BTO Research Report 402

The Effects of Different Crop Stubbles and Straw Disposal Methods on Wintering Birds and Arable Plants

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Executive Summary

1. There is now a wealth of evidence to link the declines of farmland bird species with agricultural change. A major change has been the switch from spring to autumn cereals, resulting in the loss of winter stubbles (a key foraging habitat for birds) and spring germinating cornfield flowers. The retention of stubbles is likely to be an important conservation measure, particularly for birds, but little is known about the relative cost-effectiveness of different stubble types or their management. In this study we quantify: (i) seed availability and weed populations on different stubble types and herbicide regimes; (ii) national availability and use of different stubble types by granivorous birds and local use in relation to disposal methods, seed abundance; and vegetation composition; and (iii) agronomic implications of stubble retention and management options. We use these data to provide guidelines for policy related to agri-environment schemes and farm management practices.

2. In a split-plot design experiment with different crop types, herbicide regimes and stubble cultivation, weed cover was generally higher in uncultivated stubbles that followed a reduced herbicide crop. The latter resulted in 10-50% higher weed cover in all crops except spring barley where weed cover in the conventional crop was already relatively high. Weed cover was lowest in maize stubble, and consistently lower in winter wheat than spring barley. Weed seeds were more abundant at harvest under reduced herbicide treatments (though there was no effect in oilseed rape where weed seed densities were highest). Spilt grain had largely disappeared by mid-winter. Weed seeds numbers also declined over winter except in spring barley, where they remained constant on both herbicide treatments, and in conventional wheat, where they increased. Weed seed densities at harvest were highest in linseed and rape stubbles. However, reduced herbicide regimes of all crops provided seed densities of about $5000 m^{-2}$ through the winter and, of the conventional crops, spring barley provided the best seed resources in mid-winter.

3. A national survey of farmland birds revealed that, even in the most ‘stubble rich’ arable areas of eastern England, cereal, maize, linseed, sugar beet and rape stubbles together comprised only 12% of farmland in early winter (7% in late winter); equating to just two to three fields in a 1-km square (100 ha). Approximately 70% of all stubble is cereal stubble and a high proportion of farmland birds were found on this habitat. No single stubble type supported the most birds, although rape supported high densities in early winter and, within cereal stubbles, barley supported consistently higher densities of birds than wheat, which is harvested later.

4. Intensive studies of stubbles in East Anglia also revealed high densities of birds on rape in early winter. In mid/late winter barley supported the highest, and sugar beet the lowest, densities of buntings and Skylarks, whereas finches, sparrows, thrushes and Starlings were present in highest densities on sugar beet (in one winter) and similar but low densities on barley, wheat and linseed. As at the national scale, no single crop emerged as consistently supporting the highest densities of birds (across winters and species/functional groups) but, within the widespread and long-lasting cereals, barley (spring and winter crops combined) consistently supported higher densities of granivorous birds than wheat.

5. The quality of a stubble field for birds depends on the abundance and accessibility of food within it: crop and weed seeds on the soil surface at harvest and weed seed rain in the stubble phase. In fields studied in East Anglia, weed seeds on the soil surface were most abundant in two broad-leaved crops - sugar beet and oilseed rape. Crop seeds were highest on rape and lowest on winter wheat. Crop seeds, but not weed seeds, showed a large decline in number over winter. Weed seed replenishment through germination and seed set of plants was considerable (up to 30 000 seeds/m^2), and a feature of several species that are important in the diet of farmland birds in late winter. There were some consistent differences in seed rain between crop types. It was higher on barley than wheat or linseed and, although it was low in

oilseed rape, seed rain in this crop comprised almost entirely broad leaved species important in the diet of farmland birds e.g. *Polygonum* spp..

6. At both the national and local scale, most stubble fields supported no birds at all. Only a small number held high densities of granivores and the chemical management of the preceding crop was extremely important in explaining this between-field variation. Less frequent spraying, the use of a smaller number of herbicides and/or not using glyphosate prior to harvest were overriding factors explaining differences in the abundance of weed seed in the soil (at harvest and in seed rain). Stubbles preceded by crops subject to less intensive herbicide regimes tended to have higher cover of arable weeds important in the diet of farmland birds, higher seed rain in winter and a higher density and diversity of weed seeds on the soil surface at harvest. Almost 80% of the variation in the number of granivorous birds using a field in mid-winter (expressed in terms of their energy demand) was explained by three factors: the density Chenopodiaceae and Polygonaceae seeds and the number of chemicals used on the preceding crop.

7. Food abundance is modified by accessibility but there were few marked, consistent differences between crops in sward structure (stubble plus regenerating vegetation) that would influence the accessibility of seeds on the soil surface. Thus, it seems likely that food abundance is more important than accessibility in determining use of stubbles by birds. The scope for managing stubbles to improve accessibility of seed is likely to be limited.

8. The field experiment illustrated that spring crops, reduced herbicide programmes and lack of stubble cultivation encouraged more weeds and seed in the stubble phase. Maize is not likely to be a useful stubble crop, whereas oilseed rape, linseed and barley stubbles, especially with reduced herbicide programmes, may provide good resources for birds in winter. Field surveys also showed higher weed seed abundance (seed at harvest and seed rain) in stubbles following crops with reduced herbicide load. Across all crops, broad-leaved weed seed density was highest oilseed rape and, within cereals, it was higher in barley (winter and spring combined) than wheat.

9. The value of stubbles for plants and birds could be maximised by changes in (i) crop type and extent (ii) crop management. Further research is required to investigate the viability of retaining oilseed stubble over winter but this may be a valuable option. More spring cropping should be encouraged, especially spring barley which, under conventional management, provided relatively high levels of food for birds in late winter. However, most stubble types could potentially provide higher food resources for birds in winter if they follow a crop managed under reduced herbicide use. Agronomic information indicates that winter stubbles, whilst resulting in lower gross margins from following spring crops, have few other disadvantages. Adjusting area payments or other incentives could promote spring cropping. Currently, most stubble fields support no birds, almost certainly because they provide little or no food as a result of intensive herbicide regimes in the crop (and stubble) phase. Thus simply retaining stubbles (under agri-environment schemes or in wider farm management practices) will not necessarily provide resources for farmland birds – the preceding crop and stubble must be managed sympathetically. Given the extent of cereals (and the short-lived nature of rape and beet stubbles), the management of this stubble type, rather than promotion of different crop stubble, may be the most cost effective way of enhancing winter food resources for birds at a national scale unless novel schemes were developed for rape or beet. Few agri-environment scheme stubble prescriptions specifically recommend a crop type (beyond a cereal or linseed) or reduced herbicide on the preceding crop (only within the stubble itself). We recommend four possible changes to increase the value of these stubbles for birds: (i) reduced herbicide programmes on preceding crops, (ii) restrictions on the use of pre-harvest glyphosate, (iii) promotion of barley (especially spring barley) over wheat and linseed, (iv) no stubble cultivation.

1. QUANTIFY SEED AVAILABILITY AND WEED POPULATIONS ON STUBBLES OF DIFFERENT CROP TYPES UNDER TWO HERBICIDE REGIMES

1.1 Methods

Weed cover and seed densities in stubbles of different crops were evaluated through a field experiment. Winter crops of wheat and linseed were sown in autumn 1999. The following spring, crops of oilseed rape, barley and maize were established. The range of crops gave a separation of sowing dates and harvest dates. A split-split plot design was used with three replicate blocks, with main plots comprising the five crops. These were split for conventional or reduced herbicide programmes on the crop and split again for +/- stubble cultivation after harvest. Main plots were 24x40m, divided into four sub-sub plots, each 12x20m (for treatment details see Appendix 1.1, for plot layout see Appendix 1.2).

Assessments in the plots were divided into those before harvest, crop harvests and the stubble phase. Weed populations in crops were assessed in terms of ground cover using 10x0.25m^2 quadrats per sub-sub plot (Appendix 1.3). Harvest data were derived from small-plot combine harvesters and for maize, silage weights. In the stubble phase, above-ground weed cover was assessed in 10x0.25m^2 quadrats on two occasions and on four occasions using smaller 0.09m^2 quadrats (7 per sub-sub plot). The latter quadrats were located where seeds on the soil surface were sampled using a Vortis suction sampler. This was done on four occasions: 0 (immediately after harvest), 3, 12 and 26 weeks later. In the case of sub-sub plots that were cultivated with a Dynadrive, sampling began immediately after the stubble cultivation and 3, 12 and 26 weeks later (see Appendix 1.3).

1.2 Results

1.2.1 Weeds in the crop

There were significant differences in weed cover between crops, herbicide treatment and date (Table 1.1). Conventional herbicide programmes in wheat and maize kept weed cover low. Weed cover in rape was generally high, but lower on conventional plots. Similarly, in linseed and barley, weeds were significantly reduced on conventional subplots, though significant weed cover was present.

1.2.2 Harvest

Harvest data were examined using analysis of variance on a crop-by-crop basis. There were significantly lower crop yields under reduced herbicide programmes for wheat and maize, but not the other three crops (Table 1.2). Grain moisture at harvest differed significantly between the herbicide sub-plots only for oilseed rape. In the latter, grain was significantly drier on conventional plots, probably reflecting the effect of the desiccant applied 19 days before harvest (a desiccant did not significantly reduce linseed grain moisture). In the case of oilseed rape, yields were particularly low, reflecting both a late harvest with seed shedding and a poor crop.

1.2.3 Weeds in stubbles

After harvest, the weed flora was significantly more diverse in linseed and rape stubbles than in wheat and maize (lowest – reflecting weed removal by late harvest). Generally fewest weed species were found on sub-sub plots with conventional herbicide in the preceding crop followed by stubble cultivation. In March, there were less marked differences in weed diversity across treatments, though reduced herbicide programmes remained significant (maize and barley stubbles were least diverse). The Dynadrive cultivation reduced weed diversity in rape and increased it in barley stubbles. Total weed cover differed significantly between crops, herbicide regime, stubble cultivation and date. Weed cover in maize stubbles was consistently the lowest (Table 1.3). Oilseed rape stubbles had highest weed cover in winter, though barley and linseed stubbles in autumn also had high weed cover, particularly with reduced herbicide programmes. Weed cover on conventional wheat plots were generally low. Total plant cover in stubbles, including crop volunteers, was greatest on reduced herbicide, uncultivated stubble plots (data from $0.09m^2$ quadrats, Appendix. 1.4), particularly for the first two sample periods.

1.2.4 Seeds on the soil surface

Samples taken from $0.09m^2$ quadrats from the soil surface were sieved and seeds extracted, counted and identified under a binocular microscope. Sample processing was extremely time-consuming and data are only available for samples from uncultivated subplots taken immediately after harvest and in mid-winter. Analyses of log-transformed seed numbers showed significant effects on weed and crop seed abundance of crop type, herbicide programme and time (Appendix 1.4). Unlike other crops maize did not leave crop seeds within fields (Figure 1.1). Spilt grain was lost rapidly, on all crops with low numbers recorded after 12 weeks. Rape seed numbers on the soil surface were low, reflecting low harvest yield, late harvesting and much seed loss before sampling. Weed seed numbers were generally greater on reduced herbicide plots. By mid-winter, all reduced herbicide plots had statistically similar numbers of weed seeds, around 500 per sample (= $5500m^{-2}$). On conventional herbicide subplots, rape plots had highest weed numbers immediately after harvest. Linseed and barley plots had similar, but lower weed seed densities. Wheat and maize crops were relatively free of weed seeds. By mid-winter, conventional herbicide subplots showed some striking patterns of seed numbers. Linseed and rape stubbles showed low seed numbers. Wheat stubble seed numbers had increased, while conventional barley plots had maintained weed seed numbers.

The seed data were also subjected to Canonical Correspondence Analysis. Whilst only 16% of the species variation was explained by the first two ordination axes (Figure 1.2), nearly 60% of the species-environment relation was explained. The block effect was not significant, but rape, linseed and time of sample were highly significant contributors to the model. Rape and linseed samples were clearly differentiated. Axis 2 of the ordination largely reflected the effect of sampling time and herbicide programme. Some species are associated with particular stubble types (for species codes see Appendix 1.4). For example seeds of mayweeds (*Matricaria* spp.), sowthistles (*Sonchus* spp.), *Ranunculus repens* and *Trifolium repens* were associated with rape stubbles. By mid-winter there were some marked differences in seed densities between crops (Table 1.4). For example wheat held high densities of *Cerastium fontanum* and *Viola arvensis*, compared with barley. In contrast, barley stubbles had more seeds of *Polygonum aviculare* and *P. persicaria* (spring-germinating weeds, important for a number of birds), *Sonchus asper* and *Stellaria media*.

1.2.5 Stubble structure

Herbicide treatment had little effect on stubble and weed and volunteer height in mid-winter. However, different crops had different height stubble and, except in the case of linseed, cultivation reduced stubble height (Figure 1.3). Linseed stubbles were very short, but with a dense swath of young linseed seedlings (13cm high +D: 21cm –D). Wheat and barley stubbles had dense straw stubbles in well-defined rows 12.5cm apart. Rape stubble was sparse and woody, while maize was tallest at nearly 20cm and very sparse with rows 75cm apart. Weeds were highest in wheat and in all crops were unaffected by stubble cultivation.

1.3 Discussion

This experiment tested for differences in amounts of weeds and seed on the soil surface between different crop types, herbicide regimes and stubble cultivation soon after harvest. The herbicide regimes created significantly different weed cover in all crops in summer. Nevertheless, differences were minor in linseed and spring oilseed rape. This was carried through to harvest, when there were no significant differences in yields between herbicide regimes for linseed, rape and spring barley. A comparison of crop yields with national averages indicated that spring oilseed rape yields were, however, low, reflecting a late harvest date. Results from this crop may need to be viewed with caution, as much crop seed had been shed before harvest. Spring barley yields were also lower than national averages, while other crop yields were similar or greater.

Conventional herbicide programmes significantly reduced weed cover before harvest, especially in maize (with and without the herbicide atrazine) and wheat. Weed cover was particularly high in spring oilseed rape, reflecting the difficulty of controlling broad-leaved weeds in this broad-leaved crop. Weed diversity was also highest in rape, and also in reduced herbicide treatments of barley and maize.

In the autumn and winter stubble phase, reduced herbicide use in the crop phase and no stubble cultivation resulted in more weed cover. Weed cover was consistently lowest in maize, indicating that this stubble is unlikely to benefit birds in winter. In comparison to winter wheat, spring barley stubbles were weedier. Reduced herbicides resulted in between 10 and 50% greater weed cover in all stubbles except barley where weed cover was already high and the reduced herbicide had little effect on weed cover. Reduced herbicide linseed stubbles had 11% more weed cover, wheat 18% more, rape 20% more, and maize 17% more weed cover (large quadrat estimates). With the exception of barley, reduced herbicide stubbles had more seeds in mid-winter compared with conventional plots.

Seed sample data were only available for uncultivated stubbles from the post-harvest and (mid-winter) three month samples. There were significant effects of the different stubble types and pre-harvest treatments. At harvest, spilt grain was present in all crops except maize. These had largely disappeared by mid-winter reflecting predation and germination. Weed seeds were more abundant at harvest on plots with reduced herbicide regimes, except in the case of oilseed rape, where weed densities were highest and unaffected by previous herbicide regime. By mid-winter, weed seed numbers had declined on most plots. The exceptions were spring barley, where seed densities were maintained on both conventional and reduced herbicide treatments, and conventional wheat stubbles, where seed numbers increased. Autumn cultivation and crop establishment resulted in a different weed flora compared with spring cultivation. Autumn crops had a flora dominated by autumn germinating species, while spring crops had spring germinating weeds. In terms of seed densities at harvest, linseed and rape stubbles were richest in weed seeds, though reduced herbicide regimes of all crops provided seed densities of about $5000m^{-2}$ through the winter. Of the conventionally grown crops, spring barley stubbles provided the best seed resources in mid-winter.

In summary, spring crops, reduced herbicide programmes and lack of stubble cultivation encourage more weeds and seed in the stubble phase. Maize is unlikely to be a useful stubble crop, whereas oilseed rape, linseed and barley stubbles, especially with reduced herbicide programmes, provide good resources for birds in winter.

2. BROAD (NATIONAL) PATTERNS OF UTILISATION OF DIFFERENT STUBBLE CROPS BY BIRDS

2.1 Methods

The broad patterns of use of different stubbles by birds were assessed from the JNCC/BTO Winter Farmland Bird Survey (WFBS). This national volunteer survey was originally planned to run over three consecutive winters (1999/2000 to 2001/2002). However the outbreak of Foot and Mouth Disease resulted in the third winter being postponed and for this reason we present results here for the first two winters only. A ‘supplementary report’ covering all three winters will be submitted in July 2003.

Survey squares (1-km^2) were selected using stratified random sampling, restricting the area to lowland farmland by a) selecting only 10-km squares with >30% of agricultural land (MAFF and SERAD 1988 June census data); b) excluding 1-km^2 squares classified as 'Upland' or 'Marginal Upland' (ITE Land Classification System, Bunce et al. 1996) and c) excluding 1-km^2 squares with >25% of urban or woodland cover (*ITE Landcover Map of Great Britain* Fuller & Parsell 1990). A stratified random sample of 3000 1-km^2 squares was then selected within 'Arable' and 'Pastoral' ITE Landscape Types and five geographic regions. (Note, to ensure sufficient data for regional estimates the number of squares in Wales and Scotland were increased. As arable farmland is scarce in Wales the number of arable squares was also increased and these modifications accounted for in national-scale analyses).

Bird and habitat recording were undertaken on a patch-by-patch basis within each 1-km^2 square (patch = an area >0.3ha of a single habitat). All non-farmland habitat types were excluded from the survey and most patches were fields, sub-fields (e.g. margin) or farmyards. Each patch was assigned a habitat code following Crick 1992 and Gillings & Fuller 2001 (see Appendix 2.1). Habitats were recorded on each visit to account for change. For stubbles, no distinction was made between set-aside and non-set-aside, weedy stubbles were those with arable weeds and some crop volunteers whereas clean stubbles lacked green cover and the method of stubble disposal was assessed by recording the presence/absence of chopped straw on the surface (indicating stubble had been chopped and spread rather than baled).

Each square was visited three times between early November and late February, recording birds on as many patches as possible within a four-hour time limit (patches remained the same between visits and, where possible, between years). Observers were asked to undertake surveys on calm dry days with good visibility, avoiding the first and last hours of daylight when birds may be less active/detectable. Observers walked around the edge of each patch, recording birds in three zones: boundary = hedges and other boundary structures; margin = outer 20m of the crop and interior = field beyond the margin zone, and assigning birds to the zone in which they were first detected. Birds flying over were ignored unless clearly associated with a patch (e.g. just flushed or about to land).

2.2 Analyses

2.2.1 Habitat area estimates

Since survey time was limited (four hours) very few squares received complete (100ha) coverage so the proportion of each habitat type surveyed was determined in each 1-km^2 square. The area of farmland in each 1-km^2 square was estimated using the Centre for Ecology and Hydrology’s Land Cover Map 2000 and calculating the total area under: improved grassland (subclass 14), neutral grassland (15), set-aside grass (16), calcareous grass (18), acid grass (19), arable cereals (21), arable horticulture (22) and arable non-rotational (23). Assuming that the land surveyed in a square was representative of the farmland in that square: the area of each habitat in a 1-km^2 square equalled (proportion of the surveyed area)*(area of farmland in the square). Confidence limits were calculated by bootstrapping.

2.2.2 Bird densities

Bird species were combined into functional groups for the analysis (with the exception of Skylark which was sufficiently abundant to analyse separately): i) thrushes and Starling: Fieldfare, Song Thrush, Redwing, Mistle Thrush & Starling, ii) sparrows and finches: House Sparrow, Tree Sparrow, Chaffinch, Brambling, Greenfinch, Goldfinch, Linnet, Twite, Redpoll & Bullfinch, and iii) buntings: Yellowhammer, Reed Bunting & Corn Bunting. The total number and density of each species/group was determined in fields for (a) each visit, (b) each habitat (habitat-specific means combining density estimates from all three visits), (c) birds in the field and (d) birds in the field and boundary. (Note, as counts were made from the edge of the field they are likely to underestimate cryptic species e.g. Skylark.)

2.3 Results

A total of 871, 779 and 859 1-km^2 squares were surveyed in winters 1 to three respectively (494 in all three winters, Figure 2.1). The number of squares surveyed in each WFBS region in each winter is shown in Table 2.1 along with the number initially selected. There was no significant difference in the regional spread of surveyed squares between winters, nor between the initial stratification and those actually surveyed and coverage was good with few 'gaps' (perhaps with the exception of lowland Cumbria, Cleveland and Durham). However, the stratification of squares across regions and landscape types differed slightly but significantly from the original stratification in winters one ($^{2}_{4} = 13.3$, $P < 0.01$) and three ($^{2}_{4} = 13.9$, $P < 0.01$) but not winter 2 ($^{2}_{4} = 8.7$, $P > 0.05$). Weightings were used to correct for this bias in coverage and the pre-designed bias in stratification for national scale analyses (see Appendix 2.2). In winter 1, 85% of squares received three visits, this fell to 65% in winter 2, largely due to access restrictions in February 2001 following the outbreak of Foot and Mouth Disease which prevented some third visits, and recovered to 77% in the third winter. In all three winters, <5% of squares received only one visit.

2.3.1 Habitat area estimates

A total of 21,690 (winter 1), 16,495 (winter 2) and 18,061 (winter 3) grass fields and 12,070, 9,400 and 8,630 arable fields were surveyed (Table 2.2). In both winters, approximately 10% of fields were stubbles of which cereal stubbles accounted for 70%. The area of stubble in different geographic regions and landscape type (arable vs. pastoral) and in early and late winter is shown in Table 2.3 (areas of cereal crop, and cereal, sugar beet, maize, linseed and rape stubble are presented graphically in Appendices 2.3-2.8). Cereal stubbles were the most extensive stubble type and, across regions, accounted for a maximum of 16.7% and a minimum of 5.2% of farmland in early winter. The equivalent values for the next most prevalent stubble, maize, were 4.8% and 0.5%. Seasonal changes in stubble area differed between crop types. Area of cereal stubble consistently declined over winter as did linseed and rape, although the decline was less marked. In contrast, the area of maize and sugar beet stubbles remained relatively stable. (Small sample sizes prevent regional comparisons for areas of linseed, rape and sugar beet.) Maize stubble accounted for a higher percentage of farmland in arable western and pastoral eastern England than elsewhere and cereal stubbles accounted for the highest percentage of farmland in arable east, followed by arable north England. However, even in arable eastern England cereal stubble was small, only accounting for 9.1% in early winter 1 falling to 5.4% in late winter. In winter 2 these figures were higher as wet weather prevented ploughing -16.7% falling to 11.7%. In western pastoral areas, stubble was extremely scarce; 5.2% and 7.0% in early winter 1 and 2, equating to just two to three fields in a 1-km^2 square even in early winter (Table 2.4).

Information on the method of stubble disposal was obtained by recording presence/absence of chopped straw on the field surface (indicating chopping and spreading or baling respectively). The number of fields with chopped straw was, however, generally small - 8% of cereal stubble fields in winter 1, 12% in winter 2 and 8% in winter 3 showed chopped straw on the surface (see Appendix 2.9).

Skylarks, sparrows and finches, buntings and thrushes and Starling were recorded on approximately 34,000, 26,000 & 27,000 fields in the three winters. The granivorous species (Skylark, sparrows, finches and buntings) occurred in higher densities on almost all stubble types than cereal or grass crops or bare till. In contrast, thrushes and Starlings were most abundant on grass fields. No single stubble type consistently supported the highest densities of birds although small sample sizes for some stubble types make statistical comparisons difficult. Thus, high densities of Skylarks and sparrows and finches on linseed (winter 1) and buntings and thrushes and Starling on oilseed rape (winter 1) are based on small sample sizes (145 linseed and 93 rape fields compared with 568 barley and 874 wheat fields). Similarly, high densities of thrushes on grass and in general the highest densities of Skylark were found on barley and linseed (winter 1 only) with lower but very similar densities on wheat, rape and sugar beet and lowest densities on maize. Sparrows and finches occurred in high (but variable) densities on rape, linseed and sugar beet, lower densities on barley and maize, and lowest densities on wheat. Buntings occurred in the highest densities on barley and rape (winter 1 only), followed by wheat and sugar beet with lowest densities on linseed and maize. Thrushes and starlings occurred in highest densities on linseed and maize, followed by sugar beet and rape and lowest densities on barley and cereal.

The figures for bird density (granivores only) on different crop types and the extent of these crop types were used to assess the percent of the birds counted supported by these different habitats in winter. Over 50% of Skylarks, finches, sparrows and buntings were supported on cereal stubbles, 20% on bare till and 20% on cereal crop and the remaining 10% on other stubbles (Figure 2.3 and Appendix 2.10).

2.4 Discussion

The results of this national survey provide the only quantitative estimates of the area of different stubble present, throughout the winter, in different regions of England. These habitat data were collected from a total of 684 and 596 1-km^2 squares in England in two winters and over a wide and representative geographical area. Over the three winters approximately 56,250 grass and 30,100 arable fields were surveyed, of which roughly 10-12% were under stubble, 70% of which was cereal stubble.

There was a marked increase in stubble area in the second winter and a corresponding decrease in newly sown cereal. This is likely to be due to very wet conditions in autumn/early winter 2000/2001 that prevented crop sowing (http://www.defra.gov.uk/esg/Work_htm/Notices/dec_uk.pdf). The total area (1000 of ha) of wheat, barley and oats sown by 1 December in 1999, 2000 and 2001 were 2788, 1893 and 2651, representing a drop of 32% between 1999 and 2000. The WFBS in 1999 and 2000 reveals a drop in cereal of very similar magnitude; 34% in early winter.

In the most 'stubble rich' arable areas of eastern England, the five major stubble types (cereal, maize, linseed, sugar beet and rape) comprise only 12% of farmland, falling to 7% by late winter. Stubble was, predictably, scarcest in pastoral areas of western England – 9% falling to 8% of farmland. These figures equate to just two to three fields in a 1-km^2 square in early winter of which less than half will support arable weeds and hence provide foraging resources for farmland birds (see Objective 3 and 4 and Gillings & Fuller 2001).

No single stubble type consistently supported the highest densities of birds. Barley generally supported relatively good densities of birds, high but more variable densities occurred on rape, linseed and sugar beet and generally lower densities on wheat and maize. With a third year of data it will be possible to compare these densities statistically. However, within the dominant stubble types of wheat and barley, the latter supported higher densities of the four species/groups of birds considered in both winters, with one exception (buntings in winter 1). There were very marked differences between fields and the majority of fields supported no birds at all. For example, approximately 90% of cereal stubbles held no Skylarks and between 10-25% supported more than two birds per ha. These results are supported by intensive regional surveys (Objective 3) and suggest factors other than crop play a major role in determining field use by birds. The role of physical factors, such as field size and boundary type, and crop and stubble management, such as number and frequency of herbicide use on preceding crop, are investigated under Objective 3.

The stubble that was present in winter was almost entirely cereal stubble (70%). The fact that such a high proportion of granivorous birds occurred on cereal stubbles and that other crops did not consistently support higher densities also suggests management of cereal stubbles, rather than promotion of different stubble types, may be the most cost effective way of enhancing winter food resources for birds. As in summer (e.g. Donald & Vickery 2000), sympathetic management, particularly in terms of reduced herbicide regimes on the preceding crop (see objective 3 & 4), of at least a proportion of cereals is likely to be important in reversing population declines of farmland birds.

3. UTILISATION OF DIFFERENT STUBBLE CROPS BY BIRDS IN RELATION TO DISPOSAL METHODS AND SEED ABUNDANCE ON A LOCAL LANDSCAPE SCALE

3.1 Methods

Intensive studies of birds and their food resources in stubbles were carried out from July to March over two winters (1999/2000 and 2000/01) in an area of lowland arable farmland in East Anglia. The work was carried out on conventionally managed farms (i.e. with routine use of pesticides and inorganic fertilisers), located in the Norfolk Brecklands, which may be slightly atypical of most lowland farmland in that it is an area characterised by light sandy soils (see Appendix 3.1 for map of study site). In 1999/2000, fields of five different crop types (Table 3.1) were selected at random from within three study farms. These were surveyed for birds every two weeks, from immediately after harvest to the time the fields were ploughed in, using the 'whole area search method' (Buckingham et al 1999). Parallel transects were walked across all fields at <c.75m intervals and recording the number and species of all birds flushed from the field (but not the boundary). The period one to two hours after dawn, when birds may be less active or less easily detected, was avoided, as were conditions of strong winds or heavy rain. The importance of the physical characteristics of hedgerows in influencing the use of fields by birds is well documented (e.g. Green, Osborne & Sears 1994; Parish, Lakhani & Sparks 1994, 1995) and the following variables were recorded on all fields: mean hedge height and width of each boundary section, the number of trees (>5m tall) in each boundary section ("tree frequency") and the area of wild bird cover. Boundary lengths (m) and field areas (ha) were extracted from the plot maps. Boundary variables were entered into a Detrended Correspondence Analysis and the four axis scores used as a measure of the nature of the field boundary. The following variables relating to the stubble structure and seed densities were also included in the model (for details on field methods with respect to collection of these data see objective 4): % cover of stubble, crop volunteers and arable weeds, stubble height, surface seed densities (spilt grain and weed seeds). Details of crop management were obtained from landowners (see objective 4) and included number of herbicides on preceding crop, frequency of herbicide applications, use of glyphosate prior to harvest and harvest cultivation.

3.2 Analyses and Results

3.2.2 Stubble availability and longevity

A total of 1,658 and 1,943 hectares of stubble, of five different crop types, was surveyed in winters 1 and 2. Life tables analysis (Anon 1996) was used to determine the mean number of weeks each stubble type was available. The analysis computes nonparametric estimates of the survival distribution of data that may be right-censored due to withdrawals or termination of the study (Figure 3.1 and Table 3.2)

The pattern of stubble availability was similar between seasons. Oil seed rape was harvested first and survived for only six to eight weeks (Figure 3.1, Table 3.2 & Appendix 3.2). Barley stubbles were present from mid/late July and throughout August. These declined in extent in 1999/2000 as fields were cultivated, but persisted to January 2001 as wet conditions prevented ploughing. Wheat was harvested from the beginning of August, peaked in area in early September and then declined. Linseed was harvested in early or late September, generally retained into January and then rapidly ploughed in. Sugar beet was harvested late (October/November) and ploughed and/or drilled very soon after harvest (though it too persisted into late winter 2000/01).

3.2.3 Numbers of birds on stubble fields

A total of 44,686 and 46,177 birds of 48 and 53 species were counted in winters 1 and 2 respectively. Only species which occurred on more than 5% of counts were considered in detail; Skylark *Alauda arvensis* and three functional groups – finches and sparrows (Linnet *Carduelis cannabina*, Chaffinch

Fringilla coelebs, Goldfinch *Carduelis carduelis*, Greenfinch *Carduelis chloris*, House Sparrow *Passer domesticus*, Tree Sparrow *Passer montanus*), buntings (Yellowhammer *Emberiza citrinella* and Reed Bunting *Emberiza schoeniclus*) and thrushes and starlings (Blackbird *Turdus merula*, Redwing *Turdus iliacus*, Fieldfare *Turdus pilaris*, Song Thrush *Turdus philomelos*, Mistle Thrush *Turdus viscivorous* and Starling *Sturnus vulgaris*). The mean densities of these four species/groups in early and mid-late winter are shown in Figure 3.2 and 3.3 (for individual species recorded on more than 5% of occasions see Appendix 3.3).

In the early period of the survey, densities of birds on all stubbles were low compared with mid/late winter, the exception being on oilseed rape which was absent in late winter. There were clear differences between crop types in late winter (Table 3.3). Barley supported the highest densities of buntings and Skylarks, followed by wheat with much lower densities of these species on linseed and sugar beet. Finches and sparrows occurred in extremely low densities in winter 1, in winter 2 they were recorded in the highest densities on sugar beet, followed by barley and linseed with very low densities on wheat. Thrushes and starlings were only present in any number in the second winter on sugar beet, with very low densities on barley, linseed and wheat.

In addition to differences in numbers of birds between stubble types, there were also marked differences between fields within stubble types as shown for two 'case' species, Linnet and Skylark, in Figure 3.4. The vast majority of fields supported no birds at all and very few supported >2 per hectare. This distribution suggests that major factors other than crop type influence the use birds make of stubble fields. These factors are likely to be related to the management of the stubble itself and the preceding crop, as well as 'intrinsic factors' such as soil type and boundary characteristics.

3.2.4 Factors influencing the numbers of granivorous birds on stubble fields

The extent to which individual stubble fields are used by birds is likely to be determined by three broad categories of variables: field characteristics (e.g. field size, boundary type, crop management, stubble type); food abundance (e.g. density of weed and crop seeds) and food availability (influenced by factors such as stubble density and extent of bare ground). However, previous studies suggest the key factor determining stubble use by birds in winter is food abundance, particularly the density of weed seeds (Wilson et al 1996, Robinson 2001, Robinson & Sutherland 1999, Moorcroft et al 2002). For this reason bird usage was expressed, not as numbers of birds as in most studies, but as the mean total energy requirement of the granivorous birds per two week period on each field. Energy requirements were calculated for individual species using published relationships between body mass (M, taken from Dunning 1993) and field metabolic rate (FMR, Nagy 1987): $\log(FMR) = 1.037 + 0.640 \log(M)$. All granivorous species excluding Skylark (which feeds on vegetation as well as seeds (Cramp 1988)), were included: Chaffinch, Goldfinch, Greenfinch, Linnet, Reed Bunting, Tree Sparrow, Woodlark, Yellowhammer and Turtle Dove. The level of food resources in each field was also expressed as energy. Seed weights and calorific values were taken from the ECOFLORA database (http://www2.york.ac.uk/res/ecoflora/cfm/ecofl/index.cfm) and used to calculate energy available on 26 fields for which detailed seed sample data were available (five linseed, seven oil seed rape, four sugar beet, five winter barley and five winter wheat fields).

Given the large variation in the density of birds on fields of a given crop type, data were pooled across crop types to determine whether any 'generic' relationships exist between birds and stubbles independent of crop type. Data were broken down into two time periods; July to late September and October to late of February (corresponds with the WFBS period, see Objective 2). A two-stage process was employed to identify which of a range variables relating to field characteristics, crop and weed seed densities and stubble structure (for variables considered see Appendix 3.4) explained variation in the densities of birds found on the fields. Details of how seed and vegetation data were collected are given under Objective 4 and all these parameters were only available for winter 2000/01). First, variables were entered singly and univariate models constructed in the SAS GENMOD procedure (Anon. 1996). Second, using density as the dependent variable a step forward generalised linear modelling approach was used to find a Mimimum Adequate Model. This two stage approach was employed as several of the explanatory variables may be correlated and potentially important variables may be ignored in the multivariate analysis. The mean density of seed-eating species (finches, buntings and sparrows) expressed as 'energy required' was modelled in relation to each variable in turn (Appendix 3.4), running the model and retaining the best fit from each iteration. Each of the remaining variables was then entered in turn and the variable that explained most of the remaining variation retained. This process was repeated until none of the remaining variables significantly improved the fit of the model.

In early winter, five variables considered in univariate analyses were significant, with crop and site explaining most of the variation in granivorous bird energy demand (Table 3.4). However, these univariate relationships were generally weak and explained little of the variation in the bird data. In the more robust multivariate model the mean density of oilseed rape and Polygonaceae seed (positive relationships) and number of chemicals applied to the crop (negative relationships) were important in determining the use made of stubble fields by granivorous birds.

Crop and site also explained most of the variation in the energy demand by seed-eating species in mid/late winter. The six other significant variables (Table 3.5) included positive relationships with two families of weeds seeds, Urticaceae (predominantly *Urtica urens*) and Chenopodiaceae (predominantly *Chenopodium album*), total weed seeds (expressed as energy excluding grasses) and the boundary DCA axis 3 (related positively to the amount of woodland surrounding the field – Appendix 3.4)

In the multivariate model three parameters explained 79% of the variation in bird energy demand; the density of Chenopodiaceae and Polygonaceae seeds (positive) and the number of herbicides applied to the crop (negative) (Figure 3.7 & Table 3.5).

The importance of the number of herbicides applied to crop almost certainly relates to the strong effect this has on the number of diet weed species that germinate in the subsequent stubble and set seed, i.e. on food resource levels later in the winter. Thus these three factors combined (Chenopodiaceae and Polygonaceae seeds at harvest and number of insecticides) provide an index of food for birds throughout the winter. Quantifying the number of birds supported for a given number of weed seeds or reduction in herbicides is extremely difficult due to the variation in all these factors between sites, soil types, crop types etc. Even within the two bird-rich fields in Figure 3.7 the relative importance of these three factors differed. The winter barley field had relatively few *Chenopodium* and *Polygonum* seeds at harvest (68 and 0 seeds per m^2 respectively) but only received one herbicide prior to harvest (compared to four to five in the bird-poor fields) and so will have had a high level of diet seed rain later in the winter (see objective 4). The sugar beet field received a higher number (three) of herbicides but had very high numbers of seeds at harvest (1400 *Chenopodium* and 150 *Polygonum* seeds per m^2). Thus quantifying increases in birds in relation to a given increase in weed seeds is not really possible. However, estimating the increase in active diet weeds and diet seed rain in relation to a given reduction in herbicides is slightly more straightforward and this issue is addressed in objective 4.

3.3 Discussion

In the early period of the survey, densities of birds on all stubbles were very low compared with the mid to late winter, the exception to this being oilseed rape which was absent in the latter time period. This almost certainly reflects the fact that food is generally still abundant elsewhere in farmland and that birds have not yet formed winter flocks. In mid/late winter there were differences in bird densities between stubble types. Barley supported the highest, and sugar beet the lowest, densities of buntings and Skylarks, whereas finches and sparrows and thrushes and Starlings were present in highest densities on sugar beet (second winter only) and similar but low densities on barley, wheat and linseed. As at the national scale, no single crop emerged as consistently supporting the highest densities of birds but, within the widespread and long lasting cereals, barley almost always supported higher densities of birds than wheat.

There were marked differences between fields within stubble types as well as between stubble types. Most fields supported no birds at all and very few supported >2 per hectare. This suggests that simply retaining stubbles within agri-environment schemes or in broader farm management practices will not necessarily provide valuable foraging habitats for birds. As in this study, previous studies have suggested that the key factor determining use of stubble fields by granivorous birds is the level of food resources on fields, i.e. crop and weed seeds present on or near the soil surface after harvest and weed seeds that are replenished through germination and seed set of weeds in the stubble over winter (seed rain). Crop seeds showed a marked reduction in number during the period between harvest and cultivation, whereas weed seeds did not (Objective 4). In the present study, almost 80% of the variation in the number of granivorous birds using a field in mid-winter (expressed in terms of their energy demand) was explained by three factors: the density of seeds from Chenopodiaceae and Polygonaceae seeds (both known to be important in the diet of farmland birds) and the number of chemicals used on the preceding crop. Thus, several stubble types could potentially provide food-rich habitats for birds in winter if they are weed rich, something promoted by reduced herbicide use in the preceding crop (Objective 1 and 4).

Although analyses focussed on functional groups of birds, individual species differed in their responses. In general, finch densities were high in rape immediately after harvest (e.g. Chaffinch, Greenfinch and Linnet, see Appendix 3.3) and these stubbles were preferred to others, such as barley and wheat. As rape disappeared, for Linnet, there was a clear progression onto linseed, then barley and finally sugar beet stubbles although overall densities varied between years. Other species showed more consistent preferences. For example, Skylarks were most abundant on cereal stubbles, Woodlarks were mostly found on barley stubbles whereas Mistle Thrushes tended to be found mostly on linseed and oilseed rape.

Site (i.e. farm) effects explained much of the variation in the usage of stubble fields of granivorous birds and much of this variation could be explained by the levels of weed seeds and the management regimes employed on each field. Thus, decisions made by individual farmers may be important in determining how ‘resource rich’ their fields will be for granivorous birds. Fields that had higher amounts of food available in terms of soil weed seeds and had fewer applications of herbicides preharvest tended to hold more seed-eating birds. Although we do not demonstrate a direct link between bird usage and herbicide treatment, work from the 2000/2001 winter demonstrated that densities of weed seeds in the soils were reduced by the application of glyphosate immediately before harvest and increasing application of herbicides preharvest. Seed rain from plants seeding over the winter was much lower in stubbles which had a higher number of sprays preharvest, indicating food inputs into the system throughout the winter as well as what was present in the soil after harvest were important for granivorous farmland birds (Objective 4).

Thus, to maximise benefits for birds, winter stubbles should be sympathetically managed, reducing herbicide inputs in the preceding crop (as well as the stubble) phase (Objective 4) and not cultivated (Objective 1). Their value may be further enhanced by targeting widespread stubbles that occur in western parts of the UK where local extinctions of farmland birds have been highest. Cereals are the most widespread stubble types and barley showed consistently higher densities of birds than wheat. The economic consequences of switching from wheat to winter or spring barley need further study (Objectives 1 & 5), but economic incentives to increase the levels of spring cropping with winter stubbles on a large scale could have marked benefits for birds, so long as herbicide inputs in the crop (as well as the stubble phase) are reduced.

4 QUANTIFY THE PATTERN OF SEED AVAILABILITY AND VEGETATION COMPOSITION AND COVER ON SUB SAMPLES OF FIELDS WITHIN LOCAL LANDSCAPES

4.1 Methods

4.1.1 Vegetation sampling

The vegetation in 122 fields (spread across all study farms, see Appendix 3.1 for study site map) was sampled monthly post harvest in winter 2000/01. The following variables were recorded in 20 random quadrats in each field: % cover of stubble, crop volunteers and arable weeds (to the nearest 5%), stubble height (at three random points) and maximum vegetation height. In winter 2001/02, intensive sampling on 22 fields (five oilseed rape, spring barley, winter barley and winter wheat and two linseed fields) on five farms was used to record % cover of flowering, seeding and senescent plants and seed rain (arable weeds germinating and seeding in stubble). Seed traps (Forcella et al 1996) were placed 20m apart in two parallel transects from the field edge and seed rain sampled monthly (from one month after harvest) until mid February, recording the number and species of seeds collected.

4.1.2 Surface seeds

Soil surface seeds were collected from fields between harvest and cultivation in 1999/2000 and 2000/01 using a Vortis suction sampler. This collects c. 2cm of surface soil in a 25cm^2 quadrat, but could not be used on oilseed rape, where there was too much surface debris, or late-harvested sugar beet fields where soil was often waterlogged and/or compacted. Samples from these fields were taken by scraping the top 2cm of soil off with a trowel. Seeds were extracted by eye, using a binocular microscope, from up to 10 sub-samples of 0.0625m^2 from each sample. Samples were taken at 0-2, 2-4, 4-6, 20 and 24 weeks after harvest or until the field was cultivated (when sampling ceased). In winter 1999/2000 sampling focussed on cereal crops and linseed, and in the second on rape and sugar beet (see Table 3.1).

4.1.3 Field management

Crop management and history for most fields was supplied by farmers, including information on the total number of herbicides sprayed on the preceding crop, frequency of herbicide applications, use of glyphosate prior to harvest and harvest and cultivation dates.

4.2 Analysis

Analyses were carried out with respect to vegetation structure and composition and soil seeds in winter 2000/01 and with respect to seed rain (i.e. flowering and seed set of arable weeds) in winter 2001/02. Univariate ANOVA tests were carried out on all data to establish how characteristics of the vegetation and stubble varied between crops. To control for different harvest times, analyses were carried out in relation to time after harvest rather than date, classifying surveys as 1st, 2nd, 3rd etc. post harvest period (equivalent to 1, 2, 3 etc. months for vegetation and 0-2, 2-4, 4-6 etc. weeks for seeds). The influence of site (farm), crop and management regime on volunteer and weed cover, species composition and seed availability was investigated using Repeated Measures (RM) GLM ANOVA analysis using SPSS (SPSS 1998, Version 11). Models were constructed using forward selection and tested following Norris et al (1997, 1998). Parameters considered are listed in Appendix 4.1. Arable weeds were considered in two categories ‘total weeds’ and ‘diet weeds’ - those important in the diet of farmland birds (Wilson et al 1999). The modelling was carried out for vegetation parameters and soil seed densities in (i) time periods 1 and 2 including all crops (ALLCROPS model) and (ii) time periods 1-4 only for longer-surviving cereals (CEREALS model) (Table 4.2). For further details see: Norris et al 1997, 1998.

4.3 Results

4.3.1 Herbicide management

Most fields were sprayed with glyphosate prior to harvest as this controls weeds in the crop and stubble and facilitates harvest as a desiccant. Only in the case of spring barley was a significant proportion of the fields left unsprayed (30% in winter 2001/02). These fields also tended to receive fewer applications of a smaller number of herbicides (ca. 2 applied 1-2 times compared with 3.5-4 herbicides 2-3 times on other crops, Table 4.3).

4.3.2 Structural characteristics of stubble and regenerating vegetation

Stubble structure and height varied significantly between crops. The tallest, but least dense, stubble was oilseed rape (22cm with 4% cover, next tallest linseed 14.5cm with 6% cover, Appendix 4.2) cereal stubbles were similar in height (12-13cm) but spring barley was less dense than winter barley and winter wheat. Overall, the area of bare earth was highest on winter wheat stubbles due to the lack of weed and volunteer cover. The latter was lowest on winter wheat and linseed stubble (7.3%, 4.9% respectively), highest on oilseed rape (27%, Appendix 4.3). Total and diet weed cover was highest on winter barley and linseed stubbles, but the ratio of grass and broad-leaved weeds varied; 30:70 in oilseed rape compared with 74:26 on linseed. The three most important dietary components for seed-eating birds are species of *Stellaria* (chickweeds), *Polygonum* (knotgrasses and persicarias), and *Chenopodium* (fat hen) (Wilson et al 1999) and weeds were considered in these three groups, plus *Poa* sp and 'other' weed species. Cover of meadow grass was high except in oilseed rape stubble, which had the highest proportion of *Polygonum* (mainly early flowering large-seeded knotgrasses and black bindweed). Overall, winter barley and oilseed rape had the highest percent cover of broad-leaved weeds and linseed the lowest (Figure 4.4). There were parallel differences between stubbles in the number of active (i.e. seeding) weed species and levels of seed rain. Linseed contained the fewest seeding weeds and winter barley the highest (means of 0.6 and 1.9 active diet species respectively, Appendix 4.3). The latter also had the highest levels of diet seed rain over winter 2001/02 and barley (winter and spring) were the only stubbles in which *Chenopodium* were recorded in seed rain (Figure 4.5). Oilseed rape had lowest seed rain but a high proportion of this was of broad-leaved weed seeds.

4.3.3 Soil surface seed densities

The number of crop and arable weed seeds recorded in surface soil samples during the post harvest period varied greatly, reflecting the patchy nature of arable weeds. It differed significantly between crop types ($F_{4,285}$= 7.81; p<0.001 and $F_{4,285}$= 5.67; p<0.001 respectively, averaged over the winter). In general, over the winter, weed seeds were more abundant than crop seeds and were most abundant on sugar beet (ca 5000 per m^2) and oilseed rape (ca 300 per m^2). Crop seeds were most abundant on oilseed rape stubbles (ca 800 per m^2) and lowest on cereal stubbles (ca 100 per m^2). Seeds present after harvest in winter 1 and 2 (Fig. 4.6, note different times) showed consistent differences between crops. In winter 1 there was more crop seed on the soil surface in rape and linseed stubbles than wheat or barley. There was also more weed seeds in rape stubbles than wheat or linseed. In winter 2, rape stubbles again had the most crop seeds on the soil surface with none present in beet, but with significant numbers of weed seeds. Analyses (log transformation) indicated there were few significant differences in weed seed numbers between the crops, though beet stubbles had higher initial weed seed densities in winter 2, compared with the least on wheat stubbles.

4.3.4 Vegetation height and management

Vegetation height varied significantly with stubble type in both models (ALL CROPS $F_{3,37}$=13.29, p<0.001) and CEREALS ($F_{2,34}$=4.93, p<0.013) and tended to be highest on spring and winter barley, increasing through winter until die-back from frost (Figure 4.7). In both models vegetation height declined with later harvest date (ALL CROPS $F_{1,46}$ =10.89, p<0.002, CEREALS $F_{1,38}$ =32.19, p<0.001) and, for CEREALS, with increasing number of chemicals on the preceding crop ($F_{1,38}$=41.34

P=0.049). Thus field vegetation was higher in earlier harvested fields and, for cereals, on fields with low levels of chemical application (controlling for harvest date).

4.3.5 Volunteer and weed cover and management

Volunteer cover varied significantly between stubble types (ALLCROPS, $F_{4,37}$ = 9.74, p<0.001; CEREALS, $F_{2,34}$ = 8.54, p<0.001) but this varied with site (Crop*Site $F_{4,37}$= 4.16 p<0.007 and $F_{2,34}$= 7.74 p<0.002 respectively) and time (Crop*Time $F_{3,37}$ = 12.25 p<0.001 and $F_{2,34}$= 7.91 p<0.002 respectively). In general it was highest on oilseed rape and lowest on winter wheat, gradually increasing on cereals with time after harvest. In the final ALLCROPS model, the number of spray dates was the most significant (positive) predictor of variation in volunteer cover ($F_{1,45}$ = 10.55, p<0.002). In the CEREALS model, volunteer cover declined with later harvest ($F_{3,37}$ =5.82, p<0.021) and increasing number of chemicals on preceding crops ($F_{3,37}$ =5.12, p<0.030).

Cover of diet weed species also varied with stubble type (Fig 4.8). It was lower on winter wheat than other crop types in early winter (ALL CROPS $F_{3,37}$=3.86, p<0.017) but crop type was not significant in the CEREALS model (probably because weed cover increased over time). It was generally highest on winter and spring barley throughout the season and similar on other crop types. In both models, early harvested crops had higher cover (ALL CROPS, $F_{1,45}$= 14.57 p<0.001, CEREALS $F_{1,38}$=12.08 p<0.001).

4.3.6 Number of active (seeding) species and crop management

The number of active weed species varied between sites (ALLCROPS $F_{3,9}$=7.87, p<0.005; CEREALS $F_{3,5}$=5.73, p<0.045 respectively). Whether the preceding crop had been sprayed with glyphosate or not was the only significant management factor in the ALLCROPS model, with fewer active weeds where glyphosate had been used ($F_{1,20}$=7.11, p<0.015). In the CEREALS model, the number of different herbicides sprayed on the preceding crop (negative, $F_{1,10}$=27.19, p<0.001) and stubble height (positive, $F_{1,10}$=12.74, p<0.005) were significant management factors. The number of different herbicides alone explained 43% of the variation in the number of active weed species over the four post harvest periods ($F_{1,11}$=8.56, p=0.015, r^2=0.43, B=-0.56$\pm$0.19, Figure 4.9). For both ALLCROPS and CEREALS modes, data suggested use of glyphosate (ALL CROPS), number of chemicals used and stubble density (CEREALS) best explained variation between fields in number of active weed species.

Allowing for sample variation, diet seed rain was three times higher on average on fields where the preceding crop was sprayed with only one herbicide prior to harvest as opposed to three (seeds per m^2 [mean $\pm$ s.e] 12,160 $\pm$ 6251 vs. 1246 $\pm$ 50). However, it is important to note that the variation in seed density under reduced herbicide regimes is large and will be influenced by factors such as crop and soil type, as well as management history of the field.

4.3.7 Seed rain and management

The majority of seeds recorded in the seed rain traps were of species also recorded in the diet of granivorous farmland birds. The 'total seed rain' and 'diet seed rain' models were thus very similar and here we present results for diet seed rain only. Site was important in explaining variation in diet seed rain between the first two time periods ($F_{3,10}$=7.50, p<0.006) but this relationship was modified by crop type (CEREALS $F_{4,10}$=4.89, p<0.019). At four sites there were no consistent differences between stubble types but at one site, where herbicide use was particularly low, diet seed rain was high in cereals, particularly barley, reaching 30,000 seeds/m^2 (time periods 3 and 4). In the ALLCROPS model, the diet seed rain declined with number of chemicals used ($F_{1,19}$=6.59, p<0.019). The effect of number of chemicals and harvest date varied with time ($F_{1,19}$=12.83, p<0.002 and $F_{1,19}$=6.11, p<0.023 respectively). The addition of Crop and Site and Crop*Site did not improve the model fit suggesting that crop management best explained the data.

In the CEREALS model, seed rain declined with later harvest ($F_{1,19}$=13.19, p<0.005), increasing number of chemicals (diet seed, $F_{1,19}$=15.31, p<0.004) and the use of glyphosate before harvest (diet seed; $F_{1,9}$=6.00, p<0.037). These relationships varied with time though, probably reflecting the germination (and seed set) of arable weeds post harvest.

Allowing for sample variation mean number of active diet weed species was more than twice as high on average on fields where the preceding crop was sprayed with only one herbicide prior to harvest as opposed to three (no. species per m^2 [mean $\pm$ s.e] 2.82 $\pm$ 0.56 vs 0.88 $\pm$ 0.21). However, it is important to note that the variation in seed density under reduced herbicide regimes is large and will be influenced by factors such as crop and soil type, as well management history of the field.

4.3.8 Density of crop and weed seeds in soil and management

The density of crop seeds declined with time as a result of germination and predation by birds and other animals. Site was a significant predictor of mean density of crop seeds in time periods 1 and 2 (cereals, oilseed and sugar beet) but its effect became weaker over time, as the density of crop seed declined. Spraying with glyphosate immediately prior to harvest reduced crop seed, though only two of 23 oilseed and cereal fields were left unsprayed so the result may not be robust). Later harvest date also reduced crop seed density ($F_{1,26}$=9.09, p<0.01), although this effect was modified by time (Time 1 $F_{1,27}$=9.79, p<0.001, r^2=0.27, Time 2 $F_{1,26}$=2.69, ns, r^2=0.09), probably linked to the fact that oilseed rape which sheds a lot of seeds is harvested early and winter wheat, for which shedding-resistant varieties have been developed, is harvested late.

Initially, rape seeds were the most abundant at harvest, but like other crop seed, they rapidly diminished (Figure 4.10). The most striking result was the late winter increase in weed seed in barley stubbles, when beet weed seed densities were also high. There was also an increase in weed seed densities in rape stubbles at Time 4, but no increases in wheat. There was some field-to-field variability in seed patterns, some sugar beet and rape stubble fields had many weed seeds and were especially valuable, while others had very few. Sugar beet fields were also variable in their weed seed densities with some low but others with very high seed densities in late winter (these may be of particular importance for birds).

Weed seed density varied significantly between the first two time periods ($F_{1,12}$=9.82, p<0.009); highest soil seed densities were in time period 2 but this relationship varied between sites ($F_{11,12}$=4.20, P<0.010). Weed seed densities were highest on oilseed rape and sugar beet stubbles and generally much lower on cereal stubbles. The use of glyphosate before harvest reduced the number of arable weed seeds in time period 1 and 2 ($F_{1,25}$=4.79, P<0.05) but in longer surviving oilseed rape, cereal and sugar beet stubbles there was no effect of site, crop or management variables on soil weed seed density. However, when only the cereal stubbles were considered, soil weed seed density declined with increasing number of chemicals applied to the crop ($F_{1,6}$=6.51, p<0.045).

Canonical Correspondence Analysis of the winter 2 seed data sets indicated the communities of rape and wheat stubbles differ from barley, linseed and beet stubbles (Figure 4.11). Species associated with rape stubbles included a wide range of broad-leaved weeds, including mayweeds, sowthistles and speedwells. A range of broad-leaved species were also associated with barley and beet, notably diet seeds of the Polygonaceae and Chenopodiaceae. A smaller range of species were associated with wheat, including some competitive grass weed species, such as wild oats (*Avena fatua*) and blackgrass (*Alopecurus myosuroides*). On the basis of seed composition, beet and barley stubbles may be more important for birds than the other crops, especially in late winter.

4.4 Discussion

The quality of a stubble field as foraging habitat for birds will depend on the abundance and accessibility of food within it. Food resources for granivorous birds in stubble fields comprise crop and weed seeds present on or near the soil surface after harvest and weed seeds that are replenished through germination and seed set of weeds in the stubble (seed rain). Weed seeds on the soil surface were most abundant in broad-leaved crops - sugar beet and oilseed rape. Crop seeds were also highest on rape and lowest on cereals, particularly winter wheat, for which non-shedding varieties have been developed. Chemical management of the crop also influenced weed seed abundance on the soil surface. In the first two months after harvest, across all crop types, their abundance was reduced by the use of glyphosate prior to harvest and, in long-term cereal stubbles, by increasing frequency of chemical applications in the preceding crop.

Studies to date have focussed entirely on weed and crop seed on the soil surface and have not quantified seed replenishment from germination and seed set of weeds. There are three reasons why this food source could be particularly important for birds in winter: first it can be considerable (in this study up to in 30 000 seeds/m^2); second, it replenishes seeds in late winter when other food resources are scarce and, third, many of the weed species are important in the diet of farmland birds.

The number of active weed species did not vary significantly between crops and sites but it did vary with chemical management and was higher where crops had not been treated with glyphosate before harvest. In longer lasting cereal stubbles, the number of herbicides used on the preceding crop accounted for 43% of the variation in the number of active weed species growing in the stubble fields. Seed rain levels were also strongly influenced by herbicide regime in the preceding crop, whereas crop type was only important at one of five sites, where herbicide use was particularly low. At this site diet seed rain was high in cereals, particularly winter barley, in late winter.

The number of chemicals used in the preceding crop was consistently important in determining the total and diet seed rain in the short and long term. In long-term cereal stubbles, seed rain was low in crops that had been treated with a large number of herbicides, harvested late and sprayed with glyphosate prior to harvest. The effects of crop management on seed rain in stubbles became increasingly evident as winter progressed and weeds developed. However in both short and long term (cereal) stubbles, stubbles following crops that had been treated with a smaller number of herbicides had higher levels of diet seed rain, controlling for the effects of harvest date and use of glyphosate.

Thus, the chemical management of the crop was extremely important in determining the food abundance in the subsequent stubble. Less frequent spraying, the use of a smaller number of herbicides and/or not using glyphosate prior to harvest were the overriding factors explaining differences abundance of weed and crop seed. Stubbles preceded by crops subject to less intensive herbicide regimes tended to have higher cover of arable weeds that are important in the diet of farmland birds, higher seed rain throughout the post harvest period and greater species richness and density of weed seeds on the soil surface. Nevertheless, quantifying the benefits of particular herbicide reductions is difficult. Field-to-field variability in weed flora, environmental influences on herbicide efficacy, the changing spectra of weed species controlled by particular herbicides (see project PN0940) and the availability of products for different crops all influence the impact of weed control operations. It is nevertheless clear that where reduced herbicide programmes have been practiced, there have been potential benefits for granivorous birds. In principle, herbicides that are active against the most competitive weed species, notably grasses, and which do not control bird diet species, could be selected (Marshall et al. in press). Such a principle might usefully be included in the WMSS wheat management database and form the basis of reduced herbicide programmes.

There were some consistent differences in food abundance between crop types. Within longer lasting cereal and linseed stubble, barley emerged as consistently higher in food resources for birds. Overall the cover and number of seeding broad-leaved weeds were highest on winter barley and oilseed rape, crops harvested early, and lowest on linseed. Seed rain from arable weeds was highest in winter barley, comprising grass and broad-leaved weeds in roughly equal proportions. It was low on oilseed rape but comprised almost entirely broad leaved species particularly *Polygonum* spp. In cereal stubbles that survived for four months, barley still had the greatest density of broad-leaved weeds and beet at this time often had rich seed resources.

Food abundance is modified by accessibility. The results of this study suggest far less scope for managing stubbles to improve accessibility of seed resources than their abundance. Assuming only seeds at or very close to the soil surface are available to birds, their accessibility will depend largely on structure, the stubble and regenerating vegetation (volunteer and weed cover). In general, there were few marked, consistent differences between crops in sward structure (stubble plus regenerating vegetation) that would influence the accessibility of seeds on the soil surface. Thus, it seems likely that food abundance is more important than accessibility in determining use of stubbles by birds.

5. QUANTIFY THE AGRONOMIC IMPLICATIONS, IN RELATION TO THE ENVIRONMENTAL BENEFITS, OF THE OPTIONS TRIALLED IN OBJECTIVE 1

5.1 Methods

The agronomic performance of the crops trialled in Objective 1 was assessed using economic indices. Experimental crop yields were used to calculate gross margins, using average yields where no significant yield differences were found between treatments. Variable costs were adjusted according to numbers of herbicides used. An assessment of the impacts on following crops, in terms of weed burden, was made using weed cover, species data and likely practice. Winter and spring crop rotations incorporating stubbles were evaluated in terms of gross margins and likely impact on farm practice, including the timing of operations through the year.

5.2 Results

5.2.1 Objective 1 experiment

Gross margins for the five crops grown with conventional and reduced herbicide programmes are compared with those for low, average and high yields quoted by Nix (2002) for the UK (Table 5.1).

Wheat achieved margins greater than national averages, even with a reduced herbicide programme. Winter linseed margins were similar to national averages. In contrast, spring oilseed rape margins were well below averages, reflecting late harvest and loss of rape seed. Spring barley margins were close to the national figures for low yields, irrespective of herbicide programme. Maize margins were similar to national averages for conventional, herbicide-treated crops, but the untreated crop had margins approximately half the average. On the basis of the single experiment, reduced herbicide programmes of wheat and linseed gave economically acceptable gross margins. Spring barley might need further economic support. Maize is not acceptable and the data for spring oilseed rape are not easily interpretable, though the stubbles gave the most weed cover.

Weed plant cover towards the end of the stubble phases was highest in oilseed rape stubble (80%) with other crops at around 50% cover and maize at only 20% cover. The composition of the major weeds in reduced herbicide plots is shown in Table 5.2. In most instances, except maize, the preceding crop, as volunteers, also made a significant contribution to vegetation cover. No highly competitive weed species were present. Annual meadow grass (*Poa annua*) can be difficult to control in some crops, but has a low competitive index of only 0.1 (50 plants m^{-2} give 5% crop loss), in comparison to 1.0 (five plants m^{-2}) for wild oat (*Avena fatua*), for example, the most competitive grass weed in cereals (PN0940) (Marshall et al., 2001). This loam soil site has few serious grass weeds; there was little evidence of serious weed build-up in any stubble, indicating that the reduced herbicide programmes did not, at this site, produce problems. Whilst few diet weed species were recorded at the end of winter, many were present earlier in the autumn in spring-sown crops.

5.2.2 UK arable rotations with winter stubbles

From a simple economic viewpoint, winter crops are more profitable to grow, explaining their dominance in UK arable systems. For example, average gross margins on winter and spring wheat are £500/ha and £441/ha respectively, and for winter and spring oilseed rape; £447/ha and £327/ha (Appendix 5.1). Although spring crops are less profitable, there are many options available for spring cropping. Objective 1 results demonstrate that weeds can be encouraged in winter stubbles. Objectives 2 and 3 show that these resources are used by birds. To encourage the presence of winter stubbles requires an appreciation of the economic and practical implications for landowners. In practice, a winter stubble will be followed by either a spring crop, or a summer fallow (possibly set-aside) and a subsequent winter crop. Both are included in the current options of the Countryside Stewardship Scheme. The summer fallow requires one harvest and its profit to be foregone; spring crops have lower gross margins. Whilst our results indicate that many winter crop stubbles have benefits for birds, notably barley, if many of the important weeds for birds are spring germinating, then spring crops and their following winter stubbles will need active encouragement.

Two other practical constraints to winter stubbles require consideration: weed pressure in following crops and constraints on the timing of farm operations. Weeds in winter stubbles are killed either by cultivations in spring or with herbicides or both. A proportion of the seed that remains after germination and predation on the soil surface will be incorporated into the seed bank by cultivations at this time. Bearing in mind that most competitive weed species, such as *Alopecurus myosuroides* and *Galium aparine* are mostly autumn germinating, the risk of weed build up in winter stubbles is low, with such pre-drilling activity in spring. Perennial weeds, such as *Elymus repens* and *Cirsium arvense* may provide more of a threat, but the use of herbicides pre-drilling or pre-harvest will control these species. Thus the threat of weed increases with winter stubbles followed by spring crop is only minor. If stubbles are followed by a summer fallow, then there is greater potential for autumn germinating weeds to complete their lifecycle before cultivation and drilling the next winter crop. Farmers would need to take care to prevent seeding of any such pernicious weeds in the fallow period.

With regard to timing of farm operations, it is useful to consider the peak times of farm activity, which are drilling and harvesting, and soil type. In crop rotations dominated by winter crops, harvesting and drilling takes place in August, September and October (Appendix 5.2). In contrast, these operations are well-separated temporally in a spring crop rotation. Thus from an agricultural viewpoint, incorporating more spring crops may relieve time and equipment constraints on crop establishment in the autumn. However, arable cropping on heavy clay soils is largely limited to winter crops, as spring cultivations are usually impractical. On such soils, winter stubbles are not appropriate and in previous centuries the land would have been mostly grassland. Where spring cropping is feasible, the opportunities for stubbles surviving through winter would increase, if harvesting and drilling were separated. Stubble cultivation would need to be avoided and, without some constraints on herbicide use, many stubbles would still be poor in seeds and weeds. Bearing in mind that the margins quoted include an Arable Area Payment of £225/ha (£260/ha for beans), and that the difference between winter and spring crop gross margins is of the order of £60/ha, small adjustments in support could result in significant increases in spring cropping. As many of the seeds that birds require are those from spring germinating weed species, promotion of both winter stubbles and spring crops is to be recommended.

6. PROVIDE GUIDELINES FOR POLICY DECISIONS RELATED TO CURRENT OR FUTURE AGRI-ENVIRONMENT SCHEMES SUCH AS ARABLE STEWARDSHIP

In arable landscapes dominated by winter cropping, few stubble fields are present through the winter. National and regional surveys of birds on existing stubble fields showed that, across all stubble types, the vast majority of fields (almost 90% for species like skylark and linnet) support few or no birds in winter. Models of winter bird use of stubbles show strong dependence on the energy available as weed seeds. Therefore, increasing the amount and/or improving the quality of stubble for birds means increasing the food resources in the field (especially the seeds of broad leaved arable weeds) present both at harvest and replenished through seed shed from germinating weeds during the winter. Crop seeds have largely disappeared by mid-winter, earlier in the case of rape, and are less abundant overall than weed seeds. More granivorous farmland birds can be supported if there are more high quality stubble fields, i.e. stubbles with weed seeds throughout winter.

6.1 Selection of Crop Stubble Type

The most marked differences in the use birds made of stubbles (at regional and national scales) were between fields rather than crops, although some species showed clear preferences for a particular stubble type. For example, Woodlarks showed clear preferences for barley stubbles; individual agri-environment prescriptions could be targeted to important bird species where required. Barley (especially spring barley but also winter), oilseed rape and beet were generally richer in broad-leaved weeds. Within these stubbles, barley and beet were richest in diet weed species. Linseed and winter wheat were less weed rich and maize was almost weed free. However, under current commercial practice, rape (gone by early autumn) and beet (late winter) stubbles are short lived and, under current cropping practice, only cereals will provide food resources for birds throughout the entire winter. Barley and wheat stubbles can support very large numbers of granivorous finches and buntings if rich in weed seeds. Barley, which is harvested earlier, is potentially of more value for birds than wheat because it tends to contain more active seeding weed species and thus higher weed seed numbers late in the winter. In barley stubbles, weed seed numbers increase in late winter reflecting seed shed; this was not found in wheat stubbles.

6.2 Management of the Preceding Crop and Stubble Phases

The chemical management of the preceding crop was consistently important (in field surveys and experimental work) in determining levels of weed seeds at harvest, cover of seeding weeds and subsequent seed shed. The number of weed (and crop) seeds in the soil, the number of seeding weeds (and hence seed rain) were all higher in fields where the preceding crop had received a lower number of herbicides and it had not been sprayed with glyphosate before harvest. Crop type had some influence on bird food resources, as different crops have different herbicide programmes available for them. In the stubble phase, experimental work showed that weed cover was reduced by stubble cultivation. Later harvesting date also tended to reduce weed cover. Field experimentation demonstrated that reduced herbicide programmes in most crops give more weeds. For some there were associated crop yield penalties, but with relatively small impacts on gross margins.

6.3 Recommendations for Agri-Environment Schemes

Currently, overwintered stubbles are part of both Environmentally Sensitive Area (ESA) and Countryside Stewardship (CSS) management prescriptions (Table 6.1). Few prescriptions for stubbles in current agri-environment schemes have specific recommendations for crop types (beyond a cereal or linseed) and none have recommendations for reduced herbicide regimes in the preceding crop (CSS prescription OS2 requires a reduced herbicide programme in the following spring crop). Based on this research we suggest four possible changes that would increase the value of these stubbles for birds:

1. reduced herbicide programmes on preceding crops
2. restrictions on the use of pre-harvest glyphosate

3. promotion of barley (especially spring barley) over wheat and linseed
4. no stubble cultivation (already in place in CSS)

These recommendations are not mutually exclusive. Chemical management of the crop is more important than crop type. However, conventionally managed spring barley may be equally valuable to reduced herbicide winter barley, as the former tends to receive lower herbicide inputs. Most stubble types, if they follow crops with lower herbicide inputs, can provide good food resources for birds. Nevertheless, spring-sown crops, such as spring barley and beet, tend to have more diet weed species and are thus likely to be of greater benefit to birds in winter stubbles. Further research is required into the value and viability of rape stubbles retained over winter, as experimental work indicates they may be particularly weedy.

6.4 Stubble in the Wider Countryside

Although the majority of stubble fields support few birds, the small number that do are currently a vital resource. Simply encouraging stubble retention over winter (with few specific management guidelines) may still increase the number of 'good' fields for birds. This might be achieved simply by encouraging more spring cropping, for example by adjusting arable area payments. An increase in payments for spring crops (and decrease for winter crops) would adjust gross margins and could create an incentive to delay drilling to spring. Nationally, spring cropping currently carries penalties in gross margins, compared with winter cropping. The advantage of spring crops for birds, apart from the preceding winter stubble period, is the encouragement of spring-germinating diet weed species, notably the Polygonaceae. Nevertheless, the key point is that valuable weedy stubbles are required, as simple prescriptions to 'retain stubble' may in fact rarely benefit the birds for which they are intended. Thus, the need to adjust herbicide programmes and the encouragement of barley and spring cropping in rotations is important and it may be better for birds to target smaller numbers of fields with more specific management. If these adjustments are given sufficient incentives and are built into good agricultural practice, e.g. through Integrated Farming Systems and organic farming, an increase in the number of valuable stubble fields for birds should be achieved.

Although we recommend the promotion of barley stubbles in agri-environment schemes, as the stubbles are long-lasting and are widespread across the lowland agricultural landscape, managed sympathetically, many crop stubbles can provide valuable resources for birds. In addition, novel schemes promoting the retention of weedy sugar beet and rape stubbles may be considered, although further research into the long-term benefit of the retention of rape stubbles for birds would be needed.

6.5 Further Research

1. The value of oilseed rape stubbles for birds needs further research: (i) how good are they relative to, for example, spring and winter barley over the whole winter in terms of number and diversity of birds supported? (ii) how can the value be maximised in terms of weed and crop seeds? (iii) how should the stubbles and preceding crop be managed to optimise their value e.g. would the dense volunteer cover render seeds on the soil inaccessible? (iv) what are the agro-economic consequences of rape stubble being retained over winter?
2. More detailed research into relative value of spring and winter barley: (i) are they equally important providers of weed seed in late winter? (ii) do they have similar weed flora through the stubble phase? (In this project - objective 1 experiment considered only spring barley and in the East Anglia fieldwork only small numbers of spring barley fields were small sampled)
3. Impact of different harvesting and stubble disposal methods on the spatial and temporal availability of seeds, e.g. chaff swaths, straw spreading. (This should be addressed in the supplementary report to this project but may require more detailed studies)
4. Further socio-economic studies: (i) on the impacts of modified incentives on the uptake of reduced herbicide programmes and spring cropping on different soil types, (ii) on modified rotations on different soils, including placement of set-aside.

Landscape scale-effects – where is stubble creation of most value? This is being investigated, to some extent, under other projects (e.g. BD1616), but these will not allow us to say how much stubble is required to effect a population change. This may be addressed through detailed monitoring of stubble options under agri-environment schemes, e.g. the new broad and shallow options serving as a natural experiment or by using bird and habitat data for CS 2000.

Table 1.1 Weed cover (%) in different crops treated with conventional (conv.) and reduced herbicide regimes. Means with same superscript letter are statistically the same (sed [standard error of the difference between means] =7.775;df [degrees of freedom]=60).

	Spring Reduced	Spring Conv.	Summer Reduced	Summer Conv.
Linseed	25.5^{ef}	18.3^{bcde}	62.0^{gh}	37.7^{f}
Wheat	55.6^{g}	2.8^{ab}	70.7^{ghi}	6.0^{abc}
Oilseed rape	20.7^{cde}	16.3^{abcde}	93.6^{j}	75.1^{hi}
Barley	17.6^{bcde}	9.1^{abcd}	80.9^{ij}	27.5^{ef}
Maize	22.9^{def}	0.9^{a}	146.7^{k}	3.7^{ab}

Table 1.2 Crop yields and harvest attributes for five crops grown with reduced or conventional herbicide programmes and compared with average UK yields (Nix, 2002).
ns = not significant.

Crop	Index	Conventional	Reduced	sed (df = 5)	Average UK yields (Nix)
Winter Linseed	t/ha at 8% moisture	1.23	1.55	ns	1.4
	% moisture	6.7	8.59	ns	
Winter wheat	t/ha at 15% moisture	10.41	8.99	0.408	8
	% moisture	16.11	16.21	ns	
Spring oilseed rape	t/ha at 8% moisture	0.81	0.78	ns	1.9
	% moisture	13.94	23.05	1.885	
Spring barley	t/ha at 15% moisture	4.8	4.89	ns	5.75
	% moisture	14.13	15.52	ns	
Maize	t/ha fresh	40.85	25.75	2.458	40
	t/ha dry	12.54	8.02	1.057	
	plant density	104.44	109.91	ns	

Table 1.3 Weed cover (%) in stubbles of five crops that were left (-D) or cultivated with a Dynadrive (+D) in autumn and winter. Crops had been grown with conventional or reduced herbicide programmes. (sed [standard error of the difference between means] = 20.82; df=30).

	Autumn – reduced herbicide		**Autumn – conventional**		**Winter – reduced herbicide**		**Winter - conventional**	
	-D	+D	-D	+D	-D	+D	-D	+D
Linseed	85.9	52.7	61.8	40.3	56.5	59.2	44.8	52.2
Wheat	44.8	46.4	20.6	40.3	41.1	60.0	23.1	39.1
Oilseed rape	87.4	41.9	48.3	15.0	82.3	70.3	62.0	49.1
Barley	72.4	35.8	76.0	39.0	53.2	56.6	52.3	64.5
Maize	13.8	4.1	4.8	2.4	30.9	18.8	13.5	9.8

Table 1.4 Selected species in winter seed samples (mean seeds per sample) for five different stubble types (averaged over different herbicide programmes in the preceding crop). Numbers underlined are where seed numbers differ between wheat and barley stubbles.

	Code	**Wheat**	**Linseed**	**Rape**	**Barley**	**Maize**
Anagallis arvensis	004	0	74.1	103.4	0	0.5
Cerastium fontanum	011	<u>82.8</u>	17.5	24.9	0	0.08
Chenopodium album	013	0.04	0	0.2	0	10.3
Fallopia convolvulus	016	0	5.1	1.1	0.3	0.7
Matricaria perforata	030	0	157.6	9.4	0	9.5
Poa annua	035	353.8	234.1	158.1	559.3	67.6
Polygonum aviculare	036	0	2.9	12.9	<u>1.4</u>	0.3
Polygonum lapathifolium	037	0.08	0	0.05	0	0.5
Polygonum persicaria	038	0.5	4	12.2	<u>2.2</u>	2.6
Sonchus asper	051	0.08	1.1	3.9	<u>1.7</u>	4
Stellaria media	053	0.08	1.5	8.7	<u>22.3</u>	71.7
Veronica arvensis	061	61.2	40.2	25.0	56.6	0
Viola arvensis	064	<u>104.5</u>	43.11	1.9	6.8	1.2

(Blue = Barley>Wheat, yellow = Wheat>Barley electronic version only)

Table 2.1 The number of 1-km^2 squares surveyed in three winters and five WFBS regions. Stratification = number of squares initially selected, figures in parentheses = percentage of the row total found in each region.

	E. England	N. England	W. England	Scotland	Wales
Winter 1	329 (38%)	152 (17%)	203 (23%)	104 (12%)	83 (10%)
Winter 2	261 (34%)	151 (19%)	184 (24%)	108 (14%)	75 (10%)
Winter 3	259 (35%)	259 (35%)	168 (23%)	101 (14%)	72 (10%)
Stratification	1051 (35%)	511 (17%)	694 (23%)	300 (10%)	459 (15%)

Table 2.2 The number of fields surveyed, summed across visits, summarised by stubble type. Also the number of fields of bare tillage, cereal crop and grass surveyed.
* cereal stubble that was not classified as wheat or barley.

Habitat Type	Number of fields		
	1999/2000	2000/2001	2002/2003
Barley Stubble	568	776	910
Wheat Stubble	874	1189	625
Cereal Stubble*	835	860	713
Fallow Stubble	319	400	383
O. Rape Stubble	108	93	91
Linseed Stubble	145	106	9
Maize Stubble	342	293	309
S. Beet Stubble	143	85	91
Bare Tillage	2305	2231	1491
Cereal Crop	6431	3367	4008
Grass	21690	16495	18061

Table 2.3 Percentage cover of farmland under cereal crop (CC) and different stubble types: SB = Sugar beet, C = Cereal, M = Maize, L = Linseed, R = Oilseed rape. Farmland = area (ha) of lowland farmland within each stratum (regions and ITE landscape types). Calculated from WFBS data in winter 2002/2003. E, L = Early and Late visits. A = Arable, P = Pastoral. For Middle see Appendix 2.1.

a) Winter 1999/2000

Stratum	Visit	Farmland	Percentage cover of farmland					
			CC	**SB**	**C**	**M**	**L**	**R**
E. England-A	E	3421533	39.4	1.0	9.1	0.9	0.5	0.8
	L	3407762	41.2	0.4	5.4	0.6	0.2	0.6
E. England-P	E	443678	25.3	0.0	6.8	1.6	1.5	0.8
	L	448267	29.3	0.0	6.6	0.4	0.7	0.9
N. England-A	E	601293	29.9	0.2	7.2	1.5	0.2	0.1
	L	591418	30.3	0.4	4.0	1.8	0.3	0.2
N. England-P	E	1207294	20.1	0.4	7.9	1.2	0.0	0.3
	L	1215516	20.0	0.4	5.0	1.3	0.0	0.3
W. England-A	E	752592	23.0	0.0	10.1	2.0	0.3	0.1
	L	746941	24.1	0.0	6.5	2.3	0.2	0.1
W. England-P	E	1715095	13.4	0.7	5.2	1.7	1.1	0.0
	L	1716407	14.6	0.9	4.2	1.6	0.9	0.0

b) Winter 2000/2001

Stratum	Visit	Farmland	Percentage cover of farmland					
			CC	**SB**	**C**	**M**	**L**	**R**
E. England-A	E	3443352	25.7	0.7	16.7	0.9	0.5	1.0
	L	3414814	28.4	0.3	11.7	0.6	0.4	0.9
E. England-P	E	434624	22.3	0.3	11.5	4.8	1.2	0.0
	L	431733	18.4	0.0	11.2	4.8	1.1	0.0
N. England-A	E	589222	18.8	0.0	16.1	1.1	0.9	0.2
	L	575081	18.8	0.0	11.7	1.8	0.2	0.0
N. England-P	E	1162413	10.5	0.3	13.7	1.3	0.1	0.9
	L	1178866	11.5	0.1	10.7	1.4	0.0	0.4
W. England-A	E	727635	21.1	0.1	8.9	2.3	0.1	0.0
	L	776627	27.5	0.0	7.1	2.8	0.0	0.0
W. England-P	E	1718876	10.2	0.3	7.0	2.8	1.0	0.1
	L	1737885	11.7	0.1	6.1	1.4	1.3	0.1

c) Winter 2002/2003

Stratum	Visit	Farmland	Percentage cover of farmland					
			CC	**SB**	**C**	**M**	**L**	**R**
E. England-A	E	3385783	32.2	0.7	13.1	0.2	0.1	0.7
	L	3397864	33.6	0.9	7.8	0.3	0.0	0.8
E. England-P	E	438951	21.9	0.6	12.8	0.5	0.0	0.0
	L	407677	22.6	0.7	7.3	0.5	0.0	0.0
N. England-A	E	586448	27.1	0.0	9.8	1.0	0.1	0.1
	L	585685	28	0.0	6.0	0.9	0.0	0.1
N. England-P	E	1162659	16.6	0.4	9.9	1.7	0.0	0.1
	L	1155491	16	0.3	9.3	1.7	0.0	0.1
W. England-A	E	741861	23.2	0.0	10.6	3.1	0.0	1.0
	L	738641	25	0.0	8.7	2.6	0.0	1.1
W. England-P	E	1724851	8.3	0.2	6.3	3.1	0.0	0.0
	L	1711002	9.1	0.3	6.3	2.8	0.0	0.0

Table 2.4 The mean (± SE) number of stubble fields per 1-km^2 square in each region of Britain. Separate means given for Early and Late visits in each winter. These are corrected for incomplete square coverage as for habitat area estimates.

W	Visit	E. England	N. England	W. England
1	E	2.0 ± 0.2	2.0 ± 0.2	2.2 ± 0.2
1	L	1.3 ± 0.1	1.6 ± 0.2	1.9 ± 0.2
2	E	3.0 ± 0.2	3.2 ± 0.3	2.8 ± 0.3
2	L	2.0 ± 0.2	2.6 ± 0.4	1.8 ± 0.2
3	E	1.9 ± 0.2	1.6 ± 0.2	1.6 ± 0.2
3	L	1.2 ± 0.1	1.2 ± 0.2	1.5 ± 0.2

Table 3.1 Summary of the number and area of fields surveyed for birds and the number of fields sampled for seeds and plants in the two winters 1999/2000 (W1) and 2000/2001 (W2).

	Area (ha) of fields surveyed for birds		No. of fields sampled/surveyed					
			Birds		Soil seeds		Plants	
	W 1	W 2	W 1	W 2	W 1	W 2	W 1	W 2
L	470	219	40	17	9	5	0	16
OSR	259	470	22	40	12	7	0	24
SB	213	321	12	36	0	5	0	0
B	356	467	35	36	10	5	0	28
W	361	466	31	41	8	6	0	38
Total	1658	1943	140	170	39	28	0	106

L=linseed, OSR=oilseed rape, SB=sugar beet, B=Barley, W=wheat

Table 3.2 Longevity of the stubble fields in the East Anglian study area in days (mean ± SE) estimated from the life tables analysis.

Stubbles type	1999/2000	2000/2001
Oil Seed Rape	41.77 ± 7.5	58.80 ± 6.99
Barley	93.00 ± 12.05	119.00 ± 14.12
Wheat	65.77 ± 7.9	139.57 ± 7.79
Linseed	97.75 ± 12.03	106.39 ± 13.56
Sugar Beet	15.75 ± 2.71	87.67 ± 7.29

Table 3.3 Results of the likelihood ratio tests, testing whether the density of birds on the different stubble types varied between years for the mid winter period (October to February see Figures 3.2 and 3.3.). Letters indicate stubble types supporting similar densities of birds. – = the sample size was insufficient to determine a relationship.

						Overall model statistics		
		Barley	**Linseed**	**Sugar Beet**	**Wheat**	χ^2	**df**	**P**
Finches & Sparrows	1999/2000	-	-	-	-	-	-	-
	2000/2001	a	a	b	a	29	4,726	< 0.0001
Thrushes & Starling	1999/2000	-	-	-	-	-	-	-
	2000/2001	a	a	b	a	61.42	5,594	< 0.0001
Skylark	1999/2000	a	b	b	a,b	184.02	4,588	< 0.0001
	2000/2001	a	b	b	b	112.81	4,726	< 0.0001
Buntings	1999/2000	a	b	b	a,b	21.05	4,589	< 0.001
	2000/2001	a	b	b	b	30.66	4,726	< 0.0001

Table 3.4 Significant (i) univariate relationships (ii) variables in multivariate model of log[energy demand of finches, buntings and sparrows] vs. all the independent variables for early winter 2000/2001. For explanation of variable codes see Appendix 3.2.

(i)

Parameter	**df**	χ^2	**P**
Crop	3	8.88	0.0309
Cereal	1	4.80	0.0284
Rape	1	6.43	0.0112
Stubble density	1	7.14	0.0075
Crop*site		1131.14	0.0010

(ii)

Parameter	**df**	**Estimate**	**Chi-Square**	**P**
Rape	1	0.7023	13.25	<0.001
polygonaceae	1	0.7122	5.99	0.01
nochems	1	-0.2307	4.17	0.04

Table 3.5 Significant (i) univariate relationships (ii) variables in multivariate model of log[energy demand of finches, buntings and sparrows] vs. all the independent variables for the late period during the second winter. * Significant variables only.

(i)

Parameter *	df	χ^2	P
nochems	1	4.20	0.0405
Urtica	1	4.88	0.0272
weed_seeds	1	4.96	0.0259
bound3	1	5.03	0.0250
Sugar_beet	1	6.56	0.0104
Chen	1	8.47	0.0036
Crop*site	13	44.48	<.0001

(ii)

Parameter	df	χ^2	P
Chen	1	4.94	0.0263
nochems	1	23.11	<.0001
polygonaceae	1	15.23	<.0001

Table 4.1 The number of fields surveyed at each post harvest period in 2000/01 and in 2001/02.

Preceding crop type	Post harvest period 2000/01				Post harvest period 2001/02				
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**
Winter barley (WB)	20	15	14	12	5	5	5	5	5
Spring barley (SB)	6	6	5	4	5	5	5	5	-
Winter wheat (WW)	38	34	27	26	5	5	5	3	1
Linseed (L)	16	14	-	-	2	2	-	-	-
Oilseed rape (OSR)	24	16	-	-	5	5	-	-	-
Sugar beet (SU)	22	11	-	-	-	-	-	-	-

Table 4.2 The number of different herbicides sprayed on each crop type and frequency of treatment (means values are given ± 1 s.e.), and the percentage of fields of each crop type sprayed with glyphosate immediately prior to harvest during both study years. This data excludes fields surveyed with no management information supplied by farm managers.

Year of study	Crop Type	No of fields	% sprayed prior to harvest	No of herbicides	No of spray dates
2000/01	Oilseed rape	24	92.31	3.87 ± 0.26	3.00 ± 0.20
	Linseed	16	92.86	3.64 ± 0.28	2.73 ± 0.24
	Spring barley	7	66.67	2.17 ± 0.40	1.5 ± 0.22
	Winter barley	21	76.92	3.81 ± 0.25	2.33 ± 0.16
	Winter wheat	38	87.80	3.79± 0.17	2.31 ± 0.12
	Sugar beet	27	0	6.89± 0.52	4.11 ± 0.21
	Total	133			
2001/02	Oilseed rape	5	100	3.60 ± 0.51	3.00 ± 0.00
	Linseed	2	100	3.00 ± 0.00	2.00 ± 0.00
	Spring barley	5	60	2.20 ± 0.49	1.60 ± 0.24
	Winter barley	5	40	2.80± 0.92	2.00 ± 0.55
	Winter wheat	5	20	2.60 ± 0.24	1.60 ± 0.24
	Total	22			

Table 5.1 Gross margins (£/ha) for five crops grown in experimental plots with conventional and reduced herbicide programmes compared with national averages.

	Objective 1 experiment		Nix (2002) national yield averages		
Crop	**Conventional**	**Reduced**	**Low yield**	**Average**	**High yield**
Winter wheat	651	562	406	500	594
Winter linseed	336	346	270	338	406
Spring oilseed rape	177	182	259	327	394
Spring barley	366	376	357	420	483
Forage maize	274	133	-	265	-

Table 5.2 Weed cover (%) on reduced herbicide subplots of five crop stubbles averaged over four sample times. Data for species that achieved at least 2% cover on some sub-subplots, together with bird diet species. (* = data for *V. persica*)

	No. plants m^{-2} that give 5% crop loss in wheat	Linseed	Wheat	Rape	Barley	Maize
Poa annua	50	18.3	23.6	16.8	28.4	7.5
Trifolium repens	?	3.5	0	25.3	1.9	0.8
Cerastium spp.	25	1.2	0.4	2.7	1.4	0.4
Prunella vulgaris	?	0.4	0	1.5	0.04	0.2
Ranunculus repens	?	1.6	0.6	4.7	0.8	1.4
Sonchus asper	50	0.5	0	0.5	0.2	0.03
Veronica serpylifolia	62.5*	0.5	0.1	0.6	0.4	0.2
Chenopodium album	25	0.01	0	0	0	0.01
Fallopia convolvulus	17	0.3	0	0.2	0.02	0
Polygonum aviculare	50	0.1	0	0.6	0.04	0
Polygonum persicaria	25	0.1	0	0.8	0.1	0.1
Stellaria media	25	0.2	0.2	2.1	3.1	0.6

Table 6.1 Management prescriptions for stubble within current ESAs (DEFRA 2002) and CSS (DEFRA 2001).

Scheme	Prescription
ESAs	
Breckland	Cereal or linseed stubble retained until 1 March. No pesticides between harvest and 1 March. Abide by Codes of Good Practice for water, soil and air pollution
Cotswold Hills	Cereal or linseed stubble retained until 1 March. Straw removed or chopped and spread evenly with combine-mounted chopper as part of harvesting. No use of herbicides expect under exceptional circumstances (e.g. serious infestations of grass weeds) No use or organic or inorganic fertilisers
South Downs	Arable stubble until 15 February. Abide by Codes of Good Practice for water, soil and air pollution
West Penwith	Plough cultivate and sow spring crop not before 15 March. No insecticides but herbicides and fungicides used in agreement with Project Officer. Harvest crop, remove straw and leave stubble until 15 March the following year. No pesticides or fertilisers between crop harvest and 15 March
Countryside Stewardship 2002	
Overwintered stubbles followed by a spring crop - OS1 £40/ha	Cereal stubble kept to 14 February; straw baled or chopped and spread; no stubble cultivation; no cover crop or grazing; no agro-chemicals, except in agreement with Stewardship Adviser
Overwintered stubbles followed by a low input spring cereal - OS2 £125/ha	Cereal stubble kept to 14 February; management as for OS1; followed by low-input spring cereal sown between 14 February and 20 April at no more than 100 kg/ha seed rate; can be undersown with grass or grass/legume mix; limited spectrum of herbicides before and after spring crop establishment; maximum of 50 kg/ha nitrogen fertiliser; not harvested before 31 July
Overwintered stubbles followed by a spring/summer fallow - OS3 £520/ha	Cereal stubble kept to March; management as for OS1; false seedbed by cultivating between 1 and 20 March to max. 100 mm depth; limited herbicide use before cultivation; fallow to 31 July; no fertiliser or lime; strictly limited weed control

Figure 1.1 Mean numbers of (a) crop and (b) weed seeds per soil sample from five crop stubbles, each grown with conventional herbicide programmes (+H) or reduced herbicides (-H) and sampled after harvest (T1) or three to four months later (T3).

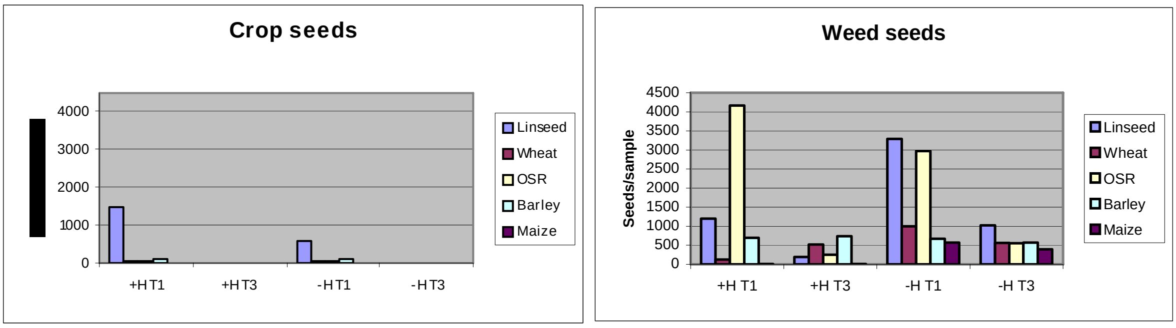


Figure 1.2 Ordination of soil seed samples from five crop stubble types taken at harvest and in mid-winter. Arrows represent the impact of explanatory factors in the CCA on ordination locations of samples (red circles in electronic version, grey circles hard copy). Plant species are represented by blue circles in electronic version or black circles in hard copy, and codes in italics (See Appendix 4).

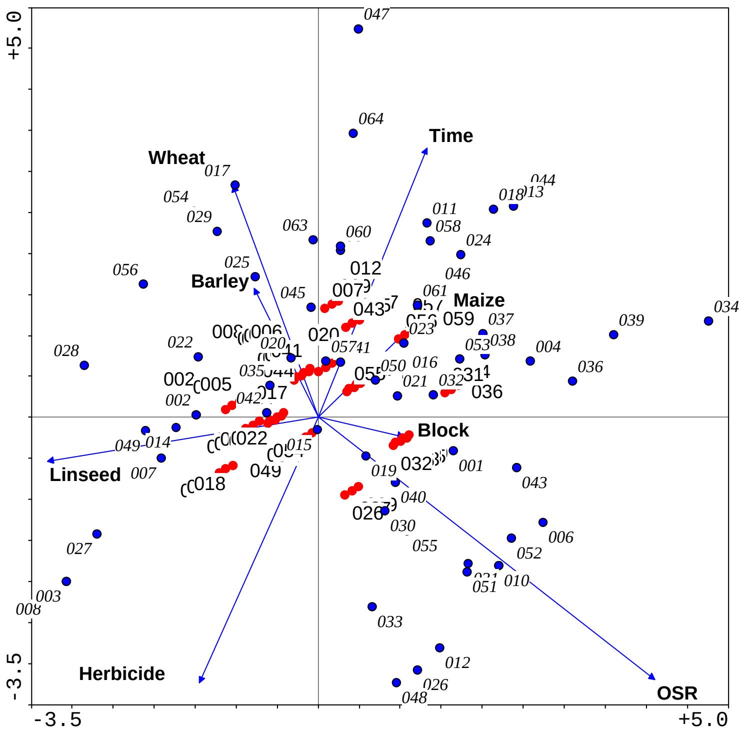


Figure 1.3 Crop stubble and weed heights on different crop stubble plots.

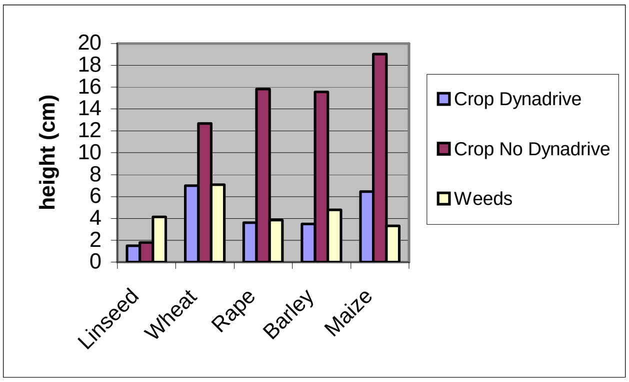


Figure 2.1 The distribution of 1-km^2 squares surveyed in three winters (each dot may represent more than a single 1-km^2 square).

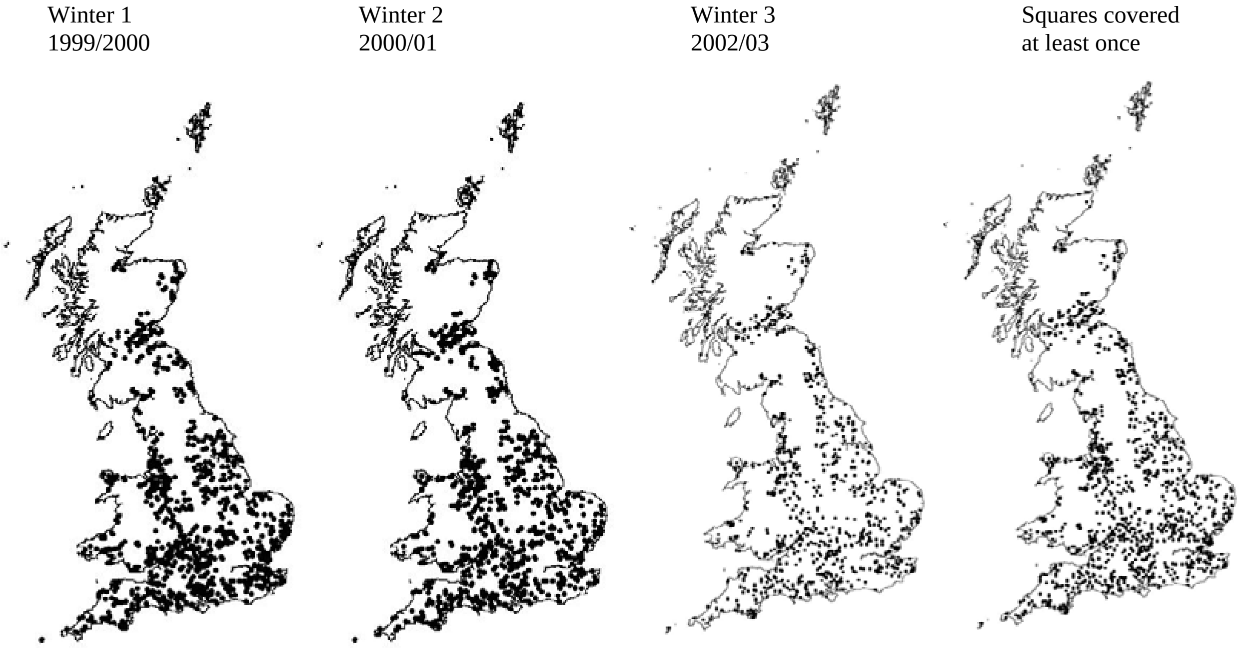
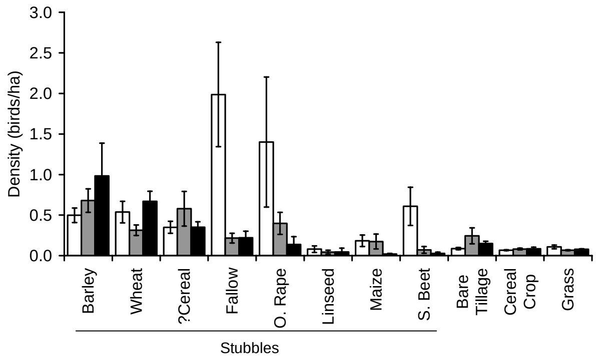
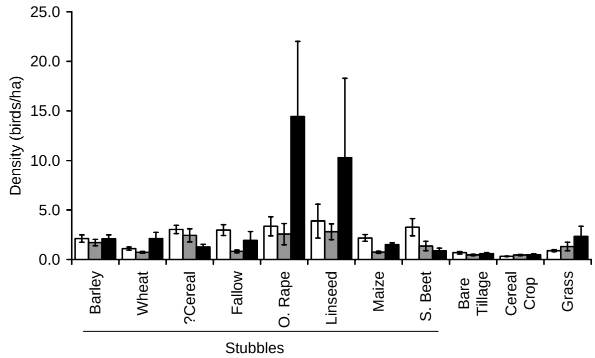


Figure 2.2 Bird densities (mean± SE) on fields across all visits in winter 1999/2000 (open bars), winter 2000/2001 (grey bars) and winter 2002/2003 (black bars) based on field edge counts. With the exception of Skylark, species were aggregated into functional groups. Data are field and boundary counts combined. (See Appendix 2.10 and 2.11).

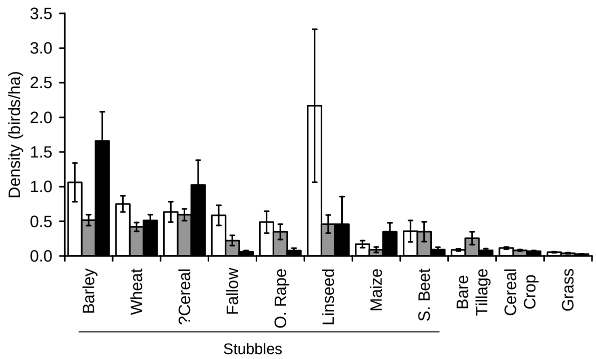
Buntings



Sparrows and Finches



Skylark



Thrushes and Starling

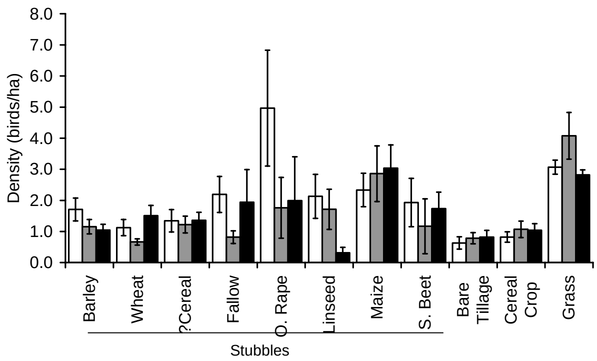


Figure 2.3 Approximate estimates of population size of granivorous birds in different habitat types, derived from the product of habitat specific density (birds/ha) and area estimate (ha). White = buntings; grey = sparrows & finches; black = Skylark.

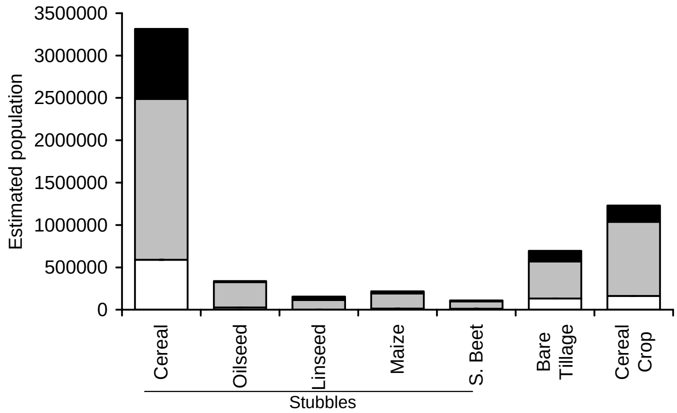


Figure 3.1 Seasonal changes in the area of stubble surveyed (hectares) in the target fields in winter 2000/01 between early July and late February.

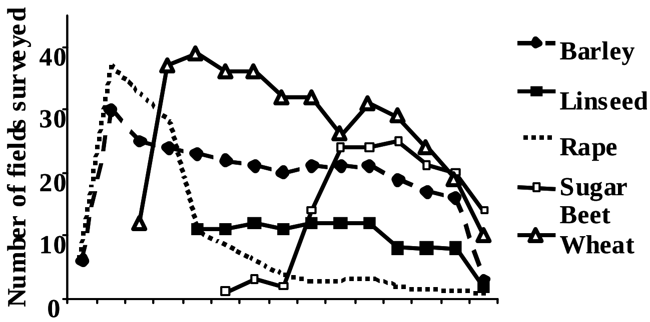


Figure 3.2 The mean densities (birds per ha $\pm$ s.e) of four bird species/groups, over two early winter periods (July-Sept) on stubble fields in East Anglia. B=barley, L=linseed, SU=sugar beet, W=wheat, OSR =oilseed rape. (blue = 1999/2000, purple = 2000/2001 electronic version; grey = 1999/2000, black = 2000/2001 hard copy).

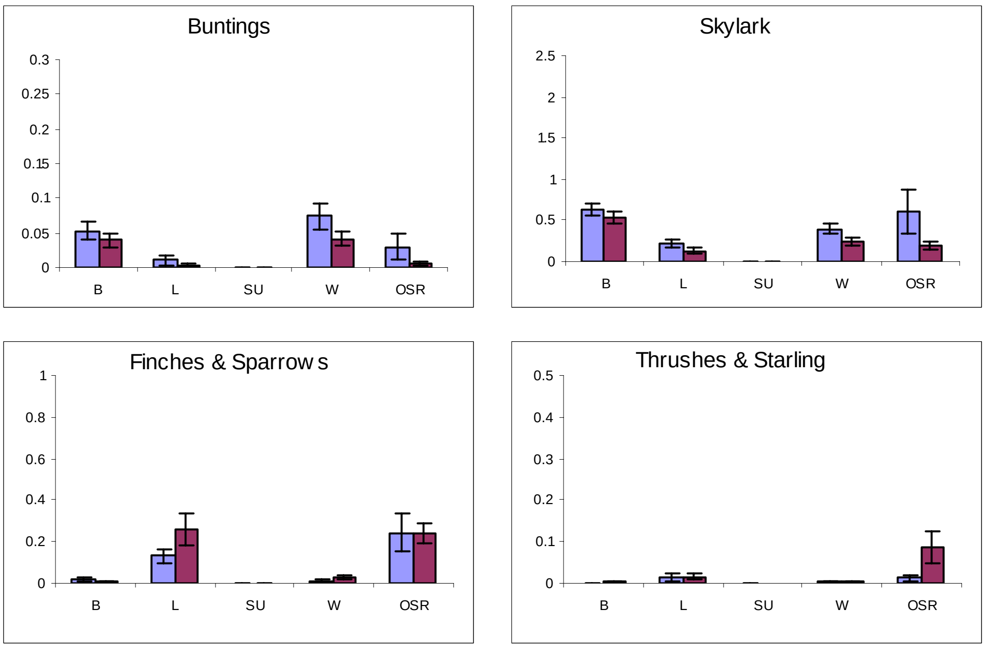


Figure 3.3 The mean densities (birds per ha ± s.e) of four bird species/groups, over two mid-late winter periods (October-March) on stubble fields in East Anglia. Crops codes as for Figure 3c.

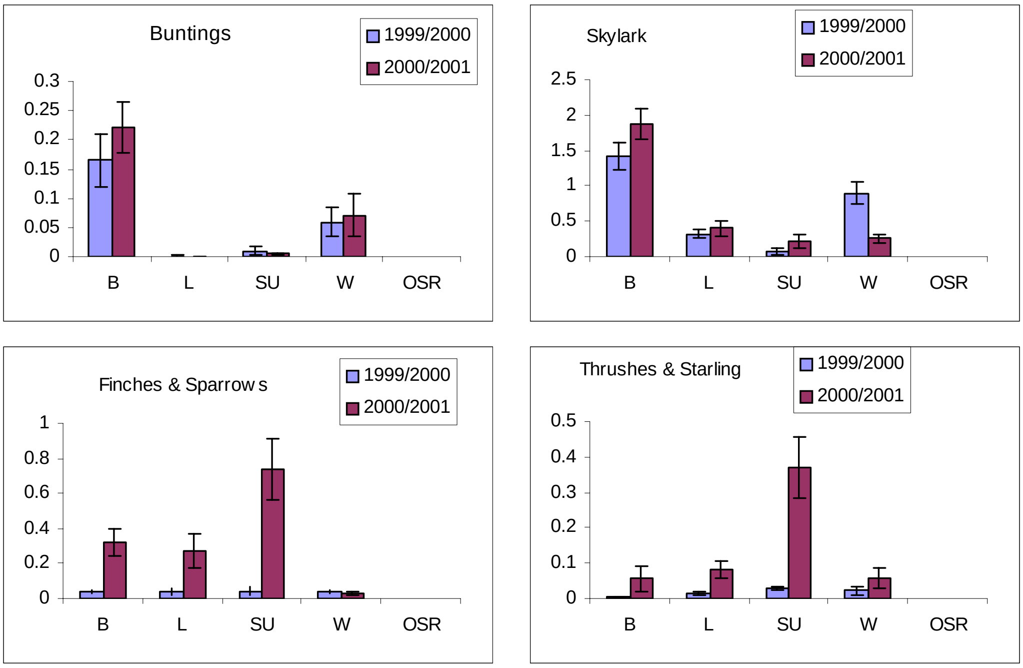


Figure 3.4 The frequency distribution of densities of (a) Skylark and (b) Linnet on fields under five different stubble types in East Anglia in two winters.

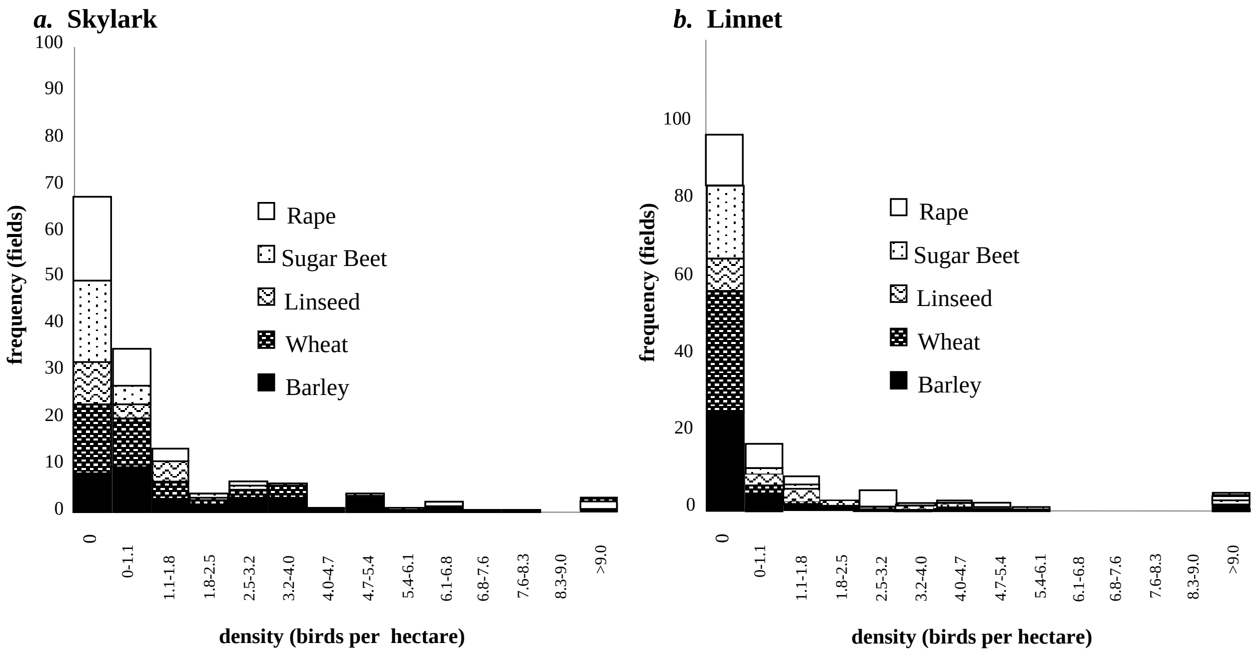


Figure 3.7 Observed and predicted relationship in bird use of stubble fields in East Anglia (expressed in terms of as energy demand). Results are from the Minimum Adequate Model multivariate model for late winter (October to February) 2000/2001 and includes three variables: density of Chenopodiaceae and Polygonaceae seeds and number of herbicides applied to the crop. Two outliers with high use by birds are a sugar beet and winter barley field.

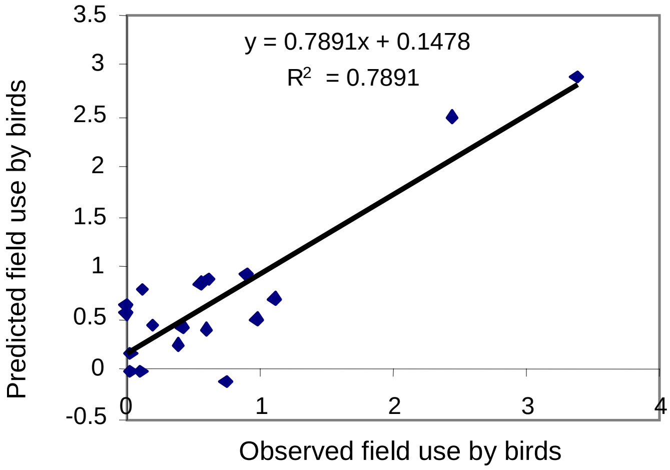


Figure 4.4 Mean cover values of weed families important in the diet of farmland birds (after Wilson 1999), *Poa* (meadow grass) and other arable weeds on each crop stubble type over the post harvest season in both survey seasons.

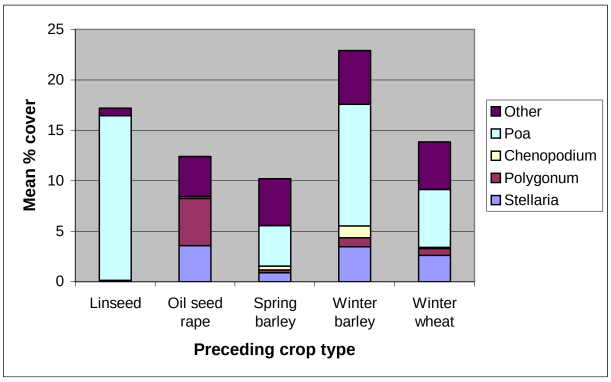


Figure 4.5 The contribution that each group of important diet weed families and other broad-leaved weeds made to broad-leaved weed seed rain on different stubble types at the second survey post harvest in 2001/02.

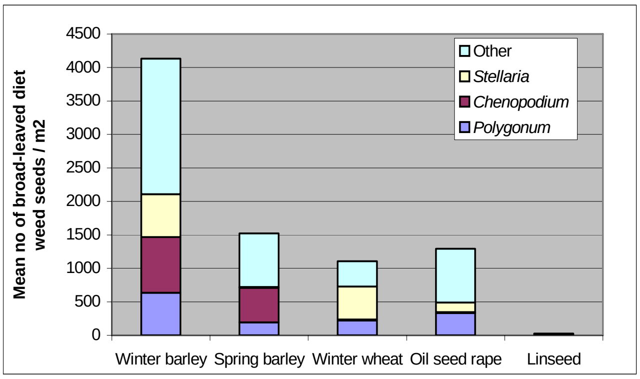


Figure 4.6 Surface crop and weed seed densities (No. per sample) in different crop stubbles (data back-transformed means) immediately after harvest in winters 1 and 2.

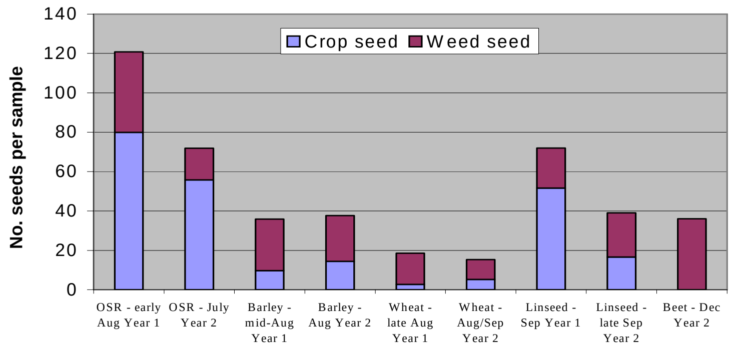


Figure 4.7 Vegetation height on each stubble type for each post harvest period, ± 1 s.e.

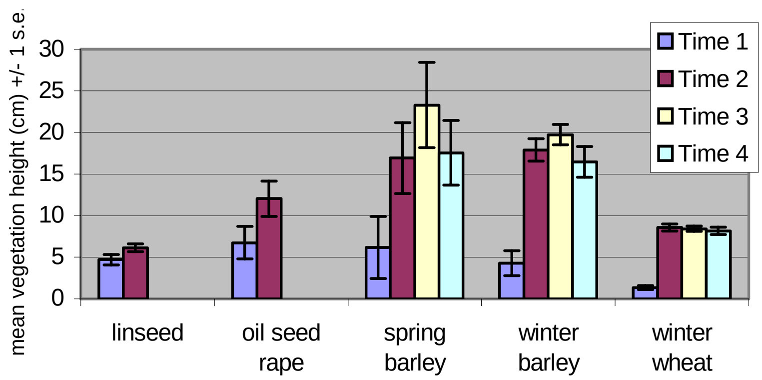


Figure 4.8 Diet weed species cover on each stubble type for each post harvest period: L = linseed; OSR = oilseed rape; SU = sugar beet; SB = spring barley; WB = winter barley; WW = winter wheat.

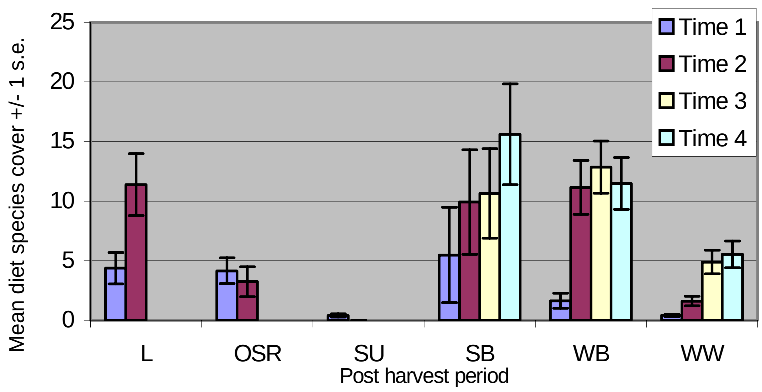


Figure 4.9 The negative relationship between mean number of active arable weed species growing on stubble fields, averaged across all four post harvest periods, and number of herbicides used on each field pre harvest.

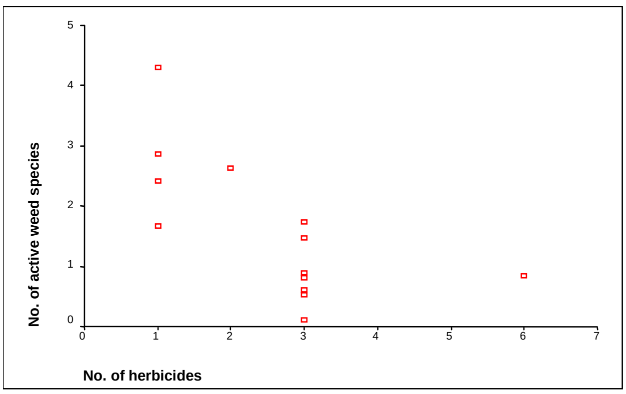


Figure 4.10 Spilt crop and weed seeds on the soil surface at five time periods (T1-T5) after harvest. Data are back-transformed means. Time is relative to harvest thus, for example T1 =July for rape and December for beet.

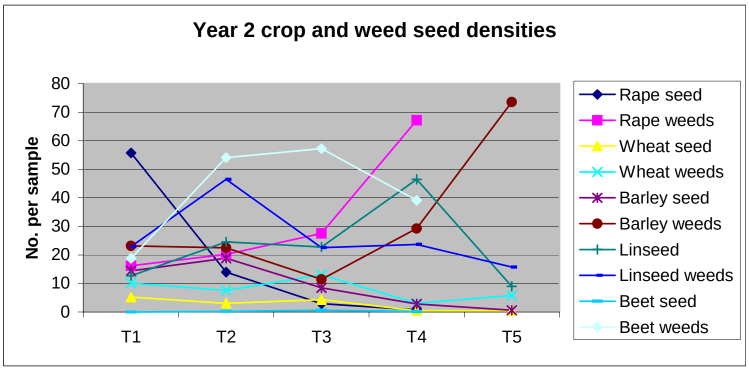
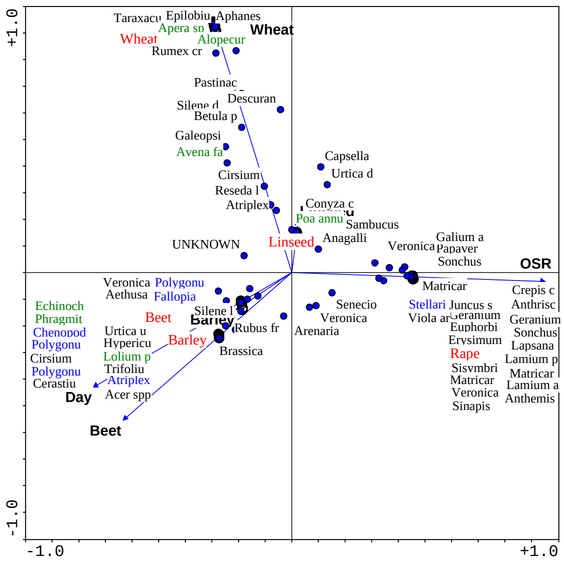


Figure 4.11 Ordination of Year 2 seed data showing the effects of different crops. The association of species with different stubbles is also illustrated. Crop seeds are in red, grass weed species in green and bird diet species in blue.



APPENDIX 1.1. TREATMENT DETAILS FOR CROP STUBBLES FIELD EXPERIMENT.

Crops:

	Sowing date	Harvest date
Winter linseed	15/10/1999	01/08/2000
Winter wheat	15/09/1999	11/08/2000
Spring oilseed rape	19/03/2000	24/08/2000
Spring barley	19/03/2000	24/08/2000
Maize	13/05/2000	18/10/2000

Herbicide programmes:
The three spring-sown crop plots had a pre-cultivation application of glyphosate.

Crop and cultivar	Conventional herbicide programme	Reduced herbicide programme
Winter linseed Cv. Oliver	amidosulfuron 13/3/00; metsulfuron-methyl 9/5/00; diquat 20/7/00;	amidosulfuron 13/3/00;
Winter wheat Cv. Claire	diflufenican + isoproturon 27/10/99; amidosulfuron 13/3/00;	tri-allate 27/10/99; isoproturon 3/11; amidosulfuron 13/3/00;
Spring oilseed rape Cv. Liaison	metazachlor 9/5/00; propaquizafop 29/5/00; glyphosate 5/8/00;	propaquizafop 29/5/00;
Spring barley Cv. Chariot	fluroxypyr 29/5/00;	
Maize Cv. Hudson	atrazine 15/5/00;	

Stubble cultivation:
Sub-sub plots were either left over winter undisturbed or were cultivated with a Dynadrive two weeks after harvest.

	Date of Dynadrive
Winter linseed	11/08/2000
Winter wheat	15/08/2000
Spring oilseed rape	19/09/2000
Spring barley	30/08/2000
Maize	20/10/2000

APPENDIX 1.2. ASSESSMENT DATES FOR CROP STUBBLES FIELD EXPERIMENT.

Weed vegetation assessments:
Large quadrats (0.25m^2); 10 per sub-sub plot; Assessments 1 and 2 before harvest.

	1	2	3	4
Winter linseed	Mid-April 00	Late-June 00	Early-Oct 00	Mid-March 01
Winter wheat	Mid-April 00	Mid-June 00	Early-Oct 00	Mid-March 01
Spring oilseed rape	Late-May 00	Mid-July 00	Late-Oct 00	Late-March
Spring barley	Mid-May 00	Early-July 00	Mid-Oct 00	Early-April 01
Maize	Mid-June 00	Early-August 00	Late-Nov 00	Mid-April 01

Field 43 very wet/waterlogged through most of November, then again from mid-January to mid-February, then very wet again from last week in February to mid-March.

Surface seed samples and vegetation cover after harvest

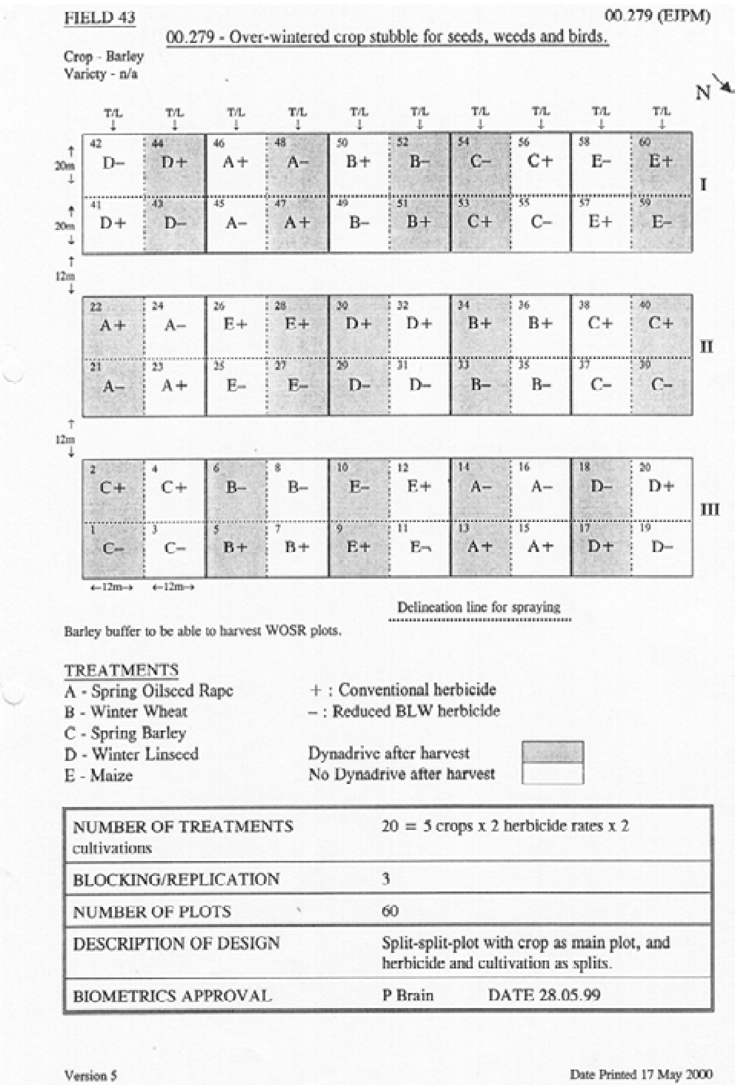
30cm by 30cm quadrats; seven quadrats sampled per sub-sub plot; three processed for seeds and all used for vegetation cover.

Target dates:

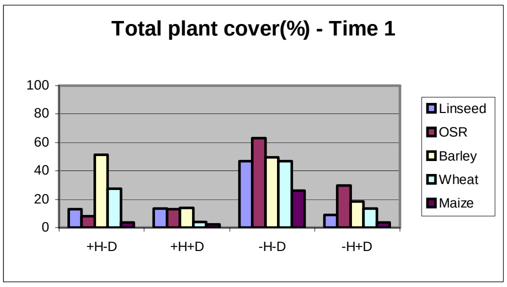
Crop	No Dynadrive or Dynadrive	Weeks after harvest 0	3	12	26
Linseed	ND	2.8.00	29.8.00	27.11.00	20.3.01
	D (11.8.00)	22.8.00	12.9.00	15.12.00	31.3.00
Wheat	ND	14.8.00	4.9.00	7.12.00	24.3.01
	D (15.8.00)	30.8.00	21.9.00	8.1.01	30.3.01
Rape	ND	24.8.00	13.9.00	18.12.00	26.3.01
	D (19.9.00)	2.10.00	23.10.00	10.1.01	10.4.01
Barley	ND	25.8.00	14.9.00	20.12.00	27.3.01
	D (30.8.00)	6.9.00	1.10.00	9.1.00	13.4.01
Maize	ND	19.10.00	28.11.00	12.2.01	20.4.01
	D (20.10.00)	27.10.00	1.12.00	19.2.01	26.4.01

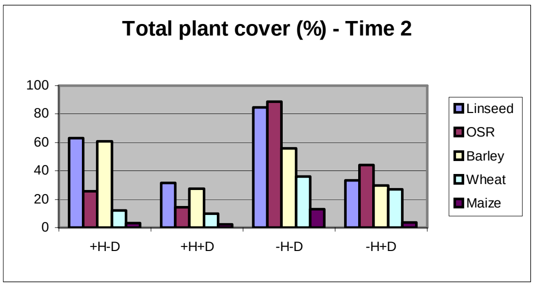
Field 43 very wet/waterlogged through most of November, then again from mid-January to mid-February, then very wet again from last week in February to mid-March.

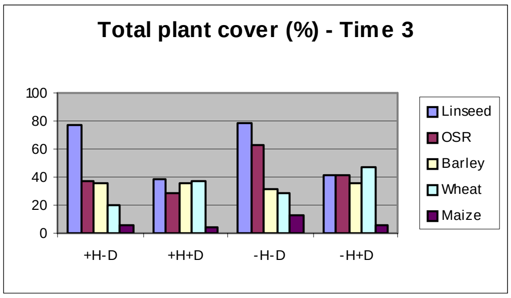
APPENDIX 1.3. **PLOT LAYOUT IN FIELD 43, LONG ASHTON RESEARCH STATION**

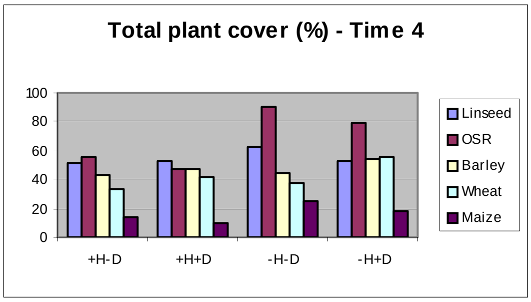


APPENDIX 1.4. AVERAGE TOTAL PLANT COVER (%) INCLUDING CROP VOLUNTEERS IN FIVE CROP STUBBLES ASSESSED IN SMALL QUADRATS ON FOUR SAMPLING OCCASIONS FROM AUTUMN TO SPRING. (+H = CONVENTIONAL HERBICIDE; -H = REDUCED HERBICIDE; +D = DYNADRIVE STUBBLE CULTIVATION)









Crop seeds	**Conventional herbicide programme**		**Reduced herbicide programme**	
	T1	T3	T1	T3
Linseed	6.77^{i}	1.55^{c}	5.01^{h}	2.45^{d}
Wheat	3.48^{e}	-0.21^{a}	3.92^{ef}	-0.27^{a}
Oilseed rape	3.88^{ef}	-0.39^{a}	4.12^{efg}	0.57^{b}
Barley	4.77^{gh}	1.62^{c}	4.49^{fgh}	1.26^{bc}
Maize	-0.69^{a}	-0.69^{a}	-0.69^{a}	-0.69^{a}
			s.e.d. = 0.416	df=148
Weed seeds				
Linseed	6.80^{efg}	4.90^{c}	8.03^{h}	6.52^{ef}
Wheat	3.22^{b}	4.94^{cd}	6.00^{cd}	5.67^{cde}
Oilseed rape	8.22^{h}	4.90^{c}	7.44^{fgh}	6.09^{e}
Barley	5.79^{cde}	6.15^{e}	6.40^{ef}	6.06^{de}
Maize	1.74^{a}	1.74^{a}	6.06^{de}	5.78^{cde}
			s.e.d. = 0.572	df=148

Crop and weed seed numbers (log.e + 0.5) in different crop stubbles at two times (T1 = 0 and T3 = 12 weeks after harvest). Crops had been grown with conventional or reduced herbicide programmes. Means of either crop or weed seeds, considered separately, with the same superscript letter are statistically the same.

Plant species recorded as seeds in Vortis seed samples from Field 43.

Code number	Species	Code number	Species
001	*Aethusa cynapium*	033	*Papaver rhoeas*
002	*Alopecurus myosuroides*	034	*Plantago major*
003	*Alopecurus pratensis*	035	*Poa annua*
004	*Anagallis arvensis*	036	*Polygonum aviculare*
005	*Aphanes arvensis*	037	*Polygonum lapathifol.*
006	*Atriplex patula*	038	*Polygonum persicaria*
007	*Avena fatua*	039	*Prunella vulgaris*
008	*Betula pendula*	040	*Ranunculus repens*
009	*Brassica napus*	041	*Raphanus raphanistrum*
010	*Capsella bursa-pastoris*	042	*Rubus fruticosus*
011	*Cerastium fontanum*	043	*Rumex crispus*
012	*Matricaria discoidea*	044	*Rumex obtusifolius*
013	*Chenopodium album*	045	*Senecio vulgaris*
014	*Cirsium arvense*	046	*Sherardia arvensis*
015	*Elymus repens*	047	*Silene latifolia*
016	*Fallopia convolvulus*	048	*Sinapis arvensis*
017	*Festuca rubra*	049	*Sisymbrium officinale*
018	*Fumaria officinalis*	050	*Solanum nigrum*
019	*Galium aparine*	051	*Sonchus asper*
020	*Geranium dissectum*	052	*Sonchus oleraceus*
021	*Gnaphalium uliginosum*	053	*Stellaria media*
022	*Hordeum vulgare*	054	*Torilis spp.*
023	*Juncus spp.*	055	*Trifolium repens*
024	*Lamium purpureum*	056	*Triticum aestivum*
025	*Lapsana communis*	057	Unknown
026	*Lepidium spp.*	058	*Urtica dioica*
027	*Linum usatissimum*	059	*Urtica urens*
028	*Lolium multiflorum*	060	*Veronica agrestis*
029	*Lolium perenne*	061	*Veronica arvensis*
030	*Matricaria perforata*	062	*Veronica hederifolia*
031	*Matricaria recutita*	063	*Veronica persica*
032	*Myosotis arvensis*	064	*Viola arvensis*

Appendix 2.1. Patch habitat coding scheme: three-level habitat classification used for the Winter Farmland Bird Survey. Each habitat code consisted of one code each from Level 1 and Level 2 and any number of codes from Level 3.

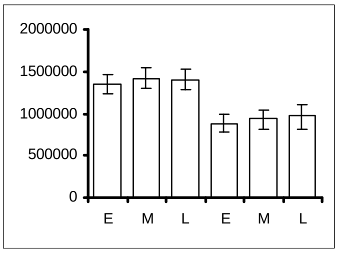
Habitat Code Level				
1	**2**		**3**	
GRASSLAND				
M	01	Improved	01	Ungrazed
	02	Unimproved	02	Recently grazed, animals absent
	03	Recently sown	03	Currently cattle grazing
	04	Unknown	04	Currently sheep grazing
			05	Currently horses grazing
			06	Currently other/mixed livestock grazing
			07	Flooded
			08	Grass less than 5cm tall
			09	Grass between 5cm and 10cm tall
			10	Grass more than 10cm tall
			11	Supplementary animal food present
CROPS				
N	01	Wheat	01	Crop less than 5cm tall
	02	Barley	02	Crop between 5cm and 10cm tall
	03	Unknown/other cereal	03	Crop more than 10cm tall
	04	Linseed/flax	04	Straw covering field
	05	Beans	05	Polythene covering field
	06	Oil seed rape	06	Maize/millet game cover
	07	Unknown/other brassicas	07	Kale game cover/animal feed
	08	Maize/sweetcorn	08	Other game cover
	09	Sugar beet	09	Flooded
	10	Fodder roots	10	Recently grazed, animals absent
	11	Potatoes	11	Currently grazed
	12	Carrots	12	Supplementary animal food present
	13	Other vegetables/flowers		
	14	Unknown/other root crops		
	15	Unknown/other crops		
	16	Game cover strip		
STUBBLES				
P	01	Wheat stubble	01	Clean stubble
	02	Barley stubble	02	Weedy stubble
	03	Unknown/other cereal stubble	03	Recently grazed, animals absent
	04	Linseed/flax stubble	04	Undersown
	05	Bean/pea stubble	05	Currently grazed
	06	Oil seed rape stubble	06	Chopped straw present
	07	Maize/sweetcorn stubble	07	Flooded
	08	Sugar beet stubble	08	Manure heaps in field
	09	Potato stubble	09	Manure spread on field
	10	Fodder crop stubble	10	Supplementary animal food present
	11	Unknown/other stubble		
OTHER AGRICULTURAL HABITATS				
Q	01	Pig field	01	Ploughed
	02	Bare soil	02	Harrowed
	03	Fallow	03	Flooded
	04	Farmyard	04	Manure heaps on field or in farmyard
	07	Orchard	05	Manure spread on field
	08	Poultry	06	Supplementary animal food present
			07	Livestock in yard
			08	Recently grazed, animals absent
			09	Currently grazed
MISCELLANEOUS				
J	01	Anything not listed above, describe on a spare sheet of paper		

Appendix 2.2. The number and percentage of 1-km squares surveyed in winter 1 and winter 2 within each WFBS region and each landscape stratum. Strata is the number of squares initially selected in each stratum. Weighting is a weight value for each stratum for each year to correct stratum specific totals so that they may be combined for national indices without causing regional bias.

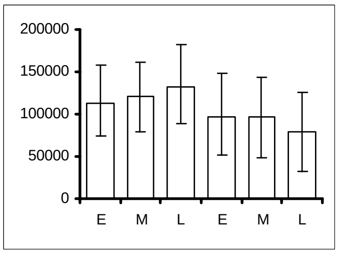
	E. England		**N. England**		**W. England**		**Scotland**		**Wales**	
	A	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**
a. Number of squares:										
W1	297	32	47	105	59	144	63	41	20	63
W2	234	27	51	100	53	131	74	34	21	54
W3	236	23	51	94	73	28	48	120	22	50
Strat	925	126	158	353	202	492	274	185	105	195
b. Percentage of total:										
W1	34%	4%	5%	12%	7%	17%	7%	5%	2%	7%
W2	30%	3%	7%	13%	7%	17%	9%	4%	3%	7%
W3	32%	3%	7%	13%	10%	4%	6%	16%	3%	7%
Strat	31%	4%	5%	12%	7%	16%	9%	6%	3%	6%
c. Weightings:										
W1	0.968	1.216	1.041	1.023	1.058	1.043	1.198	0.975	0.254	0.875
W2	1.229	1.441	0.960	1.074	1.178	1.146	1.020	1.176	0.242	1.021
W3	1.04	1.45	0.82	0.98	0.88	1.22	1.11	1.07	0.20	0.94

Appendix 2.3. Estimates of the area (ha, mean and 95% confidence limits) of Cereal Crop on lowland farmland in three regions and two ITE landscape types calculated from Winter Farmland Bird Survey data from two winters 1999/2000 and 2000/2001. E, M, L indicate Early, Middle and Late winter visits in each winter respectively. Note that for some stubbles their incidence on WFBS squares was so rare that estimates are highly variable.

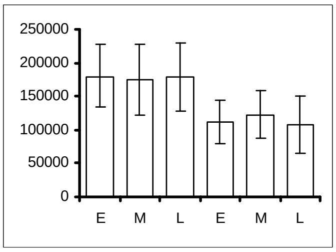
East England – Arable



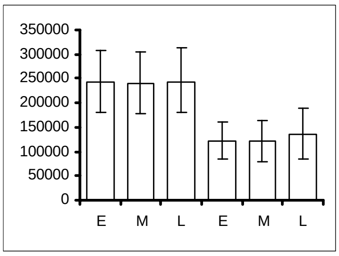
East England – Pastoral



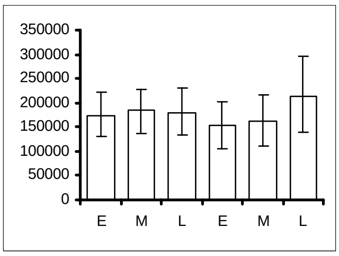
North England - Arable



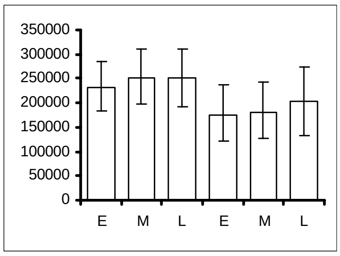
North England – Pastoral



West England – Arable

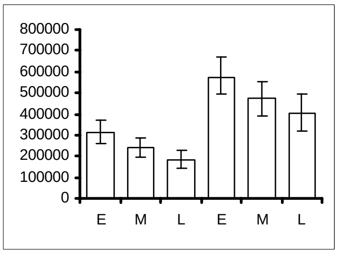


West England – Pastoral

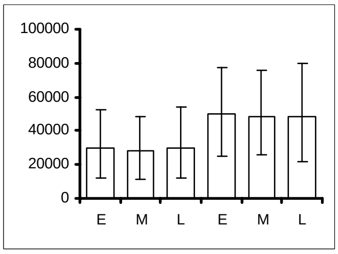


Appendix 2.4. Estimates of the area (ha, mean and 95% confidence limits) of Cereal Stubble on lowland farmland in three regions and two ITE landscape types calculated from Winter Farmland Bird Survey data from two winters 1999/2000 and 2000/2001. E, M, L indicate Early, Middle and Late winter visits in each winter respectively.

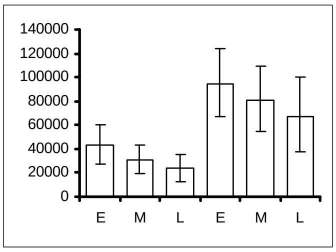
East England – Arable



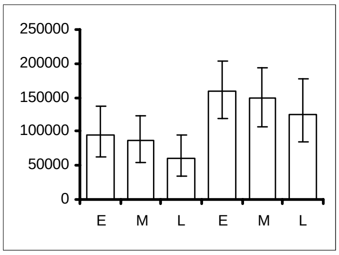
East England – Pastoral



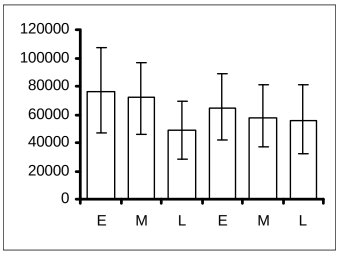
North England - Arable



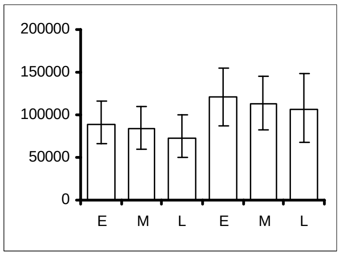
North England – Pastoral



West England – Arable

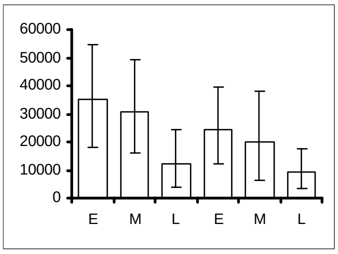


West England – Pastoral

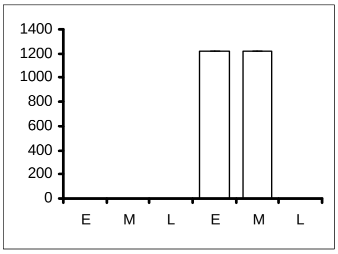


Appendix 2.5. Estimates of the area (ha, mean and 95% confidence limits) of Sugar Beet Stubble on lowland farmland in three regions and two ITE landscape types calculated from Winter Farmland Bird Survey data from two winters 1999/2000 and 2000/2001. E, M, L indicate Early, Middle and Late winter visits in each winter respectively. * In some regions/periods data were too sparse to compute confidence limits by randomisation.

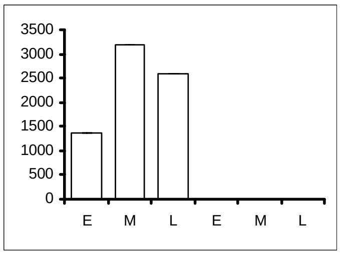
East England – Arable



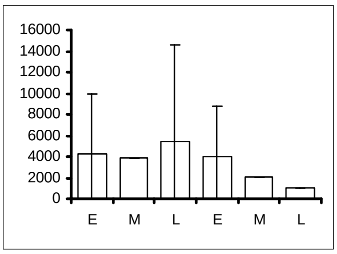
East England – Pastoral*



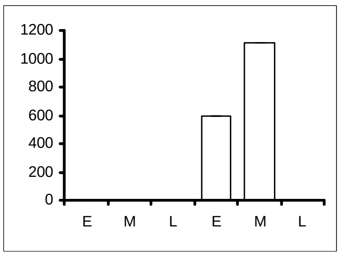
North England - Arable*



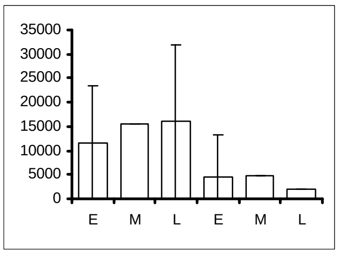
North England – Pastoral*



West England – Arable*

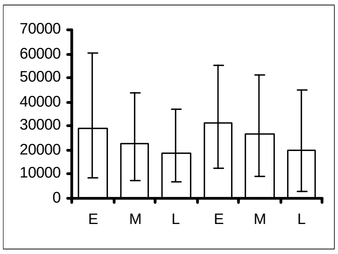


West England – Pastoral*

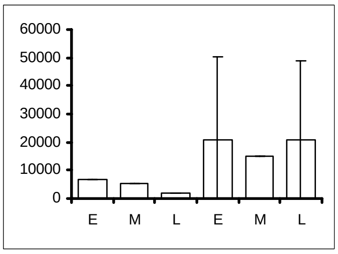


Appendix 2.6. Estimates of the area (ha, mean and 95% confidence limits) of Maize Stubble on lowland farmland in three regions and two ITE landscape types calculated from Winter Farmland Bird Survey data from two winters 1999/2000 and 2000/2001. E, M, L indicate Early, Middle and Late winter visits in each winter respectively. * In some regions/periods data were too sparse to compute confidence limits by randomisation.

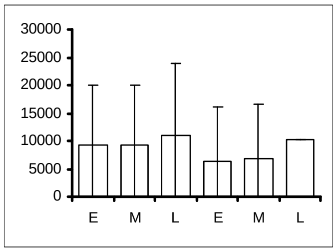
East England – Arable



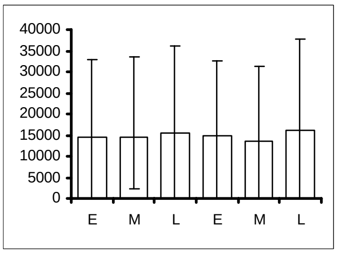
East England – Pastoral*



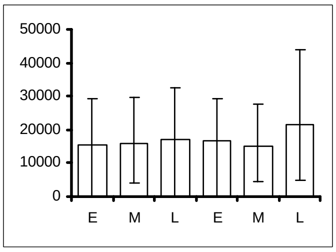
North England - Arable*



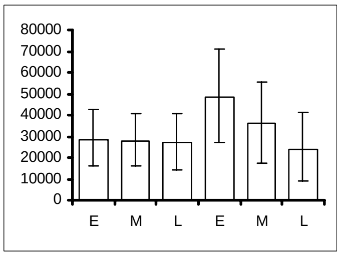
North England – Pastoral



West England – Arable

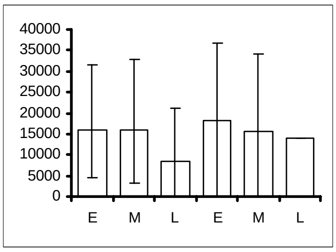


West England – Pastoral

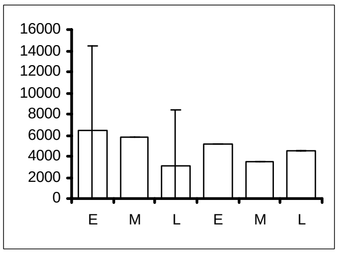


Appendix 2.7. Estimates of the area (ha, mean and 95% confidence limits) of Linseed Stubble on lowland farmland in three regions and two ITE landscape types calculated from Winter Farmland Bird Survey data from two winters 1999/2000 and 2000/2001. E, M, L indicate Early, Middle and Late winter visits in each winter respectively. * In some regions/periods data were too sparse to compute confidence limits by randomisation.

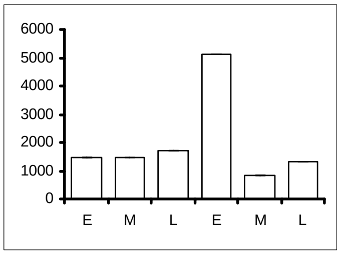
East England – Arable*



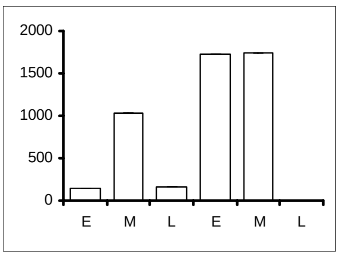
East England – Pastoral*



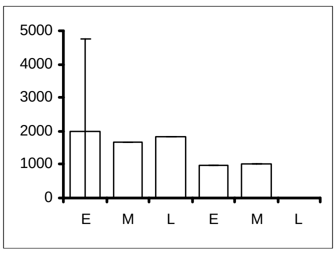
North England - Arable*



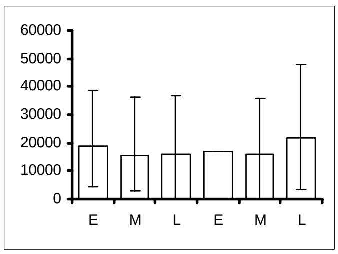
North England – Pastoral*



West England – Arable*

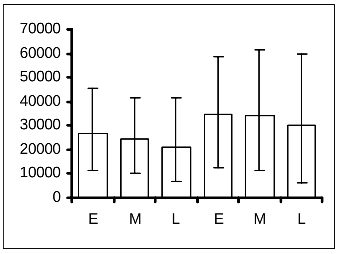


West England – Pastoral*

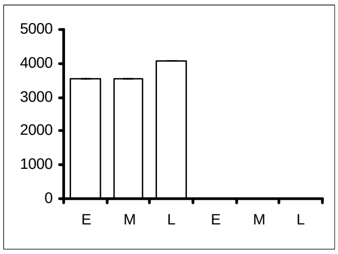


Appendix 2.8. Estimates of the area (ha, mean and 95% confidence limits) of Oilseed Rape Stubble on lowland farmland in three regions and two ITE landscape types calculated from Winter Farmland Bird Survey data from two winters 1999/2000 and 2000/2001. E, M, L indicate Early, Middle and Late winter visits in each winter respectively. * In some regions/periods data were too sparse to compute confidence limits by randomisation.

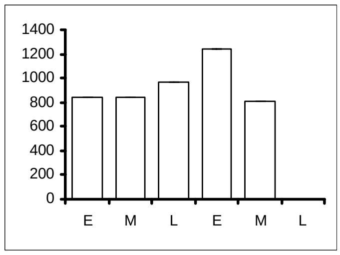
East England – Arable



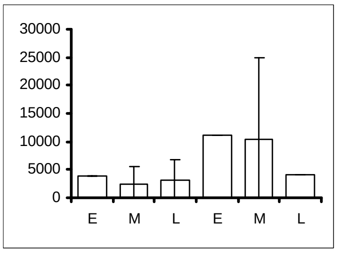
East England – Pastoral*



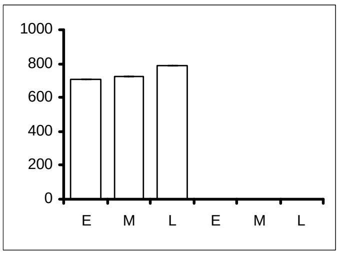
North England - Arable*



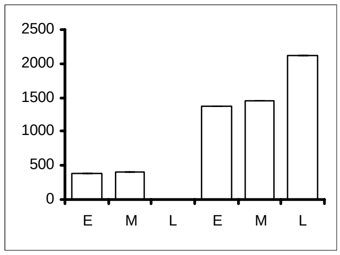
North England – Pastoral*



West England – Arable*



West England – Pastoral*

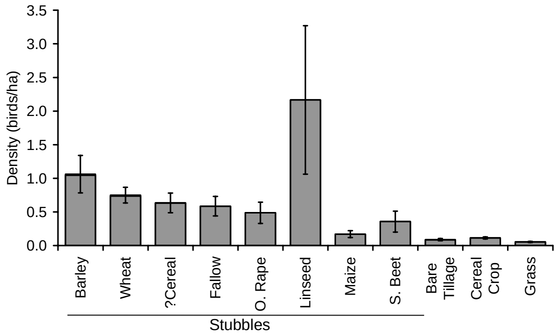


Appendix 2.9. The number of patches surveyed falling in to different categories. Total = number of patches visited. "All stubble" is the breakdown of the total into stubble types (with % of total in parentheses). "Chopped straw present" is the number of stubble patches of each type with chopped straw (with % of stubble type in parentheses).

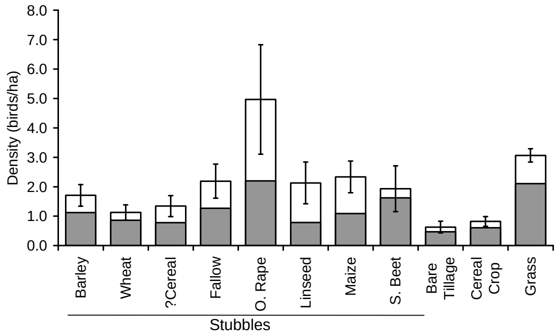
	Winter 1			Winter 2			Winter 3		
	Visit 1	**Visit 2**	**Visit 3**	**Visit 1**	**Visit 2**	**Visit 3**	**Visit 1**	**Visit 2**	**Visit 3**
TOTAL	13263	13353	12093	11344	11090	7564	10314	10200	9623
All stubble									
Cereal	901 (6.8)	793 (5.9)	566 (4.7)	1228 (10.8)	1004 (9.1)	582 (7.7)	904 (8.8)	759 (7.4)	585 (6.1)
Linseed	56 (0.4)	52 (0.4)	38 (0.3)	42 (0.4)	23 (0.2)	16 (0.2)	5 (0.0)	4 (0.0)	0 (0.0)
Bean/Pea	17 (0.1)	16 (0.1)	11 (0.1)	16 (0.1)	12 (0.1)	9 (0.1)	12 (0.1)	12 (0.1)	10 (0.1)
Oilseed	42 (0.3)	36 (0.3)	31 (0.3)	39 (0.3)	33 (0.3)	20 (0.3)	33 (0.3)	32 (0.3)	26 (0.3)
Chopped straw present									
Cereal	70 (7.8)	57 (7.2)	43 (7.6)	150 (12.2)	122 (12.2)	69 (11.9)	73 (8.1)	61 (8)	44 (7.5)
Linseed	18 (32.1)	18 (34.6)	16 (42.1)	10 (23.8)	0 (0.0)	0 (0.0)	2 (40)	2 (50)	0 (0.0)
Bean/Pea	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Oilseed	6 (14.3)	5 (13.9)	5 (16.1)	2 (5.1)	2 (6.1)	1 (5.0)	1 (3.0)	1 (3.1)	1 (3.8)

Appendix 2.10. Mean densities (± SE) of farmland birds across all visits in winter 1999/2000 based on field edge counts. Solid part of bar indicates density attributable to birds within the field, the open part of the bar being birds in boundary habitats (hedges etc). With the exception of Skylark, species were aggregated into functional groups

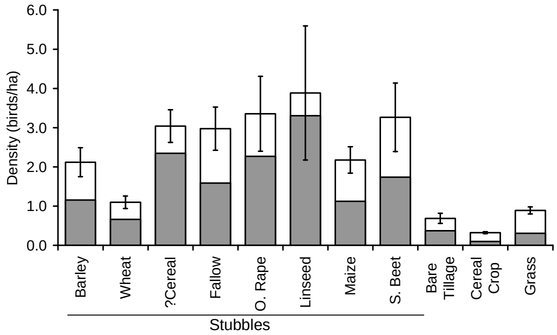
Skylark



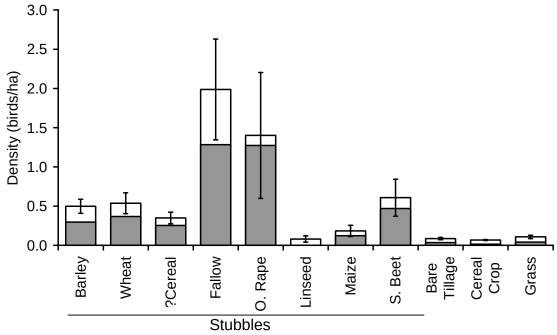
Thrushes and Starling



Sparrows and Finches

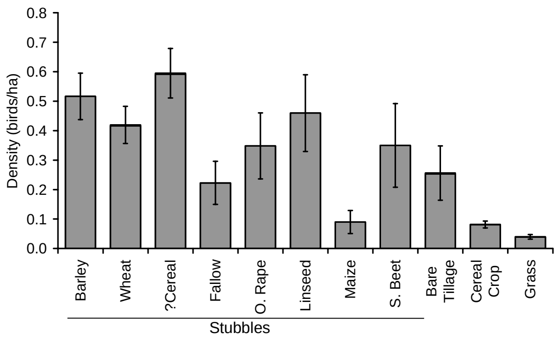


Buntings

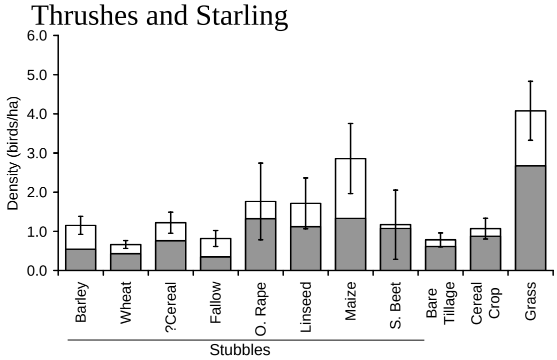


Appendix 2.11. Mean densities (± SE) of farmland birds across all visits in winter 2000/2001 based on field edge counts. Solid part of bar indicates density attributable to birds within the field, the open part of the bar being birds in boundary habitats (hedges etc). With the exception of Skylark, species were aggregated into functional groups

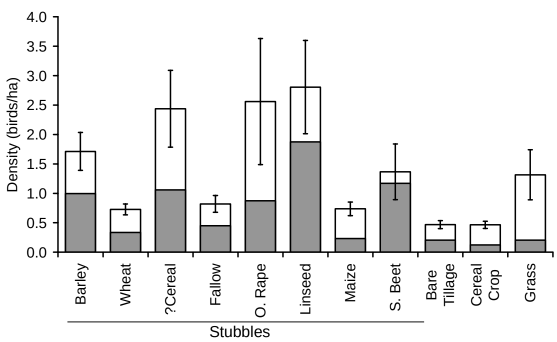
Skylark



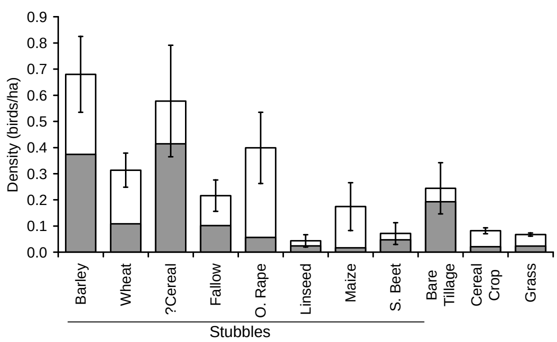
Thrushes and Starling



Sparrows and Finches

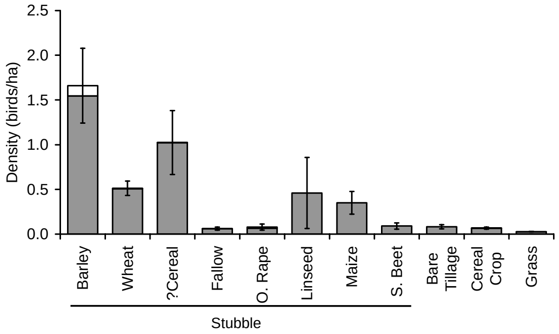


Buntings

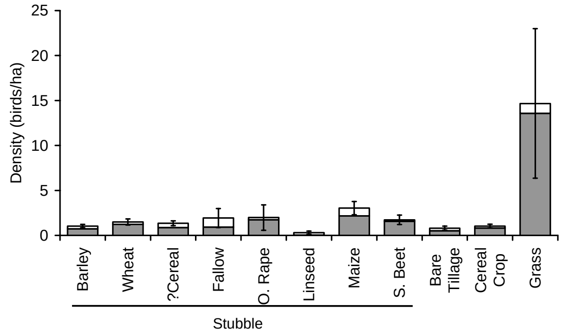


Appendix 2.12. Mean densities (± SE) of farmland birds across all visits in winter 2002/2003 based on field edge counts. Solid part of bar indicates density attributable to birds within the field, the open part of the bar being birds in boundary habitats (hedges etc). With the exception of Skylark, species were aggregated into functional groups.

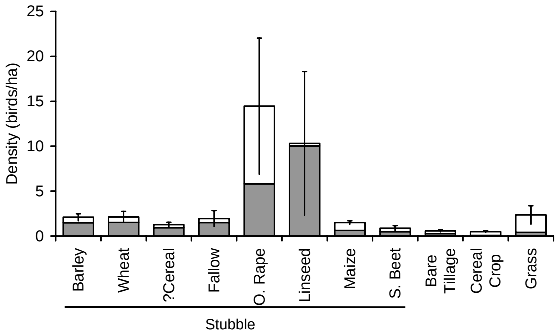
Skylark



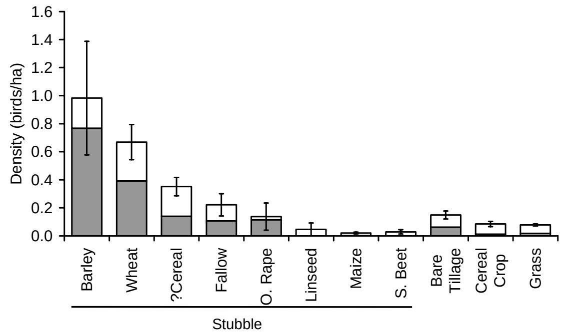
Thrushes and Starling



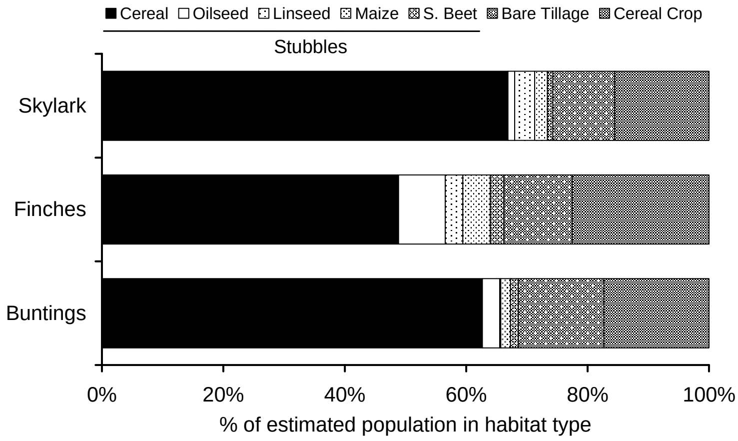
Sparrows and Finches



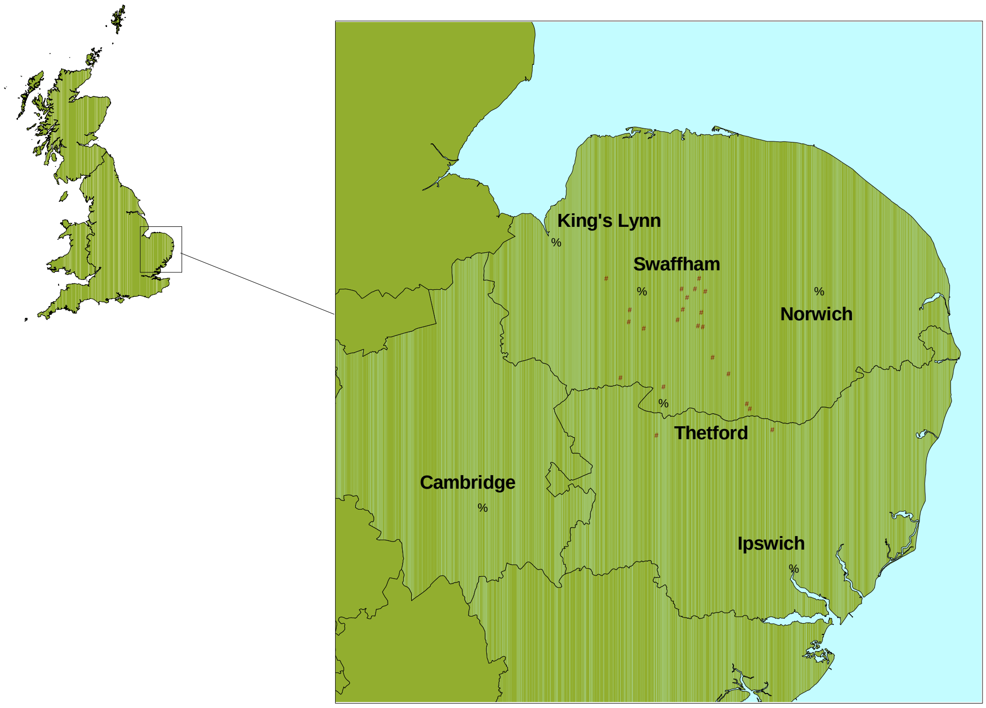
Buntings



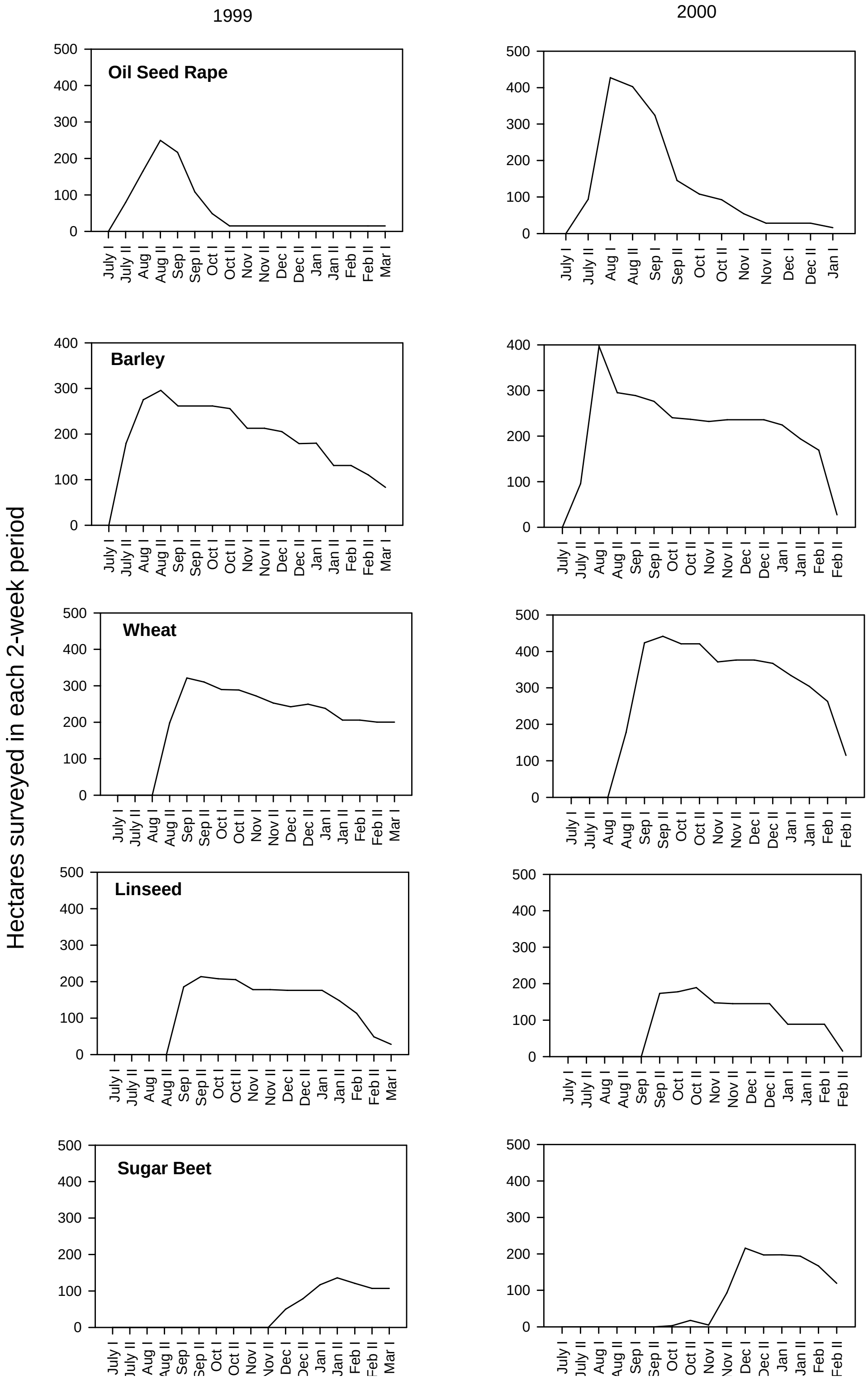
Appendix 2.13. Percentage breakdown by habitat type of the estimated population size of bird functional groups.



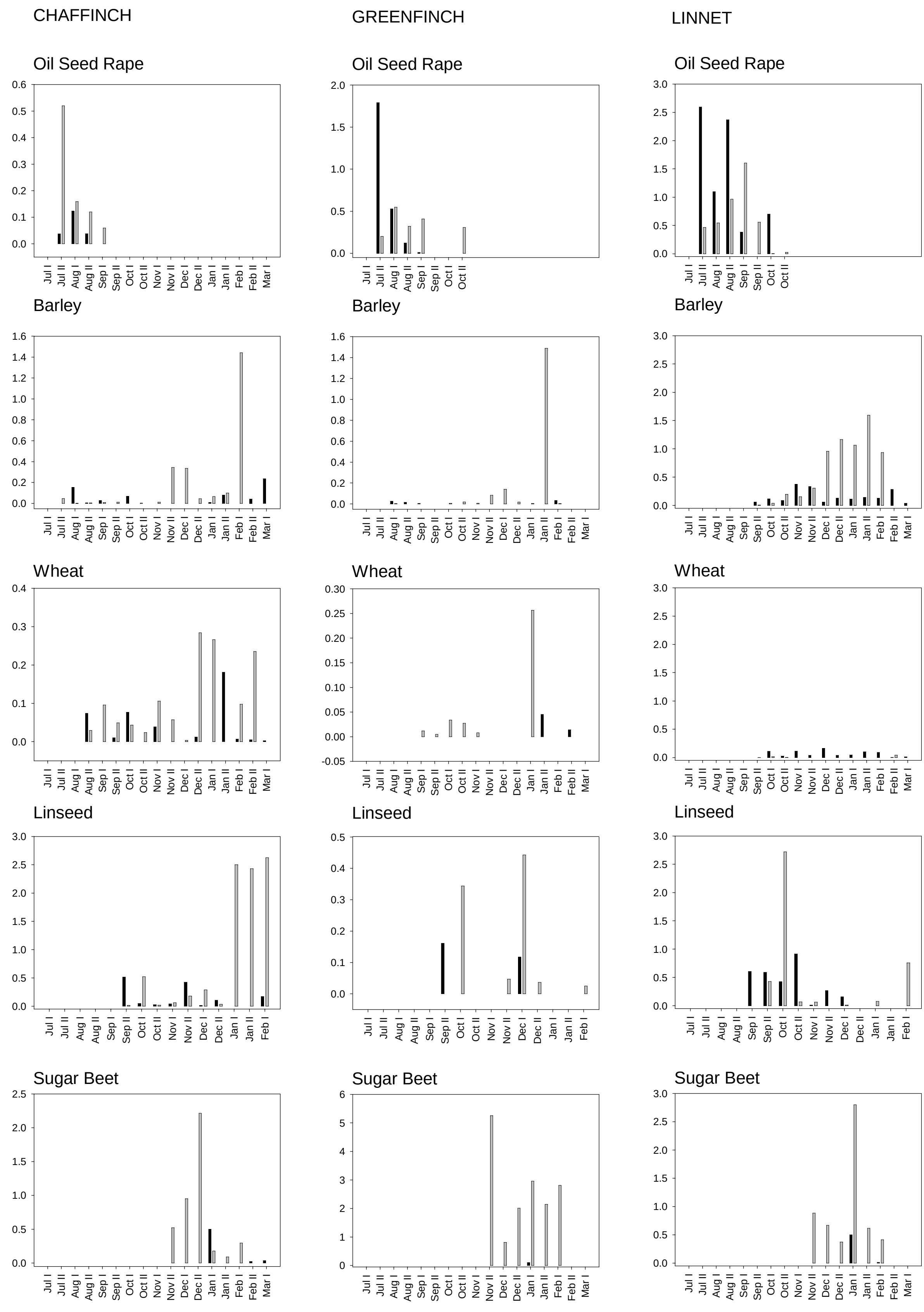
Appendix 3.1. Map of study site.



Appendix 3.2. Seasonal changes in the area of stubble surveyed (hectares) across the two winters in East Anglia by each two week period.

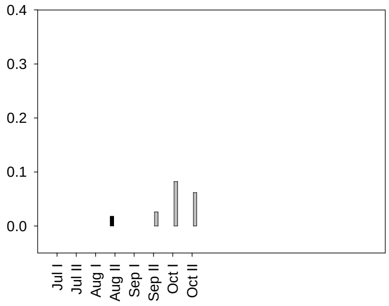


Appendix 3.3. Bird densities (birds per hectare) on different crop types in the two winters Black. Black = winter 1, Grey = winter 2.

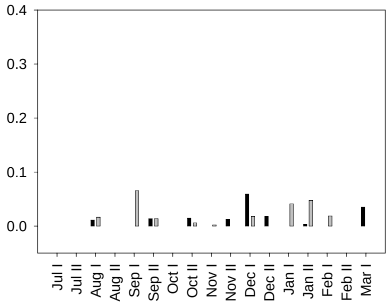


MISTLE THRUSH

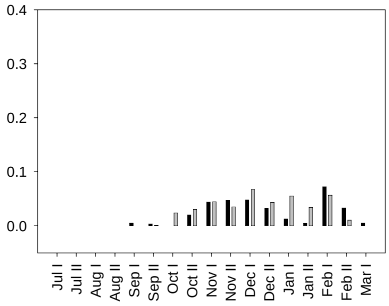
Oil Seed Rape



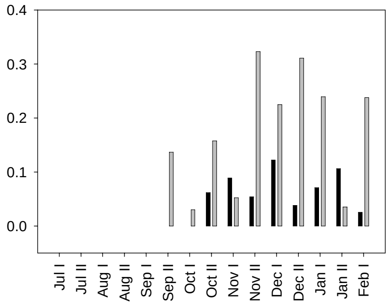
Barley



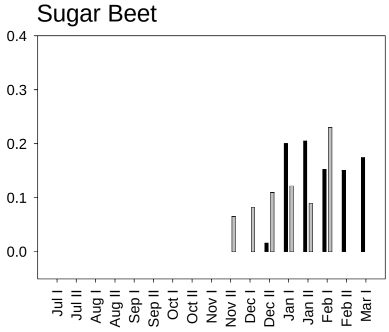
Wheat



Linseed

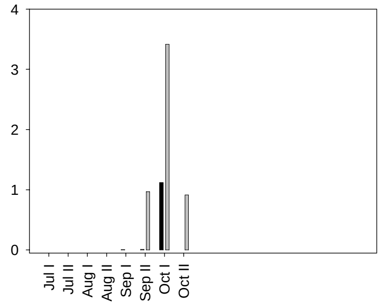


Sugar Beet



MEADOW PIPIT

Oil Seed Rape



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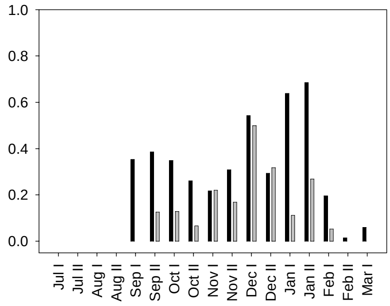
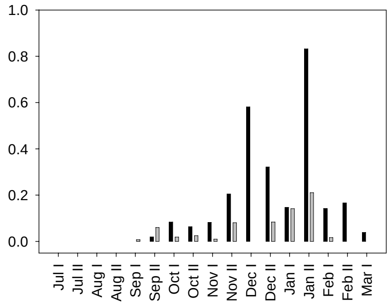


Wheat



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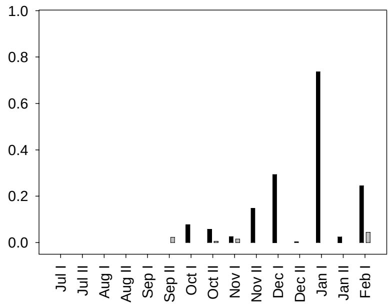
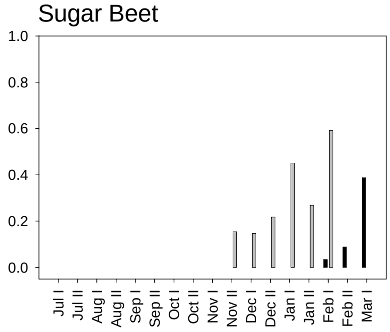
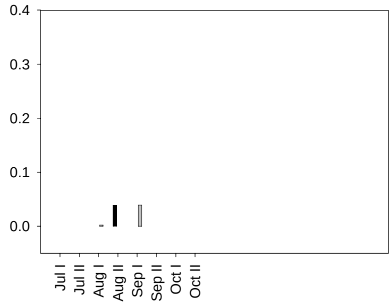


Sugar Beet

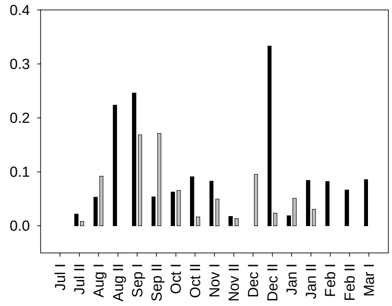


GREY PARTRIDGE

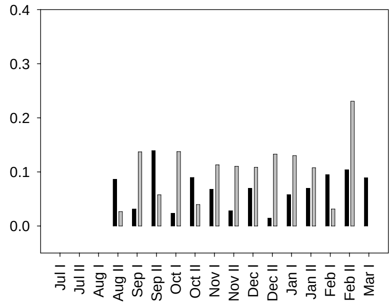
Oil Seed Rape



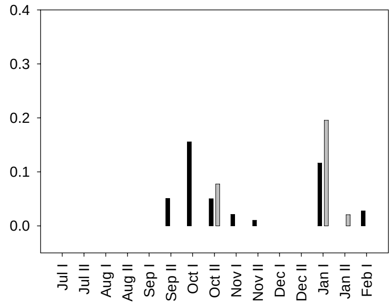
Barley



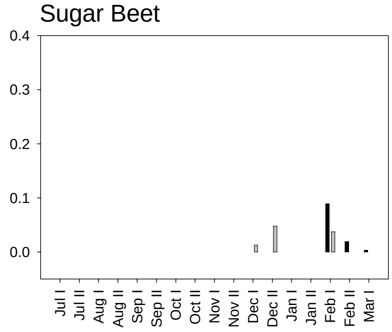
Wheat



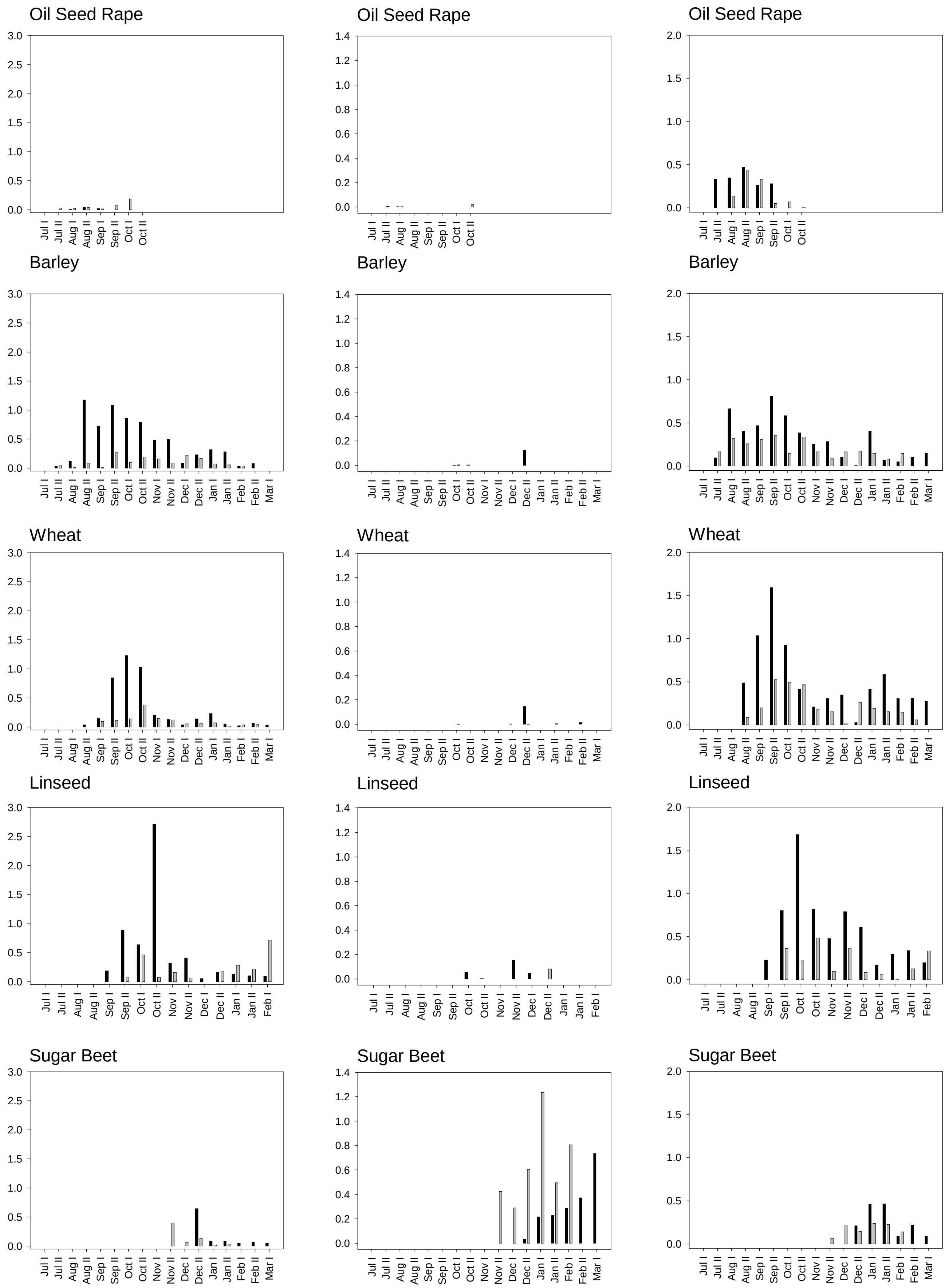
Linseed

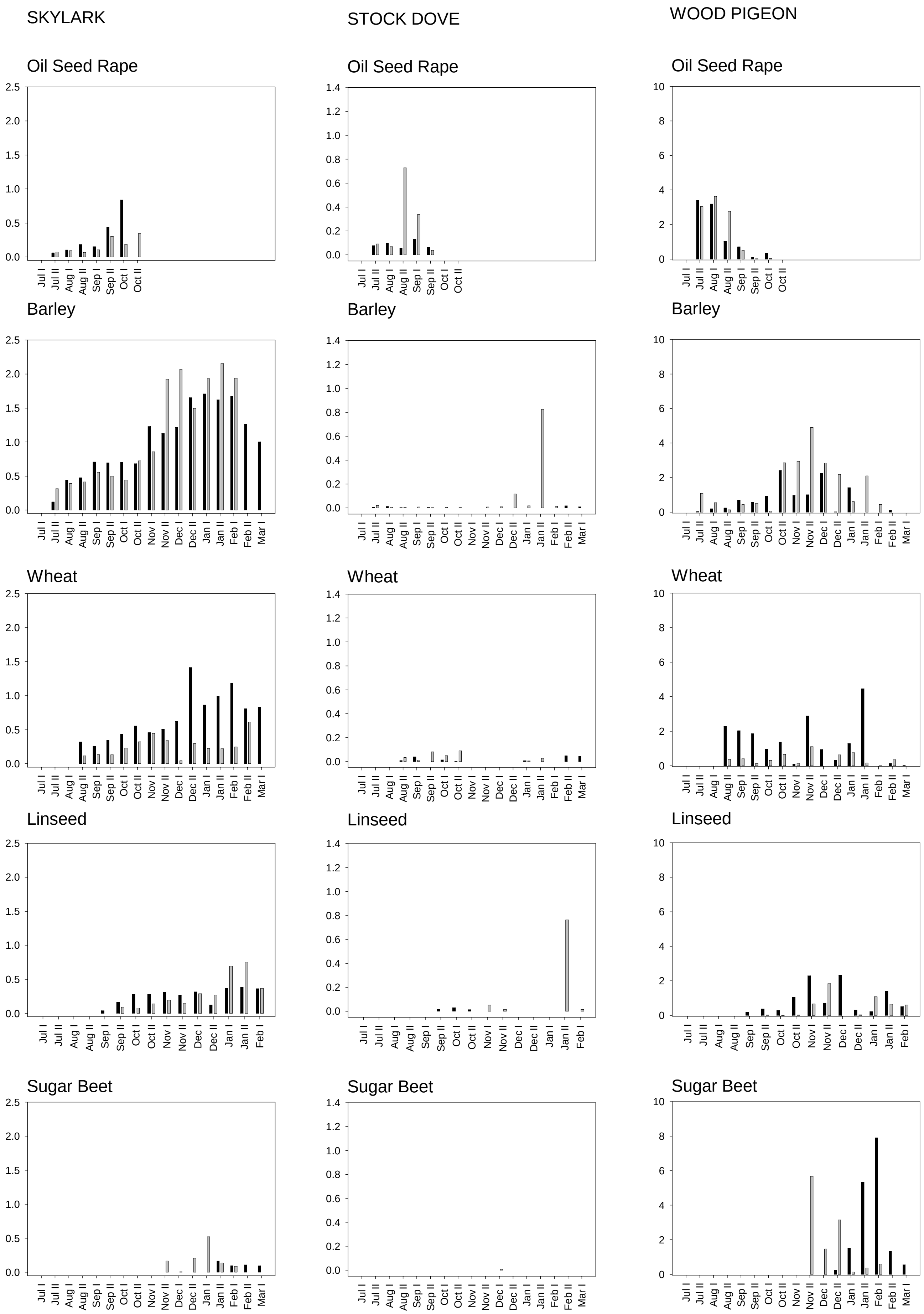


Sugar Beet



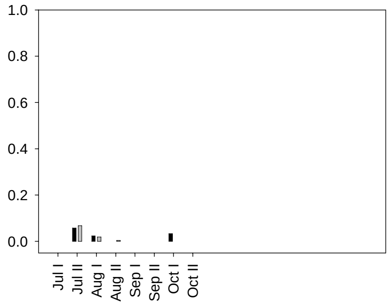
PHEASANT PIED WAGTAIL Red-legged Partridge




SKYLARK
STOCK DOVE
WOOD PIGEON
Oil Seed Rape
Oil Seed Rape
Oil Seed Rape
Barley
Barley
Barley
Wheat
Wheat
Wheat
Linseed
Linseed
Linseed
Sugar Beet
Sugar Beet
Sugar Beet

SKYLARK

Oil Seed Rape



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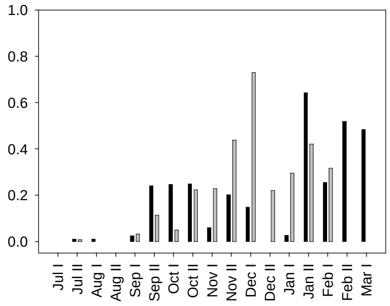

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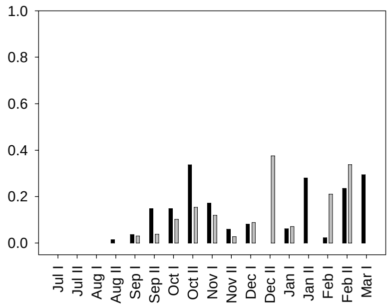
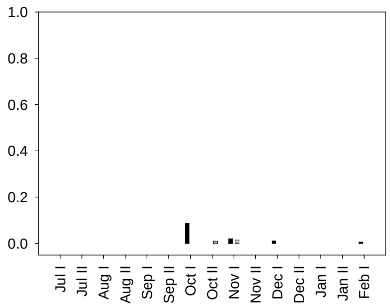
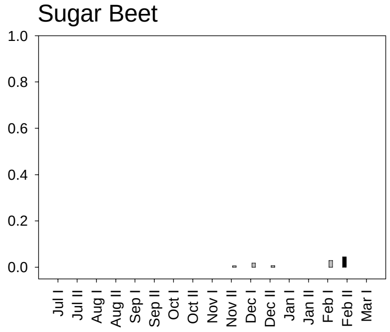


Linseed

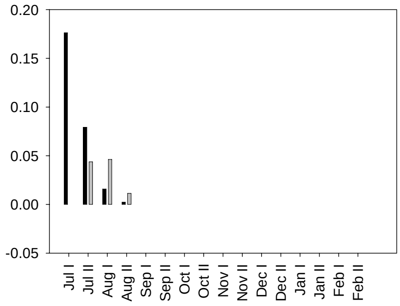


Sugar Beet



TURTLE DOVE

Oil Seed Rape



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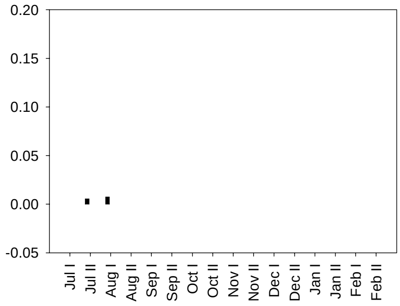
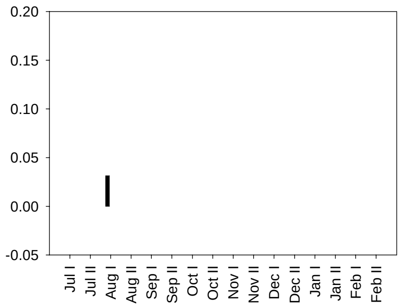
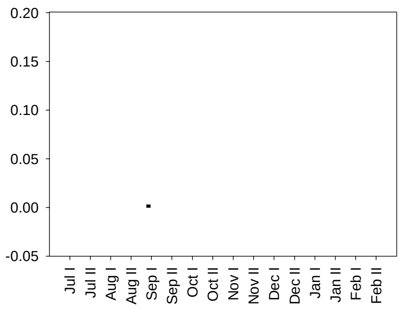


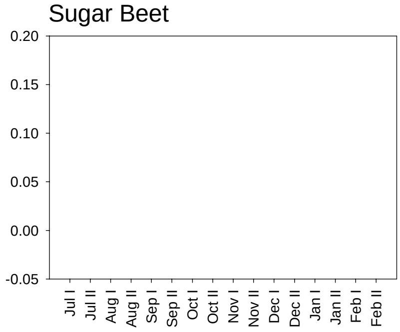
Wheat



Linseed

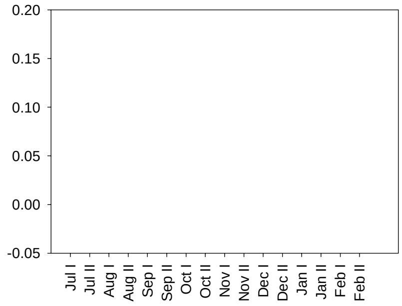


Sugar Beet



WOOD LARK

Oil Seed Rape



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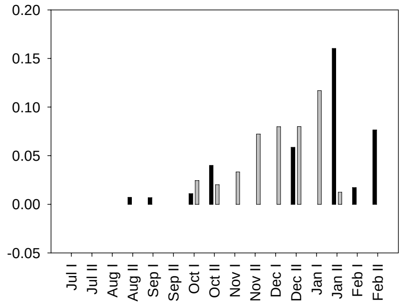
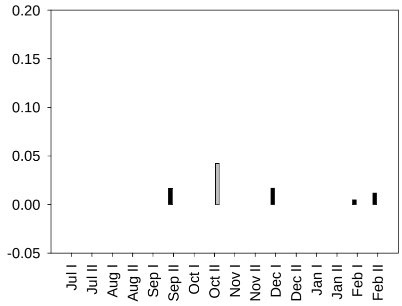
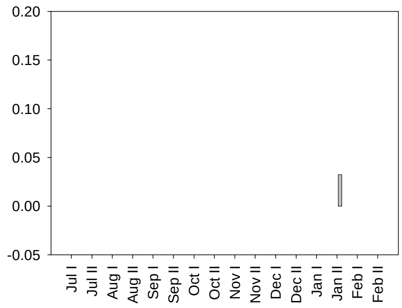


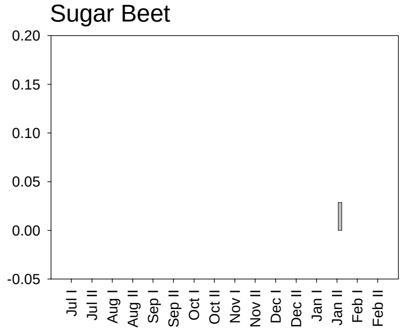
Wheat



Linseed

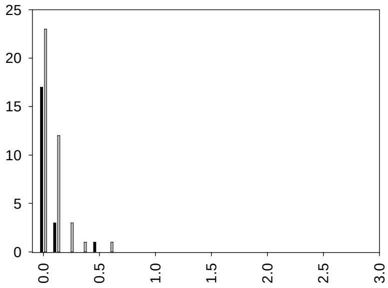


Sugar Beet

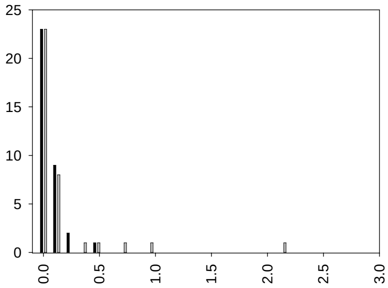


CHAFFINCH

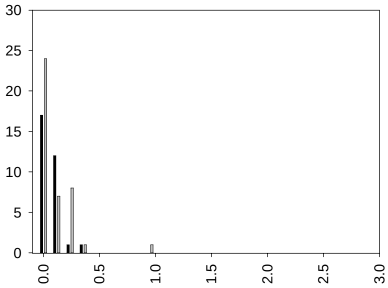
Oil Seed Rape



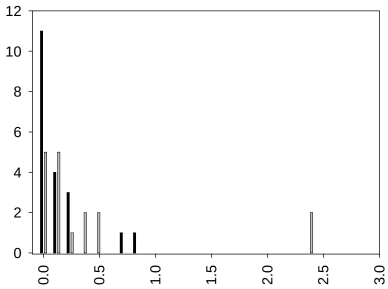
Barley



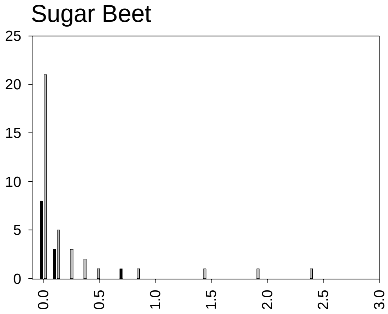
Wheat



Linseed

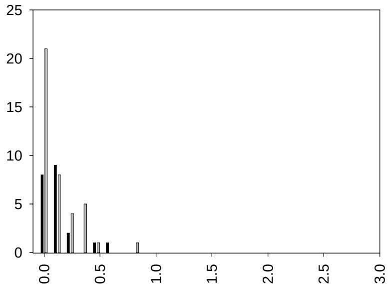


Sugar Beet

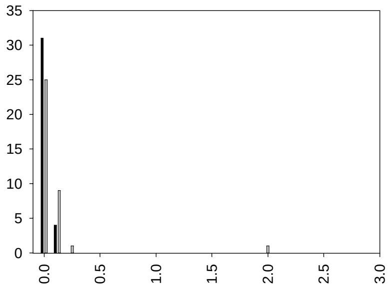


GREENFINCH

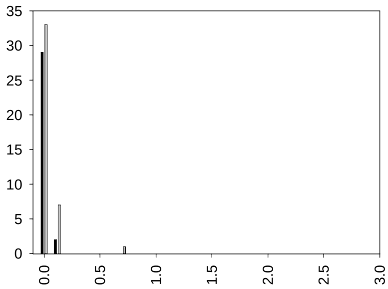
Oil Seed Rape



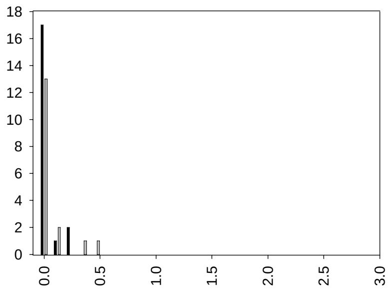
Barley



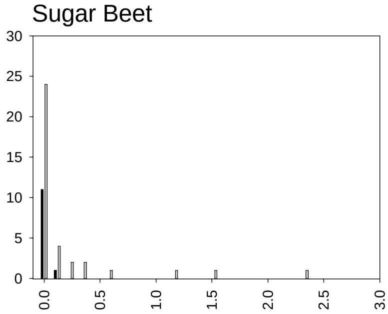
Wheat



Linseed

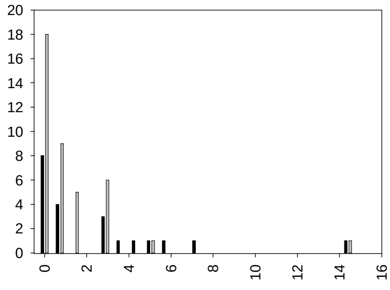


Sugar Beet

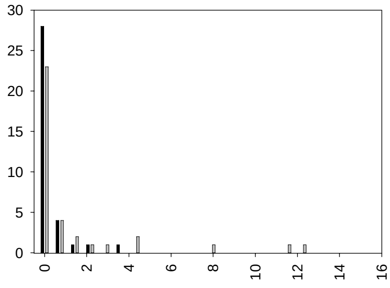


LINNET

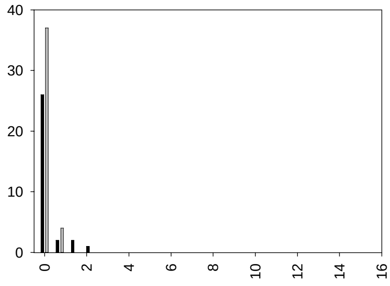
Oil Seed Rape



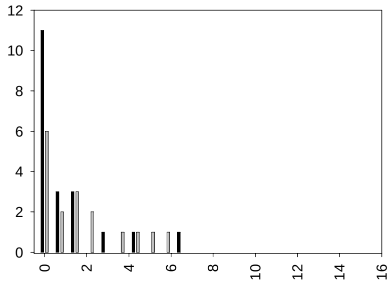
Barley



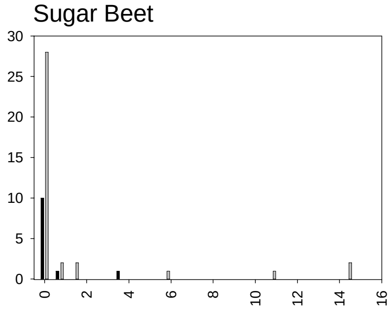
Wheat



Linseed

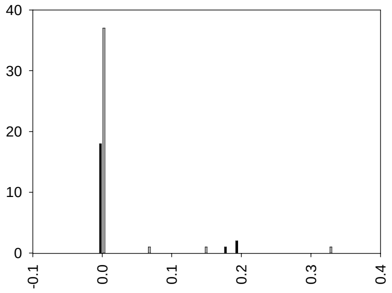


Sugar Beet

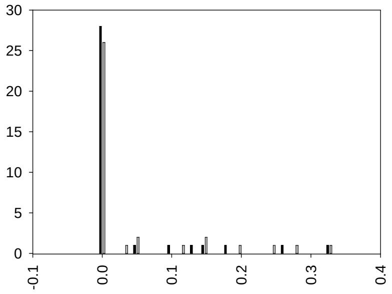


MISTLE THRUSH

Oil Seed Rape



Barley



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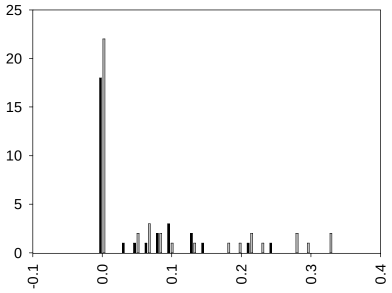
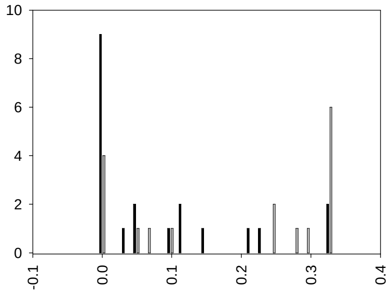
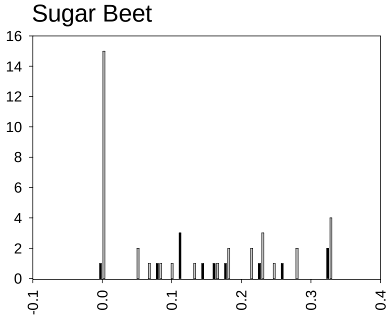


Linseed

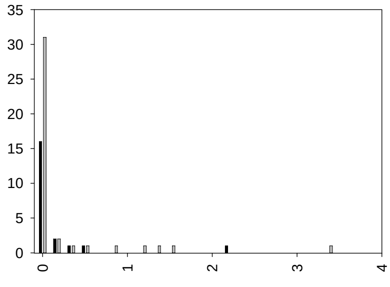


Sugar Beet

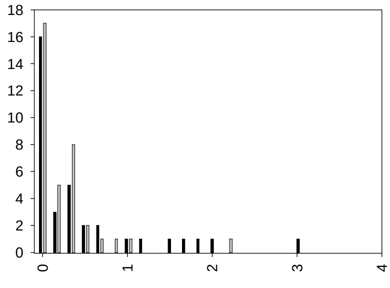


MEADOW PIPIT

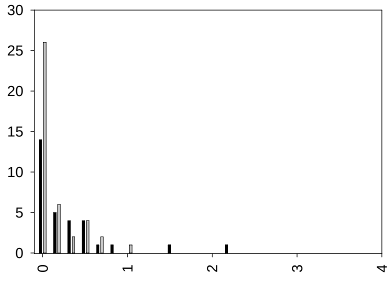
Oil Seed Rape



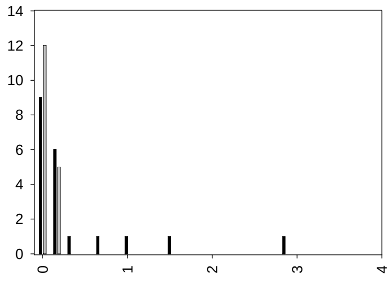
Barley



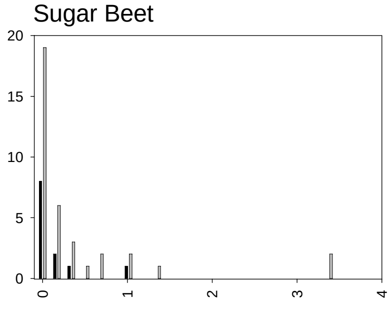
Wheat



Linseed

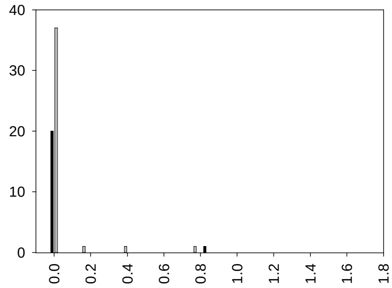


Sugar Beet

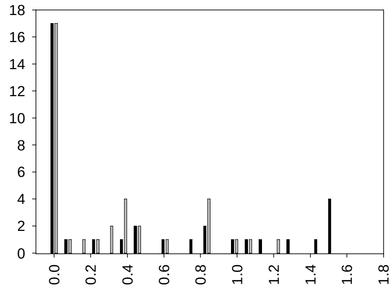


GREY PARTRIDGE

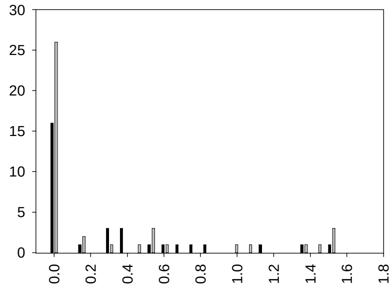
Oil Seed Rape



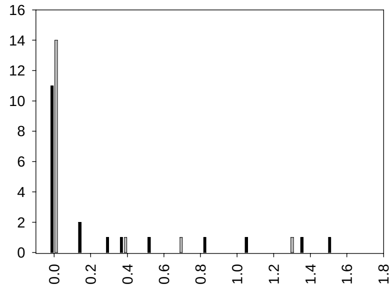
Barley



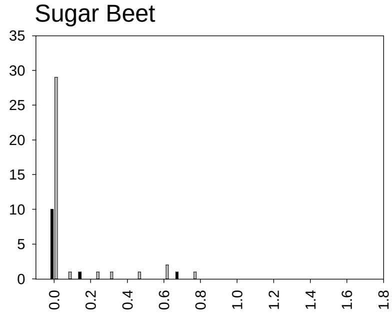
Wheat



Linseed

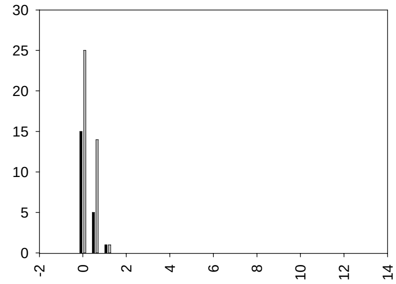


Sugar Beet

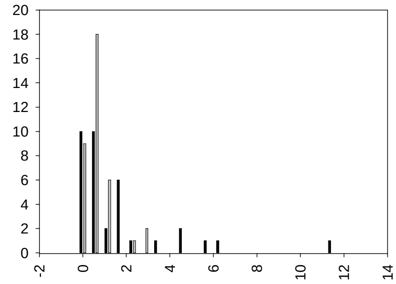


PHEASANT

Oil Seed Rape



Barley



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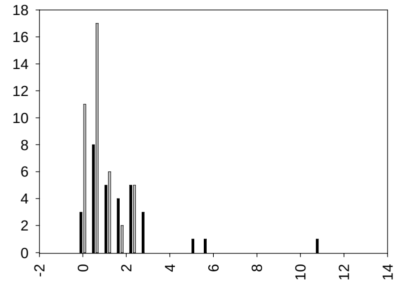

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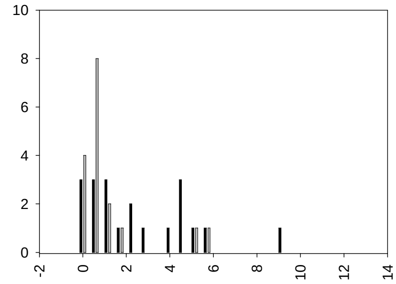
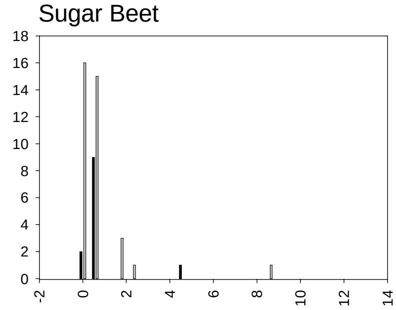
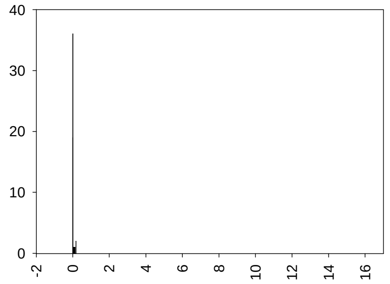


Sugar Beet

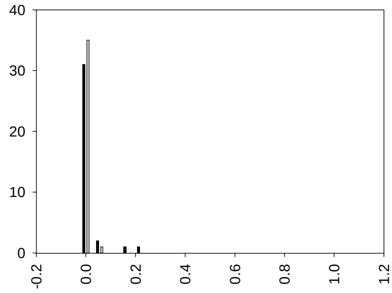


PIED WAGTAIL

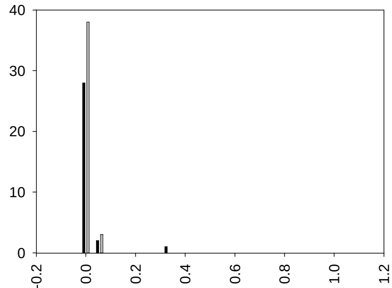
Oil Seed Rape



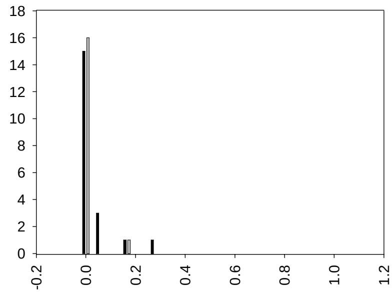
Barley



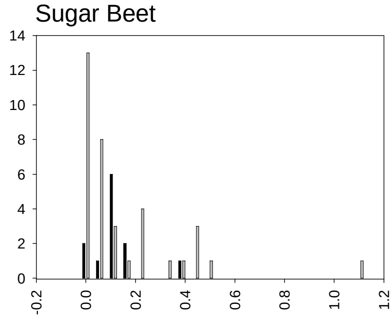
Wheat



Linseed

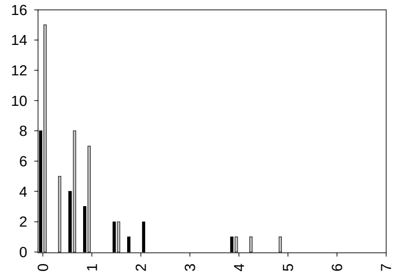


Sugar Beet



Red-legged Partridge

Oil Seed Rape



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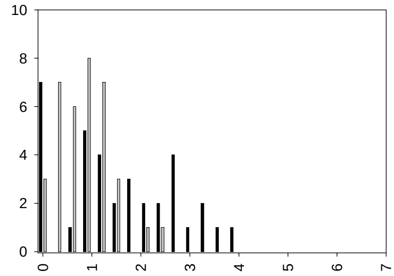
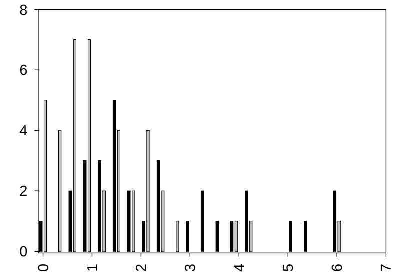


Wheat



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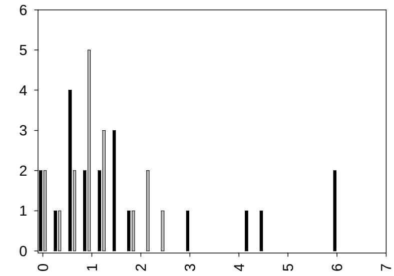
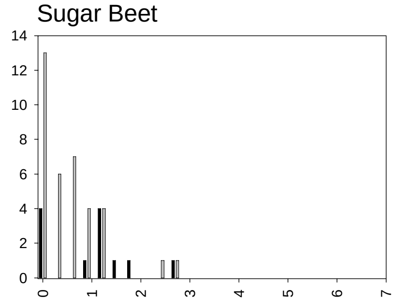
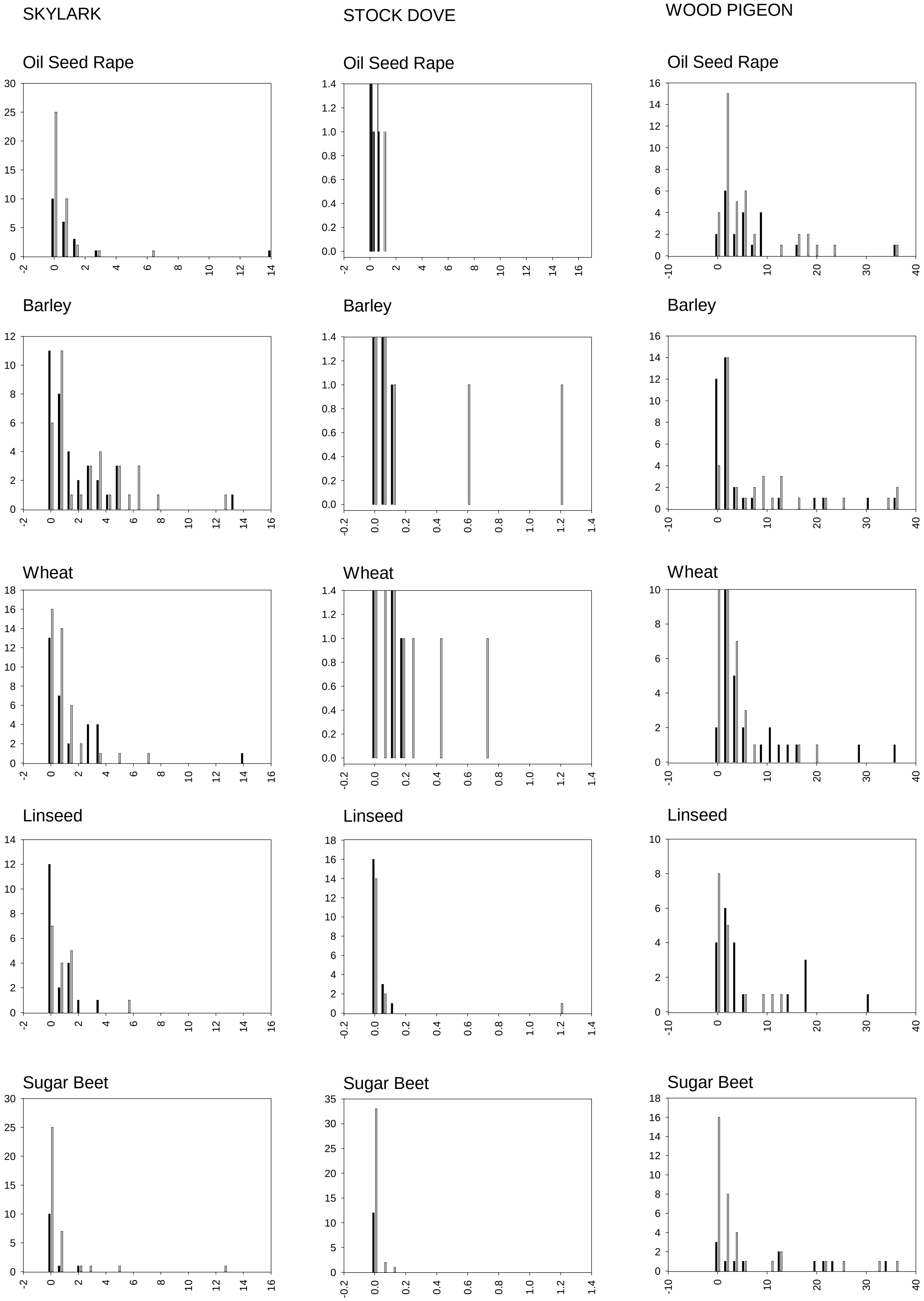


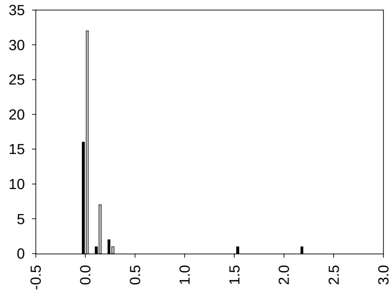
Sugar Beet



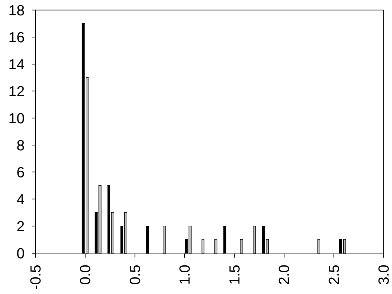

SKYLARK
STOCK DOVE
WOOD PIGEON
Oil Seed Rape
Oil Seed Rape
Oil Seed Rape
Barley
Barley
Barley
Wheat
Wheat
Wheat
Linseed
Linseed
Linseed
Sugar Beet
Sugar Beet
Sugar Beet

SKYLARK

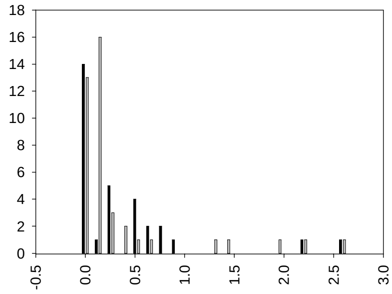
Oil Seed Rape



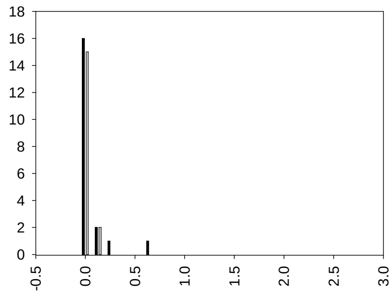
Barley



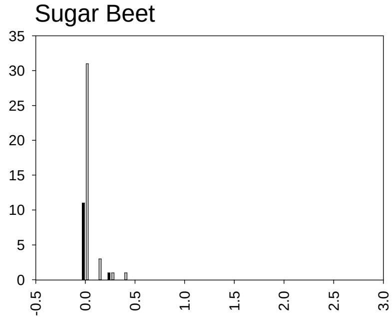
Wheat



Linseed



Sugar Beet



Appendix 3.4. Variables used in the multivariate GLM analysis.

Site	Farm
Field Characteristics	
Area	Field area (ha)
weeks	Number of weeks the stubble was available
tboundlen	Total boundary length (m)
sprayed	Stubbles sprayed after harvest or not (1=sprayed, 0=not sprayed)
Crop	Previous crop (Barley, Wheat, Linseed, Oil Seed Rape, Sugar Beet)
bound1	DCA boundary Axis 1 score: hedge length, coniferous woodland & ditch length
bound2	DCA boundary Axis 2 score: deciduous & other woodland
Bound3	DCA boundary Axis 3 score: ditch length, mixed & other woodland
Bound4	DCA boundary Axis 4 score: Hedge length, ditch length & deciduous woodland
hedlen	Proportion of boundary consisting of hedge
hedht	Mean hedge height (m)
hedgewidth	Mean hedge width (m)
treeno	Number of trees in the hedge
gamecov	Proportion of boundary consisting of game cover
nospray	Number of times the previous crop was sprayed with herbicides
nochems	Number of different herbicides applied to the crop
Pkmnveg	Peak mean weed cover during the stubble's lifetime (%)
Seed Densities (seeds per m^2)	
Cary	Mean density of Caryophyllacea seeds
Chen	Mean density of Chenopodiacea seeds
comp	Mean density of Compsitae seeds
Cruc	Mean density of Cruciferacea seeds
graminae	Mean density of Graminae seeds
Linseed	Mean density of Linseed seeds
polygonaceae	Mean density of Polygonaceae seeds
Rape	Mean density of Oil Seed Rape seeds
Sugar_beet	Mean density of Sugar Beet Seeds
umbellifer	Mean density of Umbelliferacea seeds
Urtica	Mean density of Urticacea seeds
Viola	Mean density of Violacea seeds
cereal	Mena density of cereal seeds
Poa	Mean density of Poacea seeds
% cover makeup of the stubble surface	
Bare	Bare earth (%)
self	Mean % cover of volunteers
Stubble density	Mean % cover of stubble
totveg	Mean % cover of total vegetation cover
Veg	Mean % vegetation cover
weeds	Mean % weed cover
Engergetic variables	
BIRDFOODE	Total weed seed (excluding grasses) expressed as energy
TOTALE	Mean energy supplies by all seed resources over all sampling periods.
BIRDS	Finch, bunting, sparrow and Skylark energy demand

Appendix 4.1. Definition of management (predictor) and vegetation (response) variables included in repeated measures GLM ANOVA models.
*** As the basic observations are proportions (p) for which random variation could be expected to be binomial, values were logit transformed to allow values to vary between +/- infinity (∞). *Logit* of p: y = ln {p/(1-p)}(Crawley 1993). As proportions of 1 and 0 logit transform to ∞ using this equation, where p = 1 (i.e. 100 cover) the value was changed to 0.9999 and p = 0 to 0.0001. [4] Plants of the preceding crop growing in the stubble field as weeds.**

Model code	Management (predictor) variables	Model code	Response variables
SITE Categorical	Site (farm)	VEGHT Continuous	Mean vegetation height
CROP Categorical	Crop stubble type	T_VOLCOV Continuous*	Volunteer cover[1]
HARVDAY Continuous	Crop harvest day (harvest day 1 = 19/7/00)	T_DTCOV Continuous*	Diet species cover (species recorded in the surveys whose seeds are important in the diet of farmland birds, table 5)
NOSPDAT Continuous?*	Number of dates herbicide sprayed on the field during the preceding crop cycle	T_BARCOV Continuous*	Bare cover (i.e. ground not covered by weeds, stubble or crop volunteers)
NOCHEMS Continuous?*	Number of different herbicides sprayed on the field during the preceding crop cycle	NOWEEDSP Continuous	Mean number of weed species recorded in each sample
ROTYR1 ROTYR2 ROTYR3 Categorical	Crop grown on the field in the three years preceding the present crop & its stubble, with rotation 1 being the most recent: 1 = SU, 2 = other roots & legumes, 3 = cereals & linseed/flax, 4 = fallow (set-aside/fallow, 5 = animals, 6 = OSR)	NODIETSP Continuous	Mean number of diet species recorded in each sample
SPB4HARV Categorical	Whether the preceding crop was sprayed with roundup prior to harvest (1 = sprayed before harvest, 2 = not sprayed)	NOACTSP Continuous	Mean number of active species (i.e. flowering or seeding) recorded in each sample
STHT Continuous	Mean stubble density	TOTSEED Continuous	Mean number of seeds recorded in each sample.
STDENS Continuous	Mean stubble height	DIETSEED Continuous	Mean number of seeds arising from diet arable weed species recorded in each sample

[1] Plants of the preceding crop growing in the stubble field as weeds.

Appendix 4.2. Stubble structure and vegetation characteristics of each crop stubble type surveyed during the study, combining 2000/01 and 2001/02 data where appropriate (* measured during 2001/02 only). All values given are means (± 1 s.e.). [a]Significance levels were tested using univariate ANOVA with 5 degrees of freedom (4 d.f. where sugar beet not surveyed for that characteristic). * P>0.05; ** P>0.01; *** P>0.001.

stubble/vegetation characteristic	Preceding crop type				
	winter barley	spring barley	winter wheat	oil seed rape	linseed
number of fields	25	12	46	26	19
% volunteer cover	12.53 ± 0.37	11.5 ± 0.55	7.30 ± 0.29	27.01 ± 0.51	4.89 ± 0.56
% weed cover	15.26 ± 0.31	13.42 ± 0.46	5.47 ± 0.24	7.37 ± 0.43	14.28 ± 0.47
% total vegetation cover	27.79 ± 0.46	24.92 ± 0.69	12.77 ± 0.37	34.38 ± 0.64	19.17 ± 0.70
% diet species cover	13.09 ± 0.28	11.13 ± 0.42	4.43 ± 0.22	5.44 ± 0.39	13.35 ± 0.43
% broad-leaved diet species cover	8.45 ± 0.21	6.87 ± 0.31	2.65 ± 0.17	5.17 ± 0.29	2.79 ± 0.32
% grass cover	4.64 ± 0.20	4.27 ± 0.29	1.78 ± 0.16	0.27 ± 0.27	10.56 ± 0.30
% bare cover	72.21 ± 0.47	75.08 ± 0.70	87.24 ± 0.37	65.62 ± 0.65	80.83 ± 0.71
stubble density (% cover)	10.48 ± 0.20	8.12 ± 0.28	10.52 ± 0.16	3.89 ± 0.44	6.17 ± 0.29
stubble height (cm)	12.87 ± 0.13	12.66 ± 0.18	13.20 ± 0.10	22.34 ± 0.22	14.55 ± 0.18
vegetation height (cm)	15.54 ± 0.20	17.24 ± 0.30	7.39 ± 0.16	12.97 ± 0.30	5.84 ± 0.30
number of fields	5	5	5	5	2
*number of active diet species	1.92 ± 0.06	1.23 ± 0.07	1.44 ± 0.07	1.17 ± 0.10	0.63 ± 0.16
*no of diet seeds/m^2	6851.60 ± 548.28	1870.31 ± 288.56	1708.60 ± 174.37	954.50 ± 147.24	3266.83 ± 632.78
*no of broad-leaved diet seeds/m^2	2502.60 ± 278.85	934.58 ± 198.18	821.78 ± 101.08	950.46 ± 147.18	105.38 ± 24.06
*no of grass seeds/m^2	4530.21 ± 482.65	940.43 ± 206.74	910.79 ± 138.47	4.39 ± 3.81	3242.51 ± 646.40

<u>No of observations</u>

2000/01: 6960 (linseed n=820, oil seed rape n=860, spring barley n=520, sugar beet n=340, winter wheat n=2880, winter barley n=1540)

2001/02: 1560 (linseed n=80, oil seed rape n=200, spring barley n=400, winter wheat n=380, winter barley n=500)

Appendix 4.3 Weed and volunteer cover on six stubble types cover, mean ± 1 s.e (2000-02).

	Linseed	Oilseed rape	Spring barley	Winter barley	Winter wheat	Sugar beet
Weed cover (%)	14.28 ± 0.47	7.37 ± 0.43	13.42 ± 0.46	15.26 ± 0.31	5.47 ± 0.24	0.35 ± 0.76
Broad-leaved diet weed species cover (%)	2.79 ± 0.32	5.17 ± 0.29	6.87 ± 0.31	8.45 ± 0.21	2.65 ± 0.17	0.16 ± 0.51
B-l diet weeds as a proportion of total weed cover	0.20	0.70	0.51	0.55	0.49	0.46
Volunteer cover %	4.89+ 0.56	27.01+ 0.51	11.5 + 0.55	12.53 + 0.3	7.3 + 0.29	N/a

Appendix 5.1. Average gross margins (£/ha) for winter and spring sown arable crops taken from Nix (2002). Yields are for feed, rather than milling or malting.

	Winter sown	Spring sown
Wheat	500	441
Barley	424	420
Linseed	338	-
Oats	463	400
Oilseed rape	447	327
Beans	431	409
Dried peas	375	
Maize	-	265
Sugar beet	-	1030

Appendix 5.2 Timing of drilling and harvesting operations for a number of winter and spring arable crops (Nix 2002). Actual timings will vary according to weather, region and soil type.