely, populations of species that often nest in deep heather, such as Ring Ouzel and Merlin, are concentrated in areas where moorland burning takes place, especially in England. For these species, the proportion of breeding attempts directly impacted by heather burning each year is likely to be less than 1% if burning is restricted to the standard burning season. If burning on all moorlands continued until 30th April, this proportion could rise to 4–5% for Merlin and 6–7% for Ring Ouzel.
22. No species has populations that are more concentrated within areas where moorland burning is practised than Red Grouse. The majority of Red Grouse clutches in Strathspey and Langholm are, however, not initiated until after mid-April when the main upland burning seasons in Scotland have closed. A contrastingly large proportion of Red Grouse breeding attempts in Scotland are started before the close of the extended burning season, at the end of April. However, given that boosting of Red Grouse productivity is one of the main reasons for heather burning, moorland managers will typically stop burning when Red Grouse start laying.
23. The close proximity of Langholm to the English border, coupled with the similarity in timing of breeding between Langholm and Strathspey Red Grouse (as well between populations of several wader species in south Scotland and northern England), suggests that most Red Grouse breeding attempts in England will start after the close of the upland burning season there.
24. Spatial variation in breeding phenology across most of England, Scotland and Wales, according to both the empirical information and model outputs presented in this report, is modest. Recent changes made to the upland burning season in Wales, which now ends two weeks before the standard upland season in Scotland and England, mean that the risk posed by moorland burning in Wales is now likely to be substantially lower than elsewhere in Britain.
25. The area where moorland burning within regulated dates has the potential to pose the greatest threat to breeding birds is probably in southern Scotland. Here, given the modest spatial variation detected across the UK, the timing of breeding is likely to approximate that indicated by the model outputs that are standardised to the Yorkshire Dales (just over 100 km away), but burning in some areas may continue up to the end of April, two weeks after the end of the standard season in mid-April.
26. Pre-breeding impacts of burning are not well understood. For some sensitive species such as Merlin and Golden Eagle, pre-breeding impacts could arise via disturbance caused by human activity associated with the burning. Other possible impacts will require further research before they can effectively be taken into consideration.

## 1. BACKGROUND

Rotational burning of vegetation is a common form of land management in UK upland habitats. In England, this is regulated by the Heather & Grass etc. Burning (England) Regulations 2007. These regulations restrict the time period during which burning may be carried out in upland ('Severely Disadvantaged' – see Figure 1) areas to between the 1st October and 15th April. In other areas, the relevant period is shorter, running from the 1st November to 31st March. These dates have remained the same in England since 1983 when they were introduced under the Heather and Grass Burning (England and Wales) Regulations 1983. Previously, rotational burning in all parts of England was restricted to the period between 1st November and 31st March under the first regulations, the Heather and Grass Burning (England and Wales) Regulations.

In Wales, new regulations (The Heather and Grass etc. Burning (Wales) Regulations 2008) governing the burning of heather, rough grasses and similar species came into effect in 2008. They changed the period during which such burning was deemed permissible to 1st October to 31st March in 'Severely Disadvantaged' areas (Figure 1), and to 1st November to 15th March in other parts of the country. Previously, the permitted periods for burning were the same as those in England (where they remained unchanged after a review in 2005–2007).

**Figure 1. Extent of disadvantaged (medium blue) and Severely Disadvantaged (dark blue) areas in the United Kingdom (Welsh Government 2018). In England and b) Wales, upland areas in which permissible periods for burning are longer than elsewhere are defined as having the same extent as Severely Disadvantaged (dark blue) areas.**



In Scotland, rotational burning of heather is covered by the Hill Farming Act 1946, and is permitted at all altitudes between 1st October and 15th April. This can be extended, at the discretion of the landowner or under the authority of the Scottish Executive Environment and Rural Affairs Department (SEERAD), to 30th April. The most recent iteration of the relevant guidance (Scotland's Moorland Forum, 2017) discourages such extensions of the burning season, and no longer refers to any automatic extension of the burning season at higher elevations. This guidance does, however, point out that applications for licences to carry out burning outside of the normal burning season can be made to NatureScot.

A primary aim of the regulation of vegetation burning is to protect nesting birds. Increasingly, heather cutting is also used to manage upland vegetation and is generally carried out over a similar period to burning, though it is not so tightly regulated with regard to season. Changing seasons associated with a warming climate appear to be causing a shift towards earlier nesting dates, though with some variation between areas and species, increasing the risk of overlap with periods of permitted habitat management. Nesting dates in the uplands were first investigated by BTO in 2005 (Moss *et al.* 2005) and Natural England commissioned the present study in order to repeat this analysis, to provide updated evidence to assess whether the current burning season dates remain appropriate.

The impact of heather burning on bird populations is affected by several factors other than the temporal overlap between burning seasons and nesting periods. These include the extent of land managed by rotational burning, the area of heather burned each year on this land, and the degree to which breeding birds overlap with these areas. Although heather-dominated vegetation, often referred to as 'heather moorland', is typically associated with heathland (especially dry heath), it is widespread on modified and degraded blanket bog situated on deep peat (typically classified as being > 0.4 m depth in England and Wales, and > 0.5m in Scotland). As recently as 2011, a high proportion of the heather moorland subject to rotational burning was situated on deep peat (Douglas *et al.* 2015).

There is now a presumption against burning on deep peat except in exceptional circumstances by regulatory agencies in England and Wales (<http://publications.naturalengland.org.uk/publication/6647144950005760>) and also in Scotland (<https://www.nature.scot/doc/guidance-muirburn-code>) which might be expected to reduce the incidence, frequency and size of intentional heather moorland burning on deep peat in the near future. On the other hand, data gathered by Natural England suggest that the area of moorland burned each year has increased on many grouse moors since 2010. The recently published Moorland Change Map (Natural England 2021) shows that, in the burning seasons of 2018–2019 and 2019–2020, an average of 100 km<sup>2</sup> of moorland was

burned and cut each season. This represents an annual burning rate of 17% of the total area of burned moorland estimated by RSPB and JHI, which fits with typical moorland burning regimes as described by GWCT (2021), and suggests that the extent of moorland where burning is practised has not greatly decreased since 2010.

It is also worth noting that, although rotational burning is most frequent in heather-dominated moorland, other vegetation types and habitats are also subject to burning. These include graminoid-dominated habitats such as bogs/fens and grasslands (especially those where Purple Moor-grass (*Molinia caerulea*) is dominant), scrub (especially where dominated by Common Gorse *Ulex europaeus*), and heaths dominated by dwarf shrubs other than heathers, such as Western Gorse (*Ulex gallii*). Much of the latter type of habitat can be included in heather moorland by remote-sensing mapping. Burning on these habitats is less frequent and harder to detect via analysis of aerial photographs or satellite imagery and so cannot be taken into account in these analyses, but it could still result in impacts on some bird communities.

As well as direct impacts of rotational burning on breeding birds, burning could also affect birds before they start breeding, through disturbance and reduced habitat quality. The effects of pre-breeding impacts could include reduced densities of settling birds (due to perceived lack of suitable foraging habitat or nest sites, even if this might recover over the course of the breeding season), and wasted time and energy (with possible impacts on breeding success or survival) if territory establishment or nest-building efforts are rendered obsolete by burns.

This report describes timing of breeding for a suite of upland bird species in England, Wales and Scotland; the relative importance of areas where rotational burning is carried out for these and other species; and variation in timing of arrival of partial, short-distance and long-distance migrants that breed in these areas.

## 2. METHODS

### 2.1. Areas and species of interest

This report focuses particularly on 14 'Moorland' species that are strongly associated with heather-dominated and other peatland habitats. These are: two gamebirds (Black Grouse *Tetrao tetrix*, and Red Grouse *Lagopus lagopus*), five birds of prey, including one owl (Golden Eagle *Aquila chrysaetos*, Hen Harrier *Circus cyaneus*, Merlin *Falco columbarius*, Peregrine *Falco peregrinus*, Short-eared Owl *Asio flammeus*), three waders (Dunlin *Calidris alpina*, Golden Plover *Pluvialis apricaria* and Greenshank *Tringa nebularia*), and four passerines (Meadow Pipit *Anthus pratensis*, Ring Ouzel *Turdus torquatus*, Stonechat *Saxicola rubicola* and Whinchat *Saxicola rubetra*). It might be assumed that any impacts of rotational heather burning would be especially important for such species, simply due

to the increased likelihood of this practice affecting the habitats and areas occupied by nesting pairs.

We also look at two other groups of species. One comprises 11 'Edge' species that often breed on the periphery of moorland, or in adjacent areas such as in-bye grassland. These are: one gull (Common Gull *Larus canus*); seven waders (Common Sandpiper *Actitis hypoleucos*, Curlew *Numenius arquata*, Lapwing *Vanellus vanellus*, Oystercatcher *Haematopus ostralegus*, Redshank *Tringa totanus*, Ringed Plover *Charadrius hiaticula* and Snipe *Gallinago gallinago*); and three passerines (Skylark *Alauda arvensis*, Twite *Linaria flavirostris* and Wheatear *Oenanthe oenanthe*). These species are included, along with the 14 Moorland species, in all relevant analyses and outputs (timing of breeding, breakdowns of populations supported in areas with burning and moorland, and (where relevant) timing of arrival.

The last group covered 15 'Additional Upland' bird species that regularly nest on moorland and/or adjacent habitats, but are also found in a variety of other habitats. This group comprises: one gamebird (Ptarmigan *Lagopus muta*), two raptors (Buzzard *Buteo buteo* and Kestrel *Falco tinnunculus*), two gulls (Black-headed Gull *Chroicocephalus ridibundus* and Lesser Black-backed Gull *Larus canus*), Cuckoo (*Cuculus canorus*) and nine passerines (Dipper *Cinclus cinclus*, Grey Wagtail *Motacilla cinerea*, Linnet *Linaria cannabina*, Raven *Corvus corax*, Reed Bunting *Emberiza schoeniclus*, Tree Pipit *Anthus trivialis*, Whitethroat *Sylvia communis*, Willow Warbler *Phylloscopus trochilus* and Wren *Troglodytes troglodytes*). These species are not included in modelling of factors influencing timing of breeding, but are included in breakdowns of populations supported by areas with burning and moorland (section 2.5) and timing of arrival analyses (section 2.6).

### 2.2. Environmental variables

Climate data were taken at 5-km square resolution from the Met Office's UK climate projections for 2009, available at:

<http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/download/index.html>

These data are generated for a regular 5-km grid via regression and interpolation of raw data derived from the irregular weather station network, taking into account longitude, latitude, elevation, terrain shape, coastal influence, and urban land use (Perry & Hollis 2005). To encompass conditions when the birds were breeding we used the mean of mean monthly temperatures and the mean of total monthly rainfall from the months April, May, June and July. For winter conditions, the mean of mean winter temperatures and the mean of total rainfall from the months of December, January and February before the breeding season of interest (i.e. December 2007 for 2008



survey) were calculated. The mean of these variables was then calculated for each 5-km square for the years 2008 to 2011.

Elevation (in meters above sea level) was extracted from the GGIAR-SRTM 90m raster (Jarvis *et al.* 2008, available at <http://srtm.csi.cgiar.org>) taking the mean elevation over each tetrad or hectad (depending on the scale of the analysis). Slope was calculated from elevation in ARCGIS (ESRI 2017). The slope of each elevation raster cell is the maximum rate of change in elevation in one raster cell compared to its eight neighbours. The lower slope values indicate flatter areas, higher values indicate steeper areas. The median slope was taken for each 1 km square or tetrad, as this represents mostly flat areas more effectively than mean slope.

Land cover variables, describing broad categories of habitat, were taken from the cover summary of the 2015 Land Cover Map (LCM) from the Centre for Ecology and Hydrology (Rowland *et al.* 2017). Seven land cover categories were derived from the LCM dataset: (i) semi-natural unimproved grassland (including rough grassland, neutral grassland, calcareous grassland, acid grassland and fen, marsh and swamp); (ii) mountain, heath and bog (including heather, heather grassland, montane habitats and inland rock); (iii) intensively managed arable land; (iv) intensively managed improved grassland; (v) urban and suburban habitats (including built land, and suburban land); and (vi) broadleaved woodland and (vii) coniferous woodland. The mean percentage of organic carbon in topsoil from the European soil data centre (Jones *et al.* 2003) was used as an indication of the peat content of soils.

We used the Annual Average Daily Flows (AADF) data from the department of transport for major roads (A roads and motorways) as an indicator of heavy road traffic. The AADFs are calculated from around 10,000 manual point counts and automatic traffic counters, the observed data was roads adjusted to compensate for road length (Available from: <https://www.dft.gov.uk/traffic-counts/>).

Extent of rotational heather burning management was taken from the moorland burning dataset described by Douglas *et al.* (2015). This comprises area cover statistics for 1 km squares within hectads previously known to have had rotational heather burning carried out in them. The moorland burning data include percentage cover of land judged from aerial photographs to be heather moorland and, within each 1 km square containing heather moorland, the percentage of heather moor judged (again, from aerial photographs) to have been subject to rotational burning. The fact that this dataset is restricted to hectads where heather burning had been practised means that unburned heather moorland recorded in this dataset is not necessarily representative of all unburned moorland in Great Britain. Rather, it should be considered

characteristic of unburned moorland in landscapes where rotational heather burning is known to occur.

### **2.3. Timing of breeding from BTO datasets for Moorland and Edge species**

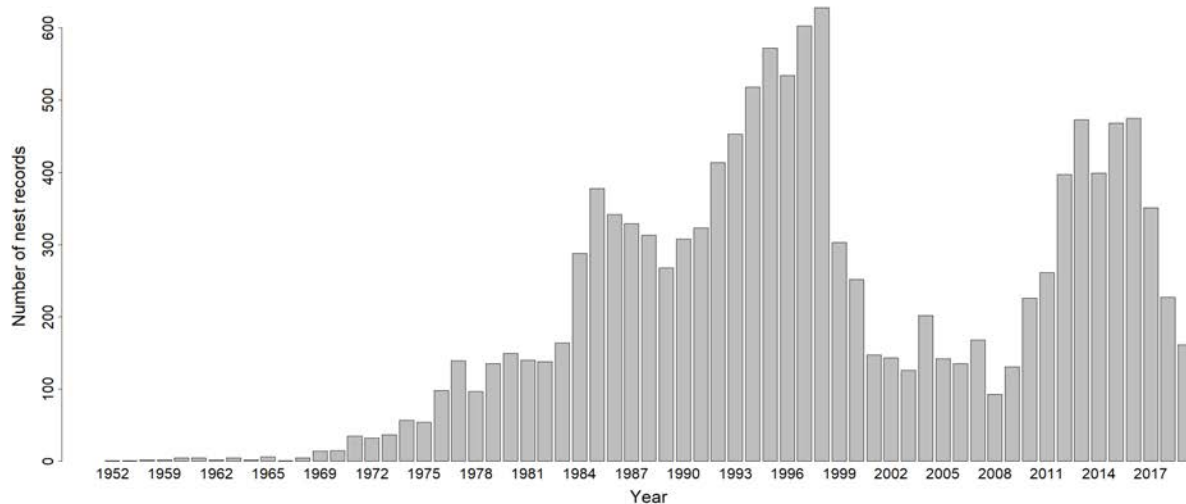
An analysis of breeding phenology was carried out using BTO demographic data drawn from the Nest Record Scheme (NRS) and the Ringing Scheme. Both datasets were restricted to the Moorland and Edge groups described in Section 2.1, and to records deriving from England, Isle of Man, Scotland and Wales. Overlap between the NRS and ringing datasets is difficult to resolve due to the facts that not all records have precise or accurate GPS locations, and that only a subset of records in one dataset correspond to records in the other; data used in any analysis were therefore restricted to that arising from a single survey. As NRS data are best suited to estimating clutch initiation (or 'laying') dates for most of the species included in our analyses (see below for analytical details), these were used preferentially in our analyses.

Records from all parts of England, Scotland and Wales contributed to these analyses. Although the practice of moorland burning is restricted to upland areas, data from lowland areas were also included in our analyses in order to maximise sample sizes. The inclusion of location, topographic and environmental variables in our models of laying date (see below) ensured that outputs reflected typical laying phenology of populations in areas subject to moorland burning.

A standard approach was taken to extraction of phenological information from NRS records (Crick *et al.* 2003), following a similar protocol to that described by Moss *et al.* (2005). For records in the NRS dataset, laying date was taken as the mid-point between the minimum and maximum estimated clutch initiation dates. These are determined for individual NRS records using automated routines, based on the evidence recorded by observers for each nest visit, including number of eggs, maximum clutch size, and growth stage of any chicks present. If the difference between minimum and maximum clutch initiation dates for a record was >10 days, or there were logical inconsistencies in the evidence recorded, the record was excluded from our analyses.

NRS data were also restricted by year and by precision of location information. Data from early years of the NRS were relatively sparse (Figure 2), so the dataset used for global analyses of laying dates for all species was restricted to records collected during the 44-year period from 1976 to 2019. It was further restricted to records for which a grid reference of 1 km or better resolution was available, in order to be able to control for effects of easting, northing, habitat and other environmental variables on laying dates. Of these 24 species, 17 are among those for which the NRS holds sufficient data to carry out routine data analyses and extracts; we restricted our NRS-based analyses to

Figure 2. Annual number of nest records with 1km or better resolution of grid reference available in the Nest Record Scheme for the 25 Moorland and Edge bird species focussed on in this report. The all-species model presented in this report utilised records from 1976 onwards, when the number of records per year averaged 286.6 (range 93 to 628). For years earlier than this period, the average number of records per year was 14.8 (range 1 to 57).



these species. Sample sizes for records with adequate grid reference data varied from just under 100 records per year to almost 600, largely owing to differing levels of investment in volunteer support.

Laying dates for all species were modelled in a single gaussian GLM as a function of year, species, elevation, easting and northing, land cover, soil organic content, road activity and proportion of heather subject to rotational burning. This approach is likely to produce robust estimates for species with smaller sample sizes, and assumes that the phenology of these upland species is likely to respond to large-scale environmental variation in a broadly similar way. Before modelling, 2019 was subtracted from all year values (effectively setting the most recent year in this dataset to 0), and all environmental variables were standardised by subtracting the values for each variable pertaining to 1 km square SE0293 (an area of managed grouse moor in the Yorkshire Dales). This allows realistic mean laying dates to be more easily extracted and inferred from the parameters of the model, and ensures that these estimates are relevant to consideration of timing of moorland burning. Predictions from this model were used to create a standardised distribution of laying dates for three focal years: 2019 (the most recent year), 2002 (the latest year included by Moss *et al.* 2005) and 1979, spanning a period of 40 years.

For each species included in the multi-species model, species-specific models of variation in laying date over time were run. These models were simpler than the model described above, including only easting, northing and elevation alongside year. Records missing grid references were included in order to increase sample sizes (each species was represented by at least 50 records spanning two or more decades). For records that lacked grid references, approximate eastings and northings were taken from the mid-point of the relevant administrative region.

All variables were standardised relative to values for square SE0293, as for variables included in the full model.

Periods at the start and end of the dataset represented by few records were excluded from single-species models. The earliest year that records contributed to individual species trends was set at the first year for which the annual number of records was five or more, and the number of records for the following 10 years was 50 or more. A similar approach was taken to exclude periods of sparse data at the end of the dataset. If the last 10 years (2010–2019) of the dataset for a species had 50 or fewer records within it, then the dataset was foreshortened at its most recent end, excluding consecutive years until the first contributing more than five records and with 50 or more records during the preceding decade was reached.

For a small number of species, laying dates for individual species modelling were extracted from pullus ringing records. This involved estimating age at ringing, either for the whole brood or for the largest chicks in each brood (see below) to derive an estimated hatch date. This hatch date, together with estimated clutch size (based on brood size) and literature-based information about typical length of incubation period and egg-laying period (BTO BirdFacts: <https://www.bto.org/understanding-birds/birdfacts>; and Handbook of the Birds of the World online: <https://birdsoftheworld.org/bow/home>), was used to estimate the date on which the first egg was laid.

Until recently, a unique brood identifier has not been included in the information associated with pullus ringing records. In order to ensure that each brood was represented by a single record, we identified groups of ringing records originating from the same site, and date, retaining only the record relating to the largest (presumed oldest) nestling for analysis. Where more than one brood of the same size was ringed at a site on

one day, we used ring order to indicate how to group pulli into broods and applied the same sub-sampling routine.

Ringing data were used for species only when at least 50 broods had been ringed per decade for two or more decades, where it was possible to estimate laying date with reasonable precision. This was possible for four species: two small passerines (Skylark and Wheatear) and two raptors (Merlin and Hen Harrier). The first two species are ringed as pulli within a sufficiently narrow window, in terms of chick age, that reasonable estimates of hatch, and therefore laying, date can be inferred from ringing phenology, taking into account brood size (eggs of passerines are invariably laid at a rate of one per day). Age at ringing for both species was estimated as approximately 10 days, and incubation period and interval between clutch initiation and the start of incubation as 14 days plus recorded brood size.

Raptors and most other non-passerines have longer nestling periods, and can consequently be ringed over a greater range of ages. For many of these species, however, the biometrics of ringed pulli can be used to age chicks to within a few days. The capacity to do so depends not only on the availability of published material describing the relationships between one or more biometrics and chick age, but on the relevant biometrics having been collected and recorded in the available ringing data. Estimated age for ringed Hen Harrier and Merlin broods was calculated from wing length for both of these species, based on published data. The relationship used to estimate Hen Harrier age was drawn from Picozzi (1980) and was  $7.1024 + 0.0945 * \text{Wing}(\text{mm})$ . The relationship used to estimate Merlin age was drawn from Hardey *et al.* (2013) and was  $0.2281 + 0.1754 * \text{Wing}(\text{mm})$ . Incubation period and the interval between clutch initiation and the start of incubation were estimated as 34 days and 4 days for Hen Harrier; and as 30 days and 3 days for Merlin.

Histograms are used to illustrate the relative numbers of clutches initiated at different times of year. This was done for NRS-based laying dates to show the overall spread of laying dates across all species, over the 44-year period from 1976 to 2019. These laying dates were then standardised, taking residuals from the global model, and adding these to predictions for 1 km square SE0293 (the reference moorland-dominated 1 km square used to parameterise other standardised model outputs) in each of three aforementioned focal years: 1979, 2002 and 2019. Histograms of individual species laying dates are also presented for two 15-year periods (1990 – 2004 and 2005 – 2019), for nine Moorland and Edge species for which there at least 100 NRS records in each of these periods. As well as histograms showing the frequencies of laying dates estimated from individual nest records during these periods, we present histograms based on modelled laying dates. These were standardised (using

values for 1 km square SE0293) to account for variation due to location (easting and northing), as for the species-specific models described above, but not including Year as an explanatory variable.

Requests for other supplementary datasets on timing of breeding of species breeding on, and adjacent to, moorland were also sent to a range of organisations and independent researchers. These requests focussed on species for which data from ringing and nest record datasets were limited, and so for which it might be useful to verify model outputs against independent datasets. All respondents were asked for data relating to timing of breeding for the species of interest that had not already been submitted to the NRS. The datasets received in response to this request were analysed individually, to extract mean laying dates, along with earliest and latest records. Corresponding estimates from the all-species model of laying dates and the relevant species-specific model (see section 2.3), based on the location and range of years each dataset was drawn from, were also calculated.

#### 2.4. Scottish Red Grouse data analysis

An analysis of timing of breeding of Red Grouse was carried out by the Game and Wildlife Conservation Trust (GWCT), based on a long-term study (1992–2016) of nesting Red Grouse in Strathspey (centred on 56° 58'N, 4°11'W), and on a shorter time series (2009–2016) collected from Langholm Moor (centred on 55°10' N, 02°55' E) during a partnership project with Scottish Natural Heritage (now NatureScot), Buccleuch Estates, Royal Society for the Protection of Birds, and Natural England in southern Scotland. This analysis built on previous reports by Moss *et al.* (2005) and Fletcher *et al.* (2013).

Nests were located by following the signal from radio-tagged incubating female Red Grouse. To minimize disturbance during egg-laying and early incubation, this was only attempted after females were expected to have laid a full clutch (from 8th May). Located nests were revisited 2–3 times per week from 15th May onwards, without flushing the female, until hatching, yielding a hatch date accurate to around 1–2 days. At Langholm, all nests in 2013 - 2015 were fitted with thermologgers to obtain exact hatch dates. Clutch initiation date (1st April = 1) for each nest was calculated as hatch date minus time taken to lay a full clutch (assuming one egg laid per day) and complete incubation (mean 21 days). For the analyses in this report, we excluded all nests that failed before hatching because an accurate clutch initiation date could not be calculated, as well as all clutches with initiation dates after 15th May as these were either confirmed or likely replacement clutches. In total, we analysed 533 nests from Strathspey (1992–2016, annual mean = 21 nests, range 5–39 nests) and 85 nests from Langholm (2009 - 2016, annual mean = 11, range 3–17).

Other factors considered for the analyses were female age, altitude, and anthelmintic treatment. As young females may start laying later than older females (Wiebe & Martin 1998, Caizergues & Ellison 2000), we classified female age at nesting as young (first-spring), old (over one year old) or unknown (Strathspey: 75 young, 245 old, 213 unknown; Langholm: 30 young, 47 old, 8 unknown). Nest-site altitude was estimated by referring to the nearest contour on 1 : 25,000 OS maps. Mean altitude in Strathspey was 380 m (260–520 m), while mean altitude at Langholm was 320 m (170–540 m). Altitude of nest sites could influence clutch initiation date through nutrient availability effects on female condition (Watson & Moss 2008). Another factor that may impact on female condition and laying date is infection with the gut parasite *Trichostrongylus tenuis* (Hudson 1986, Shaw & Moss 1990). Grouse moor management routinely involves the treatment of Red Grouse with anthelmintics, administered either directly to caught individuals (dosing) or indirectly via the consumption of medicated grit, which has been shown to increase breeding success (Hudson 1986, Newborn & Foster 2002). In Strathspey, any newly tagged females (n = 289, 53 %) were caught by gamekeepers and dosed with an anthelmintic as part of ongoing management. The remaining monitored clutches were laid by females carrying a radio-tag for a second year, which were not caught and dosed at the start of the breeding season. From spring 2008 all females also had improved access to medicated grit (GWCT 2020).

To better understand the distribution of clutch initiation dates at Strathspey and Langholm, we calculated mean annual clutch initiation dates as well as the annual number of clutches initiated before 15th April (the end of the standard burning season in Scotland and the current deadline for heather burning in England). As the burning season in Scotland can be extended until 30th April with landowner permission (The Muirburn Code 2017), we also calculated the annual number of clutches initiated before 30th April.

To test for differences in clutch initiation dates between Strathspey and Langholm during the period of data overlap (2009–2016), we used linear regression with the annual mean clutch initiation date as the response variable and site as a two-level factor. Differences in the proportion of clutches initiated within the burning season were analysed using logistic regression, with the annual number of clutches initiated by 15th April specified as the response variable, the total number of clutches included as binomial totals, and site included as a factor.

We focussed the analyses examining Red Grouse laying date trends over time on those data collected at Strathspey, where the longer time series was available. We first analysed trends in Red Grouse clutch initiation dates using linear regression, with the mean annual clutch initiation date as response variable, and year and the annual mean

altitude as continuous covariates. We then repeated this analysis separately for the period before (1992–2007) and after (2008–2016) the introduction of the new, more efficient medicated grit. To test for temporal changes in the proportion of clutches initiated within the burning season we used logistic regression, with the annual number of clutches initiated by 15th April specified as the response variable, the total number of clutches included as binomial totals, and year and the annual mean altitude included as covariates.

To account for between-nest variation in altitude, female age, dosing, and the provision of medicated grit, we analysed trends in Red Grouse clutch initiation dates in Strathspey at the level of the individual nest, using General Linear Mixed Models with normal error distribution and identity link function. Clutch initiation date was specified as the response variable, with year and altitude included as continuous covariates, female age as a three-level factor (young, old, unknown), dosing as a two-level factor (dosed, not dosed), and new medicated grit as a two-level factor (present, absent). To fit the model to the adjusted means at the annual level, year was also included as a categorical random effect. The initial model included interactions between year and each of the explanatory variables, which were dropped from the final model if non-significant. To investigate whether including females of unknown age may bias the effect of age, we repeated this analysis using a subsample of the dataset with only known-aged females (320 clutches).

## 2.5. Proportion of birds nesting in areas with rotational burning

For each of the 40 species (14 Moorland species, 11 Edge species and 15 'Additional Upland species) mentioned in Section 2.1, we estimated the proportion of the breeding population found in areas where rotational burning is practised. This was primarily in order to allow our assessments of the impacts of burning on birds nesting in these areas to be put into the context of impacts on their wider populations.

Relative abundance of birds in each tetrad was estimated from Bird Atlas Timed Tetrad Visit (TTV) breeding season count data (Balmer *et al.* 2013). Random Forest Regression Trees (RFRTs) were used to model the relative abundance of each species, with hourly TTV counts as the response variable and all of the environmental variables described in Section 2.2 as explanatory variables. Explanatory variables were mostly available at a 1 km resolution and were rescaled to tetrad level in order to correspond with Bird Atlas TTV data. All variables were retained in every model, as collinearity among explanatory variables (that is, explanatory variables that are closely correlated with one another and so are likely to bear similar relationships to the response variable) is much less problematic for random forest models than for traditional linear modelling approaches.

The models were built using the R package *randomForest* (Liaw & Weiner 2002), which is based on the random forest classifier described by Breiman (2001). A random forest is a classifier consisting of a larger number of regression or classification trees. Each tree recursively partitions a dataset; repeatedly subdividing based on thresholds values of explanatory variables that best explain variation in the dependent variable (for regression) or predict discrete outcomes (for classification). The predicted value for each terminal node (or 'leaf') of the tree is simply the sample mean of the dependent value for all data points in that subdivision. In a random forest, each tree is based on a bootstrapped dataset, generated by sampling the original dataset with replacement. For any given data point, the predicted values for each tree are averaged to yield a prediction from the whole random forest.

For the RFRTs, the number of 'trees' in each 'random forest' was set at 500, and the number of variables sampled as candidates for each tree set at 5 (derived as  $p/3$ , for which  $p$  is the number explanatory variables included in the full model). These models were used to generate relative abundance estimates (i.e. predicted TTV counts) for every tetrad in England, Wales and Scotland.

For each species, mean relative abundance was calculated for each of three categories of tetrad: 'Burn' (the 3,383 tetrads containing 1 km squares in the moorland burning dataset with heather moorland where there was evidence of rotational burning), 'Moor' (the 6,587 tetrads containing 1 km squares with heather moorland and no evidence of burning) and 'Other' (all 56,092 other tetrads). The statistical significance of differences in abundance between these categories was evaluated using T test statistics from a Generalised Linear Model. Finally, the total modelled TTV count for each species across all tetrads in England, Scotland and Wales was calculated, along with the count percentage coming from Burn tetrads in each country.

## 2.6. Migrant arrival and breeding

For migratory species known to breed on or adjacent to moorland, approximate pre-nuptial migration (or 'arrival') periods were estimated separately for England, Wales and Scotland, using BirdTrack (<https://www.bto.org/our-science/projects/birdtrack>) reporting rates from 'complete lists'. Complete lists comprise all bird species heard or seen by the observer within a 'site' (often a 1 km square) during a set period of time. Over a wider area, reporting rate can be determined as the proportion of complete lists that include the relevant species. Variation in this kind of reporting rate tends to be correlated with spatial and temporal variation in abundance (Boersch-Supan *et al.* 2019), though it can also be affected by behavioural variation of both birds and observers.

Increases in spring reporting rates for long-distance migrants are likely to be a result of two processes, the first of which relates to a straightforward increase in the

numbers of birds available for observers to encounter. This effect will apply both in areas where large numbers of birds are passing through on migration, and in breeding areas. The second process is the increase in detectability of birds engaging in courtship and territorial displays, including singing, which will apply disproportionately (though not exclusively) to birds on their breeding grounds. Correspondingly, the fall in reporting rates in mid-spring to early-summer (depending on the species) is likely to be caused by a reduction in the number of migrants encountered on passage, and decreased detectability of birds as they pair up and start to breed. This means that, for long-distance migrants, reporting rates are likely to give a good indication of the window over which pre-breeding impacts of moorland burning could manifest. National BirdTrack reporting rates were used to infer arrival periods for eight species that are obligate long-distance migrants (Cuckoo, Common Sandpiper, Ring Ouzel, Tree Pipit, Wheatear, Whinchat, Whitethroat, Willow Warbler). For these birds, the start of the pre-nuptial migration was taken as the first week in spring showing an upturn in reporting rate; the end of this period was taken as the week in spring/early summer when reporting rate peaked.

Country-wide reporting rates from BirdTrack data do not enable discrimination between birds that are wintering, on passage, or settled in the areas where they will attempt to breed. The 40 species listed in section 2.1 include 16 short-distance and partial migrants, comprising nine waders (Common Sandpiper, Dunlin, Golden Plover, Greenshank, Curlew, Lapwing, Oystercatcher, Redshank and Ringed Plover), three gulls (Black-headed Gull, Common Gull and Lesser Black-backed Gull), one owl (Short-eared Owl) and three passerines (Skylark, Meadow Pipit and Twite). During the winter, all these species are either absent from their upland breeding areas or else present at much lower densities than during the breeding season (Balmer *et al.* 2013). For these species, as well as for all the eight long-distance migrants (Cuckoo, Common Sandpiper, Ring Ouzel, Tree Pipit, Wheatear, Whinchat, Whitethroat, Willow Warbler), we extracted arrival dates from BirdTrack data collected between 2001 and 2020 from 1 km squares with heather moorland where there was evidence of rotational burning. Timing of arrival of breeding birds in these areas is assumed to be directly relevant to consideration of the risk to pre-breeding birds posed by moorland burning.

In order to increase the robustness of arrival date analyses, these were limited to species for which at least 500 records originated from 1 km squares containing heather moorland where there was evidence of rotational burning. This included 19 of the 24 species listed above (the species with fewer than 500 records were Dunlin, Greenshank, Whitethroat, Ringed Plover and Twite). For each of these 19 species, a histogram was plotted showing number of records in five-day periods between 31st January and 30th April (day 31 to day 150 in the Julian calendar). Day of arrival was also modelled for all species, with year (with

intercept set to 2019), country, and species included as explanatory variables.

## 2.7. Statistical software

Analysis of Scottish Red Grouse data was carried out in GenStat 19.1. All other analyses were carried out in the statistical software package R version 3.6.3 (R Core Team 2020), implemented in RStudio version 1.2.5033.

## 3. RESULTS

### 3.1. Timing of breeding for moorland and peripheral species from BTO datasets

From the multi-species model of laying date based on NRS records (Table 1), mean laying date (as previously noted in section 2.3, standardised to 2019, for an area of grouse moor in the Yorkshire Dales) spans a two-month period, ranging from 26th March, for Peregrine, to 26th May, for Whinchat. Over the four-decade period from which the modelled data are drawn, mean laying date across all species in the model has advanced by about one day every eight years. Other variables that have a significant effect on laying date in this model are easting, northing, conifer woodland, semi-natural grassland, rainfall and temperature. The modelled effect of all of these variables is positive. It should be borne in mind, however, that some of these effects are closely inter-correlated, so apparent relationships should be interpreted with caution.

Table 2 illustrates the percentage of laying dates from NRS data, standardised using modelled predictions for 2019, that fall before the close of each the three main burning seasons considered in this report. This figure varies considerably between both species and seasons. Overlap for all species with the Welsh upland burning season, which closes on the 31st March, is low. The breeding attempts of more than half of the species considered here do not overlap with this period at all, with the greatest overlap (31% of breeding attempts) being for Peregrine. Overlap with the main upland burning season for England and Scotland, which closes on the 15th April, is still quite low for most species – 11% or less for nine species, and greater than 50% for just two species – Lapwing (52%) and Peregrine (82%). Overlap with the extended upland burning season in Scotland is much higher for most species; greater than 50% for six species (with the greatest overlap being 96% for Peregrine), and less than 20% for just three long-distance migrants, these being Wheatear (16%), Common Sandpiper (4%) and Whinchat (0%). Table 2 also gives the standardised dates by which 5%, 50%, 95% and 100% of nests for these species have been laid. The period between the 5% and 95% quantiles varies from 30 – 84 days. Species that lay within relatively short periods, with 90% of clutches initiated within a period of 40 days or less, are 4 largely single-brooded species; two falcons, Merlin and Peregrine, and two long-distance migrants, Common Sandpiper and Whinchat. At the other

end of the spectrum are four resident species for which first egg dates span 70 or more days; Stonechat, Snipe, Skylark and Ringed Plover. All of these apart from Snipe are commonly double-brooded.

The distribution of real and standardised laying dates from NRS data reveals a modest increase in the proportion of clutches initiated before the end of each of the currently operating burning seasons over the past 40 years (Figure 3). In 1972, for the species presented here, 14.3% of clutches were started before the end of the current upland burning season in England, and the main burning season in Scotland; in contrast, only 1.6% were started before the end of the current upland burning season in Wales, and the lowland burning season in England. By 2019, these figures had increased to 20.9% and 5.0% respectively.

However, recent shifts in timing of breeding varied considerably between species (Figure A1.1). Of the nine species for which there are sufficient data to assess this, the proportion of nesting attempts started within at least one of the currently operating burning seasons increased by 10% or more for three species (Peregrine, Lapwing and Stonechat), by less than 5% for three species (Meadow Pipit, Oystercatcher and Ringed Plover) and remained similar or even decreased slightly for the other three (Ring Ouzel, Skylark and Whinchat).

The outputs from the individual species models (whether using laying dates based on NRS data or on ringing records) are broadly in line with those from the all-species model. All but two of the standardised estimates of laying date from the individual species models (Table 3) are within five days of the species-specific estimates from the global model. The biggest discrepancy (10 days), recorded for Golden Plover, is due to predictions being extrapolated 25 years beyond the dataset that the species model is based on. This suggests that laying dates estimated for individual species by the global model are not grossly inaccurate. Nevertheless, there is considerable variation among the relationships between laying date and year in these species-specific models (Table 3; Figure A2.1). Although eight of the 17 models based on NRS data (and all four of the models based on ringing data) include a significant negative relationship between laying date and year, the other nine do not; and in two of these models (Redshank and Skylark) the relationship is actually positive. Moreover, the slope of the relationship among the models for which this is significantly negative varies considerably, from -0.11 days per year (Ring Ouzel NRS model, and Wheatear ringing model) to -0.62 and -0.70 days per year (Hen Harrier and Golden Plover, respectively). Models based on longer time series showed less of an advance in laying date. The five models based on records starting before 1950 showed no advance in date, and two suggested that laying date got later over time. In contrast, 12 of the 16 models based on records from 1950 onwards suggested an advance (median 0.12 days per year).

Table 1. Parameters of a GLM model with clutch initiation date (expressed as the number of days since 31st December) as the response variable. Explanatory variables are: Year (minus 2019, in order to set the year of the latest records included in the model to zero), Species (an 18-level factor, with number of records for each species given in brackets after its name, the intercept is set to the values for Common Sandpiper), Elevation, and a number of variables at the 1 km level including: Easting and Northing; Proportional cover of seven land cover variables; mean annual Rainfall and Temperature; percentage of organic matter in soil; mean traffic flow along Roads; and percentage of moorland subject to rotational burning. All of these environmental variables are standardised relative to the values for SE0293, so that the model estimates given below apply more directly to an area in the Pennines where rotational burning is practised.

Variable	Estimate	S.E.	T	P
(Intercept)	134.23	1.94	69.34	< 0.0001
Year	-0.14	0.02	-6.88	< 0.0001
SPECIES_Common Sandpiper (n=179)	0.00	0.00	0.00	1
SPECIES_Curlew (n=124)	-11.72	2.19	-5.34	< 0.0001
SPECIES_Golden Plover (n=82)	-23.22	2.57	-9.04	< 0.0001
SPECIES_Hen Harrier (n=35)	-9.44	3.47	-2.72	0.01
SPECIES_Lapwing (n=1423)	-28.20	1.51	-18.71	< 0.0001
SPECIES_Meadow Pipit (n=1,045)	-1.45	1.55	-0.93	0.35
SPECIES_Merlin (n=160)	-10.38	2.12	-4.90	< 0.0001
SPECIES_Oystercatcher (n=918)	-11.26	1.56	-7.23	< 0.0001
SPECIES_Peregrine (n=268)	-38.76	1.84	-21.07	< 0.0001
SPECIES_Redshank (n=208)	-11.74	1.97	-5.95	< 0.0001
SPECIES_Ring Ouzel (n=789)	-7.78	1.64	-4.75	< 0.0001
SPECIES_Ringed Plover (n=121)	-3.31	2.22	-1.49	0.14
SPECIES_Skylark (n=209)	9.30	1.96	4.74	< 0.0001
SPECIES_Snipe (n=138)	-10.92	2.14	-5.11	< 0.0001
SPECIES_Stonechat (n=1,384)	-16.03	1.56	-10.26	< 0.0001
SPECIES_Wheatear (n=439)	-3.42	1.74	-1.97	0.05
SPECIES_Whinchat (n=1,131)	11.63	1.57	7.40	< 0.0001
Elevation (per m)	0.00	0.00	-0.75	0.45
Easting (per 100 km)	1.67	0.37	4.52	< 0.0001
Northing (per 100 km)	1.40	0.22	6.34	< 0.0001
Broadleaved Woodland	-0.05	0.03	-1.78	0.08
Conifer Woodland	0.04	0.02	1.89	0.06
Arable Farmland	0.01	0.02	0.58	0.56
Improved Grassland	0.02	0.02	0.90	0.37
Semi-natural Grassland	0.06	0.02	2.79	0.01
Mountain/Heath/Bog	0.04	0.02	1.98	0.05
Built land	-0.03	0.02	-1.33	0.18
Rainfall (per cm)	0.62	0.10	6.46	< 0.0001
Temperature (per °C)	1.60	0.45	3.52	0.0004
% Organic matter	0.03	0.02	1.34	0.18
Road flow	0.00	0.00	0.28	0.78
% Moorland burning	-0.02	0.03	-0.45	0.65

Table 2. Summaries of timing of breeding attempts for 17 upland species, using standardised clutch initiation dates based on NRS records. Clutch initiation dates were standardised using predicted values for the year 2019 and environmental variables for 1 km square SE0293 from the multi-species model summarised in Table 1. Three columns give the percentage of clutches initiated before each of three dates: March 31st (the end of the upland burning season in Wales); April 15th (the end of the main upland burning season in both England and Scotland); and 30th April (the end of the extended upland burning season in Scotland). The shade of red in each cell of these columns reflects the proportion of clutches started before the relevant date. The last four columns in the table give the date by which 5%, 50%, 95% and 100% of clutches represented by records in this dataset were initiated.

Species	March 31st	April 15th	April 30th	5th percentile	50th percentile	95th percentile	100th percentile
Common Sandpiper (n=179)	0	0	4	01-May	14-May	01-Jun	17-Jun
Curlew (n=124)	0	6	47	14-Apr	01-May	25-May	10-Jun
Golden Plover (n=82)	10	45	74	27-Mar	17-Apr	01-Jun	19-Jun
Hen Harrier (n=35)	0	11	43	13-Apr	03-May	03-Jun	10-Jun
Lapwing (n=1,423)	15	52	78	26-Mar	14-Apr	21-May	16-Jun
Meadow Pipit (n=1,045)	0	2	26	20-Apr	08-May	18-Jun	18-Jul
Merlin (n=160)	0	0	40	22-Apr	02-May	22-May	09-Jun
Oystercatcher (n=918)	0	8	46	12-Apr	01-May	30-May	21-Jun
Peregrine (n=268)	31	82	96	22-Mar	05-Apr	26-Apr	29-May
Redshank (n=208)	0	9	50	13-Apr	30-Apr	05-Jun	24-Jun
Ring Ouzel (n=789)	0	6	46	14-Apr	01-May	09-Jun	11-Aug
Ringed Plover (n=121)	1	11	36	12-Apr	10-May	21-Jun	30-Jun
Skylark (n=209)	0	1	20	21-Apr	25-May	04-Jul	26-Jul
Snipe (n=138)	7	27	51	29-Mar	29-Apr	18-Jun	08-Jul
Stonechat (n=1,384)	8	41	62	29-Mar	19-Apr	21-Jun	29-Jul
Wheatear (n=439)	0	2	16	21-Apr	09-May	05-Jun	19-Jun
Whinchat (n=1,131)	0	0	0	11-May	23-May	20-Jun	02-Jul



Figure 3. a) Actual: histogram of clutch initiation dates from NRS records (1976 – 2019) for the 14 Moorland and 11 Edge species; b), c) and d) histograms of clutch initiation dates based on the same data, but standardised for all environmental variables to values for square SE0293, in Yorkshire Dales, and to one of three years during this period, using predictions from the GLM summarised in Table 3: b) standardised to 1979, 40 years before the most recent year of this trend period; c) standardised to 2002, the last year for which NRS records were included in the previous report on timing of breeding of moorland birds (Moss et al. 2005); and d) standardised to 2019, the last year for which records are included in this report. Red, purple and blue dashed lines indicate dates relevant to regulation of heather burning. These are, respectively, 31st March, 15th April and 30th April. The figure above each line indicates the percentage of clutches laid before the relevant date.

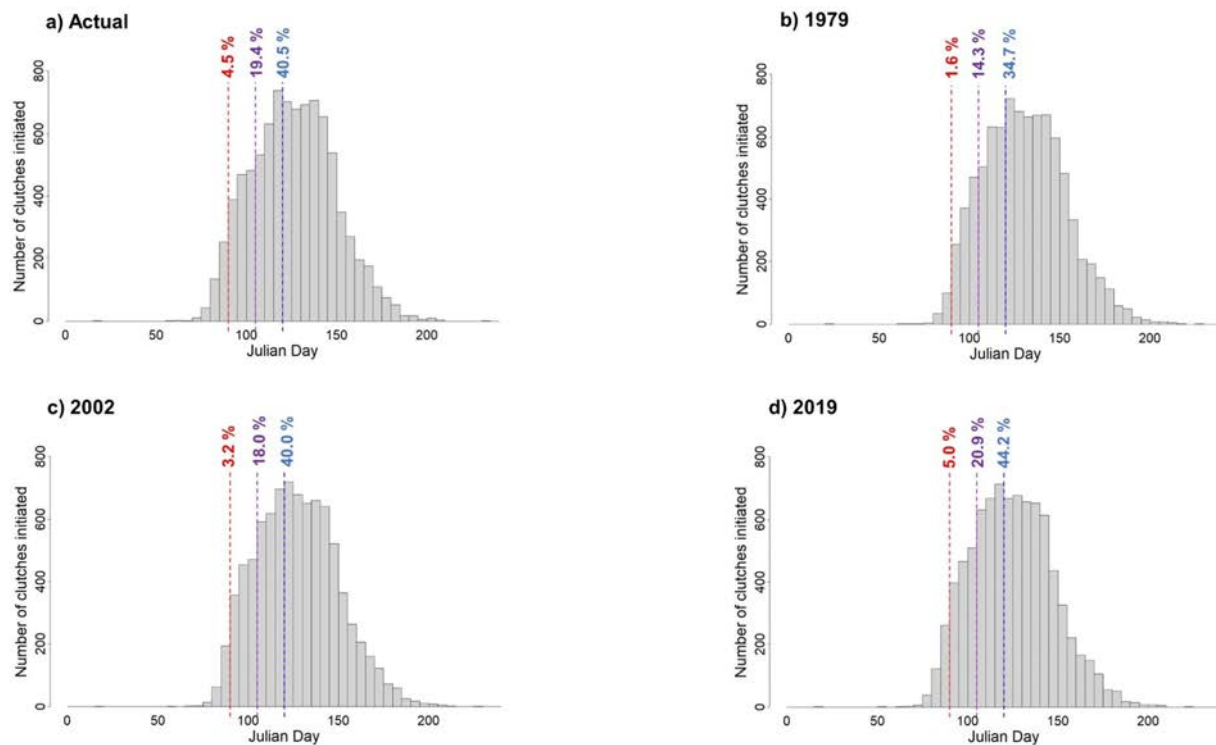


Table 3. Parameters of individual species GLM model with clutch initiation date (expressed as the number of days since 31st December) as the response variable, based on data from a) the Nest Record Scheme and b) ringing records. Explanatory variables included in each model were: Year, Easting and Northing. Sample size in each year of the trend period (see the 'Period' column) is given in Figure A2 1 in the Appendix. The value for the most recent year included in the modelled dataset was subtracted from Year values, so that the intercept of each model (given, along with 95% confidence interval, in the column 'Laying date') gives the estimated laying date for the most recent year of the trend. Moreover, Easting and Northing values included in the model were standardised relative to the values for 1 km square SE0293. Parameter values for Year, Easting and Northing (along with 95% confidence intervals) are given only for models where the effect of these parameters on laying date was significant.

Species	Source	Period	Laying date	Year	Easting	Northing
a)						
Common Sandpiper	NRS	1968–2019	134.1 (131.3–136.9)	-0.12 (-0.21– -0.03)	–	–
Curlew	NRS	1970–2000	123.4 (119.5–127.2)	–	–	–
Golden Plover	NRS	1968–1995	109.4 (102.6–116.1)	-0.7 (-1.2– -0.21)	–	–
Hen Harrier	NRS	1984–2014	110 (104.4–115.5)	-0.62 (-0.93– -0.31)	-6.72 (-10.17– -3.27)	–
Lapwing	NRS	1962–2019	107.3 (105.6–108.9)	–	–	0.91 (0.46–1.35)
Meadow Pipit	NRS	1950–2019	135.2 (133.7–136.6)	–	–	0.95 (0.66–1.23)
Merlin	NRS	1976–2009	124.1 (121.4–126.8)	-0.22 (-0.36– -0.07)	–	0.46 (0–0.91)
Oystercatcher	NRS	1962–2019	131 (130.1–131.9)	-0.12 (-0.15– -0.08)	3.31 (2.88–3.73)	-0.99 (-1.24– -0.75)
Peregrine	NRS	1974–2019	91.5 (89.4–93.7)	-0.18 (-0.29– -0.07)	-2.35 (-3.65– -1.05)	0.71 (0.16–1.27)
Redshank	NRS	1945–2013	126.6 (123.8–129.3)	0.12 (0.04–0.19)	–	–
Ring Ouzel	NRS	1952–2019	126.2 (124.3–128.1)	-0.11 (-0.17– -0.05)	-2.38 (-4.18– -0.59)	–
Ringed Plover	NRS	1956–2019	141.3 (139.4–143.1)	–	–	–
Skylark	NRS	1939–2019	141.5 (138.2–144.8)	0.08 (0–0.15)	3.35 (2.07–4.63)	–
Snipe	NRS	1940–2006	130.1 (125–135.1)	–	4.1 (1.03–7.16)	1.34 (0.01–2.68)
Stonechat	NRS	1957–2019	119.2 (117.1–121.4)	-0.14 (-0.21– -0.08)	1.37 (0.45–2.3)	0.99 (0.47–1.51)
Wheatear	NRS	1940–2018	135.9 (133.5–138.2)	–	1.39 (0.53–2.26)	0.9 (0.44–1.36)
Whinchat	NRS	1947–2019	148.4 (147.1–149.7)	–	–	–
b)						
Hen Harrier	Ringing	1997–2020	115.1 (111.5–118.7)	-0.35 (-0.54– -0.15)	–	–
Merlin	Ringing	1987–2018	120.9 (118.7–123.1)	-0.14 (-0.26– -0.02)	–	0.94 (0.47–1.41)
Skylark	Ringing	1996–2020	135 (131.2–138.8)	-0.32 (-0.59– -0.06)	–	–
Wheatear	Ringing	1975–2020	129.4 (127.9–130.8)	-0.11 (-0.17– -0.05)	1.08 (0.55–1.62)	0.67 (0.44–0.9)

Figure 4. Frequency distribution of Red Grouse clutch initiation dates from 1992 to 2016 in Strathspey. End of the burning season illustrated with red line (solid = standard season. dashed = extended season in Scotland).

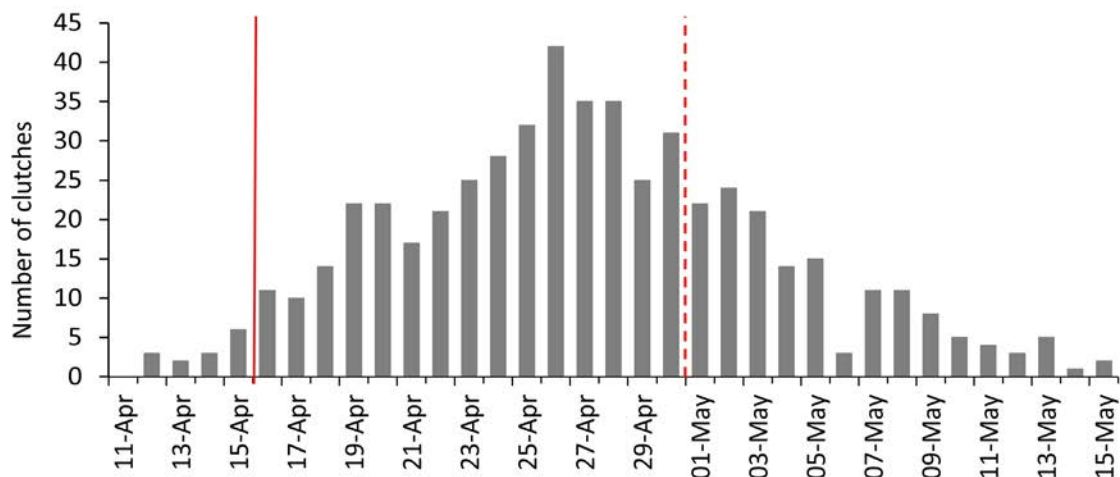


Table 4. Summary details of local nest studies that have provided datasets for analysis of timing of breeding, along with laying date information for the species and areas covered by these studies: Study (the empirical mean and range of the laying dates recorded for these datasets); Global model (the estimate and 95% confidence interval taken from the model including all species with parameters reported in Figure 1) and Species model (the estimate and 95% confidence interval taken from the relevant model for individual species, with parameters summarised in ). Study owner initials are BB (Brian Bates), RS (Ron Summers) and BE (Brian Etheridge). Laying date method gives the method (or methods) by which estimates of laying date in each dataset were generated: D (estimates based on egg density measurements); P (estimates based on observations of partially completed clutches) and H (estimates based on hatching dates, either observed directly or inferred from estimated ages of chicks).

Species	Owner	Area	Years	Records	Method	Study	Global model	Species model
Golden Plover	RSPB	Sutherland	2009–11	16	D, H	110.7 (99–139)	115.5 (111.1–119.8)	120.6 (111.2–130)
Curlew	RSPB	S Scotland, Geltsdale	2019	26	D, P, H	124.9 (113–154)	125.6 (119.6–126.9)	129.5 (120.4–127.6)
Curlew	GWCT & BB	Deeside, Speyside	2016–20	15	H	125.9 (110–136)	123.4 (119.8–127)	123.5 (120.1–126.8)
Common Sandpiper	RS & BE	Sutherland	2013–16	17	D	136.9 (121–165)	140.4 (136.7–144.1)	136.8 (133.2–140.4)
Common Sandpiper	BB	Speyside	2010–19	13	H	129.3 (121–144)	134.8 (131.5–138)	136.2 (133.4–139)
Common Sandpiper	Lancaster Uni	Cumbria	2017–19	46	D, P, H	134.1 (118–164)	134.7 (131.6–137.8)	134.2 (131.6–136.8)

Table 4 summarises the datasets and responses received from individuals and organisations approached for datasets relating to timing of nesting for the species of interest. Although typically small in size, these datasets are comprised of relatively precise data, with estimated laying dates drawn from egg density data, from observations of partially completed clutches, or from age-estimates of newly-hatched chicks. These data can, therefore, be used to validate the conclusions drawn from NRS and ringing data. Despite their small sample sizes, results from all six additional datasets correspond closely with the predictions from the global and species-specific models based on NRS data.

### 3.2. Scottish Red Grouse data analysis

#### 3.2.1. Distribution of the clutch initiation dates

Across all years, 14 of 533 Red Grouse clutches (3 %) monitored in Strathspey were initiated within the standard burning season (on or before 15 April) and 72 % within the extended burning season in Scotland (on or before 30th April, Figure 4). In years when clutches were initiated before the end of the standard burning session, the percentage varied from 3 % to 19 % of clutches monitored. However, in 18 out of 24 years (75 % of the study period) all clutches were initiated after the standard burning season had closed (Table 5). The proportion of Red Grouse clutches initiated within the burning season increased significantly between 1992 and 2016 (slope  $0.19 \pm 0.07$ ,  $\chi^2_{1,21} = 7.85$ ,  $P = 0.005$ ).

During the more recent time period (2009 to 2016, Figure 5) three out of 85 clutches (4 %) at Langholm were initiated within the standard burning season. In any one year, the percentage of clutches initiated within the standard burning season varied from 8 % to 17 %, but in six of eight years the standard burning season closed before any eggs were laid (Table 5). During the same time period, 10 of 211 (5 %) clutches in Strathspey were initiated within the standard burning season. The percentage of clutches initiated within the standard burning season varied from 3 % to 19 %, but in four of eight years all clutches were initiated after the standard burning season. Between 2009 and 2016, the annual proportion of clutches initiated within the standard burning season did not differ between sites ( $\chi^2_{1,14} = 0.21$ ,  $P = 0.65$ ).

#### 3.2.2. Changes in clutch initiation dates over time

Between the start of April 1992 and mid-May 2016, 533 Red Grouse nests were located in Strathspey, with a mean clutch initiation date of 27th April (range 12th April to 15th May, Figure 6). During this period, average clutch initiation date advanced (slope  $-0.459 \pm 0.093$ ,  $F_{1,21} = 22.05$ ,  $P < 0.001$ , Figure 7) by 0.46 days per year (95% CI 0.28–0.64 days per year). Mean clutch initiation dates were not associated with mean altitude (slope  $0.035 \pm 0.037$ ,  $F_{1,21} = 0.91$ ,  $P = 0.35$ ). When splitting the dataset into the periods before and after the introduction of the new medicated grit in 2008, however, we only identified a significant advancement in clutch initiation dates between 1992 and 2007 (slope  $-0.458 \pm 0.182$ ,  $F_{1,12} = 6.33$ ,  $P = 0.027$ ). The trend between 2008 and 2016 was

associated with greater variation between years and so was not statistically significant (slope  $-0.753 \pm 0.404$ ,  $F_{1,6} = 3.47$ ,  $P = 0.112$ ).

During breeding seasons from 2009 to 2016, 85 nests were located at Langholm, with a mean clutch initiation date of 22nd April (range 11th April to 8th May, Figure 6). During the same period, 211 nests were located in Strathspey with mean clutch initiation date of 24th April (range 12th April to 13th May, Figure 6). There was no significant difference in average clutch initiation dates between sites ( $F_{1,14} = 1.67$ ,  $P = 0.22$ ; Figure 7).

When the Strathspey data were analysed at the level of the individual nest, the final model reflected the trend over time from the linear regression based on the mean laying date, with a significant advancement in laying date across the whole time series (1992–2016, slope  $-0.481 \pm 0.179$ ,  $F_{1,526} = 7.21$ ,  $P = 0.013$ ).

Strathspey Red Grouse nests at higher altitudes were initiated significantly later than those at lower altitude (slope  $0.011 \pm 0.005$ ,  $F_{1,526} = 4.27$ ,  $P = 0.039$ , Figure 8), indicating that clutch initiation dates were 1.1 days later per 100 m increase in altitude (95% CI 0.1–2.2). Nest altitude was less variable in the most recent decade (Figure 8 and Figure 9), but there was no significant interaction between year and altitude. There was no effect of female age ( $F_{2,526} = 0.21$ ,  $P = 0.81$ ), dosing ( $F_{1,526} = 0.45$ ,  $P = 0.50$ ), or medicated grit ( $F_{1,526} = 0.30$ ,  $P = 0.60$ ) on individual clutch initiation dates. Excluding females of unknown age from the dataset did not change this result.

### 3.3. Proportion of birds nesting in areas with rotational burning

Most species in the Moorland group were more abundant in tetrads where moorland burning is practised than either in non-burned moorland tetrads, or in other tetrads (Table 6). Moorland species with notably higher densities in 'Burn' tetrads include Golden Plover, Meadow Pipit, Red Grouse and Ring Ouzel. The only two Moorland species with lower densities in 'Burn' tetrads than in either of the other two categories were Dunlin and Greenshank, which are both species that tend to reach their highest densities in wetter peatland habitats and, in the case of Dunlin, machair (Forrester *et al.* 2007; Fuller *et al.* 2010).

The pattern is more mixed for grassland/moorland Edge species, with waders in particular showing strongly contrasting patterns of association. Densities of Curlew, Lapwing and Snipe are all much higher in 'Burn' tetrads than on 'Moor' or other tetrads. Oystercatcher, Redshank and Ringed Plover are, however, less abundant on 'Burn' and 'Moor' than on other tetrads, as is Twite. Most of the widespread species are less abundant in 'Burn' tetrads than in either of the other two categories, but Cuckoo and Dipper are both exceptions to this rule.

**Table 5. Percentage of Red Grouse clutches initiated within the standard burning season (before or on 15th April) and those initiated within the extended burning season in Scotland (before or on 30th April).**

	Year	N clutches	% initiated	
			before/on 15th April	before/on 30th April
Strathspey	1992	8	0	13
	1993	11	0	27
	1994	5	0	0
	1995	0	-	-
	1996	12	0	50
	1997	11	0	73
	1998	31	0	65
	1999	39	8	79
	2000	18	0	72
	2001	18	0	28
	2002	25	0	52
	2003	32	3	88
	2004	17	0	53
	2005	24	0	83
	2006	28	0	61
	2007	30	0	80
	2008	13	0	54
	2009	20	0	70
2010	20	0	85	
2011	33	0	97	
2012	27	19	93	
2013	22	0	32	
2014	29	7	97	
2015	31	3	90	
2016	29	7	97	
	<b>All years</b>	<b>533</b>	<b>3</b>	<b>72</b>
Langholm	2009	12	0	100
	2010	8	0	100
	2011	11	0	100
	2012	12	17	92
	2013	17	0	82
	2014	12	8	92
	2015	10	0	100
	2016	3	0	67
		<b>All years</b>	<b>85</b>	<b>4</b>

Figure 5. Frequency distribution of Red Grouse clutch initiation dates from 2009 to 2016 in Strathspey and Langholm. End of the burning season illustrated with red line (solid = standard season, dashed = extended season in Scotland).

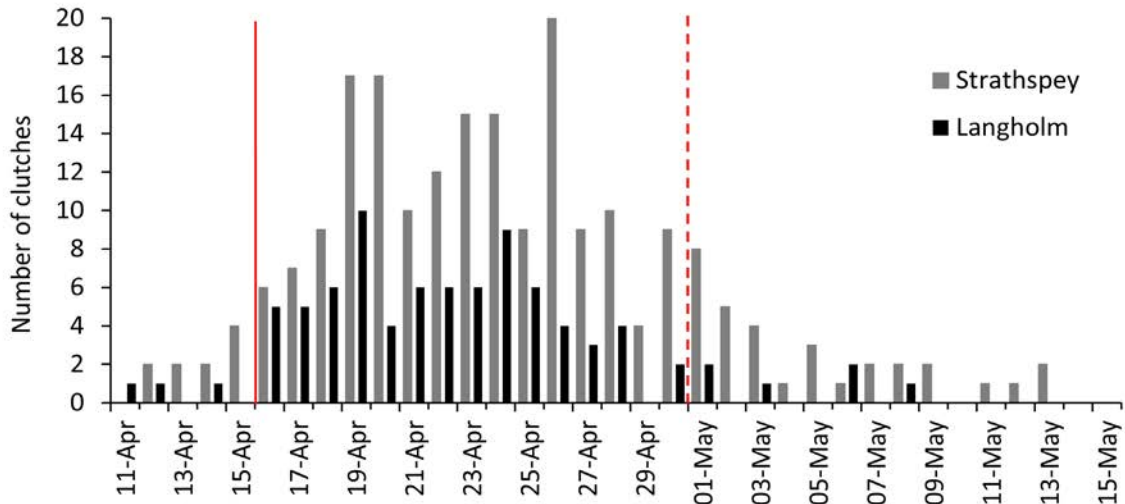


Figure 6. Clutch initiation dates from all Red Grouse nests monitored in Strathspey (1992–2016) and Langholm (2009–2016).

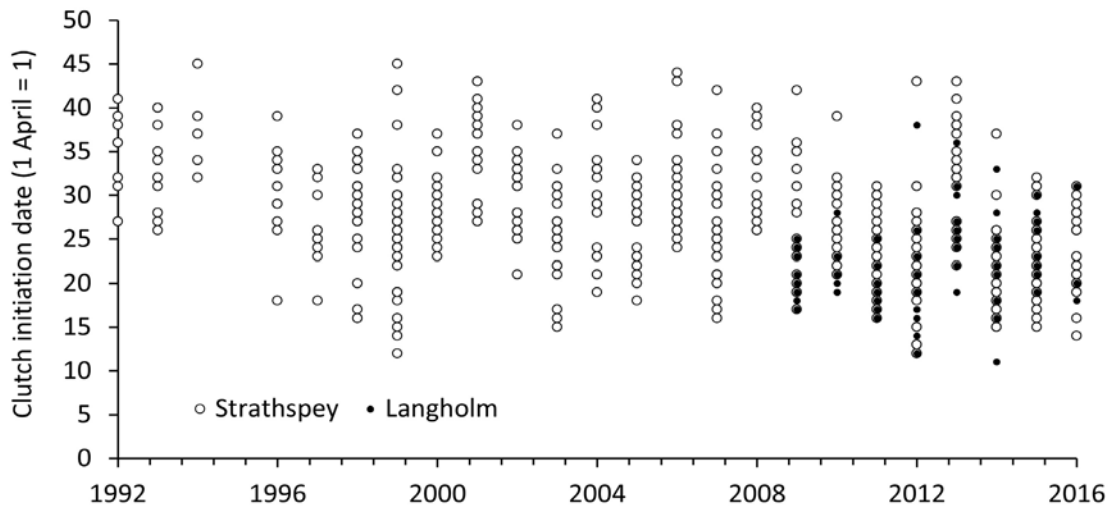


Figure 7. Annual mean clutch initiation dates for Red Grouse nests monitored in Strathspey (1992–2016) and Langholm (2009–2016). The dotted regression line shows the significant long-term trend for Strathspey.

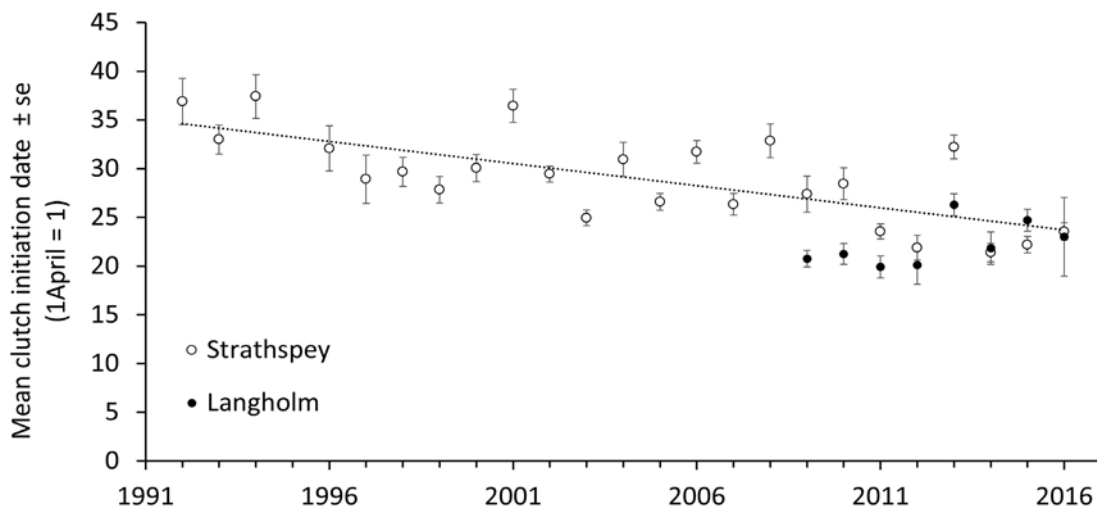


Figure 8. Red Grouse clutch initiation dates in relation to altitude of the nest (to nearest 10 m) in Strathspey 1992 to 2016 (dashed regression line).

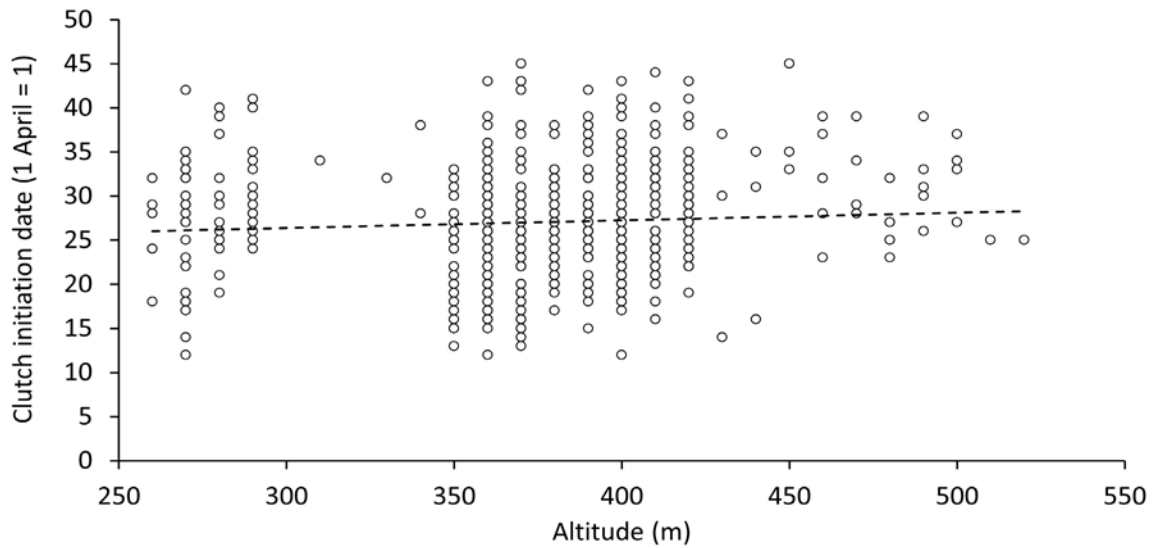
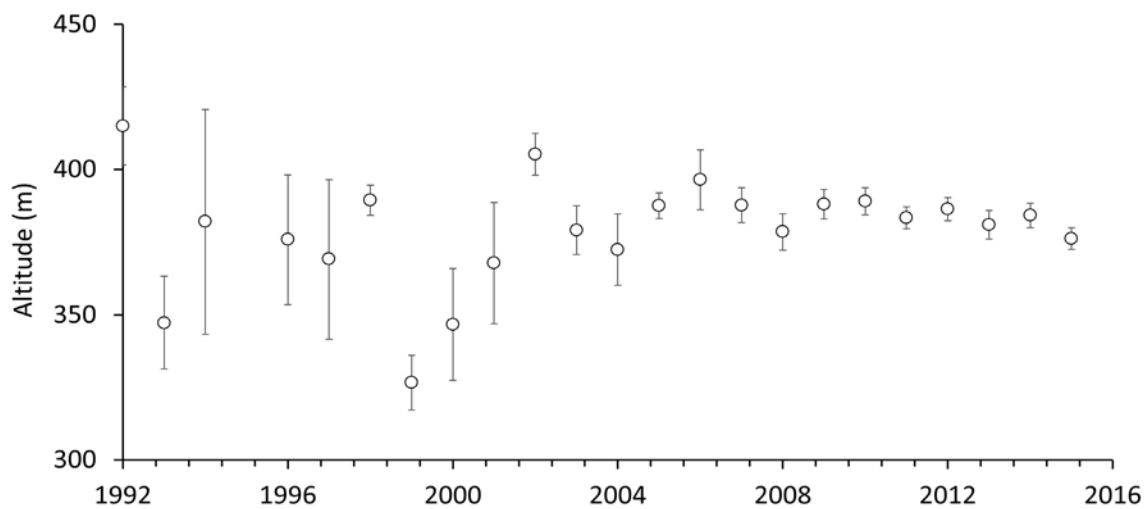


Figure 9. Annual altitude distribution of Red Grouse nests monitored in Strathspey (1992–2016).



**Table 6. Relative abundance information from modelled Timed Tetrad Visit (TTV) Bird Atlas counts.** A. For each species in three different groups of birds (Moorland, Moorland Edge, and Additional Upland species), the mean TTV count is given in each of three categories of tetrad: 'Burn' (includes all tetrads overlapping 1 km squares in the moorland burning dataset with any evidence of rotational heather burning), 'Moor' (includes all tetrads overlapping 1 km squares in the moorland burning dataset with heather moorland but no burning) and 'Other' (all other tetrads). Mean 'Burn' counts are shaded pink if they are significantly greater than counts in 'Moor' and/or 'Other', or blue if they are significantly less than counts in 'Moor' and/or 'Other', or else unshaded, if they are either not significantly different from counts in either of the other two categories, or else are different from both, but in different directions. The shading of the 'Moor' and 'Other' categories indicates the significance and direction of differences with 'Burn'. B. T test statistic and P value for each of the comparisons between modelled TTV counts in 'Burn' tetrads and those in 'Moor' and 'Other' tetrads. C. Total modelled TTV count of each species in England, Scotland and Wales, and percentage of this count coming from 'Burn' tetrads. These percentage values are shaded according to their size – the deeper the shade of red, the larger the proportion of population is likely to be supported by areas with rotational heather burning. At the top of the table, the number of tetrads in each of the three categories (followed by the percentage of the total in brackets) is given for each country. Note that, while the 'Burn' category probably includes the vast majority of burned moorland in each country, the 'Moor' category only covers a proportion of all unburned moorland.

		A. Great Britain TTVs			B. Category differences				C. Total TTV count and % in 'Burn' 1 km squares					
		Mean Counts			Burn v. Moor		Burn v. Other		ENGLAND Burn: 1,221 (4) Moor: 1,948 (6) Other: 30,658 (91)		SCOTLAND Burn: 2,095 (9) Moor: 4,934 (22) Other: 15,661 (79)		WALES Burn: 75 (1) Moor: 288 (5) Other: 5,268 (94)	
Group	Species	Burn	Moor	Other	T	P	T	P	Total	% Burn	Total	% Burn	Total	% Burn
Moor	Black Grouse	0.08	0.06	0.01	3.5	0.000	24.5	0.000	153	74	833	20	9	23
Moor	Dunlin	0.01	0.04	0.45	-1.7	0.082	-2.7	0.007	6,968	0	5,992	1	335	0
Moor	Golden Eagle	0.01	0.01	0.01	1.4	0.148	0.7	0.485	3	12	479	6	1	2
Moor	Golden Plover	0.61	0.23	0.09	13.5	0.000	38.7	0.000	2,319	61	5,497	12	167	2
Moor	Greenshank	0.01	0.02	0.02	-1.4	0.150	-3.8	0.000	46	0	1,193	3	1	3
Moor	Hen Harrier	0.01	0.01	0.01	0.1	0.919	7.2	0.000	8	29	358	9	42	30
Moor	Meadow Pipit	8.69	5.87	2.46	24.1	0.000	71.2	0.000	42,813	28	126,198	13	19,262	5
Moor	Merlin	0.02	0.01	0.00	10.5	0.000	41.3	0.000	31	62	171	29	13	11
Moor	Peregrine	0.02	0.02	0.02	1.7	0.093	2.9	0.004	319	5	430	12	191	2
Moor	Red Grouse	1.97	0.39	0.05	36.7	0.000	118.2	0.000	4,314	78	7,679	43	68	23
Moor	Ring Ouzel	0.11	0.03	0.01	17.6	0.000	51.8	0.000	206	61	604	40	61	1
Moor	Short-eared Owl	0.01	0.00	0.00	6.0	0.000	9.5	0.000	72	33	97	5	2	1
Moor	Stonechat	0.26	0.19	0.14	6.3	0.000	14.8	0.000	2,221	11	4,845	13	1,480	2
Moor	Whinchat	0.05	0.06	0.02	-2.7	0.007	8.7	0.000	205	17	1043	11	377	5
Edge	Common Gull	1.49	0.88	1.03	6.8	0.000	6.5	0.000	738	7	49,829	10	228	1
Edge	Com. Sandpiper	0.29	0.21	0.10	10.3	0.000	33.4	0.000	674	29	6910	11	239	3
Edge	Curlew	2.24	1.10	0.35	29.1	0.000	76.0	0.000	13,249	35	17,475	16	808	3
Edge	Lapwing	2.24	1.24	0.86	17.7	0.000	35.1	0.000	34,725	13	23,006	13	1,008	1
Edge	Oystercatcher	1.05	0.99	2.52	1.6	0.101	-5.4	0.000	33,034	3	52,603	5	4,995	0
Edge	Redshank	0.12	0.08	0.27	6.9	0.000	-6.7	0.000	5,724	5	5,560	3	320	0
Edge	Ringed Plover	0.02	0.05	0.43	-3.0	0.003	-11.4	0.000	3,858	0	8,383	1	855	0
Edge	Skylark	2.06	2.20	2.32	-2.7	0.007	-5.7	0.000	81,548	4	49,123	8	9,090	2
Edge	Snipe	0.33	0.17	0.11	17.9	0.000	28.6	0.000	1,437	35	5,702	10	113	3
Edge	Twite	0.01	0.02	0.09	-2.8	0.005	-11.3	0.000	130	13	3,137	1	29	5
Edge	Wheatear	0.77	0.61	0.40	8.8	0.000	21.3	0.000	4,099	22	16,317	10	3,305	2
Upland	B-headed Gull	2.37	2.58	2.16	-0.4	0.720	0.5	0.600	78,995	6	36,039	9	4,156	2
Upland	Buzzard	0.51	0.64	0.57	-11.3	0.000	-6.4	0.000	19,441	2	12,049	11	5,272	1
Upland	Cuckoo	0.16	0.13	0.11	8.5	0.000	13.9	0.000	3,240	4	3,517	11	638	6
Upland	Dipper	0.12	0.10	0.04	4.3	0.000	34.3	0.000	932	13	1,539	17	544	1
Upland	Grey Wagtail	0.16	0.18	0.09	-2.7	0.007	21.0	0.000	2,823	6	2,741	14	853	1
Upland	Kestrel	0.16	0.14	0.17	5.3	0.000	-0.5	0.608	8,314	3	1,816	16	377	2
Upland	L B-backed Gull	0.65	0.47	1.97	0.8	0.403	-3.9	0.000	35,746	4	31,937	2	6,802	1
Upland	Linnet	0.34	0.61	1.55	-11.2	0.000	-29.4	0.000	59,860	1	16,882	3	6,602	0
Upland	Ptarmigan	0.02	0.02	0.02	-2.7	0.006	6.5	0.000	3	23	496	11	4	2
Upland	Raven	0.24	0.27	0.27	-3.6	0.000	-3.3	0.001	4,323	3	7,097	9	4,161	1
Upland	Reed Bunting	0.16	0.24	0.33	-10.9	0.000	-14.2	0.000	13,661	2	4,790	6	968	1
Upland	Tree Pipit	0.18	0.21	0.08	-3.8	0.000	15.5	0.000	1,460	9	3,604	12	1,460	3
Upland	Whitethroat	0.06	0.17	1.03	-17.3	0.000	-39.7	0.000	46,091	0	5,945	1	3,707	0
Upland	Willow Warbler	3.28	4.27	1.93	-14.4	0.000	23.1	0.000	46,568	8	76,530	9	19,275	2
Upland	Wren	1.77	2.36	3.94	-15.1	0.000	-39.7	0.000	165,743	2	45,387	7	23,669	1

In all three countries, tetrads with moorland burning are disproportionately important for some species, holding larger percentages of the total population than would be expected from the land area they represent. As their populations are relatively concentrated in these areas, any risk to individual breeding attempts of these species posed by rotational heather burning could have more serious consequences for their conservation status. The importance of areas with moorland burning seems to be greatest in England, where the 4% of tetrads that have evidence of rotational burning within them support 74% of Black Grouse; 78% of Red Grouse; 62% of Merlin; and 61% of Golden Plover and Ring Ouzel. By contrast, tetrads with moorland burning are less important for bird populations in Scotland, despite accounting for 11% of the land area. The highest percentages of the Scottish populations supported by tetrads with moorland burning are 43% for Red Grouse and 40% for Ring Ouzel. Only small areas of Welsh moorland are subject to rotational burning, with just 1% of tetrads qualifying. The proportions of Welsh moorland bird populations found in tetrads with moorland burning are relatively low, though they do account for 30% of Hen Harriers, and 23% each of Black Grouse and Red Grouse.

### 3.4. Migrant arrival and breeding

Approximate arrival periods for long-distance migrants are summarised in Table 7. The lengths of these periods range from about 3 to 6 weeks, depending on species and country. The start of arrival period ranges from about 6th March (Wheatear) to 17th April (Cuckoo, Whinchat and Whitethroat), while the end ranges from 17th April (Ring Ouzel, Wheatear and Willow Warbler) to 22nd May (Cuckoo).

BirdTrack reporting rates (Figure 10) indicate that the eleven partial and short-distance migrants for which information is presented all arrive back in their upland breeding areas well before the end of even the earliest burning periods on the 15th March (in lowland Wales).

These species include Black-headed Gull, Common Gull, Curlew, Golden Plover, Lapwing, Lesser Black-backed Gull, Meadow Pipit, Oystercatcher, Redshank, Short-eared Owl and Skylark. The picture is more varied for long-distance migrants. Sightings of Cuckoo, Tree Pipit, Whinchat and Willow Warbler in their upland breeding areas are uncommon before the end of the main burning season in upland England, and the whole of Scotland, on the 15th April. Earlier long-distance migrants such as Ring Ouzel and Wheatear have, however, already started appearing in the uplands several weeks before even the earliest upland burning season closes at the end of March.

## 4. DISCUSSION

### 4.1. Timing of breeding

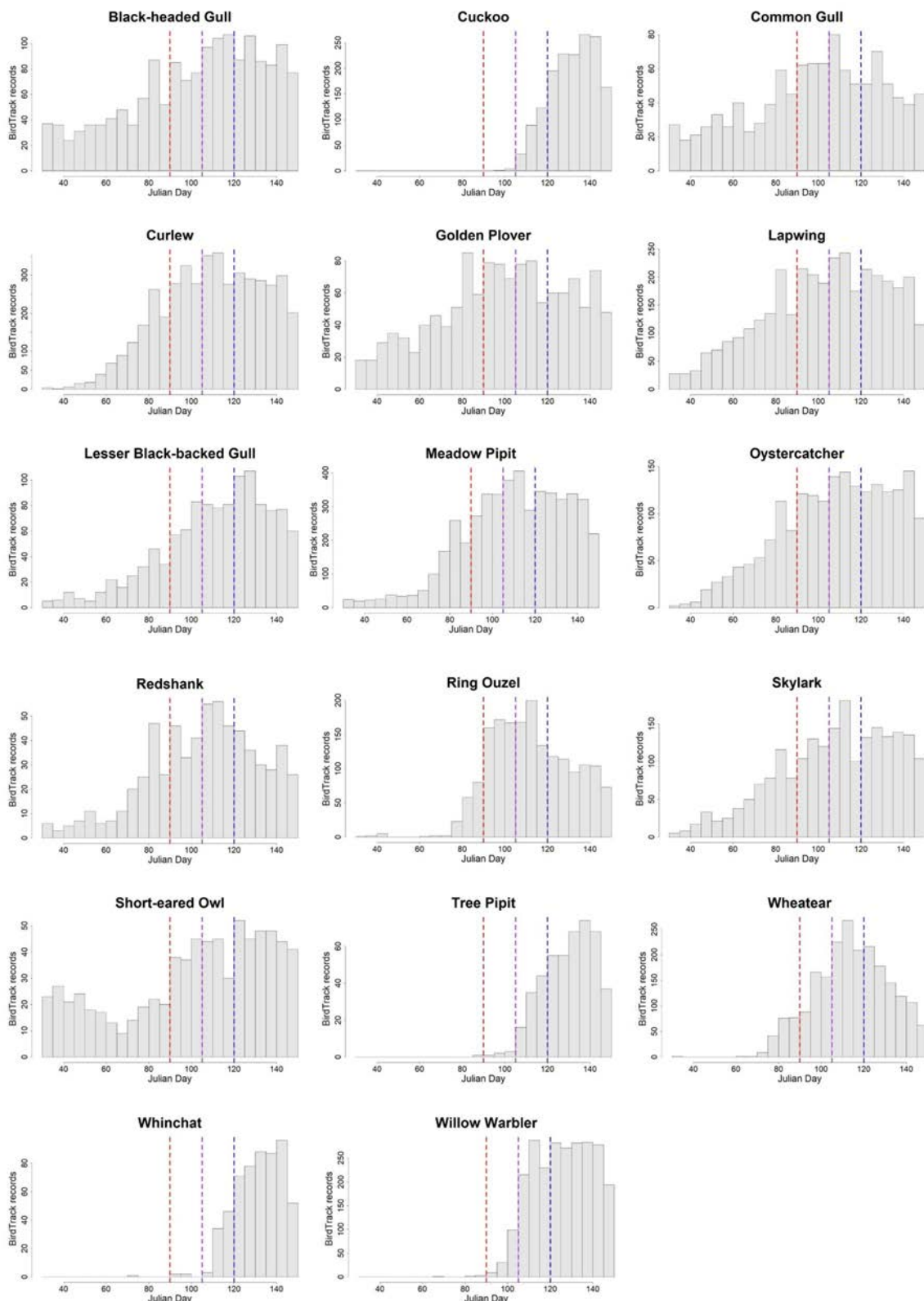
The main findings of this report suggest that, while there is some intra- and inter-specific variation, the temporal overlap between current burning seasons and the nesting attempts of upland birds remains small, despite the trend towards advancement in laying dates apparent over recent decades. Such overlaps are, unsurprisingly, greatest for early-breeding species such as Peregrine, Lapwing, Golden Plover and Stonechat. Standardised clutch initiation dates for these species overlap with the main upland burning season in England and Scotland by 41% (for Stonechat) to 82% (for Peregrine). The overlap with the extended burning season in Scotland is even greater, standing at 62% for Stonechat and 96% for Peregrine. The translation of these findings into risk at the level of the individual and population requires several other factors to be taken into consideration, including the degree of spatial matching with burned areas at different scales, the proportion of moorland burned each year and the proportion of burning that is actually carried out within the window of overlap (given that upland burning seasons run for more than six months). These factors are discussed in further detail over the following pages.

**Table 7. Approximate pre-nuptial migration periods for eight species of long-distant migrants, from reporting rates in BirdTrack. Start of the pre-nuptial migration is taken as the first week in spring showing an upturn in reporting rate (the proportion of complete lists including the species). The end of this period is taken as the week in spring or early summer when reporting rate peaks.**

Species	England	Wales	Scotland
Cuckoo	3rd April–15th May	17th April–22nd May	17th April–22nd May
Common Sandpiper	10th April–1st May	10th April–24th April	10th April–1st May
Ring Ouzel	20th March–17th April	20th March–17th April	20th March–24th April
Tree Pipit	27th March–15th May	3rd April–1st May	3rd April–15th May
Wheatear	13th March–24th April	6th March–17th April	20th March–1st May
Whinchat	17th April–1st May	10th April–1st May	17th April–15th May
Whitethroat	10th April–8th May	10th April–8th May	17th April–15th May
Willow Warbler	27th March–17th April	20th March–17th April	3rd April–8th May



Figure 10. BirdTrack reporting rates broken down by five-day periods for each of 17 species of migrant upland breeding birds. The dashed vertical lines on the histograms represent the end of the main burning season in upland areas in Wales and in lowland areas in England on the 31st March (red line); the end of the main burning season in upland areas of England and all areas of Scotland on the 15th April (purple line); and the end of the extended burning period in upland areas in Scotland on the 30th April (blue line).



## Modelling approach

The clutch initiation information presented in this report, whether derived from nest records or from ringing data, provides robust and reliable evidence for the timing of breeding of individual bird species. Such information is well-suited to informing decisions related to timing of breeding, and how this is likely to vary across species, locations and years.

The global model of timing of breeding based on NRS data showed strong influences of species, latitude, longitude, rainfall and temperature, with weaker effects of habitat. The effects of several variables, including elevation, peat, roads and moorland burning, were not significant in this model. It should be borne in mind, however, that all of the variables in these models are thoroughly inter-correlated. The apparent size and significance of some of the effects reported in the Table 1 should therefore be interpreted in the context of the whole model. For example, the apparent absence of an influence of elevation is likely to be due to a strong correlation with habitat and weather variables. Such covariation could also explain the counter-intuitive positive relationship identified between laying dates and temperature. Ultimately, the value of including these variables is to minimise the error around our estimates of breeding phenology. Had we been attempting to apportion variation to each explicitly, we would have adopted a different approach.

Variation associated with longitude and latitude was accounted for in all our models but, due to limited sample sizes, it was not possible to account for non-linear relationships with these variables or to include interaction terms. In addition, while factors, such as elevation, climate and habitat type were included in the multi-species model, they had to be omitted from models for individual species, in order to avoid overfitting and resultant generation of spurious relationships. There are likely to be other variables that could affect laying dates but are not included in any of our models, including factors such as food availability and some types of disturbance, which are not effectively captured by available national datasets. Another unaccounted source of potential variation is nest-searching effort, which may vary over time, and between different survey participants due to factors such as experience (Cooper 2014). Weather could also be a source of variation between years – both in terms of its direct effect on the timing of breeding attempts, but also through its effect on search effort for nests. All of these factors combine to explain why, for many species, there is significant variation around the central trend for timing of breeding, with the mean of observed timings for many years being substantially earlier or later than modelled values (Figure A2.1).

## Temporal change in nesting phenology

Comparing the 0.14 days per year advance in laying date identified by the all-species model with the equivalent trends in the single species models, there is substantial inter-specific variation in the rate at which clutch initiation appears to be advancing. This is unsurprising as the benefits accrued from, and constraints imposed on, advancement of laying are likely to vary between species. For example, long-distance migrants may be limited in their ability to adjust their timing of breeding because their arrival time cannot advance sufficiently (Coppack & Both 2002). Some montane species may also be able to compensate for changes in climate and seasonality by shifting the elevation at which they breed, instead of, or as well as, advancing laying (Socolar *et al.* 2017). The more positive trends of single-species models based on longer time series fit with observations that temperature changes since the first half of the 20th century were not entirely linear. Between 1930 and 1970 global temperatures actually cooled slightly, before continuing on the warming trajectory seen in more recent decades (Met Office *et al.* 2017). For some double-brooded species, such as Skylark, apparent advances in laying date due to warming temperatures could be masked or reduced by changes in the frequency of double-brooding, which has been positively associated both with warm temperatures and early breeding (Jacobs *et al.* 2013, Townsend *et al.* 2013). Variation in sample sizes is also likely to contribute to the apparent inter-specific variability in phenological trends. We note that the steepest rates of change among the species-specific models are for Golden Plover and Hen Harrier, both of which are represented by relatively short runs of data and small numbers of records per year, increasing the potential for error when extrapolating over longer time periods.

Overall, however, there is reasonably good agreement between predictions from all models for any given species, and also between model predictions and the independent datasets for the species these were available for. Care should be taken with interpretation of modelled changes, particularly for species where limited sample sizes are available. Current estimates of timing of breeding can, however, be regarded as reasonably robust, as can the conclusion that, for many species and overall among this group of upland birds, timing of breeding has advanced by several days over the past few decades.

## 4.2. Impacts of rotational burning

The proximal impacts of rotational burning on breeding birds include the destruction of nests, eggs and nestlings, as well as mortality of a proportion of unfledged precocial young, associated with ongoing breeding attempts in the burned area. At a population and community level, the effect of prescribed burning of vegetation on birds breeding in moorland that is subject to this management depends not just on the temporal overlap between burning and

breeding attempts, discussed above, but also on the type of vegetation being burned, and the behaviour and ecology of the species in question (including factors such as nesting habitat preferences and the types of nest site used).

The level of risk experienced by individual birds will be affected by small-scale habitat associations that determine the likelihood of a nest being impacted by burning. At a population level, this risk determines the proportion of active nests within larger areas where burning management is carried out that are likely to be destroyed. The most impacted nesting habitats are those dominated by vegetation such as tall heather and other heathland shrubs. These are likely to be selected for burning in order to remove old growth and stimulate new growth. This type of vegetation frequently supports the nests of species such as Hen Harrier, Merlin and Stonechat, among which the temporal overlap between burning and breeding is highest for Stonechat and low for the two raptors (Table 2). The risk that active nests will be directly destroyed by burning is, in contrast, lower for species such as Golden Plover and Lapwing. Although these are both early nesting species, for which many breeding attempts are started before the end of the burning season, they typically nest in areas dominated by short vegetation which, on rotationally burned moorland, are likely to have been recently burned.

The nest sites of ground-nesting species that breed in vegetation exhibiting a wide range of height, composition and structural characteristics, such as Meadow Pipit and Curlew (both of which are relatively late breeders), will be at intermediate risk. Breeding attempts of species that nest in trees or on crags, such as Golden Eagles and Peregrines, or which nest on the banks of rivers, streams and lochs, such as Common Sandpiper, and Dipper, are unlikely to be directly impacted by heather burning, regardless of their timing. Even if a nesting attempt is not destroyed by fire, however, disturbance associated with burning management, whether caused by proximity of the nest to fire, or by the presence and activity of humans carrying out the management, may increase the risk that eggs or chicks will be abandoned. Such impacts could be locally severe for species such as Golden Eagles that are especially sensitive to disturbance during egg-laying and incubation in March and April (Hardey *et al.* 2013).

Even for species demonstrating a strong preference for nesting in the type of vegetation typically selected for burning, destruction is far from certain. Estimates of the proportion of moorland burned annually on intensively managed moors range from 5 - 10% (Robertson *et al.* 2017) to around 15% (GWCT 2021), leaving much moorland habitat unburned each year. For species that favour nest sites in tall stands of heather and other shrubby vegetation, the relative rarity of this on many intensively managed moorlands may increase the risk that the vegetation supporting their nest sites is selected for burning.

Direct negative impacts of rotational burning on breeding birds may be wholly or partly avoided by timing burns to reduce or eliminate temporal overlap with active nests. The extent to which this is feasible, from a management perspective, may depend on the number of days with weather suitable for burning outside of the period when birds are breeding, and the ability of estates to complete their annual burning management during this window. But, even in a situation where the period in which burning is permitted overlaps with bird breeding activity, much burning is likely happen outside of this period of overlap. Burning seasons span around six months, and even the earliest breeding individuals of the earliest breeding species do not start laying until the last quarter of this period. However, in most areas of moorland, much of the autumn and winter is poorly suited to burning, especially in the wetter parts of the UK. This can result in burning activity being disproportionately concentrated during the spring part of the burning season, during the period of potential overlap with bird breeding attempts.

Rotational heather burning, along with other aspects of moorland management, may have a range of other positive and negative effects on birds (Douglas *et al.* 2017, Tharme *et al.* 2001). Positive effects of heather burning and associated management practices are suggested for several species by the fact that their relative abundance is higher in areas where rotational heather burning is carried out (Table 6). These include species such as Golden Plover that may benefit from the maintenance of high levels of heather cover (Pearce-Higgins & Grant 2006), and several species of ground-nesting birds whose breeding success may be increased by management to reduce the numbers and activity of generalist predators (Fletcher *et al.* 2010). Negative effects may include removal of scrub and trees, drying of wet areas (particularly peatland) through burning and draining, and lethal control, particularly illegal killing of some bird of prey species.

In a manner similar to agricultural operations such as ploughing and mowing, burning of vegetation could result in a short-term increase in availability of maimed and killed invertebrates and other small animals. The consequences of this for breeding and pre-breeding birds in the surrounding area could be mixed. Some species may be able to take advantage of a pulse of available food caused by burning. Availability of prey after this initial pulse could well be reduced, however, and, as a result, foraging efficiency for some species could be negatively impacted in the short or medium term. The initial pulse of food resulting from burning may also, in some situations, attract meso-predators such as corvids, which could result in increased egg and chick predation risk for breeding birds whose nesting attempts survive the fire itself (Summers *et al.* 2017).

It should also be noted that prescribed burning periods are not necessarily the same as the periods during which

burning actually takes place. Not every estate can or will burn in spring every year, with the probability depending, for example, on weather, or on how much burning they already carried out during autumn and winter. GWCT records on estate management suggest that many estates stop burning well before the 15th of April, and usually (at the latest) when keepers come across the first clutch of Red Grouse eggs (GWCT pers. comm). On the other hand, during years when the weather from October through to late winter is largely unsuitable for burning, one might expect burning activity to be disproportionately concentrated in the spring, and burning management for livestock usually peaks at this time (Natural England pers. comm). A more detailed assessment of likely burning impacts would require data on actual burning dates.

### 4.3. Red Grouse timing of breeding

The long-term data from Strathspey showed that Red Grouse clutch initiation dates advanced by an average of 0.46 days per year between 1992 and 2016, resulting in an increase in the proportion of clutches initiated within the standard burning season. Over this period, the proportion of clutches initiated before the end of the standard burning season was low, averaging 3% (range 0–19% of clutches in a single year). The majority of clutches were initiated during the second half of April, i.e. before the end of the extended burning season in Scotland, but many estates report that their burning activities cease before the 15th April each year (GWCT unpublished data).

In assessing the impact of rotational burning of heather moorland on Red Grouse, it should be borne in mind that the principal aim of this management is, in most cases, to impact positively on populations of this commercially managed species. While this does not rule out the possibility of negative impacts, particularly in a scenario where breeding dates are advancing, moorland managers should be highly motivated to ensure that their activities do not reduce the breeding productivity of their target species. Several studies have shown that traditional burning practices on moorland benefit Red Grouse populations (Tharme *et al.* 2001; Robertson *et al.* 2017; Ludwig *et al.* 2018).

During 2009–2016, when data were available for both Strathspey and Langholm and after medicated grit had been introduced in both areas, the proportion of clutches initiated within the burning season remained low in both areas (4% and 5% respectively). Despite a latitudinal difference of over 200 km, there was no significant difference in clutch initiation date or the proportion of clutches initiated within the burning season between Strathspey and Langholm. This, along with the similarity in timing of breeding between southern Scotland and northern England populations of Curlew and Common Sandpiper represented among the independent datasets considered in this report, suggests that it may be feasible

to extrapolate to moors in the Northern Pennines, most of which are 50 km–150 km from Langholm and at a similar or slightly higher range of altitudes.

At Langholm, radio-tagged females were also monitored during the Joint Raptor Study, with published median hatch dates for Red Grouse reported as 28th May in 1995 and 30th May in 1996 (Redpath & Thirgood 1997), equating to median clutch initiation dates of 28 and 30th April, respectively, based on an average clutch size of nine eggs. The median clutch initiation date during the period 2009–2016 was 23rd April (annual range 19th April to 26th April), suggesting that laying dates at Langholm may also show moderate advancement since the 1990s, although we could not formally test this hypothesis without access to the raw data.

When splitting the Strathspey dataset into the period before (1992–2007) and after (2008–2016) the introduction of the new medicated grit, the advancement of clutch initiation date was only significant for the earlier period. When Strathspey data from 1992 to 2011 were analysed, clutch initiation dates were inversely correlated with pre-breeding temperature and temperature had displayed a near-significant increase over the same time period (Fletcher *et al.* 2013). This analysis did not, however, consider the availability of new medicated grit in the latter years, which may be a contributing factor through the effects of parasites on female breeding condition (Hudson 1986, Shaw & Moss 1990). The lack of a significant change in Red Grouse laying dates over the more recent time period may be due to a relatively short run of years, resulting in wide confidence intervals around the slope estimate. Apparent trends based on such limited data do not necessarily reflect trends over the longer term, as illustrated by the changes in laying date shown in Figure A2.1.

Analyses of individual Red Grouse clutches showed no effect of female age, dosing, or medicated grit on clutch initiation dates, but there was a significant effect of altitude, with clutches initiated on average 1.1 days later per 100 m increase in altitude at both sites. Hence, clutches at lower altitude are more likely to be initiated within the standard burning season compared to those at higher altitude. It is interesting to note, for comparison, that the all-species model based on NRS-derived laying dates did not indicate a significant effect of altitude for other species. This model did, however, include several other variables that are closely related to altitude and may have acted as a proxy, including average yearly temperature, and average yearly rainfall. Whether these variables are the causal factors underpinning the observed altitudinal patterns or simply co-vary with other variables not included in our models, is unknown but this illustrates the fact that the significance of model effects cannot, on their own, definitively identify drivers of the changes we are interested in.

These analyses focussed on data collected in Strathspey. Should more resources be available in future, it may be possible to collate Red Grouse chick monitoring data from a wider geographical area. The size of chicks could be used as a proxy for age to determine hatch dates and therefore estimate clutch initiation dates (e.g. Moss *et al.* 2005). Such an analysis could be used to support and extend the current finding that, despite a significant long-term advancement in clutch initiation dates, the majority of Red Grouse clutches (95–96%) in recent years (2009–2016) were initiated after the end of the standard burning season.

#### **4.4. Relative importance of moorland subject to burning**

The risk posed by burning to a species' conservation status is dependent on both local scale habitat relationships and the proportion of the national population inhabiting areas that are typically managed using this method. The strength of association with tetrads containing burned moorland, as measured by relative abundance derived from Bird Atlas data, was, unsurprisingly, greatest for species associated with heather moors. Red Grouse benefit directly from the varied heather structures that rotational burning provides, while Golden Plover favour the short, heather-dominated swards typical of post-burn vegetation. Species such as Ring Ouzel and Stonechat, which nest in taller stands of vegetation (Fergusson-Lees *et al.* 2011), may also benefit from the maintenance of high levels of heather cover promoted by burning (e.g. Sim *et al.* 2007) but Meadow Pipits are most abundant on moorlands with high levels of grass cover (Vanhinsbergh & Chamberlain, 2001), so the relationship identified for this species may relate to an unidentified covariate. Rotationally burned moorland also supported relatively high densities of several moorland Edge species, such as Curlews and Lapwing, which probably benefit principally from other management practices, such as predator control, that are applied in tandem with burning on intensively managed moorland.

Despite the fact that tetrads with heather burning occupy only 11% of the area of Scotland, 4% of England and 1% of Wales, there are a few species whose numbers are concentrated predominantly in these areas. More than 50% of Red Grouse, Merlin and Ring Ouzel populations in England, and around 40% of the numbers of these species in Scotland, are based in tetrads with burning. The proportions of Black Grouse and Golden Plover populations supported in these tetrads are even higher in England, but lower in Scotland. None of the Welsh populations of any species are equivalently concentrated in tetrads with moorland burning, which is a comparatively restricted practice in the uplands of Wales. Considering that only 1% of Welsh tetrads contain burned moorland, the fact that these support 30% of the country's Hen Harriers and 23% of both national Red and Black Grouse populations makes them disproportionately important for these species. All other factors, such as the

proportion actually nesting in moorland, nesting habitat preferences and timing of breeding, being equal, this means that heather burning has the potential to impact the populations of these species more severely than those of species that are predominantly found in areas where this management technique is not practised. The actual impact of burning on all species will also be affected by aspects of burning management, including the periodicity with which areas of heather are burned, and the proportion of burning that takes place in the spring.

#### **4.5. Timing of arrival**

For most species, the country-wide arrival times estimated for long distance migrants in England, Scotland and Wales were very similar to the moorland-specific arrival times indicated by the graphs in Figure 10. Given that latitude and altitude might be expected to affect arrival times in similar directions, it is perhaps unsurprising that the greatest agreement in these arrival metrics among the countries was observed for Scotland. Even in England, however, only three species (Cuckoo, Tree Pipit and Willow Warbler) were recorded more than a week earlier than they started to appear in moorland areas. None of these species breed exclusively in the uplands, so differences between country-wide and moorland-specific arrival might be expected to be greater than for upland specialists, such as Ring Ouzel and Wheatear.

Of these long-distance migrants, only the earliest-returning species such as Ring Ouzel and Wheatear arrive back in significant numbers before any of the standard burning seasons has closed, though overlap is greater for the extended season in Scotland. Impacts of pre-breeding burns are likely to be greater for partial and short-distance migrants, whose breeding populations return to moorland areas well before the end of even the earliest of the currently operating burning seasons, and greatest for residents. Pre-breeding impacts of other factors such as spring weather have been shown to impact more severely on residents than on migrant species (Kluen *et al.* 2017).

#### **4.6. Conclusions**

The evidence presented in this report suggests that timing of breeding has advanced modestly for the majority of moorland species since the previous report on this issue by Moss *et al.* (2005). As a result, the proportion of breeding attempts initiated during the periods in which burning is currently permitted has increased by up to 10% for a few species, but remains within 5% of previous levels for the majority. For a few, early-breeding species, the overall proportion of upland breeding attempts falling within these periods has reached or surpassed 50%.

However, population level risk posed by burning is not determined by temporal overlap alone. It is subject to a suite of additional factors, operating at different spatial scales. These include range level overlap (the proportion of

the population that breeds in areas with rotational heather burning); landscape level overlap (the proportion of birds breeding in these areas that nest on moorland managed by heather burning); habitat level overlap (the proportion of birds breeding on moorland managed by burning that nest in habitats that are likely to be selected for burning); and annual burning extent (the proportion of burnable heather moorland burned each year). These factors are discussed individually above, but sensibly evaluating the overall significance of burning impacts for populations of moorland species requires an assessment of their combined effect, together with that of temporal overlap.

In Appendix 3, we present two worked examples that do this for Stonechat, a relatively early-nesting species that nests in tall heather, and Merlin and Ring Ouzel, two species that also nest in tall heather, but nest later than Stonechat. Overall risk for Stonechats turns out to be very low, due to high proportion of the Stonechat population that breeds in habitats other than rotationally burned moorland. The proportion of Stonechat nests likely to be destroyed by moorland burning each year is well under 1%, which is not likely to affect Stonechat populations much given that published rates of nest failure for stable and increasing populations of Stonechat can be as high as 60–70% (van Oosten 2016; Fuller & Glue 1977). For Merlin and Ring Ouzel, moorland areas managed by rotational burning are disproportionately important. Because they start nesting later than Stonechats, burning within the standard upland burning season in England and Scotland (finishing in mid-April) is unlikely to pose a serious, population-level risk to these species. However, extending the burning season to the end of April, as can be done in Scotland, increases this risk considerably for both species. If such an extension in burning season was applied to all moorland in England and Scotland, the population-level risk of burning activity to Merlin and Ring Ouzel would rise to 6–7% in England, and 4–5% in Scotland. Such losses could be significant, particularly at a local or regional level, and for species already undergoing regional or national declines (Ewing *et al.* 2011; Wotton *et al.* 2016).

From both of these worked examples it is clear that our understanding of these components of risk is uneven. The components we are least sure of are landscape scale coincidence between rotationally burned moorland and breeding birds; the proportion of birds breeding on rotationally burned moorland that nest in vegetation likely to be selected for burning; and the proportion of a single season's burning that happens during the period of potential overlap in the spring). The first two factors would require further work to be undertaken on the nesting ecology of the relevant species, while the third would require gathering and assessment of more detailed management information.

### **Spatial variation in impacts and regulation**

Spatial variation in breeding phenology, at least between areas where moorland management is important, appears to be relatively modest. The modelled estimates of timing, which have been standardised relative to an area of moorland in the Yorkshire Dales, would change less than a week in either direction if standardised to any of the other moorland dominated landscapes in the UK, from Caithness in north-east Scotland to Dartmoor in the south of Devon. Since the previous report by Moss *et al.* (2005), the end of the upland burning season in Wales has been brought forward by 15 days to 31st March. Given that both arrival time and timing of breeding information suggest that the breeding phenology of upland birds in Wales is typically within a few days of the equivalent timings in northern England, this regulatory change to the burning season is likely to have virtually eliminated the direct risks of nest destruction posed by heather burning to Welsh upland bird populations.

Permitted dates for upland burning in England and Scotland remain largely unchanged since the previous report, with the standard upland burning season in both countries closing on 15th April. In Scotland, this standard burning season can be extended in upland areas by up to two weeks, though recent guidance (Scotland's Moorland Forum, 2017) discourages such extensions. As discussed above, burning during this period of extension could have some impact on populations of high conservation concern species, particularly in the south of Scotland where timing of breeding for most species is likely to be slightly earlier than further north. It might be possible to reduce the frequency and severity of such impacts if, as suggested in recent guidance, extensions to the standard burning season beyond mid-April are restricted to exceptional circumstances, or to situations where they do not pose a threat to breeding birds, particularly high conservation value species like Ring Ouzel and Merlin. In areas where populations of these birds are monitored, this approach would be greatly facilitated by effective liaison between fieldworkers and moorland management staff, to ensure that areas occupied by breeding pairs are not burned.

One important consideration when reviewing burning regulations is the ease with which changes could be adopted by moorland managers. Climatic change resulting in advancement avian breeding may also impact on weather conditions throughout the permitted burning window, potentially reducing the number of days on which such a practice was feasible. Clearly, the number and distribution of burning days are likely to vary between different localities, and could be affected by climate, topography and edaphic factors. The ease with which moorland burning dates can be locally adapted to reduce risk to breeding birds may depend on the degree to which spatial variation in the availability of burning days matches variation in the breeding phenology of moorland bird assemblages.

### **Pre-breeding season impacts**

A wide range of residents and partial/short distant migrants, as well as some early-arriving long-distance migrants, are likely to be present on moorlands when they are being burned during late winter and spring. Whether, and to what extent, this temporal and spatial overlap impacts on the breeding success experienced by most of these species is unknown. Raptors such as Golden Eagle and Merlin are known to be sensitive to human disturbance in March and April, just prior to egg-laying (Hardey *et al.* 2013; Tjenberg 1983). In areas where these raptors settle to breed at sites on or near to moorland that is burned in the spring, human activity associated with burning could potentially result in birds abandoning their intended territories or nest sites. Whether such impacts have population-level consequences would depend on several factors, including the frequency of disturbance-mediated abandonment, the availability of alternative sites, the time required to settle at and prepare a site (Golden Eagles typically spend many weeks building or maintaining nests before breeding attempts commence, Hardey *et al.* 2013), and the consequences of any delay in breeding for breeding success, survival of fledged young, and their recruitment into the breeding population. Other possible pre-breeding impacts of burning, including short- and longer-term effects on food availability, are mostly unknown, and would require further investigation before they could be meaningfully acknowledged or countered by changes to burning practices and regulations.

## 5. REFERENCES

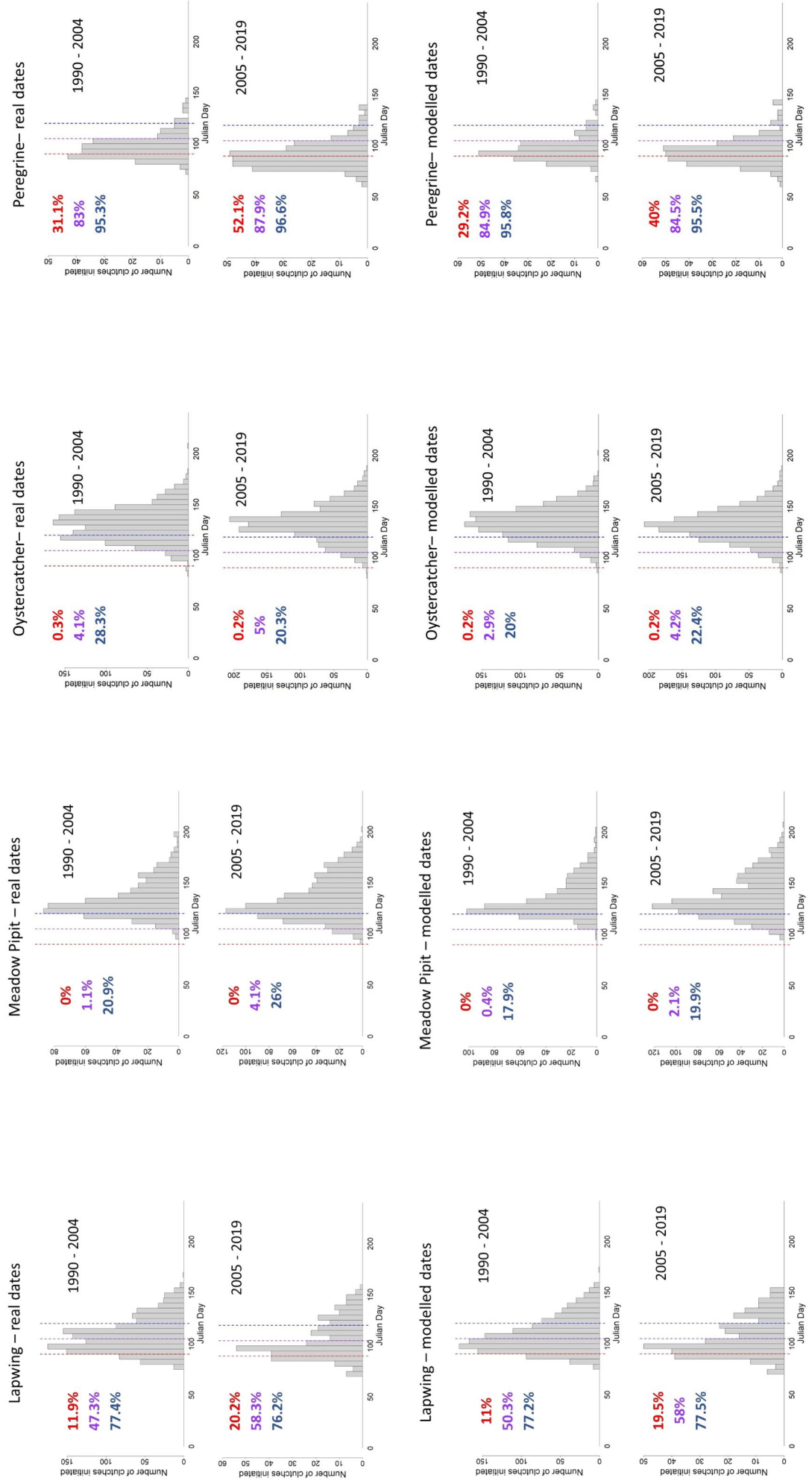
- Balmer, D. E., Gillings, S., Caffrey, B. J., Swann, R. L., Downie, I. S. & Fuller, R. J. 2013. *Bird Atlas 2007–11: the breeding and wintering birds of Britain and Ireland*. BTO Books, Thetford.
- Boersch-Supan, P.H., Trask, A.E. & Baillie, S.R. 2019. Robustness of simple avian population trend models for semi-structured citizen science data is species-dependent. *Biological Conservation* **240**: Article number 108286.
- Breiman, L. 2001. Random Forests. *Machine Learning* **45**: 5–32.
- Caizergues, A. & Ellison, L.N. 2000. Age-specific reproductive performance of Black Grouse *Tetrao tetrix* females. *Bird Study* **47**: 344–351.
- Cooper, C.B. 2014. Is there a weekend bias in clutch-initiation dates from citizen science? Implications for studies of avian breeding phenology. *International Journal of Biometeorology* **58**: 1,415–1,419.
- Coppack, T. and Both, C. 2002. Predicting life-cycle adaptation of migratory birds to global climate change. *Ardea* **90**: 369–378.
- Crick, H. Q., Baillie, S. R., & Leech, D. I. 2003. The UK Nest Record Scheme: its value for science and conservation. *Bird Study* **50**: 254–270.
- Douglas, D.J.T., Beresford, A., Selvidge, J., Garnett, S., Buchanan, G.M., Gullett, P. & Grant, M.C. 2017. Changes in upland bird abundances show associations with moorland management. *Bird Study* **64**: 242–254.
- Douglas, D.J.T., Buchanan, G.M., Thompson, P., Amar, A., Fielding, D.A., Redpath, S.M. & Wilson, J.D. 2015. Vegetation burning for game management in the UK uplands is increasing and overlaps spatially with soil carbon and protected areas. *Biological Conservation* **191**: 243–250.
- Ewing, S.R., Rebecca, G.W., Heavisides, A., Court, I.R., Lindley, P., Ruddock, M., Cohen, S. & Eaton, M.A. 2011. Breeding status of Merlins *Falco columbarius* in the UK in 2008. *Bird Study* **58**: 379–389.
- Ferguson-Lees, J., Castell, R. & Leech, D. 2011. *A Field Guide to Monitoring Nests*. BTO, Thetford.
- Fletcher, K., Aebischer, N.J., Baines, D., Foster, R. & Hoodless, A.N. 2010. Changes in breeding success and abundance of ground-nesting moorland birds in relation to the experimental deployment of legal predator control. *Journal of Applied Ecology* **47**: 263–272.
- Fletcher, K., Howarth, D., Kirby, A., Dunn, R., & Smith, A. 2013. Effect of climate change on breeding phenology, clutch size and chick survival of an upland bird. *Ibis* **155**: 456–463.
- Forrester, R.W., Andrews, I.J., McInerney, C.J., Murray, R.D., McGowan, R.Y., Zonfrillo, B., Betts, M.W., Jardine, D.C. & Grundy, D.S. 2007. *The Birds of Scotland*. Scottish Ornithologists' Club, Aberlady.
- Fuller R. J. & Glue D.E. 1977. The breeding biology of the Stonechat and Whinchat. *Bird Study* **24**: 215–228.
- Fuller, R.J., Humphreys, E.M., Wilson, J.D., Hoccom, D.G. & Calladine, J. 2010. Changes in the breeding wader populations of the machair of the Western Isles, Scotland, between 2000 and 2007. *Bird Study* **57**: 121–124.
- GWCT. 2021, 12th October 2021. Heather burning. Game and Wildlife Conservation Trust. Retrieved from <https://www.gwct.org.uk/policy/briefings/driven-grouse-shooting/heather-burning/>
- GWCT. 2020. *Best practice use of medicated grit*. Game and Wildlife Conservation Trust Advisory Service, Fordingbridge.
- Hardey, J., Crick, H., Wernham, C., Riley, H, Etheridge, B.. & Thompson, D. 2013. *Raptors: a field guide for surveys and monitoring*. 3rd Edition. The Stationery Office, Edinburgh.
- Hudson, P.J. 1986. The effect of a parasitic nematode on the breeding production of Red Grouse. *Journal of Animal Ecology* **55**: 85–92.
- Jacobs, A.C., Reader, L.L. & Fair, J.M. 2013. What determines the rates of double brooding in the Western Bluebird? *Condor* **115**: 386–393.
- Jones, R.J., Hiederer, R., Rusco, E., Loveland, P.J. & Montanarella, L. 2003. *The map of organic carbon content in topsoils In Europe: v 1.2* September - 2003. Luxembourg: Office for Official Publications of the European Communities. European Soil Bureau Research Report No. 15.
- Kluen, E., Nousiainen, R. & Lehikoinen, A. 2017. Breeding phenological response to spring weather conditions in common Finnish birds: resident species respond stronger than migratory species. *Journal of Avian Biology* **48**: 611–619.
- Liaw, A. & Wiener, M. 2002. Classification and Regression by Random Forest. *R News* **2**: 18–22.
- Ludwig, G.X., Alatalo, R.V., Helle, P., Lindén, H., Lindström & J., Siitari, H. 2006. Short- and long-term population dynamical consequences of asymmetric climate change in black grouse. *Proceedings of the Royal Society London B* **273**: 2,009–2,016.
- Ludwig, S.C., Aebischer, N.J., Bubb, D., Richardson, M., Roos, S., Wilson, J.D. & Baines, D. 2018. Population responses of Red Grouse *Lagopus lagopus scotica* to expansion of heather *Calluna vulgaris* cover on a Scottish grouse moor. *Avian Conservation and Ecology* **13**: 14.



- Met Office, Hollis, D. & McCarthy, M. 2017. UKCP09: Met Office gridded and regional land surface climate observation datasets. Centre for Environmental Data Analysis. Date accessed: 26/10/2021. <http://catalogue.ceda.ac.uk/uuid/87f43af9d02e42f483351d79b3d6162a>
- Moss, D., Joys, A.C., Clark, J.A., Kirby, A., Smith, A. Baines, D. & Crick, H.Q.P. 2005. *Timing of Breeding of Moorland Birds*. A report to Scottish Natural Heritage and Department for Environment, Food and Rural Affairs. BTO, Thetford.
- Natural England. 2021. *The Moorland Change Map*. Natural England Technical Information Note TIN179
- Newborn, D. & Foster, R. 2002. Control of parasite burdens in wild Red Grouse *Lagopus lagopus scoticus* through the indirect application of anthelmintics. *Journal of Applied Ecology* **39**: 909–914.
- Pearce-Higgins, J.W. & Grant, M.C. 2006. Relationships between bird abundance and the composition and structure of moorland vegetation. *Bird Study* **53**: 112–125.
- Perry, M. & Hollis, D. 2005. The generation of monthly gridded datasets for a range of climatic variables over the UK. *International Journal of Climatology* **25**: 1,041–1,054.
- Picozzi, N. 1980. Food, Growth, Survival and Sex Ratio of Nestling Hen Harriers *Circus c. cyaneus* in Orkney. *Ornis Scandinavica* **11**:1–11.
- R Core Team. 2020. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. URL [www.R-project.org](http://www.R-project.org)
- Redpath, S.M. & Thirgood, S.J. 1997. *Birds of prey and Red Grouse*. The Stationery Office, London.
- Robertson, G.S., Newborn, D., Richardson, M. & Baines, D. 2017. Does rotational heather burning increase Red Grouse abundance and breeding success on moors in northern England?. *Wildlife Biology* (wlb.002270): 1–10
- Rowland, C.S., Morton, R.D., Carrasco, L., McShane, G., O’Neil, A.W., and Wood, C.M. 2017. Land Cover Map 2015 (1km percentage aggregate class, GB). NERC Environmental Information Data Centre.
- Scotland’s Moorland Forum. *The Muirburn Code: management of vegetation by burning and cutting*. Scottish Natural Heritage, Inverness.
- Shaw, J.L. & Moss, R. 1990. Effects of the caecal nematode *Trichostrongylus tenuis* on egg-laying by captive Red Grouse. *Research in Veterinary Science* **48**: 59–63.
- Sim, I.M.W., Burfield, I.J., Grant, M.C., Pearce-Higgins, J.W. & Brooke, M.D.L. 2007. The role of habitat composition in determining breeding site occupancy in a declining Ring Ouzel *Turdus torquatus* population. *Ibis* **149**: 374–385.
- Socolar, J.B., Epanchin, P.N., Beissinger, S.R. & Tingley, M.W. 2017. Phenological shifts conserve thermal niches in North American birds and reshape expectations for climate-driven range shifts. *Proceedings of the National Academy of Sciences of the United States of America* **114**: 12,976–12,981.
- Summers, R., Etheridge, B., Christian, N. and Rae, S. 2017. Egg dumping by a Golden Plover in a Greenshank nest. *Scottish Birds* **37**: 135–136.
- Tharme, A.P., Green, R.E., Baines, D., Bainbridge, I.P. & O’Brien, M. 2001. The effect of management for Red Grouse shooting on the population density of breeding birds on heather-dominated moorland. *Journal of Applied Ecology* **38**: 439–457.
- Townsend, A.K., Sillett, T.S., Lany, N.K., Kaiser, S.A., Rodenhouse, N.L., Webster, M.S. & Holmes, R.T. 2013. Warm springs, early lay dates, and double brooding in a North American migratory songbird, the Black-throated Blue Warbler. *Plos One* **8**: e59467.
- Vanhinsbergh, D.P. & Chamberlain, D.E. 2001. Habitat associations of breeding Meadow Pipits *Anthus pratensis* in the British uplands. *Bird Study* **48**: 159–172.
- van Oosten. 2016. Comparative Breeding Biology of Three Insectivorous Songbirds in Dutch Dune Grasslands. *Ardea* **104**: 199–212
- Watson, A. & Moss, R. 2008. *Grouse. The Natural History of British and Irish Species*. London: Harper Collins Publishers.
- Welsh Government. 2018. *Forecasts of farm incomes in Wales, 2017-18. Statistical First Release*. SFR 22/2018. Welsh Government, Merthyr Tydfil.
- Wiebe, K.L. & Martin, K. 1998. Age-specific patterns of reproduction in White-tailed and Willow Ptarmigan *Lagopus leucurus* and *L. lagopus*. *Ibis* **140**: 14–24.
- Wotton, S.R., Stanbury, A.J., Douse, A. & Eaton, M.A. 2016. The status of the Ring Ouzel *Turdus torquatus* in the UK in 2012. *Bird Study* **63**: 155–164.

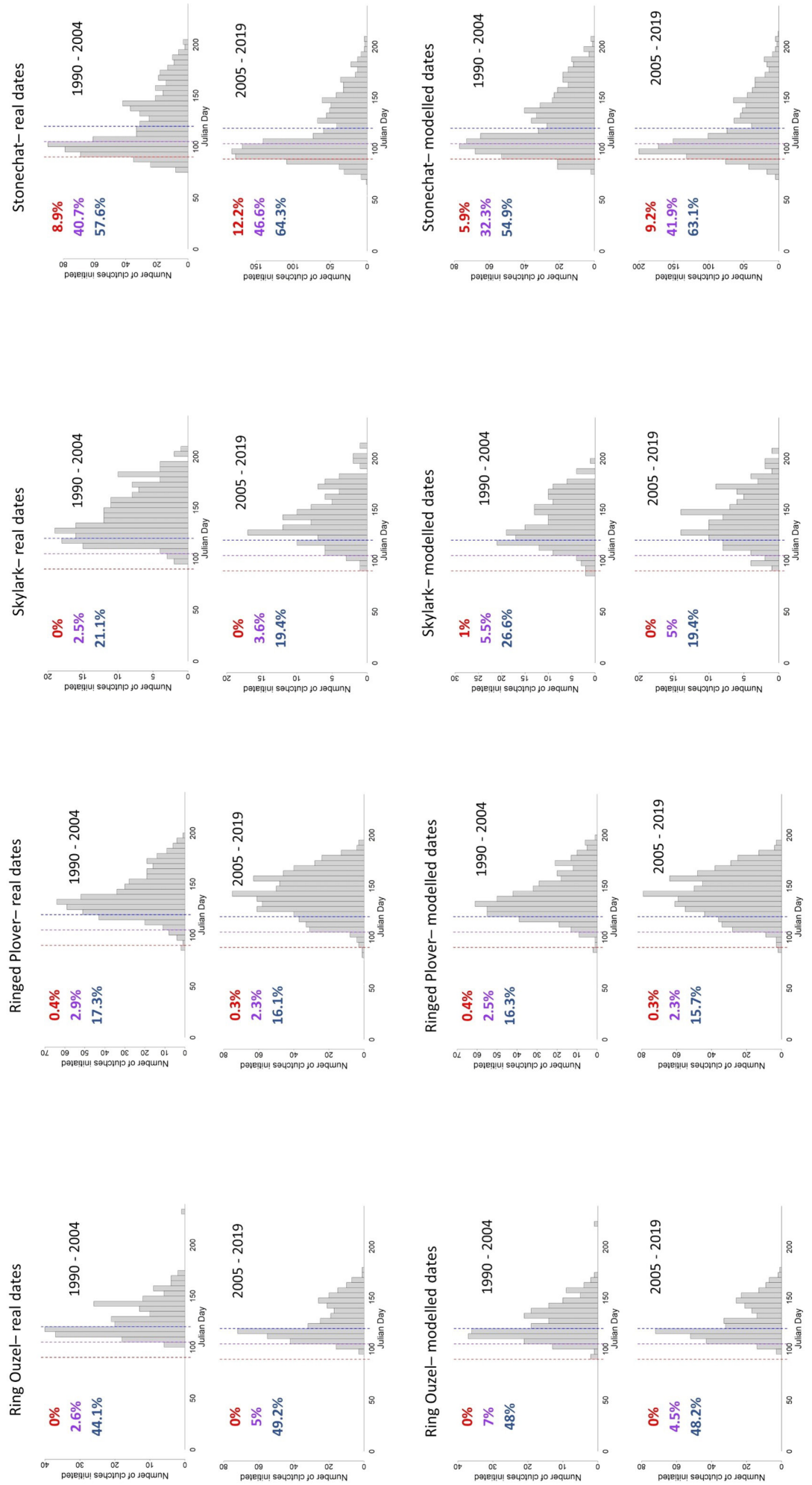
## APPENDIX 1. VARIATION IN ACTUAL AND MODELLED LAYING DATES IN TWO PERIODS.

Figure A1.1. Histograms of clutch initiation dates for 9 species (Lapwing, Meadow Pipit, Oystercatcher, Peregrine, Ring Ouzel, Ringed Plover, Skylark, Stonechat and Whinchat) based on NRS records drawn from two 15-year periods: 1990-2004, and 2005-2019. For each combination of period and species two graphs are presented, one based on the actual distribution of estimated laying dates of all the relevant records from this period, the other standardised for all environmental variables to values for square SE0293, in Yorkshire Dales. The dashed vertical lines on the histograms represent the end of the main burning season in upland areas in England and in lowland areas in Wales and in lowland areas in England on the 31st March (red line); the end of the main burning season in upland areas of England and all areas of Scotland on the 15th April (purple line); and the end of the extended burning period in upland areas in Scotland on the 30th April (blue line). The percentage of clutches started before each of these dates is given for each graph, with colour and order (top to bottom being earliest to latest) matching the lines.



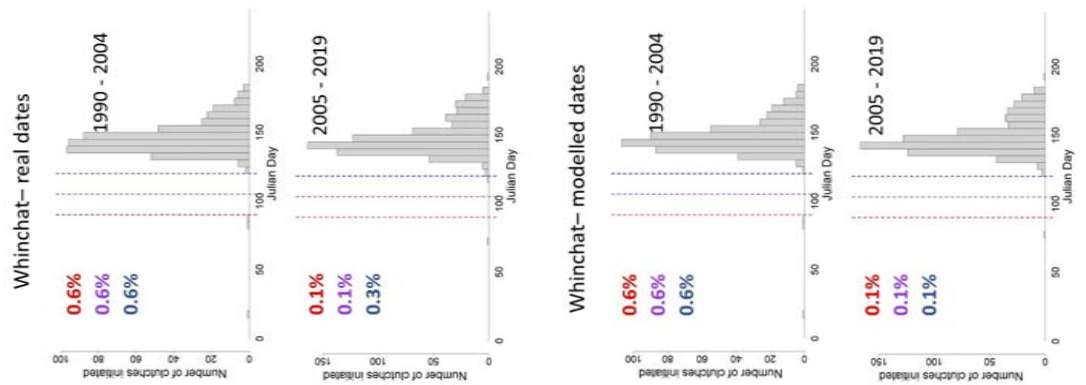
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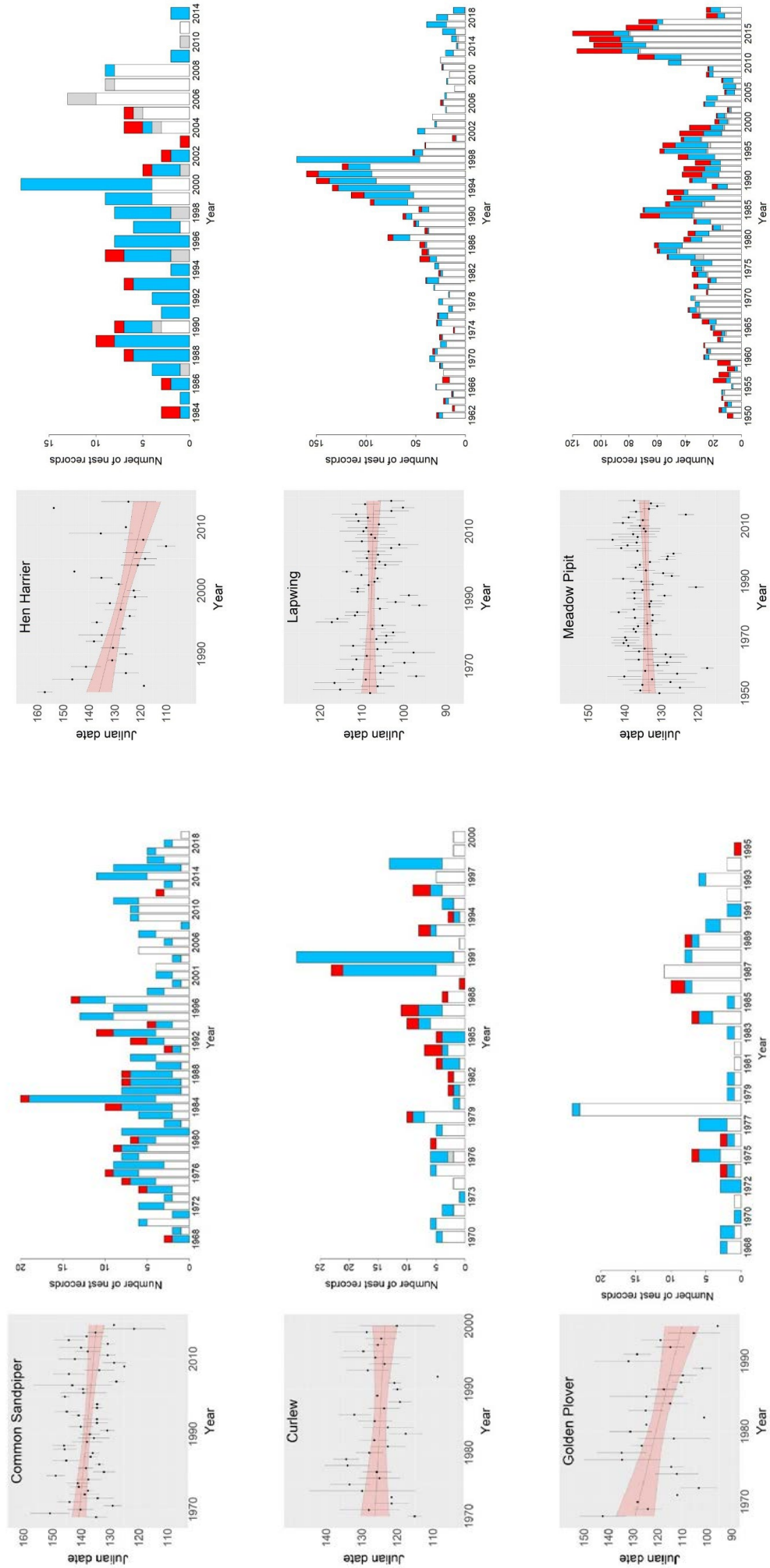
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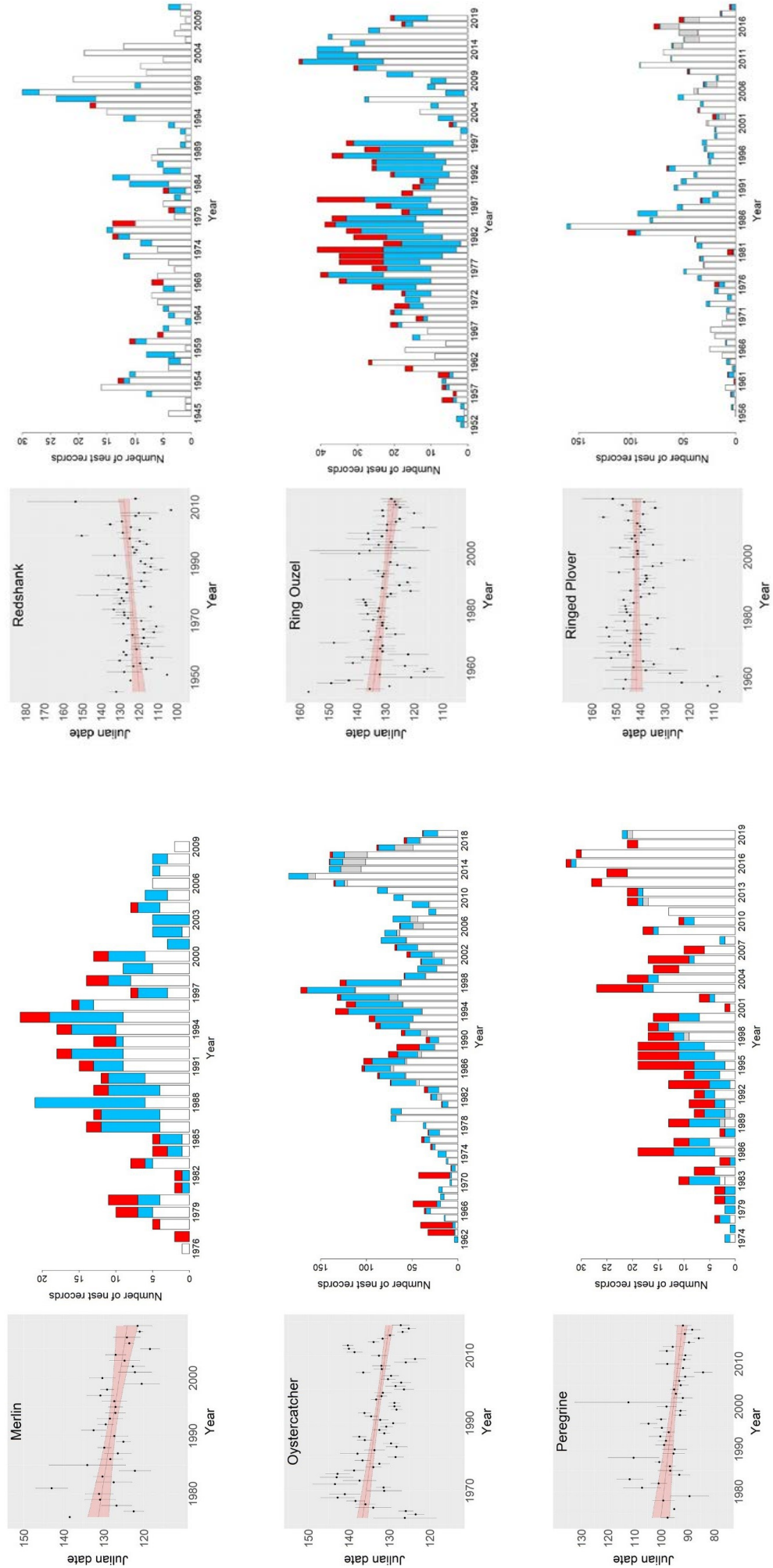
## APPENDIX 2. LAYING DATE TRENDS FOR INDIVIDUAL SPECIES.

Figure A2.1. Temporal trends in laying date from models based on Nest Record Scheme data for 17 species. For each species, the line graph represents predicted clutch initiation dates (standardised to values predicted for 1km square SE0293), with surrounding pink area showing 95% confidence intervals for this relationship. The dots show actual mean clutch initiation dates taken from nest records in each year, with black line showing standard error around these. The bar chart shows the number of nest records contributing to the model in each year, with bars split into records from England (white), Isle of Man (grey), Scotland (blue) and Wales (red).



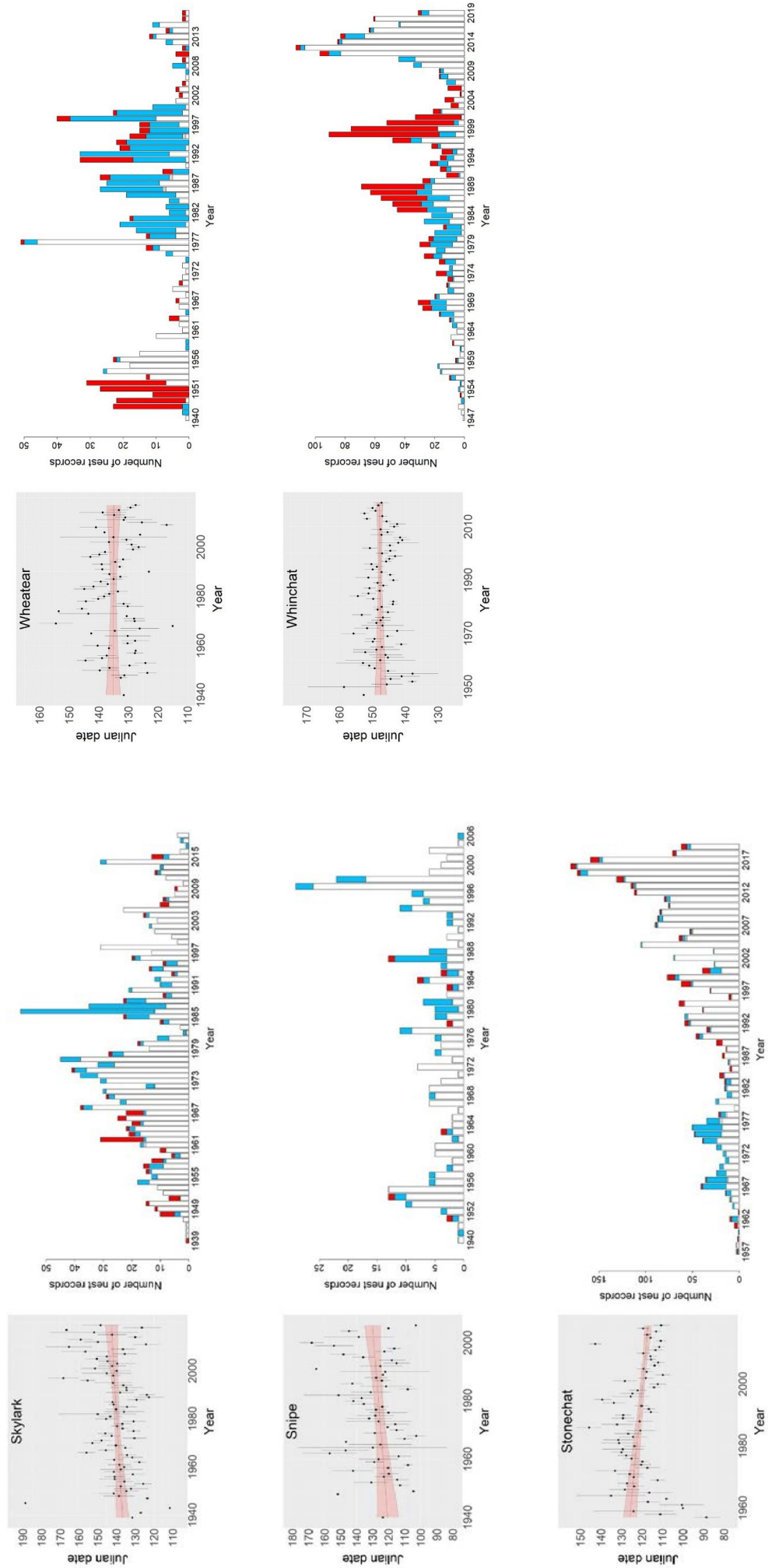
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## APPENDIX 3. WORKED EXAMPLES OF BURNING RISK.

The risk posed by burning to bird populations depends on a suite of factors that operate at different spatial and temporal scales. To evaluate the likely significance of burning impacts for populations of moorland species requires an assessment of the combined effect of each of these components of risk:

- a. Temporal overlap: the proportion of annual nesting attempts started before the end of the burning period
- b. Range level overlap: the proportion of the population that breeds in areas with rotational heather burning
- c. Landscape level overlap: the proportion of birds breeding in these areas that nest on moorland managed by heather burning
- d. Habitat level overlap: the proportion of birds breeding on moorland managed by burning that nest in habitats that are likely to be selected for burning
- e. Annual burning extent: the proportion of burnable heather moorland burned each year
- f. Spring burning: the proportion of moorland burning that actually occurs during the period of potential overlap with nesting activity in the spring.

Factors *a–d* are determined wholly or partly by bird ecology and demography, while factors *a*, *e* and *f* are influenced by management practices. If each of these elements of risk can be estimated, then the combined risk (*R*) from these different sources, expressed as the proportion of nesting attempts across the whole population likely to be destroyed by moorland burning, could be estimated by the following, very simple equation:

$$R = a \times b \times c \times d \times e \times f$$

The following two worked examples do this for: Stonechat, a species with moderately high temporal and habitat overlap (*a* and *d*) but low range level overlap with areas where burning is practised (*b*); and Merlin and Ring Ouzel, two species with lower temporal overlap (*a*) than Stonechat, but high levels of overlap at the range, landscape and habitat levels (*b – d*).

### Worked example of impact 1: Stonechat

The main upland burning season in Scotland and England overlaps with 41% of Stonechat breeding attempts, while the extended season in Scotland overlaps with 62% (factor *a*). In Scotland, 13% of Atlas TTV counts recording Stonechat occurred in tetrads where rotational heather

burning takes place, and the equivalent figure in England was 11% (factor *b*). Burned moorland actually only accounts for 11% of the tetrads we categorised as ‘burned’. Stonechat densities in these tetrads (0.26 per tetrad) were higher than in other tetrad categories (0.14 and 0.19 per tetrad), but the latter densities are high enough to suggest that this species is relatively generalist in its breeding requirements. We don’t know what proportion of Stonechats in burned tetrads actually nest on burned moorland (factor *c*), but if we assumed that the abundance of Stonechats in burned moorland is twice as high as that in other habitats in burned tetrads, about 22% (2 x 11%) would nest in this habitat. On the basis of these figures, we can estimate the proportion of Stonechats nesting in burned moorland as *b* x *c* would be 2.4% for England and 2.9% for Scotland.

Given their preference for nesting in tall heather and areas of scrub, among Stonechats breeding on rotationally burned moorlands, a liberal estimate of the proportion nesting in vegetation that could be targeted for burning (factor *d*) is 100%. We also need to take account of the proportion of burnable heather moorland that is set alight each year (factor *e*). Assuming a six-year burning rotation (consistent with the higher end of the spectrum of burning rotation intensities), with Stonechat nests on these moors spread evenly among the oldest two cohorts of heather, the heather supporting these nests would have a 50% chance of being burned in any one year. We also need to take into account how burning activity is spread through the season (factor *f*). Only the last six or seven weeks of the permitted burning window overlap with Stonechat clutch initiation dates. However, because the weather during this period of overlap may be better suited to burning than the weather during much of the remaining period, a liberal estimate is that an average 50% of heather burning each year happens during this spring period of overlap. In England, no burning carries on beyond mid-April, so the proportion of breeding attempts started during the breeding season is 41%. In Scotland, the standard burning season finishes in mid-April, but can be extended to the end of April, by which time 62% of Stonechat clutches have been initiated. Of Stonechat nests in burned moorland, we therefore estimate the percentage likely to be burned in any one year to be *a* x *d* x *e* x *f*, giving 10% for England and 10–16% for Scotland.

Multiplying all these components of risk together gives a population level of risk *R* of 0.2% of nests destroyed by burning each year for England, and 0.3–0.5% for Scotland. In the context of published, population-level rates of nest failure for this species of between 60–80% (van Oosten 2016; Fuller & Glue 1977), where predation of eggs and chicks is identified as the most likely cause, it seems likely that the direct impact of rotational burning on national Stonechat populations is comparatively negligible.



## **Worked example of impact 2: Merlin and Ring Ouzel**

Tetrads with burned moorland are disproportionately important for Merlin and Ring Ouzel, both species of conservation concern that nest preferentially in tall heather. Burned moorland areas account for around 60% of Merlins and 30–40% of Ring Ouzels in England and Scotland (factor *b*). These species are much less generalist in their breeding habitat preferences than Stonechats, and a high proportion of the birds nesting in burned tetrads are likely to be in rotationally burned moorland (we assume that factor *c* = 100%). On the basis of these figures, the proportions of Merlin and Ring Ouzel populations nesting in burned moorland, estimated as *b* x *c*, are much higher than for Stonechat (30–60%, as opposed to 2–3%).

However, temporal overlap between breeding and the standard upland burning season in England and Scotland is smaller for these species than for Stonechat, with the proportion of nest attempts occurring during this period being 6% for Ring Ouzel and 0% for Merlin (factor *a*). Assuming similar probabilities for factors *d*, *e* and *f* as estimated in the first worked example, the population level of risk *R* is 0% for Merlin, and 0.6% to 0.9% for Ring Ouzel. It should be noted, however, that extending the burning season to the end of April increases *R* considerably for both species; 6–7% in England, and 4–5% in Scotland. Such losses could be significant, particularly at a local or regional level, and for species already undergoing regional or national declines (Ewing *et al.* 2011; Wotton *et al.* 2016).







Cover image: Hugh Insley. Back cover: Liz Cutting

## Nesting dates of Moorland Birds in the English, Welsh and Scottish Uplands

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Rotational burning of vegetation is a common form of land management in UK upland habitats, and is restricted to the colder half of the year, with the time period during which burning may be carried out in upland areas varying between countries. In England and Scotland, this period runs from the 1st October to 15th April, but in the latter jurisdiction, permission can be granted to extend the burning season to 30th April. In Wales, this period runs from 1st October to 31st March.

This report sets out timing of breeding information for upland birds in England, Scotland and Wales, to assess whether rotational burning poses a threat to populations of these species, and the extent to which any such threat varies in space and time.

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