

Defra Research Report on Project BD5211

**Lapwings on agri-environment scheme fallow plots:
research to improve lapwing breeding success**

**Final Report
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Executive summary

Breeding lapwings were monitored on fallow plots provided under English agri-environment schemes and on conventional crops in two regions of southern England in 2012 and 2013. This included assessing overall productivity via regular visits to sites, as well as more intensive monitoring of individual nests and chicks. Other factors considered likely to influence lapwing productivity, such as predator abundance and chick food availability, were also measured on plots and conventional fields.

The results of the study indicate that while nest survival is higher on plots (77% hatching rate) than on conventional crop fields (65% hatching rate), chick survival is no higher; at less than 9% in both cases it is insufficient to maintain a stable population. This is supported by the results of the monitoring of overall productivity, which indicate that the number of chicks fledged per pair was 0.47 on plots and 0.32 on conventional crops (the difference between these figures was not statistically significant): less than the 0.7 that is estimated to be required. Chick survival is therefore considered to be the most important factor limiting lapwing populations on arable land from fledging sufficient young.

Chicks were lost to both starvation and predation. Fallow plots had greater abundances of invertebrates in size classes likely to be food for small chicks, but it is uncertain whether there were sufficient food items in absolute terms. Starvation rates may have been unusually high in these study years, as abnormal weather was encountered in both (very wet conditions in 2012; an extended cold spring in 2013). Both mammals and birds were identified as predators of lapwing chicks, but because the predator could not be identified for a high proportion of predated chicks, it is impossible to be certain which are the most important predators.

Fallow plots for lapwings are functioning as they were originally conceived, providing high quality nesting habitat. However, given that chick survival is the limiting factor, fallow plots are not achieving the overarching aim of sufficient productivity to maintain stable or increasing populations. If this is to be achieved then management of fallow plots may need to be altered to improve chick survival: for example by excluding predators or increasing chick food availability. Alternatively, additional agri-environment options may need to be considered, possibly in combination with fallow plots: for example, the provision of high quality chick-rearing habitat to which chicks can be moved after they hatch on fallow plots.

1. Introduction

The lapwing *Vanellus vanellus* is an iconic but rapidly declining farmland bird, whose numbers have fallen by 44% in England since 1983 (CBC/BBS joint trend at <http://www.bto.org/birdtrends2010/wcrlapwi.shtml>), and which is now 'red-listed' as a bird of conservation concern (Eaton *et al.* 2009). It is on the UK BAP list of priority species owing to international threat status, as well as the marked decline in the UK. Analysis of adult survival rate indicated no appreciable change during this period and suggests that insufficient productivity is the main driver of lapwing declines (Peach *et al.* 1994, Catchpole *et al.* 1999, Sharpe *et al.* 2008). Lapwings breed in a range of habitats, including wet grassland and moorland, but in the late 1990s, 39% of breeding lapwings in England and Wales were recorded on arable farmland: 85% on spring tillage, and 5% on set aside (Wilson *et al.*, 2001). Since the 1970s there has been a widespread switch from spring- to winter-sown crops, which has dramatically reduced the availability of suitable nesting habitat; there has also been a shift away from mixed farming, so that grass habitats (favoured chick-rearing habitat) are less commonly found adjacent to arable land (Shrubbs 2007).

The main government-funded delivery mechanisms for reversing the declines in farmland bird populations are agri-environment schemes (AES). On arable land, the main AES option available in England to benefit lapwings is the fallow plot for ground-nesting birds. This option originally arose out of a successful project to increase stone curlew populations in England (Grice *et al.* 2007) and observations that lapwings also nested on these plots. These plots are currently provided under Countryside Stewardship (option OS3), which closed to new entrants in 2004; and under Higher Level Stewardship (options HF13 & HF17), and Entry Level Stewardship option (option EF13). The latter two schemes will not accept new entrants from the end of 2014, but fallow plots are expected to form part of the succeeding English AES. Under these options, land managers are required to create fallow (un-cropped) plots of at least 2 ha (1ha for EF13) in arable fields by cultivating in spring. These options are designed to provide both nesting and foraging opportunities for lapwings.

Some monitoring of the effectiveness of fallow plots has been undertaken in England, although as with most AES options, population-level effects have not been assessed, although they should be the goal of such options. An estimated 40% of fallow plots in England are used by breeding lapwings, with occupancy more likely on plots located away from woodland and with more bare ground (Chamberlain *et al.* 2009). During the Arable Stewardship Pilot Scheme, a precursor to Countryside Stewardship, nesting lapwing densities and hatching success were higher on option OS3 than on arable crops (Sheldon *et al.* 2007). However, there is limited information on overall lapwing productivity on plots. Following roll-out within AES, anecdotal reports from farmland advisors have suggested that lapwing productivity on fallow plots may be low. RSPB data from a large sample (247-266 plots monitored annually) of stone curlew fallow plots in Hampshire, Wiltshire and Berkshire indicated a 40% decline in numbers of lapwing pairs between 2006 and 2009. Data collected by GWCT on a total sample of 79 fallow plots in Hampshire and Dorset during 2010-2011 suggested nest survival of 57% (95% CL 44-74%), but average brood survival of only 19% (95% CL 11-32%). Overall productivity was estimated at approximately 0.38-0.48 fledged young per female, which is too low for maintenance of stable lapwing populations. Based on annual survival rates of 83% and 60% for adults and first-year birds respectively (Peach *et al.* 1994), it has been estimated that each pair needs to fledge on average 0.7 young per annum to maintain a stable population. Comparison with GWCT data for wet grassland within the Avon Valley (Hampshire, Dorset) in the same years indicates that nest survival on fallow plots is higher but brood survival lower. Understanding how to

increase brood survival may be crucially important for the long-term maintenance of lapwing populations (Sharpe *et al.* 2008).

Chick survival has received less attention than nest survival, because monitoring chicks is more difficult than monitoring nests. Most research to date has been conducted on wet grassland nature reserves, where high predator densities can result in poor breeding success of lapwings (Bolton *et al.* 2007, Teunissen *et al.* 2008), but the situation in the wider countryside, where lapwings are typically nesting at lower densities, may be different. Despite considerable investment in habitat improvement through AES, it is possible that lapwing numbers are not increasing owing to low food availability for chicks or high predation rates (on nests and/or chicks). Chicks typically feed on beetles and insect larvae in grassland areas (Holland *et al.* 2006), although the diet in arable areas has been little studied. Fallow plots and surrounding arable crops may provide insufficient chick food. Predation rates of chicks on plots or in surrounding areas may be too high to maintain a stable population; or these two factors may operate together to reduce chick survival below a sustainable level.

This focus on the lapwing is justified by its listing on Section 41 of the NERC Act (2006) and the Government's England Biodiversity Strategy (EBS) Outcome 3 which seeks an overall improvement in the status of species by 2020. Through EBS Outcome 1, the Government is committed to a significant increase in arable options (including fallow plots), as part of the 200,000 ha target, by 2020 and it will be essential to ensure effectiveness and value for money. Fallow plots are among the most expensive arable AES options in terms of costs per hectare, and it is important to evaluate their effectiveness in terms of producing fledged chicks. Without such evidence, it is impossible to know whether fallow plots are a suitable option for this species, or to suggest improvements to plot management or location that are likely to improve breeding success.

2. Project objectives

The overall aim of the project was to assess the efficacy of AES fallow plots as a tool for lapwing population recovery in lowland arable and mixed farming landscapes, as compared to conventional crops available to lapwings in the landscape. To do this a range of breeding parameters of lapwings were compared between lapwings on fallow plots and conventional spring crops. Specific objectives were:

- (1) Assessment of overall breeding success on fallow plots and comparison with arable fields without AES measures.
- (2) Estimation of lapwing nest survival on a minimum of 40 fallow plots per annum and comparison with nest survival on spring cereal fields.
- (3) Analysis of distances moved and habitat use relative to availability by 40 broods hatching on fallow plots and 20 broods hatching on spring cereals per annum.
- (4) Determination of chick invertebrate diet from faecal samples in relation to invertebrate availability.
- (5) Estimation of chick survival and determination of the relative importance of starvation and predation as causes of chick mortality, including investigation of situations resulting in poor chick condition and growth rates and situations where there are high rates of predation.

3. Study areas

Fieldwork was conducted during March-July 2012 and 2013 in two regions in southern England (Figure 1). In the Wessex study area, sites were spread from north-east Dorset to the Berkshire Downs. The soils in this region are either light soils over chalk or heavier clay soils. The agriculture is mixed, with a predominance of cereal growing but some sheep and cattle grazing. Data here were collected by the GWCT. In the East Anglia study area, sites were in north Norfolk, the Fens, the Royston area, and further west, extending into Bedfordshire. This region has a higher proportion of cultivated fields and root crops are important in addition to cereal and oilseed rape (Table 1). Soils here varied between deep peat soils (in the Fens) to lighter soils over chalk and sand. Data here were collected by the RSPB.

Figure 1. Map showing the two study regions, with the locations of the main clusters of farms surveyed within each region.

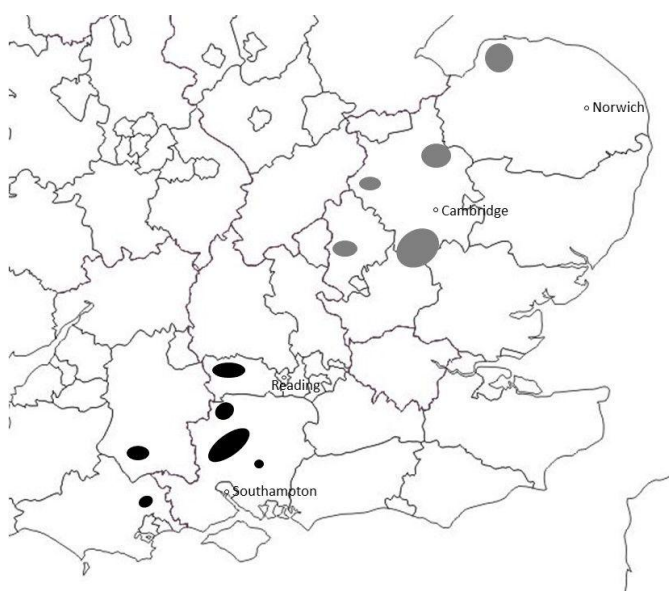


Table 1. Percentage composition of the ‘control’ crop fields used in each study region for comparison with fallow plots. The crop type categories are those used in data analysis.

Crop category	Crops	East Anglia	Wessex
Beets & roots	Fodder beet, sugar beet, potatoes, onions	48.1	0
Spring cereal	Spring barley, spring wheat, spring oats	23.1	37.1
Maize		0	37.1
Other crops	Linseed, millet, peas, beans, game cover, mint, stubble	15.4	20.0
Oilseed rape		1.9	5.7
Winter wheat		5.8	0
Grass	Pasture, ley grass	5.8	0

4. Methods

4.1 Lapwing, habitat and predator surveys

Overall breeding productivity on AES fallow plots, and on arable fields without AES measures, was assessed using a five-visit survey method (Bolton *et al.* 2011), consisting of visits within 3-week windows over the breeding season. On each visit, the total number of adult lapwings, number of sitting adults, number of alarm-calling females and numbers of young according to age class are recorded. The five-visit survey enables an accurate assessment of the number of breeding pairs and the number of young fledged per pair, whilst minimizing survey effort. The surveys yielded information on site occupancy and overall productivity per site.

Control fields with conventional crops that could be used by lapwings (spring cereals, root crops, and in one case a grass ley) were identified on the same farms as the plots: in a small number of cases they were on adjacent farms. Farms were surveyed if either the plot or the control held breeding lapwings; ideally, both were occupied.

To determine whether there were any relationships between lapwing productivity and plot character, plot management or local predator abundance, habitat and management variables were recorded. Twenty measures of vegetation height (to the nearest 1 cm with a sward stick) and percentage cover (within a visualized 2 x 2 m quadrat) were recorded at 20 m intervals across the diagonal of each plot or field on each of the five survey visits. Plot management variables (plot rotation, time in AES, predator control) were obtained from farmer surveys at the end of each field season.

Standardized counts of potential predators or signs were made for derivation of predator abundance indices. A count of all corvids and raptors on a fallow plot, the surrounding field or the boundaries of the field containing the plot were conducted upon arrival at each plot for each of the five survey visits. Survey visits were timed and all corvids and raptors flying over or settling on the plot or surrounding field during survey were recorded. Mammalian scat searches were conducted along the boundaries of fields containing fallow plots and cereal fields where radio-tagged chicks were monitored. A clear-up round was conducted at the end of April and then a repeat search made in late May. Scat search routes were 2 km in length and all fox scats and badger latrines were recorded. The scat searches were intended to provide a measure of abundance-activity close to the fallow plots rather than the number of individual foxes or badgers present.

4.2 Nest survival

Lapwing clutches were located during egg-laying and incubation. Nest finding effort was apportioned to ensure that the sample of plots and spring cereal fields with nests being monitored was maximized, rather than simply the total number of nests. Nest positions were recorded with hand-held GPS units. Eggs were measured and weighed when nests were first located to enable estimation of hatch dates from egg density (Galbraith 1988a,b). Nests were checked for signs of hatching and the presence of chicks within one day of the estimated hatch date. In cases where chicks were not evident, the presence of small egg fragments in the nest lining were taken as confirmation of hatching. Clutch predation was assumed in cases where nests were empty and contained no small egg fragments.

Temperature loggers (iButton, Maxim Ltd) were placed in nests when first found and programmed to record nest temperature at 15-minute intervals. These temperature loggers yielded

the time of clutch hatching or predation through examining when the temperature in the nest changed rapidly and then started to cycle in parallel with ambient temperature, hence avoiding the need for fieldworkers to repeatedly check nest status, although the presence of sitting females was noted whenever a site was visited. They also provided information on the likely category of nest predators, either bird or mammal predation, assumed to occur predominantly during the day or at night respectively (e.g. Teunissen *et al.* 2008).

First-egg dates were calculated for all clutches. When found during egg-laying, an average of 1.5 days per egg was used to estimate the first-egg date. For hatched clutches, first-egg date was back-calculated from the known hatch date or that estimated from the temperature logger, assuming a 26-day incubation period and 1.5-day laying interval per egg. For failed clutches, first-egg date was calculated from the estimated hatch date based on egg measurements. Owing to the time taken to locate suitable study sites in East Anglia in 2012, some early lapwing clutches were not located and hence first-egg dates for East Anglia in 2012 have been omitted from analyses of the timing of nesting.

Nest survival was calculated on the basis of days of exposure according to the Mayfield method (Mayfield 1961, 1975). In the majority of cases, the time of hatching or clutch loss was known from the temperature logger or the age of young chicks near the nest. In instances where this information could not be used, hatching date was taken as the date estimated from egg measures and predation date was taken as the mid-point between the last date when an adult was seen on the clutch and the first time that the adult was absent. We applied Johnson's (1979) 40% rule where observations of these predated clutches fell more than eight days apart.

4.3 Brood movements, chick survival and habitat use

One chick was randomly selected from each of c.30 broods in each region in each year and a 0.4g, 30-day life, transmitter (Perdix Wildlife Supplies, Warwickshire or Biotrack Ltd, Dorset) was attached. Broods were selected so that there was no more than one or, occasionally, two broods present with a tagged chick on each plot or control field at any time: if chicks died, then further chicks were tagged from other broods if they were present. Chicks were preferentially tagged shortly after hatching (mean age (\pm sd) 4.9 ± 6.1 days); however, older chicks were tagged opportunistically. Chicks were radio-tracked once every two days by triangulation from field edges, with the observer staying next to a vehicle so as not to disturb adults from their broods. Extra care was taken in inclement weather. Position fixes were recorded on 1:10,000 scale maps with the time of the fix and crop type, enabling distances travelled and time spent in different habitats to be calculated subsequently using GIS (ArcGIS). Chick range areas were calculated as minimum convex polygons for all chicks for which three or more radio-locations were obtained.

The samples of radio-tagged chicks were used to estimate chick survival and causes of mortality. On each tracking occasion, the presence or absence of an alarm-calling female, whether or not chicks were seen and fluctuation in signal strength (indicating chick movement) were noted. When a radio signal could not be detected, an extensive search was undertaken by vehicle and on foot to attempt to locate the missing radio-tag. Tag location and chick remains were used to attempt to attribute a cause of death to each chick.

4.4 Chick diet and invertebrate availability

Radio-tagged chicks were recaptured at approximately 7-day intervals to check tag attachment and biometrics and faecal samples were collected at these times to allow calculation of a condition index and estimation of diet. Samples of other broods were captured and ringed at a range of ages to increase sample sizes for condition and diet estimation.

Faecal samples were examined under a binocular microscope at 25X magnification in Petri dishes with 16 equal sectors marked on the base to aid the counting of fragments. Fragments were identified to order or family level by reference to Forsythe (1987) and Moreby (1988). Counts of prey remains were restricted to items that were readily identifiable and carried in known numbers, such as mandibles, head capsules and legs (Ausden *et al.* 2003, Hoodless *et al.* 2007). The number of earthworm chaetae was estimated from counts of eight of the 16 sectors. To account for different digestion rates of different prey taxa, published correction factors from other studies were used to estimate numbers of prey ingested (Ausden *et al.* 2003, Hoodless *et al.* 2007). The weight of prey ingested was estimated by multiplying the estimated numbers of prey ingested by the mean dry weights for each taxa given by Ausden *et al.* (2003) primarily or Hoodless *et al.* (2007) for additional taxa.

Chick food availability on fallow plots and spring cereal fields was sampled with pitfall traps (eight per plot or field) in early May, c.10 days after peak hatch of first clutches. Two lines of four traps were set at each site down the long axis of the plot or field, spaced 20 m apart. One line of traps was in the centre of the plot or field and the other mid-way between the centre and the edge. Traps were one third filled with propylene glycol, had roofing felt covers supported on nails 2 cm above the trap to reduce small mammal and amphibian captures and were set for seven days. Invertebrates were sorted to Order level (families for beetles) and into four size classes: 3-10 mm, 10-17 mm; 17-24 mm; >24 mm.

4.5 Statistical analysis

Unless stated otherwise, analysis was conducted with the plot or spring crop field as the unit of analysis. First, comparisons were made between fallow plots and spring crops using the main response variables (e.g. total productivity, nest survival rate, chick survival rate). Generalised linear mixed models (GLMM) were used, with region and year as fixed structural effects, treatment (fallow plot or spring crop) as the factor of interest and plot or field nested within site nested within region as a random effect. In cases where the iterative process of GLMMs would not converge, a generalised linear model (GLM) without the random effect was employed. Where sample sizes were appropriate, crop type, which included fallow plot and the seven crop categories listed in Table 1, was substituted for treatment and the analysis was repeated. Finally, certain response variables were modelled against variables describing fallow plot characteristics or management and predator abundance in an attempt to explain the variance between sites.

Three variables were calculated from the survey data to describe overall productivity. The proportion of lapwing pairs fledging at least one chick was analysed with a GLMM using number of young fledged per plot or crop field as the response variable and the number of lapwing pairs as the number of binomial trials with a logit link function. Mean brood size at fledging was analysed with a GLMM with Poisson errors and logarithmic link function. Both models included plot or field within site within region as a random factor. The number of young fledged per pair was analysed using a zero-inflated Poisson regression model (Lambert 1992) with the R0INFLATED procedure in Genstat 16.1. The response variable of counts (young per pair) was assumed to be distributed as a mixture of

a Poisson distribution and a degenerate distribution at zero: a GLM with a log link was used for the count model and a binomial model with logit link for the zero-inflation model.

Nest survival was estimated on the basis of exposure days according to the Mayfield (1961, 1975). Daily nest survival rate was analysed according to Aebischer's (1999) extension of the Mayfield method, i.e. a GLMM with binomial errors and logit link, using days survived as the response variable and exposure days as the number of binomial trials. Survival rates of radio-tagged chicks were analysed with similar models; i.e. a GLMM with binomial errors and logit link, with days survived as the response variable and exposure days as the number of binomial trials, but at the chick level, with chick nested within plot or field nested within site nested within region as the random effect and chick age at tagging as covariate. Chick age was known for chicks from nests that had been monitored and was estimated from bill length for chicks where the nest was not found (Beintema & Visser 1989). Analysis of chick survival rates was first conducted according to the hatching location of each chick (plot or spring crop) and then repeated with the exposure days partitioned according to whether the chick was on a fallow plot or in a spring crop each time it was located. To examine factors influencing chick survival, age at tagging, mean total invertebrates per pitfall trap, vegetation cover (estimated for 15 May), mean number of fox scats, and mean crow, gull and buzzard+red kite sightings per hour were included as explanatory variables in a logistic regression model. This was run first for all fallow plots and crop fields where lapwing chicks were radio-tracked and then repeated just for fallow plots, with the inclusion of an additional variable, proportion of time spent on the plot.

To examine chick condition, a Gompertz growth curve (Ricklefs 1967, 1968) was fitted to all the data on chick weight plotted against age. The data were described by the equation:

$$\text{Weight} = 149.34 - 146.61e^{-0.12451(\text{Age}-19.08)}$$

The residuals of chick weight from this growth curve, effectively providing a relative measure of condition between chicks, were used as the response variable in a GLMM. Chick condition was also examined by using the standard chick weights from Beintema (1994) to calculate a condition index as observed weight/standard weight to examine absolute condition of chicks. Data were analysed with GLMMs at the brood level including date category (24 April-19 May, 20 May-9 June, 10 June-9 July) as a factor and chick age as a covariate, as well as the usual fixed terms region, year and treatment and brood as the random term. Analyses first compared chicks caught on plots with those caught on any other crop type and then broken down by different crop types.

Chick ranges were calculated as minimum convex polygons in ArcGIS from the ten-figure grid references recorded during radio-tracking. Chick ranges were transformed with $\log_e(x+0.1)$ to achieve normality prior to analysis. Habitat use by radio-tracked lapwing chicks tagged on fallow plots was examined using compositional analysis (Aitchison 1986, Aebischer *et al.* 1993) with the individual chick as the unit of analysis. Proportional habitat use by each chick was calculated as the proportion of radio-locations within each habitat. Habitat availability was calculated from records of crop types within each field around plots, digitized in a GIS package (ArcGIS) and cropped to a 250m buffer centred on the middle of the plot where each chick was tagged. Computer simulations have indicated that compositional analysis can result in inflated Type I errors when analysis includes habitats with small proportional availability and 0% use (Bingham & Brennan 2004). To increase available habitat proportions at each study site and to reduce the number of null use proportions, analysis was performed on five habitat categories: fallow plot, grass, spring barley, oilseed rape (beans and maize pooled into this category), winter wheat. Null proportions were replaced by 0.006, as recommended by Bingham & Brennan (2004).

A total of 59 chick faecal samples were examined, but six of these from very young chicks were excluded because they contained no invertebrate fragments. Total numbers of animals identified per sample and their biomass equivalents were log-transformed for analysis. Comparisons of chick diet between regions and treatments were made using compositional analysis of dietary proportions calculated on the basis of dry weight ingested. For this, data were grouped into five categories: beetles, flies, spiders (spiders+harvestmen+true bugs), litter active (woodlice+millipedes+ants+earwigs), worms and larvae (earthworms+beetle larvae+Lepidoptera larvae+snails). Pitfall trap catches were summarized as means per trap. Total invertebrate numbers and those in the smallest size class were $\log_e(x+1)$ -transformed prior to analysis.

All statistics were calculated in Genstat 16.1.

5. Results

5.1 Overall productivity

Productivity was estimated for totals of 262 lapwing pairs on fallow plots and 160 pairs on spring crop fields across the two regions and years (Table 2). Crude overall proportions of pairs fledging a brood were 24.8% and 16.3% on fallow plots and spring crops respectively. The crude overall mean number of young fledged per pair was 0.47 on fallow plots and 0.32 on spring crops.

A difference in breeding success was apparent between years, with productivity higher in 2012. The proportion of pairs fledging a brood differed between years (2012 0.223, 2013 0.086, GLMM $F_{1,94.2} = 19.21$, $P < 0.001$), but there was an independent significant interaction between region and treatment (GLMM $F_{1,137.9} = 9.33$, $P = 0.003$, Figure 2). The mean size of fledged broods was higher in 2012 (2.15 young) than in 2013 (1.64 young), but no other effects were significant (GLMM year $F_{1,84.6} = 7.76$, $P = 0.007$). The mean number of fledged young per pair differed between regions, but not years or treatments (Kruskal-Wallis ANOVA, region $H = 9.97$, $n = 76,101$, $P = 0.002$; year $H = 3.36$, $n = 101,76$, $P = 0.067$; treatment $H = 1.68$, $n = 81,96$, $P = 0.195$, Figure 3).

Table 2. Totals of numbers of sites and lapwing pairs monitored within each study region each year, with estimates of total numbers of broods and young fledged. The majority of sites within each region were the same in both years.

	Fallow plots				Spring crop fields			
	Number of sites	Lapwing pairs	Broods fledged	Young fledged	Number of sites	Lapwing pairs	Broods fledged	Young fledged
East Anglia 2012	16	46	10	23	16	35	6	18
East Anglia 2013	20	46	11	20	24	57	2	2
Wessex 2012	35	89	27	54	14	24	6	11
Wessex 2013	30	81	17	27	22	44	12	20
Total	101	262	65	124	76	160	26	51

Figure 2. Differences in the proportion of lapwing pairs fledging a brood between study regions and treatments. Values are back-transformed means from a GLMM with binomial errors and a logit-link function.

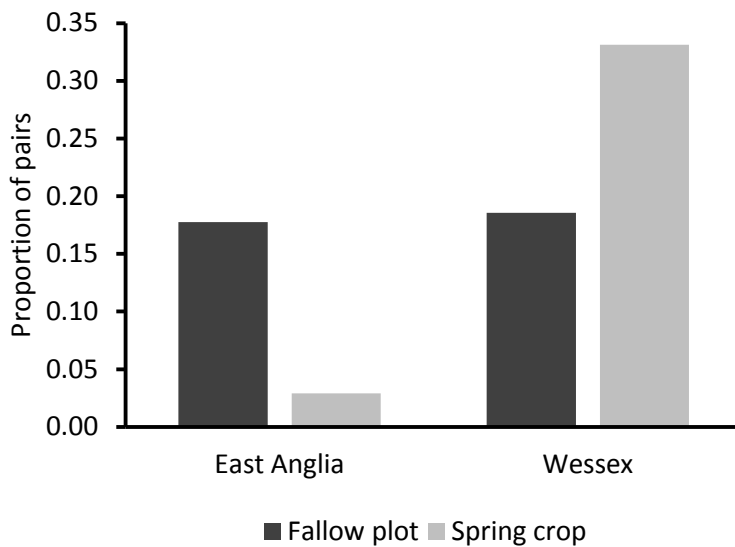
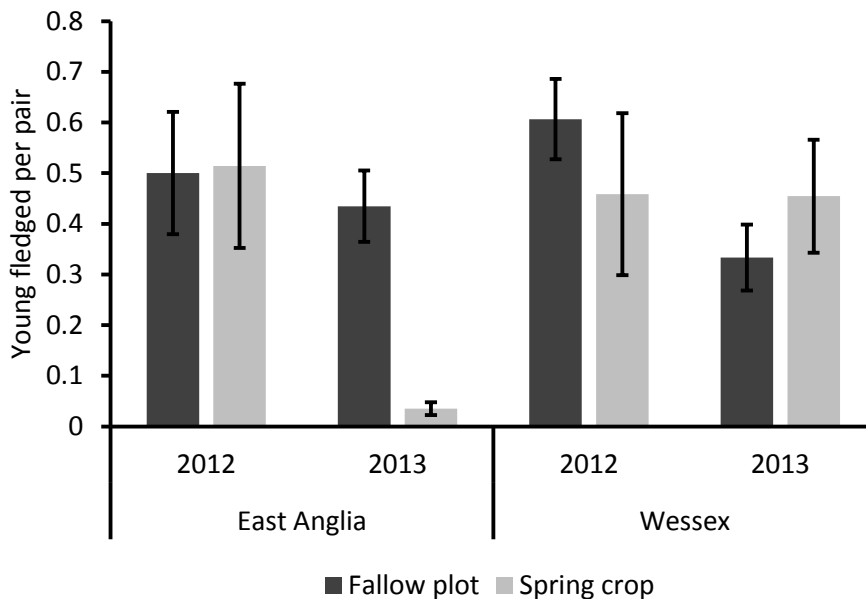


Figure 3. Mean (\pm se) number of young fledged per lapwing pair.



5.2 Timing of nesting

Egg-laying commenced significantly later in 2013 than in 2012 (Wessex only, fallow plots and spring crops, Mann-Whitney $U = 3581.0$, $n = 86, 102$, $P = 0.030$). The difference was more apparent when restricted to clutches initiated before 1 May (median first-egg date and date for first clutch of the year: 2012 5 April, 8 March; 2013 9 April, 24 March; Mann-Whitney $U = 2154.0$, $n = 71, 88$, $P < 0.001$). There was no difference in the timing of initiation of first clutches between fallow plots and spring crop fields (Wessex only, clutches initiated before 1 May, Mann-Whitney $U = 6179.0$, $n = 87$,

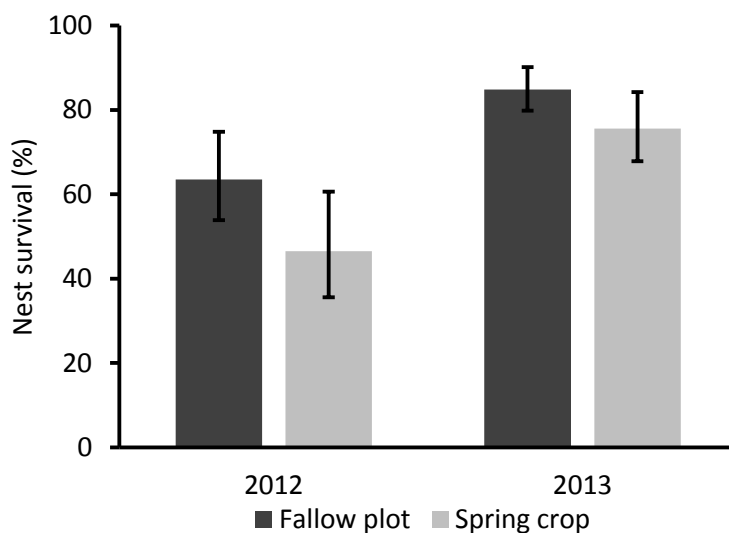
153, $P = 0.356$). There was no indication that nesting continued any later on fallow plots than on spring crop fields (median (and range) of first-egg dates excluding East Anglia 2012: fallow plots 9 April (8 March-4 June); spring cereals 10 April (13 March-31 May); Kolmogorov-Smirnoff $d = 0.099$, $n = 176, 103$, $P = 0.276$).

5.3 Nest survival

A total of 334 clutches of eggs were monitored, of which 257 (77.0%) hatched at least one chick. Nine clutches (2.7%) were destroyed by farming operations, 56 (16.8%) clutches were predated and 12 (3.6%) were apparently abandoned, although in most of the latter cases there were signs of the adult having been predated on the nest.

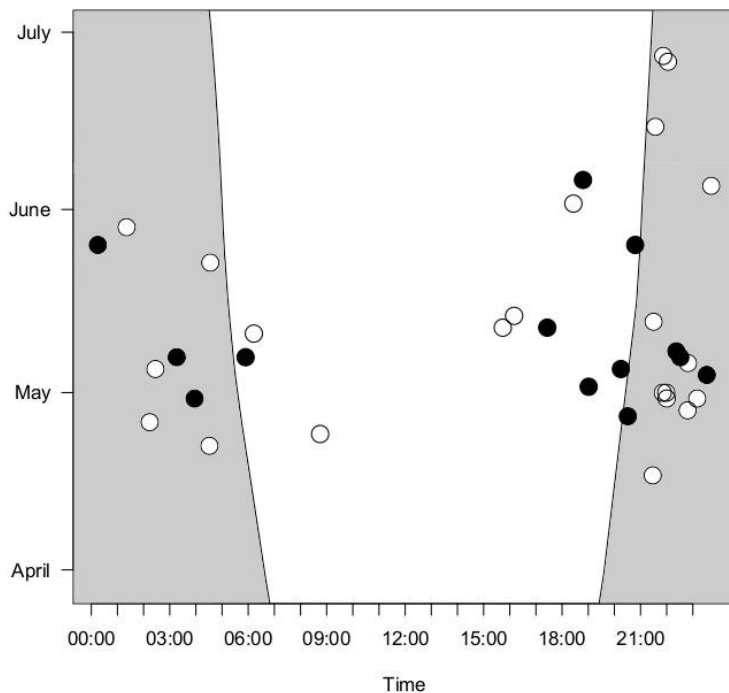
Daily nest survival rates differed significantly between years and treatments, being higher in 2013 and higher for clutches on fallow plots than on spring crop fields (year: 2012 0.9787 ± 0.0031 , 2013 0.9922 ± 0.0012 , GLM $F_{1,136} = 20.88$, $P < 0.001$; treatment: plot 0.9901 ± 0.0015 , spring crop 0.9833 ± 0.0025 , $F_{1,136} = 5.96$, $P = 0.016$). There was no effect of region and first- and second-order interactions were not significant. Nest survival for the incubation period was 77.2% (95% CL 71.5-83.3) on fallow plots and 64.5% (95% CL 56.7-73.4) on spring crops (Figure 4). Inclusion of the plot or field as a random factor nested within region and year reduced the statistical significance of the differences between years and treatments (GLMM year $F_{1,136} = 4.33$, $P = 0.039$, treatment $F_{1,136} = 1.61$, $P = 0.207$), but the direction remained unchanged and the magnitude of the differences was similar.

Figure 4. Estimated lapwing clutch survival (\pm 95% CL) for the incubation period, by year and treatment.



The timing of predation was obtained from temperature loggers for 40 clutches, including five where the adult lapwing was predated. A total of nine (22.5%) losses occurred during the day, 22 (55.0%) at night and nine (22.5%) at dawn or dusk (Figure 5). There was no difference in the timing of clutch predation between fallow plots and spring crops ($\chi^2_2 = 1.84$, $P = 0.399$) or between regions ($\chi^2_2 = 0.67$, $P = 0.714$).

Figure 5. Timing of lapwing clutch predation events on fallow plots and spring cereal fields in relation to the time of sunrise and sunset. Open symbols are East Anglia, filled ones are Wessex.



5.4 Chick survival

A total of 123 lapwing chicks were radio-tracked, comprising similar numbers per region and treatment (East Anglia, plots 38, spring crops 23, Wessex, plots 42, spring crops 20). The total exposure days for which chicks were monitored was 1352 (615 East Anglia, 737 Wessex). There was no difference in daily survival rates of radio-tagged lapwing chicks in relation to hatching location, i.e. fallow plot or spring crop field (GLMM treatment $F_{1,118} = 2.43$, $P = 0.122$, region, year, interactions and age at tagging not significant). There was still no difference in chick survival rates between plots and crop fields when the data were partitioned according to time spent on each treatment (GLMM treatment $F_{1,223} = 0.00$, $P = 0.964$, chick age $F_{1,223} = 7.37$, $P = 0.007$, region, year and interactions not significant). Estimated average daily survival rates were 0.9319 on fallow plots and 0.9308 on crops, equating to 8.5% and 8.1% survival during the fledging period respectively.

Daily survival rates partitioned by crop type ranged from 0.8319 (0.16% survival to fledging) on 'other crops' to 0.9748 (40.9% survival to fledging) on grass. However, there was no statistical difference in daily survival rate between crop types (GLMM crop type $F_{8,216} = 0.72$, $P = 0.674$, chick age $F_{1,216} = 6.84$, $P = 0.010$, region, year and interactions not significant).

Examination of the effects of possible factors influencing chick survival suggested that just vegetation cover was important, with higher survival rates as vegetation cover increased (GLM all sites: vegetation cover $F_{1,116} = 2.87$, $P = 0.093$, chick age $F_{1,116} = 4.03$, $P = 0.047$; fallow plots only: vegetation cover $F_{1,76} = 5.27$, $P = 0.024$, chick age $F_{1,76} = 3.62$, $P = 0.061$). Invertebrate abundance and predator abundance-activity explained little of the variation in chick survival across all sites and when analysis was restricted to fallow plots.

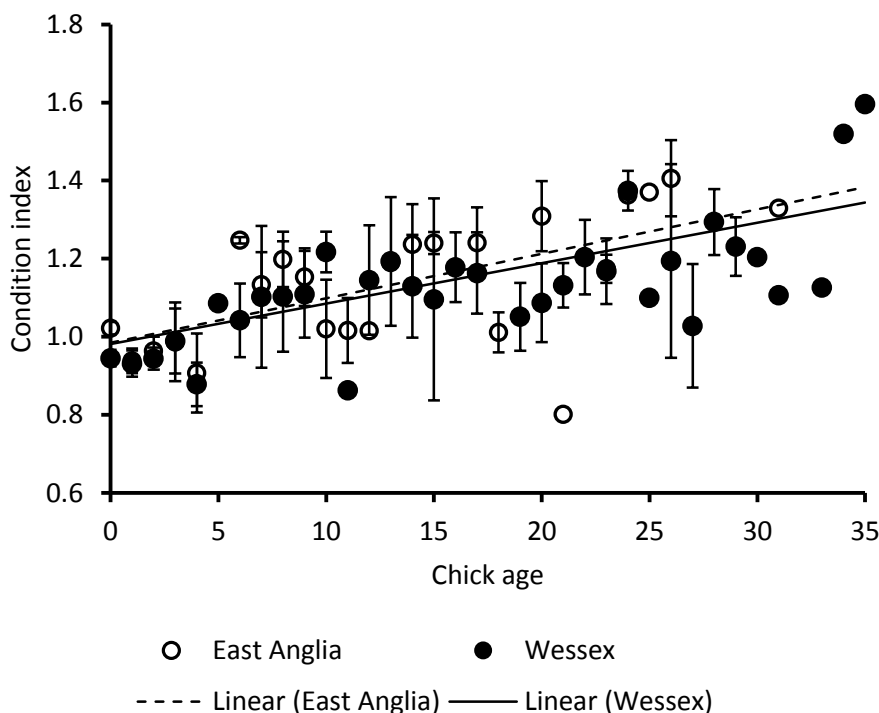
Chick death was confirmed by retrieving the radio-tag in 41 cases and in a further 44 cases chicks disappeared rapidly and predation was assumed. In these latter cases, there was no suspicion of radio failure: the batteries on a few radio-tags expired shortly before chicks fledged and the signals on these weakened gradually. Of the 85 deaths, causes were attributed as follows: 4.7% squashed by farm machinery or drowned in a ditch, 12.9% starved, 82.3% predated. In 37% of cases where predation occurred, predator identity was confirmed by retrieval of the radio-tag: 52% of known predation was by mammals (mainly foxes, as indicated by tags at the entrance of earths or the presence of scats next to remains or tags recovered within a scat) with 48% by birds (probably mainly raptors, as indicated by three tags retrieved from red kite nests and one from a buzzard nest).

5.5 Chick condition

A total of 191 lapwing broods was captured between 24 April and 9 July and 539 individual measures of chick biometrics were recorded. Mean residuals of chick weight per brood were higher in Wessex (0.117) than in East Anglia (-0.253), but did not differ between fallow plots and spring crops (GLMM region $F_{1,179.3} = 4.69$, $P = 0.032$, treatment $F_{1,246.8} = 1.08$, $P = 0.300$, year, date category, chick age not significant). There was no difference in mean residuals between crop types when crop type was substituted in the analysis instead of treatment (GLMM crop type $F_{6,232.5} = 0.81$, $P = 0.565$).

There was no difference in chick condition index between fallow plots and spring crops, but the difference between regions was close to significance and index values increased with chick age (GLMM treatment $F_{1,255} = 1.27$, $P = 0.261$, region $F_{1,255} = 3.56$, $P = 0.060$, chick age $F_{1,255} = 78.49$, $P < 0.001$; Figure 6). When analysed at the crop level, the difference between crop types was close to significance and values increased with chick age (GLMM crop type $F_{6,252} = 1.95$, $P = 0.074$, chick age $F_{1,252} = 76.55$, $P < 0.001$).

Figure 6. Chick condition index in relation to chick age.



5.6 Brood ranges and habitat use

Lapwing chick ranges in Wessex were typically small, with the majority of broods remaining within 100 m of where they were tagged. The overall mean (\pm sd) range area for both years was 2.16 ± 2.99 ha (range 0.01-17.17 ha). Chick range area was not related to age ($t_{41} = 0.88$, $P = 0.382$) or the number of radio-locations used to calculate the range area ($t_{41} = 1.58$, $P = 0.121$). Range area was larger in 2013 than 2012 (mean \pm sd, 2.13 ± 1.88 and 1.93 ± 4.23 ha respectively, $F_{1,40} = 5.40$, $P = 0.025$), but there was no difference in the range areas of chicks hatched on fallow plots and those hatched on spring crops (2.16 ± 2.04 and 2.18 ± 4.35 , $F_{1,40} = 0.49$, $P = 0.447$) and no interaction between year and treatment. Habitat use by radio-tracked lapwing chicks tagged on fallow plots in Wessex was not significantly different from random use in relation to available habitat (compositional analysis: Wilks' $\Lambda = 0.880$, $F_{4,18} = 0.615$, $P = 0.658$).

5.7 Lapwing chick diet and invertebrate availability

At least 20 invertebrate prey orders were present in the diet of lapwing chicks, but carabid beetles, other beetles, earthworms and woodlice dominated the diet in terms of numbers of prey items and biomass (Table 3).

Table 3. Estimated diet of lapwing chicks from analysis of 53 faecal samples collected from chicks on fallow plots and spring crop fields. Values are means \pm se.

Prey order	Estimated proportion of number of prey items (%)	Estimated proportion of dry weight of prey items (%)
Lumbricidae	10.59 \pm 2.86	24.57 \pm 5.01
Carabidae	20.10 \pm 3.38	31.11 \pm 4.45
Staphylinidae	5.49 \pm 1.47	2.93 \pm 1.16
Elateridae	0.25 \pm 0.25	0.16 \pm 0.16
Curculonidae	7.40 \pm 1.90	3.02 \pm 0.83
Scarabaeidae	0.65 \pm 0.59	0.15 \pm 0.11
Other adult Coleoptera	19.67 \pm 3.39	9.29 \pm 2.43
Coleoptera (larval)	5.33 \pm 1.86	4.05 \pm 1.44
Isopoda	8.18 \pm 2.93	12.87 \pm 3.80
Diplopoda	0.44 \pm 0.31	0.51 \pm 0.39
Dermaptera	0.34 \pm 0.26	0.51 \pm 0.37
Formicoidea	5.26 \pm 2.69	3.67 \pm 2.15
Araneae	3.69 \pm 1.10	1.92 \pm 0.77
Opiliones	0.14 \pm 0.14	0.09 \pm 0.09
Hemiptera	1.32 \pm 1.32	0.72 \pm 0.72
Lepidoptera (larval)	0.89 \pm 0.51	3.30 \pm 1.62
Symphyta (adult)	0.28 \pm 0.28	0.21 \pm 0.21
Diptera (adult)	6.71 \pm 1.97	0.86 \pm 0.33
Neuroptera (adult)	0.06 \pm 0.06	0.007 \pm 0.007
Stylommatophora	0.015 \pm 0.009	0.06 \pm 0.03

The mean number of corrected prey animals identified per sample was 11.1 ± 3.1 and the mean estimated dry weight of prey per sample was 45.5 ± 7.6 mg. There was no relationship between numbers of animals per sample and chick age and no difference in numbers of animals per sample between treatments (chick age $F_{1,49} = 2.01$, $P = 0.162$, treatment $F_{1,49} = 0.64$, $P = 0.428$). There was no difference in the diet composition of chicks caught on fallow plots and those captured in spring crops (Wilks' $\Lambda = 0.930$, $F_{4,47} = 0.88$, $P = 0.484$), but diet composition did differ between regions (Wilks' $\Lambda = 0.346$, $F_{4,47} = 22.18$, $P < 0.001$). Chick diets contained higher proportions of litter-active invertebrates (woodlice+millipedes+ants+earwigs) and spiders (spiders+harvestmen>true bugs) in East Anglia and higher proportions of worms and larvae (earthworms+beetle larvae+Lepidoptera larvae+snails) in Wessex.

Region, year and treatment all had independent, significant effects on total invertebrate abundance (ANOVA region $F_{1,156} = 41.08$, $P < 0.001$, year $F_{1,156} = 9.22$, $P = 0.003$, treatment $F_{1,156} = 4.40$, $P = 0.038$, interactions not significant). Invertebrate numbers were higher in East Anglia than Wessex (mean \pm se, 23.9 ± 1.7 and 12.9 ± 1.3 animals per trap respectively), higher in 2012 than in 2013 (20.9 ± 1.8 , 15.5 ± 1.4) and higher on fallow plots than on spring crops (19.4 ± 1.5 , 15.9 ± 1.6). The smallest category of invertebrates (size 3-10 mm), which was the most likely to be suitable food for lapwing chicks in the first week of life, comprised 72% of total invertebrate numbers. Region and treatment had significant effects on abundance in this category, with numbers again higher in East Anglia and on fallow plots (ANOVA region $F_{1,156} = 22.04$, $P < 0.001$, treatment $F_{1,156} = 7.10$, $P = 0.009$, mean \pm se fallow plots 15.0 ± 1.4 , spring crops 11.1 ± 1.3).

With crop type substituted for treatment, the region and year effects on total invertebrate numbers remained similar and a difference between crop types was observed (ANOVA crop type $F_{1,151} = 2.19$, $P = 0.047$). Invertebrate abundance was highest on grass (49.8 ± 41.8 animals per trap) and lowest on maize fields (10.4 ± 2.6), with fallow plots (19.4 ± 1.5) supporting similar or higher numbers of invertebrates than all crops except grass and beets+roots. A similar pattern was observed when the analysis was repeated on the smallest size class of invertebrates (ANOVA crop type $F_{1,151} = 2.95$, $P = 0.009$).

6. Discussion

The results of the two years of this study indicate that fledging rates of lapwings on fallow plots were not sufficient to maintain a stable population; nor were they significantly higher than those on alternative breeding habitat in the arable landscape. This is borne out both by the five-visit method estimating fledged chicks per pair of lapwings present, and by the modelling of nest and chick survival rates.

As expected, nest survival was high on fallow plots, with daily survival indicating that over 77% of nests survived to hatch. It was also significantly higher than on conventional crops, in keeping with a study of fallow plots in the Arable Stewardship Pilot Scheme (Sheldon *et al.* 2007). As is generally the case for waders, predation was the major cause of nest loss, and predation events were predominantly at night, or during dawn and dusk, indicating that mammals are the most common predators (MacDonald & Bolton 2008). However, given the low rate of nest predation, this is not a major issue. Fallow plots continue to act as highly suitable nesting habitat for lapwings. One aspect regarding nesting that might be worth considering is the value of fallow plots as late-season nesting habitat. Under current AES management guidelines in England, fallow plots are required to be prepared by March 20, and after that they do not receive any management until the

end of the lapwing breeding season (outside of specific derogations that might be requested by land managers; for example, to control pernicious weeds). By contrast, fallow plots for stone curlews are managed through the breeding season to maintain suitable amounts of bare ground to permit late nesting (Evans & Green 2007). While the lapwing breeding season begins earlier than that of stone curlews, vegetation growth on fallow plots for lapwings may be such that they do not provide ideal late-season nesting habitat, at a time when spring-sown crops will also have become unsuitable. The provision of such late nesting habitat may be important, even more so if it allows lapwings to re-nest following the death of young chicks, as double-brooding appears to be more important to this species than previously thought (Parish *et al.* 1997). This argument may be negated by reduced chick condition later in the season, possibly due to reduced abundance or availability of food: it has been suggested that in grassland, chicks may need to feed on earthworms to get sufficient food, and these may become less available later in the breeding season (Beintema *et al.* 1990).

Chick survival was very low, and the daily survival rate differed very little between fallow plots and conventional crops. Chick survival was not sufficient to maintain a stable population, even if nest survival were increased from its current, already high, rate. Chick daily survival rates of nearer 20% would be needed for sufficient productivity (MacDonald & Bolton 2008), although incorporating double-brooding into models of productivity may reduce this somewhat. Chick losses were mostly the result of predation or starvation, although these may interact: chicks in poor condition may be less able to escape predation, or may have to spend more time foraging, increasing exposure to predators. Nevertheless, it appears that both causes of mortality are important for lapwing chicks, and that fallow plots do not sufficiently mitigate either of these relative to conventional crops, even though plots held more invertebrates of suitable size for lapwing chicks. The results of this study do not indicate whether or not plots hold sufficient food items in absolute terms; the rates of starvation suggest possibly not, although deaths to starvation were probably inflated in 2012 due to extreme wet weather. Lapwings chicks have been found to feed preferentially on grassland elsewhere (Johansson & Blomqvist 1996), though that was not the case in this study. Chick condition was lower on grassland than arable land, though survival was (non-significantly) higher and invertebrate abundance was higher. However, sample sizes are small, and these analyses include all grass, not specifically short swards with wet features, which might be expected to provide high quality chick foraging habitat (Devereux *et al.* 2004), so these results do not rule out the possibility that provision of grass habitats near fallow plots may improve productivity.

Identification of predators is problematic in studies such as these, and even large-scale studies with intensive field work effort have a high proportion of predations for which no predator can be ascribed (Teunissen *et al.* 2008). We found evidence for both mammalian and avian predators of lapwing chicks, and therefore both must take some proportion of chicks. However, without further evidence, knowing what these proportions are is not possible. Based on evidence from this study, we can state that predation is a significant cause of mortality of lapwing chicks on arable farms, and fallow plots do not increase the likelihood that chicks will avoid being predated.

It is possible that lapwing productivity was atypical in the two study years in which field work was undertaken. The first year, 2012, saw a warm spring, prompting early laying, followed by record high levels of rainfall in both April and June. Cold and wet conditions in April are likely to have been detrimental to the synchronously-hatching first broods, reducing the time that small chicks could forage, and more chicks died of starvation in 2012 than 2013. However, overall chick survival and productivity were similar between years, and it may be that for chicks that were able to survive initial cold and wet conditions, 2012 provided more food, which may have been more accessible in

soft soils. The second year, 2013, was also a year of unusual weather, with an extremely cold spring leading to much more widespread spring planting of crops, delays to the preparation of fallow plots, and much later laying of first clutches, with several of these in winter-sown crops. There was one regional difference of interest observed; the low productivity of lapwings on control fields in the East Anglia region in 2013. Although not straight forward to explain, this does appear to be a real effect: field workers were the same in both years, so observer bias should not be an issue. East Anglia has a much higher proportion of root crops than Wessex, and it may be that these were affected in some way that meant that they were less suitable to lapwings, or more likely to harbour predators. Data collection of lapwing chick survival on fallow plots has continued in the two study areas in 2014, and this should give some indication as to whether the two years documented here are abnormal.

The results of this study indicate that fallow plots currently act to increase lapwing hatching success, but that they have no effect on lapwing chick survival, and therefore their benefits to overall productivity are limited. In this, they reflect the performance of AES in England on other habitats outside of nature reserves (Smart *et al.* 2013, 2014). Keeping in mind the caveat that highly unusual weather occurred in both years (but that continued data collection should indicate whether this had an effect on the results), the major question that arises out of these results is: are there any changes that could be made to fallow plots that would increase lapwing productivity? One possibility might be more active management of plots, as suggested above, to increase the possibility of lapwings re-nesting. Other options that might improve chick survival include plot management to make them both more attractive for lapwings (increasing the likelihood that chicks remain on plots) and to increase chick survival on plots: for example, allowing vegetation to grow on part of the plot might increase chick food availability and/or provide cover from predators. Another option is the exclusion of mammalian predators by fencing, which has been shown to improve productivity in other studies (Rickenbach *et al.* 2011, Malpas *et al.* 2013). This has been trialled in the same study areas in 2014, with a second year projected in 2015 to collect sufficient data to determine whether fences have an effect. A third option is the provision of suitable chick-rearing habitat close to fallow plots. This option reflects the reality that chicks often move off plots, even when these plots appear to be suitable; on some plots, some broods leave, and other remain. Where chick survival plays such an important part in the overall productivity of lapwings on any given farm, but chicks are mobile, then it may be unreasonable to expect fallow plots to deliver for both the egg and chick stages of lapwings. Current evidence is that fallow plots do deliver high quality nesting habitat, which is how they were originally conceived: they also have additional benefits to biodiversity (MacDonald *et al.*, 2012). However, recent evidence, including from this study, has shown that this is not sufficient for lapwing populations on arable land, and the more difficult issue of chick survival needs to be addressed. If this is to be done within AES via the option of fallow plots, then consideration needs to be given to what management is required to increase chick survival. If not, then alternative AES options may need to be developed, presumably to complement fallow plots rather than replace them.

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