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Effects of the proportion and spatial arrangement of un-cropped land on breeding bird abundance in arable rotations

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Summary

1. The response of bird abundance to the proportional availability of un-cropped land (i.e. land that could be cultivated, such as fallows, grass–flower or wild bird areas) is under-studied but of considerable significance for managing declining populations on farmland in western Europe.

2. In this study, bird abundance was examined at a scale consistent with many national monitoring schemes. Birds were counted on 28 farm sites of *c*. 100 ha, representing cereal-based and organic rotations. Sites were surveyed in summer, from 2007 to 2010, to assess the effect of the percentage cover and spatial arrangement of un-cropped land on bird abundance, with data analysed at the whole-farm (not patch) scale.

3. Un-cropped land area had significant effects on the abundance of key species (those with a high dependency on farmland) when controlling for effects of semi-natural habitats and management. On farms with < 3% of their total area as un-cropped land, the densities of birds were significantly lower than on farms with > 10% area of un-cropped land.

4. Positive, significant effects of the percentage area of un-cropped land were detected for lapwing, skylark, linnet and yellowhammer and for all highly farmland-dependent species combined. The relationship between un-cropped land and bird abundance was stronger on conventional compared with organic farms, suggesting a greater importance of un-cropped land on conventional farms.

5. Un-cropped land patch arrangement was significant for skylark and linnet abundance but generally weak amongst species compared with the availability of un-cropped land. Skylarks were positively associated with a larger relative edge effect amongst patches, whereas linnets were more associated with larger blocks of contiguous habitat.

6. *Synthesis and applications*. This study provides important evidence for a proportionate effect of habitat provision on farmland bird abundance. The relative area of un-cropped land had the strongest effect on bird abundance. Sites with < 3% (and, to a lesser extent, < 5%) un-cropped land were highly under-populated. A two-fold increase in the area of un-cropped land was associated with an average 16–53% increase in the relative abundance of key species, which has implications for the contribution of un-cropped areas towards population stabilization amongst farmland birds in Europe.

Key-words: agri-environment scheme, farmland, linnet, organic farming, population monitoring, set-aside, skylark, yellowhammer

Introduction

After almost two decades of research into farmland birds across Europe (Primdahl 1993; Kleijn *et al*. 2011), there has been considerable progress in identifying mechanistic and demographic constraints on bird populations (Robinson & Sutherland 1999; Siriwardena, Baillie & Wilson 1999; Bro *et al*. 2000; Siriwardena *et al*. 2006; Wretenberg *et al*. 2006). Despite this progress, stabilizing national populations of declining species has proved frustratingly elusive as

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populations continue to decline in many western European countries (Voříšek *et al.* 2010; Kleijn *et al.* 2011).

Huge demands on production and massive changes in land-use practice (Donald *et al.* 2006) continue to conflict with efforts to maintain viable populations of wildlife on European farmland (Green *et al.* 2005; Stoate *et al.* 2009). In England, for example, dedicated agri-environmental (AE) prescriptions have been available to farmers since 2002, and 70% of arable farms are now in such an AE scheme (Defra 2010a). However, populations have continued to decline, although the combined rate of decline amongst monitored species slowed and virtually stabilized during the late 1990s and early 2000s (Defra 2010b). One factor that may have contributed to this observed reduction in species declines is the introduction of un-cropped 'set-aside' land, together with a considerable increase in local government and European Union (EU) resources for research and farmer advice, aimed at improving efficacy amongst AE prescriptions (Kleijn *et al.* 2001; Kleijn & Sutherland 2003; Vickery *et al.* 2004a; Feehan, Gillmor & Culleton 2005; Hinsley *et al.* 2010). Owing to Common Agricultural Policy (CAP) reforms, set-aside appeared in western Europe on an unprecedented scale from 1992 to 2007. In the UK, set-aside exceeded 15% of the cropped area at its peak, affecting virtually all arable farms, in addition to true AE schemes (Gillings *et al.* 2010). Although not typically managed for wildlife, there is considerable evidence that set-aside, on average, supported a greater abundance of birds than equivalent cropped areas (Gillings *et al.* 2010), thereby potentially raising the carrying capacity of farmland. When zero rate set-aside was introduced by the EU in 2007, in some regions, an 80% loss of cereal winter stubbles was incurred by 2008 (Gillings *et al.* 2010). In the UK, replacement AE prescriptions for farmers, since 2005 have not matched this scale of loss (Davey *et al.* 2010a,b), and although circumstantial, a faster rate of decline amongst monitored bird populations (Defra 2010b) has been concurrent with this change.

Europe is faced with enormous changes in land use; therefore, landscape- and habitat-scale effects on biodiversity are high on the research agenda (Kleijn *et al.* 2011). In the past, the influence of habitat scale (proportion and extent) on farmland bird abundance has been overshadowed by research on habitat composition (e.g. Aebischer *et al.* 2000; Vickery *et al.* 2004b; Siriwardena 2010). The EU's future vision is to halt biodiversity decline by 2020. Amongst its CAP reforms are proposals to designate 7% of farmland (including hedges) to ecological focus areas (EU 2011), yet the evidence supporting such decisions is difficult to verify (cf. Davey *et al.* 2010a).

In 2006, the 'Farm4bio' project was set-up specifically to investigate the relationship between wildlife populations and the quantity and configuration of un-cropped land (land that could otherwise be cultivated). Farmland-dependent bird species were expected to respond positively to un-cropped land, as the loss of un-cropped land is one characteristic of intensive farming in Europe (Chamberlain *et al.* 2000; Donald *et al.* 2006). The scale of observation used in the study was selected on the basis that it was relevant to several national monitoring schemes in Europe.

Materials and methods

STUDY DESIGN

The field study was replicated across 28 farm 'sites' located in eastern (EA) and southern (WX) England. The sample represented varying soils types and landscapes for wide applicability across arable land in England. Rotations were predominantly winter-sown, conventional crops (winter wheat, barley and oil-seed rape), although four organic farms comprised higher proportions of rotational grassland. Each site approximated to the 100-ha scale and was prepared as one of seven treatments (Table 1): (i) 6 ha of project-managed un-cropped land arranged in strips (*c.* 6% was initially considered a maximum 'acceptable' to farmers and sufficiently contrasting against the lower ¼ rate (1·5-ha below), (ii) 1·5 ha of project-managed un-cropped land arranged in strips, (iii) 6 ha of project-managed un-cropped land arranged in 1–2 blocks, (iv) 1·5 ha of project-managed un-cropped land arranged in one block, (v) 6 ha of farmer-managed un-cropped land, (vi) 1·5 ha of farmer-managed un-cropped land, (vii) organically managed site with 1·5 ha of farmer-managed un-cropped land.

Treatments 1–6 provided a crossed 3×2 design, allowing the effects of the spatial arrangement and the proportionate area of un-cropped land to be separated. On 14 sites (treatments 1–4), plots of un-cropped land were sown specifically to enhance plant and invertebrate diversity beyond statutory measures of 'cross-compliance' (http://www.defra.gov.uk/crosscompliance). Ten 'control' sites had 'normal' farmer-managed treatments 5 and 6 (Table 1) and managed to meet the statutory minimum requirements of cross-compliance. The treatments were replicated across sites and regions, also allowing comparison between conventional and organic-farming regimes (treatment 7).

Managed and control areas of un-cropped land were established between 1996 and early 2007, so that the age of newly sown habitat was constant. Un-cropped land in treatments 1–4 comprised: (i) a pollen/nectar provider as 'floristically enhanced grassland' (FEG); (ii) a wild bird seed mixture (WBS) providing bird cover and winter bird food (cereals, brassicas and quinoa); (iii) insect-rich cover (IRC) providing invertebrate food in the breeding season (a cereal and vetch mixture); and (iv) annually cultivated natural regeneration (NR); (mean of 0·4 ha per site of each mix, i–iv). Across sites, there were varying proportions of existing un-cropped land. Annual digital maps of cropped and un-cropped land (treatment and existing) were produced giving the area and perimeter length of every patch of land including ditches, hedgerows, woodland edges and tree lines (see Analysis for all variables measured).

BIRD COUNTS

Birds were counted on all sites, by three fully trained observers, in one visit each in April, May and June, from 2006 to 2010. Each visit was standardized as whole-area searching for *c.* 4 h of duration, in which all birds seen or heard were mapped. To maintain accuracy in counting, visits avoided winds exceeding Beaufort Force 4 (light breeze) or persistent heavy rain. Flying birds that were foraging over the site were included (e.g. kestrel *Falco tinnunulus* L.). For further consistency and to avoid double-counting, birds were recorded at the

Table 1. Land-use composition of 28 farm sites sampled during the present study

Site name (ID)	Treatment	Some patches project managed?	Site area of cropped and un-cropped land (ha)	No. of fields of crops or grass	Content of the cultivatable area (as a rounded % of column '4')								Additional features			
					WC	OSR	SC	Other	SAS/ Fallow	Grass	Total un-cropped	Grass margins	Semi-natural (ha)	WBC/Game crops (ha)	Wood-land (ha)	Hedge to area ratio (m ha^{-1})
EA-2	1	Yes	107.2	8	55	17	12	0	2.3	0.0	10.9 (6.4)	3.8	0.4	1.35	3	41
EA-16	1	Yes	114.0	9	60	13	8	0	3.4	1.9	6.8 (6.8)	2.4	3.0	1.06	3	77
EA-19	2	Yes	90.9	9	58	18	8	0	1.9	1.4	7.6 (1.4)	3.0	3.5	1.03	3	50
EA-5	2	Yes	104.5	6	65	0	23	0	0.0	0.0	6.0 (1.6)	2.4	0.6	0.36	0	60
EA-8	3	Yes	123.2	5	40	14	18	1	2.1	4.2	10.3 (7.4)	0.4	7.6	3.92	3	8
EA-21	3	Yes	153.4	7	33	35	3	7	1.5	4.6	7.3 (9.2)	0.8	5.8	5.20	9	8
EA-14	4	Yes	128.0	12	60	23	9	0	0.0	2.0	2.2 (1.9)	0.1	0.9	0.86	2	70
EA-6	4	Yes	77.9	9	60	19	0	0	0.0	0.0	11.0 (1.2)	9.4	0.0	0.32	3	61
EA-24	5	Control	122.1	10	66	20	8	0	0.3	0.8	2.6 (0)	2.4	0.8	0.00	0	71
EA-10	5	Control	102.4	17	61	31	0	0	2.6	0.0	4.8 (0)	1.2	0.0	0.45	1	68
EA-13	6	Control	113.3	8	49	27	16	0	0.0	3.9	1.4 (0)	1.4	0.0	0.00	0	75
EA-23	6	Control	93.2	4	30	12	43	0	0.6	0.0	6.0 (0)	3.7	0.0	0.00	5	41
EA-26	Org		122.7	10	55	0	15	26	1.5	1.5	5.2 (0)	1.8	0.4	0.00	6	63
EA-25	Org		98.2	10	16	0	49	21	2.4	6.0	4.3 (0)	2.9	1.0	0.75	3	68
WX-8	1	Yes	106.8	4	39	8	29	18	0.0	0.0	6.0 (6.0)	0.0	2.2	1.80	2	32
WX-9	2	Yes	110.8	7	44	10	25	0	0.0	0.0	10.2 (0)	5.6	4.2	1.03	3	41
WX-10	2	Yes	111.5	11	47	18	4	14	0.1	0.0	7.5 (1.7)	6.7	2.0	0.20	0	69
WX-3	3	Yes	80.0	7	51	6	17	3	0.0	11.8	9.6 (4.8)	2.8	1.0	1.40	2	69
WX-4	3	Yes	113.4	7	30	31	29	0	8.1	0.0	8.8 (6.8)	0.0	0.8	1.40	1	20
WX-11	4	Yes	120.0	6	57	18	15	0	0.0	0.0	7.3 (1.8)	3.3	0.0	2.87	0	20
WX-1	5	Control	104.1	8	19	12	61	0	3.5	0.0	4.1 (1.6)	1.9	0.7	0.00	1	53
WX-5	5	Control	89.1	8	31	31	28	0	0.0	0.0	0.7 (0)	0.0	0.2	0.10	5	11
WX-7	5	Control	107.4	9	57	6	9	0	16.3	6.7	1.7 (0)	0.1	3.1	1.73	5	30
WX-2	6	Control	105.4	7	49	19	25	0	0.0	0.3	0.5 (0)	0.6	1.6	0.03	6	64
WX-6	6	Control	98.8	10	45	46	4	0	0.0	0.0	1.4 (1.4)	0.0	0.0	1.20	5	34
WX-12	6	Control	114.8	7	47	35	10	5	0.9	0.0	6.0 (6.0)	3.1	1.0	0.00	0	38
WX-13	Org		115.4	9	24	0	27	0	0.0	37.6	5.4 (0)	3.2	2.3	2.50	4	40
WX-14	Org		95.4	7	0	0	19	0	0.0	69.0	6.3 (0)	5.3	0.1	0.10	3	66
Means			108.0	8.2	44.6	16.7	18.3	3.4	1.7	5.4	5.7	2.4	1.5	1.1	2.8	48

Values include the percentage allocation of the total area at each site (column 4) to crops and un-cropped land (columns 6–13). Under 'Total un-cropped land', the percentage area of the whole site that was 'project managed' is given in parenthesis (not additional to 'Total un-cropped land'). Crop types are winter cereals (WC), spring cereals (SC), oilseed rape (OSR), Other (pulses and sugar beet), set-aside (SAS), grass (for grazing or silage). The grass margins were permanent or semi-permanent features, which potentially were cultivatable but here were a component of un-cropped land along with the seed producing wild bird crops (WBC).

location where they were first detected, and care was taken to avoid recording the same individuals twice.

ANALYSIS

Bird species and species groups

Bird data were analysed as individual species and in the following groups: (i) UK Biodiversity Action Plan (BAP) species, (ii) UK farmland bird index (FBI) species, used by the UK government as one measure of environmental change; and three newly defined species groups, as follows: (i) Species declining, with relatively high dependency on farmland, of special conservation interest as UK BAP species owing to long-term population declines. This group included kestrel, lapwing *Vanellus vanellus* L., grey partridge *Perdix perdix* L., skylark *Alauda arvensis* L., yellow wagtail *Motacilla flava* L., linnet *Carduelis cannabina* L., yellowhammer *Emberiza citrinella* L., corn bunting *E. calandra* L. and partly reed bunting *E. schoeniclus* L.). These species have contributed most to the declining FBI. (ii) Species contributing to the FBI whose populations have been 'stable or increasing' in the last 10 years (i.e. woodpigeon *Columba palumbus* L., stock dove *C. oenas* L., rook *Corvus frugilegus* L., jackdaw *C. monedula* L., whitethroat *Silvia communis* L., goldfinch *Carduelis carduelis* L., greenfinch *C. chloris* L.). Finally, (iii) a group of five BAP species, under decline but with a *lower dependency* on farmland owing to large populations occurring in woodland or urban environments (i.e. dunnock *Prunella modularis* L., song thrush *Turdus philomelos* Brehm, starling *Sturnus vulgaris* L., house sparrow *Passer domesticus* L., and bullfinch *Pyrrhula pyrrhula* L.). Turtle dove *Streptoplilia turtur* L., and tree sparrow *Passer montana* L., were excluded owing to very low counts.

Statistics

Analyses used generalized linear mixed models (GLMM; SAS 2006) with Poisson or negative-binomial distributions (using the best fit) and log-link error terms. Annual mean bird counts (across the three visits per year) were analysed at the site level using a log-area offset variable to account for real differences in site area (Table 1). 'Year' was added as a categorical variable and 'observer' entered as a random effect (controlling for observer effects). Preliminary tests for colinearity between explanatory variables meant variables correlated at $r = 0{\cdot}7$ or above were not entered into the same model statement as such effects can cause the signs of the regression coefficients to be counter-intuitive (Christensen 1990). To control for influences of the adjacent landscape, models included the percentage area of arable land ('%arable land') occurring in the surrounding 3 km^2 of each site, and hedgerow 'linear density' (the hedgerow-to-area ratio of the site: HAR) as landscape complexity can mitigate biodiversity loss (Tscharntke *et al.* 2005; Koh *et al.* 2010). Binomial tests were used to assess proportional differences across species groups in the collective direction of species-specific responses to the total availability of un-cropped land.

Bird abundance and the total percentage area of un-cropped land

First, the analyses concentrated on the experimental treatments only, with the area of un-cropped land entered as a categorical variable. The basic model structure included Bird annual mean = year + region + treatment + %arable land + HAR of the site. Second, a series of models replaced the categorical variable 'un-cropped land', from the treatments, with a continuous variable based on the total percentage area of un-cropped land available per farm (i.e. treatment areas plus existing areas of un-cropped land, termed '%area un-cropped land'; Table 1). The basic model structure was Bird annual mean = year + region + %area un-cropped land + %arable land + HAR. Year*region and year*%un-cropped land interactions were not significant and not retained in the final model. In 2007, delayed establishment of vegetation in treatment habitats restricted the analysis of the treatments *per se* to 2008–2010, consistent with the configuration analyses below and with the timing of parallel plant studies (Holland *et al.* 2011). However, birds began using patches of un-cropped land prior to full establishment, so the analytical period for the total area of un-cropped land included 2007, to improve analytical power. Disturbance prevented 2006 being included. Additional variables that were manually added to basic models were the areas of crop types, field margins, additional semi-natural habitats (scrub/pond-edge vegetation), WBS, FEG, IRC and NR (all were present at each site); plus ditch length and 'farm type' (conventional versus organic) and management (project versus control).

Bird abundance and the spatial arrangement of patches of un-cropped land

The structure of the total area of un-cropped land within each site, in terms of blocks or strips of land, was defined by the average perimeter-to-area ratio of patches (i.e. a smaller ratio for larger blocks). The basic model structure was as follows: Bird annual mean = perimeter-to-area ratio of patches + mean patch-area + total number of patches/site. Additional site variables were HAR, area of semi-natural habitat and '%arable land' (the landscape variable).

Results

THE AREA AND CONFIGURATION OF UN-CROPPED LAND AS SITE CHARACTERISTICS

Bird abundance and percentage area of un-cropped land

Effects from the analysis of the experimental treatments were weak but found significant effects for stock dove (treatment 3 – managed, larger blocks; $P < 0{\cdot}05$), linnet [treatments 3 and 7 (organic); $P < 0{\cdot}01$], rook and goldfinch (both treatment 7; $P < 0{\cdot}05$). For the continuous variable '%area un-cropped land' analytical effects were much stronger. Thus, between 2008 and 2010 there were positive, significant effects detected for lapwing, linnet and yellowhammer, and the declining, high dependency species (Table 2). For the period 2007–2010, statistically significant effects were again detected for linnet and yellowhammer (Table 2), and for BAP and FBI species as combined groups (LR, $\chi^2 = 16{\cdot}3$ and LR, $\chi^2 = 16{\cdot}7$, respectively; $P < 0{\cdot}01$). For both periods, the relationship for skylark approached significance. There were significant effects of organic farms for lapwing, woodpigeon, skylark, rook and goldfinch (Table 2). Thus, for conventional farms only, the relationship between bird abundance and %area un-cropped land was slightly stronger for BAP and FBI species (LR, $\chi^2 = 16{\cdot}0$, $P < 0{\cdot}0002$ and LR, $\chi^2 = 14{\cdot}2$, $P < 0{\cdot}0003$, respectively, 2007–2010) and for skylark the relationship was

Table 2. Regression analyses examining habitat effects on bird densities

	(a) Model explanatory variables								(b) Model explanatory variables									
			Total % area of un-cropped land†						Farm type		Crops				Un-cropped land type			
Species (groups)	Year	Region	2007-2010	2008-2010	%arable	HAR	*N*	Model fit	MNG	ORG	WC	SC	OSR	Pulse	NR	WBC	FEG/IRC	Model fit
Declining populations and of high farmland dependence																		
Kestrel(BAP, FBI)		*	+	+			0·35	0·56							+**			0·48
Grey Partridge(BAP, FBI)			–	–			0·75	0·99							+*EA			0·99
Lapwing(BAP, FBI)	***		$+^{0\cdot06}$	+*			0·95	1·58		+**		+**		+*	+***			0·76
Skylark(BAP, FBI)	*		$+^{0\cdot10}$	$+^{0\cdot08}$	+*		7·67	0·98		+**	–*							0·98
Yellow Wagtail(BAP, FBI)		**	+	+			0·33	0·68										0·53
Linnet(BAP, FBI)	**		+**	+**			7·22	0·97									+*	0·97
Yellowhammer(BAP, FBI)			+**	+**		+*	9·40	0·99							+*	+(*)		0·99
Reed Bunting(BAP, FBI)	*		+	+			1·15	1·67							+(*)EA			1·46
Corn Bunting(BAP, FBI)			+	+			0·64	0·49							+**			0·49
Combined			+***	+**				1·07										
Declining populations of low-to-medium farmland dependence																		
Song Thrush(BAP)	***		–	–			1·98	0·98										0·86
Dunnock(BAP)			+	–			6·71	0·99										0·99
Starling(BAP, FBI)	**	*	–*	–			2·10	1·67	– (*)		–*							0·82
H. Sparrow(BAP)			+	+			3·78	0·88										0·88
Bullfinch(BAP)			–	–			0·85	0·85										0·85
Combined			*ns*	*ns*				0·97										1·01
Stable or increasing populations																		
Woodpigeon(FBI)	***	**	+	+			73·03	0·98		+**		+(*)	+*	+(*)				0·98
Stock Dove(FBI)	***	***	+	+			2·74	0·86										1·06
Rook(FBI)	*		+	–			13·55	0·90		+*	+*							0·90
Jackdaw(FBI)	***		+	–			3·19	0·90										0·88
Whitethroat(FBI)		**	+	–			6·31	0·94										0·94
Greenfinch(FBI)	***	**	+*	–			3·76	1·03										1·03
Goldfinch(FBI)			+	–	+*		3·22	1·01		+*								1·00
Combined			+**	*ns*				0·99										0·99

In a) a basic model examines the effect of the total percentage area of un-cropped land on bird abundance on farms between 2007 and 2010 and between 2008 and 2010. Models control for year effects (Year), regional effects (Region), observer differences (random effect not shown), the percentage area of arable land present in the surrounding 3 km ('% arable'), and 'hedgerow-to-site-area ratio' (HAR). In b), the analysis examines additional effects of farm management as the difference between sites with project-managed versus farmer-managed (control) patches of un-cropped land (MNG, where '+' is a positive effect for project-managed sites) and whether sites were conventionally or organically managed (ORG, where '+' is positive for organically managed farms). The analysis shows the effects of crop types [winter cereals (WC), spring cereals (SC), oilseed rape (OSR), pulses and grassland (Grass)] and the content of managed areas of un-cropped land [winter bird crops (WBC), natural regeneration patches (NR) and floristically enhanced grass/insect-rich cover (FEG/IRC)]. Notation: + positive effect and – negative effect, with the superscript $*P < 0{\cdot}05$, $**P < 0{\cdot}01$ and $***P < 0{\cdot}001$. Parenthesis = relationships where $P \leq 0{\cdot}07$, that is, approaching statistical significance. Blank 'entries' are nonsignificant results where $P > 0{\cdot}07$, except for the un-cropped land columns where the levels of probability are shown, at or below $P = 0{\cdot}1$, to help with comparative interpretations discussed in the main text. All models incorporate Poisson or negative-binomial (log-link) error terms according to the best fit ('Best model fit' where ideally values = 1). EA = an effect for the eastern region only. BAP = species where UK Biodiversity Action Plan is in place; FBI = species contributing to the UK Farmland Bird index. *N* = annual mean count per site.

significant (LR: $\chi^2 = 6{\cdot}0$, $P < 0{\cdot}02$, 2007–2010). Generally, the positive response towards un-cropped land was strongest on conventional farms. For lapwing and rook, the effect of %area un-cropped land dropped out of the model, suggesting that the organic rotation (more grassland) was important for these two species.

For species highly dependent on farmland, the proportion of positive to negative effects (whether significant or not) was significant for both periods 2007–2010 and 2008–2010 (Binomial test, $P < 0{\cdot}04$, $n = 9$; Table 2). For stable or increasing species, the results depended on whether the 2007 data were included (Binomial test: 2007–2010, $P < 0{\cdot}001$, $n = 7$; 2008–2010: $P < 0{\cdot}45$; Table 2). For species that are less dependent on farmland, there were no significant effects of %area un-cropped land despite more negatives than positives (Table 2). Overall, a positive effect for un-cropped land was detected for 17 of 21 species (Binomial test, $P < 0{\cdot}006$) for 2007–2010 and 11 of 21 species for 2008–2010 (Table 2), so the response to un-cropped land was strongest amongst the highly dependent declining species, both collectively and individually.

In general, farms with an area of un-cropped land below 3–5% supported significantly lower densities of birds than farms with areas of 10% or more (Fig. 1). This response was strongest for the declining, farmland-dependent species (Fig. 1b), and for BAP species and FBI species (Fig. 1c). The differences between categories of the area of un-cropped land were significant for the combined declining species (LR, $\chi^2 = 11{\cdot}3$, $P < 0{\cdot}001$), and for skylark (LR, $\chi^2 = 3{\cdot}84$, $P < 0{\cdot}05$), linnet (LR, $\chi^2 = 7{\cdot}30$, $P < 0{\cdot}0004$) and yellowhammer (LR, $\chi^2 = 4{\cdot}04$, $P < 0{\cdot}006$); and for BAP species and FBI species (LR, $\chi^2 = 11{\cdot}6$, and LR, $\chi^2 = 45{\cdot}6$, respectively, where $P < 0{\cdot}001$). Differences in bird densities were not significant for species that were less dependent on farmland or for species with stable or increasing populations.

Additional effects

The effects of crop type and different un-cropped habitats on species are presented in Table 2. Non-rotational grass margins were positive and significant for five high dependency species (kestrel, grey partridge, yellowhammer, reed bunting and corn bunting) and for lapwing and reed bunting in EA region only. Lapwing showed a strong positive association with spring cereals and pulses (commoner in organic rotations; Table 1), and woodpigeon with oilseed rape and pulses. Yellowhammer showed a significant association with winter bird seed and HAR, and linnet was associated with floristically enhanced grass (Table 2).

There were no significant differences between project and control farms (Table 2), but between years, the rate of decline amongst birds was marginally slower on project-managed compared with control sites, although again the differences were not statistically significant (Fig. 2). There were no significant effects of species richness or diversity (Shannon diversity index) relative to any of the environmental variables measured or between sites (normal errors: P range 0·84–0·12).

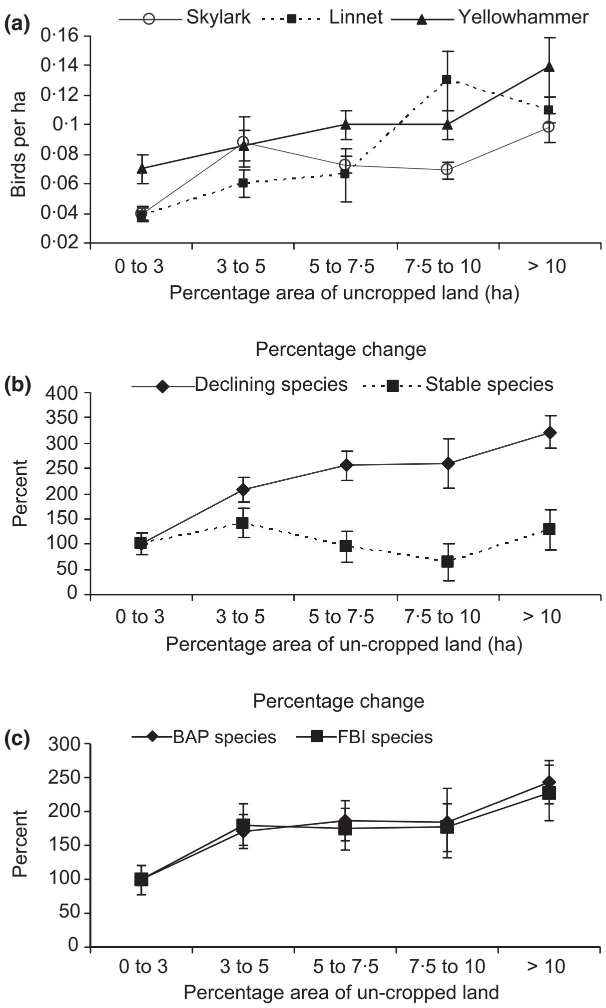

Fig. 1. Densities of bird species or groups relative to five classes of '%area un-cropped land'. In (a) densities are shown for three species of conservation concern in England (±95% CI). In (b) and in (c) for combined-species groups, the percentage differences in density (averaged across species) is calculated relative to the 0–3% category ('anchored' at 100). BAP, Biodiversity Action Plan species; FBI, Farmland Bird Index species. Both 'declining' (highly farmland-dependent, declining species) and 'stable' (stable or increasing species) groups are further described in the methods. X-axis intervals are selected to provide balanced sample sizes between categories and information on the upper and lower extremes of the availability of un-cropped land in this study.

Bird abundance and the spatial arrangement of un-cropped land

The effect of perimeter-to-area ratio of patches of un-cropped land within sites (note, not the HAR of the site) was statistically significant for skylark and linnet. For skylark, '%area un-cropped land' and the patch-level perimeter-to-area ratio of un-cropped land together were both positive and highly significant (Poisson error: $F = 10{\cdot}2$, $P < 0{\cdot}003$; $F = 8{\cdot}6$, $P < 0{\cdot}005$) suggesting that '%area un-cropped' was important when controlling for relative patch edge effect, and that a larger relative edge effect (typically strips rather than blocks) was important for a given area of un-cropped land. For linnet,

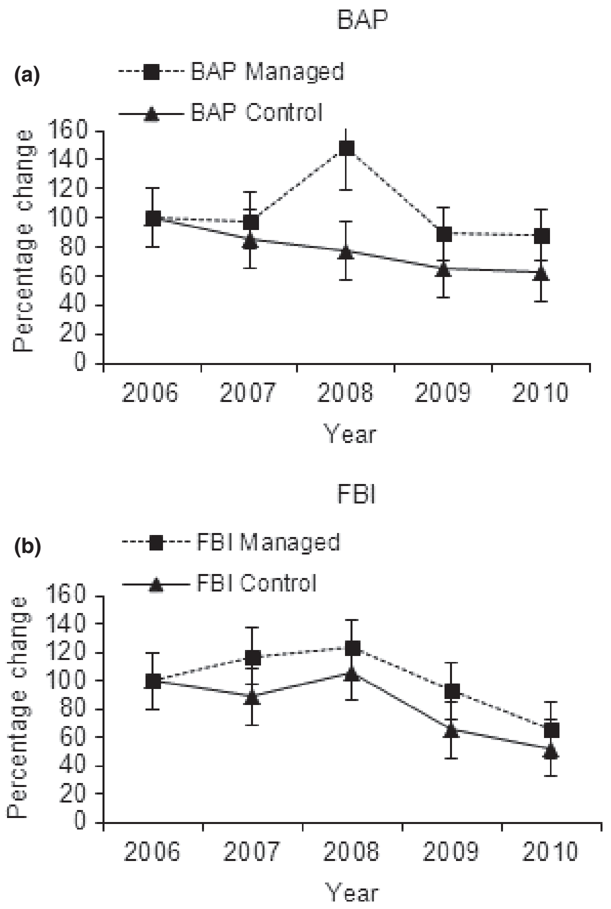

Fig. 2. Trends from 2006 to 2010 showing the percentage change in mean bird densities per ha, relative to 2006 for: (a) Biodiversity Action Plan (BAP) species and (b) Farmland Bird Index (FBI) species. The data show trends for sites where un-cropped land was project managed relative to farmer-managed sites (±95% CI).

the patch-level perimeter-to-area ratio was significantly negative (negative-binomial error: $F = 5{\cdot}8$, $P < 0{\cdot}01$) when controlling for the %area un-cropped land ($F = 7{\cdot}5$, $P < 0{\cdot}008$) indicating that this species occurred at higher abundance where larger blocks of contiguous habitat were available. For other species, including yellowhammer with a good sample size, there was no significant effect of patch size, patch number or patch-level perimeter-to-area ratio.

Discussion

MAIN EFFECT, CAVEATS AND CALIBRATIONS

Controlling for the presence of semi-natural habitats (Kleijn *et al.* 2011), management criteria and year effects, we provide important evidence of a proportional effect of habitat quantity on farmland bird abundance at a sampling resolution consistent with many annual bird-monitoring schemes in Europe (Voříšek *et al.* 2010). On cereal-based rotations, which are common across western Europe, the strongest and most detectable effect on bird abundance was the total area of un-cropped land, this effect was greater for conventional than for organic farms. Farms with <5% (with a further decline observed for farms with <3%) of un-cropped land (not including semi-natural habitats) held significantly smaller populations of farmland-dependent bird species (especially skylark, linnet and yellowhammer) compared with farms with 10% or more un-cropped land area. Farms with 10% or greater area of un-cropped land supported bird populations that were *c.* 60% larger. Generally, the most significant correlate for bird abundance, at this scale of sampling, was the availability of un-cropped land (which was, on average, under a low level of management for biodiversity). This was not true for other potentially important and accurately measured variables, including crop types, hedgerows, landscape characteristics or predator control, although each variable (except predator control) was significant for at least one bird species. In parallel studies, there was no consistent relationship between birds at the 100-ha scale and plant or invertebrate abundance measured within patches of un-cropped land (Holland *et al.* 2011). This result was probably due to mismatches in the scale of sampling (100 ha versus patch). There were indications that birds responded more positively to the availability of patches of un-cropped land which were specifically managed to enhance biodiversity (Fig. 2), where the total proportionate area of these habitats was maintained.

The abundance of linnets, yellowhammers and skylarks provided sufficient analytical power to detect relationships that were also present in other species, but were not statistically significant at the individual species-level. However, declining species that are highly dependent on farmland collectively showed a positive relationship that was absent amongst the less farmland-dependent species, but consistent with our expectations. It is conceivable that management activities pertinent to the requirements of skylark, linnet and yellowhammer would help improve conditions for the other species, as these three species represent a broad range of ecological traits that are shared by the other highly farmland-dependent species.

The present study found the spatial arrangement of un-cropped to have a weak influence on bird abundance. Skylarks' association with a larger area and edge effect suggested that large contiguous patches or smaller dispersed patches of habitat may serve a similar function in supporting territories, but that dispersed patches may offer greater edge-related heterogeneity, such as bare-ground (Schaub *et al.* 2010). By contrast, linnets, a species that is more aggregated and less territorially dispersed than skylarks (Moorcroft *et al.* 2002) were commoner in less spatially dispersed, contiguous habitat patches. We speculate that habitats arranged optimally for territorially dispersed species, such as skylark, would be discovered by the roaming, aggregating species provided that the total area of availability was maintained.

In this study, species densities on farms with <3% un-cropped land were 50–60% lower than mean estimates for densities from the national monitoring scheme in the UK (the BTO/RSPB/JNCC Breeding Bird Survey or 'BBS'; Gregory, Baillie & Bashford 2004). Based on similar methods, estimates from the present study were 0·04, 0·04 and 0·07 birds ha^{-1} for skylark, linnet and yellowhammer, respectively, compared with 0·1 (CI = 0·04–0·15), 0·11 (0·014–0·143) and 0·14 (0·1–0·25) birds ha^{-1} for the BBS over the same time period (2007–2010), during which the proportional area of un-cropped in England fell to or below 4% (Defra 2010a; the exact value being difficult to verify). Over the same period, the FBI in England declined by around 10% (Defra 2010b) and although not a test of cause and effect, the implications are that population stability or recovery may be difficult to achieve under scenarios of low un-cropped area. In an earlier study, Gillings *et al.* (2005) showed that the availability of over-winter stubbles could explain variation in the summer population trajectories of skylarks. Skylark populations declined by only 4% in survey squares with > 10% of stubbles present. In squares with < 10% of stubbles present there was a 20% decline and between 1997 and 2004 populations in the > 10% stubble category began to stabilize. Unfortunately, in our study, between the 10% upper and 3% lower extremes, differences in the densities of skylark, linnet and yellowhammer were difficult to distinguish with statistical precision for the mid-range proportions of un-cropped land, although there are indications of an increase in densities above the 5–7·5% category. It may be more important to note that a twofold or more increase, from 3% to 7·5% or from 5% to 10%, in un-cropped land was associated with average increases in abundance of 16–53%, depending on the species. Thus, despite low absolute densities, the relative two-fold increase in habitat availability suggests that national population shifts in a positive direction may be possible, even under current farming circumstances where the majority of un-cropped land was not closely managed (Davey *et al.* 2010b).

INTERPRETATION AND CONSEQUENCES

Given the widespread, persistent declines in farmland biodiversity in Europe over the last 40 years, serious attention must be given to the efficacy of AE schemes (Knop *et al.* 2006; Birrer *et al.* 2007) and to creating sufficient resources for wildlife at appropriate spatial scales, from patches to farms to landscapes (Stoate *et al.* 2009; Koh *et al.* 2010; Siriwardena 2010). With EU policy aiming to stabilize farmland biodiversity by 2020 (EU 2011), future EU guidelines may ask farmers to maintain only 7% of un-cropped habitat on farmland, inclusive of semi-natural habitats such as hedgerows. In our study, a 7% inclusive rate would be a conservative target to stabilize the decline in farmland bird populations, especially for schemes that are not closely chaperoned in the way their management for biodiversity was fulfilled on farms (Davey *et al.* 2010b). This conclusion may not be true of more targeted schemes (such as Higher Level Schemes in the UK, not tested here), but roll-out of highly targeted, closely chaperoned schemes is rarely affordable at the large geographic scale required to attend to widespread populations of farmland birds, which requires very high numbers of subscribing farmers. Further studies representing a wider range farming circumstances in Europe is needed. Further scale-dependent work should be encouraged, identifying how small-scale studies translate to landscapes, and how resources for wildlife can be varied spatially to affect changes in wide-ranging, highly dispersed populations.

Bird abundance was used as the population metric in the current study. Abundance is the most readily used and best-perceived metric of population change (cf. monitoring in Europe: Voříšek *et al.* 2010) amongst scientists, the general public and politicians. Abundance does not necessarily represent demographic processes, such as productivity, survival and immigration (Geertsma, van Berkel & Esselin 2000; Kleijn *et al.* 2011). Unfortunately, there have been few attempts to measure demographic flux (Siriwardena *et al.* 2006; Schaub *et al.* 2010) amongst birds in relation to varying proportionate scales of resources provision, and such analyses would be extremely valuable for understanding landscape effects on bird populations.

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