CSG 15

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD

Research and Development

Final Project Report

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Project title	Designing crop/plant mixtures to provide food for seed-eating farmland birds in winter
MAFF project code	**BD1606**
Contractor organisation and location	Allerton Research and Educational Trust Loddington Leics
Total MAFF project costs	£ 199,822
Project start date	01/04/98
Project end date	30/09/01

Executive summary (maximum 2 sides A4)

1. Seed-eating farmland birds have declined and evidence suggests that food supplies outside the breeding season may be a limiting factor. Game crops, Wild Bird Cover on set-aside and Wildlife Seed Mixtures (as supported under the recent pilot Arable Stewardship Scheme) may provide a valuable alternative to other sources of food during winter, which are less readily available than formerly.

2. Experiments were carried out on three farms over three years to investigate which crops were of most value as food for seed-eating birds, what were the preferences of different bird species, seed depletion rates for different crops and consumption rates on seed-heads and on the ground. Paired plots close to or at least 50m away from cover were compared at 11 sites in 1999/2000 and 13 sites in 2000/2001 to determine the effect of plot location on numbers of feeding birds. A three year large scale survey was also carried out on 192 farm plots from 161 farms selected from across English arable and mixed farming regions to obtain further information on crop use and feeding preferences, and to compare game crops, Wild Bird Cover and Wildlife Seeds Mixtures in the pilot Arable Stewardship Scheme.

3. Experimental sites were in Norfolk (sandy soil), Hetfordshire (chalk) and Leicestershire (clay). At each site nine or ten annual crops were sown in each of the three years and four biennial crops in the first and second years of the study. Birds were monitored weekly. Seed depletion and consumption was measured by counting seeds in samples of seed heads and soil, and by measuring seed shed using seed traps which were protected from seed predators. Birds in field edge/midfield plots and in the large scale survey were monitored monthly. In the large scale survey each survey plot included one “winter bird food crop” and between two and four neighbouring conventional crops.

4. In the experimental plots, Reed Bunting used millet and fat hen more than other crops, while Yellowhammer used wheat, triticale and millet. Chaffinch made disproportionately high use of the related species fat hen and quinoa. Goldfinch made more use of linseed than other crops in 1999, but there was no significant non-random use in the other years. Dunnock made more use of borage and buckwheat in one of the two years in which data were available. In 1999, Skylark used borage, barley and wheat more than other crops, with the exception of quinoa which was used

more than other crops in all three years. Greenfinches made more use of sunflower and borage than other crops early in the winter, but later in the winter, more use was made of mustard. They also used linseed in the first half of the winter. Of the biennial crops, Goldfinches made significantly more use of teasel than other crops. Greenfinch, Chaffinch, Linnet, Blackbird, Song thrush and Pheasant used kale than the other crops, with Blackbird and Song Thrush also using chicory. Only for chaffinch was there a significant relationship between bird numbers and seed abundance.

5. In comparisons of paired plots, Blackbird, Chaffinch, Greenfinch and Linnet were all significantly more abundant in field edge plots than in midfield plots. No significant effects of plot location were recorded for Song thrush, Dunnock, Skylark, Yellowhammer, Reed bunting or Pheasant. There was a significant relationship between plot size and bird numbers for Linnet, Greenfinch and Chaffinch.

6. Fat hen, quinoa, millet and chicory produced the highest numbers of seeds; triticale, wheat, fat hen, millet and quinoa produced the greatest biomass. Seed numbers on seed heads declined linearly over time, with seed depletion rate being significantly related to seed numbers before depletion. Daily depletion rates were highest for borage and oats. High values were also recorded for kale, quinoa, wheat and evening primrose in at least one year, with intermediate values recorded for kale, quinoa and wheat in other years and also fat hen and mustard. The lowest values were recorded for teasel, triticale, millet and linseed. For most crops, between 90 and 100% of seed produces was consumed. For annuals seed consumption was generally greater from seed heads than from the ground, but most seed of biennials was consumed on the ground.

7. In the large scale survey, overall bird densities were higher on “winter bird food crops” than on conventional farm crops, though the highest densities of skylarks were recorded on cereal stubbles. Kale was the highest ranked crop for the seed-eating sparrows, finches and buntings. Other high ranking crops included turnips, quinoa, cereals, linseed and oilseed rape. Canary grass was favoured by a few species but was little used by others. Buckwheat, phacelia and sunflowers were consistently low ranking crops, with sunflowers being mainly used by greenfinches, as in the experimental plots. Gamebirds and woodpigeons used maize. In general however, the same crops were favoured by passerines and gamebirds, especially in late winter.

8. The presence of weeds in crops significantly affected distribution of Grey Partridge, Tree Sparrow and Reed Bunting. Pheasant, Dunnock, Song Thrush, Greenfinch and Yellowhammer were more abundant when crops were near field boundaries. Tree Sparrows, Greenfinch and Linnet were commoner by tall hedgerows, but Corn Buntings were commoner where there were fewer and shorter hedges. Bird densities declined over winter, but numbers in November, December and February were higher in crops greater than one hectare in area.

9. There was no difference in bird distribution between crops grown on set-aside (i.e. “Wild Bird Cover”) or not (conventional game crops). However, densities of birds were lower on Arable Stewardship plots, probably because a higher proportion of Arable Stewardship plots contained the low-ranked buckwheat, sunflowers and phacelia and a lower proportion contained the highly ranked kale, linseed, quinoa and turnips than other winter bird crops

10. In terms of recommendations for future prescriptions, kale was the most widely used crop. It is however a biennial so needs to be sown in separate areas or strips (which could be adjacent) to provide seed every year. It can be mixed with quinoa (if sown in late April or early May to avoid frost), or cereals if sown earlier. Alternatively an annual mixture of cereal and linseed can be sown. Rape was a highly ranked crop but can be difficult to establish in small plots where woodpigeons are a problem. Turnips were also used by a number of species. It is likely that areas of one hectare or more would be needed to provide seed throughout the winter. Crops grown near hedgerows will provide greatest benefit for most species but a few such as skylark and corn bunting may benefit from crops grown away from cover, especially trees and tall hedges.

11. Further work could include the optimisation of crop management, investigation of potential benefits to birds and other biodiversity during the summer, and quantification of the benefits of introducing seed-bearing crops in the grass-dominated west of the UK in comparison with the arable east and mixed farm systems in the midlands.

Scientific report (maximum 20 sides A4)

INTRODUCTION

There is increasing evidence to suggest that declining survival during the non-breeding season has made a significant contribution to population decline in some bird species using farmland (Thomson *et al*., 1997;[#51] Siriwardena *et al.,* 1998[#34]). For seed eating passerines, in particular, the widespread availability of winter foraging areas in the form of weedy cereal stubbles or set-aside is considered essential to the future recovery of these species populations on arable farmland (Evans & Smith 1994[#129]; Evans 1997[#40]; Buckingham *et al*., 1999[#112]; [Henderson, 2000 #106]). However, the switch from spring to autumn sowing of most arable crops has reduced the availability of winter stubbles, and remaining stubbles and set-aside are likely to have fewer weed seeds as a result of more efficient herbicide use in the previous crop (Campbell *et al*, 1997[#6]). A recent survey found very few seeds were present on farmland in March, even on set-aside(Draycott et al, 1997[#29]) The large scale introduction of set-aside has not yet been linked to detectable increases in the population status of farmland birds (Donald & Vickery (2000)[#90]. Although set-aside was shown to be effective in providing food and nesting habitats for many bird species on farmland and occupied up to 15% of arable land (; Henderson *et al*., 2000 a, b[#106][#131]), it is likely that most set-aside was unsuitable for birds and that too little set-aside of sufficient quality was available in the countryside to influence a significant proportion of the population of these species (Donald & Vickery, 2000[#90]). One of the potential problems facing efforts to reverse declining bird populations on farmland is the difficulty of maintaining the productive capacity of farmland while incorporating the comprehensive and effective habitat changes that will benefit birds.

In the UK, many farms and landowners grow "game crops" to provide winter cover and food for game birds (Pheasant (i.e. Ring-necked Pheasants *Phasianus colchicus*), Grey Partridge *Perdix perdix* and Red-legged Partridge *Alectoris rufa*). These crops include variable mixtures of maize, millet, cereals, kale, mustard, and other seed producing plants which may also provide food and cover for indigenous seed-eating passerines (and possibly some insectivores too). In addition, there is available under the set-aside scheme comprising a "wild bird cover" option of non-harvestable mixtures of crops such as cereals, brassicas or quinoa (*Chenopodium quinoa*) to provide winter food for birds. Studies of habitat use on a farm in Leicestershire showed that wild bird cover was the favoured habitat for seed-eating birds in winter (Boatman et al, 2000)[#55]. Between 1998 and 2000, a pilot "Arable Stewardship Scheme" was run in two areas of the UK, with the aim of introducing a variety of prescriptions designed to attract and support populations of wildlife associated with arable land, including birds. Prescriptions included "wildlife seed mixtures", similar to wild bird cover on set-aside, to provide food for wintering birds. DEFRA has recently announced its intention to incorporate elements of the pilot scheme, including wildlife seed mixtures, into the national Countryside Stewardship Scheme, to be available from January 2002.

"Winter bird crops" (Game-cover, set-aside wild bird cover and wildlife seed mixtures) represent only a small proportion of the area of farmland available to birds. The contribution of winter bird crops towards increased bird biodiversity on farmland is dependent upon maximising the quality of as much of this habitat as possible if such crops are to prove an effective conservation strategy. Choice of crop, location, plot size and management may all influence its value as a feeding habitat for birds.

Project objectives and extent to which they have been met

i) *To determine which seed producing crop/plant species, of those currently thought to be of value, are most attractive to seed-eating birds on farmland.*

The results give clear indications of which crops, among those commonly grown as farm crops and/or game crops, were most attractive to birds. The two contrasting methodological approaches i.e. comparison between experimental plots within the same field and comparison of farm-scale plots in separate fields/farms in the large scale survey gave consistent results in terms of preferences, so that we may have confidence that the data reflect real preferences among bird species.

ii) *To determine rates of seed loss through (a) shedding, (b) consumption on the plant and (c) consumption on the ground, and the extent to which birds utilise seed on the plant and on the ground.*

Rates of seed shedding, consumption on the plant and on the ground were all determined, however the extent of utilisation by birds can only be inferred from these data as it proved impossible to observe birds within the crops with sufficient accuracy to estimate levels of feeding on the plant versus the ground. It was generally necessary to flush the birds to obtain accurate counts, due to the densities of many of the crops surveyed.

iii) *To investigate the effect of seed crop location with respect to cover on bird feeding activity throughout the winter and seed depletion rates.*

Effects of seed crop location were investigated in paired plots, one near a hedgerow and one away from cover, and also using data from the large scale survey. Several species were more abundant in field edge than midfield plots, but corn buntings were more common where there were fewer and lower hedges.

iv) *To derive relationships between numbers of birds feeding and seed depletion rates, for use in determining block size needed to feed birds throughout the winter.*

Relationships between seed abundance and bird numbers in experimental plots were only significant for one species, Chaffinch, so it was not possible to derive general relationships between bird numbers and seed numbers. This is probably because numbers of birds feeding often varied considerably between sampling occasions so that numbers seen on a particular visit were not necessarily representative of the whole period since the previous visit However, there was a positive effect of plot size in paired plots for Linnet, Greenfinch and Chaffinch, showing that large plots supported more birds of these species. Results from the survey showed an inverse relationship between bird density and plot size, suggesting that smaller plots were likely to have been depleted more quickly. Numbers of birds were higher in larger plots in February (also November and December), suggesting that more seed was available at this time.

v) *To quantify the use of (a) cover crops grown for game (b) mixtures grown under the "Wild Bird Cover" set-aside option, (c) "Wildlife Seed Mixtures" grown under Arable Stewardship Scheme agreements in pilot areas, as food sources by birds.*

No difference was detected between crops grown on set-aside (i.e. as "Wild Bird Cover") or not ("game crops"). However, bird densities were lower for most species on Arable Stewardship plots, probably because a higher proportion of arable stewardship plots contained the lower ranked crops buckwheat, sunflower and phacelia, and a lower proportion contained the highly ranked crops kale, linseed, quinoa and turnips, than other winter bird crops.

vi) *To produce guidelines for use by Ministry project officers, farmers, advisors and other interested parties on selection, establishment and siting of seed crops, interim reports will allow use of preliminary results.*

Interim reports have been produced for MAFF/DEFRA in 1999 and 2000 in addition to the annual CSG12 reports. Guidance notes have also been produced for project officers in the pilot Arable Stewardship Scheme during the project. A final set of guidelines will follow submission of the present report.

vii) To publish the results in refereed scientific journals

Results have been presented at the British Ecological Society winter meeting and a paper has been submitted for a conference in March 2002 on "Birds and Agriculture". Papers for submission to refereed journals are in preparation for submission following approval of this report.

METHODS

Experimental studies

Study sites and field methods: Crop comparison experiments

Experimental studies were carried out in three winters, 1998/99, 1999/2000 and 2000/2001, at three study sites. These were at Flitcham (Norfolk; sandy soil), Royston (Hertfordshire; chalky soil) and Loddington (Leicestershire; clay). At each site of nine or ten annual crop or other seed-bearing plant species were sown each year in a randomised block design with three replicates. In 1998, all crops were sown in spring at all sites, but in the second and third years, cereals were sown in the autumn at Loddington to avoid potential drilling problems on the heavy soil if the weather was wet in spring. Other crops were sown in spring as they were not suited to autumn sowing, but as the ideal sowing time was later than for cereals, the risk of problems was less. Plot size was 50m x 12m at Flitcham, 20m x 16m at Loddington and 20m x 12m at Royston. Four biennial crop species were also sown in spring 1998 and 1999 at each site, but not in 2000 as these crops take two years to mature.

Details of annual crops sown at each site in each year are given in Table 1. In the third year, some crops (borage, buckwheat and oats) which had proved unattractive to birds or whose seed had been exhausted very quickly were replaced by other crops (barley, forage rape and vetch). Unfortunately crops of forage rape and vetch failed so no data on these species were obtained. Fat Hen (*Chenopodium album*, normally considered a weed) was sown at Flitcham because the farmer was keen to grow it and had stocks of seed. It was not grown at the other sites because of problems with farmer acceptability. Biennial crops sown were kale (*Brassica oleracea*), teasel (*Dipsacus fullonum*), chicory (*Cichorium intybus*) and evening primrose (*Oenothera biennis*)at all three sites in both years.

Crop	Latin name	1998/99	1999/00	2000/01
Barley	*Hordeum sativum*			F,L,R
Borage	*Borago officinalis*	L,R	L,R	
Buckwheat	*Fagopyrum esculentum*	F,L,R	F,L,R	
Fat Hen	*Chenopodium album*	F	F	F
Forage rape	*Brassica napus*			F,L,R
Linseed	*Linum usitatisimum*	F,L,R	F,L,R	F,L,R
Millet	*Panicum effusum*	F,L,R	F,L,R	F,L,R
Mustard	*Sinapis album*	F,L,R	F,L,R	F,L,R
Oats	*Avena sativa*	F,L,R	F,L,R	
Quinoa	*Chenopodium quinoa*	F,L,R	F,L,R	F,L,R
Sunflower	*Helianthus annuus*	F,L,R	F,L,R	F,L,R
Triticale	*X Triticale*	F,L,R	F,L,R	F,L,R
Vetch	*Vicia sativa*			L,R
Wheat	*Triticum aestivum*	F,L,R	F,L,R	F,L,R

Table 1. Annual crops sown by site and year. F=Flitcham; L=Loddington; R=Royston

At each site, birds were monitored at weekly intervals from October to March. Wherever possible, counts were carried out before 11.00 and rain or strong winds were avoided. On each occasion the observer walked along the series of plots, recording numbers of each bird species seen feeding in, or flushed from, each plot.

At one site, seed samples were collected each year from the site with the best selection of crops in terms of establishment and growth i.e. Flitcham for annuals and Loddington for biennials. However in year 3 establishment of some annual crops was less good at Flitcham so samples for these crops were collected from Loddington instead. Two crops, millet and triticale, were sampled from both sites in this year to provide a comparison.
Five randomly selected seed heads were collected from each plot at monthly intervals in 1998-99 and two-weekly intervals in 1999-2000 and 2000-2001, from early October to early March or until seed was exhausted if earlier,

and the numbers of seeds per head determined in the laboratory. For wheat, oats, triticale and linseed plots, each sample consisted of 10 seed heads, and for buckwheat, mustard, quinoa and fat hen, five seed heads. Seeds were extracted from each seed head and counted. For quinoa and fat hen which have large numbers of seeds in each seed head, a 10% sample was counted.

Soil surface samples were taken from plots at the same site, monthly in 1998 and every two weeks in succeeding years, to determine the abundance of seeds available to foraging birds on the ground. At five randomly selected sites within each plot, soil from an area of $120cm^2$ was scraped from the surface to a depth of 1cm. Seeds were removed from the soil in the laboratory by washing through a series of sieves of different mesh sizes between 3.35 and 0.5mm. Soil and other small debris was washed through the sieves, leaving seeds and any larger material behind, which was then dried in the oven. Seeds were separated by hand, identified and counted in a petri dish, using a binocular microscope. In 1999, weed seeds were also separated and counted.

Seed traps positioned in the crops (three per plot in year one, six in years two and three) were used to determine the timing and rate of seed shed from the crops. These consisted of plastic funnels mounted in plastic tubing which was partially sunk into the ground, leaving enough tubing projecting above ground to deter climbing insects. Wire mesh over the top of the funnel excluded birds and small mammals, and seeds falling into the trap were collected in small muslin bags tied over the bottom of the funnel spout. The muslin bags were emptied weekly in 1998-99 and two weekly in succeeding years.

Study sites and field methods: Effect of plot location

At eleven additional sites in 1999-2000 and thirteen in 2000-2001, pairs of cover strips of the same crop type, one mid-field and one against a hedge, were selected to test the effect of adjacent cover on the use of crops by birds. Each pair of crop strips was visited once each month from October to March. The observer walked along the edge of each strip, recording numbers of each bird species seen feeding in, or flushed from each strip. In the case of field edge strips, the number of birds in adjacent hedges was also recorded. Sites are listed in Appendix 1

Analysis

Generalized Linear Modelling was used to test for non-random use of crops, following log-transformation (log10 (x+1)) of the bird count data. Crop type was weighted by the number of plots monitored. Each variable was dropped in turn from the model and the difference in the regression mean sum of squares used to test for statistical significance at P=0.05. Significant variables were returned to the model. Where there were significant interactions between crop type and year or month of observation, differences between crops were tested within years or months, as appropriate. Effects of seed abundance on plants, in seed traps, and in soil samples were subsequently tested for each bird species in the same way. The same GLM approach was used to test for effects of plot location in relation to field boundaries as a two level factor (mid-field and field edge).

Examination of plots of changes in seed numbers against time revealed that for all crops there was a period of linear decline in seed numbers. Seed count data were smoothed by taking moving averages to the third order, and linear regression analysis carried out over the period of linear decline to allow comparison of rates of depletion. Seed consumption from seed heads and soil over the period of linear depletion was calculated using the following formulae:

$$H_{(d2-d1)} = h_{d2}-(h_{d1}+t_{d2})$$
$$S_{(d2-d1)} = (s_{d1}+t_{d2})-s_{d2}$$

where: $H_{(d2-d1)}$=seed consumed per m2 from seed heads between times d1 and d2
$S_{(d2-d1)}$=seed consumed per m2 from soil between times d1 and d2
h = number of seeds per m^2 on seed heads
t = number of seeds per m^2 in seed traps
s = number of seeds per m^2 on soil

Changes in seed consumption over time were analysed using linear regression.

Large-scale Survey

Study sites and field methods

The field survey gathered data over three winters 1998/1999, 1999/2000 and 2000/2001, from farms selected arbitrarily from arable and mixed farming regions of England). On each farm an observer was allocated a plot (sometimes two plots over 1 km apart) comprising one winter bird crop up to four neighbouring conventional fields. Each month from October to March, the observer walked around the perimeter of the winter bird crop then once through the crop where this was permissible. The observer then covered the perimeter of each conventional field before walking across the middle of that field once. The location of all birds seen or heard on fields or boundaries were recorded, along with field content and an estimate of crop height (cm). Observers noted whether the crop was pure with the soil between crop stems clean (weed-free) or whether non-crop plants occupied at least 50% of the intra-crop spaces (weedy). Observers also recorded the proportion of each field boundary that was a hedge or wood edge and estimated the average hedge height. Individual birds were recorded in the first field or boundary that they were seen in, with subsequent movements ignored. Visits were made throughout the day but not in heavy rain or in wind greater than force four.

Analysis

Our main emphasis was to compare habitat preferences of gamebirds (Ring-necked Pheasant (herein, “Pheasant”), Red-legged Partridge and native Grey Partridge) with seed-eating passerines (Alaudidae, Passeridae, Fringillidae, Emberizidae). However, all species that habitually forage on or near the ground were analysed, including insectivorous species such as Dunnocks *Prunella modularis*, and thrushes (Turdidae).

Conventional crop types were classified as: (i) *Bare soil*; (ii) *Cereal stubbles*; (iii) *Grassland*: improved, permanent, grazed or ungrazed; (iv) *Non-cereals:* potatoes, carrots and legumes; (v) *Sugar Beet*; and (vi) *Winter cereals*: wheat, barley or oats.

Winter bird crops included: (1) *Buckwheat*: seed-producing annual, usually mixed with other cover crops; (2) *Canary grass (*Phalaris *species)*: tall perennial grasses grown as cover for Pheasants; (3) *Cereals*: wheat, barley, oats or triticale that drop seed over winter, providing food and cover for birds; (4) *Kale*: a hardy biennial crop often used as a cover for gamebirds throughout the winter but producing a seed head and food in during the second winter; (5) *Linseed*: grown separately as a commercial crop for seed or mixed with cover crops for winter birds; (6) *Maize*: used mainly as a cover crop but produces a seed “cob” generally mixed with millet; (7) *Millet*: provides gamebird cover (hardy red “Tanka” variety) or seed (white millet); (8) *Mustard*; and related “Texsel Greens” are grown mainly for early winter gamebird cover in southern latitudes; (9) *Phacelia*: an annual or biennial seed-producing cover; (10) *Quinoa:* an exotic, hardy, tall annual providing a prolonged seed-drop for birds; (11) *Rape*: forage rape provides hardy, brassica cover in winter and is often mixed with linseed for seed for gamebirds; (12) *Sorghum*: tall maize-like plant without a seed cob, used as gamebird cover; (13) *Sunflowers*: grown as an annual seed crop but providing relatively little cover; (14) *Teasels:* added to cover mixes as a source of food for seed-eating passerines; (15) *Turnips*: stubble turnips provide brassica cover for winter birds.

Winter bird crops were grown either as single crops or as mixtures. For mixed crops (such as kale, maize and sunflowers), the total number of birds of a species was divided by the number of component crops. This prevented pseudo-replication of the overall bird count data for each crop mix on each visit, but assumes that the area covered by each component crop in a mix was equal, and that birds were evenly distributed throughout the mix. The analysis is conservative in terms of identifying the different preferences of birds for component crop types.

The relationship between bird abundance and crop type was analyzed by Generalised Linear Modelling with a log-link function and Poisson error term. The models were fitted to the summed bird count data from each individual field on each farm site, for each of the six visits, The analysis provided controls for sample year, plot and hedgerow length and height, crop weed content crop height and field area. The models returned Type 3 likelihood-ratio (LR) significance values for each independent variable in turn, while controlling for all other factors in the equation. The square root of the scaled deviance/degrees of freedom was used as an over dispersion factor in significance tests. The differences in bird densities among crop types were calculated relative to the commonest crop on farmland, winter cereals, for which true densities were calculated. Using a similar procedure we tested for the effects on bird’s use of crops of (1) the presence or absence of weeds, (2) the crop’s designation as set-aside or not and (3) the crops designation as an Arable Stewardship prescription, relative to conventional winter bird crops. The composition of Arable Stewardship crops was compared to conventional winter bird crops by comparing the proportion of plots that contained each crop component (Goodness of fit).

RESULTS

Experimental studies

Use of annual seed-bearing crops

The species present in annual seed-bearing crops in sufficient numbers for statistical analysis comprised Chaffinch *Fringilla coelebs*, Goldfinch *Carduelis carduelis*, Dunnock, Skylark *Alauda arvensis*, Reed Bunting *Emberiza schoeniclus*, Yellowhammer *Emberiza citrinella*, Greenfinch *Carduelis chloris* and Linnet *Carduelis cannabina*. All but Linnet showed non-random use of crop species in at least one year (Table 2).

For Reed Bunting and Yellowhammer, crop use was consistent between years. Reed Bunting used millet and fat hen more than other crops, while Yellowhammer used wheat, triticale and millet. For other bird species, there were significant interactions between crop and year and results were analysed separately for each year. Chaffinch made disproportionately high use of the related species fat hen and quinoa. Goldfinch made more use of linseed than other crops in 1999, but there was no significant non-random use in the other years. Dunnock made more use of borage and buckwheat in one of the two years in which data were available. In 1999, Skylark used borage, barley and wheat more than other crops, with the exception of quinoa which was used more than other crops in all three years.

For Greenfinch, there were significant interactions between crop and month and the results were therefore analysed separately for each month. Early in the winter, this species made more use of sunflower and borage than other crops (significantly so in September), but later in the winter, more use was made of mustard (significantly so in December). Some use was also made of linseed in the first half of the winter.

There was no significant seed abundance effect, except in the case of Chaffinch. With crop in the model for this species, seed abundance on plants ($F_{1,22}$=4.40, P=0.048) and on the ground ($F_{1,22}$=7.89, P=0.01) were significant in 1998, and without crop, seed shed was significant in 1998 ($F_{1,29}$=5.31, P=0.029) and 1999 ($F_{1,41}$=6.22, P=0.017). For most species, crop type was therefore having a greater effect than overall seed abundance. For Chaffinch, the influence of seed abundance (on plants and on the ground) in 1998 reflects the wide range of plant species used, even though quinoa was used disproportionately. The relationship between Chaffinch numbers and seed shed reflects the ground-feeding behaviour of this species. The seed traps (seed shedding) probably reflect seed abundance on the ground better than sampling seed on the ground directly, as much of the seed will already have been eaten by the time the sampling takes place.

Use of biennial seed-bearing crops

The species present in biennial seed-bearing crops comprised Blackbird *Turdus merula*, Song Thrush *Turdus philomelos*, Dunnock, Goldfinch, Greenfinch, Chaffinch, Linnet, Reed Bunting and Pheasant. Non-random use of crops was observed in at least one of the two years for all species except Dunnock and Reed Bunting. Use of crops was consistent between years. Goldfinches made significantly more use of teasel than other crops. All other species made more use of kale than the other crops, with Blackbird and Song Thrush also using chicory (Table 3).

As with the annual crops, significant relationships between bird and seed abundance were found only for Chaffinch. In this case, seed abundance on the plant was a significant predictor of bird abundance (with crop in model: $F_{1,59}$=4.66, P=0.035; without crop: $F_{1,62}$=4.46, P=0.039).

Species	Period	SF	Oats	Wheat	Fat Hen	Lin seed	Quinoa	Buck-wheat	Triti-cale	Millet	Mus-tard	Rape	Borage	Barley	F (df)	P
Chaf-finch	1998	127 ±62	28 ±62	16 ±62	211 ±62	57 ±62	45 ±62	3 ±82	10 ±58	119 ±62	217 ±62	-	217 ±62	-	ns	
	1999	51 ±52	0 ±52	5 ±52	123 ±52	11 ±52	347 ±52	5 ±52	0 ±52	9 ±52	51 ±52	-	51 ±52	-	1.89 (9,54)	0.009
	2000	0 ±71	-	6 ±71	432 ±71	11 ±71	0 ±71	-	0 ±71	0 ±71	0 ±71	0 ±71	0 ±71	0 ±71	3.29 (5,30)	0.017
Gold finch	1998	22 ±45	01 ±45	34 ±45	177 ±45	99 ±45	19 ±45	110 ±45	14 ±45	119 ±45	22 ±45	-	22 ±45	-	ns	
	1999	53 ±59	0 ±59	0 ±59	67 ±59	327 ±59	0 ±59	0 ±59	0 ±59	0 ±72	53 ±59	-	53 ±59	-	2.22 (9,54)	0.034
	2000	16 ±39	-	1 ±24	16 ±39	5 ±23	11 ±24	-	0 ±15	0 ±19	4 ±19	16 ±39	75 ±24	75 ±24	ns	
Dun-nock	1999	2 ±9	13 ±9	7 ±9	22 ±17	2 ±9	29 ±9	43 ±9	33 ±9	21 ±10	10 ±11	-	41 ±12	-	2.01 (11,172)	0.030
	2000	16 ±41	-	24 ±25	111 ±25	18 ±16	11 ±25	-	50 ±16	2 ±16	164 ±25	16 ±41	16 ±41	14 ±25	3.83 (8,65)	0.001
Skylark	1998	0 ±38	43 ±38	6 ±38	98 ±38	44 ±38	107 ±38	9 ±36	72 ±38	47 ±38	0 ±38	-	0 ±38	-	ns	
	1999	0 ±11	5 ±11	28 ±11	10 ±20	10 ±11	43 ±11	4 ±11	18 ±11	3 ±12	3 ±14	-	44 ±14	-	ns	
	2000	01 ±41	-	60 ±17	2 ±24	1 ±17	67 ±25	-	11 ±13	13 ±15	2 ±21	1 ±41	76 ±25	66 ±17	2.20 (9,100)	0.028
Reed Bunting	All years	02 ±19	19 ±21	14 ±17	103 ±31	55 ±14	32 ±17	9 ±21	41 ±41	107 ±14	45 ±17	2 ±19	2 ±21	21 ±31	3.64 (11,185)	0.001
Yellow hammer	All years	09 ±28	81 ±29	157 ±24	11 ±34	4 ±24	38 ±26	17 ±31	152 ±22	138 ±24	9 ±33	12 ±60	31 ±35	25 ±44	4.63 (12,342)	0.001
Green finch	Sept.	658 ±111	1 ±117	14 ±103	41 ±170	133 ±103	29 ±103	22 ±122	3 ±95	7 ±103	42 ±130	37 ±241	639 ±137	63 ±247	2.23 (12,46)	0.025
	Oct.	1186 ±69	5 ±64	0 ±58	30 ±84	52 ±58	1 ±58	2 ±66	3 ±54	12 ±58	43 ±63	15 ±102	328 ±73	25 ±152	ns	
	Nov.	268 ±63	3 ±59	0 ±54	22 ±77	154 ±54	4 ±54	16 ±66	5 ±47	46 ±53	126 ±64	1 ±93	46 ±67	16 ±140	ns	
	Dec.	159 ±54	13 ±51	6 ±46	113 ±66	50 ±46	4 ±46	27 ±52	9 ±43	3 ±46	438 ±55	5 ±80	4 ±57	30 ±120	2.78 (12,57)	0.005
	Jan.	74 ±53	10 ±50	7 ±45	11 ±65	5 ±45	5 ±51	9 ±51	6 ±42	5 ±45	298 ±54	2 ±78	5 ±56	57 ±117	ns	
	Feb.	11 ±47	21 ±43	5 ±39	17 ±57	108 ±39	4 ±39	21 ±45	14 ±37	8 ±37	91 ±47	13 ±68	16 ±49	75 ±103	ns	

Table 2. Mean (± se) x10^3 bird numbers in experimental plots of annual seed-bearing crops. SF = Sunflower.

Species	Kale	Evening Primrose	Teasel	Chicory	F (df)	P
Blackbird	134±25	8±25	17±25	134±25	3.89 (2,12)	0.05
Chaffinch	175±30	15±29	105±34	34±79	4.94 (3,74)	0.004
Greenfinch	358±42	7±42	98±54	98±54	10.88 (2,40)	0.001
Pheasant	75±12	23±12	4±15	9±29	4.50 (3,46)	0.008
Song Thrush	32±8	6±8	5±13	32±8	3.59 (2,23)	0.044
Goldfinch	2±33	87±32	339±38	24±88	10.88 (2,40)	0.001

Table 3. Mean (±se) x 10^3 bird numbers in experimental plots of biennial seed-bearing crops for 1999 and 2000.

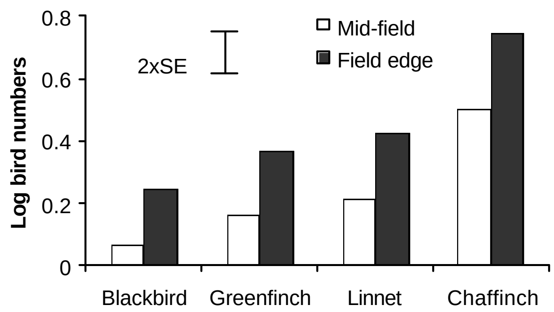


Figure 1. Log mean numbers of birds recorded using field edge and mid-field plots of seed-bearing crops.

Effect of plot location

Data were available for comparison of the use of mid-field and field edge plots for Blackbird, Song Thrush, Dunnock, Skylark, Greenfinch, Linnet, Chaffinch, Yellowhammer, Reed Bunting and Pheasant. For Skylark and Pheasant, there were significant interactions between plot location and month. There were no significant effects of plot location when data for these species were analysed by month.

There were significant effects of plot location on abundance of Blackbird ($F_{1,119}$=19.84, P<0.001), Chaffinch ($F_{1,119}$=9.11, P=0.003), Greenfinch ($F_{1,119}$=8.02, P=0.005) and Linnet ($F_{2,85}$=7.14, P<0.001). In each case, abundance was higher on field edge plots (Figure 1). There was also a positive effect of plot size for the three primarily seed-eating species, Linnet ($F_{1,119}$=16.40, P<0.001), Greenfinch ($F_{1,119}$=17.64, P<0.001) and Chaffinch ($F_{1,119}$=9.47, P=0.003).

Seed production, depletion and consumption

There was a large amount of variation between crops and years in the number and biomass of seeds produced (Table 4). Borage had far fewer seeds than any other crop, however, it shed its seeds very early and some shedding may have occurred before the start of recording. The largest numbers of seeds were produced by the closely related species fat hen and quinoa. Millet and chicory produced large numbers in 2000, but numbers were smaller in earlier years. The cereals triticale and wheat consistently produced high biomass of seeds compared with other crops, but fat hen, millet and quinoa also produced similar quantities in high yielding years.

Crop	No. seeds						Biomass (g)					
	1998/1999		1999/2000		2000/2001		1998/1999		1999/2000		2000/2001	
	mean	*SE*	mean	*SE*	mean	*SE*	mean	*SE*	mean	*SE*	mean	*SE*
Barley					2,189	*1224*					100.5	*56.19*
Borage	3	*1*	32	*6*			0.1	*0.02*	0.6	*0.11*		
Buckwheat	1,078	*141*	687	*239*			31.0	*4.05*	19.8	*6.88*		
Chicory			502	*89*	48,487	*9474*			1.0	*0.17*	92.1	*18.00*
Evening Primrose			4,537	*634*					2.7	*0.38*		
Fat Hen	45,568	*4,574*	182,310	*53104*			31.9	*3.20*	127.6	*37.17*		
Kale			266	*19*	2,152	*308*			1.1	*0.08*	9.0	*1.29*
Linseed	7,162	*1,065*	5,127	*286*			48.7	*7.24*	34.9	*1.95*		
Millet (F)	1,595	*802*			18,356	*2673*	6.5	*3.29*			75.3	*10.96*
Millet (L)					62,809	*7504*					257.5	*30.76*
Mustard			3,899	*694*	12,227	*5303*			27.7	*4.93*	86.8	*37.65*
Oats	2,052	*302*	3,928	*983*			35.7	*5.26*	68.3	*17.1*		
Quinoa	19,797	*2798*	58,470	*11520*	126,423	*29110*	55.4	*7.84*	163.7	*32.25*	354	*81.51*
Sunflower	11,747	*1439*					52.4	*6.41*				
Teasel			4,703	*1569*	7,932	*545*			13.2	*4.39*	22.2	*1.53*
Triticale (F)	6,799	*300.1*	11,487	*1659*	3,571	*575*	238.7	*10.53*	259.7	*58.23*	125.4	*20.20*
Triticale (L)					11,635	*4982*					408.4	*174.87*
Wheat	3,271	*250.7*	5,777	*1019*	3,846	*525*	152.7	*11.71*	166.4	*47.60*	179.6	*24.53*

Table 4. Mean numbers and biomass of seeds per m^2 present on crop seed heads before depletion (*SE* = standard error; F = Flitcham; L = Loddington).

For all crops there was a period of seed depletion during which the number of seeds present on the seed heads declined linearly over time, though this period started at different times for different crops. During this period, between 90 and 100% of seeds were lost from the seed head. There was a highly significant relationship, over all crops and years, between the rate at which seeds were lost from the seed heads (seed depletion rate) and the number of seeds present before seed loss started ($F_{1,32}$=2597.3; P<0.001, Figure 2). There was also a highly significant relationship between the same variables expressed as biomass ($F_{1,32}$=89.53; P<0.001).

Depletion rate as a proportion of seed present before depletion is shown in Table 5. Borage shed its seed most rapidly. Oats also shed seed early, being exhausted by November or early December, whilst wheat retained seed until December or early January and triticale until late January or early February. Mustard seed was fully depleted by early November in year 2 but persisted until mid January in year 3. Quinoa and fat hen both persisted until mid December/early January, linseed until early January, whilst millet retained seed until between mid December and early February. Of the biennials, Kale was exhausted by early December, evening primrose by mid December and teasel by mid-late January, whilst chicory persisted until January or February.

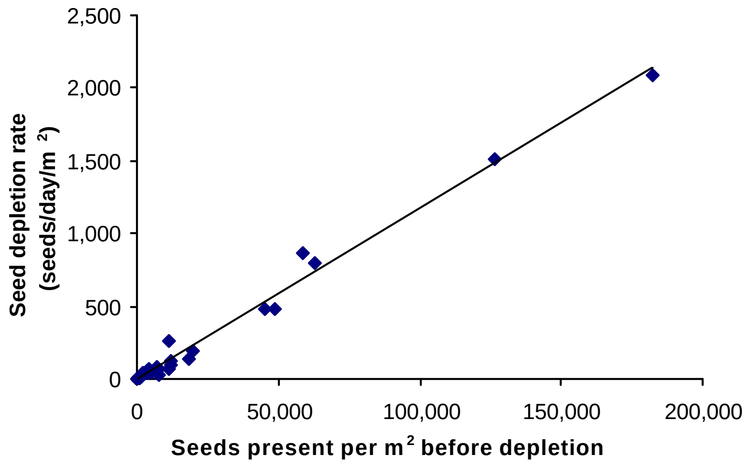


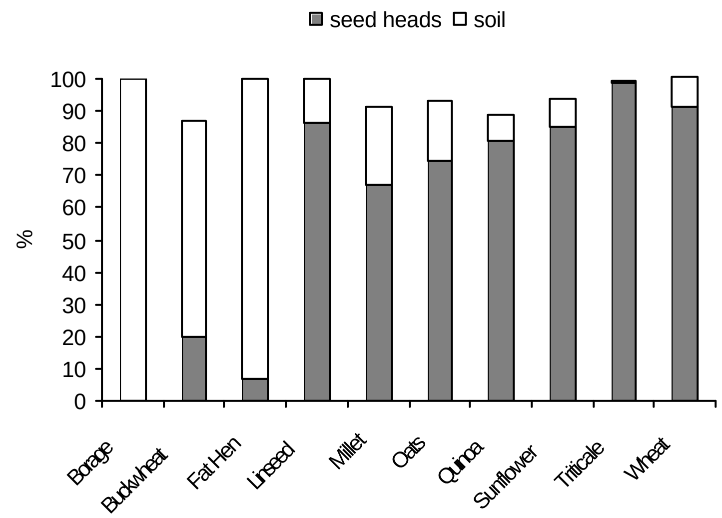
Figure 2. Relationship between seed depletion rate and the number of seeds present on the seed heads before depletion. Regression equation: seed depletion rate = 0.0117h ±0.0002 – 2.65 where h= number of seeds present before depletion. The regression accounted for 98.7% of the variance.

For most crops, between 90 and 100% of the total seed production were consumed over the period of linear depletion (Figure 3). Occasionally, due to natural biological variation in the data, estimates of seed consumed on the seed head and the soil added up to more than 100% of seed recorded on the seed heads at the beginning of the depletion period; in such cases estimates were adjusted pro rata to give a total of 100% for ease of comparison. Unadjusted means are given in appendix 2. For the cereals barley, triticale and wheat, most seed consumption appeared to take place from the seed heads. However, seed consumption on the soil may have been underestimated for these species because they showed a tendency for whole seed heads to fall from the stems which may not have been adequately sampled by the seed traps. Oats were the exception among the cereals, especially in the second year when most consumption was measured from the ground, probably because oats shed their seed more rapidly than the other cereals. In 1999, very little seed remained on the seed heads by early November, but in 1998 seed persisted on the seed heads for another month. For three other early shedding species, borage, kale and evening primrose, consumption was only recorded from the ground, similarly for teasel which retained its seeds for longer. Consumption of chicory seed was only recorded from the ground in one year, but from both seed heads and ground in another. For the remaining species, consumption was recorded from both seed heads and the ground, though consumption from seed heads was usually greater.

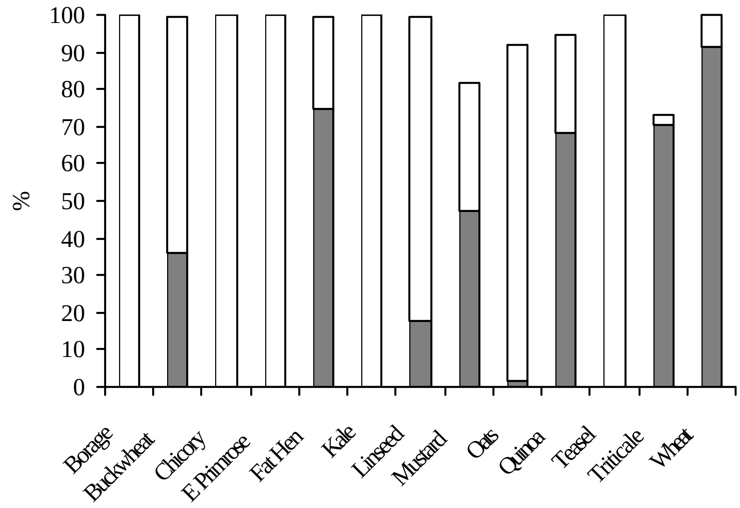
Crop	1998/9	1999/00	2000/01
Borage	1.69	2.38	
Buckwheat	0.88	1.65	
Chicory		0.89	1.00
Evening Primrose		1.60	
Fat Hen	1.05	1.30	
Kale		1.29	1.68
Linseed	1.12	0.88	
Millet	1.05		0.74
Mustard		1.35	0.81
Oats	1.74	1.76	
Quinoa	1.00	1.76	1.19
Teasel		0.90	0.41
Triticale	0.89	0.62	1.03
Wheat	1.72	1.02	1.51

Table 5. Daily depletion rate as a percentage of seeds present on crop seed heads before depletion at Flitcham

1998-1999



1999-2000



2000-2001

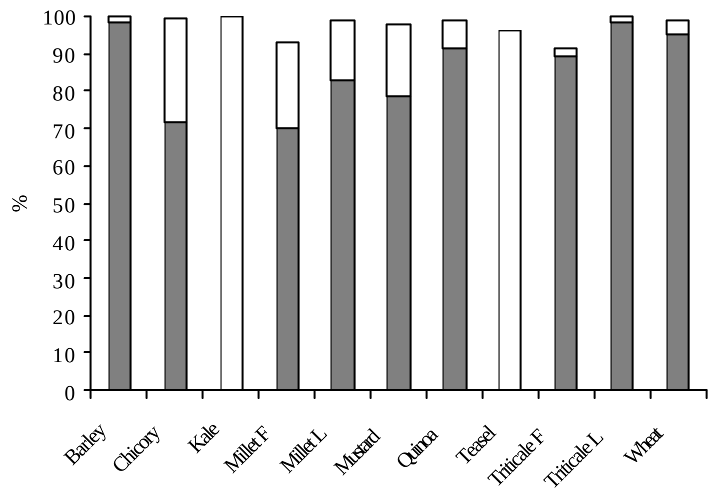


Figure 3. Percentage of seed present before depletion consumed on seed heads or on the ground. Where estimates total to more than 10%, they have been adjusted *pro rata* to total to 100% for comparative purposes.

Large-scale Survey

Across all three years, data were collected from 192 farm plots from 161 individual farms across England with 122, 130 and 82 farm plots surveyed in winters 1, 2 and 3 respectively.

Species

Significant responses to crop type were recorded for 18 bird species (at a=0.05), of which six are subject to national Biodiversity Action Plans, and 11 contribute to the national farmland bird index (Table 6). No significant differences between crops were recorded for indicator species; Stock Dove *Columba oenas*, Jackdaw *Corvus monedula* or Starling *Sturnus vulgaris* or for seed-eating species, House Sparrow *Passer domesticus* and Brambling *Fringilla montifringilla*. Species, of potential conservation interest, such as Twite *Carduelis flavirostris*, Lesser Redpoll *Carduelis flammea* and Cirl Bunting *Emberiza cirlus* were recorded too infrequently for a detailed statistical assessment of their habitat preferences. The strongest model fits used a combination of field and boundary counts of each species, since in winter birds tend to be distributed according to the availability of food rather than nest sites.

Overall, densities of birds on winter bird crops were higher than on conventional crops (Table 6). For Skylark, however, highest densities were recorded on cereal stubbles. For Rooks *Corvus frugilegus* winter cereals and cereal stubbles were important. For Grey Partridge, grassland and non cereals were important while non cereals (legumes or root crops) were important for Reed Buntings (Table 6b).

	Winter bird crops														
Species	**BK**	**CG**	**CL**	**K1**	**K2**	**LI**	**ML**	**MU**	**MZ**	**PH**	**QU**	**RA**	**SU**	**TE**	**TU**
PH	1.1	2.7	2.5	0.9	1.6	1.9	1.0	0.9	1.9	0.9	1.4	1.4	0.8	0.8	1.4
P.(BAP)/(FI)	0.0	0.0	0.8	0.3	2.7	0.5	0.7	0.6	0.7	0.0	0.7	1.6	0.3	0.8	1.0
RL	1.2	1.0	1.0	0.6	2.0	2.0	0.7	0.9	1.8	0.7	0.9	1.4	1.1	1.8	0.7
WP (FI)	0.7	0.1	0.9	0.5	2.0	0.4	1.5	1.3	5.1	0.6	1.2	3.1	1.6	1.7	1.8
S.(BAP)/(FI)	0.0	0.0	0.5	2.1	1.1	1.6	1.3	0.5	0.9	0.0	0.5	0.8	0.5	0.0	1.3
D.	1.5	1.2	1.5	2.1	2.2	1.4	1.3	1.3	1.7	0.9	1.7	1.4	1.3	1.4	2.3
B.	0.9	1.0	1.3	1.5	2.0	0.9	1.0	1.2	1.2	0.7	1.4	1.3	1.0	1.2	2.1
ST(BAP)	1.6	4.1	1.3	2.5	2.5	0.9	1.3	0.6	1.3	0.9	2.2	1.9	0.8	2.0	2.3
RO(FI)	0.0	0.0	0.1	4.5	0.7	0.8	0.7	0.7	0.7	0.0	0.5	0.6	0.4	0.0	0.1
TS (BAP)/(FI)	0.0	0.0	1.4	2.8	4.5	2.0	2.4	2.1	2.1	0.0	2.5	3.4	1.2	0.8	0.0
BF (BAP)	0.0	1.5	0.8	1.3	2.4	0.8	1.3	1.6	2.4	0.0	2.9	0.0	0.0	0.0	0.8
GO(FI)	1.2	6.7	3.0	0.8	1.3	2.1	1.0	0.4	0.8	0.5	0.9	0.6	0.6	0.8	0.5
GR(FI)	3.2	6.2	2.9	2.7	4.5	4.2	2.7	2.9	3.1	3.9	8.0	3.0	5.3	2.5	4.5
LI(BAP)/(FI)	0.2	1.1	0.5	0.9	1.8	1.8	0.4	1.9	0.8	0.2	0.9	1.2	0.6	0.2	1.3
CH	1.6	1.9	2.9	3.2	6.0	2.7	1.7	1.1	2.1	0.3	2.6	1.7	1.5	1.6	3.8
RB(BAP)/(FI)	1.0	0.0	1.8	2.3	2.7	1.1	1.8	1.8	2.1	3.1	2.7	3.2	2.1	2.2	10.1
Y. (FI)	0.6	11.8	2.9	1.0	1.9	1.9	1.0	0.8	1.0	0.2	1.2	1.9	0.6	1.7	1.8
CB(BAP)/(FI)	0.0	0.0	3.0	3.4	0.1	2.9	0.2	3.4	0.6	0.0	3.4	0.0	0.0	0.0	2.1
TMD	*1.1*	*5.7*	*1.4*	*1.6*	*4.2*	*0.8*	*1.3*	*1.9*	*3.1*	*0.6*	*2.2*	*1.7*	*1.5*	*1.5*	*1.8*

Table 6a. Densities of birds on winter bird crops relative to winter cereals, for which true densities are given in for each species (ha^{-1}). Abbreviations: Winter bird crops: buckwheat (BK), canary grass (CG), cereals (CL), 1st-year kale (K1), 2nd-year kale (K2), linseed (LI), millet (ML), mustard (MU), maize (MZ), rape (RA), phacelia (PH), sunflowers (SU), teasels (TE), turnips (TU) and quinoa (QU); Bird species: Ring-necked Pheasant (PH), Grey Partridge (P.), Red-legged Partridge (RL), Woodpigeon (WP), Skylark (S), Dunnock (D), Blackbird (B), Song Thrush (ST), Tree Sparrow (TS), Bullfinch (BF), Goldfinch (GO), Greenfinch (GR), Linnet (LI), Chaffinch (CH), Reed Bunting (RB), Yellowhammer (Y) and Corn Bunting (CB). Species subject to national Biodiversity Action Plans are denoted (BAP). Those contributing to the farmland bird index are denoted **(FI).**

Species	Conventional field types							Top three crops (all types)	Model effects			
	BK	BA	CS	GR	NC	SB	WC		Crop	Hedge		N
							True density		*P*	% bnd	Hgt (m)	
PH	1.1	1.8	1.5	1.7	0.6	0.8	*0.07*	**CG, CL, MZ**	***	***	ns	1162
P.(BAP)/(FI)	0.0	1.5	1.1	2.1	0.0	0.1	*0.09*	**K2, GR, RA**	***	ns	ns	238
RL	1.2	1.3	1.4	0.8	1.4	1.4	*0.12*	**LI/K2, MZ**	***	ns	ns	1132
WP (FI)	0.7	1.8	1.1	1.5	1.6	2.5	*0.76*	**MZ, RA, SB**	***	ns	ns	7713
S.(BAP)/(FI)	0.0	1.1	2.5	1.3	0.7	1.5	*0.24*	**CS, K1, LI**	***	ns	ns	1264
D.	1.5	1.3	1.3	1.3	1.6	1.6	*0.06*	**TU, K2, K1**	***	+*	ns	294
B.	0.9	1.1	1.1	1.4	1.1	3.8	*0.15*	**SB, TU, K2**	***	ns	ns	467
ST(BAP)	1.6	1.0	0.9	0.9	1.3	1.5	*0.02*	**CG, K1/K2**	***	+*	ns	147
RO(FI)	0.0	0.8	1.6	0.6	0.3	0.6	*0.55*	**K1, WC, CS**	*	ns	ns	1913
TS (BAP)/(FI)	0.0	0.1	1.0	1.9	0.0	0.7	*0.00*	**K2, K1, RA**	*	ns	+***	93
BF (BAP)	0.0	0.9	0.7	2.1	1.0	0.0	*0.02*	**QU, K2, MZ**	***	ns	ns	67
GO(FI)	1.2	1.1	1.3	2.1	3.3	0.3	*0.18*	**CG, NC, CL**	***	ns	ns	836
GR(FI)	3.2	0.9	4.1	1.3	4.4	3.3	*0.06*	**QU, CG, SU**	***	+*	+***	1496
LI(BAP)/(FI)	0.2	0.2	1.9	1.0	2.8	0.3	*0.11*	**NC, MU/CS**	***	ns	-*	1526
CH	1.6	1.0	1.7	1.4	2.7	0.9	*0.22*	**K2, TU, K1**	***	ns	ns	2328
RB (BAP)/(FI)	1.0	0.9	2.5	2.1	4.1	0.0	*0.19*	**TU, NC, RA**	***	ns	ns	847
Y. (FI)	0.6	0.8	1.6	0.9	0.6	0.5	*0.22*	**CG,CL, RA/LI**	***	+**	ns	217
CB (BAP)/(FI)	0.0	0.3	3.4	0.0	0.0	3.3	*0.06*	**CS/ KI/MU/QU**	*	-*	-*	49
TMD	*1.1*	*0.3*	*0.6*	*0.4*	*0.4*	*0.3*	0.2					

Table 6b. Densities of birds on conventional farm crops relative to winter cereals, for which true densities are given in for each species (ha^{-1}), and summary of model effects. *P* shows significant effects of crop type (followed by boundary length (% bnd) and hedge height (hgt)) for each bird species. **P*<0.05, ***P*<0.01, ****P*<0.001. *N* is a rounded mean number of birds recorded on each visit in each year. TMD is true mean density (ha^{-1}) across species for each crop. Abbreviations: bare earth (BA), cereal stubbles (CS), grassland (GR), non-cereal stubbles (NS) and sugar beet (SB); bird species abbreviations are as in Table 5a

Across all eighteen species, kale, particularly in its second year, was the most consistent crop to appear in the top three crops preferred by birds (Table 6a). Kale received the highest average rank among crops for seed-eating species (sparrows, finches and buntings (Figure 4)). Turnips were also one of the preferred crops of Dunnock, Blackbird, Chaffinch, and Reed Bunting, and received the highest average rank among the three insectivorous species (Figure 4). Quinoa was especially important for Greenfinch, Bullfinch *Pyrrhula pyrrhula*, Corn Bunting *Miliaria calandra* and Tree Sparrow *Passer montanus* (for two of three winters), and was among the higher average ranked crops for seed-eating and insectivorous functional groups, and among the BAP species (Figure 4). High ranking crops included cereals (stubbles or seeding crops) and oilseed rape for buntings and linseed for finches and buntings. Canary grass was utilized by Song Thrushes, Pheasants, Greenfinch, Goldfinch and Yellowhammers but was otherwise a low ranking crop, especially amongst BAP species (Figure 4). Buckwheat, phacelia and sunflowers were consistently low ranking crops with sunflowers being mainly exploited by Greenfinches. Maize was important for Pheasants, Red-legged Partridges and Woodpigeons *Columba palumbus* (Table 6). Although the ranked crop preferences of Pheasants and Red-Legged Partridges were weakly correlated with those of other species (Figure 5), second year kale, seeding cereals, rape and linseed were the preferred crops of all groups.

Weed content, set-aside and boundary effects

The distribution of Grey Partridge, Tree Sparrow and Reed Bunting were significantly influenced by the presence of weeds in the crops (that is: in kale, maize and quinoa - *P*=0.05; in kale, millet and mustard - *P*=0.01; and in kale, maize and cereals - *P*=0.01, respectively).

The positioning of winter bird crops near boundaries was significant for Pheasant, Dunnock, Song Thrush, Greenfinch and Yellowhammer (Table 6b). Tree Sparrows, Greenfinch and Linnet were commoner by taller hedgerows and Corn

Buntings significantly commoner where there were less hedges and lower hedges (Table 6b). Whether a winter bird crop was designated set-aside or not made no significant difference to the distribution of any species.

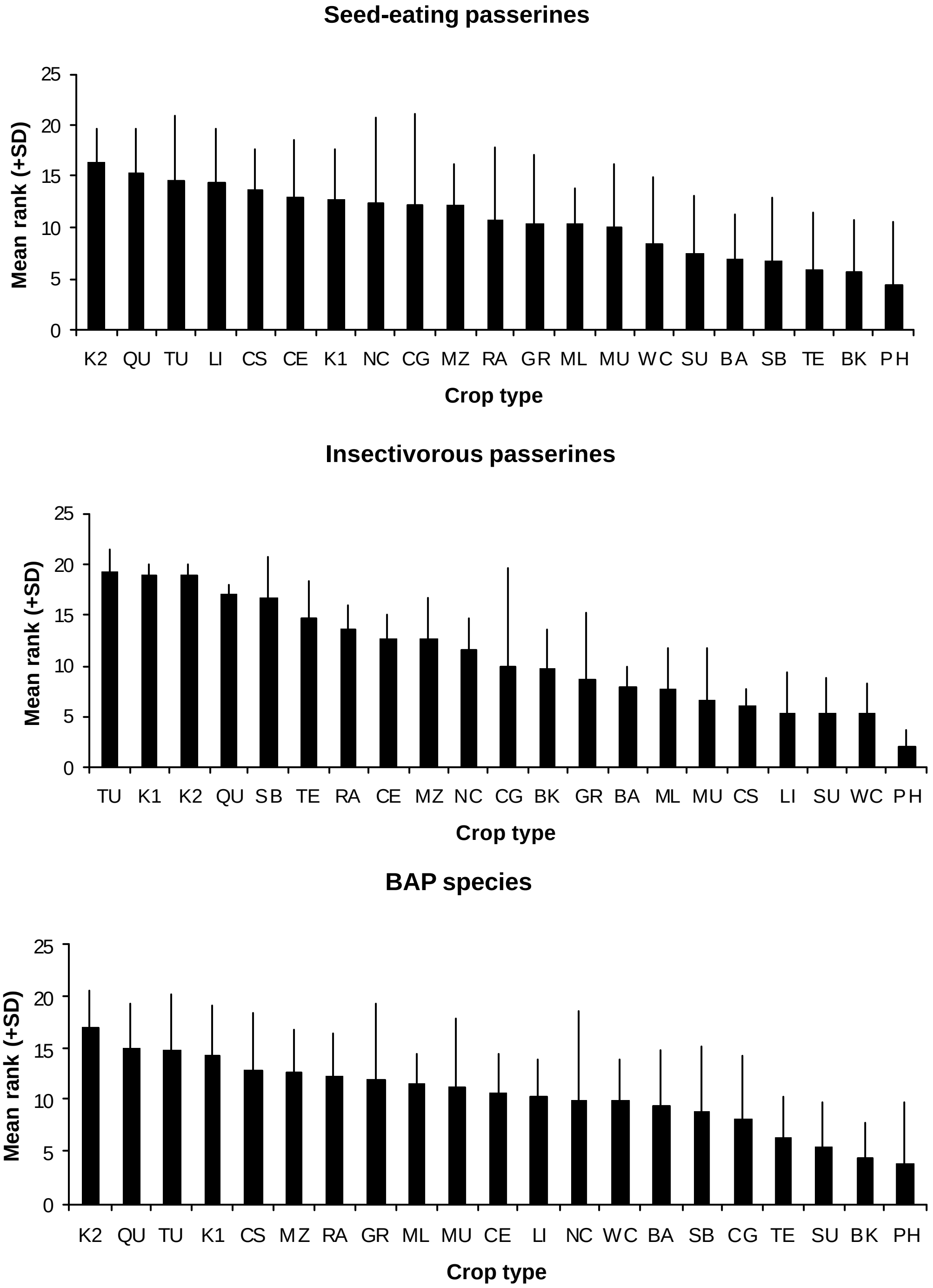
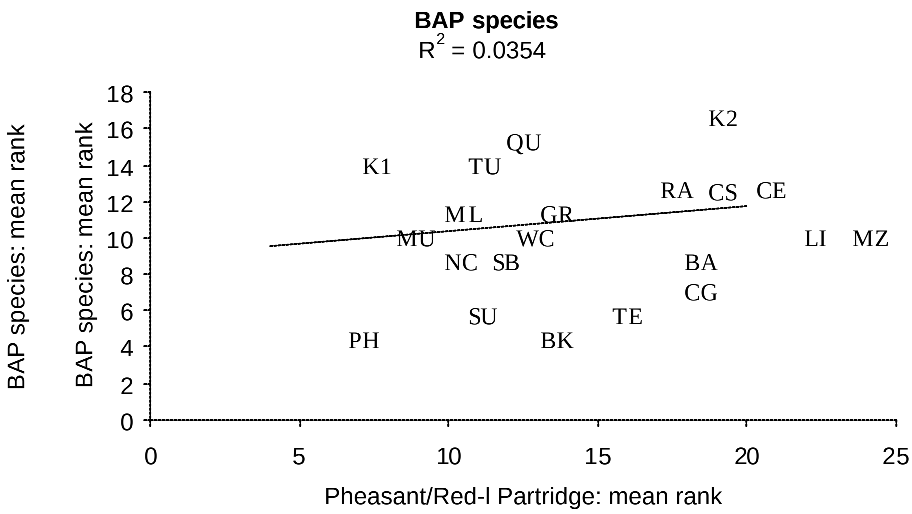


Figure 4. The distribution of three categories of birds, Seed-eating Passerines (Bullfinch, Goldfinch, Greenfinch, Chaffinch, Linnet, Tree Sparrow, Reed Bunting Yellowhammer, Corn Bunting); Insectivorous Passerines (Dunnock, Blackbird and Song Thrush); and Biodiversity Action Plan (BAP) Species (Grey Partridge, Song Thrush, Tree Sparrow, Bullfinch, Linnet, Corn Bunting and Reed Bunting), in relation to winter bird crop type (mean rank ? 1 SD). Crop types are: bare ground (BA), buckwheat (BK), cereals in seed (CE), canary grass (CG), cereal stubble (CS), grassland (GR), 1st-year kale (K1), 2nd-year kale (K2), linseed (LI), millet (ML), mustard (MU), maize (MZ), non cereals (NC), phacelia (PH), quinoa (QU), rape (RA), sugar beet (SB), sunflowers (SU), teasels (TE), turnips (TU) and winter cereals (WC).



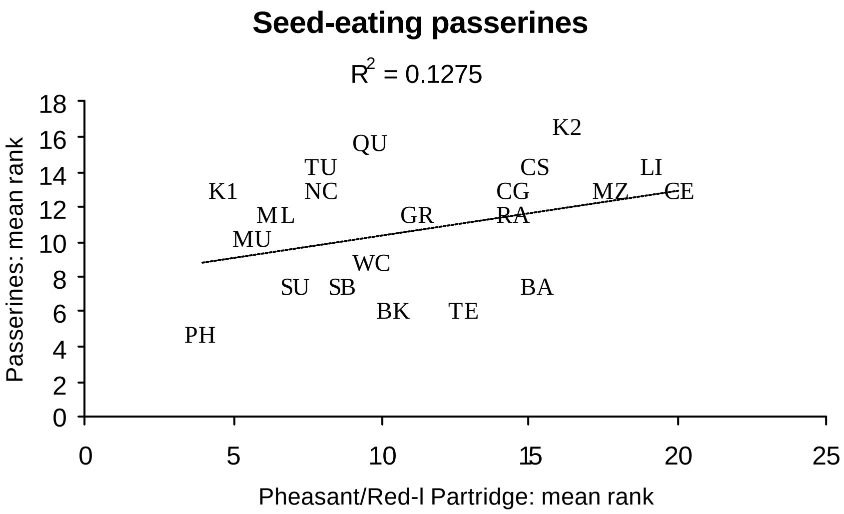


Figure 5. Comparing the crop preferences (mean rank) of Ring-necked Pheasants and Red-legged Partridges with (A) Biodiversity Action Plans (BAP) species (Grey Partridge, Song Thrush, Tree Sparrow, Bullfinch, Linnet, Corn Bunting and Reed Bunting) and (B) Seed-eating passerines (Bullfinch, Goldfinch, Greenfinch, Chaffinch, Linnet, Tree Sparrow, Reed Bunting Yellowhammer, Corn Bunting). Crop types are: bare ground (BA), buckwheat (BK), cereals in seed (CE), canary grass (CG), cereal stubble (CS), grassland (GR), 1st-year kale (K1), 2nd-year kale (K2), linseed (LI), millet (ML), mustard (MU), maize (MZ), non cereals (NC), phacelia (PH), quinoa (QU), rape (RA), sugar beet (SB), sunflowers (SU), teasel (TE), turnips (TU) and winter cereals (WC).

Changes in usage by date and field area

Although bird densities in general declined on winter bird crops over winter (Figure 6a & albeit with higher numbers on larger crop areas in February; Figure 6b), bird densities on kale declined by only 31% between October and February, compared to 75% on sunflowers (Figure 6c).

As for the winter in general, in late winter (February/March), kale, cereal stubbles, maize, quinoa and linseed were again of high average rank for passerines, and gamebirds (Figure 7). In fact the correlation between the mean ranks of crops for the gamebirds and passerines was stronger in late winter than for the winter as a whole (r^2 = 0.43 for seed-eaters; r^2 = 0.19 for insectivores).

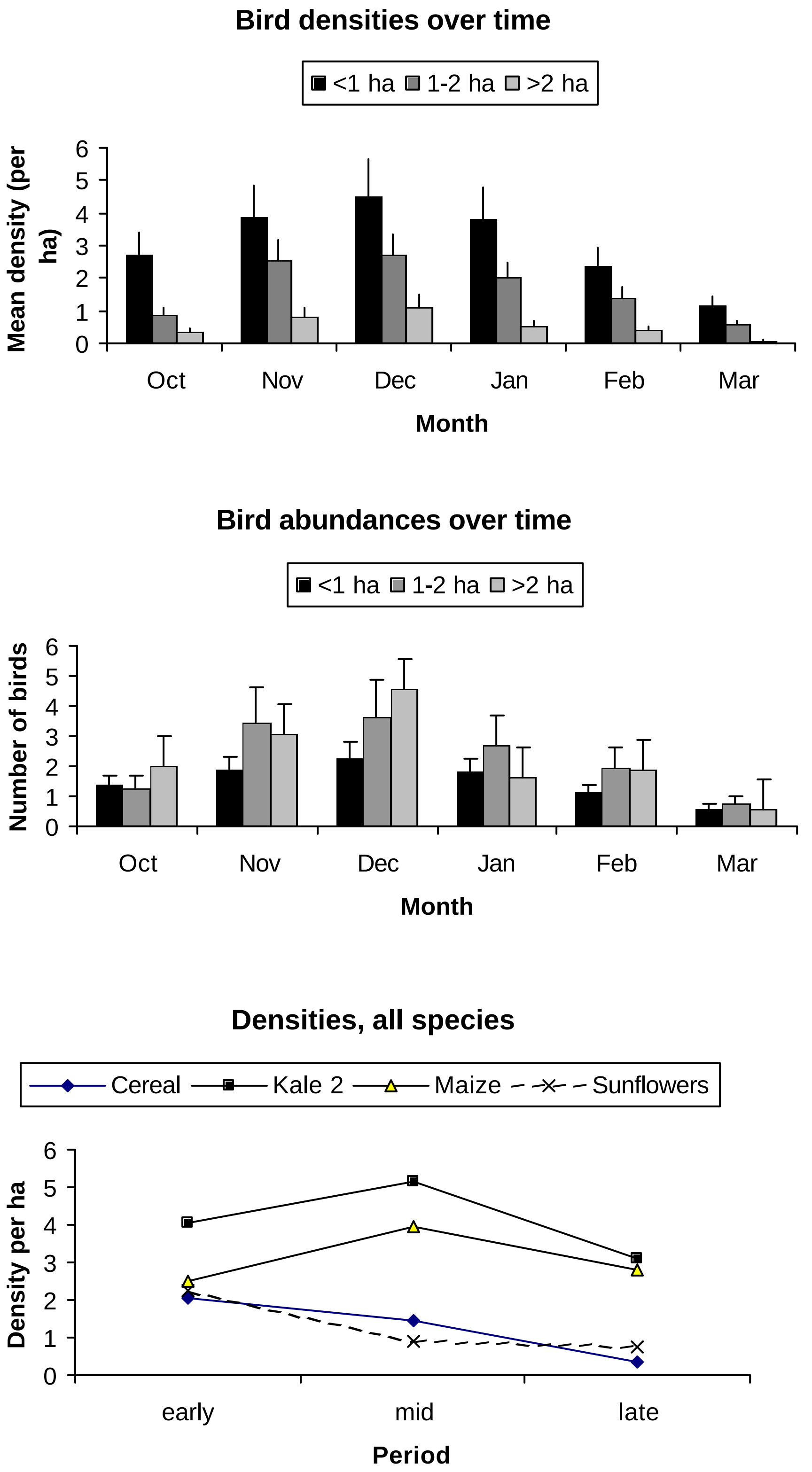


Figure 6(a) Mean densities (ha^{-1}) and **(b)** mean abundances of birds (per area category) (all species combined +1SD) on winter bird crops of <1 ha in area (<1 ha; mean n per month =101), between 1 and 2 ha in area (1-2 ha; mean n per month =30) and over 2 ha in area (>2 ha; mean n per month =28) over the winter period October to March. **(c)** Is the change in densities of birds on four crops over the winter period: early (October/November), (mid) December/January and late (February/March).

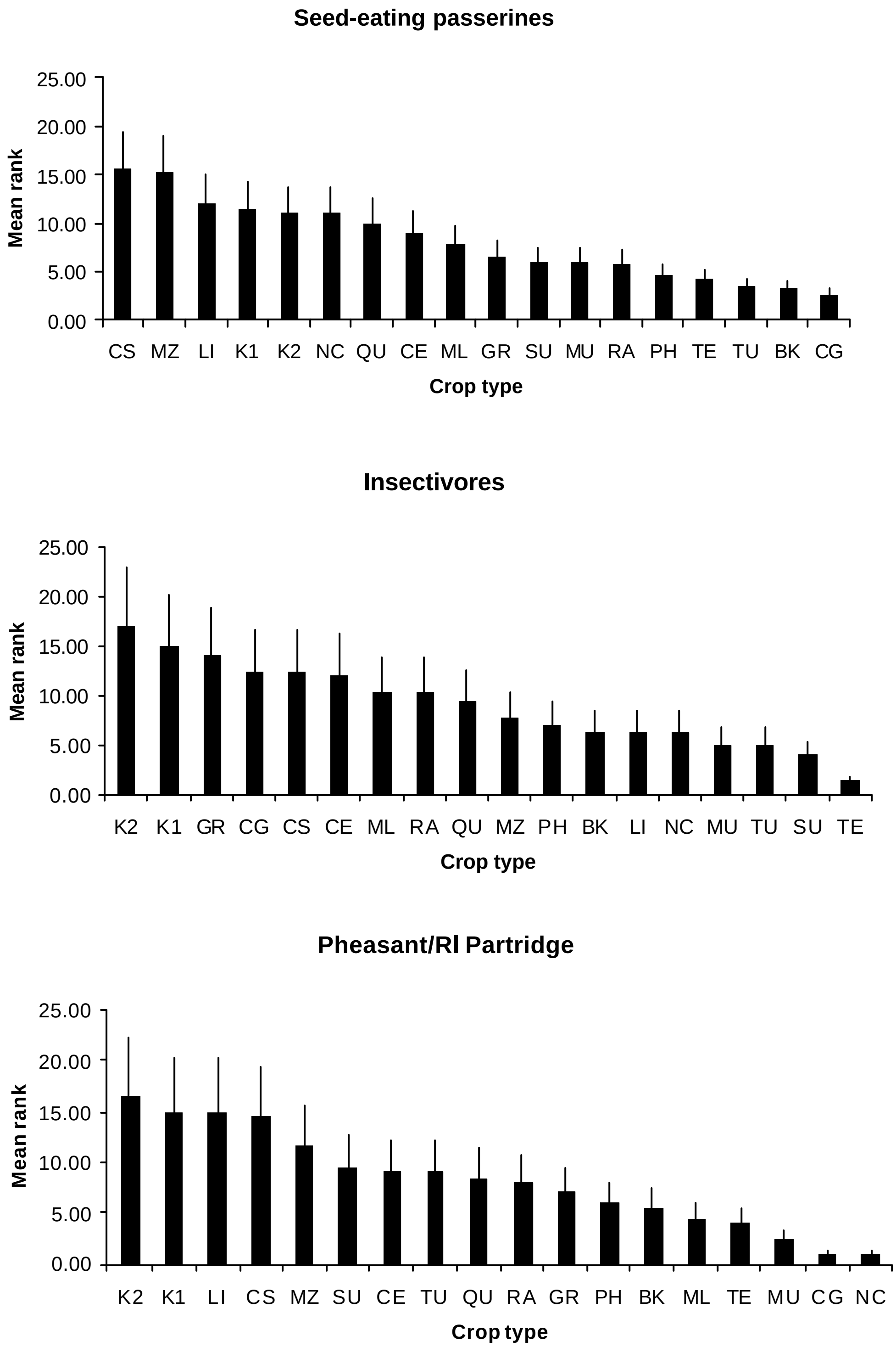


Figure 7. Mean ranks (+1SD) of crop types for three species groups using winter bird crops during late winter (February/March).

Arable Stewardship

Densities of birds on 28 Arable Stewardship plots were lower than on conventional winter bird crops, for 17 of the 18 species (Sign Test, $P<0.001$), the exception being Bullfinch. The difference was statistically significant for Pheasant, Red-legged Partridge, Skylark, Blackbird, Song Thrush, Goldfinch, Greenfinch, Linnet and Chaffinch. The frequency of component crop types in conventional winter bird crops was also statistically different from Arable Stewardship crops

(Chi-squared: = 68.1 df=15, *P*<0.01). A higher proportion of Arable Stewardship winter bird crops contained buckwheat, sunflowers and phacelia than conventional winter bird crops. A lower proportion of Arable Stewardship patches contained kale, linseed, quinoa and turnips than conventional winter bird crops (Figure 8).

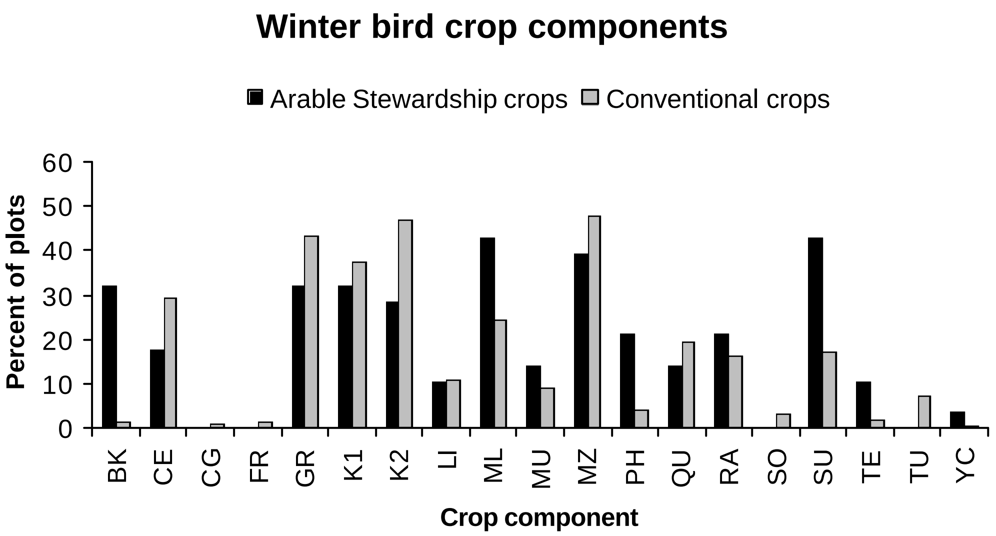


Figure 8. The frequency of component crops in conventional (*N*=192) and Arable Stewardship (n=28) winter bird cover. Crop types are: buckwheat (BK), cereals in seed (CE), canary grass (CG), fathen (FH) grassland (GR), 1st-year kale (K1), 2nd-year kale (K2), linseed (LI), millet (ML), mustard (MU), maize (MZ), phacelia (PH), quinoa (QU), rape (RA), sugar beet (SB), sorgum (SO), sunflowers (SU), teasels (TE), turnips (TU) and yellow cover (YC). Goodness of fit: Chi-squared: $?^2_{18}$=68.8, df =18, *P*<0.001.

DISCUSSION

In the large scale survey, we found that the densities of birds on most wild bird crops exceeded those recorded on conventional field types. Exceptions such as Skylark and Rook preferences for cereal stubbles, and Grey Partridges in grassland are consistent with previous studies of these species.

Results in terms of bird species preference for crop types were generally consistent between experimental plots and survey approaches, where the same species were represented. Thus, few birds used buckwheat, and only Greenfinch used sunflower and borage, preferring these crops to those such as quinoa and fat hen which were favoured by other species in the experimental plots, though the survey results recorded substantial use of quinoa by Greenfinches. In experimental plots, efforts were made to keep weed growth to a minimum, but weeds were inevitably present and would have formed an additional weed source. In 1999, weed seeds on the soil were recorded in addition to crop seeds to check whether the presence of weeds was influencing the results. Space does not permit the inclusion of these data here, but there was variation between crops in weed seed numbers, with the highest numbers in quinoa and buckwheat. However, hardly any birds were recorded feeding in buckwheat, so it seems unlikely that the presence of weeds had a significant effect on crop preference results. In the large-scale survey, crops were recorded as “weedy” or “non-weedy”, and the presence of weeds significantly affected the distribution of three species, Grey Partridge, Tree Sparrow and Reed Bunting. However, crops recorded as “weedy” had at least 50% of intra-crop spaces occupied by weeds, so that a substantial proportion of the total seed available was probably weed seeds in these crops.

Species attracted to kale included gamebirds, seed-eating passerines and insectivorous passerines, among which several were the subject of national recovery programmes (ie., BAP species). Kale was therefore among the top three most important crops for Grey Partridge, Skylark, Song Thrush, Tree Sparrow (in weedy kale), Bullfinch and Corn Bunting. Several other brassicas, such as turnips, rape and mustard also predominated amongst the high ranking winter bird crops, being especially attractive to buntings. Cereals, such as triticale, or cereal stubbles also provided a preferred habitat for several species from across functional groups (Pheasant, Skylark, Goldfinch, Linnet and buntings). Other than brassicas, quinoa was another high ranking crop, utilized by several species that included Tree Sparrows and Corn Buntings, both of high conservation priority. In experimental plots, fat hen attracted high numbers of most species other than greenfinch and linnet. Fat hen is known to be important in the diet of a wide range of seed-eating birds (Wilson *et al*., 1996, 1999[#9; #1]), but sowing of species regarded as weeds is likely to be unacceptable to most farmers, and quinoa forms a convenient substitute. As it is not frost-hardy, quinoa does not persist in the UK, so is not a threat to commercial crops. Linseed was a high ranking crop in the survey for seed-eating passerines, and was favoured by goldfinch, greenfinch and reed bunting in experimental plots.

Buckwheat, sunflowers and *Phacelia* were generally associated with low densities of birds. As mentioned above, sunflowers were specific to Greenfinches. Canary grass although of low average rank, supported high densities of Pheasants, Song Thrushes and Yellowhammers, especially in late winter. For, Yellowhammers, this association is consistent with this species' preference for grass-seed, grass margins and cereals fields.

Maize was a common winter bird crop, but its value to birds was equivocal. Maize used by Pheasants and Red-legged Partridges as cover and the cob may have attracted Woodpigeons that were common in maize crops. However, companion crops that invariably accompany maize were not always identified, thus millet in particular was probably under represented in the current survey and its status for attracting birds under estimated or masked by maize. In experimental plots, millet was important for Reed Bunting and Yellowhammer, and was also used by Chaffinch and Goldfinch.

Teasel was preferred to other biennial crops by goldfinches in the experimental plots. This is consistent with previous studies (Wilson *et al*., 1996), though not confirmed by the survey. Goldfinches also used plots of evening primrose (not represented in the survey), and thrushes used plots of chicory, also not recorded in the survey.

In late winter, bird densities on winter bird crops declined and the relative differences between crop "preferences" was more extreme as the choice of effective crops was reduced. In late winter, key crops were again kale, cereal stubbles and maize in southern latitudes.

Rates of seed consumption were high, generally between 90 and 100% of total seed production over the period of linear depletion. Depletion rate was a function of the amount of seed present at the start of the depletion period, however there was some variation between crops in the proportion of seed lost per day. Borage had the highest depletion rate as a proportion of seed present before depletion, whilst teasel and chicory had the lowest proportional rates i.e. their seed persisted longest. Triticale retained seed longer than other cereals and quinoa, fat hen, linseed and millet also retained seed into the new year. Kale was intermediate in terms of seed retention. Results from the large scale study showed that bird densities were lower on larger plots, and that birds continued to use these plots until March, indicating that the earlier exhaustion of seed supplies on the experimental plots was probably a result of their relatively small size. Birds were still using large plots of kale in late winter, and the rapid seed depletion in small plots may have been a result of the preference of most bird species for this crop.

With a few exceptions, a large proportion of seed was consumed on the seedheads. For cereals, this proportion may have been overestimated in some cases due to entire heads becoming detached from stems. In contrast, little or no seed of biennials was recorded as being consumed on seed heads. Biennials were more variable than annual in plant size and distribution, and in some cases the amount of seed may have been overestimated because seed traps were close to large plants. Seed traps were positioned when plants were still small, thus avoiding any possible artificial bias in favour of large plants, but because of the labour-intensive nature of seed processing work, numbers of seed traps in each plot were small and so some overestimation may have occurred by chance.

Birds are not the only seed predators present in arable fields, and it is likely that seed was also consumed by small mammals (especially wood mice *Apodemus sylvaticus*) and carabid beetles. In the second winter of the study, 5m x 5m enclosures were erected in plots of wheat, linseed and quinoa to exclude mice and beetles. Space does not permit presentation of these data here, but seed depletion was more rapid outside than inside these enclosures.

Implications of the results

The ability of Kale to attract both gamebirds and passerines throughout the winter suggests that this crop can increase the general level of bird biodiversity on farmland at all latitudes. Quinoa was also attractive to a range of species and can be grown with kale, providing seed in the first year. For an annual mixture, our results suggest that combinations of brassicas and cereals such as triticale (which provided seed for longer than other cereals) may provide an optimal choice of crops for attracting birds in both abundance and variety, though establishment of rape can be difficult where pigeons are a problem. Linseed could be added to attract species such as Linnet and Goldfinch. Cereals could also be grown with early sown kale. Sowing kale in March is beneficial where the soil is likely to dry out in late spring, but quinoa should not be sown until late April or early May as it is not frost hardy. In some situations it may be easier to sow adjacent strips of single species stands to avoid conflict of management requirements. Crop husbandry is considered further in the guidelines produced separately from this report. Comparisons of Arable Stewardship agreement and non-agreement plots showed the importance of crop choice; bird densities were lower on agreement plots, where a lower proportion of preferred crops were grown.

Seed was exhausted in small plots before the end of the winter and results from the large scale survey suggest that a plot size of 1-2 ha is needed to ensure availability of seed throughout the winter. Crops sown near hedgerows attracted more birds of several species, but a few species, particularly skylark, avoid hedgerows and may benefit from crops planted away from cover where this is feasible.

POSSIBLE FUTURE WORK

The results of this project have shown which crops are likely to provide the greatest value as food for seed-eating birds in winter. However, further work would be beneficial in certain areas:

i) In order to obtain the greatest benefit (and value for money where an agri-environment payment is made), crops should produce a reasonable yield of seed. Experience of growing the different crops and consultation of the literature has enabled some recommendations to be made regarding crop husbandry, but further work, particularly on the need for and use of fertiliser and weed control, would enable these to be more specific.

ii) Other work [Boatman, 2000 #83]; Murray *et al*, in press[#116]) has indicated that crops sown as wild bird cover can provide nesting and foraging areas for skylarks and pheasants, and attract butterflies in summer. Similar benefits may arise for other species of birds and nectar-feeding insects such as bumble bees. Quantification of use in summer by species of conservation interest could allow added value to be obtained from seed mixtures by tailoring composition and management to provide food and habitat throughout the year.

iii) Declines of seed-eating birds have been particularly severe in the grassland-dominated west of the UK. Re-introducing seed bearing crops here could have a proportionally greater benefit in terms of maintaining populations of these species.

TECHNOLOGY TRANSFER

Open days have been held on the Allerton Trust's farm at Loddington in Leicestershire on which the principles of the work have been demonstrated throughout the project. These included theme days for Countryside Stewardship project officers and Arable Stewardship agreement holders. At the conclusion of the project a press day was held to achieve wider publicity for the findings.

Interim reports, guidelines and advice have been made available during the project to DEFRA and the Rural Development Service (formerly MAFF/FRCA). A final set of guidelines will be produced following submission of this report. Reports have also appeared in the DEFRA Research and Development Newsletter and the BTO News. Two oral papers were presented at the British Ecological Society Winter Meeting in December 2000, and a paper has been submitted for presentation at a conference on Birds and Agriculture in March 2001. Papers will be prepared for refereed journals following approval of this report.

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