

GPS-tracking breeding Curlews in the Yorkshire Dales: breeding success, home range size, and habitat use

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BTO, The Nunnery, Thetford, Norfolk IP24 2PU
Tel: +44 (0)1842 750050 Email: info@bto.org
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**Farming in Protected
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Executive summary

Introduction

1. The primary means by which Curlew conservation interventions are delivered in farmed landscapes is via agri-environment schemes (AES). Understanding how breeding success, home range, and habitat use vary in different habitats and landscapes will be an important part of delivering effective, targeted Curlew AES options.
2. The Yorkshire Dales National Park hosts high densities of Curlews, breeding across a habitat gradient from heather moorland at higher elevations, unimproved grassland fringing the moorland, to improved grassland (pasture, hay meadow, and silage fields) at lower elevations. Predator control is conducted across all habitats, but intensity varies according to complex, site-specific factors.

Methods

3. We fitted GPS tags to 19 adult Curlews in April 2023 and April 2024 in the Yorkshire Dales National Park and inferred nest and brood locations and breeding outcomes from movement patterns of the tagged birds using a recently-developed method. For a subsample of these birds, inferences were ground-truthed against field observations.
4. We examined variation in home range sizes at different stages of the breeding season, movements during the chick-rearing period, and the extent to which birds nesting in different habitats utilised the range of habitats available.

Results

5. We were able to infer fledging success for 26 out of 30 breeding attempts across the 2023 and 2024 breeding seasons. Failure to determine fledging outcomes primarily arose from the tendency of females to leave the breeding grounds before expected fledging dates being indistinguishable from brood-rearing failure.
6. Hatching success per pair per year was 60% ($n = 30$) and fledging success per pair per year was 38% ($n = 26$). Assuming 1.6 fledglings per successful breeding attempt, this suggests 0.62 fledglings per pair per year, a near-stable population.
7. Estimating nest and brood survival probabilities using Mayfield analysis, nests in improved grassland had the highest chance of fledging at least one chick (59%), compared to 48% in heather moorland and 35% in unimproved grassland. These differences were not statistically significant ($p > 0.19$). The monitored nests in improved grassland were protected from mowing operations so these values are not likely to be representative of other Curlew breeding areas.
8. Inferences from GPS movement patterns matched ground-truthing field observations in 92% of cases for both hatching ($n = 25$) and fledging ($n = 12$) outcomes.
9. Birds nesting in improved grassland spent c. 93% of the incubation and chick-rearing periods in this habitat and did not use alternative habitats frequently. Birds nesting in unimproved grassland used other habitats more frequently during incubation and chick-rearing (unimproved grassland 71%, improved grassland 14%, heather moorland 15%). Heather-moorland-nesting birds were most likely to use alternative habitats (heather moorland 46%, unimproved grassland 41%, improved grassland 13%).
10. Birds held relatively small territories during the nesting and chick-rearing period, compared to studies in different landscapes, and those which successfully fledged broods did not make large movements before fledging, with most ($n = 5$) chick-rearing pairs moving less than 250 m, and all ($n = 8$) less than 500 m.

Discussion

11. Our results show that inferring breeding outcomes from GPS data can generate useful information on breeding success, home range size, and habitat use that would be difficult to capture using other methods. However, it is time-consuming, and requires expensive equipment, special permits and expertise, so it is not feasible for long-term, extensive monitoring of a breeding population.
12. This study shows that in areas subject to landscape-scale predator control, as is common in the Yorkshire Dales National Park, well-targeted, field- and farm-level interventions aimed at mitigating potential negative impacts of agricultural operations (especially harvesting silage) and high stocking densities could significantly increase breeding productivity for Curlews and other ground-nesting birds.

13. We caution against interpreting these findings more broadly and would recommend that in areas where brood home ranges may be much larger (e.g. intensive predator control is not taking place, Curlew breeding density is lower, and field boundaries are less extensive or more permeable), field or farm level interventions are unlikely to have such a positive impact.

1. Introduction

Curlews *Numenius arquata* nest across a range of natural (e.g. blanket bogs and wetlands), semi-natural (e.g. meadows and moorlands), and highly modified (e.g. managed grassland and arable) habitats across Europe (Bocher et al. 2024). In the UK, the highest breeding Curlew densities are found in farmland on the fringes of moorland where predator control is carried out (Calladine et al. 2022). Between 1995 and 2023, the UK lost approximately half of its breeding Curlews (Heywood et al. 2025), with the biggest declines in farmland areas with high levels of predator activity (Douglas et al. 2014, Bell & Calladine 2017, Calladine et al. 2022). Across the UK and Europe, the proximate cause of population decline is low breeding productivity associated with unsustainable levels of nest and chick predation (Baines et al. 2023, Viana et al. 2023). The UK remains internationally important for the species, holding an estimated 19–27% of the global breeding population (Brown et al. 2015). Curlews are well-loved, charismatic birds, and have become ‘flagship’ species for the rural communities and landscapes where breeding populations persist (Colwell et al. 2020).

Curlew conservation in farmed landscapes is largely delivered via agri-environment schemes (AES), whereby farmers or landowners are given financial incentives for improving environmental conditions on their land, often targeted at specific habitats or species (O’Brien & Wilson 2011). To date, whilst AES may have mediated wader declines in the UK in some cases (Smart et al. 2014), they have largely failed to stabilise and recover wader populations more widely (Heywood et al. 2025). AES are currently undergoing significant revision (Defra 2023), facilitating opportunities to improve the targeting, scale, and delivery of interventions designed to improve outcomes for Curlews, other wader species, and ground-nesting birds more generally.

Understanding how habitat use and home range vary in different landscapes may be an important part of delivering effective, targeted Curlew AES options. However, there are few published studies that have reported on the home range and habitat use of breeding Curlews (Bocher et al. 2024), and only two in the UK (Ewing et al. 2017, Taylor et al. 2020). Taylor et al. (2020) found breeding Curlew home ranges in the Welsh uplands were on average 1.54 km² (0.01–7.81 km²), and smaller during chick-rearing (0.21–0.35 km²). However, these findings were based on a small sample and may be unrepresentative of different habitats and breeding densities, given that Curlew home range size may vary with breeding habitat (Bocher et al. 2024). Additionally, landscape configuration, the quality of foraging habitat, and the density of breeding pairs could all influence the size of home ranges and the extent to which Curlews use surrounding habitats.

The Yorkshire Dales National Park supports high densities of Curlews, nesting across a broad habitat gradient, generally composed of extensive heather-dominated grouse moors at higher elevations, through large areas of unimproved pastoral grassland fringing the grouse moors at mid-elevations, to improved grassland (pasture, hay meadow, and silage fields) at lower elevations (Jarrett et al. 2017). Throughout much of the national park, predator control by grouse moor managers is conducted not only on moorland, but also on surrounding farmland, and its intensity varies according to complex, site-specific factors. Little is known about the ways in which this landscape configuration is used by Curlews nesting at different points on this habitat gradient, and the design of AES options for Curlews in the Yorkshire Dales would benefit from evidence on how individual birds use this suite of habitats.

To address this knowledge gap, we deployed GPS trackers on adult Curlews on their breeding grounds. This allowed us to examine variation in home range size, chick-rearing movements and habitat use across this gradient of elevations and farmland habitats. The extent to which birds breeding on the moorland fringe spend significant time in adjacent farmland habitats (and vice versa) is also an important question for the effective design of monitoring and survey schemes (Grant et al. 2000). To gather information on breeding success, we employed a recently-developed method that assesses breeding outcomes from GPS tracking data (Bowgen et al. 2022) and compared these estimates to those obtained from traditional monitoring methods in the field. Because our sample of birds bred along a gradient of habitats present in the Yorkshire Dales, the GPS method allowed us to compare nesting and fledging success of the GPS tracked birds nesting in improved

grassland, unimproved grassland, and heather moorland. Additionally, Curlews nesting in improved grassland in our study area were subject to interventions by the Bolton Estate and neighbouring farms to protect nests and broods during grass harvesting. This provided an opportunity to assess the effectiveness of such measures.

2. Methods

2.1. Study site

The study area largely comprised farmland on and surrounding the Bolton Estate in Lower Wensleydale, though two farms in Upper Wensleydale were also included. Study area fields included a range of grassland management types, but all supported livestock farming in some form, either directly via grazing, or indirectly via grass crops (hay or silage) grown for livestock feed. The Bolton Estate undertakes intensive predator control with a team of two gamekeepers on its grouse moor and surrounding non-moorland ground. The Bolton Estate and other landowners granted fieldworkers access to land, and estate gamekeepers and farmers directed fieldworkers to known breeding areas. These areas were watched by BTO fieldworkers to identify breeding territories or specific nest locations in which to direct catching attempts for Curlews.

2.2. Catching and GPS tags

We used GPS tags to track the movements of breeding Curlews in April 2023 and 2024. We targeted breeding Curlews in heather moorland and farmland, targeting a range of farm field-use types (silage, hay meadow, and permanent pasture) along a rough transect of elevation, across a representative range of land uses. We watched known breeding areas to identify breeding territories or specific nest locations in which to direct catching attempts for Curlews. We targeted birds that were either at, or very near, the nesting stage and so thought more likely to respond territorially to the presence of a decoy. We caught all Curlews within their nesting territories (often close to nests if eggs had been laid) using a remotely triggered, spring-powered clap net (Clark et al. 2025; Figure 1.). The mechanism can be set quickly, allowing re-positioning and removal with minimal disturbance. We used an audio lure playing Curlew breeding calls and a decoy bird (a 'decoy' Curlew prepared from a bird found dead, on a remote-controlled rotating mechanism) to attract Curlews to the catching area. When we caught a bird, we moved it away from the catching area and removed the clap net from the catching location to minimise disturbance.

Figure 1. A fieldworker setting a remotely triggered, spring-powered clap net, with an audio lure playing Curlew breeding calls and a decoy bird. Photo credit: Rich Bunce Walking Photographer / BTO.



We fitted each captured Curlew that we deemed suitable for GPS tagging (not visibly unhealthy and meeting the minimum body weight threshold for a tag device at < 3% body weight, including the mass of the metal and colour rings) with a 13 g solar-powered Ornitela GPS–GSM tag (OT-E10-3G v. C56-S.1), Vilnius, Lithuania (www.ornitela.com/ornitrack) using an elasticated leg loop harness (Polymax silicone cord 3007102, Polymax Ltd) with a neoprene base to raise the device above the feathers. In addition to the tags, we fitted all birds with a BTO numbered metal ring and an individual combination of colour rings, the latter to allow field identification (including after tags had reached the end of their lifespan). We took morphometric measurements (bill length, weight, wing length, tarsus and toe) and determined sex based on bill length (Summers et al. 2013), weight, and breeding behaviour. The fieldworkers who conducted all capture, ringing, and tagging activities had the necessary permits, endorsements, and permissions to comply with British and Irish legal and regulatory requirements.

The GPS tags recorded location data every five to 30 minutes (depending on battery status, 24 hours per day), and uploaded these data daily to an online database via the mobile phone network. Drawing on the use of similar harnessed GPS tags by European Curlew researchers, we expected tags to remain attached for up to two years, after which the leg loops typically break, and the tag and harness detach cleanly without harming the bird. The GPS tag battery was partially depleted during the winter months (when sunlight levels were lower) and increased again the following spring. Nine birds provided two years of data.

2.3. Data management

We conducted all analyses in R and RStudio (R Core Team, 2023; Posit Team, 2023). The 19 deployed tags continuously, automatically uploaded data to an online data repository and analysis platform (Movebank) directly from online Ornitela databases. We used the ‘move’ package in R (Kranstauber et al. 2023) to download and filter the data, retaining only GPS locations recorded up to the end of July 2024 where accelerometer data indicated speeds below 4 m s⁻¹ (indicating birds on the ground).

2.4. GPS-based analysis of breeding status

We used the *recurse* package (Bracis et al. 2018) to identify Curlew breeding status (Bowgen et al. 2022) and to estimate the nest location. We identified breeding stages (pre-breeding, incubation, chick-rearing, and post-breeding) by visually inspecting plots showing the frequency of revisits to specific locations (Figure 2).

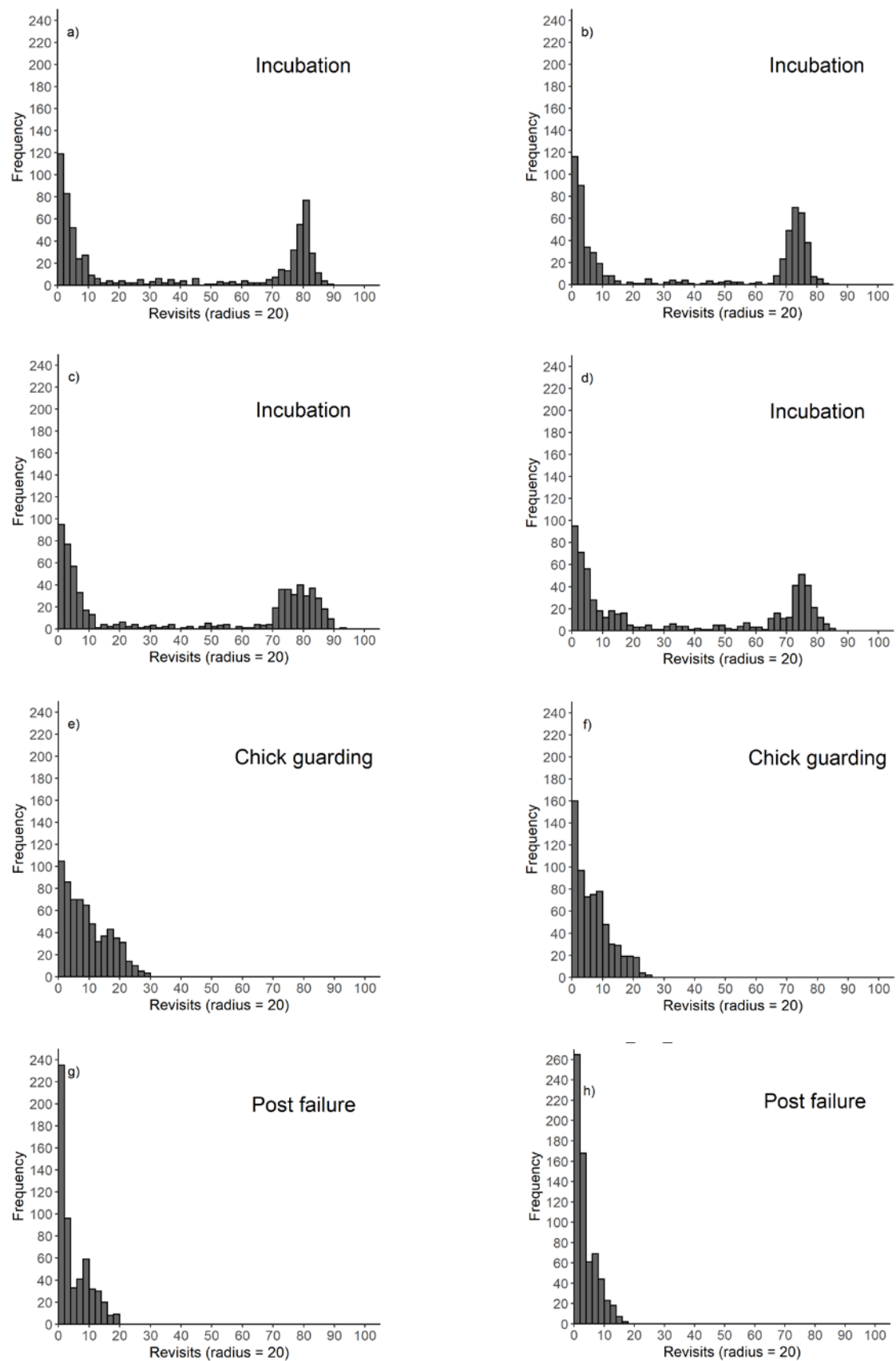
We inferred the onset of incubation when birds were repeatedly observed returning to the same location (Figure 2, a–d). Successful hatching was inferred when movements increased and the bird less-frequently returned to this location, but daily movements remained highly restricted (Figure 2, e–f), indicating chick-rearing. When these behaviours persisted for more than 30 days, approximating the 32 to 38 days required for a Curlew chick to fledge (Berg 1992, Grant et al. 1999), we inferred successful fledging of at least one chick. Brood failure was inferred when birds ceased to associate with a specific location (Figure 2, g–h) within 30 days of estimated hatching. We adopted a 30-day threshold, rather than 32 to 38 days, to minimise misclassification due to uncertainty in hatch date estimates and changes in adult behaviour with brood age, which could otherwise increase false negatives (i.e. incorrectly inferring brood failure). Field observations also indicated high brood survival above 30 days. Nonetheless, our categorisation of fledging success may include an unknown proportion of late failures.

We also present breeding success in 2023 and 2024 in terms of fledged chicks per pair, using Baines’ et al. (2023) mean Curlew fledged-brood size of 1.6 chicks, which broadly aligned with our own field observations of fledged brood sizes (Section 2.5).

2.5. Ground-truthing of breeding success

We ground-truthed nest locations by finding and monitoring nests of a subsample of GPS-tagged birds in the field. We located nests at GPS-tagged birds’ territories during the nest establishment phase (mid April to early May) or using GPS data to generate geospatial coordinates for potential nest sites (using the location with the highest number of revisits), which we then visited to confirm the nest location. For most nesting attempts monitored (n = 19), we ground-truthed nest initiation date (clutch completion and beginning of incubation), nest outcomes, and nest outcome dates by monitoring nests in the field. We used known clutch completion dates (if the nest was found with an incomplete clutch), or back-calculated estimated clutch completion dates (subtracting 28 days from hatch date) using: 1) known hatch dates (if the nest hatched); or 2) estimated hatch dates, using length, breadth, and weight egg measurements (if the nest did not hatch).

Figure 2. Example weekly 'recurse' frequency plots. In (a), (b), (c), and (d) high numbers of revisits to particular locations indicate incubation. The more sloped distribution in the number of revisits to particular locations in (e) and (f) indicate chick-rearing. In (g) and (h) the left-skewed pattern indicates neither incubation or chick-rearing is taking place. Figure reproduced from Bowgen et al. (2022).



We estimated outcome date using temperature loggers, nest cameras, and nest visits every seven to 10 days (and at least every three days from estimated hatch dates) to ascertain accurate outcome dates. However, due to landowner concerns regarding monitoring disturbance in 2023, a minority of nesting attempts ($n = 8$) were monitored exclusively from distance. These were watched with a telescope at distance (c. 100 to 200 m), attempting to view incubating birds (or other nesting behaviours, such as mobbing, or birds on sentry) when nesting, or broods (or chick-rearing behaviours such as birds on sentry and mobbing) when chick-rearing. For a further sub-sample of hatched nests, we attempted to ground-truth brood outcomes by conducting a minimum of weekly (often more frequent) visits to territories, up to five weeks from hatching (depending on brood survival), to estimate brood outcomes and timings of outcome events, recording any direct observations of broods, or chick-rearing behaviours from adult Curlews (e.g. persistent and vociferous alarm-calling, mobbing chick predators, and reticence to leave the area when disturbed).

2.6. Nest and chick survival

Daily survival rates during the incubation and chick-rearing periods were estimated using the Mayfield method (Mayfield 1975), which calculates the daily probability of failure as the proportion of failures per total exposure days. We calculated daily nest and chick survival rates for the three main nesting habitats (heather moorland, unimproved grassland, and improved grassland), and we also used fieldworker-collected habitat categories of improved grassland field types to calculate nest and chick survival rates in improved pasture, hay meadow, and silage fields (all classified as improved grassland in the UK Centre for Ecology & Hydrology (CEH) Land Cover Map). A generalised linear model (GLM) with a binomial error distribution, logit link, and log-transformed exposure days as an offset was used to test for statistically significant differences in daily survival rates between habitats.

2.7. Home ranges

To quantify the size of the areas used by breeding Curlews, utilisation distributions (UDs) were calculated using the 'adehabitatHR' R package (Calenge & Fortmann-Roe 2023), including the home range (95% UD) and the core area (50% UD). Home range and core area were calculated through creating Kernel Density Estimation (KDE, utilisation distributions with a grid of 500) for each bird using the entire dataset between the arrival and departure from the breeding grounds, as well for each breeding stage identified.

2.8. Arrival and departure from breeding grounds

We reported the date of departure from and arrival to the breeding grounds for the 13 birds carrying tags that remained functional across the end of the first breeding season (2023) and the start of the second breeding season (2024). Birds that did not travel more than 50 km from the nest site were not included.

2.9. Nest site fidelity

We calculated the distance between years of nest sites known to belong to the same breeding individuals to assess between-year fidelity to nest locations. In instances where birds made multiple nesting attempts within the same year, we report the distance between first nesting attempts of the year, and we report known distances between different nesting attempts within the same breeding season.

2.10. Chick-rearing movements

For those birds that successfully fledged one or more young, we plotted the mean daily position of adult birds during the chick-rearing period to assess how far broods moved and whether there were any systematic movements to different habitats.

2.11. Habitat use

Using the 'terra' and 'tidyterra' R packages (Hijmans 2023, Hernangomez 2024) and the UK Land Cover Map (LCM) 2021 in 10 m raster format (Marston et al. 2023), we assessed habitat use of GPS-tagged birds. After visual inspection of the LCM of the study area, using our on-the-ground knowledge of the habitats, we determined that distinctions between some similar habitat categories in the LCM were not accurate in Wensleydale. We therefore combined: 'acid grassland' and 'calcareous grassland' to form 'unimproved grassland'; and 'bog', 'heather grassland' and 'heather shrub' to form 'heather moorland'. We did not include any other habitat with 'improved grassland' (this category included some improved pasture, hay meadow,

and silage fields). When comparing habitat use between birds nesting in different habitats, we restricted this comparison to these three key breeding and foraging habitats (improved grassland, unimproved grassland, and heather moorland), which between them accounted for > 97% of all GPS fixes. We grouped the habitat use plots by the habitat of the nest area, as we thought that this would be an important factor in determining the habitat use of individual birds.

Additionally, a Resource Selection Function (RSF) was used to compare habitat use of Curlews GPS-tagged in this study with the availability of different habitats in the landscape. For each real fix, 20 dummy points were generated for each real relocation (henceforth called 'fix') to provide pseudo-absences. Following Macgregor et al. (in prep) for each dummy point, a distance and direction were determined using a hybrid stratified-random protocol. Distance was randomly drawn from a log-normal distribution fitted to the observed set of flight distances (defined as the linear distance between the first and last fixes in a sequence of consecutive possible flight fixes). Direction was selected randomly from 100 possibilities spaced at 3.6° intervals. The chosen distance and direction were applied to a fix to generate a randomly-selected point that was plausibly within a single flight's distance of a known relocation. Twenty dummy points were generated relative to each fix, so that the set of dummy fixes should be broadly reflective of the habitat resources accessible to the tracked Curlews.

The same environmental variables were extracted for each dummy location as for the real GPS locations. These included LCM 2021 habitat, elevation, cumulative precipitation and day/night in addition to the information relating to the relevant tagged birds. Again, we combined LCM habitat classes as described above into improved grassland, unimproved grassland, heather moorland, and other (this category included coniferous and broadleaved woodland, and arable). RSFs were then modelled following the approach of Macgregor et al. (in prep), modelling the probability of Curlew presence in each habitat as a function of habitat type (nesting habitat versus non-nesting habitat) and four covariates: elevation data (extracted from the EuroDEM digital elevation model; EuroGraphics 2023); rainfall (extracted from the ECMWF ERA5 dataset (Copernicus Climate Change Service (C3S) 2023) on an hourly basis, using cumulative precipitation in the preceding seven days as the variable); day/night and sex. We used a binomial generalised linear mixed-effects model (GLMMs) with a logit link. We fitted two-way interactions between habitat type and each covariate. We included a random effect of individual bird ID and a term that upweighted GPS fixes by a factor of 20 (to account for ratio of fixes to dummy points) in all models.

3. Results

We caught and applied GPS tags to 17 Curlews in April 2023 and two in April 2024, 19 Curlews (16 males and three females) in total across both years (Figure 3). Thirteen Curlews (12 males and one female) provided data in both breeding seasons, i.e. they were GPS-tagged in April 2023, and their tag remained on for at least part of the 2024 breeding season.

3.1. Breeding success inferred from GPS data

Across 2023 and 2024, all GPS-tagged birds for which we had sufficient data made at least one nesting attempt. Overall hatching success 2023–2024 was 60% (n = 30) and fledging success was 38% (n = 26), indicating a productivity of 0.62 fledglings per pair per year.

In 2023, all 17 GPS-tagged Curlews made a first nesting attempt. Of these, 10 (59%) hatched at least one chick; seven (41%) failed to hatch any chicks. Three (43% of the seven failed at nesting) birds attempted to re-nest after failure, but all three nesting attempts failed to hatch any chicks. Of the 10 Curlews that hatched at least one chick, GPS data on chick-rearing movements allowed us to infer outcomes for eight (80% of) broods. Of these eight Curlews, we estimated seven (88%) fledged at least one chick, whilst one (12%) fledged no chicks. Overall, taking the 15 GPS-tagged Curlews whose outcomes we could infer from incubation to failure or fledging in 2023, seven (47%) pairs fledged one or more chicks. Assuming a mean fledged brood size of 1.6, this indicates a productivity of 0.75 fledglings per pair in 2023. Two birds left the breeding grounds after we inferred young had fledged, whilst five others stayed within the breeding area.

Of the two unknown fledging outcomes in 2023, one (OrangeNoir) was a female that left the breeding grounds before 30 days since hatching had passed, for which we could not distinguish between brood failure or

females' natural tendency to leave broods before fledging. The other was a male (Xmas) who displayed movements consistent with chick-rearing well beyond the duration expected from other successful pairs; in this case, we were not confident assigning success to this bird, that may have been revisiting specific locations for reasons other than an active brood, so we assigned its outcome as unknown.

Figure 3. Estimated nest site location for all birds in Wensleydale, North Yorkshire, in 2023 and 2024, coloured by Curlew name. Basemap credit: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community (Esri 2025).



In 2024, 13 birds made a first nesting attempt, six (46%) of which hatched at least one chick and seven (54%) which failed to hatch any chicks. One (14% of the seven birds that failed at nesting) bird attempted to renest after failure and hatched at least one chick. Of the seven pairs that hatched one or more chicks on their first or second attempt, GPS data on chick-rearing movements allowed us to infer outcomes for five (71% of) broods. Of these five Curlews, we estimated three (60%) fledged at least one chick, whilst two (40%) fledged no chicks. Overall, taking the 11 GPS-tagged Curlews whose outcomes we could infer from incubation to fledging in 2024, three (27%) pairs fledged one or more chicks. Assuming a mean fledged brood size of 1.6, this indicates a productivity of 0.44 fledglings per pair in 2024.

Both unknown fledging outcomes in 2024 were females that left the breeding grounds within 30 days of hatching (which could not be distinguished between failure or females' natural tendency to leave broods before fledging).

3.1.1. Breeding success by habitat

Daily nest survival was 0.992 in heather moorland ($n = 4$), 0.981 in improved grassland ($n = 16$), and 0.976 in unimproved grassland ($n = 12$). This gives a probability of hatching of 79% on heather moorland, 59% in improved grassland, and 50% in unimproved grassland. Daily chick survival was 1 in improved grassland ($n = 3$), 0.986 in heather moorland ($n = 3$), and 0.990 in unimproved grassland ($n = 7$). This gives a probability of fledging (given a successfully hatching nest) of 100% in improved grassland, 70% in unimproved grassland, and 61% in heather moorland. Combining the survival rates at the nesting and chick-rearing stage gives a probability of a nesting attempt successfully fledging at least one chick of 59% in improved grassland, 48% in heather moorland, and 35% in unimproved grassland, but no significant differences in nest or brood survival were found between habitat types (all $p > 0.19$).

Of the 16 breeding attempts in improved grassland, four were in improved pasture, six were in silage, and six were in hay meadow. Daily nest survival was 0.990 in improved pasture, 0.988 in silage, and 0.975 in hay meadow. Daily chick survival was 1.000 in hay meadow and silage, and the outcome of nests hatching in improved pasture was unknown so daily chick survival could not be calculated. These differences in nest or brood survival were not statistically significant.

3.2. Ground-truthing of breeding success

Fourteen nest site locations estimated by the recurse analysis of the GPS data were validated by a fieldworker observing the area and searching for the actual nest to ground-truth the GPS-based estimate. Thirteen of the 14 ground-truthed nest locations were within 7 m of the estimated nest location. In the other instance there was a difference of 696 m, due to the recurse analysis misidentifying a roost location on a small river gravel bank as a nest site. One nest found by fieldworkers was missed in the GPS analysis, where the nest failed before laying was complete.

Twenty-seven nesting attempts from the 19 GPS-tagged Curlews were monitored in some capacity by a fieldworker, either monitoring the nest directly (14 nesting attempts) or from distance (13 nesting attempts). Of 25 nesting attempts with both inferred outcomes from GPS analysis and field observations, the two methods agreed for 23 attempts (92%). In one of the other cases, GPS analysis indicated nest failure, but four chicks hatched, though the brood died within the first five days of hatching. In the other case, field monitoring estimated a nesting attempt failed close to hatching, but GPS analysis estimated that it hatched and fledged at least one chick. In this case, the temperature logger had malfunctioned so we could not use it to discern the nest outcome; we recorded one broken egg (and no signs of hatching in any other egg) on the penultimate nest visit (10 June), then an empty nest cup with an apparently predated eggshell three days later (13 June) (Figure 3). The nest camera footage showed no chicks leaving the nest, and Jackdaw *Coloeus monedula* and Rook *Corvus frugilegus* predated nest contents (Figure 4).

Figure 4. Nest that had been erroneously recorded as failed on penultimate visit by fieldworkers (left), with damaged egg and yolk in nest cup, and final visit (right), with eggshell remains suggesting predation. Photo credit: Paul Noyes / BTO.



For the 10 nesting attempts where GPS inferences and field observations both provided sufficiently precise dates to compare incubation and outcome timing, clutch completion dates estimated from field data were on average 1.70 days (± 1.40 SE) earlier than GPS estimates. When accounting for both positive and negative differences, the mean absolute difference was 3.70 days (± 0.87 SE). For the 10 nesting attempts which allowed comparison between nest outcome date (hatch or fail), outcome date estimated from field observations was on average 0.20 (± 0.63 SE) days earlier than GPS estimates, and correcting for positive and negative differences, the mean difference was 1.40 (± 0.43 SE).

For the 12 chick-rearing attempts that were monitored by fieldworkers, one (8%) outcome inferred from GPS data did not match field observations. No chick observations or adult chick-rearing behaviour was observed around the nest site during brood monitoring visits after hatching, so the brood was deemed to have failed, but the GPS analysis estimated that at least one chick fledged. In this case (LimeNoir in 2023), GPS movements (Figure 8f) suggest the brood moved soon after hatching to, or nearby, another field, which had another breeding pair in it (Bee in 2023, Figure 8.e), so it is possible that activity of each was confused, as ground-truthing deemed Bee successfully fledged chicks (though both adult males were colour-marked and GPS-tagged, clear sightings of colour-mark combinations were not possible on key monitoring visits).

Figure 5. Jackdaw and Rook scavenging nest contents after what we had deemed abandonment based upon field observations, but was most-likely successful hatching and subsequent scavenging of unhatched egg(s). Photo credit: Paul Noyes / BTO.



3.3. Curlew home range and core areas

Mean core area size across all breeding stages was 28 ha (0.28 km²), median = 5.2, range = 1.5–359 ha, and mean home range size was 191 ha (1.91 km²), median = 71, range = 9.8–1,593 ha. During the incubation period, core area, mean = 4 ha (0.04 km²) and home range, mean = 34 ha (0.34 km²) were much smaller. During the chick-rearing period, core area, mean = 52 ha (0.52 km²) and home range, mean = 253 ha (2.53 km²) were larger. The range of values for home ranges and core areas across all breeding stages for tagged birds is large (Figure 6), although there is less variation in the data during the incubation and chick-rearing period, and one bird made long-distance movements during the chick-rearing period (Figure 6).

3.4. Arrival and departure dates

The earliest arrival on the breeding grounds in 2024 by a bird tagged in 2023 was 4 February, and the mean arrival date (n = 13) was 17 February. The earliest departure date from the breeding grounds in 2023 was 13 June (a male bird which failed at the incubation stage twice). The mean departure date in 2023 was 1 July, and in 2024 it was 27 June. The mean departure date across both years for birds which were unsuccessful was 3 July, and for successful birds it was 4 July. Four birds remained close to the breeding grounds, within the Yorkshire Dales, during the autumn and winter between the 2023 and 2024 breeding seasons (Figure 7).

Figure 6. Data for both years are shown. 'Core area' is the home range (as defined through Kernel Density Estimation) that contained 50% of the fixes from breeding birds, while 'home range' is the area where 95% of fixes were located. 'Area' is log transformed due to the long tail to the data. Each dot represents an individual bird's mean ranging behaviour for that period of the breeding season, and the violin plots illustrate the distribution of these datapoints. 'All fixes' shows the core area and home range for the whole period during which the bird was present on the breeding grounds.

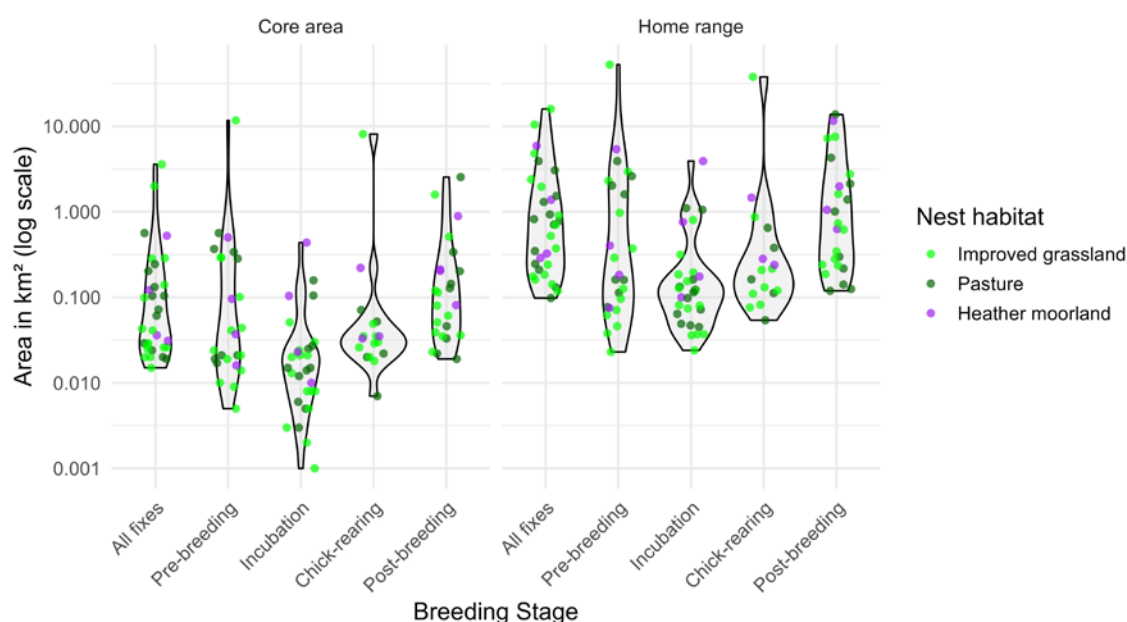


Table 1. Summary statistics describing the sizes of Curlew core areas (> 95% of fixes) and home ranges (> 50% of fixes) across different stages of the breeding season.

Breeding period	Mean (Ha)	Median (Ha)	Minimum (Ha)	Maximum (Ha)
Core area (> 95% of fixes)				
Pre-breeding	59	3.7	0.5	1,169
Incubation	4	1.5	0.1	44
Chick-rearing	52	3.3	0.7	801
Post-breeding	31	9.8	1.9	254
All fixes in breeding grounds	28	5.2	1.5	359
Home range (> 50% of fixes)				
Pre-breeding	306	18	2.3	5,255
Incubation	34	12	2.4	391
Chick-rearing	253	21	5.4	3,780
Post-breeding	242	73	12	1,370
All fixes on breeding grounds	191	71	9.8	1,593

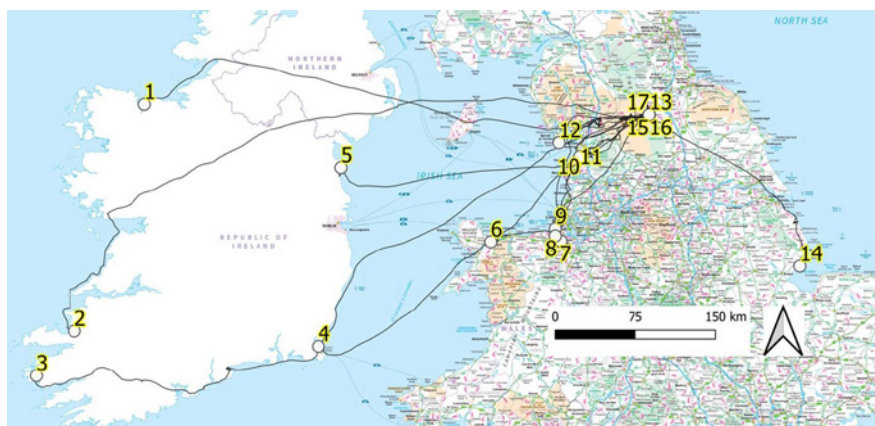
3.5. Nest site fidelity

The mean distance between first nests of tagged individuals between 2023 and 2024 was 103 m, and the range was 3–181 m (Table 2). For one bird, the locations of three failed nest sites were recorded in the same year: the second nest was 928 m from the first nest, and the third nest was 467 m from the first nest (and 596 m away from the second nest).

Table 2. Distance (m) between nest sites in subsequent years (2023 and 2024) for the same individual.

Curlew Name (sex)	Distance (m) between 2023 and 2024 first nest sites
Alderman (M)	181
Bee (M)	50
Carlos (M)	70
Colin (M)	181
Cote (M)	83
GreenLime (M)	68
Hunters (M)	125
LimeOrange (M)	119
OrangeLime (M)	3
OrangeWhite (M)	145

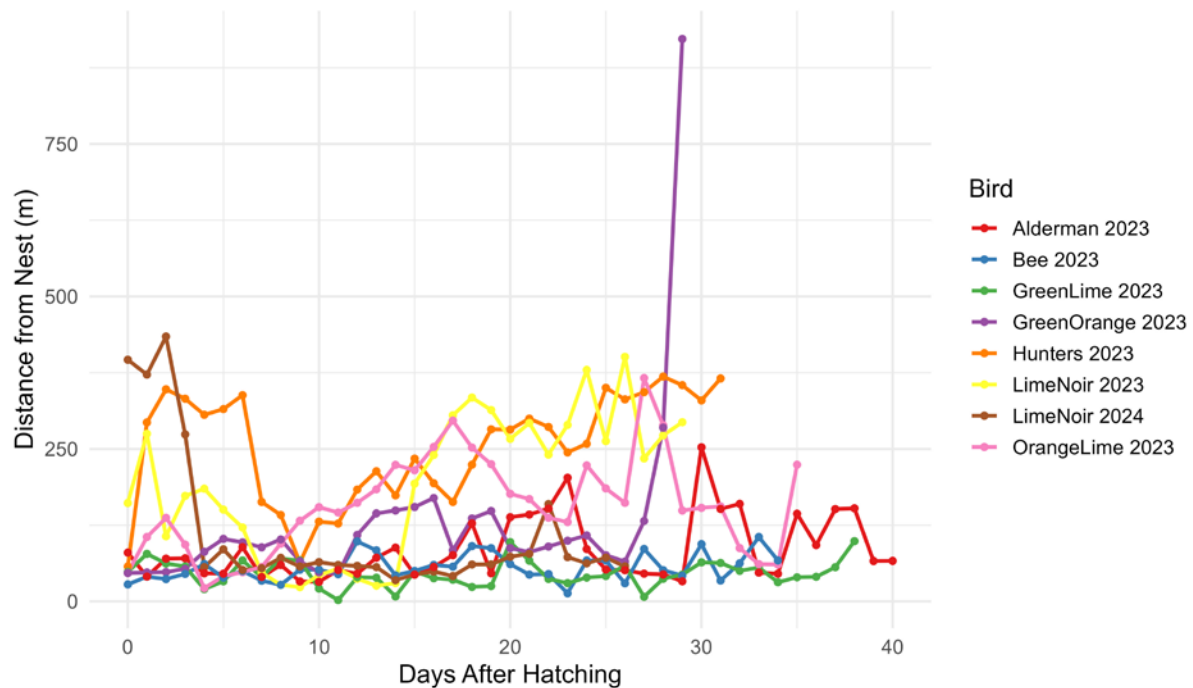
Figure 7. Autumn migration routes to final wintering location (white circle with yellow-bordered number label) from breeding grounds (Yorkshire Dales National Park) for the 17 Curlews GPS-tagged in 2023. Birds labelled 13, 15, 16, and 17 overwintered within the Yorkshire Dales, so migration routes are not visible at map scale. Basemap: Ordnance Survey (OS) Miniscale (Ordnance Survey 2025).



3.6. Movements during the chick-rearing period

During the chick-rearing period the birds remained relatively faithful to their nesting areas with no long-distance movements to different areas observed. The furthest distance that broods moved during the chick-rearing period was approximately 350 m (Figure 8).

Figure 8. Distance from nest site of adult male birds during the chick-rearing period for successful pairs. It is likely that for 'LimeNoir 2024' and 'Hunters 2023' the nests hatched a few days later than estimated, which would explain why the birds were further from the nest for the first few days after estimated hatching and then moved closer. Equally, it would seem likely that for 'GreenOrange 2023' the long-distance movements at the end of the period are because the young had fledged – see Figure 9d.



Figures 9. Movements during the chick-rearing period (a–h). For each breeding attempt estimated to have successfully fledged chicks, we plotted the mean daily position of the adult bird, which we assume to roughly approximate the location of the brood. The estimated location of the nest is shown in yellow. The red dots represent the first quartile of the chick-rearing period and green the last quartile. Basemap credit: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community (Esri 2025).

Figure 9(a). Alderman 2023.

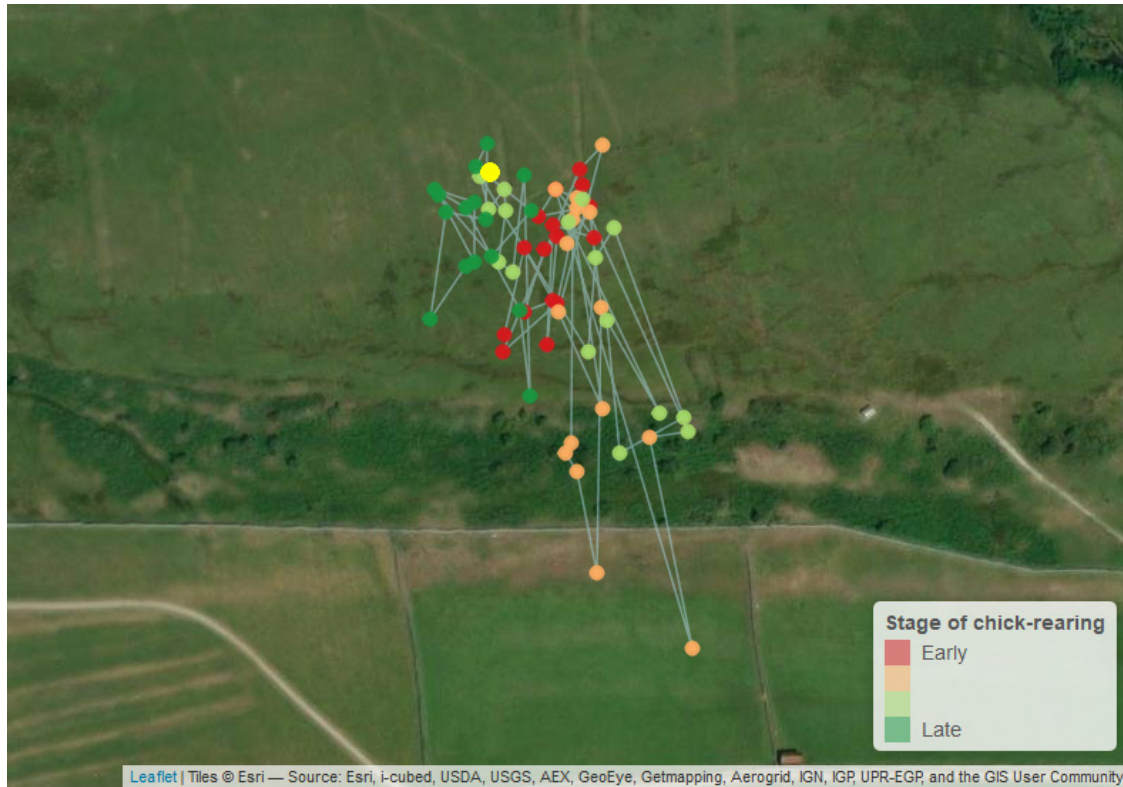


Figure 9(b). Hunters 2023.



Figure 9(c). GreenLime 2023.



Figure 9(d). GreenOrange 2023. Chicks may have fledged two days earlier than the estimated date.



Figure 9(e). Bee 2023.

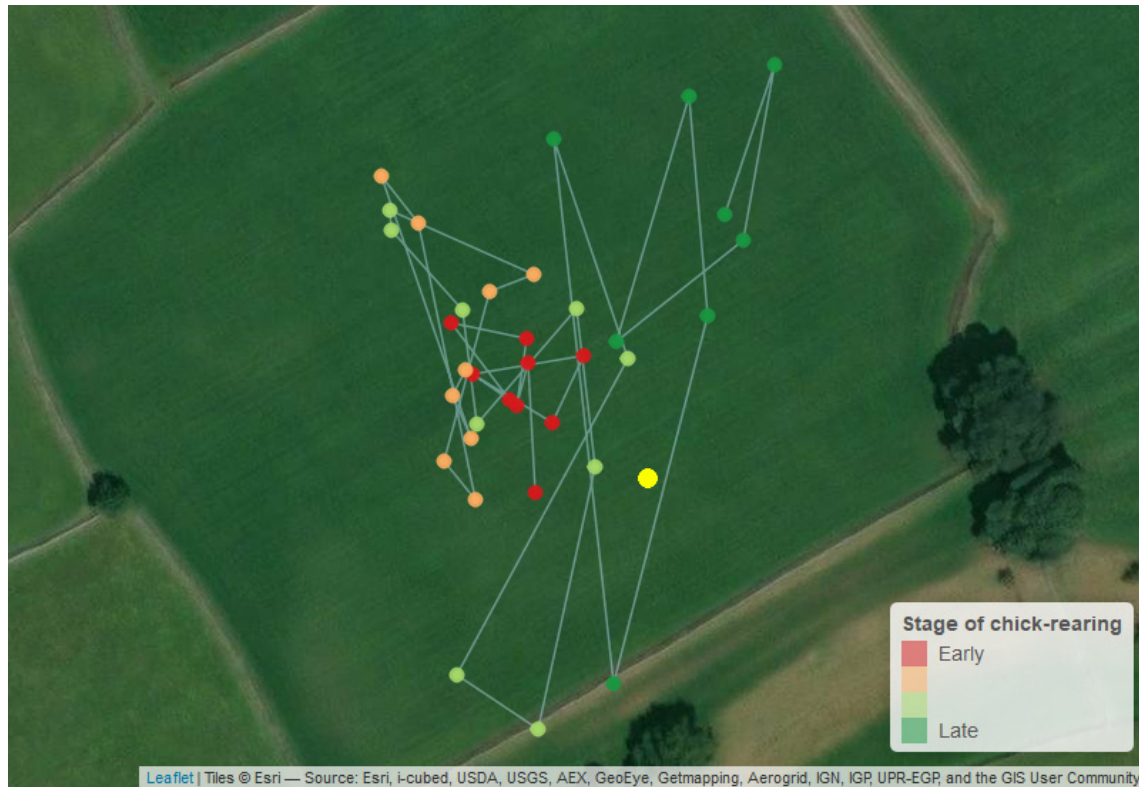


Figure 9(f). LimeNoir 2023.



Figure 9(g). LimeNoir 2024. The eggs are likely to have hatched a few days after the estimated date.



Figure 9(h). OrangeLime 2023.



3.7. Curlew habitat selection

There was variation in the extent to which birds nesting in heather moorland, unimproved grassland, and improved grassland remained in their nesting habitat, or used adjacent habitats. Heather-moorland-breeding birds (n = 4) spent less than 50% of their time in heather moorland each year, a high proportion of the remaining time in unimproved grassland and less time in improved grassland (Figure 10). In contrast, unimproved-grassland-nesting birds (n = 12) spent about 70% of their time in unimproved grassland and split the remaining time between heather moorland and improved grassland, with variation between individual birds. Improved-grassland-nesting birds (n = 16) spent almost all their time in improved grassland with little use of alternative habitats.

Figure 10. Proportion of GPS fixes in the three main habitats used by Curlews in the Yorkshire Dales by year. Breeding attempts by individual birds are shown, grouped by the nesting habitat of the bird.

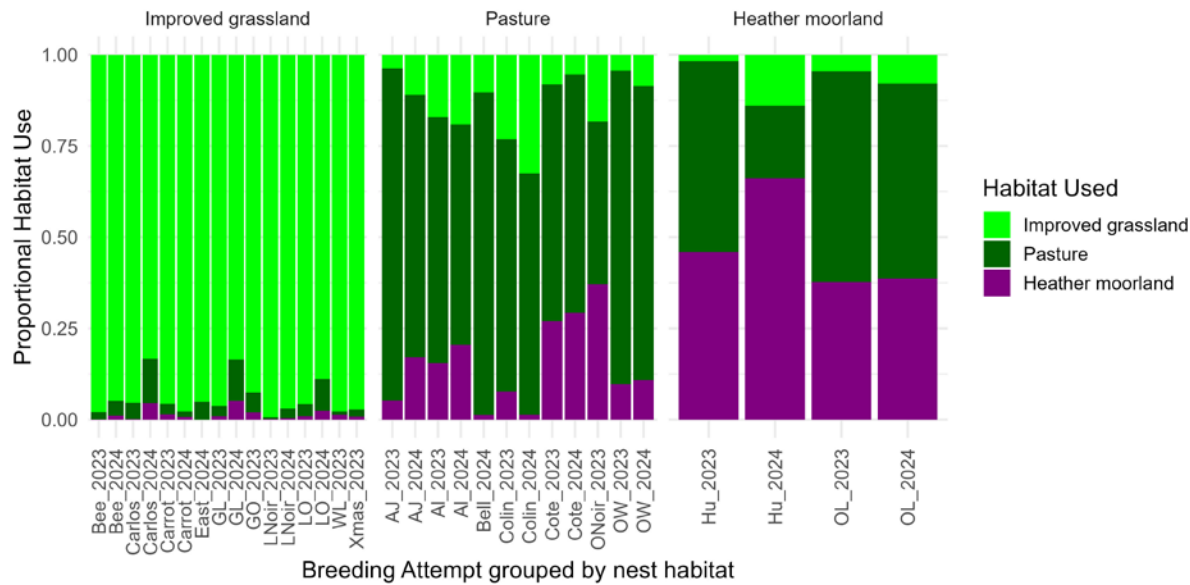
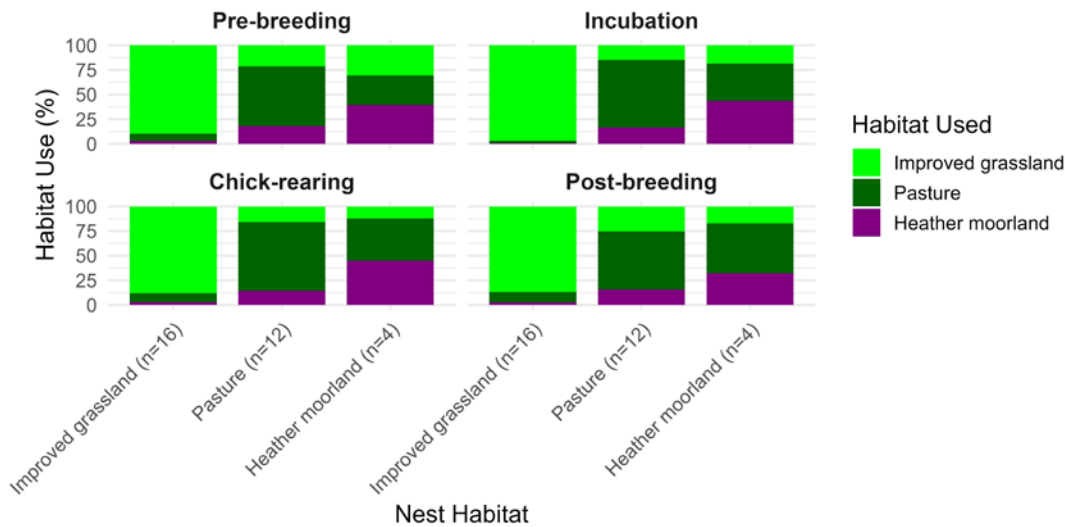


Figure 11. Proportion of GPS fixes in the three main habitats used by Curlews nesting in different habitats by breeding season stage.



The highest percentage of GPS point habitats was in improved grassland, followed by acid grassland and calcareous grassland before heather grassland and then other habitats.

Table 3. Habitat preferences of GPS tagged birds. Real fix locations (%) shows the percentage of all fixes by land cover category from the 2021 UK CEH Landcover map. Dummy locations are randomly replicated points within a flight distance of real fix locations (20 dummy points for each real fix) so locations which were available to birds. When real fix locations are higher than dummy locations for a habitat, the birds are selecting for that habitat (and vice versa). Most nests of tagged birds were in improved grassland, which explains the high proportion of fixes in this habitat.

Land Cover Map habitat category	Year	Real fix locations (%)	Dummy locations (%)
Improved grassland	2023	56.2	47.6
	2024	52.3	45.3
Pasture	2023	31.7	33.2
	2024	33.7	34.9
Heather moorland	2023	8.8	9.9
	2024	11.2	11.3
Other (inc. woodland and arable)	2023	3.5	9.3
	2024	2.8	8.5

4. Discussion

This study produces novel data on the movements of Curlews during the breeding season in the Yorkshire Dales National Park. We demonstrate that GPS tag data can be used to accurately identify and locate nesting attempts and assess breeding success. We also show that such data can provide valuable information on territory size, the movement of nest sites between years, the movement of family groups during the chick-rearing stage and identify how birds use the improved and unimproved grassland, and heather moorland habitat gradient in the Yorkshire Dales. While there are few other studies that have produced similar information using GPS-tagged Curlews, the findings here in terms of territory size are relatively consistent with similar studies (Bowgen et al. 2022; Bocher et al. 2024). Benefits and limitations of the analytical approach are discussed in Section 4.1., and then in Section 4.2. and 4.3. we consider our findings on breeding success and home ranges respectively, and then in Section 4.4. we briefly summarise the implications of these findings.

4.1. Uses and limitations of GPS-tagging in breeding Curlew studies

In this study we used a recently-developed method (Bowgen et al. 2022) to locate breeding attempts and infer breeding outcomes. The ground-truthing of inferred outcomes demonstrates that this method can generate robust data on Curlew breeding behaviour. To replicate this level of detail using fieldworker-led data gathering would be time-consuming, require expert fieldworkers, and involve frequent nest and brood visits (Jarrett et al. 2024). Additionally, the data on how birds nesting in different habitats use the gradient of grassland, pasture, and heather moorland provide valuable management information that would be especially difficult to gather using alternative methods. However, catching adult Curlews during the breeding season is time-consuming, requires expensive equipment, special permits, and expert fieldworkers to deploy the tags and operate the catching equipment, so is not a method that would be feasible for long-term, extensive monitoring of a breeding population.

The land cover dataset used in this study to classify habitats (Marston et al. 2023) is the most widely used in the UK but has limitations, specifically in relation to the classification of grassland habitats. The ground-truthed accuracy (the probability that a pixel is correctly classified) of the 10-class LCM we used here is estimated at 73% for improved grassland and 76% for semi-natural grassland, with most of the errors being overlap between these two categories (Marston et al. 2023). These are coarse categories with much variation

of management within each category; intensively-managed silage and traditional hay meadow are both classed as 'improved grassland' (from visual inspection of the dataset). Given the vast differences in stocking and cutting dates between these field types, the aggregation of these field types limits the value of our analyses. A habitat map which distinguishes improved pasture, silage, and hay meadow would be valuable for understanding the effect of field management and habitat mosaics on Curlew breeding success.

Another key challenge of interpreting the tag data is that our sample of GPS-tagged Curlews is non-randomly selected. Curlews nesting in improved grassland are likely to be over-represented in the dataset of tagged birds, due to difficulties in catching birds on heather moorland and pasture at higher elevations; thus, improved grassland is the habitat most frequently used by the GPS-tagged birds in the study (Table 3). We cannot, therefore, use these data to make robust inferences about the relative importance of the different habitats, although we can assess the extent to which birds nesting in specific habitats use a broader range of habitats or predominantly utilise their nest habitat (Figures 10 and 11). However, even in making these comparisons, it should be noted that the frequency with which different habitats are used is likely to be influenced by the configuration and proximity of available alternative habitats around each nest site. For example, the heather-moorland-nesting birds in this project, were nesting on the moorland fringe very near to unimproved and improved grassland, which is likely to explain the high use of these habitats amongst our sample of heather moorland nests.

The length of the incubation and chick-rearing periods assessed by the GPS analysis vary by a few days from those assessed by fieldworkers; this may be due to high site fidelity to a nest site before a clutch is complete being hard to distinguish for true incubation commencing on a full clutch when only one of a pair is GPS-tagged. Equally, it is challenging to accurately determine the day that eggs hatch or chicks fledge (Figure 8), which is likely to explain unusual movements at the start and end of the chick-rearing period (Figures 8b and 8e). Future analyses of habitat use and brood movements using ground-truthed timing of breeding events would improve the accuracy of resource selection functions and movement maps (e.g. Figures 8b and 8e). Furthermore, our categorisation of fledging where chick-rearing adults displaying chick-rearing behaviours more than 30 days after estimated hatch date may have incorrectly included some late-failing broods that did not fledge any chicks (potentially overestimating fledging success); however, survival of wader chicks at this age tends to be high (Beintema 1995). Increasing the number of days of chick-rearing we considered as successful fledging beyond 30 days would also incur error, through increasingly greater risk of 'false-negatives', where errors in estimated hatch dates and increasingly erratic adult late-chick-rearing movements could incorrectly determine late brood failure. It may also be difficult to detect breeding attempts when nests are predated before a full clutch is laid. Refining GPS analysis by ground-truthing all these outcomes would be challenging because fieldworkers would also likely find it difficult to identify failed incomplete clutches and late-failing broods.

Our results also indicate that nest and brood outcomes estimated by fieldworker observations in the field are overwhelmingly accurate; only two out of 27 nest or brood outcomes estimated from field observations was revealed as incorrect through GPS-tagging analysis. This supports the approach of local Curlew projects, which often depend upon fieldworker nest and brood monitoring to estimate breeding success in their project areas. Nevertheless, the two incorrect outcomes do suggest that in some cases caution should be employed when determining nest and brood outcomes. When a nest appears to fail near to hatching, the possibility of partial predation after one or more chicks have hatched should be considered. In this instance, the continued adult presence and behaviour was wrongly assigned to other pairs in an area of high breeding Curlew density, so this type of error may be less of a risk in low-density Curlew breeding areas. Nesting densities also confused field observations in the other incorrect field outcome (LimeNoir in 2023), further highlighting the additional sources of error when monitoring Curlews at high densities. Nevertheless, this level of error (4% in total) would not preclude local projects from assessing Curlew productivity, nor investigating the impacts of their conservation interventions.

Our estimated brood home ranges suggest that repeated visits to the nesting field and neighbouring fields, within a circumference of approximately 300 m from the nest, should provide sufficiently high probabilities of re-encountering chick-rearing adults and broods to estimate breeding success. However, how brood home ranges vary with factors such as habitat quality, breeding density and field boundaries is poorly understood, so we caution against extrapolating these findings beyond the Yorkshire Dales or similar landscapes, where brood movements may be limited by the unusually high densities of breeding Curlews, habitat quality, and impassable

field boundaries (i.e. drystone walls).

4.2 Breeding success in the Yorkshire Dales and similar landscapes

The high rates of nesting success and fledging success (relative to lowland mainland in the UK) are broadly comparable to other studies of Curlew productivity on farmland in the British uplands, across managed moorland and moorland fringe habitats and gradients of predator control effort (e.g. Baines et al. 2023) and indicate a roughly stable population within our sample. This supports previous research indicating the importance of landscape-scale predator control for Curlew conservation in the UK (Fletcher et al. 2010, Calladine et al. 2022, Baines et al. 2023, Baines 2024). Baines et al. (2023) found high, but variable Curlew productivity in their British upland study sites, ranging from 1.05 fledglings per pair on farmland adjacent to grouse moor (where predator control tends to be more intensive) to 0.27 on farmland not adjacent to grouse moor (where predator control tends to be less intensive). Using similar assumptions to Baines et al. (2023), we estimated 0.62 fledglings per pair per year over both years (0.75 in 2023 and 0.44 in 2024); comparing this to the estimated 0.68 fledglings per pair per year needed to achieve a stable global population size (Viana et al. 2023), our sample appears to represent a near-stable population. Although we did not investigate how breeding success varied by proximity to grouse moor or background predator control or predator activity, our estimated productivity is consistent with the range of Curlew productivity Baines et al. (2023) reported in the uplands. The breeding success of the Curlews we GPS-tagged indicates that Curlew populations in 'strongholds' such as the Yorkshire Dales National Park may be more vulnerable than local adult abundance suggests. These landscapes, where Curlew conservation is likely most cost-effective, should be prioritised for wader AES options, as well as protection from threats (such as increases in woodland cover or renewable energy development).

Whilst differences in nest and brood survival between habitat categories were not statistically significant, it is notable that the highest breeding productivity across the three habitats was recorded in improved grassland, and did not differ greatly between improved pasture, silage fields, and hay meadow. Though pasture, silage fields, and hay meadow were indistinguishable in the freely available satellite-imagery-based land cover maps we used in our analyses, their management is drastically different, and Curlews nesting in each likely face different probabilities of nest and chick survival. Silage is thought to incur lower ground-nesting nest and chick survival due to mechanical destruction and greater exposure to predation and weather post-cutting (Buckingham et al. 2015). However, for the fields in which our sample of GPS-tagged birds in silage bred, the Bolton Estate and farm collaborate each year (including our study years) to avoid mowing in the immediate vicinity of nests and broods (i.e. leaving areas around nests unmown and locating and translocating broods to safety). Therefore, the breeding productivity reported here is unlikely to be representative of silage fields in the wider landscape, because of both the mowing interventions and predator control. Nevertheless, it does indicate that in areas subject to predator control at sufficient scale (Fletcher et al. 2010), interventions in improved grassland to prevent nest and brood destruction by farm operations may deliver sufficient breeding productivity to stabilise these populations (i.e. although not statistically significant, our results suggest that broods can survive in and around recently cut silage fields in areas of background predator control).

4.3 Home ranges and habitat use

The reported home ranges in this project are smaller than a similar study in the Welsh uplands of a lower density breeding population (Taylor et al. 2020). While individual birds do use a wide-range of open habitats in the Yorkshire Dales, they do so more frequently in the pre- and post-breeding periods, and during the incubation and chick-rearing periods home ranges are smaller and uses of alternative habitats are less common (Figure 8, Figures 9a–h, and Figure 11). In particular, birds that nest in improved grassland do not spend significant amounts of time in alternative habitats (Figure 10), nor do they appear to make long-distance movements during brood-rearing (Figures 9a–h). However, birds using heather moorland and unimproved grassland also tend to use improved grassland habitats, presumably for better foraging opportunities (Ewing et al. 2017). In contrast, birds nesting in improved grassland appear much less likely to make foraging trips to unimproved grassland or heather moorland habitats. We also found that in all the broods monitored to fledging, movements of broods were relatively small, with few movements beyond the nesting field or away from the nesting area.

That heather-moorland-breeding birds spend significant time in unimproved and improved grassland supports previous findings that surveyors may underestimate Curlew density in moorland habitats and overestimate Curlew density in adjacent unimproved and improved grassland if they are not aware of this, as identified in Grant et al. (2000).

4.4 Implications

The key findings of this study (noting the relatively small sample sizes) are the:

- Near-stable overall breeding success;
- Small home range estimates;
- Absence of long-distance brood movements;
- Relatively high breeding productivity in improved grassland (particularly silage fields), in an area subject to predator control at sufficient scale, when nests and broods are protected from cutting; and
- The strong fidelity of silage-nesting birds to silage habitats throughout the breeding season.

Taken together, these findings suggest that in areas with landscape-scale predator control, like much of the Yorkshire Dales National Park, well-targeted, small-scale interventions at the field or farm level (specifically those that reduce risks to nests and broods from cutting and grazing) could significantly improve breeding productivity. However, we caution against generalisation of these results beyond landscapes like the Yorkshire Dales; in landscapes without intensive predator control and where Curlew breeding densities are lower, similar small-scale interventions are unlikely to achieve the same positive outcomes.

5. References

- Baines, D., Fletcher, K., Hesford, N., Newborn, D. & Richardson, M. 2023. Lethal predator control on UK moorland is associated with high breeding success of Curlew, a globally near-threatened wader. *European Journal of Wildlife Research* **69**: 6.
- Baines, D. 2024. Ten years on from a predator removal experiment in the English uplands: changes in numbers of ground-nesting birds and predators. *Journal for Nature Conservation* **84**: 126788.
- Beintema, A.J. 1995. Fledging success of wader chicks, estimated from ringing data. *Ringling & Migration* **16**: 129–139.
- Bracis, C., Bildstein, K. & Mueller, T. 2018. Revisitation analysis uncovers spatio-temporal patterns in animal movement data. *Ecography* **41**: 1,801–1,811.
- Bocher, P., Donnez, M., Chenu, A., Sviridova, T., Fort, J., Garthe, S., Jiguet, F., Piha, M., Elts, J., Marja, R., Amelineau, F., Robin, F., Rosseau, P. & Schwemmer, P. 2024. Home ranges and hatching success of threatened Eurasian Curlew in north-eastern Europe relates to habitat type: natural vs. agricultural landscapes. *Global Ecology and Conservation* **50**: e02851.
- Bowgen, K.M., Dodd, S.G., Lindley, P., Burton, N.H. & Taylor, R.C. 2022. Curves for Curlew: identifying Curlew breeding status from GPS tracking data. *Ecology and Evolution* **12**: e9509.
- Buckingham, D.L., Giovannini, P. & Peach, W.J. 2015. Manipulating grass silage management to boost reproductive output of a ground-nesting farmland bird. *Agriculture, Ecosystems & Environment* **208**: 21–28.
- Berg, A. 1992. Factors affecting nest-site choice and reproductive success of Curlews *Numenius arquata* on farmland. *Ibis* **134**: 44–51.
- Bell, M. V. & Calladine, J. 2017. The decline of a population of farmland breeding waders: a twenty-five-year case study. *Bird Study* **64**: 264–273.
- Brown, D., Wilson, J., Douglas, D., Thompson, P., Foster, S., McCulloch, N., Phillips, J., Stroud, D., Whitehead, S., Crockford, N. & Sheldon, R. 2015. The Eurasian Curlew – the most pressing bird conservation priority in the UK. *British Birds* **108**: 660–668.

- Calenge C. & Fortmann-Roe S. 2023. adehabitatHR: Home Range Estimation. R package version 0.4.21.
- Clark, N.A., Ewing, H., Franks, S., Green, R.E. & Sheldon, R. 2023. Remote-triggered, spring-powered Clap Net. Presented at the International Wader Study Group Conference, 29 September to 3 October 2023, Sylt, Germany. Info available at: www.waderstudygroup.org/conferences/2023-sylt-germany [accessed 18 July 2025].
- Calladine, J., Border, J., O'Connell, P. & Wilson, M.W. 2022. Modelling important areas for breeding waders as a tool to target conservation and minimise conflicts with land use change. *Journal of Nature Conservation* **70**: 126267.
- Colwell, M., Hilton, G., Smart, M. & Sheldrake, P. 2020. Saving England's lowland Eurasian curlews. *British Birds* **113**: 279–292.
- Copernicus Climate Change Service (C3S). 2023. ERA5 hourly data on single levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). 10.24381/cds.adbb2d47 [accessed on 3 January 2024].
- Defra. 2023. Environmental Land Management update: how government will pay for land-based environment and climate goods and services [Online]. Defra. Last updated: 21 June 2023. Available at: <https://www.gov.uk/government/publications/environmental-land-management-update-how-government-will-pay-for-land-based-environment-and-climate-goods-and-services> [accessed on 6 March 2025].
- Douglas, D.J., Bellamy, P.E., Stephen, L.S., Pearce-Higgins, J.W., Wilson, J.D. & Grant, M.C. 2014. Upland land use predicts population decline in a globally near-threatened wader. *Journal of Applied Ecology* **51**: 194–203.
- Esri. 2025. "Imagery" [basemap]. Scale Not Given. "World Imagery". 27 June 2025. Available at: <https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08feb2a9> [accessed 22 July 2025].
- EuroGraphics. 2023. EuroDEM [Online]. Last updated: October 2023. Available at: www.mapsforeurope.org/datasets/euro-dem [accessed on 6 March 2025].
- Ewing, S.R., Scragg, E.S., Butcher, N. & Douglas, D.J.T. 2017. GPS tracking reveals temporal patterns in breeding season habitat use and activity of a globally Near threatened wader, the Eurasian Curlew. *Wader Study* **124**: 206–214.
- Fletcher, K., Aebischer, N. J., Baines, D., Foster, R. & Hoodless, A. 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.
- Grant, M.C., Orsman, C., Easton, J., Lodge, C., Smith, M., Thompson, G., Rodwell, S. & Moore, N. 1999. Breeding success and causes of breeding failure of Curlew *Numenius arquata* in Northern Ireland. *Journal of Applied Ecology* **36**: 59–74.
- Grant M.C., Lodge C., Moore N., Easton J., Orsman C. & Smith M. 2000. Estimating the abundance and hatching success of breeding Curlew *Numenius arquata* using survey data. *Bird Study* **47**: 41–51.
- Hernangomez, D. 2024. Tidyterra: tidyverse Methods and ggplot2 Helpers for terra Objects.
- Heywood, J.J.N., Massimino, D., Baker, L., Balmer, D.E., Brighton, C.H., Gillings, S., Kelly, L., Noble, D.G., Pearce-Higgins, J.W., White, D.M., Woodcock, P., Workman, E. & Wotton, S. 2025. The Breeding Bird Survey 2024. *BTO Research Report* **787**. British Trust for Ornithology, Thetford.
- Hijmans, R. 2023. Terra: Spatial Data Analysis. R package version 1.7-29
- Jarrett, D., Calladine, J., Wernham, C. & Wilson, M. 2017. Monitoring breeding waders in Wensleydale: trialling surveys carried out by farmers and gamekeepers. *BTO Research Report* **703**. British Trust for Ornithology, Thetford.
- Jarrett, D., Lehikoinen, A. & Willis, S.G. 2024. Monitoring wader breeding productivity. *Ibis* **166**: 780–800.
- Kranstauber B., Smolla M. & Scharf, A. 2023. Move: Visualizing and Analyzing Animal Track Data. R package version 4.1.12.
- Macgregor, C.J. & Bowgen, K.M., et al. Elevation, tide and light cycles combine to influence near-coastal habitat

selection decisions in Eurasian Curlew *Numenius arquata*. In prep.

Marston, C.G., O'Neil, A.W., Morton, R.D., Wood, C.M. & Rowland, C.S. 2023. LCM2021 – the UK land cover map 2021. *Earth System Science Data* **15**: 4,631–4,649.

Mayfield, H.F. 1975. Suggestions for calculating nest success. *Wilson Bulletin* **87**: Article 2.

O'Brien, M. & Wilson, J.D. 2011. Population changes of breeding waders on farmland in relation to agri-environment management. *Bird Study* **58**: 399–408.

Ordnance Survey. 2025. OS Miniscale. Available at: <https://www.ordnancesurvey.co.uk/products/miniscale> [accessed 22 July 2025].

Posit Team. 2023. RStudio: Integrated Development Environment for R [Online]. Posit Software, PBC, Boston, MA. Available at: <http://www.posit.co/> [accessed on 6 March 2025].

R Core Team. 2023. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Smart, J., Wotton, S.R., Dillon, I.A., Cooke, A.I., Diack, I., Drewitt, A.L., Grice, P.V. & Gregory, R.D. 2014. Synergies between site protection and agri-environment schemes for the conservation of waders on lowland wet grasslands. *Ibis* **156**: 576–590.

Summers, R.W., Pálsson, S., Etheridge, B., Foster, S. & Swann, B. 2013. Using biometrics to sex adult Eurasian Curlews *Numenius a. arquata*. *Wader Study Group Bulletin* **120**: 71–74.

Taylor, R.C., Bowgen, K.M., Burton, N.H.K. & Franks, S.E. 2020. Understanding Welsh breeding Curlew: from local landscape movements through to population estimations and predictions. *NRW Evidence Report* **485**. Natural Resources Wales.

Viana, D. S., Santoro, S., Soriguer, R. C. & Figuerola, J. 2023. A synthesis of Eurasian Curlew (*Numenius arquata arquata*) demography and population viability to inform its management. *Ibis* **165**: 767–780.

APPENDIX

Table A1. Breeding outcomes and timings for different stages of breeding for each GPS-tagged Curlew, as estimated from GPS analysis.

Bird ID	Sex	Year	Return to breeding grounds (*or start of tagging if before first incubation)	First incubation start (*or start of tagging if after first incubation)	First incubation failure	Second incubation start	Second incubation failure	Chick-rearing start (hatch date)	Post-breeding success (fledge date)	Post-breeding failure (brood failure date)	Fledging success	Departure from breeding grounds (*or end of data)	Days of data in breeding area
GreenLime	♂	2023	N/A	*13/04/2023	N/A	N/A	N/A	22/05/2023	29/06/2023	N/A	YES	02/07/2023	79
		2024	16/02/2024	08/04/2024	13/05/2024	N/A	N/A	N/A	N/A	13/05/2024	N0	*22/05/2024	95
Alderman	♂	2023	*25/04/2023	09/05/2023	24/05/2023	N/A	N/A	N/A	N/A	N/A	N0	13/07/2023	78
		2024	20/02/2024	22/04/2024	N/A	N/A	N/A	21/05/2024	23/07/2024	N/A	YES	26/08/2024	138
LimeNoir	♂	2023	*13/04/2023	17/04/2023	N/A	N/A	N/A	18/05/2023	16/06/2023	N/A	YES	16/06/2023	63
		2024	19/02/2024	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N0	23/06/2024	124
LimeOrange	♂	2023	*18/04/2023	28/04/2023	N/A	N/A	N/A	25/05/2023	N/A	19/06/2023	N0	08/07/2023	80
		2024	21/01/2024	17/04/2024	02/05/2024	N/A	N/A	N/A	N/A	02/05/2024	N0	09/09/2024	132
Cote	♂	2023	N/A	*26/04/2023	19/05/2023	03/06/2023	14/06/2023	N/A	N/A	14/06/2023	N0	27/06/2023	61
		2024	06/03/2024	18/04/2024	N/A	N/A	N/A	15/05/2024	10/06/2024	14/06/2023	YES	01/07/2024	116
Eastender	♂	2023	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		2024	N/A	*27/04/2024	22/05/2024	N/A	N/A	N/A	N/A	22/05/2024	N0	21/06/2024	54
Hunters	♂	2023	*22/04/2023	23/04/2023	N/A	N/A	N/A	14/05/2023	14/06/2023	N/A	YES	18/06/2023	56
		2024	16/02/2024	15/04/2024	N/A	N/A	N/A	11/05/2024	N/A	16/05/2024	N0	15/06/2024	119
Colin	♂	2023	N/A	*28/04/2023	20/05/2023	N/A	N/A	N/A	N/A	N/A	N0	06/07/2023	68
		2024	28/02/2024	15/04/2024	24/04/2024	15/05/2024	N/A	16/06/2024	N/A	26/06/2024	N0	28/07/2024	150

Bird ID	Sex	Year	Return to breeding grounds (*or start of tagging if before first incubation)	First incubation start (*or start of tagging if after first incubation)	First incubation failure	Second incubation start	Second incubation failure	Chick-rearing start (hatch date)	Post-breeding success (fledge date)	Post-breeding failure (brood failure date)	Fledging success	Departure from breeding grounds (*or end of data)	Days of data in breeding area
Carrot	♀	2023	*11/04/2023	10/05/2023	13/05/2023	18/05/2023	23/05/2023	N/A	N/A	23/05/2023	N0	20/06/2023	69
		2024	02/03/2024	08/05/2024	N/A	N/A	N/A	08/06/2024	N/A	N/A	Unknown	20/06/2024	109
Bee	♂	2023	*17/04/2023	30/04/2023	N/A	N/A	N/A	05/06/2023	09/07/2023	N/A	YES	22/07/2023	95
		2024	05/02/2024	24/04/2024	14/05/2024	N/A	N/A	N/A	N/A	N/A	N0	11/07/2024	156
OrangeLime	♂	2023	*19/04/2023	21/04/2023	N/A	N/A	N/A	22/05/2023	26/06/2023	N/A	YES	06/07/2023	77
		2024	15/03/2024	16/04/2024	01/05/2024	N/A	N/A	N/A	N/A	01/05/2024	N0	06/07/2024	112
OrangeWhite	♂	2023	N/A	*27/04/2023	18/05/2023	N/A	N/A	N/A	N/A	N/A	N0	30/06/2023	63
		2024	*19/02/2024	28/04/2024	25/05/2024	N/A	N/A	N/A	N/A	25/05/2024	N0	30/06/2024	131
Carlos	♂	2023	*24/04/2023	05/05/2023	N/A	N/A	N/A	04/06/2023	10/07/2023	N/A	YES	01/08/2023	98
		2024	13/02/2024	11/05/2024	N/A	N/A	N/A	09/06/2024	09/07/2024	N/A	YES	09/07/2024	146
AndersonJack	♂	2023	*16/04/2023	23/04/2023	30/04/2023	N/A	N/A	N/A	N/A	N/A	N0	04/07/2023	78
		2024	17/02/2024	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N0	*29/03/2024	40
Bell	♀	2023	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		2024	N/A	*24/04/2024	N/A	N/A	N/A	16/05/2024	N/A	N/A	Unknown	06/06/2024	26
GreenOrange	♂	2023	*18/04/2023	19/04/2023	N/A	N/A	N/A	29/05/2023	27/06/2023	N/A	YES	27/06/2023	69
		2024	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Bird ID	Sex	Year	Return to breeding grounds (*or start of tagging if before first incubation)	First incubation start (*or start of tagging if after first incubation)	First incubation failure	Second incubation start	Second incubation failure	Chick-rearing start (hatch date)	Post-breeding success (fledge date)	Post-breeding failure (brood failure date)	Fledging success	Departure from breeding grounds (*or end of data)	Days of data in breeding area
OrangeNoir	♀	2023	*14/04/2023	15/04/2023	N/A	N/A	N/A	13/05/2023	N/A	N/A	Unknown	13/06/2023	59
		2024	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Whitelime	♀	2023	*19/04/2023	03/05/2023	28/05/2023	01/06/2023	N/A	N/A	N/A	N/A	Unknown	12/06/2023	53
		2024	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Xmas	♂	2023	N/A	*23/04/2023	N/A	N/A	N/A	26/05/2023	N/A	N/A	Unknown	07/07/2023	74
		2024	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A



Cover images, Curlew fieldwork, by Rich Bunce Walking Photographer

GPS-tracking breeding Curlew in the Yorkshire Dales: breeding success, home range size, and habitat use

This study uses GPS tags, fitted to adult Curlews in the Yorkshire Dales National Park, to infer nest and brood locations and breeding outcomes from movement patterns of the tagged birds. For a subsample of these birds, inferences were ground-truthed against field observations. Variation in home range sizes at different stages of the breeding season, movements during the chick-rearing period, and the extent to which birds nesting in different habitats utilised the range of habitats available, were examined.

The results show that inferring breeding outcomes from GPS data can generate useful information on breeding success, home range size, and habitat use that would be difficult to capture using other methods. The work also demonstrates that in areas subject to landscape-scale predator control, as is common in the Yorkshire Dales National Park, well-targeted, field- and farm-level interventions aimed at mitigating potential negative impacts of agricultural operations (especially harvesting silage) and high stocking densities could significantly increase breeding productivity for Curlews and other ground-nesting birds.

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