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Appendix 4. Published paper relating to Objective 3. Published in 2000 in *Ecology and Conservation of Lowland Farmland Birds* (edited by N.J. Aebischer, A.D. Evans, P.V. Grice & J.A. Vickery) British Ornithologists' Union, Tring.

The contribution of hedgerow structure to the value of organic farms to birds

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A previous study comparing the abundance of bird species on organic and conventional farm hedgerows in England and Wales found that 8 out of 19 species showed evidence of significantly higher density on organic farms. However, the precise management factors to which birds are responding remain unclear; organic farms also differed in field boundary structure in a way likely to make them more attractive to many species of bird. The data from this study were re-analysed by considering the effects of farm management on species abundance at the level of the individual hedgerow. All 19 species showed a significantly higher abundance on organic farms in at least one season of one year. Several species were more likely to occur in larger hedgerows. When controlling for hedge structure, 10 species showed reasonable evidence of a significantly higher abundance on organic farms, but in many cases, this was only in one season. Wren *Troglodytes troglodytes*, Blackbird *Turdus merula* and Great Tit *Parus major* showed the most consistent results across years and seasons. Only Yellowhammer *Emberiza citrinella* showed a significantly higher abundance on conventional farms. Eight species no longer showed consistent significantly higher abundance on organic farms in these models, indicating that hedgerow management alone is likely to be important for a number of bird species. For the other 11 species, overall differences in abundance between farm types are likely to be caused by management features other than hedge structure, including food abundance or interactions between a number of potentially beneficial management practices characteristic of organic farming.

Many farmland bird species have shown population declines and contractions in range in the UK over the past three decades (Marchant *et al.* 1990, Gibbons *et al.* 1993, Fuller *et al.* 1995, Siriwardena *et al.* 1998). The many changes in agricultural management that have occurred over the same period have been considered by many as the most likely cause underlying these population declines (Fuller *et al.* 1995, Baillie *et al.* 1997), although there are many different (and not mutually exclusive) ways in which individual components of this agricultural "intensification" may have affected bird populations (O'Connor & Shrubb 1986, Chamberlain *et al.* 1999a).

The number of farms managed organically has increased greatly in northern Europe in recent years (Lampkin 1990), although they still cover only 0.3% of arable land in England (Gardner & Brown 1998). Organic management adopts less intensive practices that to some extent are characteristic of the pre-intensification management of three to four decades ago, particularly the use of rotations involving grass leys and legumes on organic arable farms, the use of green manure rather than artificial fertiliser and the predominance of mixed, rather than solely arable or grassland enterprises. However, it cannot necessarily be assumed that organic farms are the same in every respect as the majority of farms before intensification. For example, pesticides have been used on farms for many decades (Grigg 1989) and those used in the 1950s and 1960s may have been more harmful to wildlife than those used today, so the absence of synthetic pesticides on organic farms is a novel management approach (but note that some natural pesticides are used on organic farms).

Organic farming may be expected to benefit birds in a number of ways. For example, the greater diversity of land use due to mixed farming and the traditional rotations used may be expected to benefit species which prefer a range of habitats e.g. Skylark *Alauda arvensis* (Schläpfer 1988) and Lapwing *Vanellus vanellus* (Galbraith 1988); abundance of both weeds and invertebrates may be higher on organic farms owing to the absence of synthetic pesticides (Campbell *et al.* 1997) that would increase food supplies for many species; and the use of rotational leys, particularly those undersown with grass and clover in the preceding crop, is likely to be a beneficial habitat for Grey Partridge *Perdix perdix* (Potts 1986) and potentially a number of other species. In addition to crop management, organic standards also include guidelines for the environmentally sympathetic management of all farm habitats (UKROFS 1992), so hedgerows, probably the most important feature to the farmland bird community (Lack 1992), are likely to be of higher quality on organic farms.

There is evidence that organic farming may be beneficial to a number of bird species (Braae *et al.* 1988, Petersen *et al.* 1995, Chamberlain *et al.* 1999), and particularly Skylarks

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(Wilson *et al.* 1997). Identifying the specific aspects of organic management (e.g. cropping regime, hedgerow structure, fertiliser or pesticide input) responsible for the detected differences proved difficult in the former three studies. Chamberlain *et al.* (1999b) found that there were significant differences in field size, the occurrence of spring cereals and bare till and the number of crop types between organic and conventional farms. More strikingly, there were large differences in hedgerow dimensions and the number of trees per hedge between farm types, and these differences in hedgerow "quality" appeared the most likely reason for overall differences in bird abundance at the farm level. Other studies have demonstrated that organic farmland has greater abundance and availability of weeds and certain invertebrate groups (Dritshillo & Wanner 1980, Hald & Reddersen 1990, Moreby *et al.* 1994, Brooks *et al.* 1995), but these differences are not universal across all invertebrate taxa, and certain species or species groups show greater abundance on conventional farms (Moreby *et al.* 1994).

Whilst there is evidence that organic farming is generally beneficial to the farmland bird community, there remains the need to understand which specific aspects of organic management cause the most variation in significant organic / conventional contrasts (Fuller 1997). This is important because it will help to identify those management changes that may have the greatest potential to agri-environment schemes outside organic farming systems, and in particular whether merely structural changes in management (which in this study refers to hedgerow management), as opposed to inputs to farming systems (e.g. pesticide and fertiliser applications), are sufficient to be incorporated in future conservation strategies to ensure healthy farmland bird populations. This study attempts to separate the structural effects of organic management from the effects of inputs to farming systems on bird abundance. Firstly, we summarise the results of previously published comparisons of bird abundance between organic and conventional farms (Chamberlain *et al.* 1999b). We then present results of a new analysis of bird abundance in which we are broadly able to control for the effects of hedgerow structure. These results are reviewed in conjunction with those from other species-specific studies such as that of Wilson *et al.* (1997), which include data on feeding ecology and reproductive success, and with results from invertebrate and plant sampling on organic and conventional farms (Brooks *et al.* 1995). It is hoped that management recommendations can arise from this study, and also that the results may help us to understand the recent declines of many farmland bird populations.

METHODS

Bird survey

The bird data were derived from a large-scale survey of bird communities on organic and conventional farms in England and Wales carried out over three years by staff and volunteer members of the British Trust for Ornithology (BTO). Detailed methods are given elsewhere (Chamberlain *et al.* 1999b), and only a summary will be given here. Bird surveys were carried out over three breeding seasons and two autumn / winter periods between 1992 and 1994. Study sites were selected on a paired basis, with each organic farm being paired with a nearby (within 5 km) conventional farm. This pairing procedure was carried out to control for individual differences between observers (the same observer visited both farms in a pair) and for geographical variation, the farms covering a wide range of landscapes across England and Wales, which show much variation in bird community irrespective of farming system. A total of 22 farm pairs were studied, although this varied between 10 and 22 farm pairs depending on the sample (sample refers to each season and year combination throughout this paper). There were only four farm pairs, which were surveyed in each season of each year, so there were partially overlapping samples of farms between successive seasons. Each farm was visited usually four times during the breeding season (once a month from April-July) and three times each in the autumn (September-November) and winter (December-February). During each visit, all birds seen in each separate hedgerow unit (defined as any continuous length of hedge unbroken by large gaps or intersections) were recorded. Habitat information on hedge dimensions and structure was also recorded.

Statistical methods

Bird density at the farm level was originally compared between organic and conventional farms using Wilcoxon matched pairs tests, with field boundaries and fields being analysed separately (Chamberlain *et al.* 1999b). Only the 19 most commonly occurring hedgerow species, present on at least five farm pairs in at least one sample, were considered (Table 1). The relationship between birds and farm management was explored further in a new analysis modelling bird abundance in relation to the effects of farm type (organic or conventional) in conjunction with a number of structural habitat variables at the level of the individual hedgerow (other field boundaries held very few birds and were not considered). This was achieved by modelling species count in a given hedge in relation to habitat variables using Poisson regression with a logarithmic link function. The dummy variable "farm pair" was used in all models to take into account variation

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Table 1. Bird species considered in the comparative analysis of abundance on organic and conventional farms, and the seasons in which they were analysed.

Species	Season
Wren *Troglodytes troglodytes*	All
Dunnock *Prunella modularis*	All
Whitethroat *Sylvia communis*	Breeding
Blackcap *S. atricapilla*	Breeding
Willow Warbler *Phylloscopus trochilus*	Breeding
Robin *Erithacus rubecula*	All
Blackbird *Turdus merula*	All
Redwing *T. iliacus*	Autumn, winter
Song thrush *T. philomelos*	All
Fieldfare *T. pilaris*	Autumn, winter
Blue Tit *Parus caeruleus*	All
Great Tit *P. major*	All
Long-tailed Tit *Aegithalos caudatus*	All
Chaffinch *Fringilla coelebs*	All
Bullfinch *Pyrrhula pyrrhula*	All
Greenfinch *Carduelis chloris*	All
Goldfinch *C. carduelis*	All
Linnet *C. cannabina*	All
Yellowhammer *Emberiza citrinella*	All

between locations and individual observers. If a bird species was absent from either farm type within a farm pair, then those data were dropped from the model so sample sizes varied between species.

Initially, bird count was modelled in relation to farm pair and each habitat feature separately, i.e. one model per individual habitat variable including farm type (organic or conventional). For hedges, these were hedge length (continuous variable, log-transformed), height (defined into four categories, < 2 m, 2-3 m, 3-4 m and over 4 m), width (four categories, < 2 m, 2-3 m, 3-4 m and over 4 m), density of trees per hedge (continuous variable), density of gaps over 0.5 m wide per hedge (continuous variable), and ditch (presence/absence). Hedge length had significant positive effects on bird count in virtually every species (see below). Rather than consider this as a predictor variable, hedge length was used as an offset, so derived estimates were per unit of hedge length (i.e. we were effectively modelling density). The final stage was to enter "farm type" (organic or conventional) and associated interaction terms with habitat variables into the model along with any variables that individually had significant effects in the initial analysis. Collinearity of predictor variables was avoided, with more than one habitat variable appearing in each model only if they were not significantly correlated. In cases where there was significant inter-correlation, the variable with the largest sample size was chosen. For each year the order of sample size was hedge height, hedge width, tree density, gap density and ditch presence. (These differences arose because observers sometimes did not record all hedgerow features). In all cases, significance refers to Type 3 analyses produced in the GENMOD procedure in SAS, which provides a test of the partial effect of a given variable when taking into account effects of all other model variables (SAS Institute 1996). The models were fitted without intercept terms and were scaled according to the model deviance using the DSCALE option in SAS to correct for over-dispersion. Significance of variables was determined using *F*-tests.

RESULTS

Summary of differences at the farm level

Eight bird species showed significant differences in density in hedgerows between farm types at the whole farm level in at least one season of one year. These are summarised in Table 2 (based on Chamberlain *et al.* 1999b). There were no species where densities were significantly higher on conventional farms. There were also three species where densities were significantly higher in open fields, Woodpigeon *Columba palumbus* (1993 winter), Skylark (1993 breeding season) and Yellowhammer *Emberiza citrinella* (1992 autumn). In addition, the density of all species combined was significantly higher on organic farms in 1992 autumn and 1994 breeding season. A similar paired analysis on habitat extent at the farm level showed that organic farms had generally higher, wider hedges, more trees per field boundary, smaller fields, a greater number and diversity of field types, a greater proportion

Table 2. Bird species showing significant differences (Wilcoxon matched pairs test) in density in hedgerows between organic and conventional farms at the whole farm level (from Chamberlain *et al.* 1999b). No survey was undertaken in the autumn or winter of 1994. A complete list of species considered is given in Table 1. In each case, organic farms held higher densities than conventional farms.

Year	Breeding season	Autumn	Winter
1992	none	Blackbird Blue Tit Great Tit Chaffinch Greenfinch	Redwing Chaffinch
1993	none	Blackbird	Bullfinch
1994	Robin Blackbird Greenfinch	n/a	n/a

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of spring cereals and a greater proportion of bare till than conventional farms. The autumn of 1992 had the greatest number of significant differences in bird density (Table 2) and was the only period when both hedge height and width were significantly higher on organic farms, and also the only year when the number of field types was significantly higher on organic farms. There is therefore an implication that overall differences were caused by differences in structural components of management.

Modelling the effects of farm type in individual hedges

Species abundance in hedges was modelled in relation to farm pair and farm type only. The significance of farm type in these models in each sample is given in Table 3. Each of the 19 species showed a significantly higher abundance on organic farms in at least one sample. On many occasions these differences were highly significant, although there were certain species where relationships were much weaker (e.g. Whitethroat *Sylvia communis*, Long-tailed Tit *Aegithalos caudatus*, Linnet *Carduelis cannabina*). These results contrast with the more conservative farm-level results where only eight species showed significant differences between farm types. There was only a single species, Greenfinch *Carduelis chloris*, that showed a significantly higher abundance on conventional farms in a single season, although this result was contradicted in other years.

Hedgerow features were significantly related to bird abundance in many species. A summary of the results is shown in Table 4. Hedgerow length was significantly related to count in every species in at least one sample and for most species in every sample. This was used as an offset in all subsequent models. Hedge height and width also had significant effects in many species. Typically, larger hedges supported a higher abundance of birds (e.g. Wren *Troglodytes troglodytes*, Willow Warbler *Phylloscopus trochilis*, Robin *Ericathus rubecula*, Blackbird *Turdus merula*, Great Tit *Parus major*), although there were some species that showed a peak in abundance at intermediate height and/or width categories (e.g. Blackcap *Sylvia atricapilla*, Long-Tailed Tit, Greenfinch, Yellowhammer), the tallest hedges in particular holding relatively low numbers of birds. Two species, Whitethroat and Linnet, showed a negative relationship between abundance and hedge size.

Table 3. A summary of the effects of farm type (organic or conventional) on the commonest bird species in hedgerows. The variable farm pair was also included in each model and was significant in the majority of cases. Positive signs indicate a higher abundance on organic farms, negative signs indicate a higher abundance on conventional farms. ns: not significant, +/-: $P < 0.05$, ++/—: $P < 0.01$, +++/—: $P < 0.001$. A blank cell means not applicable (recorded on fewer than 5 farm pairs).

Species	1992 breeding	1993 breeding	1994 breeding	1992 autumn	1993 autumn	1992 winter	1993 winter
Wren	ns	++	ns	+++	ns	++	ns
Dunnock	ns	ns	ns	+++	ns	++	ns
Whitethroat	+	ns	ns				
Blackcap	ns	ns	+++				
Willow Warbler		+	+++				
Robin	ns	+++	+++	+	ns	ns	+++
Blackbird	ns	+	++	+++	+++	+++	++
Redwing				+++	+++	+++	+++
Song Thrush	ns	+++	+++	+	+++	+	++
Fieldfare				ns	++	ns	+++
Blue Tit	ns	++	ns	+++	+++	+	+++
Great Tit	+++	+	ns	+	++	++	+++
Long-tailed Tit	ns	ns	+	ns	+	ns	ns
Chaffinch	ns	++	ns	+++	+	+++	++
Bullfinch	ns	ns	+	+++	++	+++	+++
Greenfinch	ns	+++	+++	+++	—	ns	ns
Goldfinch	ns	+	ns	ns	+++	ns	+
Linnet	ns	ns	ns	+	+		ns
Yellowhammer	+++	ns	ns	++	ns	ns	ns

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Table 4. A summary of the effects of hedgerow habitat variables on bird abundance. The number of samples where significant effects were detected ($P < 0.05$) is shown out of a total of seven (3 breeding season, 2 autumn and, 2 winter periods) apart from birds only considered in particular seasons (Table 1). Hedgerow length (log-transformed) was used as an offset in each model apart from when considering the effects of hedgerow length itself. Farm pair was included in each model and was significant in each case. Signs in parentheses indicate positive effects (+), negative effects (-), non-linear effects or non-consistent trends between years (+/-).

Species	Length	Height	Width	Tree density	Gap density	Ditch presence
Wren 7	7 (+)	4 (+)	5 (+)	3 (+)	0	2 (+/-)
Dunnock 7	7 (+)	4 (+/-)	2 (+/-)	3 (+)	0	2 (+/-)
Whitethroat 3	7 (+)	1 (-)	2 (-)	1 (-)	0	0
Blackcap 3	5 (+)	3 (+/-)	1 (+)	1 (+)	1 (-)	2 (+/-)
Willow Warbler 3	7 (+)	3 (+)	3 (+)	3 (+/-)	0	2 (+)
Robin 7	7 (+)	5 (+)	3 (+)	3 (+)	0	4 (-)
Blackbird 7	7 (+)	6 (+)	4 (+)	2 (+)	1 (-)	5 (+/-)
Redwing 4	3 (+)	4 (+)	3 (+/-)	3 (+)	0	4 (-)
Song Thrush 7	7 (+)	6 (+/-)	3 (+)	1 (+)	1 (+)	2 (-)
Fieldfare 4	7 (+)	4 (+/-)	4 (+)	2 (+)	4 (+)	4 (-)
Blue Tit 7	7 (+)	6 (+)	4 (+/-)	5 (+)	2 (+/-)	4 (+/-)
Great Tit 7	7 (+)	5 (+)	1 (+)	4 (+)	3 (+)	3 (+/-)
Long-tailed Tit 7	5 (+)	4 (+/-)	6 (+/-)	3 (+)	4 (+)	4 (-)
Chaffinch 7	7 (+)	7 (+)	5 (+/-)	5 (+)	2 (+/-)	5 (-)
Bullfinch 7	6 (+)	4 (+/-)	4 (+/-)	2 (+)	2 (-)	4 (-)
Greenfinch 7	6 (+)	6 (+/-)	7 (+/-)	0	2 (-)	3 (-)
Goldfinch 7	7 (+)	0	1 (+)	1 (+)	1 (-)	1 (+)
Linnet 7	6 (+)	5 (-)	6 (-)	1 (-)	4 (+)	4 (-)
Yellowhammer 7	7 (+)	5 (+/-)	5 (+/-)	2 (+/-)	3 (+)	2 (-)

Tree density was typically correlated with hedge size (see below) and therefore showed similar relationships. The presence of ditches had inconsistent effects between years in a number of species, and generally tended to be positively related to bird abundance in the breeding season, but negatively related in the autumn and winter. Hedgerow gap density had the fewest significant effects and showed either positive or negative effects depending on species.

There was a high degree of significant inter-correlation in the variables, in particular hedge height, hedge width and tree density were significantly positively correlated with each other in most samples (Table 5). The probability of ditch presence and the density of gaps per hedgerow unit also tended to increase with increasing hedge size, but ditch presence and gap density were negatively related. In the following analyses, species showing a significant effect of farm type alone (Table 3) were analysed in relation

Table 5. Hedgerow habitat variables not showing significant relationships in pairwise analyses. Results are from Spearman rank correlations with the exception of ditch presence/absence that was analysed in relation to other variables using logistic regression. All other pairwise tests were significant ($P < 0.05$) and showed positive relationships with the exception of ditch presence and gap density. Autumn and winter showed very similar results and are not separated in this table.

1992 breeding	1992 autumn/winter	1993 breeding	1993 autumn/winter	1994 breeding
height *v.* gaps	width *v.* gaps	width *v.* ditch	height *v.* tree density	height *v.* ditch
width *v.* gaps		tree density *v.* ditch	width *v.* tree density	width *v.* ditch
ditch *v.* gaps			gaps *v.* tree density	tree density *v.* ditch
			ditch *v.* tree density	gaps *v.* ditch
			height *v.* ditch	

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Table 6. Species showing significant effects of farm type (i.e. organic or conventional) when added to a model including farm pair and significant habitat variables detected in univariate analyses (Table 4). Non-significant terms were dropped from the models. Parameter estimates for farm type (FTYP) are organic relative to conventional, estimates for tree density (TREE) and density of hedgerow gaps (GAPS) are continuous (analogous to slope). Hedge height (HGHT) and width (WDTH) are given as ranks (lowest/narrowest = 1) and are placed in order of parameter estimates from lowest (i.e. fewest birds) to highest. Estimates for ditch (DITCH) are present relative to absent. Farm pair was in every model and was significant in each case. *: $P < 0.05$, **: $P < 0.01$, ***: $P < 0.001$.

Species	Model deviance	df	Variable	Parameter estimate and/or significance
1993 breeding season				
Wren	880	723	FTYP	0.304±0.107**
			TREE	0.024±0.006***
			DITCH	0.372±0.156*
Willow Warbler	306	545	FTYP	0.761±0.379***
			HGHT	1,2,3,4**
Robin	781	727	FTYP	0.178±0.215*
			HGHT	1,2,3,4***
Song Thrush	263	604	FTYP	1.875±0.686***
			HGHT	1.875±0.686***
			FTYPxHGHT	*
Chaffinch	943	731	FTYP	0.251±0.107*
			TREE	0.021±0.008*
1994 breeding season				
Blackcap	131	342	FTYP	0.704±0.313*
Robin	447	448	FTYP	0.305±0.144*
			HGHT	1,2,4,3***
Blackbird	605	479	FTYP	0.142±0.230*
			DITCH	0.483±0.219*
Song Thrush	233	409	FTYP	1.547±0.583***
			FTYPxHGHT	*
Bullfinch	90	289	FTYP	0.201±0.515**
			WDTH	1,2,3,4***
1992 autumn				
Wren	760	926	FTYP	0.517±0.143***
			TREE	0.085±0.036*
Dunnock	878	913	FTYP	1.196±0.468***
			HGHT	4,1,2,3*
Blackbird	2025	917	FTYP	0.542±0.125***
			HGHT	1,2,3,4***
			DITCH	-0.559± 0.193**
Redwing	2497	793	FTYP	0.745±0.273***
			HGHT	2,1,3,4***
Blue Tit	1525	894	FTYP	-0.163±0.194***
			HGHT	1,2,3,4***
			FTYPxHGHT	***

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Table 6. continued

Species	Model deviance	df	Variable	Parameter estimate and/or significance
Chaffinch	2561	882	FTYP	-0.707±0.477**
			HGHT	1,2,3,4***
			DITCH	-0.344± 0.280**
Bullfinch	407	758	FTYP	1.345±0.570***
			HGHT	1,4,2,3***
Yellowhammer	1913	766	FTYP	-1.235±1.581**
			WDTH	4,2,1,3*
			DITCH	-0.508± 0.261***
			WDTHxFTYP	***
1993 autumn				
Blackbird	1429	706	FTYP	0.237±0.114*
Blue Tit	1375	705	FTYP	0.369±0.111***
			DITCH	-0.310±0.136*
Great Tit	714	686	FTYP	0.527±0.202**
			GAPS	0.378±0.087***
			GAPSxFTYP	*
Chaffinch	2361	691	FTYP	-0.397±0.151*
			HGHT	1,2,4,3***
			DITCH	-0.607±0.212**
1992 winter				
Wren	661	802	FTYP	0.255±0.123*
Redwing	2954	679	FTYP	1.162±0.368***
			HGHT	1,2,3,4***
Great Tit	801	775	FTYP	0.563±0.161***
			TREE	0.104±0.021***
			TREExFTYP	**
Chaffinch	3259	760	FTYP	0.865±0.336***
			TREE	0.091±0.026**
			DITCH	-0.588±0.278
			TREExFTYP	***
Bullfinch	316	652	FTYP	-1.114±0.274***
			HGHT	1,3,2,4***
			HGHTxFTYP	***
1993 winter				
Blackbird	1091	586	FTYP	0.227±0.102*
Fieldfare	2116	453	FTYP	1.116±0.235***
Blue Tit	1114	656	FTYP	0.465±0.133***
Great Tit	676	519	FTYP	0.336±0.137*
Chaffinch	2270	590	FTYP	0.364±0.140**
			WDTH	4,1,2,3**
Bullfinch	259	427	FTYP	1.172±0.882**
			WDTH	1,4,2,3*

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Table 7. The effects of habitat variables on bird abundance on organic and conventional farms separately. Each species showed a significant interaction between farm type and the given habitat variable in Table 6. Farm pair was included in each model and was significant in each case. Parameter estimates are given for continuous variables and the order of categories, ranked according to parameter estimates per category, are given for class variables under the 'Habitat effect' column. Habitat variable codes are given in Table 6. ns: not significant, *: $P < 0.05$, **: $P < 0.01$, ***: $P < 0.001$.

Species	Year	Habitat variable	Habitat effect	
			Organic	Conventional
Song Thrush	1993 breeding	HGHT	2,1,3,4*	4,1,2,3**
	1994 breeding	HGHT	3,1,4,2 ns	2,1,4,3***
Great Tit	1992 winter	TREE	0.054±0.060 ns	0.122±0.027***
	1993 autumn	GAPS	0.179±0.047***	0.348±0.077***
Yellowhammer	1992 autumn	WDTH	4,3,2,1***	1,4,2,3***

to both farm type and habitat. Habitat variables were entered into models along with farm type and farm pair if (i) they showed a significant effect in the univariate analyses and (ii) they were not significantly related to any other habitat variables (Table 5) that had a larger sample size.

Table 6 gives a summary of the results for species showing a significant effect of farm type on abundance. Farm-pair effects were significant in every case, demonstrating the regional variation in bird communities and/or differences between individual observers. There was no significant effect of farm type on bird abundance in the 1992 breeding season when including significant habitat variables. A large number of species showed a significant effect of farm type on abundance in other years. The autumn of 1992 showed the greatest number of significant differences in common with the whole farm analysis (Table 2). There were a total of ten species that showed significantly higher abundance on organic farms only in at least one sample (Wren, Dunnock *Prunella modularis*, Blackcap, Willow Warbler, Robin, Blackbird, Redwing *Turdus iliacus*, Song Thrush *Turdus philomelos*, Fieldfare *Turdus pilaris* and Great Tit), one species that showed significantly higher abundance on conventional farms only in at least one sample (Yellowhammer), three species that showed conflicting effects of farm type in different samples (Blue Tit *Parus caeruleus*, Chaffinch *Fringilla coelebs*, Bullfinch *Pyrrhula pyrrhula*) and five species that showed no significant effect in any sample (Whitethroat, Long-tailed Tit, Greenfinch, Goldfinch, and Linnet). The species showing the most consistent effects of farm type across samples were Blackbird (significant in four samples), Wren and Great Tit (significant in three samples).

The differences between organic and conventional farms were clearly not consistent across years in certain species and this may have arisen for a number of reasons e.g. differences between study sites, differences in weather conditions or differences in population size between years. A detailed consideration of how these differences between years arose is beyond the scope of this paper, but there is certainly no strong evidence that populations of these species are likely to benefit consistently from either organic or conventional management, and they will not be considered further. Interpretation of effects in species that showed significant results in a consistent direction across years was often complicated owing to significant interaction effects between habitat and farm-type variables. There were three such species: Song Thrush, Great Tit and Yellowhammer. Further analysis was carried out on these species by considering the effects of habitat in organic and conventional farm types separately. For the two species more abundant on organic farms, the effects of habitat had more highly significant effects and effects of greater magnitude (higher parameter estimates) on conventional farms (Table 7). For Yellowhammer, differences were less pronounced, but bird abundance tended to be highest on smaller hedges on organic farms and medium-sized hedges on conventional farms.

DISCUSSION

Organic farms held a greater number of certain species and greater numbers of all species combined than conventional farms at the level of the whole farm, particularly in hedgerows outside the breeding season. There are many components of organic management that are potentially beneficial to birds. For example, organic farms tended to have higher, wider hedgerows than conventional farms. There was also a higher density of trees per field boundary on organic farms. All of these

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features are known to affect the farmland bird community (Green *et al.* 1994, Parish *et al.* 1994) and seem to be particularly important for species that are primarily associated with woodland or woodland edge habitat (Lack 1992). Chamberlain *et al.* (1999b) showed that many of the differences in density detected between farm types at the farm level were likely to have been due to differences in structure of hedgerows, although it was difficult to tease apart the relative effects of the measured structural variables and unmeasured variables associated with organic management. This was attempted here by re-analysing the data at a finer scale.

All species showed some evidence of a higher abundance on organic farms in at least one sample in a relatively simple comparison at the level of the individual boundary (Table 3). There were a number of species that no longer showed effects of organic management (Whitethroat, Long-tailed Tit, Greenfinch, Goldfinch, and Linnet) or that showed conflicting results according to the sample (Blue Tit, Chaffinch, Bullfinch) when controlling for the effects of hedgerow structure. For these species, differences in hedgerow structure alone are likely to have caused overall differences between farm types. There were eleven species that showed significant effects of organic management independent of the effects of hedgerow structure: Wren, Dunnock, Blackcap, Willow Warbler, Robin, Blackbird, Redwing, Song Thrush, Fieldfare, Great Tit and Yellowhammer (the last species being the only one to have a higher abundance on conventional farms). However, four of these species showed significance in only a single sample (Willow Warbler, Blackcap, Dunnock and Fieldfare).

Certain caveats need to be placed on the interpretation of the data. Firstly, we have considered the effects of hedgerow structure and farm type on individual field boundary units within farms. These boundary units are not independent for any given farm site. To some extent this can be taken into account by including variables that encompass variation caused by individual farm sites (i.e. farm pair and farm type), but this does not entirely remove the problem and there may be pseudoreplication in the data due to considering boundaries close together as independent. This is likely to artificially inflate the differences observed between farm types. Secondly, the level of significance was often weak. If we were to apply a more conservative significance level to this analysis because of the large number of repeated tests (e.g. divide 0.05 by the number of species considered per sample = 0.003), then a number of results would become non-significant. In particular, there would no longer be any evidence of differences in abundance between farm types for Blackcap and Robin and the number of samples where significant results were detected would be reduced (e.g. Blackbird reduced from four to one significant sample). Owing to these caveats, application of a lower significance level of $P < 0.001$ would provide a more conservative analysis. In this case, 17 out of 33 results presented in Table 6 are not significant and the majority of significant results come from 1992 autumn and winter. Despite the above caveats, there were still a number of species that showed highly significant ($P < 0.001$) effects of farm type independent of the effects of hedgerow structure: Wren, Willow Warbler, Blackbird, Song Thrush, Redwing, Fieldfare and Great Tit.

In comparison with the analysis at the whole farm level, there were relatively few species that showed similar results at the two different scales. Greenfinch was significant in two years at the whole farm level, but there was no significant difference between farm types at the field boundary level. Similarly, Great Tit, Blue Tit and Chaffinch showed significantly higher densities on organic farms at the whole farm level in the autumn of 1992, but at the field boundary level there was no such relationship. Indeed, the latter two species showed higher estimates of abundance on conventional farms. These results indicate that hedgerow structure was responsible for the overall difference. Redwing, Chaffinch, Bullfinch (one sample each) and Blackbird (three samples) showed similar results at different scales in at least one sample. Blackbird in particular has therefore shown some of the most consistent effects of farm type. However, Blackbird is the commonest species recorded overall, so tests will have greater power to detect significant results. For the scarcer species (e.g. warblers, Linnet, Bullfinch), the likelihood of detecting significant differences is reduced.

Differences in abundance could have arisen owing to structural differences that were not measured. For example, habitat adjacent to field boundaries can have important effects on bird abundance. Bradbury & Stoate (2000) found that Yellowhammers preferred short dense hedgerows, ditches and wide rough grass margins adjacent to arable crops and avoided field boundaries adjacent to pastures and leys. However, there was no significant overall difference in Yellowhammer abundance between farm types independent of the above effects. The greater abundance of Yellowhammers on conventional farms recorded by the present study may not have arisen if there had been adequate controls for adjacent habitat.

Food resources

Organic farms may have held greater food resources for birds than conventional farms owing to the absence of pesticide and artificial fertiliser inputs. Brooks *et al.* (1995), working on a sub-sample of farms used in this study, compared the abundance of a number of invertebrate and plant groups between organic and conventional winter cereal fields. A summary of their results is presented in

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Table 8. Earthworm species and five carabid species were significantly more abundant on organic than conventional winter cereals. There was no significant difference in abundance for seven carabid species, adult or larval Diptera, small invertebrates or Coleoptera. There was a significantly higher abundance of staphylinids on conventional farms (Table 8). Previous studies have also shown that certain invertebrate species may be significantly more abundant on conventional farmland (Moreby *et al.* 1994). In addition to sampling organic and conventional cereal fields, invertebrate sampling was also carried out on organic grass leys (these are characteristic of organic management and no equivalent field type was available for comparison on conventional farms). These had significantly higher abundance of larval Diptera, small invertebrates and Coleoptera than either organic or conventional cereal fields. Therefore, organic farming is not universally beneficial to all invertebrate species and effects due to large-scale structural management (i.e. use of grass leys) may be just as important as inputs to crops.

There was a higher diversity of weed seeds on organic farms. Broadleaved weeds were more abundant on organic farms whilst grass weeds predominated on conventional farms (Table 8). This may indicate a benefit of organic farming for birds since a recent review of the diet of granivorous farmland bird species found that, with the exception of cereal grain, the seeds of broadleaved weeds were of greater general importance in avian diets than the seeds of grasses (Wilson *et al.* 1999). There will always be exceptions, however. A recent study of Linnets (Moorcroft *et al.* 1997) has shown a marked preference for rape seeds as nestling food. Since oilseed rape is not grown on organic farms, for this species there may be both benefits and costs associated with organic management and indeed, there was no significant difference in Linnet abundance between farm types after including significant habitat variables.

Studies of the feeding ecology of Skylarks and Yellowhammers have broadly supported the contention that organic farmland holds greater food resources, as organic crops were selected and conventional crops avoided more than expected by foraging birds (Bradbury & Stoate 2000, Wilson in press). However, no concomitant effect on reproductive performance in terms of clutch size, brood size at fledging or nest success has been detected in either of these studies (Wilson *et al.* 1997, Bradbury & Stoate 2000), each of which could be expected to increase with

Table 8. A summary of the differences in the abundance of plants and invertebrates between organic and conventional winter cereal fields. The units are counts for each species group except for all weed seeds where both count and diversity were analysed. Differences between pairs of organic and conventional fields were tested using analysis of variance that included effects of site (i.e. individual farm) and farm type (organic or conventional). Full details are given in Brooks *et al.* (1995). ns: not significant.

Species group	Sampling method	Results
Carabidae	Pitfall trap	Organic > conventional for five spp.; ns for seven spp.
All invertebrates	Soil core and vacuum sampling	ns (both methods)
Staphylinidae	Vacuum sampling	Conventional > organic
Adult Diptera		ns
Dipteran larvae	Soil core	ns
Invertebrates < 5 mm long		ns
Coleoptera		ns
Earthworms		Organic > conventional
All weeds	Quadrat	ns
Grass weeds		Conventional > organic
Broadleaved weeds		Organic > conventional
All seeds	Vacuum sampling	ns
All seeds (diversity)		Organic > conventional
Grass seeds		ns
Broadleaved weed seeds		Organic > conventional

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increasing food abundance. Furthermore, there is no evidence to suggest that nestling growth rate or condition varies significantly between farm types for either Skylark (J.D. Wilson unpubl.) or Yellowhammer (Kyrkos 1997). In this present study, Yellowhammers were more abundant on conventional field boundaries in autumn 1992, but at the whole farm level, they occurred at significantly higher densities in fields in the same year (Chamberlain *et al.* 1999b). This pattern could arise because of differences in food resources in fields: on conventional farms, Yellowhammers may be more likely to use hedgerows as fields hold little food. For Skylarks, this may be due to density-dependent effects on reproductive performance, so the benefits of greater food resources on organic farms are counteracted by the higher density of breeders (and hence greater competition) on these farms. Detecting such effects would require much more intensive studies.

Implications for conservation

To what extent can the findings of the studies presented here help us to understand the declines in many species of farmland bird? Clearly, hedgerow is a very important habitat on farmland. It is also a habitat that has reduced greatly on farmland since the Second World War (Moore 1987, Barr *et al.* 1993) and the loss of this habitat alone may have been an important factor in the decline of farmland species. However, Gillings & Fuller (1998) found that hedgerow loss on a local scale was relatively unimportant and argued that decreases in habitat quality, which in terms of hedgerows includes height, width, presence of trees and presence of adjacent uncultivated field margins, were more likely to have caused population declines. Brooks *et al.* (1995) showed that invertebrate food resources were particularly high on organic grass leys, but in cereal fields certain invertebrate groups differed between farm types and a probable cause for this was absence of pesticides and artificial fertilisers. For both of these, use has increased substantially over the past three decades, so effects on bird populations via their food supply seem plausible. Indeed, this seems to have been a contributory factor in the decline of the Grey Partridge (Rands 1986). However, it was not clear from the results presented here how differences in food resources should have affected birds, given that there was no difference in reproductive success between farm types and not all invertebrate groups were affected in the same way.

The adoption of organic management practices may benefit certain declining species on farmland, notably Blackbird and Song Thrush. For certain other species considered in this paper such as Whitethroat, Long-tailed Tit, Greenfinch and Goldfinch, management to encourage larger hedgerows with more trees irrespective of general farmland management should have beneficial effects. It could be argued that organic management would be generally beneficial to birds, whether due to hedgerow structure, cropping regimes or lack of artificial inputs, and its widespread adoption could help reverse some of the recent population declines. However, there is likely to be variation in specific management practices within organic farms (Fuller 1997). The intensity of the surrounding farmland may affect the value of a given organic farm, possibly by concentrating birds into a good habitat, or conversely by reducing the relative value of that organic farm owing to isolation and "contamination" from neighbouring farming practices. Also the time under organic management may be important, as previous management practices may have effects on the environment a number of years after they were last employed. For example, attempts at restoring arable weeds after the cessation of herbicide treatment has proved difficult, restoration of the floral community only being achieved after several years (Dessaint *et al.* 1997).

In conclusion, there is convincing general evidence that organic farming systems are beneficial to most bird species in comparison to the intensive systems that they replace. However, organic farms combine many different management practices applied to both cropped and uncropped land. More evidence is needed of the benefits of these practices when adopted in isolation within conventional systems in order to show (i) which aspects of organic management practice offer the greatest benefits to bird populations, and (ii) whether interactions between the effects of different practices do result in organic systems offering biodiversity benefits that are greater than the individual management practices in isolation.

This work was funded jointly by the Ministry of Agriculture, Fisheries and Food and the World Wide Fund for Nature UK. We are grateful to the volunteer observers who undertook the censuses and to the farmers who allowed access to their land. We are grateful to Rob Fuller for his input to the project and to Steve Freeman for statistical discussion.

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