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Bird Study

ISSN: 0006-3657 (Print) 1944-6705 (Online) Journal homepage: www.tandfonline.com/journals/tbis20

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To cite this article: David Baines & Nicholas J. Aebischer (15 Jun 2026): High and stable Eurasian Curlew *Numenius arquata* numbers on low-intensity farmland and moorland managed for Red Grouse *Lagopus scotica* recreational shooting in northern England, Bird Study, DOI: 10.1080/00063657.2026.2685164

To link to this article: https://doi.org/10.1080/00063657.2026.2685164

Published online: 15 Jun 2026.

https://doi.org/10.1080/00063657.2026.2685164

High and stable Eurasian Curlew *Numenius arquata* numbers on low-intensity farmland and moorland managed for Red Grouse *Lagopus scotica* recreational shooting in northern England

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ABSTRACT

Capsule: Upper Teesdale in northern England supported 1,764 pairs of Eurasian Curlews (95% CL: 1,486–2,145), representing approximately 3% of the UK population; successful breeding and repeat counts indicated recent stable numbers.

Aims: To estimate breeding numbers by extrapolating from habitat-specific densities, nesting success (including three other wader species) from camera traps and population status from repeat counts.

Method: Birds were surveyed using transect-based methods in six habitat types within 114 1 km × 1 km grid squares. Linear densities estimated from transects in each habitat were converted into areal densities by comparing transect results with those from block surveys within the same grid squares. Habitat-specific densities were multiplied by habitat availability in the study area to give habitat-specific totals, which were summed to estimate total population size. Clutch survival was monitored using camera traps. Population status was assessed from repeat surveys approximately 10 years apart.

Results: All but one surveyed square supported Eurasian Curlews, with densities highest in rough grazing and grass-moor habitats at mid-elevations. Twice as many Eurasian Curlews occurred on blanket bog managed by burning and cutting than on unmanaged bog. Abundance from whole-square searches (block surveys) was 29% higher than from transect surveys in the same squares. Summed habitat-specific totals gave 1,764 pairs. Estimated clutch survival of Eurasian Curlews was 0.51, averaging 0.71 for four wader species combined. The most frequent clutch predators detected were Eurasian Badgers *Meles meles*, Stoats *Mustela erminea* and Sheep *Ovis aries*. Eurasian Curlews fledged 1.0 chick per pair, double the number needed to sustain numbers. Repeat surveys indicated that breeding numbers were stable in recent years at both scales.

Conclusions: High densities and high breeding success of Eurasian Curlews occurred within connected open-ground upland habitats within designated protected landscapes, where licensed culling of predators and management of blanket bog by gamekeepers to produce Red Grouse *Lagopus scotica* for recreational shooting, together with wildlife-friendly farming, were widely practised.

ARTICLE HISTORY
Received 19 July 2025
Accepted 22 April 2026

Waders are declining globally following a combination of direct habitat loss and degradation due to agricultural intensification and afforestation, associated increases in some generalist predators in modified habitats, and climate change (Baines 1988, Ratcliffe 2007, Douglas *et al.* 2014, Franks *et al.* 2017, Pearce-Higgins *et al.* 2017). Of the 20 wader species regularly breeding in the UK, 80% are categorized using IUCN extinction risk criteria as ‘Near Threatened’ nationally (Stanbury *et al.* 2017). The Eurasian Curlew *Numenius arquata* (hereafter ‘Curlew’) is one such near-threatened wader, not only within the UK but also globally. In the UK, Curlew populations declined by an estimated 49% (95% CI 55–42%) between 1995 and 2021 (Harris *et al.* 2022). The UK population, estimated at 58,500 pairs in 2016, represents about a quarter of the global breeding population (Woodward *et al.* 2020), with larger national-level populations found only in Finland and Russia. The rate of decline in the UK is one of the highest recorded, and hence is having a greater adverse impact on the global population than those in any other country (Brown *et al.* 2015).

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Low breeding success of Curlews is considered to drive the UK decline rather than changes in adult survival (Taylor & Dodd 2013, Cook *et al.* 2021); this often involves high rates of clutch predation (Fletcher *et al.* 2010, Colwell *et al.* 2020), with more than half of Curlew clutches being predated in 71% of 21 studies reviewed by MacDonald & Bolton (2008). Predation is mostly by nocturnally-active mammals such as Red Foxes *Vulpes vulpes*, Eurasian Badgers *Meles meles* (hereafter 'Fox' and 'Badger') and Stoats *Mustela erminea* (Robson 1998, MacDonald & Bolton 2008, Zielonka *et al.* 2019), but can also involve crows *Corvidae* and gulls *Laridae* (Jackson 2001). In Europe, over half of the published studies that measured Curlew breeding success report fewer than the 0.5–0.6 fledglings per pair per year that are required to sustain numbers (Grant *et al.* 1999, Brown *et al.* 2015).

Historically in the UK, Curlews predominantly occupied the northern uplands but colonized lowland grassland and arable crops of southern England from the late nineteenth century (Holloway 1996). Following agricultural intensification after the Second World War, lowland habitat extent and quality, together with the waders they host, have declined (Smith 1983, Wilson *et al.* 2005). Fewer than 500 pairs of Curlews now remain south of a line between The Wash in eastern England and north Shropshire in western England, where breeding success is as low as 0.1 fledglings per pair (Colwell *et al.* 2020). UK strongholds are increasingly restricted to moors and upland hill farms in mainland northern England and Scotland, and the island chains of Scotland, especially Orkney and Shetland (Balmer *et al.* 2013). Even there, significant declines of Curlews, together with Northern Lapwings *Vanellus vanellus* (hereafter 'Lapwing') and Dunlins *Calidris alpina*, have occurred in half of the upland areas receiving repeat surveys (Sim *et al.* 2005). There, wader declines have been linked with habitat changes, especially afforestation (Hancock *et al.* 2009, Amar *et al.* 2011), some following the cessation of management of moors for grouse-shooting (Ludwig *et al.* 2019).

A remaining stronghold for Curlews in northern England is the Northern Upland Chain, a local nature partnership covering five protected landscapes. Combined, they total almost 6,635 km^2 and comprise the Northumberland National Park (1,050 km^2), the Yorkshire Dales National Park (2,179 km^2), the North Pennines National Landscape (almost 2,000 km^2), the Nidderdale National Landscape (603 km^2) and the Forest of Bowland National Landscape (803 km^2) (Northern Upland Chain Local Nature Partnership 2024). Here, statutory designations at large landscape scales may have helped prevent major habitat changes by promoting the retention of low-intensity farming and semi-natural habitats, such as Heather moorland and peatlands. A primary land use in at least four of these five protected landscapes is the high-intensity recreational shooting of Red Grouse *Lagopus scotica*, which has been associated with higher densities of ground-nesting birds, including waders (Tharme *et al.* 2001). In the fifth landscape (the Northumberland National Park), where intensive grouse-shooting is less common, the benefit of the legal killing of predators on moors managed for grouse shooting (hereafter 'grouse moors') to ground-nesting birds was demonstrated in a 10-year replicated experiment: predator removal led to a three-fold increase in the breeding success of Curlews and other waders, and subsequent increases in their breeding numbers (Fletcher *et al.* 2010). Ten years after the experiment ended, predator numbers had increased again, and wader numbers had declined (Baines 2025). That these findings are more widely applicable across the UK was shown by Curlew breeding success being an average of four-fold higher across 18 grouse moors than on nearby paired moors, where predators were not killed but where habitat was similar (Baines *et al.* 2023).

Within this large connected series of protected landscapes in northern England, where generalist predators are routinely removed, we predicted that numbers of Curlews would be high, relatively stable, and their breeding success would also be high. We assessed this by conducting a habitat-based sample survey of Curlews in Upper Teesdale, part of the North Pennines National Landscape, selected owing to its logistical proximity to our field station. Here, we measured habitat-specific densities, estimated population size, measured breeding success and considered recent changes in numbers from repeat surveys.

Methods

Survey area

Upper Teesdale in the North Pennines National Landscape of northern England is the head of a wide glacial valley through which the River Tees flows from its source near Cross Fell, the highest point in the North Pennines at 893 m. The survey area lay upstream of Cotherstone village in Teesdale (latitude 54.57254°N, longitude 1.9832°W), whilst its boundaries followed the watersheds containing the River Tees and its tributaries with an altitude range of 170–873 m a.s.l. (Figure 1). The study area comprised

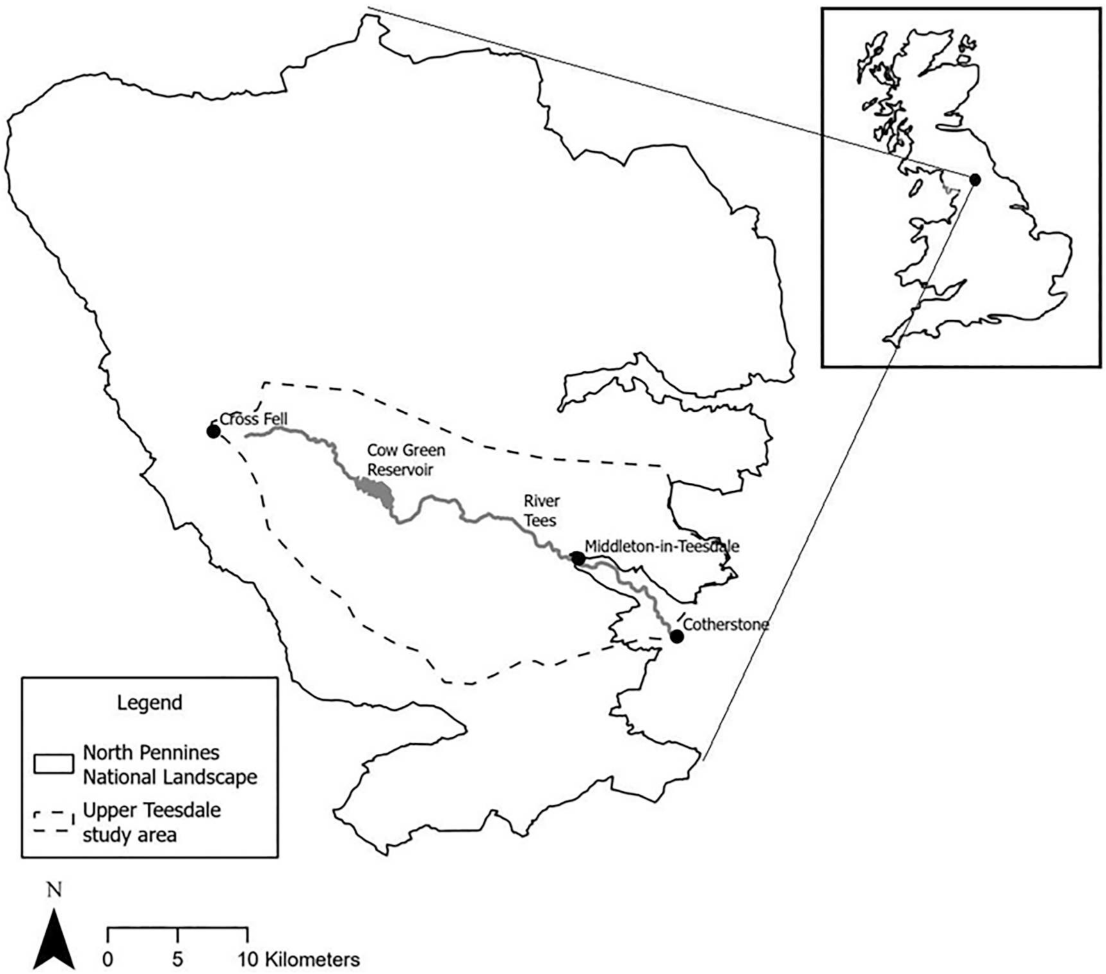

Figure 1. The Upper Teesdale study area within the North Pennines National Landscape, together with the location within Great Britain.

488 Ordnance Survey grid squares of 1 km × 1 km, of which 471 were considered suitable Curlew habitat of unenclosed moorland, and enclosed fields mostly within 2 km of the moor boundary (Table 1). The climate is cool, with a year-round mean daily temperature of 5.7°C, and wet, with an average of 1,523 mm of rain per annum recorded from the weather station at Widdybank Fell at an altitude of 510 m (Pigott 1978). These climatic conditions create a short growing season for vegetation, which limits the extent and intensity of agricultural practices to low-intensity mixed-livestock grazing, principally of Sheep, but also Cattle *Bos taurus*, chiefly on small, tenanted farms, but with some owner-occupied farms.

Table 1. The number of 1-km grid squares dominated by each of six main habitat types in Upper Teesdale, with the number sampled for bird surveys and their altitudinal distribution.

Dominant habitat type	No. of 1-km grid squares	No. squares surveyed	Mean altitude of survey squares (m) (range)
Inbye grass fields	105 (22%)	22 (19%)	304 (215–430)
Rough grazings	38 (8%)	14 (12%)	370 (300–450)
Grass moor	67 (14%)	28 (25%)	491 (270–675)
Heather moor	71 (15%)	11 (10%)	482 (315–715)
Blanket bog (managed)	102 (21%)	18 (16%)	513 (343–670)
Blanket bog (unmanaged)	88 (18%)	21 (18%)	618 (460–740)
Other #	17 (3%)	–	–
Overall	488	114	466 (215–740)

Open water (7 squares), Woodland (5), Montane (4), Human settlement (1).

The moors and marginal farmland constituting the Upper Teesdale study area have several international and national designations for their habitats and assemblages of breeding birds. The land forms part of the North Pennine Moors Special Protection Area (1,472 km^2), designated for the Hen Harrier *Circus cyaneus*, Merlin *Falco columbarius*, Peregrine Falcon *F. peregrinus* and European Golden Plover *Pluvialis apricaria* (hereafter 'Golden Plover') (English Nature 2001), and includes the Moor House-Upper Teesdale Special Area for Conservation (388 km^2), with priority features including blanket bog, dry grassland and alpine and boreal heath. National designations within the area include the Moor House-Upper Teesdale National Nature Reserve (NNR) (74 km^2) (chief habitats: blanket bog, northern hay meadows and limestone grassland) and six large upland Sites of Special Scientific Interest (SSSIs): Upper Teesdale SSSI (140 km^2) (dry heath, wet heath, blanket bog), Moor House and Cross Fell SSSI (137 km^2) (blanket bog, sub-montane and montane heath), Lune Forest SSSI (63 km^2) (blanket bog, heath, acid and limestone grasslands), Cotherstone Moor SSSI (24 km^2) (blanket bog, dry heath, acid grassland), Teesdale Allotments SSSI (13 km^2) (enclosed rough grazings) and part of the Bollihope, Pikestone, Eggleston and Woodland Fells SSSI (79 km^2) (dry and wet heaths, blanket bog). Upper Teesdale is renowned for its diversity and abundance of breeding waders, hosting 11 breeding species (Coulson 1978).

Nine large estates make up most of the Upper Teesdale study area. Seven are privately owned and the moorland is primarily managed for recreational grouse-shooting. One estate is owned by the Ministry of Defence (MoD) and managed for army training, but grouse are also shot there. The remaining estate, Moor House, is owned by Natural England and forms part of the Moor House-Upper Teesdale NNR, where grouse are not shot. During the study, 22 full-time gamekeepers were employed collectively across the seven privately owned grouse moors, with some additional gamekeeper activity on the MoD estate. Operating under UK Government General Licences GL38, GL40 and GL42, gamekeepers legally killed generalist predators at a landscape scale across the entire areas of the private estates, primarily to create surpluses of Red Grouse on the dominant Common Heather *Calluna vulgaris* (hereafter 'Heather') moorland habitats for recreational shooting, but also to benefit other birds, notably the Black Grouse *Lyrurus tetrix* and Grey Partridge *Perdix perdix*, and also waders, including those nesting on the farmland. Gamekeepers also had agreed neighbourly access to the Moor House estate to kill Foxes and corvids. Prior to 2021, when regulations were tightened to restrict burning over blanket bog to protect its ecosystem services (DEFRA 2021), gamekeepers managed the Heather on the private estates by rotational strip burning, and since 2021 by Heather cutting, to create a structurally heterogenous sward favoured by many ground-nesting birds. Virtually all Heather-dominated moorland on the MoD estate and that on the Moor House part of the NNR are no longer managed either by burning or cutting, but only by low-intensity Sheep grazing, with burning having ceased at Moor House at least 70 years ago (Lee *et al.* 2013).

Selection of survey squares

A combination of personal knowledge, preliminary field visits and aerial images was used to assign the 488 squares to one of six main habitat types whose cover proportionally dominated each square: enclosed grass fields, enclosed rough grazing, grass moor, Heather moor and blanket bog, the latter sub-divided into managed (ericaceous vegetation burnt or cut to benefit Red Grouse) or unmanaged. These habitat types, described in more detail below, formed an altitudinal succession from the enclosed grass fields on the valley floor and lower slopes, through the larger rough grazing on the mid-slopes, to unenclosed grass and Heather moor on the upper slopes, and blanket bog on the upper slopes and hill summits (Table 1). Only 17 squares (3% of the land cover) were dominated by open water, woodland, montane (above the natural treeline, usually over 700 m; Thompson & Brown 1992) and urban (Middleton-in-Teesdale village, latitude 54.6229°N, longitude 2.0779°W); they were considered of low importance to Curlews and were excluded from the survey.

Habitat descriptions are as follows:

(1) Grass fields (locally known as 'inbyes') were enclosed by stone walls or fences and either grazed year-round by Sheep or Cattle (pastures) or left livestock-free between May and July to grow a silage or hay crop (meadows). Pastures differed in Soft Rush *Juncus effusus* encroachment, often in relation to the influence of the presence and condition of sub-surface drains on the water-table. Being on mineral soils, inbyes were agriculturally more productive and annually received organic farmyard manure or inorganic fertilizer, together with infrequent applications of lime to maintain the pH.

(2) Rough grazings (known locally as 'allotments'), also enclosed by walls or fences, were larger and less productive than inbye grass fields and received no fertilizer or lime applications. Not being drained, they were wetter, giving rise to rush infestation, which often dominated together with coarse grasses. They were managed by grazing with Sheep, either seasonally or year-round, and occasionally with Cattle from late spring to autumn.

(3) Moorland was divided into unenclosed grass moor (also known as acid grassland) and Heather moor, combining both dry and wet heath. Grass moor had historically high Sheep densities, often year-round, resulting in loss of Heather to grasses such as Mat-grass *Nardus stricta* and Purple Moor-

grass *Molinia caerulea*. Where Sheep densities were lower or seasonally restricted, Heather remained and was managed by strip burning or, more recently, cutting to favour Red Grouse.

(4) Blanket bog occurred on the higher, gently sloping valley sides and hill summits, where seasonal waterlogging promoted depositions of deep peat. The dwarf shrub vegetation was usually grazed seasonally by Sheep. Managed bogs were those where burning or cutting of ericaceous swards was conducted to favour Red Grouse abundance by promoting protein-rich flowers of Hare's-tail Cottongrass *Eriophorum vaginatum* (Whitehead *et al.* 2021, Heinemeyer *et al.* 2023), eaten by grouse in early spring (Moss *et al.* 1990), by increasing the nutritious quality of new Heather shoots (Heinemeyer *et al.* 2025), and by creating heterogeneity in vegetation structure.

We aimed to survey 20 randomly selected squares from each of the six habitat types. Some squares had their habitat type reclassified following field surveys so final sample sizes for each habitat differed from intended (Table 1). Overall, 114 squares were surveyed, this being 24% of those available: 33 squares were surveyed in 2020 and 81 in 2021.

Survey methods

Birds were surveyed in spring using Breeding Bird Survey (BBS) methods, whereby an observer walked along two parallel 1-km transects, separated by 500 m, within a 1 km × 1 km grid square. Each transect was situated 250 m in from the square boundary and aligned west–east across the square. Bird positions were assigned to three distance bands from the transects (< 25 m, 25–100 m, >100 m) (Massimino *et al.* 2025). For four peripheral squares, one transect lay outside the study area and was not surveyed. Except for three squares where access permission was granted late, squares were surveyed twice, first between mid-April and mid-May, then repeated mid-May to mid-June. Surveys commenced just before dawn and were completed by 09.00 local time, to coincide with peak bird detectability (Reed *et al.* 1985). Groups of four or more birds were classed as a flock and were excluded. It was assumed that all birds present were breeding or had bred in the square. Summary details of the abundance of 51 bird species encountered are provided in Appendix 1.

Domestic livestock within 200 m of the transects were counted in each square on each visit and converted into mean livestock densities. Site-specific livestock grazing pressure, being based on observations from two days only in the bird breeding season, may not fully represent those throughout the farming year. For example, only Sheep were observed during the surveys, with Cattle being grazed outside later in spring and through to the autumn. Altitude (m) in each square was recorded as the average of the maximum and minimum altitudes.

A preliminary examination of the Curlew data collected in 2020 revealed that a key assumption of distance sampling, i.e. that animals do not move before detection, was systematically violated. Most Curlews were seen only when flying, having first moved away from the observer. In such cases, the distance estimator underestimates abundance (Buckland *et al.* 1993). Instead, we calibrated transect counts against abundance counts by pairing them with block surveys (Brown & Shepherd 1993: 'B&S') covering the whole of the same square, for each of 16 squares on one moor in 2021. In the B&S block surveys, an observer searched for birds to within 100 m of each part of the square and plotted bird locations on 1:25,000 Ordnance Survey maps. There were two observers, one carrying out a BBS survey and the other a B&S survey within two days of each other. This avoided influencing the second count through familiarity with the ground and bird locations gained from the first count.

The survey method was randomized within a visit × observer 'Latin Square design' replicated across squares to avoid temporal and observer biases. The number of Curlews seen per visit and observer by each method were compared within a generalized linear model (GLM) with a Poisson error distribution and logarithmic link function, with square as a blocking factor and observer, survey method and visit nested within square as explanatory factors. Because neither the first nor the second survey could be carried out on all 16 squares on the same date, visit effects were considered to vary across squares whereas observer effects were kept constant. The coefficient of method measured how much (on a logarithmic scale) BBS estimates fell short of B&S estimates; it provided a conversion term (or exponentiated, a conversion multiplier) that converted estimates of linear density from BBS transects (birds km^{-1}) into area density estimates (birds km^{-2}).

The BBS counts from the full set of 114 squares were analysed in relation to habitat type using a GLM with Poisson error, logarithmic link, offset equal to ln(cumulative transect lengths across visits per square, in km), dependent variable equal to sum of counts across visits to each square, with the main habitat in each square as the explanatory factor. The constant was omitted so that, when exponentiated, the six habitat coefficients represented habitat-specific Curlew linear densities (birds km^{-1}). Each exponentiated value was converted to an equivalent B&S areal density value by doubling it to obtain the number recorded per BBS square (two 1-km transects), then applying the conversion multiplier from the previous model. This was then multiplied by the number of squares of that habitat type in the study area to give the number of Curlews within each habitat category. The sum of the habitat-specific totals gave an estimate of population size in Upper Teesdale. The associated 95% confidence interval was obtained as the 2.5th and 97.5th percentiles of 5,000 totals calculated as described above from random realizations of the six habitat coefficients (second GLM), and from the method coefficient (first GLM) drawn from normal distributions with means equal to their estimates and variances equal to the square of their standard errors.

The relationships between Curlews, livestock (Sheep) densities and altitude were examined by univariate Poisson regression with offset ln(cumulative transect length) as above, fitting both linear and quadratic terms. Each was then added in turn to the habitat model to establish whether they explained additional variation in Curlew abundance to habitat alone.

Wader breeding success

For nest studies, to test whether a high abundance of Curlews was associated with high breeding success, an initial 12 nests were monitored in 2014. In 2022 and 2023, camera traps were positioned at a further 53 Curlew nests in Upper Teesdale and the adjacent valley of Weardale. To provide broader estimates of wader hatching success and the identification of clutch predators, nests of Golden Plovers, Lapwings and Eurasian Oystercatchers *Haematopus ostralegus* sharing the same habitats as Curlews were also monitored using cameras, giving 137 wader nests. Nests were located whilst conducting other ecological fieldwork or routine management either by staff of the Game & Wildlife Conservation Trust or moorland gamekeepers. Hatching success for each species was estimated as the proportion of clutches from which one or more chicks hatched from clutches of known fate. Additionally, clutch survival was measured by calculating daily survival probabilities expressed over the full incubation periods of 29 (Curlew), 30 (Golden Plover), 28 (Lapwing) and 27 (Oystercatcher) days (Cramp & Simmons 1983), expressed as nest survival probabilities following Mayfield (1961). Whether a clutch had hatched was initially determined from field evidence. Hatched clutches had small egg-shell fragments in the nest lining (Green *et al.* 1987) and typically had alarm-calling adults present. Failed clutches were those where nests were empty and there were no alarm-calling adults. Later examination of camera footage vindicated all clutch fate decisions made in the field and provided reliable information on the identity of clutch predators.

In 2014, a pilot study in Upper Teesdale considered whether the behaviour of adult Curlews could be used to estimate breeding success. Curlews were surveyed five times, with successive visits at least one week apart. One visit occurred within each of the periods 14–25 April, 6–22 May and 26 May to 10 June to estimate pair density (Grant *et al.* 2000, Baines *et al.* 2023). A further two visits were conducted two weeks apart in the periods 16–30 June and 1–13 July to assess whether pairs had chicks. Pairs were classified as having chicks if they alarm-called vociferously and persistently whilst flying in circles around the observer. Repeated alarm behaviour of adults in the same locality over visits 3–5 was used to estimate the proportion of pairs that had chicks at a typical fledging age in visit-4 and mostly visit-5. Twenty-five pairs of Curlews, including 12 of their nests, were monitored using these methods to estimate hatching and fledging success. Counts of chicks in individual broods were not conducted. Equivalent data from two other grouse moors in the North Pennines National Landscape and four in the nearby Yorkshire Dales National Park were extracted from Baines *et al.* (2023) for comparison.

Repeat counts to assess Curlew population status

As part of a survey of moorland birds in the UK (D. Baines unpubl. data), 21 1-km grid squares were surveyed for Curlews using BBS methods within the Upper Teesdale study area in the period 2007–11, then repeated in 2019–21, on average 10 years (range: 8–12) later. Repeat surveys were also conducted in 25 squares in the wider North Pennines National Landscape, but outside of Teesdale. To establish whether trends in Teesdale were the same as those in the wider North Pennines National Landscape, the sum of the counts from the two visits were the response variable in a GLM Poisson regression, square as a blocking factor and region (Upper Teesdale or North Pennines National Landscape) and period (2007–11 or 2019–21) and their interaction as explanatory factors. Output means and 95% CL were back-transformed and divided by two to give Curlews observed per visit per 1-km grid square, i.e. per 2 km of transect. All analyses were conducted using GenStat (18th edition, Rothamsted Research, Harpenden, UK).

Results

The abundance of Curlews and some other waders

The 51 bird species encountered included nine wader species, with one or more wader species found in all squares. Curlews were present in all but one (99%) square at a mean 3.3 birds km^{-1} (maximum 11.5) in those occupied squares. Golden Plovers were present in 69% at 1.8 birds km^{-1} (max 11.0) and Lapwings in 62% at 4.0 birds km^{-1} (max 22.5).

Curlew linear abundance showed a four-fold difference between habitat types ($F_{5,108} = 11.92$, $P <$ 0.001), being highest on rough grazings and grass moor, intermediate on managed blanket bog, Heather moor and in inbye fields, and lowest on unmanaged blanket bog (Table 2). Curlew abundance was unrelated to Sheep density but showed a quadratic relationship with altitude increasing up to 389 m before decreasing at higher altitudes ($F_{2,111} = 15.33$, $P < 0.001$; linear coefficient 0.0139 ± 0.0045, $t_{111} = 3.08$, $P = 0.003$; quadratic coefficient $0.000018 + 0.000005$, $t_{111} = -3.57$, $P < 0.001$). When included in Curlew models containing habitat, neither Sheep density nor altitude were significant.

The comparison between Curlew abundances from transects (BBS) and those from blocks (B&S) found that whilst detection differed between observers ($\chi^2_1 = 6.65$, $P = 0.010$) there was a significant difference between survey methods ($\chi^2_1 = 14.39$, $P < 0.001$; difference between methods on logarithmic scale 0.251 ± 0.066, $z = 3.79$, $P < 0.001$). Exponentiating the difference gave a multiplier of 1.285 (95% CI: 1.203, 1.373), i.e. 28.5% more birds were recorded on blocks than on 2-km transects.

Curlew densities from BBS transect surveys (birds km^{-1}) converted into B&S block-survey densities (birds km^{-2}) are presented in Table 2. Curlew densities varied almost five-fold between habitats, ranging from 16.2 birds km^{-2} and 11.8 birds km^{-2} in grid squares assigned as rough grazings and grass moor respectively to only 3.4 in squares assigned as unmanaged blanket bog. Managed blanket bog was associated with densities more than double those on unmanaged bog. Squares dominated by rough grazings supported 18% of Upper Teesdale's Curlews, despite forming only 8% of the land cover. Similarly, grass moor squares supported 22% of the birds on 14% of the area. Conversely, unmanaged blanket bog hosted only 8% of the birds on 18% of the area. Other habitats hosted birds roughly in relation to their areas.

Based on the habitat-specific density estimates, the Upper Teesdale population size was 3,527 (95% CL: 2,969, 4,323). Assuming that all birds bred, which is not always the case (Bowgen *et al.* 2022), and did so in pairs, this gave 1,764 breeding pairs.

Hatching and fledging success

Of the 12 Curlew clutches monitored in 2014, nine hatched (75%), similar to the 37 of the 50 Curlew nests of known fate (70%) that hatched in 2022–23 when monitored remotely using cameras (Table 3). Of the 136 wader nests monitored using nest cameras, 126 had a known fate, with 98 hatching (78%), 24 being predated (19%) and four abandoned (3%). Clutch survival probability for the four most-encountered species (Curlew, Golden Plover, Lapwing and Oystercatcher) in 2022–23 following Mayfield (1961) averaged 0.72, varying from 0.53 for Curlews to

Table 2. Number of Curlews in Upper Teesdale, calculated using habitat-specific coefficients from a Poisson regression of Curlew BBS counts against the main habitat type in each square. Linear densities (birds km^{-1}) were obtained by exponentiating the coefficients, then converted to Brown & Shepherd areal densities (birds km^{-2}) and extrapolated to habitat-specific totals across Upper Teesdale based on habitat extent. Habitat types are given in order of decreasing densities of Curlews that they supported.

Habitat type	Regression coefficient (± SE)	Linear density (birds km−1) (95% CL)	Areal density (birds km^{-2}) (95% CL)	Squares in Upper Teesdale (%)	Curlews in Upper Teesdale (95% CL; %)
Rough grazings	1.843 ± 0.129	6.32 (4.90, 8.13)	16.23 (12.21, 21.18)	38 (8%)	617 (464, 805; 18%)
Grass moor	1.526 ± 0.111	4.60 (3.70, 5.72)	11.82 (9.22, 15.24)	67 (14%)	792 (618, 1,021; 22%)
Blanket bog (managed)	1.121 ± 0.161	3.07 (2.24, 4.21)	7.88 (5.63, 11.06)	102 (21%)	804 (574, 1,128; 23%)
Heather moor	0.860 ± 0.234	2.36 (1.49, 3.74)	6.07 (3.72, 9.89)	71 (15%)	431 (264,702; 12%)
Inbye grass fields	0.775 ± 0.173	2.17 (1.55, 3.05)	5.58 (3.89, 7.96)	105 (22%)	586 (408, 836; 17%)
Blanket bog (unmanaged)	0.272 ± 0.233	1.31 (0.83, 2.07)	3.37 (2.11, 5.31)	88 (18%)	297 (186, 467; 8%)
Total across all habitats				**471**	**3,527 (2,972–4,292)**

Table 3. Hatching success (% of clutches that hatched), clutch survival probabilities and clutch predators for clutches of known fate in four wader species in Upper Teesdale and Weardale, monitored using nest cameras in 2022 and 2023, with equivalent hatching success for Curlews in 2014 monitored without cameras.

Species	*n*	% hatch	Nest days	Daily survival probability	Clutch Survival probability	Clutch predators
Curlew (2014)	12	75%	–	–	–	–
Curlew (2022–23)	50	70%	699	0.97854	0.53	Stoat (5), Badger (3), Sheep (3), Fox (1), unknown predator (2)
Golden plover (2022–23)	14	93%	277	0.99639	0.89	Badger (1)
Lapwing (2022–23)	46	76%	483	0.97723	0.52	Badger (2), Sheep (2), Black-headed Gull (1), Sheep (1), Sparrowhawk# (1), unknown predator (2)
Oystercatcher (2022–23)	16	94%	269	0.99628	0.90	Ferret (1)

Incubating adult flushed from nest and killed by Sparrowhawk, clutch subsequently deserted.

0.90 for Oystercatchers (Table 3). Twenty-four wader clutches were predated, and predators were identified by cameras at 20 of them: six were predated by Badgers, five each by Stoats and Sheep and one by each of Fox, feral Ferret *Mustela putorius furo*, Black-headed Gull *Chroicocephalus ridibundus* and Eurasian Sparrowhawk *Accipiter nisus*, the latter predating the incubating adult Lapwing causing desertion of the clutch.

Of the 25 pairs of Curlews monitored by adult behaviour in 2014, 16 (64%) fledged one or more chicks (Table 4). This estimate falls within the range of 50–100% fledging success from six other managed grouse moors in the North Pennines National Landscape or the Yorkshire Dales National Park. Assuming a generic mean brood size of 1.6 (Baines *et al.* 2023), this equated to 1.0 fledglings per pair in Teesdale and a mean of 1.1 across all seven sites. All estimates surpassed the estimated 0.5–0.6 fledglings per pair required to sustain numbers.

Repeat counts to assess population status in Curlews

Repeat surveys on an average of 10 years apart showed trends in Curlew densities in Upper Teesdale to be consistent with those in the wider North Pennines National Landscape (period × region: $F_{1,44} = 1.06$, $P = 0.31$), where they occurred at similar densities ($F_{1,45} = 1.16$, $P = 0.29$). Combining Teesdale and the wider North Pennines data, and comparing across survey periods, showed a non-significant 10-year change in abundance of only −3%, with a mean of 7.6 birds per 1-km grid square in 2007–11 and 7.3 in the period 2019–21 ($F_{1,45} = 0.30$, $P = 0.59$).

Discussion

The Upper Teesdale study area supported 1,764 pairs of Curlews, which represented 3% of the UK population, estimated at 58,500 pairs in 2016 (Woodward *et al.* 2020). Densities of Curlews varied four-fold between six habitat types, being lowest at almost two pairs km^{-2} on unmanaged blanket bog and highest at eight pairs km^{-2} on enclosed rough grazings. The mean density of almost four pairs km^{-2} across the study area is relatively high for mainland UK, being a whole magnitude higher than the 0.3 pairs km^{-2} recorded across wet lowland grasslands in England and Wales (Wilson *et al.* 2005) and an upland area of North Wales (Johnstone *et al.* 2017), both where numbers were in steep decline. Our densities were also two to three-fold higher than those recorded in paired enclosed upland farmland and unenclosed moorland sites in six mainland UK landscapes (*Douglas et al.* 2023). Instead, they were more comparable to densities across an array of farmland habitats on the islands of Shetland and Orkney in northern Scotland (van der Wal & Palmer 2008, Douglas *et al.* 2021).

Repeated Curlew surveys spanning an average of 10 years showed high breeding densities in Upper Teesdale and the wider North Pennines National Landscape to be stable over approximately one Curlew generation. The population of 1,764 pairs represents 0.5–0.7% of the global population of 255,000–355,000 pairs cited by Brown *et al.* (2015), which may now be higher given the stability in our study area and the on-going declines elsewhere. The national and international importance of the population of Curlews in Upper Teesdale, and more widely within the Northern Upland Chain in northern England, is heightened by their high reproductive rate. A mean of 1.1 fledglings per Curlew pair was measured across multiple sites and over four breeding years. This is double the value required to sustain numbers (Grant *et al.* 1999), suggesting that the local population should have increased. That numbers merely remained stable suggests that source-sink dynamics may be operating over a much wider geographical area, possibly reducing rates of decline outside of these

Table 4. Estimated Curlew hatching success (proportion of pairs that hatched chicks) and fledging success (proportion of pairs that fledged any chicks) in Upper Teesdale in 2014, with comparative values from two other grouse moors in the wider North Pennines National Landscape (NPNL) and four grouse moors in the Yorkshire Dales National Park (YDNP) taken from Baines *et al.* (2023).

Site	Year	Pairs	Hatching success	Fledging success
Upper Teesdale	2014	25	0.75	0.64
South Northumberland (NPNL)	2018	22	0.68	0.64
Eden Valley (NPNL)	2016	20	0.80	0.70
Hawes (YDNP)	2016	14	0.79	0.71
Wensleydale (YDNP)	2017	19	0.68	0.68
Swaledale (YDNP)	2016	11	1.00	1.00
Arkengarthdale (YDNP)	2017	16	0.94	0.50
All sites		**127**	**0.79**	**0.68**

strongholds for Curlews in the uplands of northern England.

The diversity and abundance of ground-nesting birds in Upper Teesdale, including 11 wader species described by Coulson (1978), also remained evident in this survey, with nine wader species found. Those species unrecorded were Ringed Plover *Charadrius hiaticula*, still a regular annual breeder on reservoir shores in the dale, and Dotterel *C. morinellus*, an infrequent breeder in montane habitats. Neither of those habitats were sampled in this survey. The Teesdale uplands, together with the wider North Pennines National Landscape, are characterized by their managed grouse moors. The link between grouse moors and high wader abundance has been established over landscape scales for parts of eastern Scotland and northern England, including the North Pennines (Tharme *et al.* 2001), and supported by a case study at Langholm Moor in south-west Scotland (Ludwig *et al.* 2019). Similarly, Curlew abundance at regional and national UK levels was positively associated with areas managed for grouse or other recreational shooting, and negatively with generalist predators (Franks *et al.* 2017, Littlewood *et al.* 2019).

There are many active Curlew conservation projects in the UK (see www.curlewaction.org.), and whether similar positive responses to management by Curlews can be delivered outside of grouse moors remains to be seen. The chief difficulty appears to lie with increasing breeding success, especially in the presence of high numbers of meso-predators (Roos *et al.* 2018). Beneficial manipulation of breeding habitat and seasonal control of Foxes and Carrion Crows *Corvus corone* over five years across six paired UK sites failed to reduce predator indices sufficiently to increase Curlew nesting success (Douglas *et al.* 2023). In contrast, experimental year-round culling of the same predators, together with Stoats and Weasels *Mustela nivalis*, over eight years in Northumberland (northern England) resulted in three-fold higher breeding success amongst Curlews, Lapwings and Golden Plovers and subsequent increases in their breeding abundance (Fletcher *et al.* 2010). The latter was reversed after experimental culling ceased (Baines 2025). Similarly, reinstatement of predator culling, combined with some moorland habitat improvements, over 10 years at Langholm in south-west Scotland was associated with partially restored numbers of Curlews, Golden Plovers and Common Snipes *Gallinago gallinago* (Ludwig *et al.* 2019), following earlier declines after predator culling had largely stopped (Baines *et al.* 2008). These findings for breeding success of Curlews in relation to predator levels were mirrored across several UK regions, with a mean four-fold higher breeding success (1.1 fledglings per pair) on grouse moors where predators were culled compared to similar moorland habitats where predators were not culled (0.3 fledglings per pair) (Baines *et al.* 2023), adding further support to the necessity of culling predators at landscape scales for successful conservation of Curlews.

Nevertheless, it is important to establish which predators impact upon waders and under what circumstances. Mammalian predation of clutches, mostly nocturnally, was responsible for 70% of predation events at wader nests in a review of European studies (MacDonald & Bolton 2008), and 88% in a similar review of nest-camera studies in the UK (Barton *et al.* 2026). The biggest impacts were often by Foxes, Badgers and Stoats (Zielonka *et al.* 2019, Ewing *et al.* 2023), whilst birds predated only 10% of clutches. Given that the UK hosts some of the highest densities of Foxes and corvids in Europe (Roos *et al.* 2018), and despite eggs not being a major dietary item of these generalists, their incidental predation is likely to be contributing to wader declines (Vickery *et al.* 1992).

The relative importance of different clutch predators can vary markedly between sites. In this study, gamekeepers routinely killed Foxes, Stoats and corvids across virtually all of the study area, resulting in them being few in number; only one wader clutch was predated by a Fox and none by corvids. Instead, it was mustelids, principally Badgers (legally protected in the UK), but also Stoats, that were responsible for almost two-thirds of predation events where the predator could be identified. These findings from cameras support field evidence also gathered in Teesdale by Robson (1998), who found that Stoats predated seven of eight Curlew clutches where the predator was identified. Removal of an apex predator may cause a mesopredator release (Rees *et al.* 2023), and in this case the removal of Foxes by gamekeepers may have caused an increase in Stoats, which are more difficult to control efficiently and so have an impact on prey, in this case breeding waders. However, Sheep predated four clutches; this type of predation had previously been recorded at a single nest by Zielonka *et al.* (2019), and is mentioned by Colwell *et al.* (2020), with ungulates (predominantly Sheep) forming 6% of predation events amongst wader clutches in a review by Barton *et al.* (2026). Nest monitoring equipment may, however, deter or attract potential clutch predators, thereby affecting rates of predation and possibly biasing data collected on predator identity (Richardson *et al.* 2009). Being domesticated and inquisitive, Sheep may have been drawn to the nest locality by the presence of the camera, a possible bias that future studies need to be aware of and avoid.

Recent radio-tracking studies have revealed that the spectrum of predators of wader chicks is wider than first envisaged, and can also involve Common Buzzards *Buteo buteo* and Red Kites *Milvus milvus* (Teunisson *et al.* 2008, Mason *et al.* 2018, Mason *et al.* 2021). Although raptors are protected and cannot be legally killed, their illegal persecution continues on some grouse moors (Newton 2021) and could, in part, explain why wader numbers and their breeding success remain high on many grouse moors (Baines *et al.* 2023). However, no raptors were illegally killed on study sites during the Northumberland (Fletcher *et al.* 2010) or Langholm studies (Ludwig *et al.* 2019), illustrating that the (legal) lethal control of generalist predators at appropriate scales and intensities by experienced personnel can lead to measurable benefits for Curlews and other waders without resorting to the illegal killing of raptors.

The high degree of environmental protection afforded to the landscape of Upper Teesdale through multiple designations, together with its climatic limitations for agriculture, have probably helped retain low-intensity farming and semi-natural habitats. Curlew abundance was higher in rough grazings and grass moorland habitats at mid-levels on the valley slopes than in either inbye fields or blanket bogs on the valley floor and hill tops respectively. These settlement patterns explained the quadratic relationship with altitude shown by Curlews, which became non-significant when altitude was included in models alongside habitat. Planted coniferous woodland comprised only 1% of the survey area and it is likely that the socio-economic importance of grouse shooting on the higher slopes helped retain Heather-dominated habitats (Robertson *et al.* 2001), and guard against afforestation and its associated impacts on ground-nesting birds, including Curlews (Douglas *et al.* 2014, Franks *et al.* 2017, Robertson *et al.* 2017).

Similarly, low-intensity mixed livestock farming on the lower slopes and valley floor has promoted High Value Nature Farming, which delivers greater heterogeneity in vegetation structure and invertebrate prey for passerines and waders within sympathetically managed rush pasture than conventional farming (Evans *et al.* 2006). In herb-rich hay meadows the later mowing dates avoid nesting waders (Parish *et al.* 2001). Curlew abundance on moorland is also higher where vegetation structure is more heterogeneous (Pearce-Higgins & Grant 2006). Structural heterogeneity is increased by burning and cutting, which elsewhere in the North Pennines resulted in increases in Curlews and Golden Plovers (Douglas *et al.* 2017), and in our study was associated with twice as many Curlews as unmanaged bogs. Forms of vegetation management over blanket bog that minimize possible impacts on carbon stores and peatland hydrology must be maintained to provide structural heterogeneity for nesting and brood-rearing, with patch connectivity provided at appropriate scales. In England, recently updated restrictions imposed by the UK Government on burning, particularly on designated sites (DEFRA 2021), may lead to further national declines in moorland waders should equivalent Heather-cutting not form an able substitute for burning. This is particularly important given changes in national and local grazing policies in the last few decades that have dramatically reduced the number of grazing Sheep in the English uplands, e.g. at the Moor House NNR in Upper Teesdale (Milligan *et al.* 2016).

The stable, high-density, successfully-breeding population of Curlews in Upper Teesdale was associated with the retention of an assemblage of open-ground habitats at a landscape scale, through a combination of grouse shooting, a virtual absence of afforestation, site designation and wildlife-friendly farming, with the latter limited in its intensity by the cool, wet climate. The likelihood of sustaining Curlews outside of grouse moors, some nature reserves, and offshore islands would be higher if appropriate conservation measures were applied in the long term and over sufficiently large contiguous areas of suitable habitat. Within such areas, there is a general consensus that high numbers of generalist predators limit breeding success. In Upper Teesdale, predators were extensively removed through licensed year-round killing by experienced personnel deploying legal methods. Elsewhere, local successes have been reported where predators have either been excluded or were supplied with seasonal diversionary food (Mason *et al.* 2021). Predator removal interventions are often intensive in their nature, and outside of grouse moors may not be suited to UK agri-environment schemes (Douglas *et al.* 2023). Through wider acceptance of the delivery of high wader abundance as a by-product of sustained grouse-shooting, it may be possible to deliver greater benefits for Curlews through targeting conservation initiatives involving simultaneous predator removal and habitat management towards areas close to fringes of existing grouse moors. Doing so may enable generally successful management techniques for waders to be expanded, further enhancing the scale effect whereby neighbouring estates are successfully practicing predator removal, rather than attempting to recreate it in isolation elsewhere.

Acknowledgements

This study was hosted and supported by Teesdale landowners and their gamekeepers. Field assistance was provided by Holly Appleby, Maddie Benton, Michael Richardson, Angus Smith and Philip Warren.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was funded by Roger Henderson QC on behalf of the G. & K. Boyes Charitable Trust, Harry Henderson, Matt Ridley and the Raby Estate through donations to the Game & Wildlife Conservation Trust.

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Appendix 1. The number and percentage of 114 Ordnance Survey 1-km grid squares occupied by 51 bird species encountered during the study, together with their mean and maximum encounter rates on transect counts (birds km^{-1}) for those present in five or more squares

Species	Squares where present (%)	Mean birds km^{-1}	Maximum birds km^{-1}
Eurasian Curlew *Numenius arquata*	113 (99%)	3.3	11.5
Meadow Pipit *Anthus pratensis*	110 (96%)	6.7	15.0
Red Grouse *Lagopus scotica*	83 (73%)	3.5	15.8
Eurasian Golden Plover *Pluvialis apricaria*	79 (69%)	1.7	11.0
Eurasian Skylark *Alauda arvensis*	75 (66%)	1.7	6.5
Northern Lapwing *Vanellus vanellus*	71 (62%)	4.0	22.5
Black-headed Gull *Chroicocephalus ridibundus*	70 (61%)	3.1	32.5
Greylag Goose *Anser answer*	56 (49%)	1.5	6.5
Eurasian Oystercatcher *Haematopus ostralegus*	48 (42%)	1.5	5.5
Common Pheasant *Phasianus colchicus*	40 (35%)	0.9	4.3
Carrion Crow *Corvus corone*	40 (35%)	0.8	4.5
Mallard *Anas platyrhynchos*	38 (33%)	0.8	3.3
Lesser black-backed *Gull Larus fuscus*	38 (33%)	0.7	3.3
Common Snipe *Gallinago gallinago*	32 (28%)	0.9	5.3
Jackdaw *Corvus monedula*	31 (27%)	2.1	3.3
Common Redshank *Tringa totanus*	31 (27%)	1.0	5.3
Short-eared Owl *Asio flammeus*	28 (25%)	0.3	0.8
Eurasian Wren *Troglodytes troglodytes*	27 (24%)	0.6	2.0
Black Grouse *Lyrurus tetrix*	25 (22%)	1.9	5.3
Northern Wheatear *Oenanthe oenanthe*	25 (22%)	0.4	1.8
Eurasian Woodcock *Scolopax rusticola*	17 (15%)	0.5	2.3
Common Buzzard *Buteo buteo*	14 (12%)	0.4	1.0
Grey Partridge *Perdix perdix*	12 (11%)	0.6	1.0
Canada Goose Branta canadensis	11 (10%)	0.8	1.9
Rook *Corvus fruvilegus*	10 (9%)	1.3	3.5
Common Wood Pigeon *Columba palumbus*	9 (8%)	0.8	5.0
Dunlin *Calidris alpina*	9 (8%)	0.6	3.0
Common Kestrel *Falco tinnunculus*	8 (7%)	0.3	0.3
Common Sandpiper *Tringa hypoleucos*	7 (6%)	0.6	1.3
European Stonechat *Saxicola torquata*	5 (4%)	0.4	1.8
Common Cuckoo *Cuculus canorus*	5 (4%)	0.3	0.5

Note: Present in four squares: Merlin *Falco columbarius*, Northern Raven *Corvus corax*, Red-legged Partridge *Alectoris rufa*, Common Reed Bunting *Emberiza schoeniclus*; in three squares: Ring Ouzel *Turdus torquatus*, White-throated Dipper *Cinclus cinclus*, Grey Wagtail *Motacilla cinerea*, Pied Wagtail *Motacilla alba*, Common Starling *Sturnus vulgaris*; in two squares: Common Blackbird *Turdus merula*, Common Gull *Larus canus*, Great Tit *Parus major*, Eurasian Teal *Anas crecca*; in one square: Eurasian Blue Tit *Parus caeruleus*, Sedge Warbler *Acrocephalus schoenobaenus*, European Sparrowhawk *Accipiter nisus*, Willow Warbler *Phylloscopus trochilus*, Western Barn Owl *Tyto alba*, Barn Swallow *Hirundo rustica*; Common Swift *Apus apus* present but not recorded.