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Fodder crop management benefits Northern Lapwing (*Vanellus vanellus*) outside agri-environment schemes

Running title: Conservation benefits of fodder crop management

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Abstract

To date, agri-environment schemes (AES) have had limited success in reversing biodiversity loss over greater spatial extents than fields and farms, and vary widely in their cost-effectiveness. Here, over nine years, we make use of the management initiative of a farmer in an upland livestock farming landscape in Scotland, undertaken wholly outside AES, to examine its effect on breeding densities of Northern Lapwing *Vanellus vanellus*. Management designed by the farmer involved planting a *Brassica* fodder crop for two consecutive years followed by reseeding with grass, with eight out of 17 fields at the farm undergoing this management since 1997. After controlling for other habitat parameters of importance, the density of breeding Lapwings was 52% higher in fields that had undergone fodder crop management than those that had not. Densities were highest in the first year after the fodder crop was planted, prior to reseeding with grass, but remained above levels in control fields for approximately seven years after the fodder crop was last planted. Very high Lapwing densities (modelled density = 1 pair ha^{-1}) in the year after the fodder crop was planted likely result from the heterogeneous ground surface created by grazing of the crop providing an "attractive" nesting habitat. Continued high densities following reseeding with grass may partly be accounted for by philopatry, but the fact that they are field-specific also suggests that these fields continue to offer enhanced foraging conditions for several years. Fodder crop management was implemented at the study

site to fatten lambs over winter and ultimately improve grass condition for grazing. This system is therefore based on active farming and benefits both the farmer and breeding Lapwings. As such, it may be possible to implement it more widely without the need for high agri-environment payments. More generally, it is an example of the land owner being actively involved in developing conservation solutions in partnership with environmental research, rather than being seen as a passive recipient of knowledge as has typically been the case with the design of AES. Such approaches need to be adopted more consistently in designing interventions for environmental outcomes on farmland, but may be of particular importance in the UK if the certainties of European Union AES are to come to an end.

1. Introduction

Agriculture is the principal land use across Europe and accounts for over 40% of the European Union (EU) land area (European Commission, 2017). The EU's Common Agricultural Policy (CAP) has been instrumental in directing public subsidy to production and thus driving agricultural intensification, with attendant widespread wildlife losses that have been particularly well documented for birds (Donald et al., 2006). Recognising the negative impacts of agricultural intensification on biodiversity, 'greening' of the CAP since the early 1990s has included agri-environment scheme (AES) funding designed to encourage the adoption of environmentally friendly management practices by compensating for lost income. To date, the success of AES in halting biodiversity loss has been mixed and more associated with the scale of implementation (farms) than the scale of policy ambition (national biodiversity loss) (Kleijn et al., 2011; Whittingham, 2011). Problems include implementation at too small a spatial scale (O'Brien and Wilson, 2011; Broyer et al., 2014), lack of appropriate measures for certain species, taxa or farming systems (Redpath et al., 2010; Fuentes-Montemayor et al., 2011) or conversely a large range of prescriptions that vary in their effectiveness or fail to deliver all a species' requirements (Smart et al., 2013). However, when schemes are targeted effectively, are adaptable, and farmers are given site specific advice, they can provide the desired conservation benefits, at least locally or for species whose populations have been reduced to very small size and geographical range (Wilson et al., 2010; Schmidt et al., 2017).

Farmland breeding shorebirds (waders) have suffered large population declines as a result of agricultural change (Wilson et al., 2009) and are a good example of the problems in ensuring AES success described above. In the Netherlands and the UK, two of the most important countries in Europe for this bird assemblage (Birdlife International, 2004), there is good evidence of localised demographic or population benefit but little translation of these local successes to reversal of national population declines (Kleijn and Zuijlen, 2004; Verhulst et al., 2007; O'Brien and Wilson, 2011; Smart et al., 2014).

The need to deliver cost-effective conservation benefits for shorebirds on farmland is now urgent, and alternatives to AES which provide both conservation and economic benefits and could be promoted without the need for compensatory payments should be explored (e.g. Osgathorpe et al., 2011), especially given the planned exit of the UK from the EU and potential accompanying loss of CAP payments for agri-environment measures. Here, we evaluate an unusual and innovative fodder crop management system implemented on an upland grassland farm in Scotland that is associated with nationally exceptional breeding densities of waders, particularly Northern Lapwing *Vanellus vanellus,* (McCallum, 2012), but which is implemented primarily for husbandry and commercial reasons, and not for conservation purposes. The management system involves planting the forage brassica ‘tyfon’ (*Brassica campestris* x *B.rapa*) for two consecutive years in a field that was previously pasture, prior to reseeding the field with grass (see Table 1 for timeline). This process improves grass productivity after reseeding (EBLEX, 2008), as well as providing fodder (stubble turnips) for fattening of lambs over the winter (Koch et al., 1987). The ground is limed during fodder crop management in order that the optimum soil pH for fodder crops and grass growth is obtained prior to reseeding.

In this study we examine the utility of this management in supporting high densities of breeding Lapwings. Specifically, we test i) whether fields with a prior history of fodder crop management have higher Lapwing densities and ii) whether the density of breeding Lapwings is related to the number of years since fodder crop management. We also test whether vegetation height or percentage bare ground varies between grass fields that had previously undergone fodder crop management and those that had not.

2. Methods

2.1 Study Site and fodder crop management

The study took place in 2003 and from 2006 to 2011 on 315 ha of commercially farmed grassland (56º 4’40.06”N 4º 0’45.00”’W) in Scotland, at 140 – 320 m altitude. The farmland supports approximately 1200 black-faced sheep and 50 limousin cross cattle and comprises 120 ha of “in-bye” land (140 – 270 m altitude) and 195 ha of “out-bye” (175 – 320 m altitude). “In-bye” is the local term for agriculturally improved, enclosed fields below the moorland wall, and “out-bye” is the land beyond the moorland wall where vegetation is semi-natural in character (Gray, 2000) grading from acid grassland to moorland dominated by ling heather *Calluna vulgaris*.

Unusually for Scottish farmland, fodder crop management has been used in the study area to keep sheep on in-bye fields over winter. This management has been in place since 1997, and by 2011 eight fields had been placed in this management regime (Figure 1), whereas the remaining nine had been subject to no cultivation or reseeding. Data collected on these 17 fields, making up the 120 ha of in-bye land, support the analyses presented here. Fodder crop management involves planting of tyfon in late June or early July for two consecutive years, after which the field is reseeded with grass (perennial rye-grass *Lolium perenne* and white clover *Trifolium repens* seed mix) in June or July of the third year (Table 1). All fields that have undergone tyfon cultivation have then remained as grass since reseeding.

Prior to sowing tyfon, soil pH was tested by the farmer. Lime (5 tonnes ha^{-1} $annum^{-1}$) was applied for up to three consecutive years with the first application at the time that tyfon was first planted with the objective of raising soil pH to 5.8 to coincide with grass reseeding. The range of soil pH in the in-bye fields that had not undergone fodder crop management was between 4.7 and 5.5 and it is likely that pH prior to fodder crop management fell within this range across all in-bye fields. Fertiliser (NPK, 2:1:1, 250 kg ha^{-1}) was applied at the same time as tyfon or grass was planted. Fields that had not been subject to tyfon cultivation received this fertiliser less frequently, and were limed no more frequently than once every five years.

Lapwings arrive to nest from the beginning of March and leave at the end of June or early July. Planting of tyfon or reseeding with grass thus occurs at the end of the breeding season so that Lapwing use is only potentially affected in the year after management has occurred (Table 1).

2.2 Lapwing and habitat surveys

To test whether field use of breeding Lapwings was related to fodder crop management, the number of breeding Lapwing pairs in each in-bye field was counted in 2003 and from 2006 to 2011. In each year either one (2003 and 2006-2007) or two (2008-2011) survey visits were made. Where only one survey visit was made, this was between 1st and 21st May. When an additional visit was made, this was between 18th and 30th April with at least 18 days between surveys. Surveys were carried out on foot, walking to within 100 m of all points of each field and scanning ahead (up to

400 m) with binoculars from appropriate vantage points to record all Lapwings (O'Brien and Smith, 1992). Annual totals of Lapwing pairs were calculated for each field by halving the number of individuals recorded (Barrett and Barrett, 1984). Flocks of birds not exhibiting signs of breeding behaviour were excluded. Lapwings were counted on at least 12 in-bye fields in all years of the study, with all 17 fields counted in four years. Table 2 shows the number of fields in each treatment where Lapwings were counted in different years.

Data on field characteristics likely to influence the suitability of a field for breeding Lapwings were measured using ArcGIS 9.2 (ESRI, 2006), or in the field. The length of streams and ditches and field boundaries were obtained from the OS Mastermap Topography Layer (EDINA Digimap Ordnance Survey Service). These data were used to calculate the density of streams and ditches per hectare by dividing the total length of these within each field by field area. This provides a measure of field wetness, as breeding Lapwings are reliant on wet habitats (Rhymer et al., 2010; Schmidt et al., 2017). Both field slope and enclosed boundaries affect field suitability for Lapwings which require an open view to allow early detection of predators (Elliot, 1985; Milsom et al., 2000). Field slope (degrees) was extracted from the OS digital terrain map (EDINA Digimap Ordnance Survey Service), using the Spatial Analyst toolbox to first convert the data to raster and then using zonal statistics to extract slope for each field. The proportion of the field perimeter with enclosed boundaries (either trees or buildings) was calculated by measuring the length of perimeter made up of trees or buildings and dividing this by total field perimeter. The remaining field boundaries were either stone walls (farm boundary or boundary between in-bye and out-bye fields) or rylock fences (boundaries between in-bye fields).

Vegetation height and percentage bare ground were measured in one field that had been planted with fodder crop in the previous year and had not yet been reseeded with grass (in March and June 2009), grass fields with a prior history of fodder crop management (n = 5 in March 2009 and 4 in June 2009) and grass fields with no prior history of fodder crop management (n = 4 in March 2009 and 6 in June 2009). Bare ground was estimated by eye within a 1 m^2 quadrat at 9 or 10 random locations within each field. Vegetation height was measured with a ruler at 5 locations within the quadrat (one central location and at the four corners).

2.3 Data analysis

Two generalised linear mixed effects models (GLMMs) were implemented to test the relationship between Lapwing field use and field management history. The first tested whether fields which had undergone fodder crop management had higher densities of Lapwings than those that had not, whilst controlling for the characteristics of a field likely to influence its suitability for use by breeding Lapwings. Once a field had been planted with tyfon, it was included in the “fodder crop” treatment group for all Lapwing surveys after the date this occurred. Lapwing count per field within a single year was the response variable and field identity was specified as a random (grouping) factor. The key explanatory variable was whether or not a field had undergone fodder crop management prior to the Lapwing survey (fixed factor, yes or no), with length of streams and ditches (divided by field area), slope and the proportion of the field boundary that was enclosed included as covariates. Non-significant habitat covariates ($p > 0.05$) were sequentially removed from the model in a step-wise fashion. The model was fitted using log link and Poisson error and $\log_e$ (field area) as an offset. Only the count from the survey visit made between 1st – 21st May was used, as this survey visit was available for all fields in all years. An additional model using all available survey data gave comparable results.

The second model focused only on treated fields and tested whether Lapwing density was related to the length of time (years) since a field had last undergone fodder crop management. Any field sown with tyfon in the summer before Lapwing counts was assigned a value of ‘year =1’ (whether in the first or second year of the two-year tyfon regime). In the year following reseeding, this value was incremented to ‘2’, and was incremented by one, annually thereafter, up to a maximum of 13 years since a field had last been planted with fodder crop. The model was implemented as the first model (including the same habitat covariates within the starting model), but whether or not a field had undergone fodder crop management was replaced, as the response variable, with the number of years since tyfon was last planted.

Two further GLMMs were used to test whether the percentage of bare ground or vegetation height varied between grass fields with or without a history of fodder crop management. In the first model, percentage bare ground was the response variable, and whether or not the field had previously been planted with tyfon the key explanatory variable; the model was fitted with logit link using binomial errors. Visit (March or June) was included as an additional fixed factor with sample location nested within field included as a random factor. In the second model vegetation height was the response variable and was modelled using Gaussian error structure; sample location nested within field, and field, were fitted as random factors.

GLMMs were implemented using the MASS package (Venables and Ripley, 2002) in R version 3.4.0 (R Development Core Team, 2017). The effect size of categorical variables was calculated using the lseans package (Lenth, 2016). Models were checked for overdispersion by comparing the residual deviance with the residual degrees of freedom. Pseudo r^2 (from now on referred to as r^2) was calculated by correlating the predicted values with the observed data and squaring this (Zuur et al., 2009).

3. Results

3.1 Lapwing density and fodder crop management

In total, 250 territorial Lapwing pairs were recorded over 17 in-bye fields and seven years using data from the survey visit carried out between 1st and 21st May, giving a mean annual density over the whole study area of 0.34 (95% confidence interval: 0.22 – 0.46) pairs ha^{-1}. The highest count was obtained in 2006, when 54 pairs were recorded on 12 fields, equating to a site density of 0.58 pairs ha^{-1}. The modelled, field-by-field density of breeding Lapwings on fields with a prior history of fodder crop management was 52% higher than fields without a prior history of fodder crop management; 0.32 (95% confidence interval: 0.23 – 0.45) pairs ha^{-1} vs. 0.21 (95% confidence interval: 0.16 – 0.28) pairs ha^{-1}, having controlled for an inverse association between Lapwing density and field enclosure (Table 3). The density of wet features was only significant at the 10% level ($p = 0.09$) and was therefore removed from the model. The r^2 for this model was 0.30.

In fields which were planted with tyfon (n = 8), we recorded 129 pairs of Lapwings over the seven years of the study. The density of Lapwing pairs was highest the year after the fodder crop was last planted with modelled density = 1 pair ha^{-1} and declined at a rate of 16.5% per annum thereafter (i.e. once the field had been returned to grass, Table 4, Figure 2). Densities fell to approximately the same as control fields around seven years after the fodder crop was last planted. As with the previous model, there was an additive effect of field enclosure with lower Lapwing densities in more enclosed fields. The density of wet features was not a significant predictor of Lapwing density. This model explained 38% of variation in the Lapwing counts.

3.2 Vegetation structure and fodder crop management

The percentage of bare ground was highest in the field that had been planted with the fodder crop in the previous year and had not yet been reseeded with grass, however due to the lack of replication these data were not analysed further (Figure A.1, Appendix A). However, there was no difference in the percentage of bare ground ($t_{9,93}$ = -1.2, p = 0.26) or vegetation height ($t_{9,102}$ = 1.3, p = 0.23) in grass fields with a prior history of fodder crop management and those without.

4. Discussion

Mean Lapwing density across the seven years of our study was double the density that O'Brien and Bainbridge (2002) identified as constituting a key site for breeding Lapwing on Scottish farmland (16.8 pairs km^{-2}). In-bye fields that had previously been planted with the fodder crop supported 52% more breeding Lapwing pairs than control fields, whilst controlling for other habitat parameters that influence field suitability for breeding Lapwings. Lapwing densities were highest the first year after the fodder crop was last planted, once the crop had been grazed but prior to the field being returned to grass. A possible mechanism for the positive effect of fodder crop establishment and subsequent grazing by sheep on breeding Lapwing is its creation of a highly heterogeneous ground surface, with a high percentage of bare ground (Figure A.2, Appendix; McCallum 2012), which disguises eggs, and provides clearer views to adults of approaching predators than more heavily vegetated substrate (Klomp, 1954; Berg et al., 2002). Fodder crop management provides an alternative mechanism to spring tillage for creating the mosaic of grassland and bare ground that is favoured by breeding Lapwings because it provides good chick rearing habitat (grassland) and good nesting habitat (bare or sparsely vegetated ground) close to each other (Shrubb, 2007). Mixed farming systems have largely been replaced in marginal farmland areas such as our study area by livestock farms (Wilson et al., 2009). Indeed, our study overlapped in timing with a substantial decline in breeding Lapwing pairs close to our study site (approximately 20 km away), where the loss of spring cropping contributed to a very high (88%) decline in breeding Lapwing pairs in 25 years (Bell and Calladine, 2017).

The density of breeding pairs of Lapwing at the study site declined steeply once the fodder crop field was reseeded with grass, but for at least five years it remained higher than fields with no prior history of fodder crop management, despite similar vegetation structure between treated and un-treated fields. Lapwings exhibit high site fidelity (Thompson et al., 1994). Consequently, the declining density of breeding Lapwings with increasing time since a field was last planted with tyfon could result from initial attraction of birds into the field when the nesting structure is good (i.e. when the fodder crop has been grazed over winter), followed by high local recruitment of philopatric birds. Whilst this study cannot exclude this possibility, it is notable that the fodder crop management system in place on this study farm generated big differences in Lapwing density between individual fields on the same farm, which suggests that field-specific management is also a cause. The likely mechanism is that liming, an integral component of fodder crop management, has a prolonged benefit for breeding Lapwings because it increases soil pH relative to non-limed fields for several years, thus increasing suitability of these fields for earthworms and thus for foraging Lapwings (McCallum et al., 2016).

At first sight our results contrast with previous research which suggested that declines in breeding Lapwing density on in-bye pasture resulted from agricultural improvements such as reseeding and use of inorganic fertiliser (Baines, 1988; Taylor and Grant, 2004), both of which are part of fodder crop management in the current study. In northern England, densities of breeding Lapwing were considerably lower on improved in-bye pasture in comparison to unimproved in-bye pasture (0.14 vs 0.54 pairs ha^{-1}; Baines, 1988); our study found Lapwing density over seven times higher than that found by Baines (1988) on improved grassland in the first year after reseeding. The likely explanation for this apparent anomaly lies in the multivariate nature of agricultural intensification. For example, reducing soil acidity may be beneficial to soil invertebrates and predators such as Lapwings. However, if this is associated with other aspects of agricultural intensification such as drainage and high livestock densities then the costs to these species may exceed the benefits (Beintema and Muskens, 1987; Wilson et al., 2009; Sabatier et al., 2015).

As well as Lapwings, Common Redshank (*Tringa totanus*), Eurasian Curlew (*Numenius arquata*) and Snipe (*Gallinago gallinago*) all bred in our study area and whilst the seven-year mean density on the in-bye for these species did not reach the minimum densities required for key sites in Scottish farmland based on a 1992 survey (O'Brien and Bainbridge, 2002), densities were higher than 98%, 84% and 77% respectively, of a resurvey of a subsample (89) of these sites conducted in mainland Scotland in 2005 (O'Brien and Wilson, 2011). These densities suggest that wider implementation of fodder crop management may not only benefit breeding Lapwing but a wider assemblage of farmland-breeding shorebirds.

In addition to the relationship with fodder crop management, Lapwing density was higher in fields with less enclosed field boundaries and this is consistent with previous research (Milsom et al., 2000). We found only a marginally significant effect of the density of wet features on Lapwing distribution across all in-bye fields and it is possible that field scale variability in wetness was at too small a spatial scale to detect a strong relationship between Lapwing distribution and field wetness, as Lapwings would have had access to wet areas in adjacent fields. Farm scale analysis shows that site wetness is one of the main determinants of Lapwing distribution (McCallum et al. 2015) and it is therefore important that, any management strategy attempting to increase numbers of breeding Lapwings, is targeted at fields and farms that are otherwise suitable for this species.

Greenhouse gas emissions resulting from quarrying and transport of lime, coupled with carbon dioxide release from soil following lime application (Biasi et al., 2008), could mean that liming as a conservation measure is viewed as controversial. This coupled with potential changes in sward composition due to liming and negative impacts of ploughing on botanically rich swards (Jefferson 2005), mean that fodder crop management should only be implemented as a conservation measure on species-poor, sown grassland fields which have already undergone agricultural improvement and that lime should only be used in response to soil pH below that recommended for agricultural grass production (McCallum et al., 2016).

4.1 Conclusions

This study made use of a long-term natural experiment at an upland farm in Scotland and found that high densities of breeding Lapwings are associated with a fodder crop management system operating outside agri-environment support. Fodder crop management provides an alternative mechanism to create the habitat mosaic of mixed farming favoured by Lapwings that has largely been lost from UK farmland, and may be particularly beneficial in high-rainfall upland areas, especially over acidic bedrock where leaching tends to reduce soil pH over time (White 2006). Here, its effects in raising soil pH to levels at which densities of earthworms, a key prey resource for grassland-breeding shorebirds, are higher, could have particular benefits for breeding shorebirds, as suggested by an association between Lapwing distribution in Scotland and higher altitude areas with relatively high soil pH (McCallum et al., 2015). Improvements in soil conditions for earthworms brought about by liming persist for several years after the field has been returned to grass and therefore have lasting benefits in terms of grass growth for the farmer and for species dependent on earthworms as a prey resource (McCallum et al., 2016).

Fodder crop management was implemented at our study site without the use of agri-environment payments, as a means for the farmer to fatten lambs over the winter and ultimately to improve productivity of the grassland; benefits for breeding Lapwings were a bi-product of this. However, when Lapwings began breeding in fields undergoing fodder crop management, the farmer delayed planting from May to July to avoid destroying Lapwing nests, but in doing so risked lower fodder crop yield (John Vipond, SAC *pers comm*). Wider implementation of fodder crop management at sites which are otherwise suitable for breeding Lapwing could improve breeding habitat for a species which has undergone substantial declines, without the need for substantial agri-environment funding. However, further research is required to establish the extent of any loss of income incurred by delaying planting to assess whether some compensatory payment would be needed to allow farmers to implement this management in a way that brings benefits for Lapwings or other grassland-nesting shorebirds.

Crucially, fodder crop management differs from most agri-environment options in that it involves actively farming, rather than receiving a payment to limit farming levels, for example by excluding livestock from key fields during the breeding season. This is likely to be more appealing to farmers (Alistair Robb, Townhead Farm *pers comm.)*. Of more general interest and importance, it is also a simple example of the land manager being actively involved in developing conservation solutions in partnership with environmental research (Keeler et al., 2017) rather than being seen as a passive recipient of knowledge as has typically been the case with the design of AES. Such approaches need to be adopted more consistently in designing interventions for environmental outcomes on farmland, but may be of particular importance in the UK if the old certainties of EU AES are to come to an end.

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References

Baines, D., 1988. The effects of improvement of upland, marginal grasslands on the distribution and density of breeding wading birds (Charadriiformes) in Northern England. Biol. Conserv. 45, 221-236.

Barrett, J., Barrett, C., 1984. Aspects of censusing breeding lapwings. Wader Study Group Bull. 42, 45-47.

Beintema, A.J., Muskens, G.J.D.M., 1987. Nesting success of birds breeding in Dutch agricultural grasslands. J. Appl. Ecol. 24, 743-758.

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.

Berg, Å., Jonsson, M. Lindberg, T., Källebrink, K.G., 2002. Population dynamics and reproduction of Northern Lapwings Vanellus vanellus in a meadow restoration area in central Sweden. Ibis 144, 131 - 140.

Biasi, C., Lind, S.E., Pekkarinen, N.M., Huttunen, J.T., Shurpali, N.J., Hyvonen, N.P, Repo, M.E., Martikainen, P.J, (2008) Direct experimental evidence for the contribution of lime to CO_2 release from managed peat soil. Soil Biol Biochem, 40, 2660-2669.

BirdLife International, 2004. Birds in Europe: population estimates, trends and conservation status Downloaded from http://www.birdlife.org/datazone/userfiles/file/Species/BirdsInEuropeII/BiE2004Sp3153.pdf (accessed 15 August 2012).

Broyer, J., Curtet, L., Chazal, 2014. How to improve agri-environment schemes to achieve meadow bird conservation in Europe? A case study in the Soane valley, France. J. Ornithol. 155, 145 – 155.

Donald, P.F., Sanderson F.J., Burfield, I.J., van Bommel, F.P.J. 2006. Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990-2000. Agric. Ecosyst. Environ. 116, 189-196.

EBLEX 2008. Beef and sheep BRP Manual 1: Improving pasture for better returns. www.eblex.org.uk/betterreturns . Funded by DEFRA. EBLEX, Huntingdon.

EDINA Digimap Ordnance Survey Service. OS MasterMap Topography Layer, http://edina.ac.uk/digimap (accessed August 2010).

Elliot, R.D. 1985. The exclusion of avian predators from aggregations of nesting lapwings (Vanellus vanellus). Anim. Behav. 33, 308-314.

ESRI Inc, 2006. ArcGis 9.2 http://www.esri.com.

European Commission, 2017. Eurostat Statistics Explained: Land cover, land use and landscape, available at ec.europaeu/Eurostat/statistics-explained/index.php/Land_cover,_landuse_and_landscape, last (accessed 21st August 2017).

Fuentes-Monteymayor, E., Goulson, D., Park, K.J., 2011. Pipistrelle bats and their prey do not benefit from four widely applied agri-environment management prescriptions. Biol. Conserv. 144, 2233-2246.

Gray, J.N., 2000. At home in the hills: Sense of place in the Scottish Borders, Berghahn Books, Oxford, UK.

Jefferson, R.G., 2005. The conservation management of upland hay meadows in Britain: a review. Grass Forage Sci. 60, 322-331.

Keeler, B.L., Chaplin-Kramer, R., Guerry, A.D., Addison, P.F.E., Bettigole, C.,Burke, I.C., Gentry, B., Chambliss, L., Young, C., Travis, A.J., Darmont, C.T., Gordon, D.R., Hellmann, J., Kareiva, P., Monfort, S., Olander, L., Profeta, T., Possingham, H.P., Slotterback, C., Sterling, E., Ticktin, T.,Vira, B., 2017. Society is Ready for a New Kind of Science – Is Academia? BioScience 67, 591-592.

Kleijn, D., Van Zuijlen, G.J.C., 2004. The conservation effects of meadow bird agreements on farmland in Zeeland, The Netherlands, in the period 1989 – 1995. Biol. Conserv. 117, 443-451.

Kleijn, D. Rundlof, M., Scheper, J., Smith, H.G., Trsharntke, T. 2011. Does conservation on farmland contribute to halting biodiversity decline? Trends Ecol. Evolut. 28, 474-481.

Klomp, H., 1954. De terreinkeus van de Kievit, *Vanellus vanellus* (L.). Ardea 42, 1-139.

Koch, D.W., Ernst Jr, F.C., Leonard, N.R., Hedberg, R.R., Blenk, T.J,Mitchell, J.R. 1987. Lamb performance on extended-season grazing of tyfon. J. of Anim. Sci. 64, 1275-1279.

Lenth, R. V. (2016) Least-Squares Means: The R Package lsmeans. J. Stat. Softw. 69, 1-33.

McCallum, H.M., 2012 Ecology and conservation of breeding lapwings in upland grassland systems: Effects of agricultural management and soil properties. PhD Thesis, Biological and Environmental Sciences, University of Stirling.

McCallum, H.M., Park, K.J., O'Brien, M.G., Gimona, A., Poggio, L. Wilson, J.D., 2015. Soil pH and organic matter content add explanatory power to Northern Lapwing Vanellus

vanellus distribution models and suggest soil amendment as a conservation measure on upland farmland. Ibis 157, 677-687.

McCallum, H.M., Wilson J,D., Beaumont, D., Sheldon, R., O'Brien M., Park, K.J., 2016. A role for liming as a conservation intervention? Earthworm abundance is associated with higher soil pH and foraging activity of a threatened shorebird in upland grasslands. Agric. Ecosyst. Environ. 223, 182–189.

Milsom, T.P., Langton, S.D., Parkin, W.K., Peel, S., Bishop, J.D., Hart, J.D., Moore, N.P., 2000. Habitat models of bird species' distribution: an aid to the management of coastal grazing marshes. J. Appl. Ecol. 37, 706-727.

O'Brien M., Bainbridge, I.,2002. The evaluation of key sites for breeding waders in lowland Scotland. Biol. Conserv.103, 51-63.

O'Brien, M.G., Smith, K.W., 1992. Changes in the status of waders breeding on wet lowland grasslands in England and Wales between 1982 and 1989. Bird Study, 89, 165-176.

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.

Osgathorpe, L., Park, K.J., Goulson, D., Acs, S., Hanley, N. 2011. The trade-off between agriculture and biodiversity in marginal areas: Can crofting and bumblebee conservation be reconciled? Ecol. Econ. 70, 1162-1169.

R Development Core Team, 2017. R: A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. http://www.R-project.org/.

Redpath, N., Osgathorpe, L., Park, K.J., Goulson, D., 2010. Crofting and bumblebee conservation: The impact of land management practices on bumblebee populations in northwest Scotland. Biol. Conserv. 143, 492-500.

Rhymer, C.M., Robinson, R.A., Smart, J., Whittingham M.J., 2010. Can ecosystem services be integrated with conservation? A case study of breeding waders on grassland. Ibis 142, 689-712.

Sabatier, R., Durant, D., Ferchichi, S., Haranne, K. Leger, F., Tichit, M., 2015. Effects of cattle trampling on ground nesting birds on pastures: an experiment with artificial nests. Eur. J. Ecol. 1, 5 – 11.

Schmidt, J.W., Eilers, A., Schimkat, M., Krause-Heiber, J., Timm, A., Siegel, S., Nachtigall, W., Kleber, A., 2017. Factors influencing the success of within-field AES fallow plots as key sites for the Northern Lapwing *Vanellus vanellus* in an industrialised agricultural landscape of Central Europe. J. Nat. Conserv. 35, 66 – 76.

Shrubb, M., 2007. *The Lapwing.* T & AD Poyser, London.

Smart, J., Bolton, M., Hunter, F. Quayle, H., Thomas, G., Gregory, R.D., 2013. Managing uplands for biodiversity: Do agri-environment schemes deliver benefits for breeding lapwing *Vanellus vanellus*? J. Appl. Ecol. 50, 794-804.

Smart, J., Wotton, S.R., Dillon, I.A., Cooke, A.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.

Taylor, I.R., Grant, M.C., 2004. Long-term trends in the abundance of breeding lapwing Vanellus vanellus in relation to land-use change on upland farmland in southern Scotland. Bird Study 51, 133-142.

Thompson, P.S., Baines, D., Coulson, J.C., Longrigg, G., 1994. Age at first breeding, philopatry and breeding site-fidelity in the Lapwing *Vanellus vanellus*. Ibis 136, 474-484.

Venables, W.N., Ripley, B.D., 2002. Modern Applied Statistics with S, fourth Ed. Springer, New York.

Verhulst, J., Kleijn, D., Berendse, F., 2007. Direct and indirect effects of the most widely implemented Dutch agri-environment schemes on breeding waders. J. Appl. Ecol. 44, 70 – 80.

White R.E., 2006. Principles and Practice of Soil Science: The Soil as a Natural Resource, fourth ed. Blackwell Publishing, Oxford, UK.

Whittingham M.J., 2011. The future of agri-environment schemes: biodiversity gains and ecosystem service delivery? J. Appl. Ecol. 48, 509-513.

Wilson, J.D., Evans A.D, Grice, V.G., 2009. Bird Conservation and Agriculture. Cambridge University Press, Cambridge.

Wilson, J., Evans, A.D.. Grice, P.V., 2010. Bird conservation and agriculture: a pivotal moment? Ibis, 152, 176-179.

Zuur A.F., Ieno E.N., Walker, N.J., Smith G.H., 2009. Mixed Models and Extensions in Ecology with R. Springer Science+ Business Media, New York.

Figure Captions

Figure 1. Fields at Townhead Farm with dates that tyfon was planted marked for fields that have a history of fodder crop management (grey fields). In-bye fields with no history of fodder crop management are white and out-bye fields are black. Backward diagonal lines show a small area of woodland on the farm which was not surveyed and the forward diagonal lines show the farm buildings and yard.

Figure 2. Predicted change in Lapwing density with increasing number of years since the fodder crop was last planted (solid line) for a field with mean enclosed boundaries within the data set (0.14), showing ± 95% confidence interval The grey shaded area indicates that the field was in grass at this stage (i.e. fields were reseeded with grass after the end of the breeding season in the year after the fodder crop was last planted, meaning that the first breeding season a field was grass was two years after the fodder crop was last planted). The dotted line represents the predicted Lapwing density from fields with no prior history of fodder crop management, generated from the previous model. Raw data for fields with a prior history of fodder crop management are shown by the open circles.

Tables

Table 1. Timings of fodder crop management process in comparison to Lapwing use at the study site.

Farm management	Late June / July	Autumn / winter	March
Year 1	Tyfon planted	Tyfon grazed	Most of crop has been grazed
Year 2	Tyfon planted	Tyfon grazed	Most of crop has been grazed
Year 3	Grass planted	Grazing excluded for grass growth	Grass grazed
Lapwing activity	Leave for wintering grounds	Absent	Arrival for breeding

Table 2. Number of fields within each treatment type that were surveyed for breeding Lapwings in each year of the study.

	Number of in-bye fields surveyed		
	Fodder crop at some point prior to Lapwing survey	No fodder crop prior to survey	Total
2003	2	10	12
2006	4	8	12
2007	6	9	15
2008	6	9	15
2009	7	10	17
2010	7	10	17
2011	8	9	17

Table 3. Statistical summary for final GLMM assessing the relationship between Lapwing density ($\log_e$-transformed) and field management history (i.e. whether or not a field had undergone fodder crop management).

	DF	Parameter estimate ± SE	t- value	p-value
Fodder crop prior to survey (yes compared to no)	87	0.44 ± 0.17	2.49	0.0145
Proportion field enclosed	15	-5.28 ± 1.22	-4.34	0.0006

Table 4. Statistical summary for GLMM assessing the relationship between Lapwing density and number of years since a field was last planted with fodder crop). Lapwing density was also associated with field enclosure, but not with the density of wet features or field slope.

	DF	Parameter estimate ± SE	t- value	p-value
No. years since fodder crop last planted	31	-0.18 ± 0.05	-3.7	0.0008
Proportion perimeter enclosed	31	-4.97 ± 1.45	-3.4	0.014

Fig 1

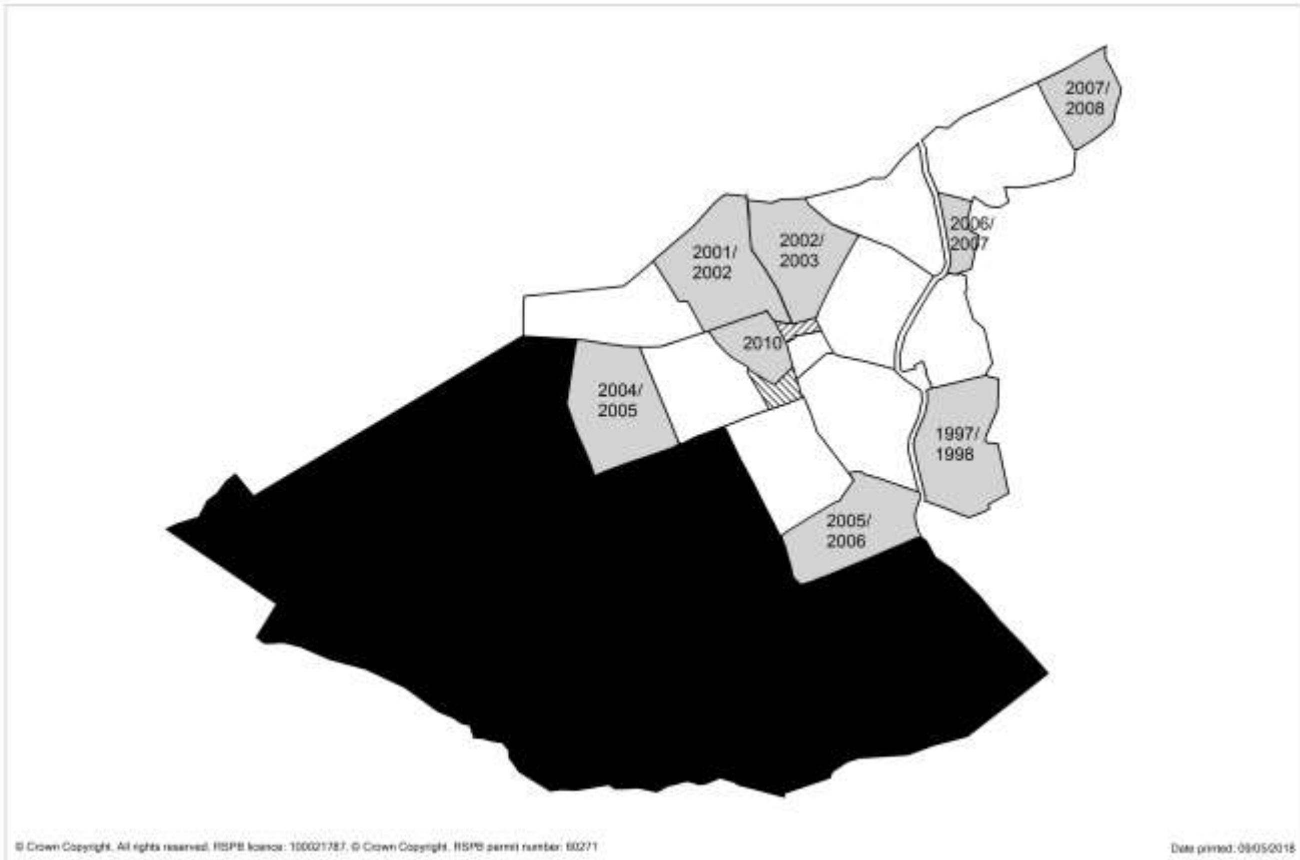

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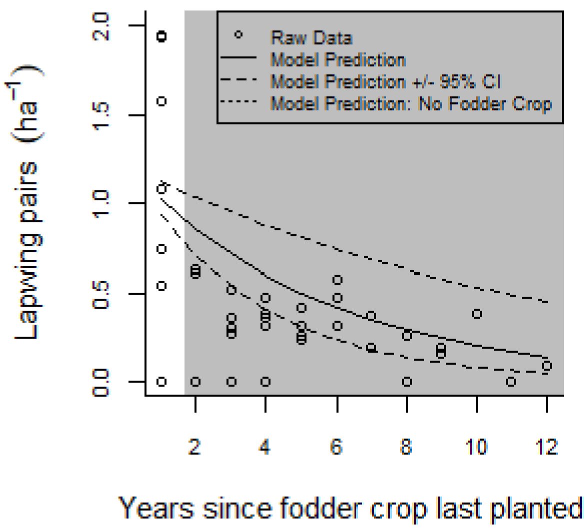
Fig 2


Raw Data
Model Prediction
Model Prediction +/- 95% CI
Model Prediction: No Fodder Crop
Lapwing pairs (ha^{-1})
0.0
0.5
1.0
1.5
2.0
2
4
6
8
10
12
Years since fodder crop last planted