BTO Research Report No. 313

The Colworth
Sustainable Agriculture Project

The Response of Birds, Invertebrates and Plants to Crop Structure and Management Manipulations on Arable Farmland

Authors

Ian Henderson*, Neil Ravenscroft[†] Nigel Clark*, Stephen Holloway*

*British Trust for Ornithology
The Nunnery
Thetford
Norfolk IP24 2PU

[†]Ecological Research Associates
SWT Trading Co
Brooke House
Ashbocking
Suffolk IP6 9JY

A report by the British Trust for Ornithology under contract to Unilever Research

March 2003

British Trust for Ornithology, The Nunnery, Thetford, Norfolk, IP24 2PU
Registered Charity No. 216652

CONTENTS

Page No.

LIST OF TABLES

Page No.

LIST OF FIGURES

Page No.

LIST OF APPENDICES

Page No.

1. EXECUTIVE SUMMARY

1. Except for Skylark, concentrations of territories tend to be associated with key boundary features including mature trees, scrub or thick hedges.

2. In both summers, oilseed rape and peas were associated with the highest densities of Skylarks (on peas) and Whitethroats and Reed Buntings (in oilseed rape). However, in 2000, peas attracted high densities of other foraging species, particularly when flowering. However, this effect was not so apparent in 2001 with the pea crop located further away from key boundaries. Interestingly, in 2001, most Skylark territories were located on or near to their territories in 2000 (i.e. field 43), suggesting that field location is a powerful variable in territory selection.

3. For Yellowhammers, access to marginal grassy vegetation and bare ground, by tracks and roads, was imperative for adults provisioning young. Among crops, oilseed rape was used in preference to other crops and relatively little use was made of winter cereals. Pre-breeding birds fed extensively on weedy ground or cultivated ground that was oilseed rape in the previous year of the rotation.

4. The baseline survey and the timed counts suggested that there were positive associations with sustainable pesticide areas for several bird species, including Skylark and Linnet (Table 3). Responses to fertiliser inputs were equivocal, while crops following minimal cultivation tended to support slightly lower densities of birds than deep-plough GAP crops.

5. The densities of birds foraging on the SAP area was significantly higher during the second winter (2000/2001) than during the first winter (1999/2000) probably due to the retention of stubble fields in to February and March. Rooks, Jackdaws, Woodpigeons and Stock Doves were particularly abundant during the second winter. Flocks of Skylark, Yellowhammer and Tree Sparrow were especially notable in winter 2 compared to winter 1. Despite high densities of birds in late winter 2001, the numbers of breeding territories of birds did not increase in summer 2001. Skylark, Linnet and Yellowhammer territory densities were high in both years, and within the upper half of the range of densities recorded in previous studies on farmland. Skylarks were especially numerous on oilseed rape in summer 2000, with close to maximum densities for farmland (1.25 birds per hectare or over 0.5 pairs/ha). In 2001, Skylarks avoided rape, probably because of the woodland adjacent to this field. Interestingly, they were more polarised on the previous year's rape field, that was now spring and winter wheat. Comparable densities to rape in 2000 were recorded in 2001 on the sustainable patch of spring wheat but densities were very low elsewhere on the field (Table 2).

   Lapwing and Grey Partridge were recorded too infrequently to judge their relative numbers between years. Both species were scarce on site in both summers and only Grey Partridge breed there in small numbers (perhaps two pair maximum: one pair per 30 ha). In prime arable/grassland marginal habitats they may increase to perhaps five times this density.

2 INTRODUCTION

The decline in populations of many widespread farmland birds, simplified vegetation characteristics and a low abundance and diversity among invertebrate species (e.g. Morris 2000) is one of the major issues facing conservation scientists today throughout Europe (Donald *et al* 2001). A great deal of research has focused on understanding the causal mechanisms underlying these declines (e.g. Aebischer *et al*. 2001) and there is now a shift in research needs towards 'trailing solutions' for population recovery and increases in biodiversity in general.

For birds, crop diversification (including spring crops and non cropped areas such as set-aside) is currently viewed as a key requirement for higher densities of foraging and breeding birds on farmland (Wilson *et al.* 1997). Spring crops (including peas) provide birds with accessible vegetation in which to forage and nest (Wilson *et al.* 1997). Typically, they follow over-winter stubbles that provide food for seed-eating birds (Donald & Evans 1994; Wilson *et al.* 1997; Buckingham *et al*. 2000).

Where an indigenous flora (weeds) develops within crops or stubbles, the crop's value to birds is enhanced (Donald & Evans 1994; Buckingham *et al.* 2000). Structural and botanical variation encourages birds to exploit attendant invertebrates and seeds, and provide gaps in the vegetation to aid access for foraging (Schön 1999; Wakeham-Dawson & Aebischer 1999; Henderson *et al*. 2000). Field composition also affects invertebrate-feeding bird species, such as Song Thrush, since Buckingham *et al*. (2000) found that Song Thrushes preferred weedy stubbles to crops or grassland in summer especially where annual weeds, such as fumitory and field pansies, thrived on worked ground. Grasses and indigenous weeds are also a reservoir of invertebrate food for finches, buntings and Grey Partridge (Rands 1985, 1986, Potts 1991).

Apart from field content, chemical inputs onto farmland are widely considered to have been at least partly responsible for reducing the suitability of crops and grassland for birds. Evidence of their impact is mainly circumstantial but low pesticide and herbicide inputs can result in increased grassland invertebrate populations (particularly of sawfly larvae on which the partridge chicks depend (Potts 1986). Carbamate compounds, organophosphates, contact/fumigant nematicides and fungicides are all highly toxic to earthworms and may lead to depleted populations on farmland (Edwards & Bohlen 1977; Jenkins 1984). The larvae of Lepidoptera, on which many birds feed their offspring in summer, can occur at higher densities in unsprayed field margins than in sprayed margins (Rands & Sotherton 1986; Dover *et al*. 1990) and pyrethroids can also result in a sustained depletion of sawfly larvae on farmland habitats (Jenkins 1984).

Repeated applications of inorganic fertilisers tend to favour plants that respond to high nitrogen or phosphorus loads, often at the expense of species that prefer a less nutrient-rich environment. This results in lower plant species diversity in crops (fewer weeds) or on grassland (more uniform sward) and reduces attendant invertebrate populations accordingly (Vickery *et al*. 2001). There are, however, some important plant species for birds that respond to high nutrient levels, such as fat hen (*Chenopodium* spp.) and nettle species (*Urtica* spp.) Meanwhile, the organic systems' use of mechanical weeding and copper sulphate, are both potentially destructive to ground nesting birds and invertebrate communities in crops.

Within the research programme for the Colworth Sustainable Agriculture Project (SAP), extensive bird, invertebrate and plants surveys were carried out to identify associations and influences of modern agriculture on levels of biodiversity. The remit of the research included manipulations of crop input levels (of fertilisers an pesticides) and cultivation techniques against which the distribution and abundance of animal and plant populations are compared. This information is used to develop recommendations that will maintain, if not increase both conservation and scientific interest of the site as well as maintain the commercial viability of the farm. Certainly, outside of funded agri-environment schemes, this latter factor is essential for widespread uptake, amongst farmers, of measures to enhance biodiversity.

3 METHODS

3.1 Site Description

The Colworth Sustainable Agriculture Project (SAP) (grid) is a 61 ha plot within a 150 ha commercial farm. The soil composition is predominantly 50:50 clay/silt ("greensand"). The site lies within the River Great Ouse catchment area which is a designated Nitrate Vulnerable Zone (NVZ). This places restrictions on applied nitrates between September and February inclusive.

Deciduous woodland borders the SAP along the northern and southern boundaries, hawthorn *Cratagus monogyna* scrub and a grassy railway embankment form the eastern edge, while open arable fields abut the western border (Figure 1). The SAP area supported a variety of hedgerows, woodland edge and open boundaries. Details of these, including the dimensions of boundaries and adjacent woodland were assessed in a preliminary analysis. Field boundary units comprised relatively uniform lengths of boundary, in terms of height or structure. Boundaries were subdivided where distinct changes in structure or height occurred, with sub-divisions analysed in relation to bird distribution. Estimates of hedgerow height (m) and width (m) were accompanied by visual estimates of shrub composition and content as well as a count of the number of mature trees (>5m) present within each boundary section. Thus, in total the site comprised 123 m ha^{-1} of boundaries (including ditches and tracks) and 83 m ha^{-1} of wooded boundary, including hedgerows and woodland edge. Mean hedgerow height and width was 2.77 m and 3.1 m respectively (width included rough herbage between the hedge and crop but not margins or tracks). As a proportion of the total hedgerow length on the site, hedgerows comprised at least 68.0% hawthorn, 43.7% blackthorn *Prunus spinosa*, and 30.3% elder *Sambucus nigra* among the dominant shrub species. Mature trees (mainly oak *Quercus robur* and ash *Fraxinus excelsior* were present along 27.2 % of total boundary length, or 12.8% of all boundaries excluding woodland edge. In summary, non-woodland boundaries comprised a mixture of 3 m high hedgerows and open boundaries with mature trees present but thinly distributed.

The SAP comprises eight fields (Table 1) averaging 7.5 ha. Until 1999, the site was dominated by winter cereals but now a more complex rotation includes set-aside, vining peas, spring wheat and spring rape (described below). In crops, blackgrass *Alopecurus myosuroides*, is a special problem in areas of high fertility, for which the crop rotation may be used to break sequential cereal crops with herbicide-controlled fallows (e.g. "set-aside").

3.2 Habitat: Crop Rotation and Within Field Treatments

Cropping patterns

During the pre-experimental, baseline year of the study (year 1 = 1999/2000), five of the eight fields contained winter wheat (42.5 ha), with one field each of winter sown oilseed rape (9.5 ha) and vining peas ("Harrier" (9.0 ha); Table 1). The site entered a seven-year rotation, adopting conventional principles defined as "Good Agricultural Practices" (GAP), where all fields were subject to deep ploughing, autumn applications of molasses (to aid organic breakdown in the soil) and pre-emergent, non-residual herbicides ("glyphosate") to form a "stale" seed-bed. Post-emergent herbicides, insecticides and fungicides (Table 1) were applied, typically in response to emerging problems on crops rather than as predicted, pre-emptive control measures. In subsequent crop years, within the cropping plan, areas of winter wheat gave way to between 8 and 9 ha of natural regeneration set-aside, 9.25 ha of spring sown wheat in years 2 (2000/2001) and 3 (2001/2002), with 50% of 8.11 ha of oilseed rape being spring-sown in year 3, so increasing overall crop complexity over time.

Design of field trials

In year 2 (2000/2001), intra-field trials were established in quarter or half sections of fields. Each section was subject to a different treatment level of fertilisers, pesticides and/or cultivation technique (ie., deep plough versus minimum ("shallow") tillage). The experimental plan was designed to quantify spatial and temporal relationships between birds, invertebrates and plants with crop types and crop treatments, while using the crop rotation to dissociate within-field affects from adjacent, non-cropped habitats features. Such features included boundary height, boundary length to field area ratio (BAR) or the presence of woods, field margins and game cover crops.

The arrangement of treatments within field sections, within the overall experimental design are presented in Figure 2. They describe a patchwork arrangement where five fields are assigned to two sets of treatments: (i) low (minimum or MIN) versus normal (GAP) pesticide rates in one direction, and (ii) low versus normal fertiliser rates in a direction perpendicular to (i). A third treatment will be applied to a selection of some fields (see Figure 2) in which the cultivation methods is altered between normal deep-ploughing (GAP) and "minimum tillage" (MIN), using a flatlift, heavy disc and press. Two particular fields (42 and 44-46) were split into two equal sections rather than four, with one half receiving all three GAP treatments, while the other half received all three minimum treatments of pesticides, fertilisers and minimum tillage.

The overall design gave both within-field and between-field replications of treatments, resulting in 21.5 ha of each treatment (i.e. normal/low fertilisers or normal/low pesticide inputs) in each year from seven field types with approximately 10 ha of each treatment per year on winter wheat alone. Minimum treatments were designed as extreme measures, at a risk to crop development or yield. However, the actual definitions of low or minimum treatments varied between years and between crops (see Appendix 1).

3.3 Plant and Invertebrate Recording

Plant recording

The weed flora of all 28 sections of the eight fields was recorded. Three transects were installed in each section of each field, running from a field edge 25 m into the crop. Four 1m^2 quadrats were located on each transect; at 1 m, 5 m, 10 m and 25 m, giving a total of 12 quadrats per plot, 24 or 48 per field (depending on the number of experimental plots) and 336 throughout the study area. Within each quadrat all plant species were recorded (diversity) and the number of plants of each species counted (abundance). The positions of quadrats in crops were marked with 1.5 m white PVC flexi-canes driven into the soil and standing proud of crops. Two visits were made, on the 28th and 29th May 2002 and the 10th and 11th July 2002, to record weed diversity and abundance in all quadrats.

Invertebrate sampling

The fauna of six of the eight experimental fields was recorded (fields 37-40, 39, 41, 42, 43 and 44-46). This selection resulted primarily from a requirement to reduce the timescale involved in recording given the intensity of study required in the collection of samples and the identification and counting of specimens. The fields included in the study were those in which pesticide inputs were varied, either specifically or as part of an overall sustainable treatment. The two fields excluded were those that had no pesticide variation (fields 45 and 47).

A single pitfall trap was installed at the same point as each plant quadrat along transects into each field section within the fields studied (at 1 m, 5 m, 10 m and 25 m). Therefore, there were 12 pitfalls in each field section, 24 or 48 in each field, and 240 throughout the study area. Pitfall traps were standard disposable dispensing coffee cups in white plastic, 6.5 cm diameter and 9 cm depth. Two were used per trap, one inside the other, for added robustness and to ease trap removal. Each trap contained about 3 cm of fluid, comprising about 90% water and 10% anti-freeze, with a little detergent.

Traps were opened for two sampling periods of a week between the 29th May and 5th June and the 10th and 17th July 2002. A third window was planned for autumn but crop development meant that the only fields available were 43 and 44-46 (both winter wheat). Traps were opened for the period between the 16th and 23rd September 2002. At the end of each sampling period, trapped invertebrates were transferred to sealable pots containing alcohol for preservation before identification.

Four groups of ground-dwelling arthropods were separated from each sample: spiders (Araneae), harvestmen (Opilionidae), carabid beetles (Carabidae) and staphylinids (Staphylinidae). The species occurring in each sample was recorded and the numbers of each species in each sample counted.

In addition to pitfall sampling, fields were sampled with sweep-netting after each of the first two pitfall windows. This was undertaken mainly to provide further information on the spider fauna of the study area. The data was not quantitative and is not used in analyses.

Data analysis

The diversity of plants or invertebrate group occurring in each section within each field was represented as a mean of the number of species occurring in all quadrat or pitfall samples taken within that section. Similarly, the number of plants or invertebrates (plant abundance or invertebrate activity-density) in each section was represented as a mean of the number of individual plants or invertebrates occurring in all quadrats or pitfall traps in that section. The abundance of pitfall-sampled invertebrate populations is usually referred to as activity-density, as the surface activity of individual species determines whether or not they are caught. This may cause unequal trap probabilities in data from different locations, but in this study the habitat structure of the study area does not differ dramatically and components of the same overall fauna may be expected in each**.**

Data was pooled regardless of sampling date or distance into the crop. The rationale of the transect recording system was to provide a sample across the variation expected between the edges of crops and in-field, and all fields were expected to vary similarly. It was assumed that confining samples to either the edge or to a selected distance into the crop would, given the variation in sizes and shapes of fields, leave samples prone to unequal influence from differences in boundary features and possibly the impacts of previous margin management. Data from different sample dates were pooled only if the same number of samples had been taken at each date. There were seasonal variations in the invertebrate data especially, but it is reasonable to expect seasonal influences on the presence and abundance of these species to vary similarly across the study area.

3.4 Birds

3.4.1 Abundance and species richness between crops and crop treatments

The baseline survey

Changes in the abundance and species richness of birds on the SAP were measured in two ways, giving different levels of detail. First, throughout the year, for each year of the study, an experienced observer visited the site once a month between September and March, and twice a month from April to the end of August (before 11.00 h) to map bird distribution in summer and winter using a standardised method (Common Birds Census: Marchant *et al.*1990). Here, the observer walked the boundary of every field and through the middle of each field, recording all birds seen or heard onto a large-scale (1:25000) map of the site. Each contact with a bird (termed a "registration") was marked with an activity code to identified singing/displaying birds, foraging birds, birds in transient flight (i.e. those not clearly associated with particular habitats), the sex of birds and any individuals seen carrying food or nest material. No counts were carried out in persistent heavy rain or wind levels above Beaufort force 4. During the summer, breeding territories were identified from clusters of registrations and displaying birds allowing an estimation of breeding population size to be determined for most species from year to year. These data also allowed the distribution of birds on the site to be compared over time, in order to assess change in relation to cropped and non-cropped habitats. The baseline survey provided a benchmark of bird distribution and species richness against which to compare the effects of field treatments on bird distribution, bird abundance, species richness and breeding population size (generically termed "biodiversity"). It also allowed a comparison of the bird community at Colworth with other farmland studies in the UK, for context and representation.

Point counts

In addition to the baseline survey, point counts were carried out between May and August (before 11.00 h) in field treatment years 2001 and 2002. These were timed bird counts, of 30 minute duration, taken from a series of vantage points around the site, that allowed a more detailed assessment of bird frequency of movement within field, and in relation to the treatments applied to each field. The observer moved systematically from one crop (and one point count) to another, covering all crops, with the start point chosen by random allocation of the first field. Maps were analysed for maximum counts of (a) all bird registrations and (b) singing individuals, to provide a relative index of bird activity for each crop treatment. For birds foraging over a field, in flight, such as swallows *Hirundo rustica*, a record was halved, for example, where an undisturbed individual crossed or flew between two particular fields or field treatments. This gave equal weight to bird/treatment associations without pseudo-replicating the data.

Analyses

For pesticides, it was anticipated that there would be differences in bird densities on fields between GAP and MIN treatments since both herbicides and insecticides potentially reduce food resources for birds either directly or indirectly via the food chain (e.g. Table 2). In particular, pyrethroid insecticides potentially reduce the invertebrate fauna that adult birds may feed to their young, so this group of chemicals was also analysed independently of the whole “pesticide” category. For fertiliser inputs and cultivation techniques their anticipated effects were much more difficult to predict and to formulate hypotheses for, since both GAP and MIN treatments could be beneficial to different plants or animals.

In testing for relationships between birds and treatments, it was also necessary to account for alternative sources of variation in bird numbers caused by their response to crop type, boundary type and field geometry. The analyses therefore used (i.e. repeated measures for repeated visits to the site) General Linear Model. This linear regression technique, allowed within and between treatment affects to be analysed under single analytical models. Models incorporated Poisson (quantified response) or binomial (presence/absence) error transformations, for zero-inflated data that is at least, of typical of bird-count data. Models also include adjustments for field area or boundary length (as offset variables) and adjustments for over or under-dispersion (“clumping” in bird distribution) using square-root/degrees of freedom. Output statistics include Likelihood ratio (LR) approximations to the Chi-squared distribution which test for significant differences (at α=0.05) in birds in relation to independent variables (i.e. different field treatments, field types, boundary type and field location). Additional statistical tests that were used on summary data sets are identified in the text where appropriate.

4 RESULTS

4.1 General Responses of Biodiversity

4.1.1 Plants

The overall weed flora was similar to 2001: 71 species were recorded in 2002 compared with 73 in 2001. The diversity of weeds in each field section was also similar to 2001 (r=0.75, n=28, P<0.001, Table 3 & Figure 3) although their abundance was very different owing to the changes in crop in all fields (r=0.03, n=26, P=0.89). The most widespread weeds were black grass *Alopecurus myosuroides* (occurring in 25 of 28 field sections), cleavers *Galium aparine* (23 of 28), annual meadow grass (20), prickly sow-thistle *Sonchus asper* (19), fool's parsley *Aethusa cynapium* (17), fat hen *Chenopodium album* (16) and rape *Brassica napus* (15). The diversity and abundance of weeds in the fields varied greatly (Table 3): most field sections supported a weed flora of a dozen species or so, but apart from black grass and cleavers weeds were virtually absent from the winter wheat crop in field 47. Field sections 45A & B (the winter crop sections) were also quite clean of weeds, whereas sections 39A & B and 41A & B were extremely weedy (i.e. in the (MIN) "sustainable" pesticide treatments of the two pea fields).

4.1.2 Invertebrates

The total number of specimens identified in 2002 was greater than 2001, increasing from 21,310 to 34,670. The number of ground beetles (carabids) recorded rose only slightly (from 14,155 to 15,936) but the number of rove beetles (staphylinids) doubled (from 1954 to 3858) and the number of spiders almost trebled (from 5201 to 14,867). These increases may in part be owing to changing management on the farm, but also to seasonal effects and the slight increase in recording effort (field 39 was included in 2002). The increases were across most field sections (Table 3). An overall increase in the diversity of species recorded from the site (Table 4) was due also to the increased recording effort resulting from a third year of sampling and the difference in the timing of the samples, capturing species with different seasonal presence.

Spiders

The samples in 2002 produced a minimum of 64 different species of spider. Sweep netting produced a minimum of 16 different species of spider. Nine species (one by sweep netting and pitfall trapping and eight by pitfall trapping alone) were identified during 2002 that were not found during the 2000 or 2001 programmes but 29 species found in 2000 or 2001 were not seen in 2002. This could in part be explained by the "missing" species having been recorded from fields not sampled in 2002 and by difficulties experienced with the sweep netting.

A minimum of 95 different species of spider has now been recorded from the site over the three years the programme has been running. The extra sampling effort continues to show Colworth to have a spider fauna more species rich than those reported from other arable sites by Dinter (1995) and Idinger *et al.* (1996). Further sampling effort would still be expected to further increase the number of species recorded. The species composition of the pitfall trap catches was similar to that from the previous year and remains typical of the fauna reported from arable fields by Dinter (1995), Harwood *et al.* (2001), Idinger *et al.* (1996) and Topping & Sunderland (1995).

The activity density of spiders tended to increase from the June to the July sampling period although the data from field 37-40 provided a notable exception. In the two fields sampled for a third time in September Linyphiid activity density declined following the July peak. The activity density of the Lycosidae was generally higher during the June sampling period than during July but the differences between the sampling periods were less clear-cut than for Linyphiidae. The timing of the sampling in 2002 meant that the large numbers of males caught during the May 2001 sampling period were not seen this year.

Carabid beetles

A total of 49 species of ground beetle were identified during the trapping programme in 2002. This includes seven new species but eight species recorded in 2000 or 2001 were not recorded in 2002. A total of 57 species have now been recorded from Colworth confirming the high species richness of the ground beetle fauna in comparison with that reported from other arable sites by Hawthorne & Hassall (1995) and Idinger *et al.* (1996). The species composition remains typical of that reported from arable crops by de Snoo *et al*. (1995) and by Ulber & Wolf-Schwerin (1995).

There was no clear pattern to the changes in activity density between June and July with a decrease occurring in fields 37-40 and 41 and a combination of increases and decreases in field 39, 42, 43 and 44-46 apparently depending on the treatment. The activity density of particular species showed consistent variation between the June and July samples. In accordance with the data of Thomas *et al.* (2001), the activity densities of *Nebria brevicollis* and *Pterostichus cupreus* were higher in the June samples than in July but rose again in September with the emergence of the second generation of beetles. The activity density of *Pterostichus melanarius* was expected to be highest in the July samples. Although this was the case in most of the fields there were some contradictory data from fields 39 and 37-40.

Staphylinid beetles

A minimum of 51 species of rove beetle was identified from pitfall traps during 2002. This total includes 48 adult species identified to specific level and three species identified only to generic or higher level. Eleven of these species were additional to the species identified in previous surveys but 18 species recorded previously were not seen again this year. *Tachyporus dispar* was absent from 2001 samples along with *T. solutus* and a reduced occurrence of *T. nitidulus*. All these species occurred widely in 2002, suggesting that natural population cycles are having a pronounced influence on the data.

4.1.3 Birds

Trends in abundance and species composition

From the systematic sampling of birds, species composition on the SAP area was generally typical of lowland farmland Britain. Characteristic and predominant species therefore included common hedgerow-based species: Woodpigeon, Wren, Robin, Chaffinch, Dunnock, Blackbird, Whitethroat, Blue Tit, Linnet and Yellowhammer, as well as skylark on open farmland. In winter, transient and fluctuating flocks of cardueline finches

(Greenfinch, Linnet and Goldfinch), Skylark, Yellowhammer, Rook and Jackdaw, Woodpigeon and Stock Dove and occasionally Tree Sparrow occurred. Notably, three common and widespread species in the UK were virtually absent from the site, particularly in summer; they were Collared Dove, Starling and House Sparrow. Lapwing and Rook, though frequently recorded in flight, were also uncommon on the SAP site, and especially in summer. One pair of Grey Partridges was recorded in the baseline year.

Whole farm trends in species richness and abundance

Together with records of passage migrants, such as Redstart and Wheatear but excluding birds in direct flight over the site, the mean number of species recorded on each visit to the SAP area was 47 in 2000 and 2001, increasing by 17% to 55 in 2002. Although the number of breeding species remained constant at around 42, the total number of breeding territories increased by 8.7%, to 224 in 2001 and by 15% to 235 in 2002 (Table 5 and Figure 4). This increase in abundance was in contrast to adjacent woodland species (i.e. greater Spotted Woodpecker, Wren, Long-tailed, Blue, Marsh and Coal Tit species, Nuthatch, Treecreeper, Blackcap, Garden Warbler, Willow Warbler and Chiffchaff) which increased by only 3%, and this increase was not statistically significant (P=0.61; Figure 6). Thus the change in bird breeding population associated with farmland on the SAP farmland was probably not due to increased observer effort on sites or other observer biases, since the same observer gathered data on both farmland and woodland species.

Species of high conservation concern and species contributing to the national farmland bird indicator increased by 35% (Chi-squared: χ^2_1=3.9, P=0.05) and 30.5% (χ^2_1=3.9, P=0.05) respectively between 2000 and 2002. For the BAP species, the number of pairs contributing to the group was small and dominated by Skylark and Yellowhammer, but notable increases in the abundance of Grey Partridge probably reflect a genuine increase in breeding density (albeit from zero or one to two pairs), very much against the national trend for this species (Table 5).

In terms of abundance, there was an overall significant increase of 32%, from 182 in 2000 to 243 in 2002 (log transformed Z-test: z= 1.94, P=0.07, n=42; Table 5).

In winter, species richness showed a small, non-significant declined on fields from 23 species in winters 1 and 2 to 19 in winter 3, and on fields and boundaries from 47 species in winter 1 to 46 in winters 2 and 3, but there was a small increase in the total abundance of birds seen per visit and over the winter as a whole. Thus, with Woodpigeons excluded, bird abundance increased by 34.6% on fields between winters 1 and 2 (repeated measures; GLM Likelihood ratio test (LR): χ^2_1=3.9, P=0.05; Figure 5), but not between winters 1 and 3. Woodpigeons were very abundant in the first two winters and so forced a negative rather than positive trend.

Species that increased in abundance between winters included Grey Partridge (25%, though due to a small sample size the change was not statistically significant; t-test: t=1.1, P<0.10; Figure 8), Stock Dove (48%), Skylark (75%, significant increase; t=2.12 P<0.05; Figure 4), Meadow Pipit (75%), Linnet (19% over all increase (76% between winters 1 and 2) and Yellowhammer (i.e. a 16% increase in buntings (mainly Yellowhammer) especially in winter 2, with the difference being marginally non significant; t=1.8, P<0.07; Figure 6). Lapwing and Song Thrush also increased from “unrecorded” to “present” at very low density (0.002 and 0.01 birds ha^{-1} respectively). There was a general significant decline in the numbers of finches recorded (t=2.28, P<0.05; Figure 6), especially for chaffinch, goldfinch and greenfinch between winters 1 and 3. For the latter two species this reflects a national trend for farmland birds in winter with birds increasingly occupying garden habitats.

For seasonal changes in abundance, peaks occurred on fields between January and February of the second winter (2000/2001; Figure 5). These included high counts of Skylark, Tree Sparrow, Linnet and Yellowhammer, which coincided with the presence of late winter stubbles (see also Figure 12).

4.2 Factors Influencing the Distribution of Plants and Invertebrates

4.2.1 Field descriptions

Development of weeds in three fields (39, 41 & 42) prevented a crop being harvested. Further descriptions of the differences of weed flora are restricted to three fields (43, 44-46 & 47).

4.2.2 Field 43: Cultivation and pesticide combination in winter wheat

43A experimental pesticide (MIN), experimental cultivation (MIN); 43B normal pesticide (GAP), experimental cultivation (MIN); 43C normal pesticide (GAP), normal cultivation (GAP); 43D experimental pesticide (MIN), normal cultivation (MIN).

Plants

There were pronounced differences in weed diversity and abundance between the four sections, and the experimental (MIN) cultivation plots were consistently less weedy than the normal (GAP) cultivation sections in combination with both pesticide treatments.

Section 43A was relatively clean in comparison with the other sections (Figure 7). A mean of 1.4 species per m^2 occurred, with some rape, sow-thistles and groundsel *Sinapis arvensis*, but hardly any cleavers (0.33 plants per m^2) or black grass (0.21 plants per m^2).

43B was the cleanest section of the four, with very few weeds (mean species density 0.46 per m^2). No cleavers occurred, and there was only a scattering of black grass and sow-thistle.

43C was quite weedy (second most weedy, Figure 7), mainly owing to the large number of plants of cleavers (mean density 6.5 per m^2), and a few fool's parsley. Diversity was relatively low (species density 1.04 per m^2) and there was no black grass.

43D was the most weedy section (twice the species density of 43A - 3.1 per m^2, and twice the number of plants as 43C at 13 per m^2 (Figure 7). Cleavers was abundant (4.4 per m^2), as were sow-thistles, fool's parsley and chickweed. The section also supported the most rape of the four.

Invertebrates

There was no difference in the species diversity and activity-densities of the three invertebrate groups in the four field sections (Table 3 and Figure 7).

4.2.3 Field 44-46: All treatments in winter wheat

44-46A all treatments normal (GAP); 44-46B all treatments sustainable (MIN).

Plants

There was little difference in the flora of the two sections (44-46A: mean species diversity 2.04 per m^2, weed abundance 4.1 per m^2; 44-46B 2.1 species per m^2 and 3.9 weeds per m^2) and the sections were relatively clean (low weed density). Species composition was similar between sections, although there was no rape or perennial rye-grass *Lolium perenne* in 44-46A (GAP treatments). Cleavers occurred at similar density in each section (44-46A 0.92 per m^2, 44-46B 0.71 per m^2).

Invertebrates

The beetle fauna of this field was impoverished and the diversity of the spider fauna had also fallen to low levels compared with both 2001 and the other fields in 2002. Diversity and activity-densities in the two field sections were largely similar for the groups although greater numbers of spiders and carabids were recorded in 44-46B (Table 3).

4.2.4 Field 47: Cultivation and fertiliser combination in winter wheat

47A experimental cultivation (MIN), normal (GAP) fertiliser; 47B normal (GAP) cultivation, normal (GAP) fertiliser; 47C normal cultivation (GAP), experimental fertiliser (MIN); 47D experimental cultivation (MIN), experimental fertiliser (MIN).

Plants

All sections of this field were weed-free apart from black grass and cleavers. Black grass has been infesting this field in recent years and it is believed to be spreading across the field from the south-west (sections 47A and B) to the north-east (47C and D). Certainly, it was most abundant in sections A and B in 2002 (10.6 and 13.9 plants per m^2 respectively) compared with section C (4.6 per m^2) and D (absent) (Figure 8), although the latter two sections were also those with experimental fertiliser applications. Black grass was virtually the only weed recorded in sections A & B, whereas cleavers was occasional in sections C and D (0.83 plants per m^2 in section D).

4.3 Factors Affecting Bird Distribution

4.3.1 Landscape effects

The principal features that determine the distribution of birds on the SAP area are summarised in Table 6. They included field location and boundary variables that are strong determinants of bird distribution both as independent variables and as combined variables. As combined variables they represent an aspect of field geometry; the relative length of wooded boundary (woodland edge and hedgerow) divided by field area or the Boundary to Area Ratio - BAR). Although crop rotation will help control for the effects of features such as field location and boundary characteristics, it is still important to quantify their influence in order to determine whether the physical composition of the site can be improved for increased biodiversity. Table 6 also shows the relative influence of crop type and within field management treatments of fertilisers, pesticides and cultivation method, which, to a greater or lesser extent, explain variation in the distribution of birds on the site.

Field location

There were significant differences in the densities of both skylarks and boundary-based species on fields in relation to field location (Table 6 and Figure 9). These are explained, as expected, by field sections being more enclosed for boundary-based species (Figure 10 a and c) but more open in aspect and greater in area for Skylarks (Figure 10 b and d). The relationships between bird density, boundary to field area ratio (Figure 10 a and b), indicate that higher densities of Skylarks than are currently measured at the site, at 0.35 birds ha-1, could be supported on the SAP if hedgerows were removed (Figure 10b). The converse, however, is true for most other species (for which there was a combined mean density of 0.46 birds ha-1 on fields, if extra hedgerows were added (Figure 10a). However, for the SAP area, the average BAR of 87 m ha-1, lies between the density asymptotes of both Skylarks and "other bird species" (Figure 10 a & b), and may already be close to the optimal proportion of fields and boundaries for maximising overall bird abundance and diversity. There was a very slight increase in bird species richness in relation to a higher boundary to area ratio, although the difference was not statistically significant (Figure 11).

Crop type or field content

In summer, there were significant differences between the densities of birds on different field types (Table 6), with significantly higher densities of boundary-based species (i.e. thrushes, finches and buntings) being recorded in oilseed rape and weedy stubbles than in spring wheat, vining peas and especially winter wheat (Figure 12a), and the lowest densities of these species (combined) were recorded in clean cereal stubbles (Table 6). For Skylarks, significantly higher densities of birds (almost nine times) were recorded in weedy stubbles and in clean cereal stubbles and some areas of winter wheat. However, in general, winter wheat held almost twice the density of skylarks recorded in clean cereal stubbles (Figure 12a). Thus, oilseed rape and weedy stubbles (and to a lesser extent peas) significantly increase biodiversity amongst birds by increasing average densities within the rotation adopted on the SAP (that is, compared to uniform fields of winter wheat) (Fig 13).

In winter, stubble fields supported significantly higher densities of Skylarks (rape and cereals stubbles; (LR): χ^2_6=3.9, P=0.05), finches (especially rape stubbles; LR: χ^2_6=91.9, P<0.01) and buntings (rape and cereal stubbles (LR): χ^2_6=25.1, P<0.05) compared to tilled land containing wheat or winter oilseed rape (Figure 12b).

Boundary effects

Of 34 boundary sections identified, from 32 bird species, the typical distribution of birds on boundaries around the site was concentrated around the thicker well-developed hedgerows (e.g. Appendix 3). There was a shallow but significant positive correlation between bird linear density and boundary hedge height (Spearman's Rank: *Rho*= 0.1, n=660, *P*<0.01) and width (*Rho*=0.05, n= 721, *P*<0.01). Mean hedge height used by birds was 3.13 (sd=1.3) compared to 2.29 (sd=1.2) for zero counts. Tall, broad hedges with mature trees (10a, 2, 5, 12 16 and 21) or thick blackthorn-dominated boundaries by scrub-rich habitats supported the strongest populations of breeding birds. In contrast, none of the open boundaries supported breeding birds although they may have contributed to the use of adjacent fields by Skylarks that avoid structured boundaries and for which there was a significant negative correlation (*Rho*=0.1, n= 889, *P*<0.01) .

4.3.2 Within field treatments

Fertilisers

When controlling for field type, the baseline survey data showed higher densities of Skylarks on low application areas of winter wheat (1.45 times higher than on normally fertilized crop areas; Table 6). Higher densities of other bird species were found on GAP fertiliser treatments (Table 6) with and without controls for crop type. There were few significant relationships between bird densities and fertiliser application rates among individual species (only Skylark; Table 7), although data from both baseline and point count sources suggest that higher densities of birds tended to be found on areas subjected to GAP fertilized treatments.

Pesticides

Significantly higher densities of Skylarks and other species were found associated with minimum pesticide treatments (Table 6) when analysed across all field types (i.e. those without controls of field type). However, this effect, though still negative (i.e. more birds on low pesticide areas), was no longer significant on winter wheat alone (Table 6). Although there were few significant relationships between bird densities and pesticide application rates for individual species (but see Skylark and Linnet, in contrast to fertiliser treatments, higher densities of birds predominated within the low (MIN) pesticide areas of crops for both baseline and point count data (Table 7). The response of Skylarks and Linnets could lead to more specific hypotheses being pursued with respect to these species diets and certain component chemicals within the broad “pesticide” category.

Among individual pesticide products, on winter wheat, there were significantly higher densities of boundary-based species associated with low inputs of pyrethroid insecticides (“Hallmark & Zeon; *P*<0.05) and Cypermethrin (*P*<0.005) as well as slug pellets (*P*<0.005). For Skylarks, there was a strong negative relationship on winter wheat with the combined products of Zeon & Hallmark (*P*<0.001), but not Cypermethrin or slug pellets. No strong relationships were found between bird densities and application rates of herbicide products. Nevertheless, attempts to identify functional relationships between either fertiliser (e.g. urea) or pesticide products (e.g. Cypermethrin) that both vary in application rate between crop sections, and bird densities are shown in Figure 14. For both urea and Cypermethrin the trends are negative (note for urea that this is against the general response of birds to GAP rate fertilisers). On the basis of these types of “models” however, moderation between GAP and MIN treatments might be attempted in future, although currently such relationships lack data and therefore detail. One consistent feature of this exercise was that zero treatments (of fertiliser or pesticide) appeared to be linked to greater variation in bird densities (Figure 14). This may indicate that food resources are less predictable before treatments are applied, perhaps because the pre-treatment weed flora or invertebrate fauna are more heterogeneous.

Cultivation

There were no significant relationships between cultivation method and bird densities for combined bird categories (Table 6) or among individual species except for an apparent

association between swallow
Foraging densities and GAP treatments (Table 7). In general, the effects of cultivation method are difficult to assess given a lack of consistent relationships between treatment and bird densities.

5. RELATIONSHIPS BETWEEN BIRDS, INVERTEBRATES AND PLANT SPECIES RICHNESS

There were positive correlations between both Skylark and boundary-based bird species and both beetle and spider activity densities for the SAP area as a whole (Figures 15 and 16) however these associations were generally weak and frequently inconsistent between the first and second experimental years. For Skylark, among the positive correlations between bird density and the densities of beetles, spiders and plant species richness (Figures 15 and 16), only the correlation with plants was statistically significant (Table 2). For non-Skylark species, beetle densities were significantly correlated with bird densities on fields but no other consistent relationships, between birds, invertebrates and plants was found.

In terms of responses to management treatments, the general trend for birds was for higher densities on low pesticide areas of the site, higher densities on GAP fertiliser sectors of the site and a generally equivocal response towards cultivation treatments (Table 6 & 7). This was not the case for invertebrates, where densities of both beetles and spiders were generally higher on GAP pesticide areas of the site.

.

6. DISCUSSION

In the last three years at Colworth, there has been a general increase in biodiversity on the site at least for invertebrates and birds. For birds, this has meant a real increase in breeding densities on the site, as well as an increase in bird abundance and therefore the probability of encountering a particular bird species on single visits. Birds have increased against the prevailing national trend, which is still in shallow decline following 25 years of rapid decline. Among species which form part of the “Quality of Life” national bird index for farmland (Appendix 4), 14 of the 20 on the Governments list occur regularly at Colworth (Table 5) and lapwing has begun to appear more regularly. Thus, while the breeding populations of most indicator species have at least remained stable (none have declined), those species that have increased have done so by an average of 35% in three years. This group includes Grey Partridge (albeit from just one to two breeding pairs), Skylark, Linnet and Yellowhammer that are species of national conservation concern on farmland. At this rate, and with this increasing contribution from previously declining species, the national index would probably meet its target of reversing the decline trend in the farmland bird index by the year 2020.

Changes to bird densities can operate in two ways. First, through physical alterations to breeding and foraging habitats (better breeding conditions and access to food within the landscape). Second, directly through the food chain and the provision of habitats for invertebrates and seed producing plants.

Landscape and habitat composition

A very significant proportion of the variation in bird distribution on the Colworth site is explained by existing long-term, permanent features such as the ratio of the boundaries to crop area at the site and boundary quality. Physical factors, such as well-wooded hedgerows are strong determinants of bird spatial distribution on farmland, especially for breeding territories in summer (Lakini *et al*. 1996). Thus, a higher ratio of wooded boundary to field area can be associated with increased bird densities of boundary-based species but with diminishing returns, so producing an optimum value at which bird species density and richness can be maximized. At Colworth this is close to 100 m wooded hedge per hectare of field, slightly higher than the site average of 80 m/ha. A slight increasing boundary density on the site would therefore increase mean levels of bird biodiversity per ha (for Blackbirds, Robins, Whitethroats, Linnets and Yellowhammers for example) but at the expense of Skylarks, which have a negative relationship with wooded boundary density. The site optimum for both these bird groups (boundary species and skylark) is probably about close to the optimum, given that other species, such as Lapwing or Golden Plover in winter, are potential additions to the site, given a more open aspect.

Field margins have also changed on the site, in the last three years, especially in terms of added variety in composition. Although not tested for explicitly within the current analysis, margins are important for several bird species, especially Yellowhammer (Morris *et al.* 2002). Our own studies have shown that margins and tracks are key habitats for Yellowhammers (Lang 2000), for which structural components (as opposed to plant species composition) are especially important that allows both access to food and nest sites (Morris *et al*. 2000). In addition, in winter, wild bird cover adds food to the site, although currently the main beneficiaries of plant mixes are greenfinches. A detailed recent literature on applications of wild bird cover crops and the response of bird species to mixes identifies key components, especially crops such as kale, quinoa and seeding cereals (e.g. triticale) that provide the greatest benefit to the widest range of bird species. Winter bird crops are also generally more affective when located in a warm aspect, by wooded boundaries (Boatman 2002, Henderson *et al.* in press) (Appendix 4).

For effects between field types the single most important crop on the SAP area is oilseed rape, used by a diverse number of species, including Blackbird, Whitethroat and Reed Bunting and Yellowhammer as a foraging or nesting resources. Weedy fallows were also important for bird species in both variety and abundance, supporting slightly lower densities of boundary based bird species than rape, but higher densities of Skylarks. Vining peas added further to the crop mosaic with a low-growing flowering crop that supported higher densities of Skylarks than winter wheat and, in some years, exceptionally high numbers of other bird species during the flowering period. In addition, combinations of vining peas and nearby summer fallows are the only combination of fields that are likely to attract Lapwings to the site to breed. As such, these three field types provide most of the variety of habitats required by farmland birds, including dense flowering plants, open, low-growing flowering plants, and open weedy fallows. Their retention and management is likely to have a greater impact on site bird biodiversity than that given to winter wheat, except in that winter wheat is so dominant in the area that it covers on the site.

Within crop treatments

In general, the precise diet of birds varies widely from location to location, but some key food categories that have been found in bird diets from sources beyond the Colworth SAP are shown in Table 2 for eight species. Bird densities on crops are generally very low so that, typically, species are combined on the basis of shared dietary characteristics, but at the potential risk of obscuring subtle but important underlying relationships with plants or invertebrate groups. Nevertheless, some invertebrate or plants groups are common to the diet of several birds species (see Table 2 and Table A below), from which it is possible to formulate hypotheses about expected responses of birds to treatments, through the food chain (Table A below).

Table A. A summary of farmland bird diets and predicted responses to field treatments.

	Key dietary items	Fertilisers		Pesticides		Cultivation		Mechanical weeding
Species		**Expected response**	**Observed response**	**Expected response**	**Observed response**	**Expected response**	**Observed response**	**Expected response**
Grey partridge	Grass seeds, lepidoptera and sawfly larvae and “ground” beetles.	+ive? Perhaps grasses response treatment	+	-ive. Loss of chick food, e.g. invertbrate. Larvae	?	+	?	
Skylark	Weed seed shoots and diurnal beetles.	-ive: higher crop density, loss of inverts with organic content.	+	-ive: loss of weed seeds and invertebrates	-ive	+	?	ive: if direct threat to nests or broods.
Lapwing (plovers), blackbird, song thrush, starling	Earthworms, beetles and cranefly larvae.	-ive? Long term loss of organic content	+	-ive: e.g. potential pyrethroid impact on non target species.	-ive	+ive impact of minimum tillage on earthworms	+/-	-ive: if direct threat to nests or broods.
Whitethroat	Beetles and bugs	+/-	+/-	-ive, if reduced populations of beetles and bugs especially from spray drift.	-ive	Non	?	Non
Linnet	Rape, charlock and small weed seeds.	Increase with rape, decrease in other crop habitats.	+	-ive if reduced weed-seed value in crops. +ive in rape	-ive	-ive: if weeds composition reduced	?	+/-
Reed bunting, yellowhammer	Grass seeds, lepidoptera larvae	?	?	-ive: if impact on sawfly or lepidoptera larvae	-ive	Non	?	+ive: if general invertebrate levels increased

Fertilisers

For plants, an equivocal response was probably expected given that some species would respond to high fertilisers rates and some to low rates of application, though with an expected, general loss of plant species richness. For invertebrates, the predicted response was probably as for plants, with a general expected loss of variety but not necessarily overall abundance. For birds, there was likely to be general expected negative response to GAP fertiliser rates due to lower expected range of arable weeds or attendant invertebrates available, although, some key plants species that are used by birds (such as fat hen

Chenopodium alba) respond to higher nitrogen inputs. It may be that links between taxa cannot be readily understood without specific reference to plant species (those that are important to birds) and their response to treatments. Sustainable or moderate treatments, that lie somewhere between current GAP and MIN rates, would be difficult to define without reference to specific chemical applications.

Pesticides

Although for birds there was a clear and expected general negative association with pesticide inputs, the correlations were mainly weak and also inconsistent with other taxa. Again, as for fertiliser treatments, such analyses are likely to be more productive if based on individual chemicals with known or more predictable effects on areas of the food chain. Currently the dataset for such an analyses may be too small.

Cultivation method

Predicting the effect of cultivation method on birds and possibly other taxa, is genuinely difficult and an equivocal response from “biodiversity” was not unexpected. The loss of plants species richness to MIN cultivation treatments was interesting and may help formulate stronger hypotheses for other taxa.

Acknowledgements

The authors would like to thank Jos van Oostrum (Unilever) for project management, Alan Green and Innes McEwen (Unilever) for help and advice on the Colworth Estate, and Nicola Read (BTO) for report management and secretarial assistance. The project was funded by Unilever PLC.

References

Buckingham, D.L., Evans, A.D., Morris, A.J., Orsman, C.J., & Yaxley, R. (1999) Use of set-aside in winter by declining farmland bird species in the UK. *Bird Study*, **46**, 157-169.

Chamberlain, D.E., Wilson, A.M., Browne, S.J. & Vickery, J.A. (1999) Effects of habitat type and management on the abundance of Skylarks in the breeding season. *Journal of Applied Ecology*, **36**, 856-870.

Dinter, A. (1995) Estimation of epigeic spider population densities using an intensive D-vac sampling technique and comparison with pitfall trap catches in winter wheat. In: Toft, S. & Reidel, W. (eds.) *Arthropod natural enemies in arable land I. Acta Jutlandica*, **70**, 23-32.

Donald, P.F. & Evans, A.D. (1994) Habitat selection by Corn Buntings *Miliaria calandra* in winter. *Bird Study*, **41**, 199-210.

Dover, J.W., Sotherton, N.W. & Gobbett, K. (1990) Reduced pesticide inputs on cereal field margins: the effects on butterfly abundance. *Env. Entomology*, **15**, 17-24.

Edwards & Bohlen (1995) *The Biology and Ecology of Earthworms*. Kluwer Academic Publishers.

Harwood, J.D., Sunderland, K.D. & Symondson, W.O.C. (2001) Living where the food is: web location by linyphiid spiders in relation to prey availability in winter wheat. *Journal of Applied Ecology*, **38**, 88-99.

Hawthorne, A. & Hassall, M. (1995) The effect of cereal headland treatments on carabid communities. In: Toft, S. & Reidel, W. (eds.) *Arthropod natural enemies in arable land I. Acta Jutlandica*, **70**, 185-198.

Henderson, I.G., Critchley, N.R., Cooper, J. & Fowbert, J. (in press) Breeding season responses of Skylarks *Alauda arvensis* to vegetation structure in set-aside (fallow arable land). *Ibis.*

Henderson, I.G., Cooper, J., Fuller, R.J. & Vickery, J. (2000a). The relative abundance of birds on set-aside and neighbouring fields in summer. *Journal of Applied Ecology*, **37**, 335-347.

Henderson, I.G., Vickery, J.A, & Carter, N. (In press) The use of winter bird crops on farmland by seed-eating and insectivorous species in lowland England. *Biol. Conserv.*

Henderson, I.G., Vickery, J.A. & Fuller, R.J. (2000b) Summer bird abundance and distribution on set-aside fields on intensive arable farms in England. *Ecography*, **23**, 50-59.

Idinger, J., Kromp, B. & Steinberger, K.-H. (1996) Ground photoelector evaluation of the numbers of carabid beetles and spiders found in and around cereal fields treated with either inorganic or compost fertilisers. In: Booij, C.J.H. & den Nijs, L.J.M.F. (eds.) *Arthropod natural enemies in arable land II. Acta Jutlandica*, **71**, 255-267.

Jenkins, D. (1984) *Agriculture and the Environment.* Proceedings of the 13th ITE symposium. Institute of Terrestrial Ecology, Cambridge.

Lack, P.C. (1986) *The Atlas of Wintering Birds in Britain and Ireland*. Poyser, Carlton.

Lang, D. (2001) Yellowhammers and sustainable agriculture: responses to variable pesticide load, fertiliser application, cultivation method and crop type MSc submitted to the University of East Anglia.

Marchant, J.H., Hudson, R., Carter, S.P. & Whittington, P. (1990) *Population Trends in Breeding British Birds*. British Trust for Ornithology, Tring.

Potts, G.R. (1991) The environmental and ecological importance of cereal fields. In: Firbank, L.G., Carter, N., Darbyshire, G.F. & Potts G.R. (eds) *The ecology of temperate cereal fields. 32nd symposium of British Ecological Society*: 3-21. Blackwell, Oxford.

Rands, M.R.W. (1985) Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. *Journal of Applied Ecology*, **22**, 49-54.

Rands, M.R.W. (1986) The survival of gamebird (Galliformes) chicks in relation to pesticide use on cereals. *Ibis*, **128**, 57-64.

Rands, M.R.W. & Sotherton, N.W. (1986) Pesticide use on cereal crops and changes in the abundance of butterflies on arable farmland. *Biological Conservation*, **36**, 71-82.

de Snoo, G.R., van der Poll, R.J. & de Leeuw, J. (1995) Carabids in sprayed and unsprayed crop edges of winter wheat, sugar beet and potatoes. In: Toft, S. & Reidel, W. (eds.) *Arthropod natural enemies in arable land I. Acta Jutlandica*, **70**, 185-198.

Schön, M. (1999) Zur Bedeutung von Kleinstrukturen im Ackerland: Bevorzugt die Feldlerche (*Alauda arvensis*) Störstellen mit Kümmerwuchs? *J. Ornithol*, **140,** 87-91.

Thomas, C.F.G., Parkinson, L., Griffiths, G.J.K., Fernandez Garcia, A. & Marshall, E.J.P. (2001) Aggregation and temporal stability of carabid beetle distributions in field and hedgerow habitats. *Journal of Applied Ecology*, **38**, 100-116.

Topping, C.J. & Sunderland, K.D. (1995) Methods for monitoring aerial dispersal by spiders. In: Toft, S. & Reidel, W. (eds.) *Arthropod natural enemies in arable land I. Acta Jutlandica*, **70**, 245-256.

Tucker, G.M. (1992) Effects of agricultural practices on field use by invertebrate-feeding birds in winter. *Journal of Applied Ecology*, **29,** 779-790.

Ulber, B. & Wolf-Schwerin, G. (1995) A comparison of pitfall trap catches and absolute density estimates of carabid beetles in oilseed rape fields. In: Toft, S. & Reidel, W. (eds.) *Arthropod natural enemies in arable land I. Acta Jutlandica*, **70**, 77-86.

Wakeham-Dawson, A. & Aebischer, N.J. (1998) Factors determining winter densities of birds on Environmentally Sensitive Area arable reversion grassland in southern England, with special reference to Skylarks (*Alauda arvensis*). *Agriculture, Ecosystems & Environment*, **70**, 189-201.

Wilson, J.D., Evans, J., Browne, S.J. & King, J.R. (1997) Territory distribution and breeding success of Skylarks *Alauda arvensis* on organic and intensive farmland in southern England. *Journal of Applied Ecology*, **34**, 1462-1478.

Table 1. Field dimensions (size ha) and details of the seven year crop rotation at Colworth. Crop varieties for 2003/2003 are: 1^{st} WW= Claire, $2^{nd}/3^{rd}$ WW = Consort, SpW= Paragon, WOSR = Canberra; SpOSR= Senita, V.Peas= TBC.

Field no.	**37-40**	**39**	**41**	**43**	**45**	**42**	**44-46**	**47**
Size (ha)	*9.5*	*3.0*	*5.18*	*9.00*	*9.00*	*8.11*	*8.68*	*8.57*
1999/2000	WOSR	1^{st} WW	2^{nd} WW	2^{nd} WW	V. Peas	1^{st} WW	1^{st} WW	2^{nd} WW
2000/2001	1^{st} WW 1^{st} SpW	2^{nd} WW	3^{rd} WW	V. Peas	1^{st} WW 1^{st} SpW	2^{nd} WW	SAS	WOSR
2001/2002	SAS	V. Peas	V. Peas	1^{st} WW	2^{nd} WW 2^{nd} SpW	WOSR SpOSR	1^{st} WW	1^{st} WW
2002/2003	**1^{st} WW 1^{st} SpW**	**1^{st} WW**	**1^{st} WW**	**2^{nd} WW**	**WOSR SpOSR**	**1^{st} WW**	**V. Peas**	**SAS**
2003/2004	V. Peas	2^{nd} WW	2^{nd} WW	WOSR	1^{st} WW 1^{st} SpW	SAS	1^{st} WW	1^{st} WW
2004/2005	1^{st} WW 1^{st} SpW	WOSR	WOSR	1^{st} WW	SAS	1^{st} WW	2^{nd} WW	V. Peas
2005/2006	2^{nd} WW 2^{nd} SpW	1^{st} WW	1^{st} WW	SAS	1^{st} WW 1^{st} SpW	V. Peas	WOSR	1^{st} WW

Table 2. The principal diet (and status at Colworth) of eight representative bird species on the Colworth SAP area. Dietary information is drawn from the literature (NB. ++ item is means especially well represented in at least one study). In brief, favoured broad-leaved plants include fat hen and goosefoots *Chenopodium* species, hawksbits, hawhweeds and thistles (Compositae), knotgrass (Poygonum) chickweeds & campions (Charophyllacae), clovers & vetches (Fabacae) and docks & sorrels *Rumex* species. Among grasses, annuals such as annual meadow grass *Poa annua* and various fescues *Festuca* species may be important as food for birds and as a refuge for invertebrates.

Species	Local status	Basic habitat preferences	Identified plant and animal food	
			Winter	Summer
Grey Partridge	Uncommon	Tall sparse grassland	Grass, cereals and clovers (leaves); knotgrass++.	Sawfly, grass-moth larvae; Beetles (leaf–beetles and weevils adults); Seeds – Chickweeds/campions, grasses (e.g Poa annua).
Lapwing	Non breeding and scarce in winter	Short vegetation or bare ground.	Earthworms	Earthworms ++; Ground beetles; moth larvae; grasshoppers; ants.
Skylark	Low breeding density in cereals, scarce in winter.	Short vegetation or bare ground	Cereal grain & leaves, knotgrass.	Leaf–beetles, weevils & ground beetles (adults). Veg: Chickweeds, Poa grasses, fat hen (autm).
Song Thrush	Present but not common on the farmed habitats.	Shady cover, damp margins, non-cereal crops.	Earthworms & Cepea & Helix snails. Autumn: fruit	Cepea snails, also beetles; Moth & butterfly larvae; earthworms.
Blackbird	Common and widespread	Fields, margins and shady cover.	Seeds, berries, slugs, earthworms and beetles adults and larvae.	Earthworms, beetles and lepidoptera adults and larvae.
Whitethroat	Common and widespread	Brambles, rank vegetation, low hedges or scrub.	Insects and spiders	Espec. Beetles (Coleoptera) and bugs (Hemiptera).
Linnet	Scarce	Weedy stubbles, crops or margins. Oilseed rape.	Cruciferae (charlock, shepherd's-purse), knotgrass.	Cruciferae; knotgrass, fat hen, goosefoots, dandelions, thistles, hawksbeards.
Yellowhammer	Often recorded but not common	Cereals, grasses and larger weed seeds (apparently not crucifers, e.g. rape).	Cereal grain, grass seeds (e.g. Fescues, Lolium & Poa spp.) (Compositae for beetles). Autumn= beetles, grass seeds & fruit seeds.	Moth & butterfly larvae; spiders; weevils & ground beetles (adults) to chicks (++); Grasshoppers.

Table 3. The mean diversity and abundance / activity-densities of biodiversity groups in the sections of the fields at Colworth in 2001 & 2002.

	Mean weed diversity		Mean weed abundance		Mean spider diversity		Mean spider activity-density		Mean carabid diversity		Mean carabid activity-density		Mean staphylinid diversity		Mean staphylinid activity-density	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**
37-40a	5.8	3.5	28.0	42.3	3.4	6.6	6.8	24.5	3.8	5.3	27.9	40.7	1.7	2.1	2.3	3.0
37-40b	5.1	2.8	34.0	42.1	4.5	11.0	8.1	65.3	2.9	6.8	21.8	45.5	1.3	1.6	2.3	2.0
37-40c	6.4	2.5	45.0	-	5.8	9.2	15.3	52.1	4.5	3.5	32.4	14.5	2.0	1.1	4.5	1.2
37-40d	4.2	2.4	59.0	-	4.5	10.0	9.1	38.5	5.5	4.8	35.1	22.8	3.7	2.1	18.3	3.0
39a	7.8	7.3	43.4	81.6	-	7.5	-	30.4	-	5.9	-	18.2	-	3.2	-	14.4
39b	5.9	7.2	23.8	69.6	-	7.3	-	20.5	-	5.7	-	20.0	-	3.7	-	10.8
39c	3.1	3.5	11.4	14.6	-	6.0	-	22.5	-	4.2	-	42.8	-	3.5	-	11.8
39d	2.6	3.3	9.3	13.4	-	5.8	-	17.0	-	3.7	-	39.0	-	2.7	-	7.4
41a	8.3	6.5	56.0	48.3	5.1	5.1	13.7	16.4	4.5	3.3	28.4	14.3	1.2	2.1	2.5	6.0
41b	8.4	9.9	45.0	89.0	5.5	6.1	17.5	21.0	4.1	4.3	18.4	22.1	1.4	2.7	3.5	8.1
41c	2.5	3.6	33.0	30.4	4.9	7.1	10.6	30.8	3.4	4.3	13.8	44.1	0.9	3.3	3.2	12.0
41d	2.4	4.4	21.0	55.1	4.7	6.1	8.6	26.0	3.3	4.6	10.2	42.0	1.0	3.5	2.6	15.2
42a	3.6	6.7	17.0	73.1	4.1	4.9	9.3	14.0	3.6	2.5	10.9	8.2	1.0	1.5	2.6	4.5
42b	4.6	3.3	87.0	21.0	4.6	7.9	8.6	29.8	3.8	7.0	11.8	35.9	1.2	3.5	1.6	8.6
43a	2.5	1.4	13.0	1.9	4.1	5.1	7.2	31.7	2.6	5.1	41.5	30.5	1.4	2.5	3.3	4.4
43b	2.0	0.5	17.0	0.5	4.2	5.3	8.5	24.5	3.1	5.9	53.7	35.2	1.6	2.5	4.2	4.6
43c	2.5	1.0	29.0	7.1	3.8	5.0	6.6	27.0	3.1	5.7	53.5	32.6	1.4	2.6	4.3	6.1
43d	3.8	3.1	38.0	13.0	3.8	6.2	7.4	32.7	2.5	5.6	40.7	27.7	1.2	2.9	2.6	5.8
44-46a	2.6	2.0	35.0	4.1	5.0	5.3	13.7	13.7	2.9	4.4	8.7	16.0	0.5	2.0	0.5	5.7
44-46b	2.0	2.1	32.0	3.9	5.0	6.2	17.6	21.1	2.0	4.9	3.5	22.7	0.9	1.5	1.1	5.3
45a	3.3	1.5	24.0	4.5	-	-	-	-	-	-	-	-	-	-	-	-
45b	3.3	1.6	111.0	3.4	-	-	-	-	-	-	-	-	-	-	-	-
45c	4.0	5.8	24.0	47.9	-	-	-	-	-	-	-	-	-	-	-	-
45d	2.5	3.1	18.0	108.0	-	-	-	-	-	-	-	-	-	-	-	-
47a	2.5	0.8	8.4	10.6	-	-	-	-	-	-	-	-	-	-	-	-
47b	2.1	0.9	17.0	14.0	-	-	-	-	-	-	-	-	-	-	-	-
47c	2.1	0.8	5.1	4.9	-	-	-	-	-	-	-	-	-	-	-	-
47d	2.4	0.3	9.7	0.9	-	-	-	-	-	-	-	-	-	-	-	-
Overall	**3.9**	**3.3**	**31.9**	**31.0**	**4.6**	**6.7**	**10.5**	**28.0**	**3.5**	**4.9**	**25.8**	**28.7**	**1.4**	**2.5**	**3.7**	**7.0**

Table 4. Number of invertebrate species recorded at Colworth 2000-2002. Entries are species recorded from pitfalls. Entries in brackets are totals including sweep-netting.

	Number of species in each year			**Cumulative number of species**	
	2000	2001	2002	2000-2001	2000-2002
Spiders	58	57 (71)	55 (66)	72 (86)	82 (95)
Carabids	41	41	49	50	57
Staphylinids	42	40	48	54	64

Table 5. Change in status of birds recorded in summer on the SAP area and adjoining boundaries. (BAP) refers to species of high conservation concern, usually associated with national biodiversity action plans; (I) refers to species contributing to the national indicator for farmland bird; (W) refers to species analyses within a "woodland" group of birds, that infrequently forage on the ground and that are least likely to be affected by changes in agricultural management.

Species		**Breeding pairs**				**Mean no. birds per visit**				**Recent national trend**
		2000	**2001**	**2002**	**Trend**	**2000**	**2001**	**2002**	**Trend**	
Buzzard	*Buteo buteo*	0	0	1?	+	0	0	1	+	+
Sparrowhawk	*Accipiter nisus*	0	0	0	=	0.3	0.3	0.3	=	=
Hobby	*Falco subbuteo*	0	0	1?	+	0	0	1	+	+
Kestrel(I)	*Falco tinnunculus*	1	1	1	=	0	1	1	+	-
Grey Partridge(BAP, I)	*Perdix perdix*	1	1	2	+	1	1	6	+	-
Red-legged Partridge	*Aclectoris rufa*	1	1	1	=	1	2	2	+	+
R-necked Pheasant	*Phasianus colchicus*	1	1	1	=	1	1	6	+	=
Lapwing(BAP, I)	*Vanellus vanellus*	0	0	0	=	0	0	3	+	-
Woodpigeon(I)	*Columba palumbus*	20?	20?	20?	=	17	12	21	+	+
Stock Dove(I)	*Columba oenas*	4	3	5	+	4	4	4	=	+
Turtle Dove(BAP, I)	*Steptopelia turtur*	1	1	1	=	0.3	0.3	0.3	=	-
Cuckoo	*Cuculus canorus*	1	1	1	=	1	0	1	=	-
Little Owl	*Athene noctus*	1	1	1	=	0	0	1	+	=
GS Woodpecker (W)	*Dendrocopus major*	2	2	2	=	1	1	2	+	+
Green Woodpecker	*Picus viridus*	1	1	2	+	1	1	2	+	+
Skylark(BAP, I)	*Alauda arvensis*	13	13	17+	+	24	18	28	+	-
Swallow	*Hirundo rustica*	1	1	1	=	1	2	1	=	+
Pied Wagtail	*Motacilla alba*	1	1	1	=	1	1	1	=	=
Dunnock	*Prunella modularis*	11	13	15	+	4	5	7	+	-
Wren(W)	*Trogolodytes trogolodytes*	16	19	16	=	8	9	8	=	=
Robin(W)	*Erithacus rubecula*	17	17	20	+	13	10	13	+	-
Blackbird	*Turdus merula*	9	8	8	-	7	8	12	+	-
Song Thrush(BAP)	*Turdus philomelos*	2	3	3	+	1	2	1	=	-
Lesser Whitethroat(W)	*Sylvia curruca*	3	3	1	-	2	2	2	=	-
Whitethroat(I)	*Sylvia communis*	11	14	12	=	11	8	13	+	=
Garden Warbler(W)	*Sylvia borin*	0	2	1	=	0	1	1	+	-
Blackcap(W)	*Sylvia atricapilla*	6	4	3	-	4	2	3	-	-
Willow warbler	*Phylloscopus trochilus*	6	8	8	+	3	7	4	+	-
Chiffchaff(W)	*Phylloscopus collybita*	1	2	3	+	1	1	2	=	=
Nuthatch(W)	*Sitta europaca*	3	2	3	=	1	0	1	=	+
Treecreeper	*Certhia familiaris*	2	3	2	=	2	1	2	+	=
Blue Tit(W)	*Parus caerulus*	10	10	10	=	14	7	13	=	+
Great Tit(W)	*Parus major*	8	8	8	=	7	8	7	=	+
Marsh Tit(W)	*Parus palustris*	3	2	3	=	6	1	8	+	-
Long-tailed Tit(W)	*Aegiathos caudatus*	2	2	2	=	2	2	6	+	+
Carrion Crow	*Corvus corone*	2	2	2	=	3	2	2	-	+
Jackdaw(I)	*Corvus monedula*	4	4	4	=	1	1	4	+	+
Rook	*Corvus frugilegus*	0	0	0	=	0	1	1	+	+
Jay(W)	*Garulus glandarius*	2	2	2	=	1	2	2	+	-
Magpie	*Pica pica*	2	2	2	=	2	1	1	-	+
Bullfinch(BAP, I)	*Pyrrhula pyrrhula*	2	2	3	+	1	3	3	+	-
Goldfinch(I)	*Caruelis carduelis*	1	1	1	=	1	1	1	=	=
Greenfinch(I)	*Carduelis chloris*	2	3	3	+	1	3	1	=	=
Linnet(BAP, I)	*Carduelis cannabina*	5	7	8	+	6	3	5	-	-
Chaffinch	*Fringilla coelebs*	15	15	15	=	12	11	11	-	+
Reed Bunting(BAP, I)	*Emberiza schoeniclus*	2	3	3	+	2	3	4	+	-
Yellowhammer(BAP, I)	*Emberiza citrinella*	12	14	16+	+	12	18	23	+	-
Total		**208**	**224**	**235**	+	**182.6**	**168.6**	**242.6**	+	-
No. of species		**41**	**42**	**42/44?**						

Also occasional records of: mallard*, collared dove*, meadow pipit, redstart, goldcrest*, sedge warbler*, spotted flycatcher(W)*, mistle thrush*, coal tit(W)*, starling*, house sparrow*, lesser redpoll*, crossbill and corn bunting(BAP, I). Species marked * may breed locally but were not confirmed as such for the SAP or immediately adjacent habitats.

Table 6. The results of regression analyses showing factors affecting the distribution of birds at Colworth. These include field and boundary variables and within field treatments.

Skylark						
Variables	**Chi-square**	***P***	**d.f.**	**Dispersion**	**Preference summary**	**Highest density relative to WW**
Field (crop) type	138.5	0.001	5	1.67	GW, VP, RA, SW, WW, CS	GW=45.8
Field location	67.1	0.01	7	0.99	37,43,42,41,45,47,44,39	
Fertilisers (all crops)	4.18	0.04	1	2.2	GAP	2.5
(winter wheat only)	3.69	0.05	1	1.2	MIN	1.45
Pesticides (all crops)	6.68	0.02	1	2.2	MIN	0.45
(winter wheat only)	0.11	ns	1	1.2	MIN	1.16
Cultivation (all crops)	26	ns	1	2.2	GAP	2.14
(winter wheat only)	1.5	ns	1	1.2	MIN	1.42
Boundary variables	*Correlation*					
height	-0.1	0.001				
BAR	see Fig. 10					
Other species on fields						
Field (crop) type	144.2	0.001	5	0.4	RA, GW, SW, VP, WW, CS	RA=6.9
Field location	240.8	0.001	7	0.35	37,47,41,39,45,42,44,43	
Fertilisers (all crops)	4.12	0.05	1	1.04	GAP	1.84
(winter wheat only)	7.6	0.005	1	0.45	GAP	7.69
Pesticides (all crops)	8.21	0.004	1	1.04	MIN	1.77
(winter wheat only)	0.45	ns	1	0.45	MIN	1.76
Cultivation (all crops)	1.2	ns	1	1.04	GAP	1.25
(winter wheat only)	0.5	ns	1	0.45	MIN	1.76
Boundary variables	*Correlation*					
height	0.1	0.001	23			
BAR	see Fig 10					

NB. for field location field 37=field 37-40, field 44=field 44-46.

Table 7. Showing trends towards GAP or MIN treatments of fertilisers, pesticides or cultivation techniques for a range of bird species using farmland. Only those denoted * are statistically significant at *P*<0.05.

	Fertiliser		Pesticides		Cultivation	
Species	Baseline	Point counts	Baseline	Point counts	Baseline	Point counts
Grey partridge	GAP	GAP	MIN	GAP	MIN	GAP
Wood pigeon		GAP		MIN		MIN
Skylark	MIN	GAP*	MIN	MIN*	MIN	GAP
Swallow	GAP	GAP	MIN	MIN	GAP	GAP*
Dunnock	GAP	GAP	MIN	MIN	MIN	GAP
Pied wagtail	GAP		MIN		GAP	
Yellow wagtail	MIN		MIN		MIN	
Blackbird	GAP	GAP	MIN	GAP	GAP	MIN
Whitethroat	GAP	GAP	GAP	MIN	MIN	MIN
Carrion crow	GAP	GAP	MIN	MIN	MIN	GAP
Starling		GAP	MIN			GAP
Chaffinch		GAP				
Linnet	GAP	GAP	MIN*	MIN*	GAP	GAP
Reed bunting	GAP	GAP	GAP	GAP	GAP	MIN
Yellowhammer	GAP	MIN	GAP	GAP	MIN	MIN

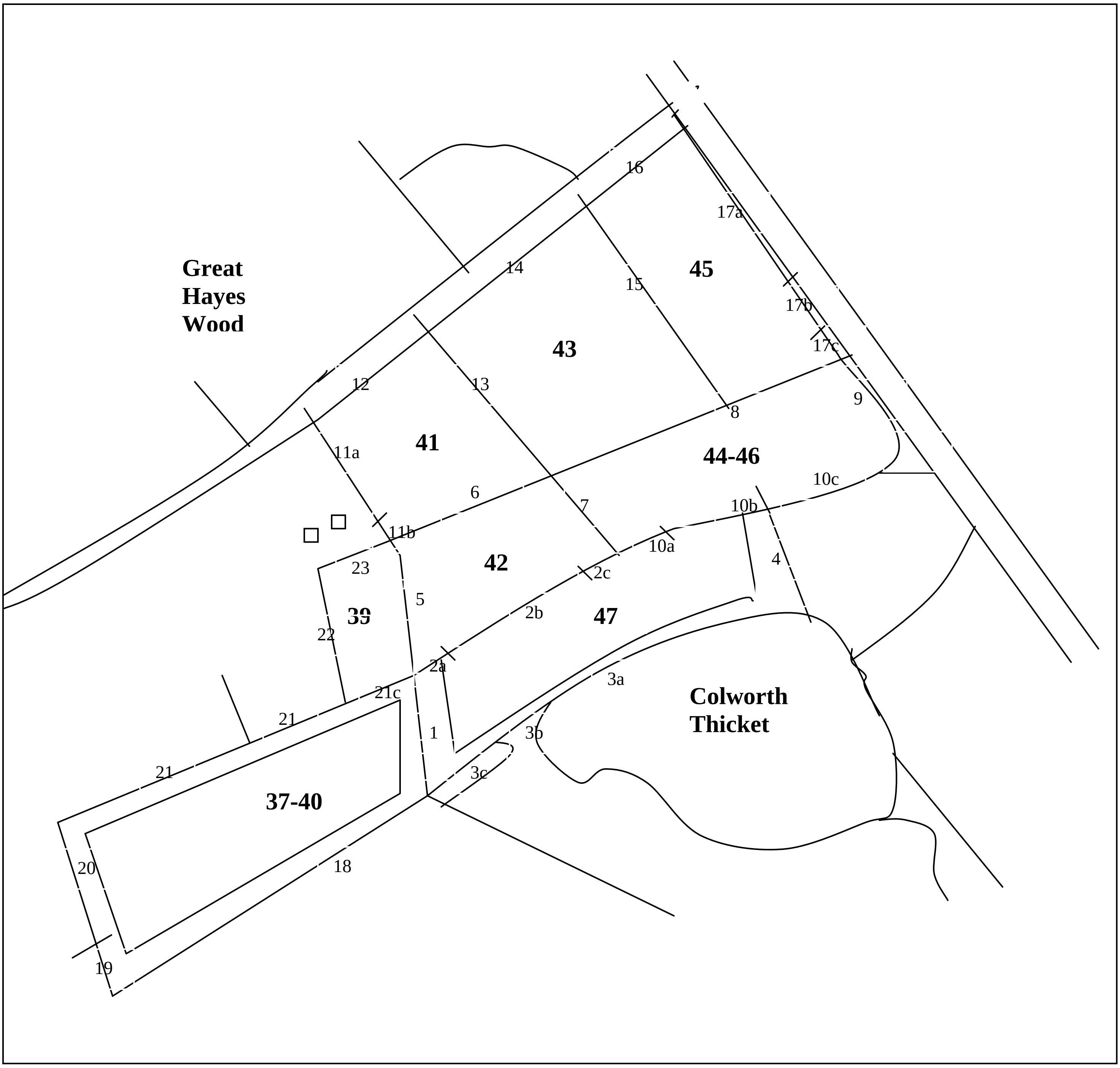


Figure 1. Schematic representation of Colworth SAP with fields in bold and boundaries labeled 1 to 23.

Figure 2. The experimental design of field treatments applied to the SAP area in summer 2001 and 2002. The precise varies from year to year depending on the content of the field under study. However, the basic format included normal (GAP) or low (SUS or MIN) applications of fertilisers and pesticides, as well as deep plough (GAP) or minimum (SUS) methods of tillage.

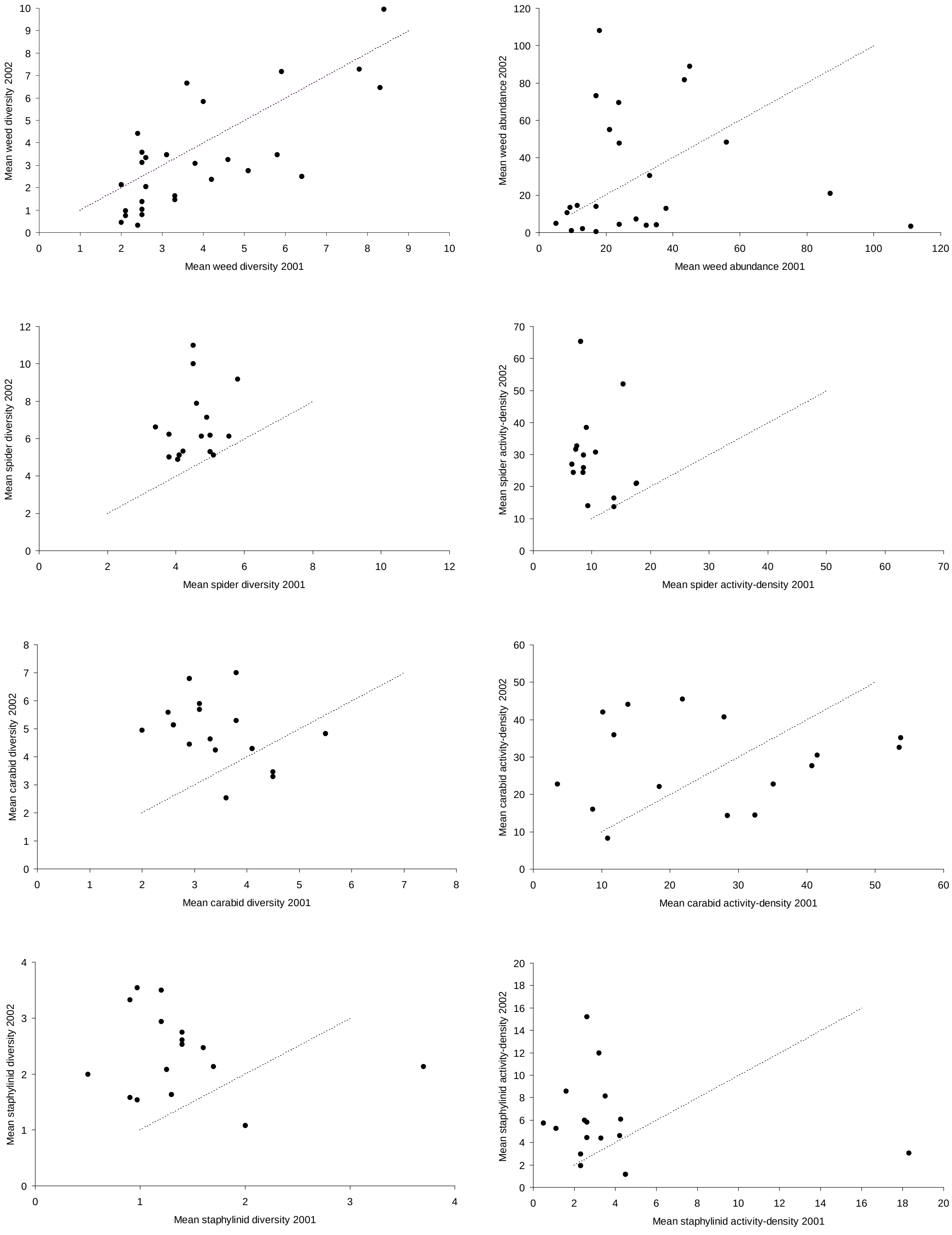


Figure 3. The relationships between the diversity and abundance of biodiversity groups recorded in 2001 and 2002 in the sections of the fields at Colworth. Diversity is the mean number of species recorded per quadrat ($1m^2$) or pitfall and abundance and activity-density is the mean number of plants or invertebrates recorded per quadrat or pitfall. The dashed line indicates parity.

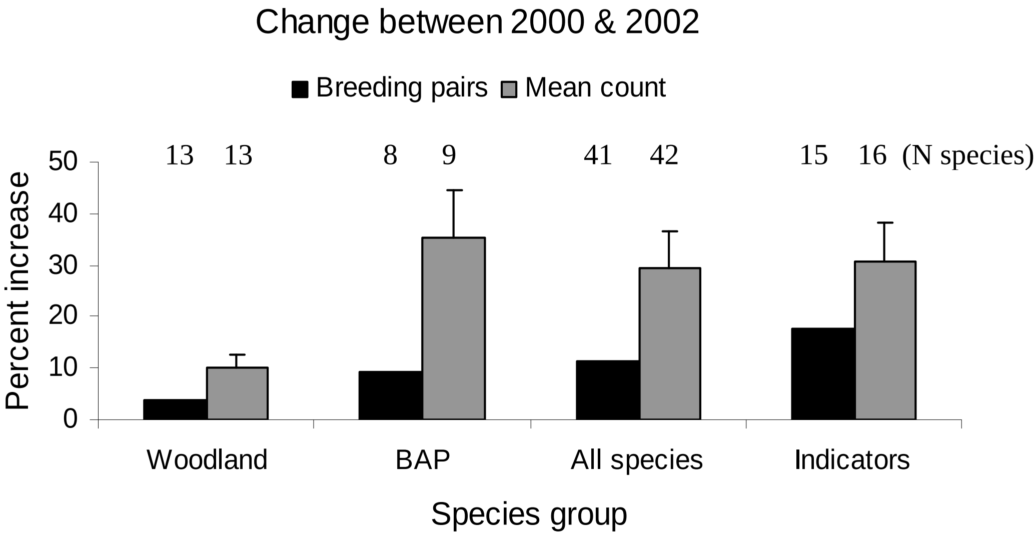


Figure 4. Mean densities of five bird groups on field types in winter, relative to winter wheat (on which the density =1) across all three winters combined (i.e. 1999/2000, 2000/2001 & 2002/2002. Insectivores include Blackbird, Song Thrush, Pied Wagtail and Meadow Pipit; finches include Goldfinch, Greenfinch, Linnet and Chaffinch; buntings include Yellowhammer and Reed Bunting. *indicates a significant difference compared to winter cereals where P<0.05.

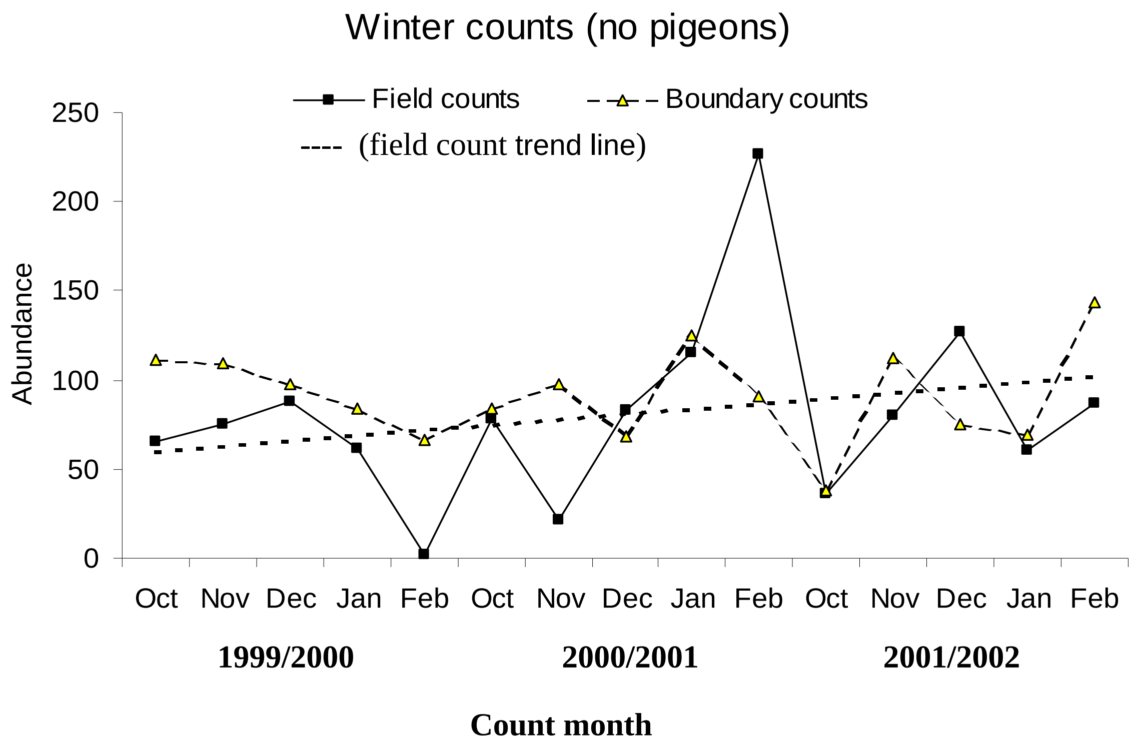


Figure 5. Time series trend showing the total number of birds recorded using fields and boundaries on the SAP area in each month between October and February for three consecutive winters (1999/2000, 2000/2001 & 2002/2002). These data exclude Woodpigeons since a single flock can overwhelm the combined data set. The effect of including Woodpigeons on the overall trend is discussed in the text (Results section).

Increas **Pea** **Declining**

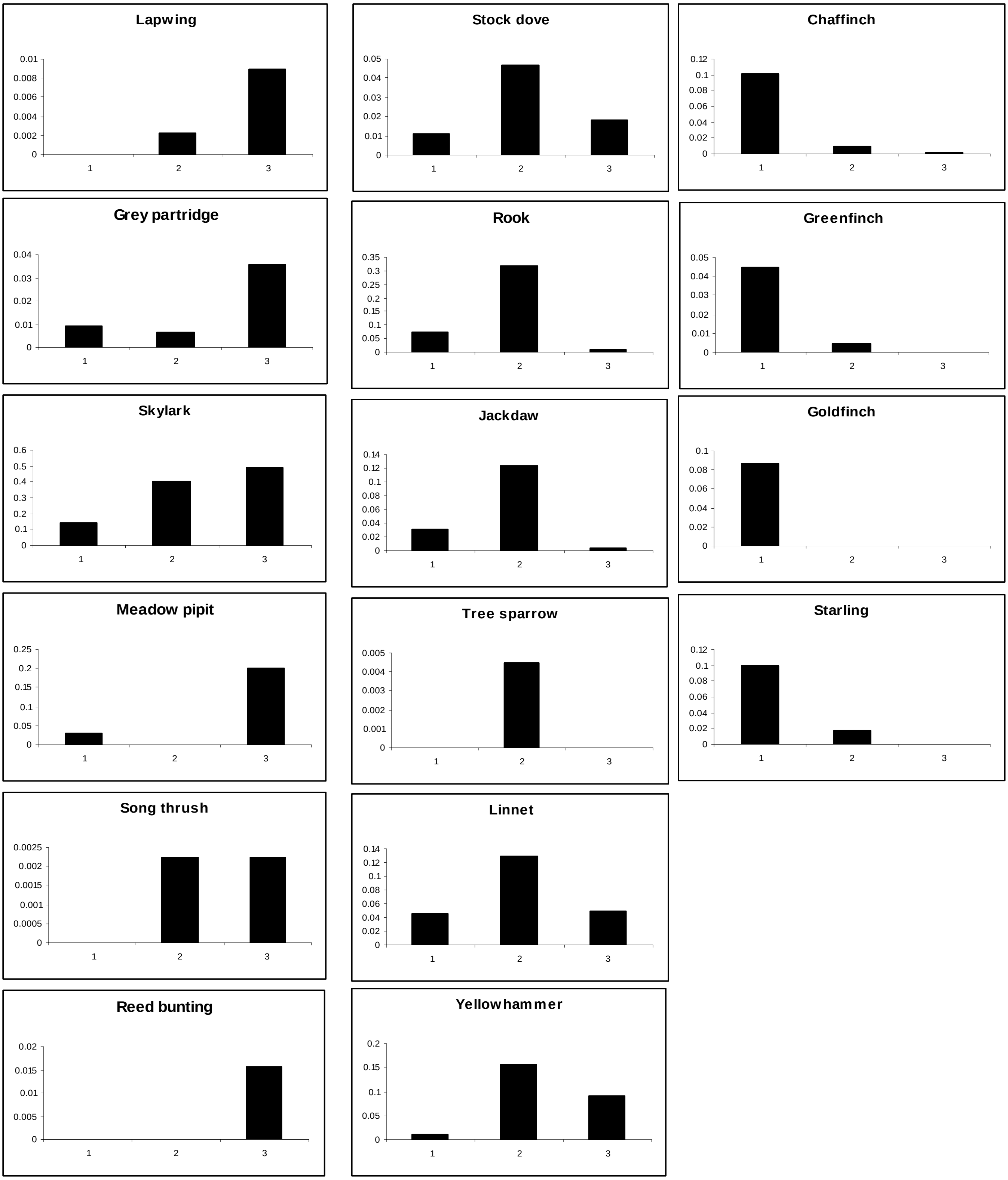


Figure 6. Mean densities of 16 bird species on the SAP area for three consecutive winters (1= 1999/2000, 2=2000/2001 and 3=2002/2002, showing increasing (column 1) peaking (column 2) and decreasing (column 3) trends.

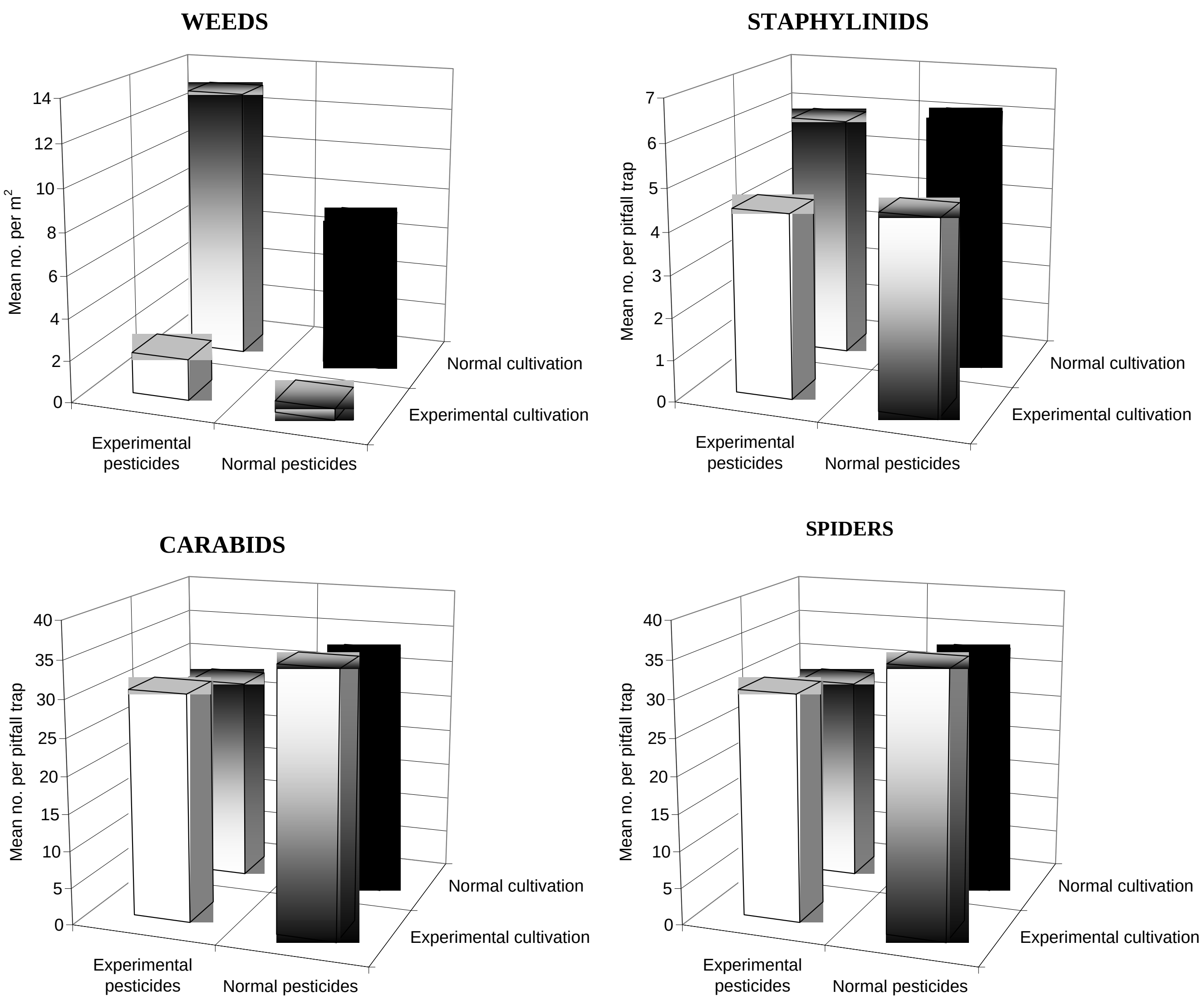


Figure 7. The mean abundance of weeds and activity-densities of invertebrates in field 43.

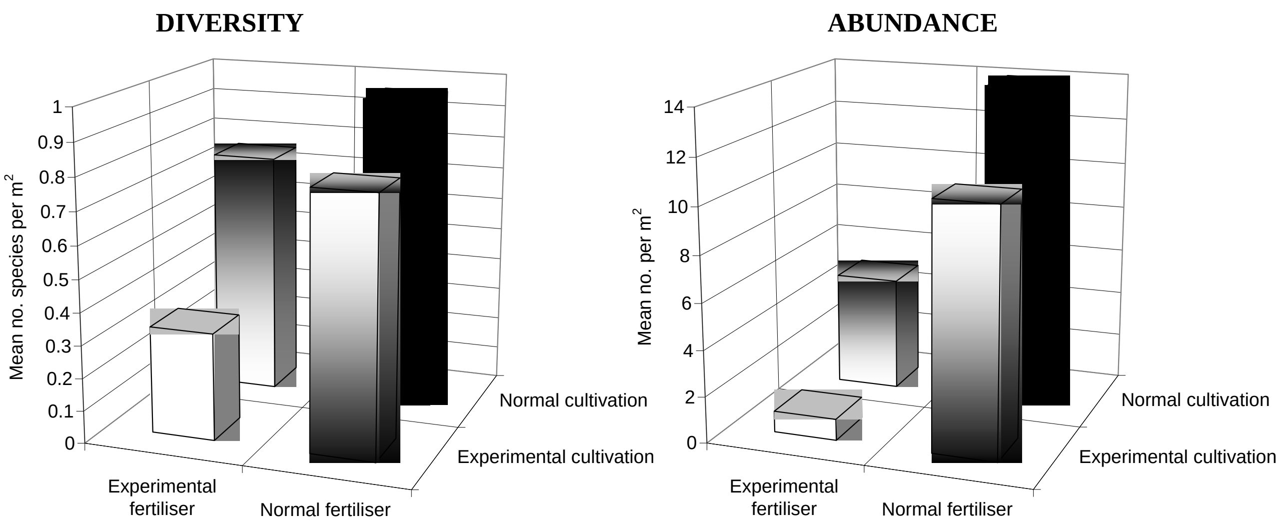


Figure 8. The mean diversity and abundance of weeds in field 47.

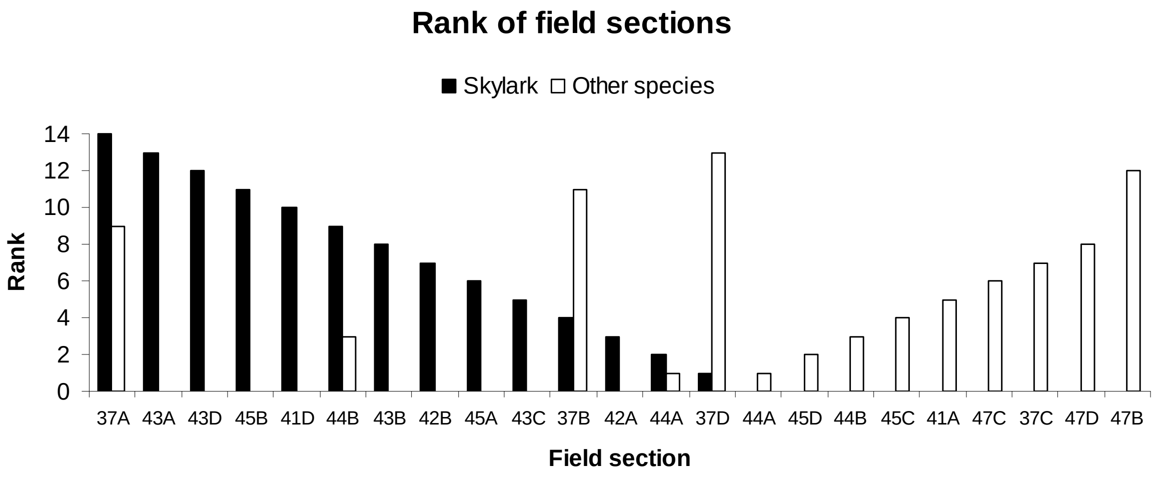


Figure 9. (a) shows the preference rank of field sections (see Figure 2) for Skylarks and non-Skylark species respectively, for which the preferences are largely mutually exclusive.

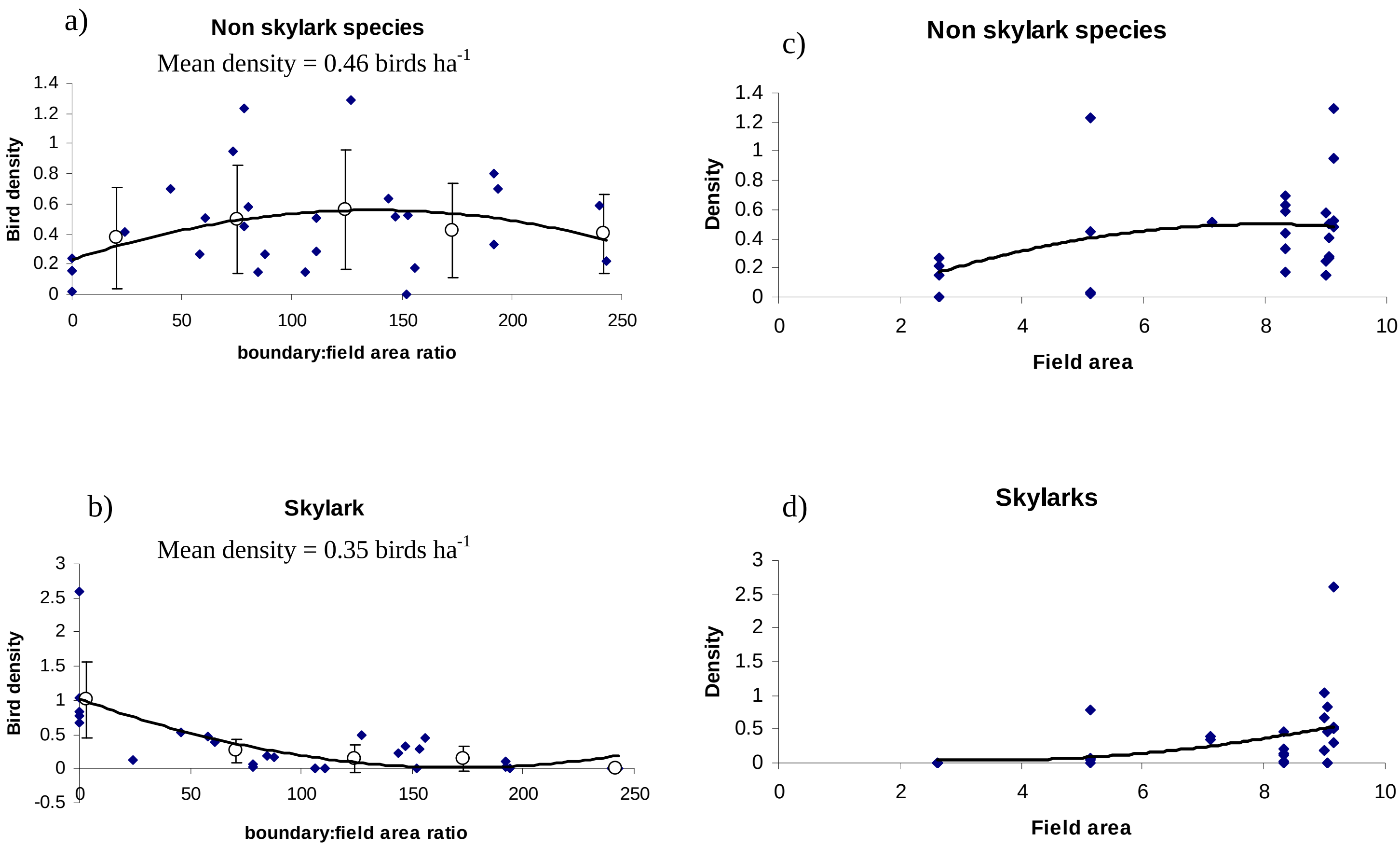


Figure 10. Relationships with field geometry: Graphs (a) and (b) show the relationship between bird density and boundary to field area ratio for non-Skylarks species and Skylarks respectively. Figures include means densities (open circles) with error bars (1 x SD). Graphs (c) and (d) show the relationship between bird densities and field area for non-Skylark species and Skylarks respectively.

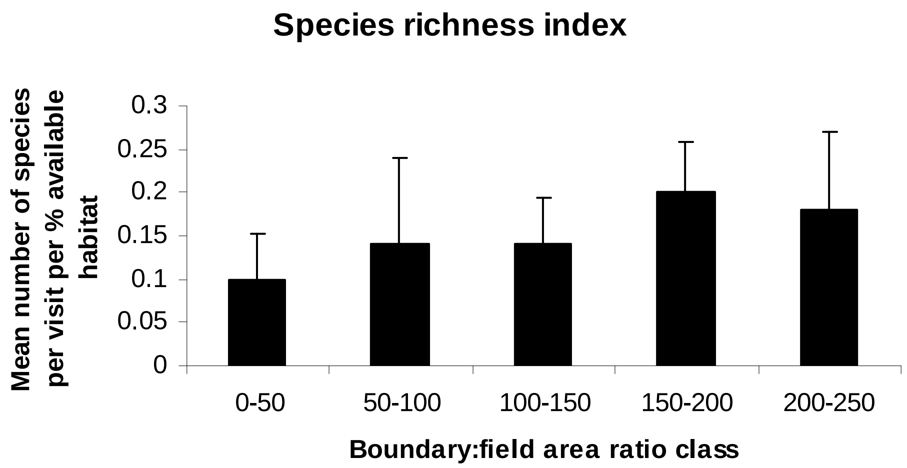


Figure 11. Mean species richness in bird in relation to the proportion of wooded-boundary per field area (i.e. increasing hedgerow density). Error bars= standard error.

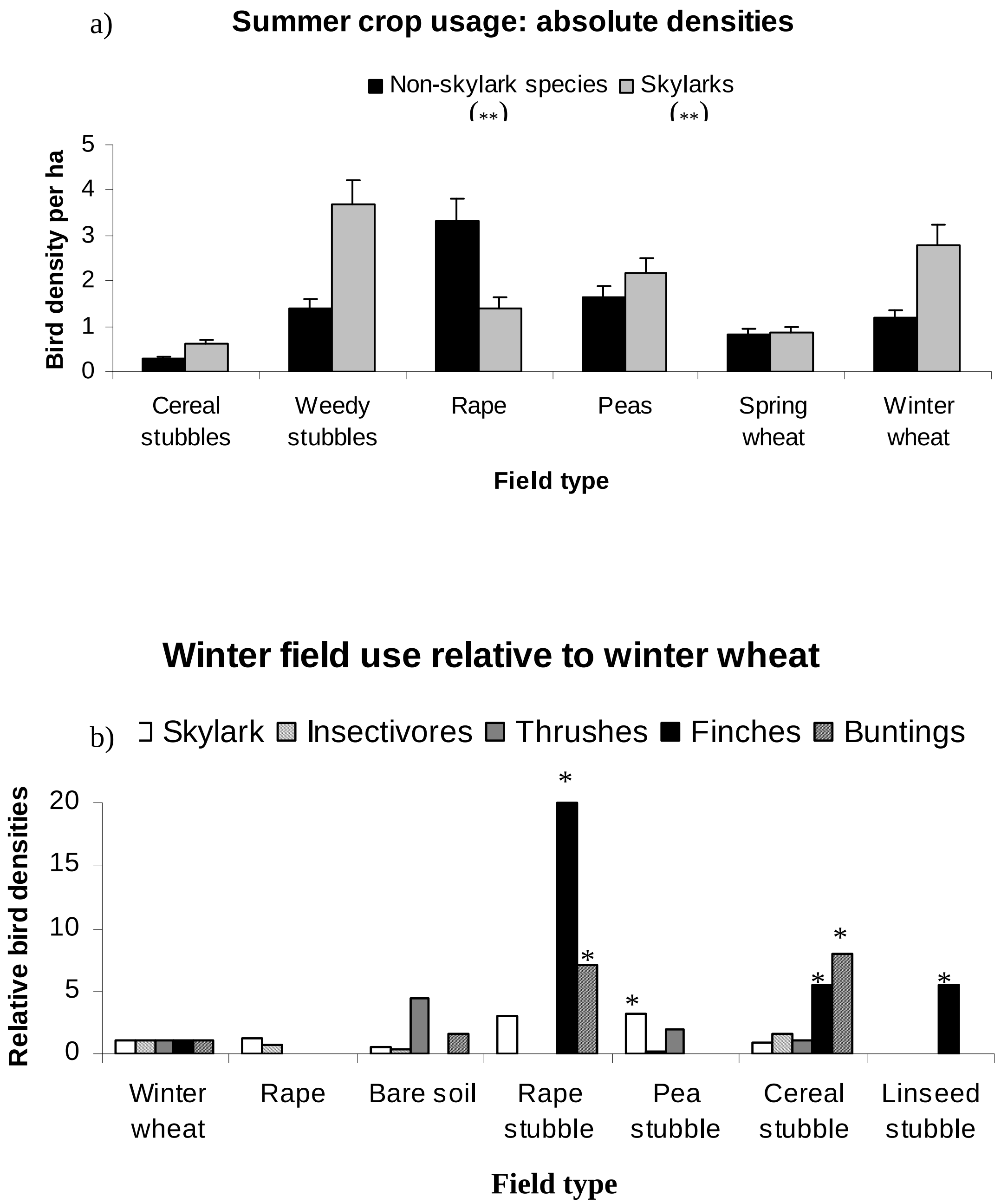


Figure 12. (a) Summer mean densities of bird (non-Skylarks are thrushes, Whitethroat, finches and buntings) on field types where ** denotes significant difference (P<0.001) across field types. (b) Relative mean densities of five bird groups in relation to field type from data combined over three winters (1999/2000, 2000/2001 and 2002/2002). The densities given here are relative to winter wheat for which the density is 1, with significant differences indicated as (*). Insectivores include: Blackbird, Song Thrush, Pied Wagtail and Meadow Pipit; finches include: Goldfinch, Greenfinch, Linnet and Chaffinch; buntings include: Yellowhammer and Reed Bunting.

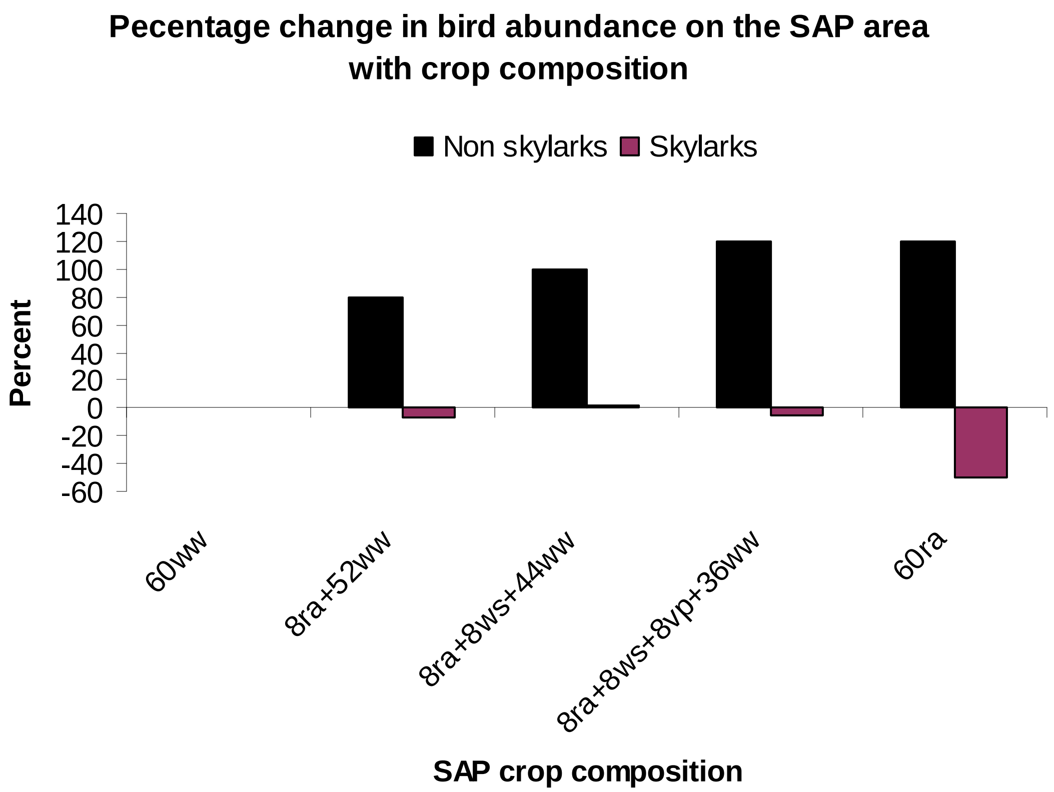


Figure 13. The percentage change of non-Skylark species of birds (thrushes, Whitethroat, finches and buntings) and Skylarks relative to 100% winter wheat ("60ww"), in relation to different crop composition scenarios for the whole SAP. X-axis notation shows the area of crop followed by the crop type (e.g. 60ww = 60ha winter wheat). Other crop types are rape (ra), weedy stubbles (ws) and vining peas (vp).

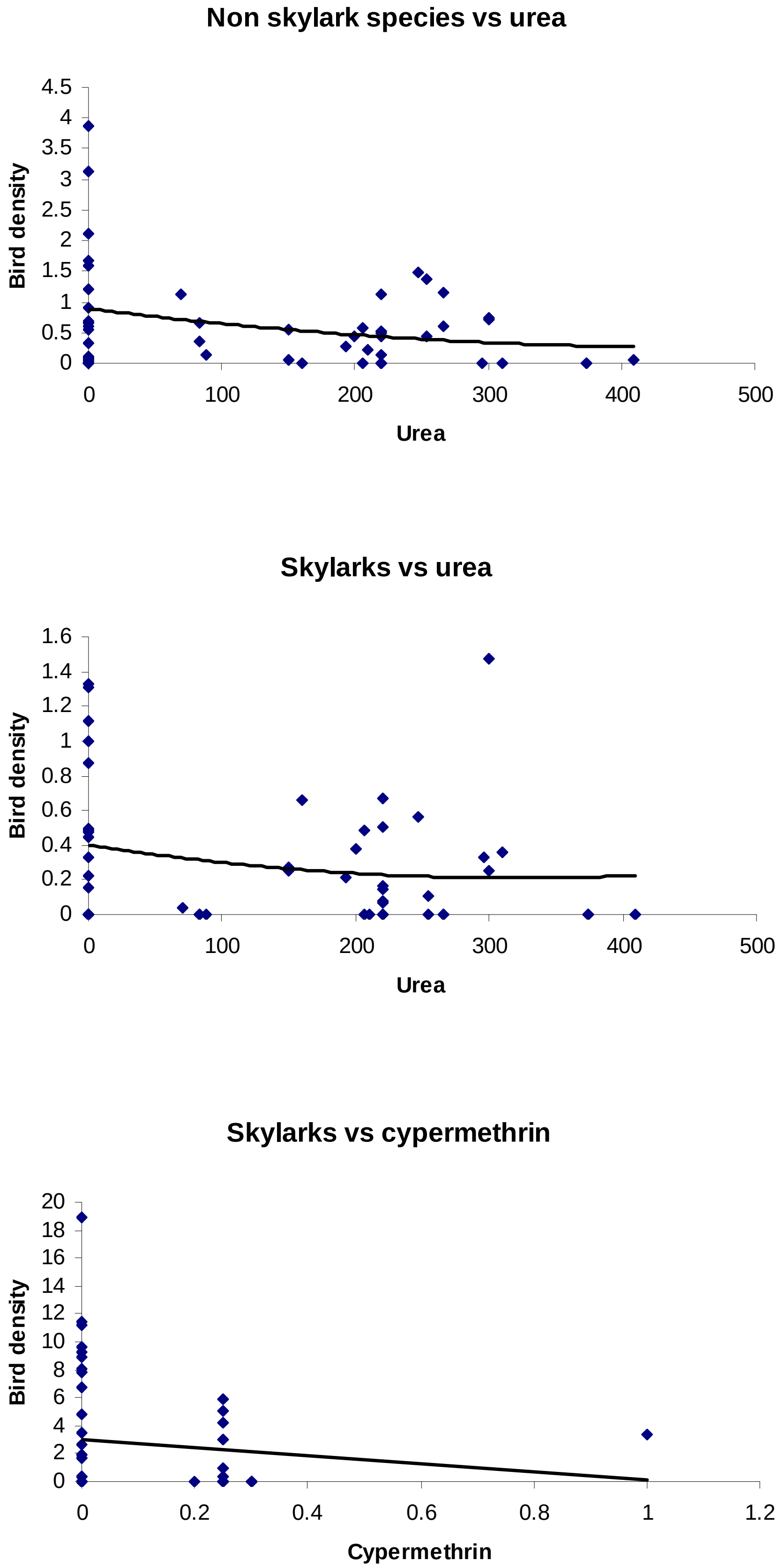
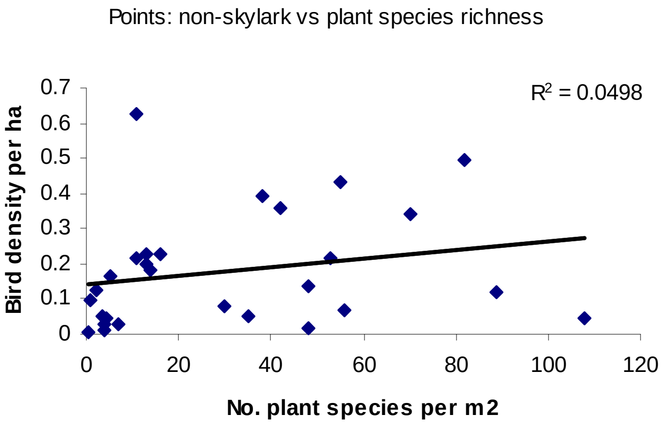
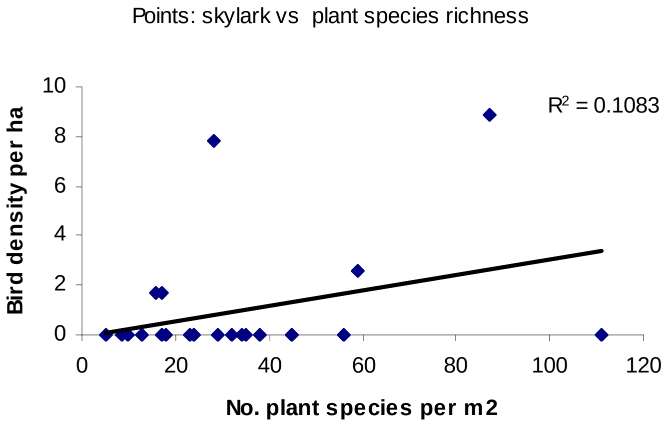


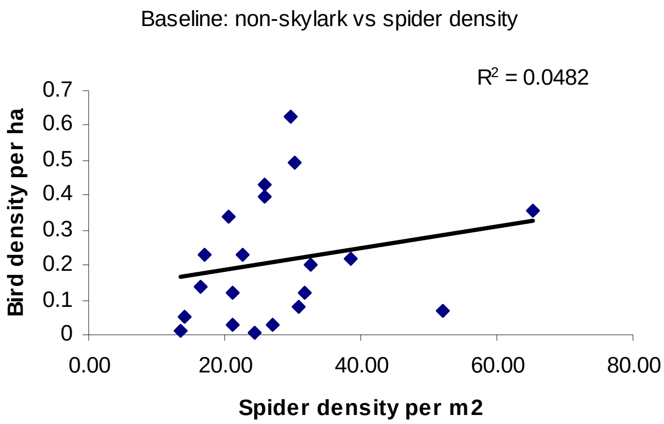
Figure 14. The relationships between bird densities and two chemicals, urea (a) & (b) and the pesticide "Cypermethrin" (c).

Non-skylark species and skylarks with plant species richness

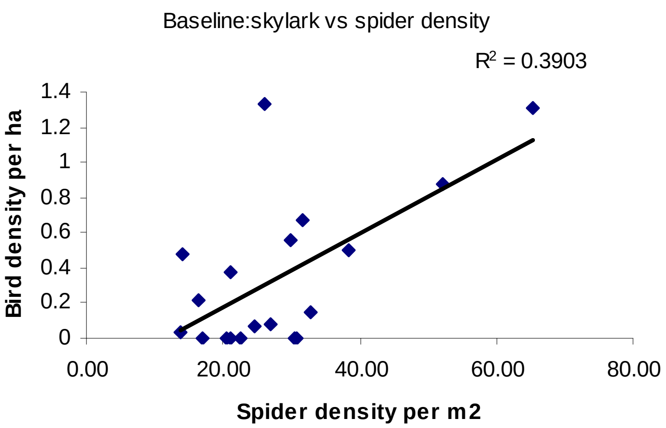




Non-skylark species and spiders



Skylarks and spiders



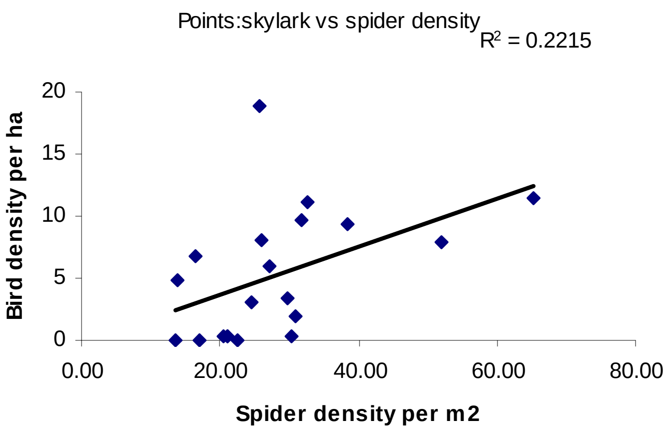
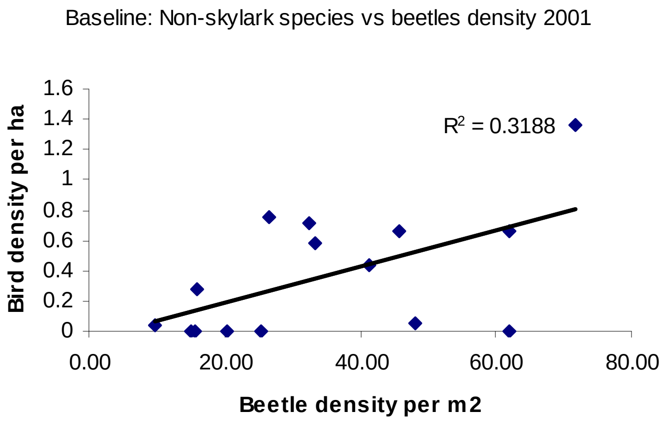
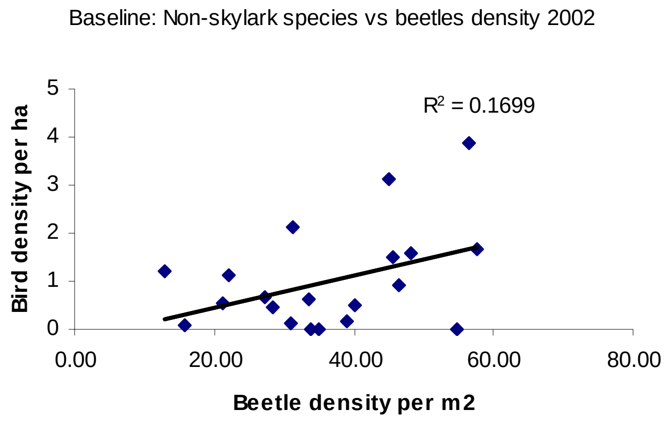
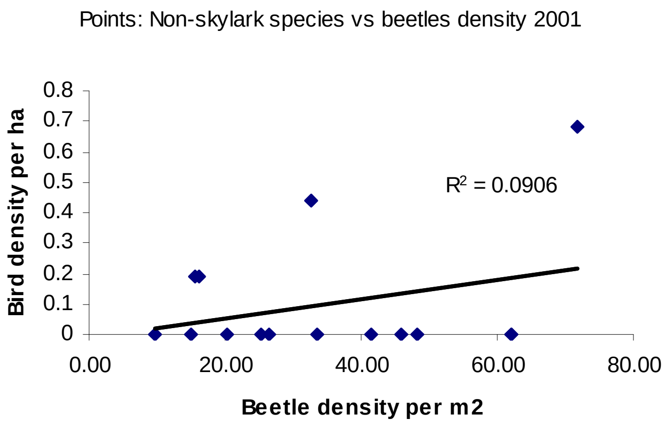


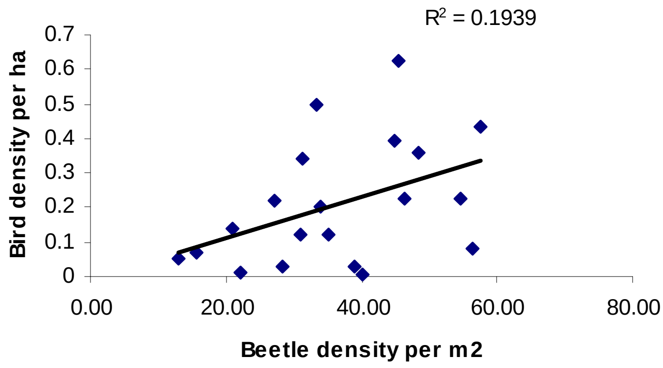
Figure 15. Correlations between birds and plant "diversity" and birds and spider densities for Skylarks and non-Skylark species (ie., thrushes, finches and buntings). Bird data either come from the baseline survey or point counts as indicated.

Non-skylark species

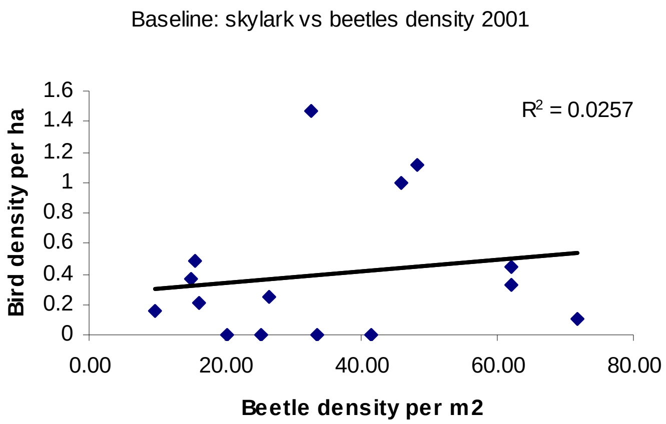








Skylark



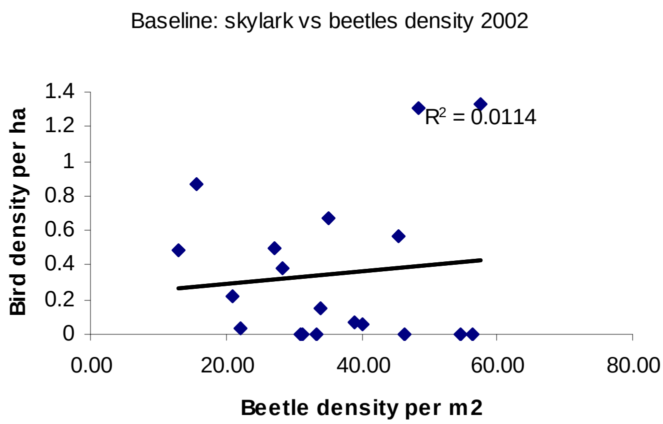


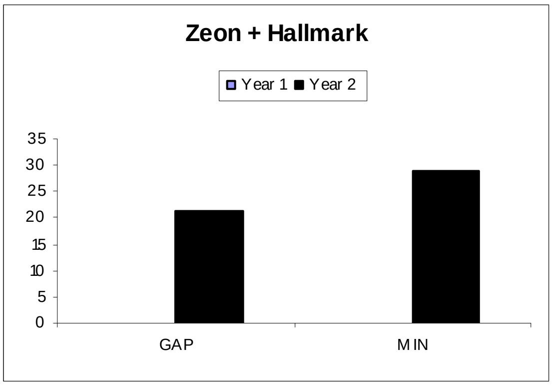
Figure 16. Correlations between birds and beetle densities on fields from baseline survey data and point count data (not shown for skylark). Non-Skylark species include thrushes, finches and buntings.

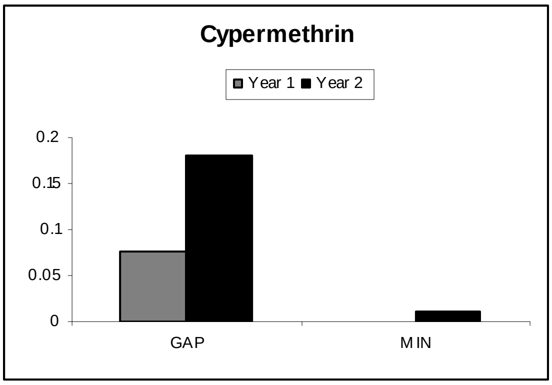
Appendix 1A. Pesticides: The application purpose and of crop chemicals used at Colworth.

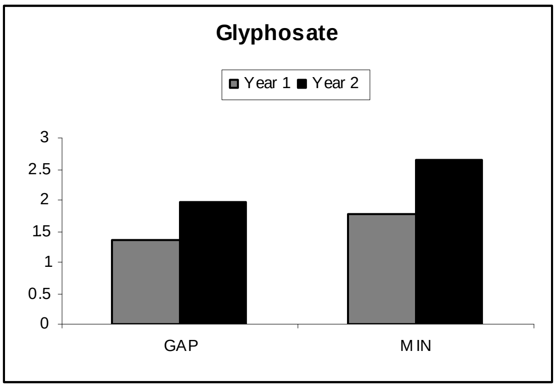
Product name	Target spp	Comments?
Cypermethrin	Used against aphids and other virus vectors, pea and bean weevil, cabbage stem flea beetle and pollen beetle in WOSR	Used in a wide range of crops. Contact/stomach acting pyrethroid insecticide. Very harmful to bees – should not spray on crops in flower.
Hallmark +Zeon	Flea beetle	Lambda-cyhalothrin – contact and ingested pyrethroid insecticide.
Carbetamex	Slugs	Spread as pellets
Sting	Glyphosate :General herbicide.	Cheaper than Roundup – slightly weaker formulation
Katamaran	Blackgrass, annual meadow grass, annual dicots, cleavers and poppies in Winter Oilseed Rape.	Fairly new product of metazachlor and quinmerac – may be used pre or post emergence.
Opogard	Annual dicotyledons and annual grasses in peas/beans. Applied pre-emergence.	Widely used in pea production – BEW use field history as a guide to requirement for application. Formulated w/ terbutryn and terbuthylazine – terbutryn won't be available from 2007 – BASF currently researching new molecules to replace it.
Lexus	Flupyrsulfuron-methyl - Annual dicots and blackgrass in winter wheat	Often tank-mixed with Stomp (pendimethalin)
Marathon	Blackgrass and wild oats in winter wheat	Mixed with Sprayprover before application.
Stomp	Ann. Dicots & cleavers in cereals	Pendimethalin – often tank mixed with Lexus or IPU (isoproturon)
Starane	Ann. Dicots. and cleavers in cereals	Fluroxypyr – was measured in 2001 in field 37-40 for cleaver control w/reduced rate – showed good control with no traceable leachate.
Ally	Ann. Dicotyledons in W Wheat	Well established chemical – metsulfuron-methyl – may also be marketed as "Jubilee"
Twist	Brown rust, Septoria spp and Powdery mildew in Winter wheat.	Trifloxystrobin – from "new" strobilurin chemistry – keep flag leaf cleaner for longer -> prolongs grainfill -> increases yield. Slight drawback is that it can delay maturity and subsequent harvest by prolonging greening.
Opus	Triazole fungicide (epoxiconazole) v's. Brown rust, eyespot, fusarium, P. mildew, Septoria and Yellow Rust in Winter wheat	Been around for years – still a useful disease combatant, particularly when mixed with Strobilurins.

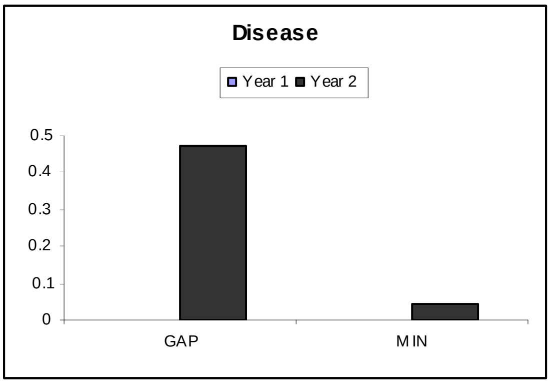
Appendix 1B. Definitions of GAP and MIN pesticide treatments based on mean applications (across treatment blocks) of pesticide groups. The figures show average GAP and MIN pesticide treatments on all crops in year 1 (2001) and year 2 (2002). For most products, GAP treatments were genuinely greater than MIN treatments with the exception of Zeon+Hallmark on all crops (but not on winter wheat –see Table) in 2002.

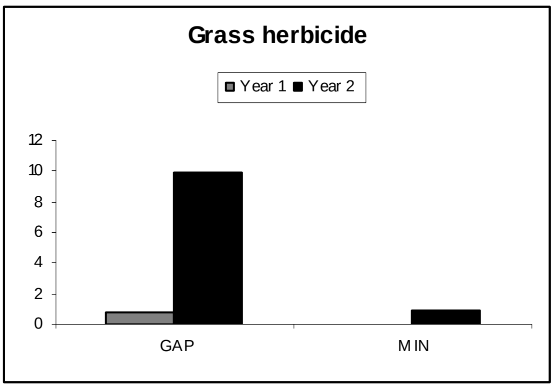
year	All crops	General herbicide Glyphosate	Fungicides mdisea	Cypermethrin mpyret1	Zeon + Hallmark mpyret2	Marathon, Lexus, Kata'. mgrass	Dicot Stomp	Dicot Starane	Dicot Ally	All dicots	Slug applic.
2001	GAP	1.34686	0	0.07552	0	0.72674	0.10059	2.94381	11.736	14.7804	0
2001	MIN	1.75859	0	0	0	0	0	0.09798	0.6838	0.78178	0
2002	GAP	1.97521	0.47172	0.18145	21.4153	9.97672	1.47905	0.34511	2.4767	4.30086	6.945
2002	MIN	2.62917	0.04385	0.0115	29.0263	0.9203	0.13804	0.03221	0	0.17025	0.2793
	Winter wheat										
2001	GAP	1.17262	0	0.01993	0	1.7282	0.2392	4.36346	20.1827	24.78536	0
2001	MIN	1.59976	0	0	0	0	0	0.04902	0.6098	0.65882	0
2002	GAP	0.65182	0.93818	0.24517	13.53	19.6134	2.94201	0.68647	5.412	9.04048	12.3377
2002	MIN	0	0	0	0	0	0	0	0	0	0

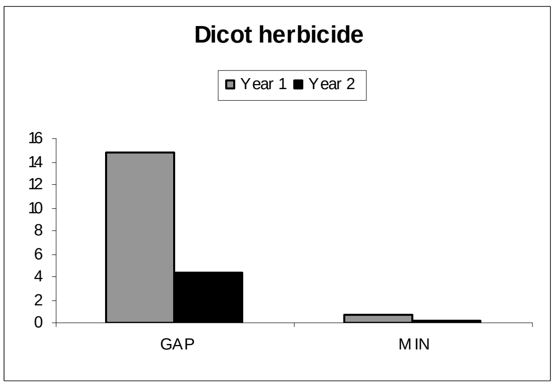




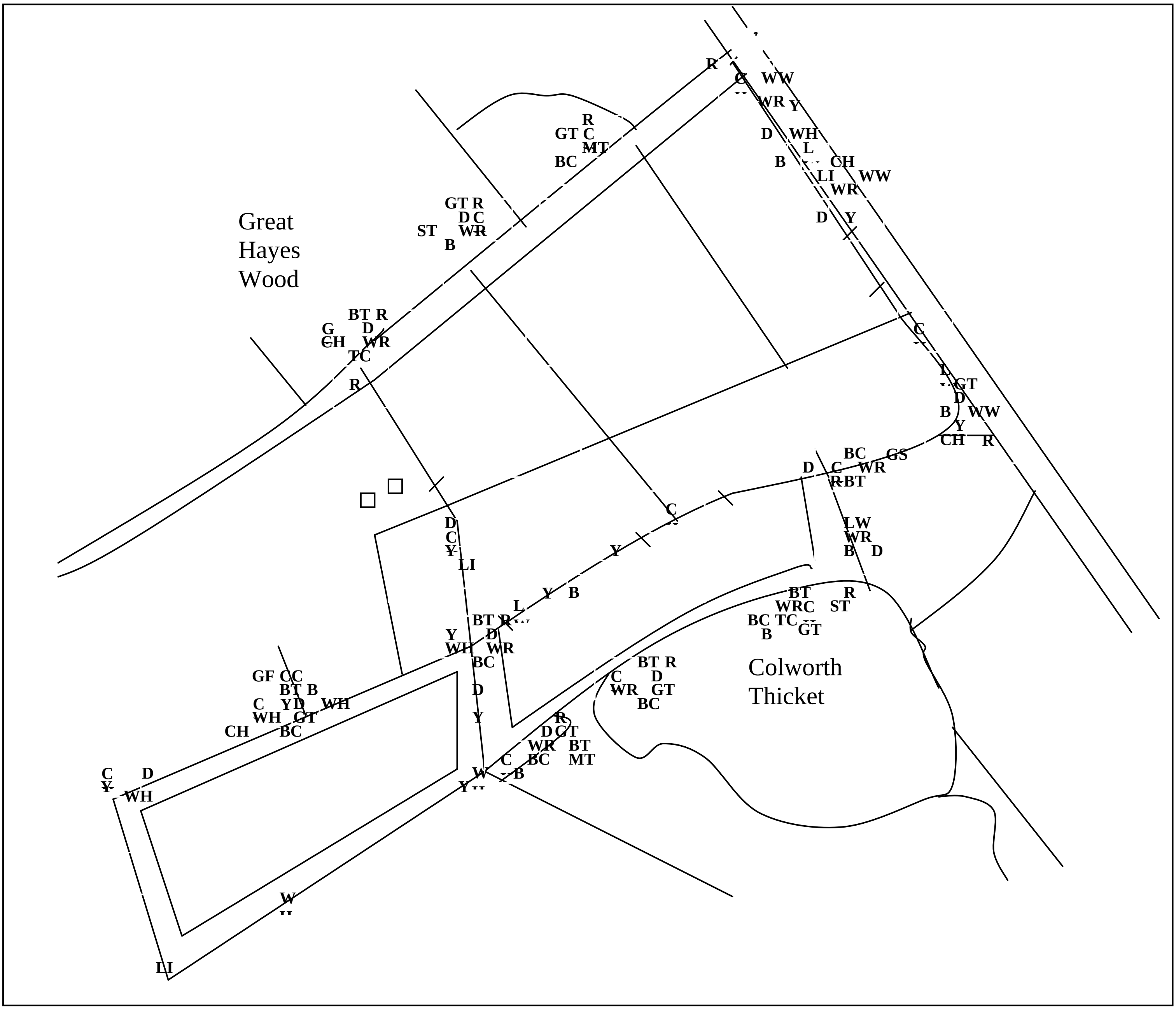








Appendix 3. The typical distribution of bird breeding territories on the Colworth SAP area (abbreviations are defined in Appendix 2).



Appendix 4. Increasing biodiversity on arable farmland

Non cropped habitats

100 m of varied but, typically, tall (3 m by 3 m wide) hedges per ha with basal vegetation.

Grass margins

Warm, accessible margins, that is, with rank vegetation (e.g. brambles) and an open, tussocky-based grass-flower mix/structure nearer to the crop or track. Open access to tracks or crops allows partridge chicks to dry off in wet conditions (this reduces mortality through chilling).

Margins, may take the form of grass-only strips or grass and wild flower strips (subsequently referred to as grass/wildflower strips), and can provide seed resources for birds (Wilson *et al*. 1999) and support a range of phytophagous insects (Morris & Webb 1987). Grass seeds provided by grass-only strips are fed on by a range of species (Wilson *et al*. 1999) including Starling (*Sturnus vulgaris*), Dunnock (*Prunella modularis*) House Sparrow (*Passer domesticus*), Tree Sparrow and Yellowhammer (Cramp 1988; Cramp & Perrins 1994). Grass-only margins also provide suitable habitat for invertebrates such as elaterid and carabid beetles and tipulid larvae which are important dietary items for Grey Partridge (Potts 1996), Yellowhammer (*Emberiza citrinella*) (Bradbury & Stoate in press) and Skylark (*Alauda arvensis*) (Donald 1999). Compared with modern cereal fields, they support higher numbers of graminivorous sawfly larvae, plant bugs and hoppers and lepidopteran larvae (Barker & Reynolds 1999). Compared with many other margin types, however, grass-only strips tend to support a low variety of broad-leaved weeds which may lead to a relatively low abundance and diversity of invertebrates (e.g. Morris 2000; Vickery *et al*. in press). Where grass-only strips form a dense sward this can hamper foraging by birds (Weibel 1998; Barker & Reynolds 1999).

Grass/wildflower strips, are more likely to provide food for birds over a longer period of the year than grass-only swards, as different plants will flower and seed at different times. Most grasses flower in mid-summer, while some dicotyledonous species will flower before or after this period (Clapham *et al*. 1968; Fitter *et al*. 1980). In addition, grass/wildflower strips are more likely to support a greater range of invertebrate species than grass-only strips, as they provide a greater variety of host plants for phytophagous species and thus their invertebrate predators (e.g. Kirkham *et al*. 1994; Thomas *et al*. 1994; Baines *et al*. 1998). The presence of perennial herbs will promote numbers of Hemiptera, Hymenoptera and Aranaea which may colonise margins very quickly, usually within 12 months (Thomas *et al*. 1994).

Seed availability is heavily influenced by the cutting regime. Both are usually mown in August or September to prevent scrub encroachment. This will also help maintain biodiversity (Smith *et al*. 1993) and leave a short sward in autumn/winter which will facilitate foraging by birds such as thrushes that feed on ground dwelling invertebrates. However, such frequent cutting may reduce the value of grass margins for ground-nesting birds such as partridges (e.g. Rands 1987, 1988) and yellowhammers (Stoate *et al*. 1998) both of which may benefit from leaving part of the strip, nearest the hedge, uncut.

Grass-only and grass/wildflower strips may also benefit small mammals and hence increase hunting opportunities for raptors, such as Kestrels (*Falco tinnunculus*) and Barn Owls (*Tyto alba*) (Harris & Woollard 1990; Tew *et al*. 1992).

Scrub corners

Other than whitethroat, warbler densities are generally “poor” at Colworth except for the railway embankment. Measures above will help, but scrub “banks” in wider field corners or margins against taller trees are exceptionally valuable for these and other species.

Crops

Varied crop structure, including rape, weedy fallow and/or a low growing non-cereals (especially peas, beans or beet) within the rotation.

Increase the soil organic content…

Pesticides identify which……

Winter

Stubbles

Stubbles, especially disked (lightly disturbed) cereal stubbles or weedy non-cereal stubbles, retained as late as possible through the winter. Barley and rape stubbles are generally identified as the type of stubbles most utlised by birds, both containing a higher average weed content than winter wheat stubbles (Robinson *pers comm.*).

Winter bird crops

Ideally a warm location by a boundary. Drill in parallel strips rather than mixes (unless set-aside claim) to easy cultivation and “clashes” and different management needs between plant types. Include (1) brassicas, especially kale, where possible (kale is biennial and supports invertebrate feeding birds, such as Wren, Dunnock, Blackbird and Song Thrush, as well as seed-eating finches and Grey Partridge) needs careful establishment and pest control; (2) quinoa (very good for many species, including finches and Tree Sparrows, with good cover and tall structural complementation to brassicas) and (3) a seeding cereal such as triticale. Seeding cereals are essential for buntings that require large grass-seeds in their diet. Kale, quinoa and seeding cereals persist well into late winter. Good alternatives for small finches include millet and possibly linseed. Sunflowers have very limited biodiversity value (mainly for Greenfinches but some other species) and poor winter longevity. Phacelia and buckwheat are poor for birds but grown as a nectar source for insects (Boatman “Guidelines For Growing Seed Crops To Feed Farmland Birds In Winter 2002; Henderson *et al.* in press).