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RESEARCH ARTICLE

Woodland proximity limits benefits of conservation land management for farmland breeding waders

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Abstract

1. Breeding waders have suffered long-term population declines, both in Europe and globally, and are species of high conservation concern in Europe, where populations are associated with farmed land. Negative effects of the presence of woodland edge on breeding waders have been demonstrated mainly for coniferous plantations, but it is not known if the same relationship exists for broadleaved woodlands and whether conservation interventions for waders might be compromised by the presence of woodland in the wider landscape. This issue is particularly pertinent given the increased interest in woodland cover expansion for ecological restoration and climate change mitigation.
2. Here we analyse data on four wader species of international conservation concern between 2000 and 2015 in an area of the Scottish uplands targeted by wader conservation interventions. We test for each species: (1) change in density over time at the farm scale; (2) associations between wader density and habitat variables at the field scale; and (3) edge effects of distance to broadleaf and conifer woodland on wader density.
3. Wader densities declined between 2000 and 2015 by >50% for Northern Lapwing and >40% for Common Redshank. Effects of habitat variables varied by species with Eurasian Curlew and Common Snipe densities greater in fields with a higher proportion of rush (to c. 40% cover); and Common Redshank and Common Snipe densities higher in wetter fields. Densities of all four waders were greater further from woodland edge, whether coniferous or broadleaved, with modelled wader densities extremely low within 100 m of woodland. Additional 100 m distance bands resulted in increases in predicted wader density of c. 10% extending to 500 m for Curlew and 700–900 m for Lapwing, Snipe and Redshank.
4. *Policy implications*. Where grassland breeding wader assemblages may be put at risk by tree planting, buffer zones >500 m should be implemented to mitigate the negative effect on wader species, with further distances having the greatest benefits. Equally, the benefits of conservation measures for breeding waders will be reduced within similar proximities to existing woodland cover. Fields selected for

wader AES management should be in open areas, much further from the woodland edge than the current policy recommendations.

KEYWORDS
Agri-environment schemes, climate mitigation policy, curlew, farmland breeding waders, grassland, lapwing, tree planting, woodland

1 | INTRODUCTION

Changes to agricultural practices, especially intensification of production since the 1950s, have caused widespread losses of European farmland wildlife (Burns et al., 2021; Raven & Wagner, 2021; Rigal et al., 2023). Agricultural intensification is especially challenging for ground-nesting birds, which often use agricultural land as nesting habitat but are affected by a wide range of farming operations including crop choice, drainage, cultivation, sowing and harvesting times, agrochemical use and livestock densities (Newton, 2017). At a landscape scale, these challenges may be exacerbated by existing forestry and woodland planting that reduce habitat availability, fragment previously open landscapes (Andren, 1994) and increase in predator abundance (e.g. Franks et al., 2018; Kaasiku et al., 2022). Efforts to increase tree cover in the UK are being driven by climate change mitigation and ecological restoration as well as timber production objectives (IPCC, 2021) and are often targeted at agriculturally marginal areas (O'Neill et al., 2020) which might otherwise act as refuges for species dependent on low-intensity farmland (Bignal & McCracken, 1996).

Many ground-nesting farmland breeding shorebird species (waders; Order Charadriiformes) have sustained long-term and severe declines since the late 1960s on European farmland (Roodbergen et al., 2012; Silva-Monteiro et al., 2021) and are now of high conservation priority (e.g. BirdLife International, 2021; Brown et al., 2015). Intensive research into their breeding ecology and habitat requirements on agricultural land has led to the development of targeted agri-environment scheme (AES) measures (e.g. Newton, 2017; Verhulst et al., 2007). These conservation measures have largely focused on grazing management to create the desired nesting habitat and reduce trampling of nests, rotational cutting and changes to the timing of agricultural management to reduce mortality from machinery and water management to provide wet features for foraging habitat.

Whilst degradation of habitat quality on farmland has contributed to breeding wader population declines (Franks et al., 2018), increases in tree cover further fragment and reduce the extent of previously open landscapes (Andren, 1994) favoured by these birds (Ratcliffe, 2007). Behavioural avoidance of tall features can therefore lead to displacement of waders in areas of new planting. Additionally, as woodland matures, avian and mammalian predator densities may increase, resulting in higher nest predation and hence lower densities of breeding waders (Franks et al., 2017; Kaasiku et al., 2022; Pálsdóttir et al., 2022; Roos et al., 2018; Valkama et al., 1999). This 'edge' effect has been observed for waders over several hundred metres from plantation forest edge (Douglas et al., 2014; Kaasiku et al., 2022; Wilson et al., 2014). Thus, tree planting can cause direct loss of wader habitat and may also render surrounding habitat unsuitable (Amar et al., 2011; Sanderson et al., 2013) irrespective of whether wader management is being delivered. This is of particular concern in the UK uplands where marked wader declines are occurring (e.g. Bell & Calladine, 2017), concurrently with tree planting commitments by national governments, with England and Scotland pledging to increase woodland cover to 12% (from 10%) by 2050 (DEFRA, 2021) and to 21% (from 18%) by 2032, respectively (Scottish Government, 2019). To date, the evidence base for the effects of woodland edge on waders has been dominated by studies of coniferous, plantation woodlands; there is an important knowledge gap on whether similar edge effects occur with native broadleaved woodland (although see McGrory et al., 2024).

Studies of the effectiveness of targeted AES prescriptions for farmland breeding waders indicate that, outside protected areas (such as nature reserves), they often do no better than slow population declines (Franks et al., 2018; Hawkes et al., 2025; Jellesmark et al., 2021; O'Brien & Wilson, 2011; Smart et al., 2013). If interactions with woodland in the landscape are reducing the effectiveness of agri-environment or other conservation management interventions for waders, then this may contribute to the wider problem of mixed success of AES and wader interventions in delivering their nature conservation objectives (Douglas et al., 2023; Kleijn & Sutherland, 2003).

In this study, we focus on four farmland breeding wader species of international conservation concern (Northern Lapwing *Vanellus vanellus*, Eurasian Curlew *Numenius arquata*, Common Snipe *Gallinago gallinago*, Common Redshank *Tringa totanus*) between 2000 and 2015 in a key breeding area in the Scottish uplands of the UK, characterised by marginal agricultural land, wetlands, conifer plantations and native broadleaved woodland. Although present in our study area, we do not include Eurasian Oystercatcher *Haematopus ostralegus* due to a lack of available data on this wader species at the time of analysis. This area has been a target for wader conservation interventions since the 1980s and has been subject to several different AES over several iterations and policy reforms during the period of this study (Table S1). Key elements of wader management in Scotland are rush control (i.e. for dense *Juncus* spp.), elevated water management and grazing restrictions delivered in larger (>1 ha) open fields or areas at least 30 m from woodland (Scottish Government, 2024). For descriptions of wader AES options, see Table 1. Since 2008,

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TABLE 1 Variables used to predict wader density at the field scale, showing data source, mean and range for continuous variables and level descriptions for categorical variables.

Variable	Type	Description	AES wader management
Data source: SWWI field surveyors			
Year	Ordinal	Year of survey as four levels: • 2000 • 2005 • 2010 • 2015	
Livestock units (LU/ha)	Ordinal	Number of livestock in the field on the day of the survey converted into LU/ha by: (cattle × 1.0 + calves × 0.6 + sheep × 0.12 + horses × 1.0)/field area in ha (Chesterton, 2006) and categorised into four levels: • None (0 LU/ha) • Light (<0.6 LU/ha) • Moderate (0.6–1 LU/ha) • Intensive (>1 LU/ha)	*Manipulate grazing management during the breeding season: exclude livestock from 1 April to 12 May; exclude livestock from 15 April to 26 May; or restrict livestock to 1 LU/ha from 15 March to 15 June. ØGrazing is excluded between 1 April and 30 June
Vegetation height	Ordinal	Estimated by eye and categorised by dominant type (>75%) into five levels: • Bare (no vegetation) • Short (< ankle height) • Medium (at ankle height) • Long (> ankle height) • Mixed (combination—no dominant type).	*ØBest practice is for a varied sward between 5 and 15 cm during the breeding season to benefit a wide range of waders (Scotland's FAS, Technical Note TN688, 2023) *The sward may contain occasional tussocks of taller vegetation ØHay and silage must be cut in a wildlife friendly manner (e.g. cut from the middle outwards with a 2 m strip of uncut and unsprayed field margins) after 30 June
Land use	Factor	Recorded by field surveyor into category with six levels: • Arable • Managed grassland • Marsh & wetland • Rough grazing, heath & moorland • Unmanaged rank grassland • Rush pasture.	
Rush cover	Covariate	Estimated by eye. Mean: 8.0% Range: 0%–80%	*ØRush management available as a capital item with best practice 20%–30% rush cover in small patches, to benefit a wide range of wader species or <10% if targeting Lapwing (Scotland's FAS, Technical Note TN688, 2023)
Standing water	Covariate	Estimated by eye. Mean: 5.0% Range: 0%–50%	*ØFields can be enhanced for waders by creating and/or maintaining wader scrapes to provide wet features (available as a capital item). For best practice, scrapes should hold water from early March until late June, be at least 20 m^2 in area and no more than 45 cm deep in the middle with gently sloping edges (Scotland's FAS, Technical Note TN688, 2023)
Data source: UK Ordnance Survey Digital Data			
Area	Covariate and offset	Area in hectares. For offset, Log_e transformed so that the response variable was expressed as density (birds ha^{-1}). Mean: 6.8 ha Range: 0.4–135.3 ha	*AES wader management must be implemented in areas of ≥1 ha if targeting Lapwing and/or Curlew

(Continues)

TABLE 1 (Continued)

Variable	Type	Description	AES wader management
Slope	Covariate	Mean of all points that fell within a field (50-m grid) in degrees. Mean: 2° Range: 0–8°	
Elevation	Covariate	Mean of all points that fell within a field (50-m grid) in metres. Mean: 220 m Range 180–320 m	
x and y co-ordinates	Covariate	Field centroid point. Used to check for spatial autocorrelation (SAC) in the final models	
Data source: Google EARTH PRO			
Enclosure score	Covariate	Proportion of field boundary consisting of trees, hedges, scrub or buildings. Mean: 0.2 Range: 0.0–0.9	*$^{\varnothing}$Open landscapes not enclosed by tall features (Scotland's FAS, Technical Note TN688, 2023)
Data source: Forestry commission's National Forest Inventory (NFI) Scotland 2015			
Distance to woodland	Covariate	Shortest linear distance (m) to nearest woodland edge from field centroid point. Mean: 233 m. Range: 0–768 m. Data was natural $\log_e$ transformed for analysis.	*$^{\varnothing}$Best practice is for a buffer strip of at least 30 m between the wader field/area and hedgerows, scrub, trees or woodland (Scotland's FAS, Technical Note TN688, 2023)
Woodland type	Factor	NFI 'Interpreted Forest Types' (IFTs) used to create two woodland levels. • Conifer (consists of conifer and mixed (predominantly conifer) IFTs) • Broadleaf (consists of broadleaved and mixed (predominantly broadleaved) IFTs)	

Note: Where applicable, the management advice is provided for the wader AES option for grazed grasslands 'Wader Grazed Grasslands' (*) and the wader AES option for hay and silage fields 'Wader and Wildlife Mown Grasslands' ($^{\varnothing}$) accessed from the Scottish Government's Rural Payments Service, www.ruralpayments.org on April 2024.

wader management (the Strathspey Wetlands and Wader Initiative—SWWI) has also been providing conservation advice to ensure effective targeting and delivery of wader AES as well as voluntary wader management outside such schemes. Despite this, the breeding success of waders in the Badenoch and Upper Strathspey has declined between 2007 and 2019 (Buxton et al., 2022).

Using SWWI bird and habitat data, we wished to understand the extent to which field scale interventions for breeding waders might be compromised by the impacts of woodland in the wider landscape. To address this question, we:

- quantified changes in wader density over time at the farm scale (objective 1);
- tested for field scale associations between wader density, topography and habitat features promoted by AES management (e.g. rush and water cover) to assess the extent to which breeding wader habitat associations in this landscape are consistent with available management options in current and recent AES in Scotland (objective 2); and
- tested the extent to which these associations are modified by 'edge effects' of distance to woodland and whether this differed between broadleaf and coniferous planting to assess the extent to which the presence of woodland at the landscape scale may be compromising wader conservation objectives (objective 3).

2 | MATERIALS AND METHODS

2.1 | Study location

The study farms are within the Badenoch and Strathspey (hereafter, Strathspey) region of the Cairngorms National Park in the Scottish Highlands (Figure 1). The Strathspey area covers 2354 km^2 and comprises the floodplain and catchment of the River Spey from Loch Laggan in the southwest to Grantown-on-Spey in the north-east. The soils in the valley are primarily humus-iron podzols with a wide alluvial plain composed of silts, sand and waterborne pebbles, while the surrounding hillsides and mountains support peat soils (Soil Survey of Scotland Staff, 1981). The median topsoil pH ranges from 5.0–5.9 in the valley to <4.0–4.9 on surrounding hillsides. Land use is predominantly agricultural with a mix of arable (spring barley and forage crops) and grazed and mown grassland for beef suckler cattle herds and sheep, as well as wetlands, moorland grazing for sheep and woodland cover comprised of both native woodland and conifer

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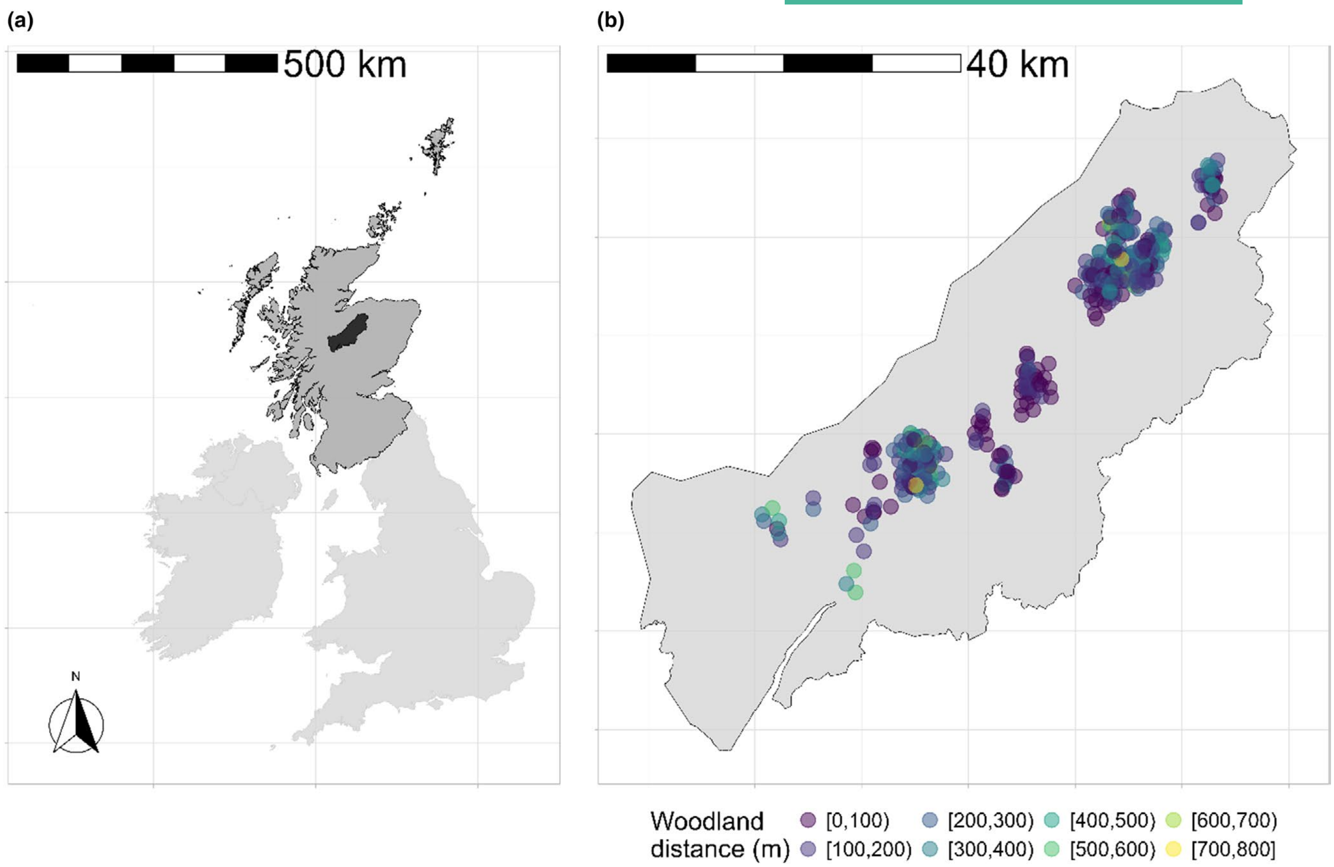

FIGURE 1 (a) Map of the United Kingdom and Ireland (light grey) showing the Badenoch and Strathspey study area (black) in Scotland (dark grey). (b) Jittered location of the study fields ($n = 341$) used to test objective 3 showing the 100 m distance categories to the nearest woodland (>0.5 ha in size) from each field's centroid location.

plantation. In total, this creates a complex landscape of mixed, mainly low-intensity farming. In this area, most waders breed at elevations of 200–400 m on upland farmland habitat (Buxton et al., 2022).

2.2 | Farm and field sample size

Field scale data on farmland wader abundance and habitat variables were collected by the SWWI for 2000, 2005, 2010 and 2015. Farms volunteered to be included in surveys, with the number of farms and survey area increasing over time. To account for this increase in survey effort and increased coverage of area, we restricted analysis to a subset of the farms and fields, retaining only those that were included in all survey periods. This yielded 41 farms (c. 6780 ha) for farm scale tests of change in wader density over time (objective 1). For field scale tests of habitat associations (objective 2) we further restricted our analysis to fields that were spatially consistent through time (e.g. fields were not split into smaller fields between survey periods) resulting in 20 farms ($n = 123$ fields; c. 845 ha). To test for woodland edge effects (objective 3), we used the most recent wader dataset (2015) only to match with the availability of woodland data (see below). Because of this, we were able to use all fields and farms surveyed in 2015 resulting in 33 farms and 341 fields (c. 4035 ha). No ethical approval was required for this study and permission for access for field data collection was granted by the land managers in support of the Strathspey wader surveys. No permits were required for fieldwork, but surveys were conducted under a disturbance licence in locations where species protected under Schedule 1 of the Wildlife & Countryside Act (1981) were known or likely to be present.

2.3 | Bird and environmental data

Lapwing, Curlew, Redshank and Snipe were counted on a field-by-field basis by trained volunteer surveyors using the methods recommended by O'Brien and Smith (1992). Three survey visits were made either 1–4 h after dawn or 3 h before dusk avoiding cold, wet or windy weather. Survey visits were at least 1 week apart with the first visit conducted between 18 and 30 April, the second visit between 1 and 21 May and the third visit between 22 and 19 June. Surveys were conducted on foot and surveyors walked field-by-field to within 100 m of all points in each field and scanned 200–400 m ahead with binoculars recording the number and behaviour of all waders. Surveyors scanned ahead from a vantage point for each field to reduce the risk of re-counting birds that had moved between fields from being re-counted. The route taken was reversed between visits. Birds recorded as juveniles, migratory or exhibiting no breeding behaviour were excluded from formal analysis as we were interested in breeding birds only. We also excluded groups of 10 or more individuals as these were deemed to be non-breeding or migrant birds (Franks et al., 2017). The maximum count across the three visits at the field scale was then used as the response variable in data analysis. For analyses at the farm scale, the maximum count was calculated by summing the maximum count of each field.

The habitat, topography, land use and woodland proximity data were collected at the field scale (Table 1). Data on habitat and land use were collected by the surveyors once per survey year, either during the first or second bird survey visit in April or May. Data on the location of woodlands was extracted from the Forestry Commission's National Forest Inventory (NFI). Woodland data from the NFI was not available for earlier years of our study, and therefore we restrict this analysis to 2015 only. The NFI dataset classifies woodland patches >0.5 ha into 'Interpreted Forest Types' (IFT) based on aerial images. In this analysis, we have combined the IFT Conifer and Broadleaved category with their respective IFT mixed category. The IFT mixed categories are defined as the dominant type (i.e. >50%). Most of the nearest woodlands to fields in our study were classified as conifer ($n=159$) or broadleaved ($n=135$) with only one mixed broadleaved and 12 mixed conifer woodlands. The distance to woodland variable was derived as the nearest linear distance from the field centroid location to woodland edge to capture the fields' location in space and control for non-uniform shapes of fields and woodlands (Figure S1). Slope and elevation data were extracted from the UK Ordnance Survey Digital Data. Field elevation was included to control for characteristics of the study area landscape, which may influence land management and habitat in the area. For example, lower elevations are closer to the floodplain and may consist of higher value farmed land than higher elevations which are more typical of less intensive farmed land and moorland.

Data on predator abundance was not available for this study. Predator control of Red Foxes *Vulpes vulpes* and Carrion Crow *Corvus corone* and mustelids is conducted variably across the valley by farmers and gamekeepers (pers comm., SWWI). However, the level of control is unquantified, and we were therefore not able to include information on predators and control in this study.

2.4 | Statistical analyses

Statistical analyses were conducted in R version 4.3.2 (R Core Team, 2023).

2.4.1 | Farm scale change in wader density over time (objective 1)

To test whether densities of the four wader species have changed between years a generalised linear mixed model (GLMM) was fitted using the lme4 package (Bates et al., 2015) with farm specified as a random intercept to account for repeat measures (Zuur et al., 2009). The response variable was the maximum count recorded at the farm across the three farm visits, offset by (Log_e) of farm area (ha) so it is expressed as density (birds ha^{-1}). Each wader species was fitted as a separate model specifying a log link and a negative binomial error structure to account for overdispersion in Poisson models. The Lapwing model showed zero-inflation and was fitted as a zero-inflated negative binomial model (ZINB) using the glmmTMB package (Brooks et al., 2017). Where spatial autocorrelation was detected in the model residuals, an exponential spatial covariance structure was fitted using glmmTMB. The predictor variable in these models was the categorical fixed effect of survey year (2000, 2005, 2010 and 2015).

2.4.2 | Field scale associations between wader density and environmental variables (objective 2)

To test for associations between wader density and environmental variables GLMMs were used to model the maximum count of each species in each field, offset by Log_e of field area (ha). As above, models were fitted with a negative binomial distribution to account for dispersion. A nested random effect (intercept term) of field identity nested within farm was fitted to account for the repeated measures sampling design and spatial clustering of fields within farms. Year was fitted as a categorical fixed effect (2000, 2005, 2010 and 2015). Habitat variables, topography and land use were included as fixed effects and were a mix of both categorical and continuous predictors (Table 1). Polynomial terms for the habitat variables of '% rush cover' and '% water cover' were also included to account for potential non-linear effects.

2.4.3 | Effects of woodland proximity (objective 3)

To test for edge effects of woodland on wader density in the 2015 data, the same model as for objective 2 was fitted but with a random effect of farm, to account for spatial clustering of fields within a farm. Woodland variables were then added, which comprised distance to woodland edge (including a quadratic term), type of woodland (broadleaf or conifer) and the interaction term; the latter to test whether the effect of woodland distance differed between predominantly conifer and broadleaved woodland. Because woodland edge contributed to the enclosure score (Table 1) of some fields ($n=134$) we 'de-coupled' the enclosure score for the woodland analysis only. To achieve this, when woodland edge contributed to the field boundary, the length of this feature was removed in the calculation of the enclosure score. In addition, fields which had single or small patches of trees *within* the field parcel were excluded from this analysis ($n=33$ fields).

To better understand whether woodland proximity might limit the impact of in-field management for waders, we calculated predicted estimates of density at 100 m bands (0–1 km) for each wader species from the final model (see below).

2.4.4 | Model selection, validation and post hoc tests

Explanatory variables were assessed for collinearity prior to modelling using pairwise correlations for covariates and chi-square tests of independence for categorical variables (Figure S2; Table S2). Covariates had acceptable pairwise correlations (≤0.70; Dormann et al., 2013), but several categorical and ordinal variables were not independent and there were model convergence issues, so an iterative multi-step approach to modelling was used (Pearce-Higgins & Grant, 2006). We first modelled univariate relationships between count and predictor variables retaining significant ($p < 0.05$) predictors for subsequent multivariate model fitting. We then fit the multivariate model, removing covariates with high variance inflation factors (VIFs ≥3), retaining the predictor that had the strongest relationship with the response variable based on the univariate models. The minimum adequate models (MAMs) were obtained using Wald Chi-Square tests and likelihood ratio tests (LRT) of nested models to evaluate the contribution of each variable to the model at each stage of a backwards stepwise model approach. A nominal 5% significance level was used as the criterion to include or reject terms, until the MAM was found in which all variables were significant at the 5% level (Murtaugh, 2009). Stepwise deletion for model selection has been shown to perform as well as other methods, particularly when the initial full model is based on existing knowledge of the species (Murtaugh, 2009) and was therefore deemed suitable for this study. The MAMs were checked for spatial autocorrelation (SAC) using x and y coordinates of the centroid of each field in a Moran's I test, temporal autocorrelation with a Durbin–Watson test, and for normality and homogeneity of model residuals using the DHARMa package (Hartig, 2020). When SAC was detected in model residuals the use of spatial correlation terms in the glmmTMB package was explored. The significance of categorical variables was tested using post hoc Tukey contrasts with effect sizes calculated using the emmeans package (Lenth, 2024). Estimates of wader density were calculated using the *ggpredict* function (ggeffects package; Lüdecke, 2018) with the covariates rush cover and water cover fixed at 30%, and enclosure at 0, to capture recommended management for waders (e.g. Scotland's FAS, Technical Note TN688, 2023). Continuous predictor variables were centred and scaled using the scale function to aid interpretation of regression coefficients in the model (Schielzeth, 2010). Theoretical conditional R^2 values were calculated for each model using the piecewiseSEM package (Lefcheck, 2015) and represent model fit (Nakagawa et al., 2017).

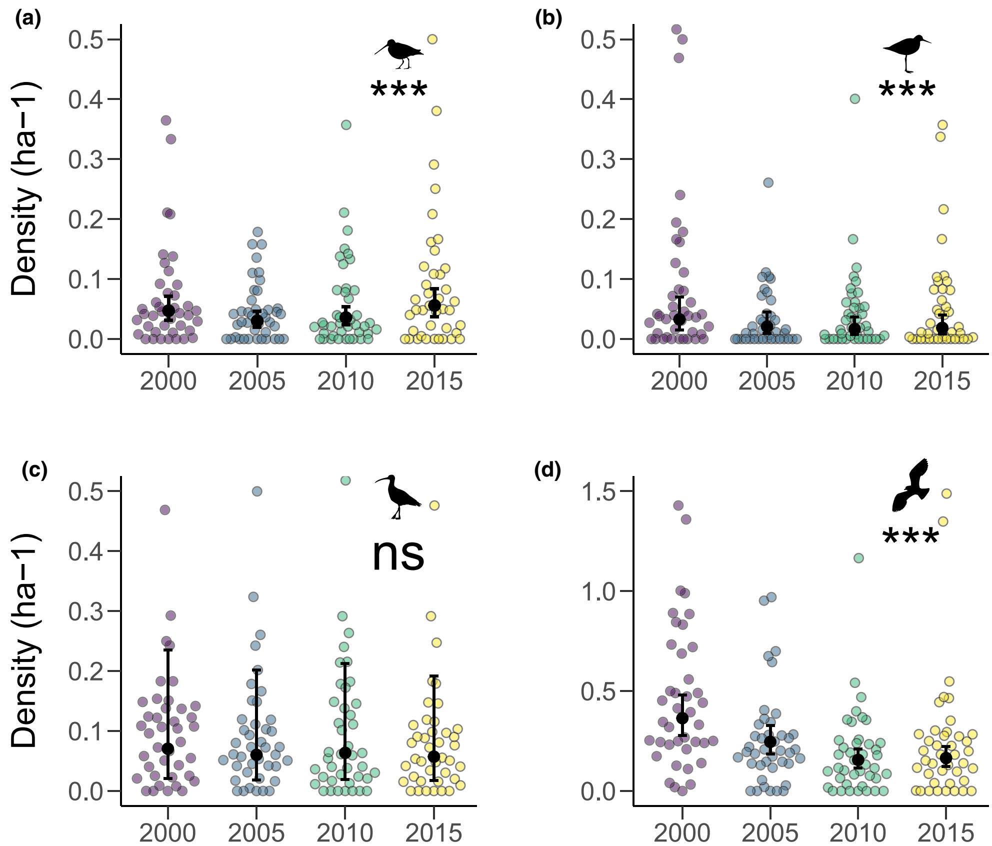

FIGURE 2 Predicted wader density ha^{-1} (black filled dot) with 95% CI (whiskers) by year at the farm scale (n=41 farms) with raw data displayed as filled circles (purple = 2000; blue = 2005; green = 2010; yellow = 2015). (a) Snipe; (b) Redshank; (c) Curlew; (d) Lapwing. Significance of the variable 'year' in the model is denoted by *'s: ***$p < 0.001$ and with ns referring to no significance ($p > 0.05$). Note that y-axes are on different scales.

3 | RESULTS

3.1 | Farm scale change in wader density over time

In 2000, the density of farmland waders was 0.07 Curlew ha^{-1}, 0.36 Lapwing ha^{-1}, 0.03 Redshank ha^{-1} and 0.05 Snipe ha^{-1}. By 2015, the density of Lapwings had more than halved (0.16 ha^{-1} by 2015) and declined by 44.4% for Redshank (0.02 ha^{-1} by 2015), with no significant change for Curlew (Table S3). The largest falls in density occurred in the first 5 years of monitoring, followed by stabilisation from 2005 (Redshank) or 2010 (Lapwing) and with a non-significant increase in Snipe density between 2010 and 2015 of 0.04 ha^{-1} to 0.06 ha^{-1} (Table S3; Figure 2).

3.2 | Field scale association between wader density and environmental variables

Modelled density of farmland waders at the field scale fell from 2000 to 2015 for Lapwing (0.59 ha^{-1} in 2000 to 0.23 ha^{-1} by 2015), Curlew (0.10 ha^{-1} in 2000 to 0.06 ha^{-1} by 2015) and Redshank (from 0.03 ha^{-1} in 2000 to 0.01 ha^{-1} by 2015), with no significant change for Snipe (0.02 ha^{-1}), all when holding other explanatory variables at their means (Table S4). For Lapwing and Redshank, the largest fall in density occurred in the first 5 years of monitoring, while for Curlew the largest change in density was between 2010 and 2015 (Figure S3).

There was a strong, inverse relationship between wader density and field enclosure score (Table 2). For Curlew and Snipe, enclosure score was the largest parameter estimate within their respective models. As the proportion of the boundary enclosed rose from 0% (an open field) to 5% (a twentieth of the field with a boundary of hedges, trees or other tall features), bird densities in 2015 declined by 10% for Redshank (0.0230 to 0.0207 ha^{-1}) and by >99% for Lapwing (0.2860 to 0.0016 ha^{-1}), Curlew (0.0787 to <0.0001 ha^{-1}) and Snipe (0.0237 to <0.0001 ha^{-1}). In addition, for Lapwing, densities were higher on flatter fields, and Redshank densities were higher on fields at lower elevation and hence on, or closer to, the floodplain.

The effects of environmental variables on wader densities varied between species. Curlew and Snipe densities were greater in fields with a higher proportion of rush, and Snipe and Redshank densities were higher in wetter fields (Table 2). There were no significant interaction effects of environmental variables with year, nor additive effects of vegetation height, livestock density and field use on wader density.

3.3 | Effects of woodland proximity

After controlling for other variables, wader density increased significantly with (log-transformed) distance from woodland for all four

TABLE 2 Minimum adequate models (MAMs) of wader density ha^{-1} at the field scale via negative binomial GLMMs.

		Wader species parameter estimates ± SE and test statistic			
Predictor	**Type (df)**	**Curlew**	**Lapwing**	**Redshank**	**Snipe**
Year	Factor (df = 3)	— (χ^2 = 9.12*)	— (χ^2 = 57.08***)	— (χ^2 = 9.65*)	—
Enclosure score	Covariate (df = 1)	−0.33 ± 0.09 (z = −3.66***)	−0.23 ± 0.09 (z = −2.56*)	−0.45 ± 0.18 (z = −2.58**)	−0.44 ± 0.19 (z = −2.31*)
Slope	Covariate (df = 1)	—	−0.35 ± 0.11 (z = −3.10**)	—	—
Elevation	Covariate (df = 1)	—	—	−1.18 ± 0.34 (z = −3.54***)	—
Rush	Covariate (df = 1)	0.24 ± 0.09 (z = 3.50***)	—	—	0.33 ± 0.10 (z = 3.32***)
Water	Covariate (df = 1)	—	—	0.53 ± 0.15 (z = 3.61**)	0.29 ± 0.08 (z = 3.57***)
I(Water^2)	Covariate (df = 1)	—	—	−0.05 ± 0.03 (z = −2.13*)	—
Random effects		σ^2 = 2.68 $\tau_{00Field:Farm}$ = 0.00 τ_{00Farm} = 0.57 $ICC_{(adjusted)}$ = 0.18 $N_{groups\ Field}$ = 123 $N_{groups\ Farm}$ = 20	σ^2 = 1.60 $\tau_{00Field:Farm}$ = 0.33 τ_{00Farm} = 0.26 $ICC_{(adjusted)}$ = 0.27 $N_{groups\ Field}$ = 123 $N_{groups\ Farm}$ = 20	σ^2 = 4.46 $\tau_{00Field:Farm}$ = 0.75 τ_{00Farm} = 1.31 $ICC_{(adjusted)}$ = 0.32 $N_{groups\ Field}$ = 123 $N_{groups\ Farm}$ = 20	σ^2 = 4.39 $\tau_{00Field:Farm}$ = 1.40 τ_{00Farm} = 0.73 $ICC_{(adjusted)}$ = 0.33 $N_{groups\ Field}$ = 123 $N_{groups\ Farm}$ = 20
Goodness of fit (R^2)		AIC = 990.0 R^2_m = 0.068 R^2_c = 0.241	AIC = 1875.0 R^2_m = 0.1357 R^2_c = 0.343	AIC = 785.7 R^2_m = 0.155 R^2_c = 0.320	AIC = 587.2 R^2_m = 0.070 R^2_c = 0.374

Note: Sample size = 492 observations (n = 123 fields per year from 20 farms) with significant levels indicated by *'s where: ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$. Note that covariates were scaled and centred prior to analysis for ease of coefficient interpretation.

species, with no clear thresholds (Figure 4; Table 3). When predictions of wader density were modelled at 100 m bands of increasing distance from woodland edge, increases in wader density were predicted with every 100 m increase (Table S6). Almost no waders occur on fields whose centre is less than 100 m from woodland edge, and there are then >20% increases in density with each distance band up to 400 m for Redshank, 300 m for Snipe, 500 m for Lapwing and 200 m for Curlew, and further c. 10% increases per distance band predicted up to distances of 500 m for Curlew, 700 m for Snipe and 900 m for Redshank and Lapwing.

Differences in some field scale associations with other explanatory variables (Table 3 compared with Table 2) arise from the much-reduced subset of data used in this analysis (2015 only), rather than from the introduction of the woodland variables (see Table S5). The main exception is that the strong effect of the field enclosure score disappears for Lapwing, Redshank and Snipe and is weakened for Curlew. This confirms that the main impact of field enclosure arises from woodlands forming field boundaries.

Lastly, there was no significant interaction effect of distance to nearest woodland edge and woodland type on wader density for any species, indicating that the effect of distance to woodland edge on wader density is similar for both conifer and broadleaved woodland.

4 | DISCUSSION

4.1 | Changing wader densities

All four wader species declined across the study area between 2000 and 2015, despite it being one of the UK's largest mainland assemblages of breeding waders and a focus of conservation effort. These results are broadly consistent with long-term trends of breeding waders on farmland in other UK upland areas considered to hold an important assemblage of waders (e.g. Bell & Calladine, 2017), as well as in the wider landscape of the UK and more generally within Scotland over the same period (Harris et al., 2017). In this study, the largest declines occurred in the first 5 years of monitoring, followed by stabilisation of densities of Redshank from 2005 onwards and Lapwing after 2010 and a 50% increase in densities of Snipe following 2005. Curlew populations have been maintained despite severe decline in the wider countryside (Brown et al., 2015). Data at the farm (and field) level were not available to explicitly test for an effect of AES or SWWI advice on wader density. However, other studies throughout the UK have identified positive responses of waders to targeted management advice in addition to AES management (Hunt et al., 2023; O'Brien & Wilson, 2011; Smart et al., 2013). SWWI was initiated in 2008, and

TABLE 3 Minimum Adequate Models (MAMs) of wader density ha^{-1} at the field scale exploring woodland variables modelled via negative binomial GLMMs.

		Wader species parameter estimates ± SE and test statistic			
Predictor	**Type (df)**	**Curlew**	**Lapwing**	**Redshank**	**Snipe**
Log_{10}(distance to woodland)	Covariate (df = 1)	0.36 ± 0.12 (z = 2.95**)	0.73 ± 0.13 (z = 5.40***)	0.63 ± 0.20 (z = 3.21**)	0.47 ± 0.16 (z = 2.98**)
Enclosure score	Covariate (df = 1)	−0.33 ± 0.14 (z = −2.35*)	—	—	—
Rush	Covariate (df = 1)	—	—	−0.01 ± 0.24 (z = −0.05)	0.72 ± 0.13 (z = 5.78***)
I(Rush^2)	Covariate (df = 1)	—	—	−0.48 ± 0.19 (z = −2.51*)	—
Water	Covariate (df = 1)	—	—	0.16 ± 0.16 (z = 1.01)	—
I(Water^2)	Covariate (df = 1)	—	—	−0.39 ± 0.16 (z = −2.49*)	—
Vegetation height	Factor (df = 4)	—	— (χ^2 = 14.90**)	—	—
Livestock	Factor (df = 4)	— (χ^2 = 15.86**)	—	—	—
Random effects		σ^2 = 3.13 τ_{00Site} = 0.46 N_{groups} = 33 $ICC_{(adjusted)}$ = 0.13	σ^2 = 2.30 τ_{00Site} = 1.43 N_{groups} = 33 $ICC_{(adjusted)}$ = 0.38	σ^2 = 4.03 τ_{00Site} = 2.97 N_{groups} = 33 $ICC_{(adjusted)}$ = 0.42	σ^2 = 3.33 τ_{00Site} = 1.22 N_{groups} = 33 $ICC_{(adjusted)}$ = 0.27
Model goodness of fit		AIC = 578.4 R^2_m = 0.109 R^2_c = 0.227	AIC = 1107.6 R^2_m = 0.120 R^2_c = 0.380	AIC = 465.5 R^2_m = 0.075 R^2_c = 0.332	AIC = 499.3 R^2_m = 0.149 R^2_c = 0.392

Note: Sample size = 341 observation from year 2015 (n = 33 farms) with significant levels indicated by *'s where: ***p < 0.001; **p < 0.01; *p < 0.05. Note that covariates were scaled and centred prior to analysis for ease of coefficient interpretation.

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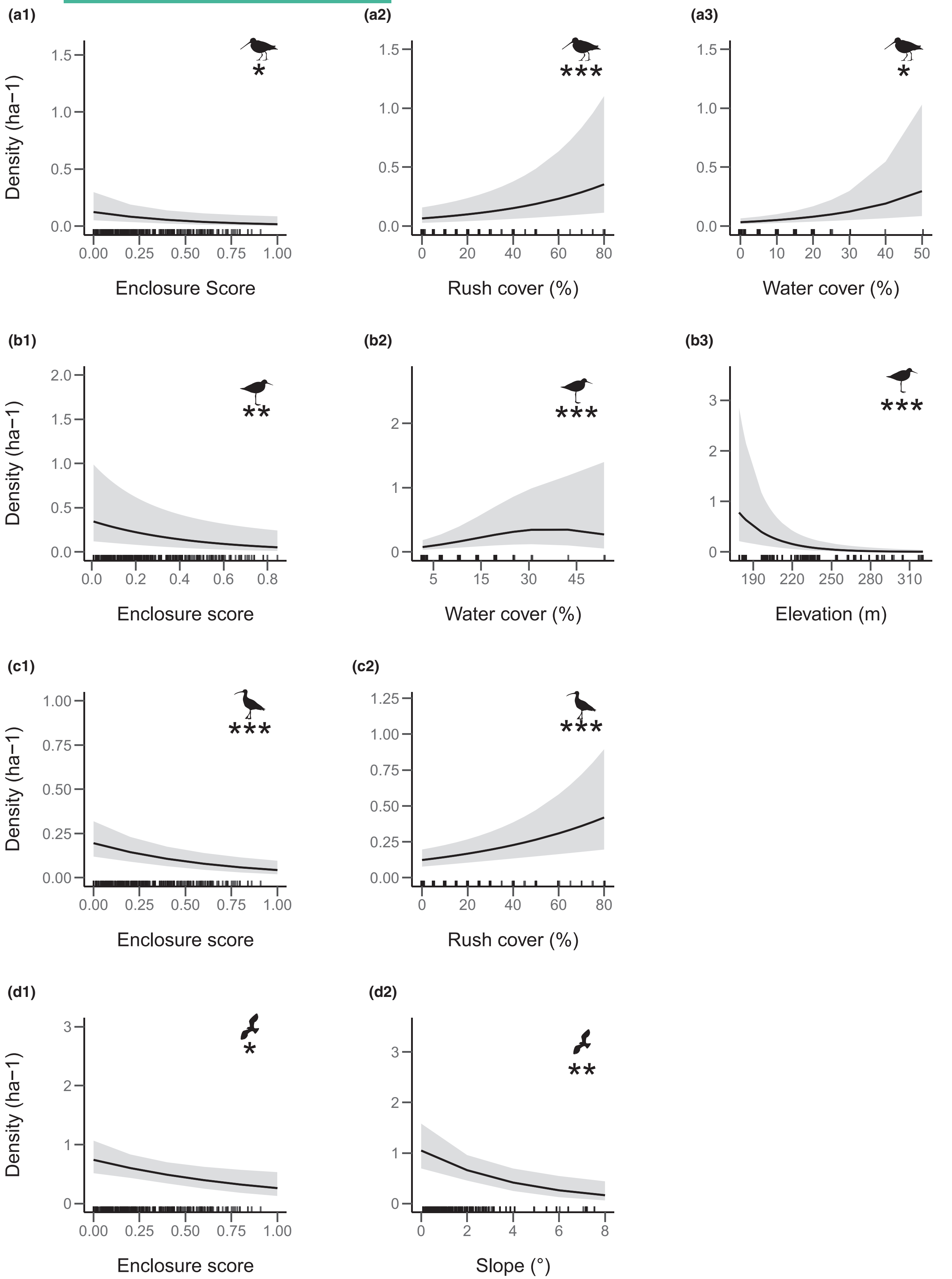

FIGURE 3 Predicted wader density ha^{-1} shown in solid black line with shaded 95% CI at the field scale as a function of significant habitat variables (when holding non-focal variables constant at 30% rush cover, 30% water cover and 0.0 enclosure score to capture recommended management for waders and the reference level 2000 used for Year). (a) Snipe; (b) Redshank; (c) Curlew; and (d) Lapwing. Distribution of the raw data covariates shown as rugs. The *y*-axis in all plots is wader density per ha. Significance of variable denoted by *'s: ***$p<0.001$; **$p<0.01$; *$p<0.05$. Note that *y*-axes are on different scales.

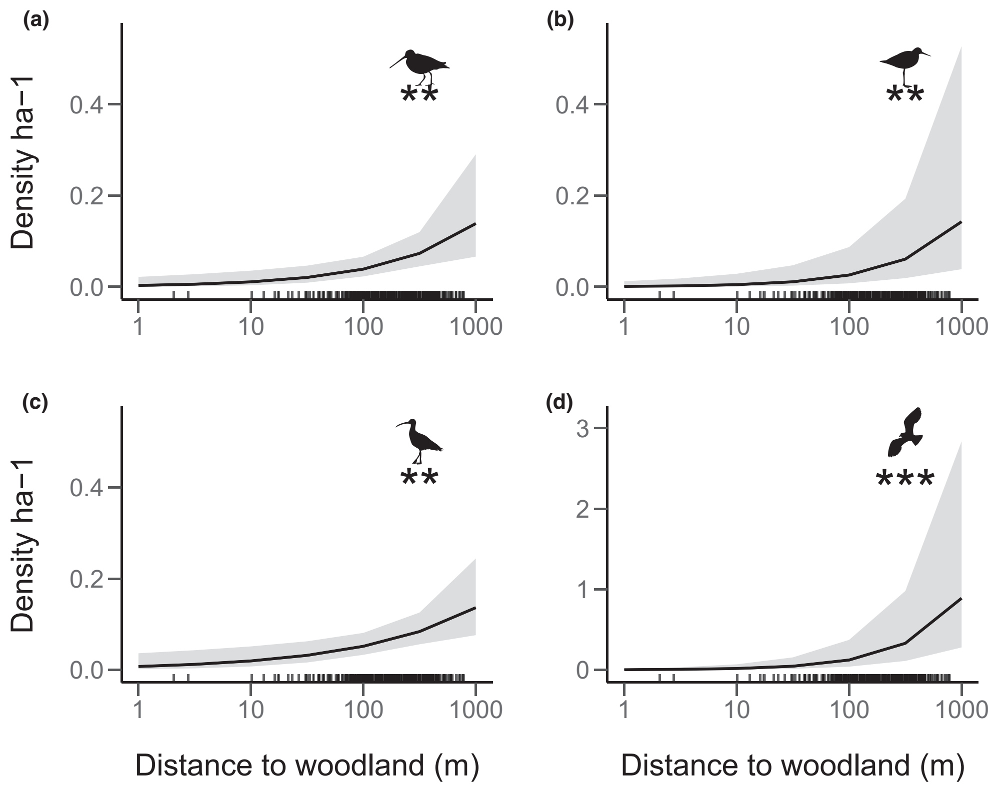

FIGURE 4 Predicted wader density ha^{-1} for year 2015 shown in solid black line with shaded 95% CI at the field scale as a function of distance to woodland (holding non-focal variables constant at 30% rush cover, 30% water cover and 0.0 enclosure score to capture recommended management for waders. The reference level 'Bare' and 'None' were used for Vegetation height and Livestock, respectively) for (a) Snipe; (b) Redshank; (c) Curlew; and (d) Lapwing. Distribution of the raw data covariate shown as rugs. Significance of variable denoted by *'s: ***$p<0.001$; **$p<0.01$. Please note difference in y-axis scale between plots.

this advice may have strengthened the impact of wader management in the area helping to stabilise declines but not reverse them.

4.2 | AES habitat management and targeting

In this study, species response to rush and water varied: Curlew and Snipe densities were greater in fields with a higher proportion of rush (although benefits of rush cover over 40% are limited), with Redshank and Snipe densities higher in wetter fields after controlling for other habitat variables. There was no association between Lapwing density and either rush or water. This suggests that the farmed landscape in the study area is, on average, in favourable condition for Lapwing in terms of having the desired low rush cover and presence of some wet features as shown in other studies for this species (Eglington et al., 2010). High rush cover creates a tall, dense sward that can limit wader foraging opportunities and reduce the availability of nesting sites, especially for species that prefer to nest in more open fields. The optimal rush cover varies by wader species, with the management advice suggesting broadly 20%–30% rush cover to benefit a range of species or a lower rush cover of <10% if targeting Lapwing (Scotland's FAS, Technical Note TN688, 2023). This aligns with our results and suggests that for wader species which benefit from higher levels of rush such as Curlew and Snipe our study area would benefit from greater coverage of rush (Figure S4). Longer-billed species such as Redshank and Snipe also benefit from wetter conditions which provide softer, wetter soil for probing for earthworms and tipulid larvae (Hoodless et al., 2007; Smart et al., 2006). There was also some evidence that field slope and elevation influenced density of some species, suggesting that AES prescriptions may be more successful on flatter fields for Lapwing and at lower elevations for Redshank, closer to the floodplain. Floodplain areas adjacent to the river Spey are likely to be wetter due to periodic flooding, and therefore, management, here, may be better targeted at Curlew, Redshank and Snipe, which prefer higher levels of standing water and can occupy areas with higher rush cover.

Given known edge effects of woodland or other tall features (e.g. Douglas et al., 2014; Kaasiku et al., 2022; Pálsdóttir et al., 2022; Wallander et al., 2006; Wilson et al., 2014), selection of fields for wader AES is targeted at larger, open fields and in Scotland, good practice guidance of greater than 30 m from woodland is recommended (in England a distance is not specified but it is recommended that AES should not be implemented adjacent to woodland). Accordingly, we found strong negative effects of enclosure score or distance to woodland (woodland being the main form of enclosure) on all four wader species, which operated continuously over several hundred metres. Most fields in our study (97%) were at least 30 m from woodland, but only 47% were >200 m from woodland and only 15% >400 m. This highlights that most fields are within just a few hundreds of metres of woodland in this landscape. The results of this study suggest that AES management and other conservation interventions are unlikely to have any beneficial effect on fields within 100 m of woodland edges, whether coniferous or broadleaved. In addition, beneficial effects will remain compromised over much greater distances, with model outputs predicting increases of c. 10% in wader density for each additional 100 m of distance from woodland edge out to 500 m for Curlew and 700–900 m for Lapwing, Snipe and Redshank. This evidence supports recent guidance on woodland creation within England, which recommends a 500 m–1 km buffer from high density wader areas when determining upland woodland suitability (DEFRA, 2024). In addition, it is likely that studies examining associations between wader distribution and agricultural management (including ours in Table 2 and Figure 3) will be rendered statistically noisier by effects of woodland in the landscape if these are not accounted for.

4.3 | Policy implications

Woodland proximity may be suppressing the effectiveness of wader-targeted AES measures, and this phenomenon may be further exacerbated by increased tree cover (e.g. through planting) if areas are not carefully targeted. We recommend that buffers of at least 500 m from suitable wader habitat should be implemented for new tree planting locations on farmland, with additional benefits to waders over greater distances. For greatest benefits, fields selected for wader AES management should be in open fields further away from woodland than the current recommendations suggest and that delivery of rush management should consider the wader species being targeted to promote a diverse landscape suitable for a range of wader species.

AUTHOR CONTRIBUTIONS

Emma J. Sheard: Conceptualisation; methodology; formal analysis; visualisation; writing—original draft; writing—review and editing. Kirsty J. Park: Funding acquisition; conceptualisation; methodology; writing—original draft; writing—review and editing; supervision. Des B. A. Thompson: Writing—review and editing; supervision. Jeremy D. Wilson: Funding acquisition, conceptualisation; methodology; writing—original draft; writing—review and editing; supervision.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

Data is available at DataSTORRE: Stirling Online Repository for Research Data, http://hdl.handle.net/11667/264 (Park, 2025).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1. Cartoon graphic of plausible fields (open polygons) and woodland parcels (green filled polygons). The field centroid location is shown as an open circle. Solid red lines represent the distance from a fields' centroid to its nearest woodland, while solid blue lines represent the distance from a fields' edge to its nearest woodland. We believe that both are valid measures to calculate distance but felt that in our landscape the centroid location was more appropriate to capture the unusual shapes of fields/woodlands and the location in space from the context of a bird using a field.

Figure S2. Correlogram showing the Pearson's correlations (r) between numerical explanatory variables. LEFT: objective 2 of the field level data ($n = 492$ fields). RIGHT: objective 3 of the field level data including woodland variables. No correlations had $r > 0.7$ for variables that were used in formal analysis.

Figure S3. Objective 2: Predicted wader density ha^{-1} shown in solid black circle with 95% CI as whiskers at the field scale as a function of significant habitat variables (holding non-focal variables constant at 30% rush cover, 30% water cover and 0.0 enclosure score to capture recommended management for waders). (A) Redshank; (B) Curlew; and (C) Lapwing. Significance of variable denoted by *'s: ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$. Note that y-axes are on different scales.

Figure S4. Density distribution of rush cover of the fields used in analysis (objectives 2 and 3).

Table S1. Brief history of agri-environment schemes targeted for the benefit of farmland waders within Scotland. Information summarised and compiled from legislation.gov.uk and gov.scot. *An extension to AECSs has been temporarily applied in Scotland to cover time-lag between release of future scheme following the current reform.

Table S2. Chi-square test of independence for all pairwise comparisons of the categorical variables along with their observed frequency in analysis for (A) objective 2; and (B) objective 3. Note that the Chi-square test results can be unreliable when values of <5 are in the contingency table (particularly when zeros are present which we have here).

Table S3. Estimated marginal means and contrasts for objective 1. Significant *p* values highlighted in bold.

Table S4. Estimated marginal means and contrasts for objective 2. Significant *p* values highlighted in bold.

Table S5. Model summary data for objective 3 MAMs without woodland variables. Sample size = 341 observation from year 2015 ($n = 33$ farms) with significant levels indicated by *'s where: ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$. Note that covariates were scaled and centred prior to analysis for ease of coefficient interpretation.

Table S6. Model predicted estimates of wader density (95% CI) at 100 m distance bands to woodland for year 2015 (when holding non-focal variables constant at 30% rush cover, 30% water cover and 0.0 enclosure score to capture recommended management for waders. The reference levels were used for categorical variables: Vegetation height fixed at Bare and Livestock fixed at None). Increase is the increase in wader density (and percentage increase in brackets) at each consecutive 100 m distance band from woodland.

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