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Managing uncropped land in order to enhance biodiversity benefits of the arable farmed landscape: The Farm4bio project

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by

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CONTENTS

1. ABSTRACT

The primary aim of the Farm4bio project was to determine whether management of uncropped land for biodiversity on conventional arable farms could achieve significant and measurable increases in biodiversity that were at least equivalent to those attained on organic farms in primarily arable cropping systems. Using 28 sites each of approximately 100 ha, treatments were established in which the proportion of uncropped land, its management (project-managed, farmer-managed or organic) and spatial configuration was manipulated. On project-managed farms, 1.5-6 ha of four habitats were established (floristically enhanced grass, wild bird seed, insect-rich cover and natural regeneration) to provide key resources for wildlife. Uncropped land on farmer-managed sites consisted of Environmental Stewardship options (predominantly grass margins) and game cover (usually maize). Plants, invertebrates, birds and mammals were assessed over three years following two baseline years.

The proportion of uncropped land (1-18%) was positively related to plant diversity and butterfly diversity in the field boundaries and bee density in the uncropped plots, and numbers of skylarks, linnets, yellowhammers and other farmland birds that are highly dependent on farmland. Overall a positive response to the proportion of uncropped land was found for 17 of the 21 bird species. Farms with <3% uncropped land supported approximately 60% less birds than those with >10%, and even those with <5% were relatively under-populated. The habitats established on the project-managed farms were effective at increasing some invertebrate groups (wild bees, butterflies and chick-food insects) and yellowhammers. On organic compared to conventional farms there were more weed species in the crops, plus more lapwings, wood pigeons, skylarks, rooks and hares. These groups were most likely responding to the organic crops rather than the management of uncropped land. Uncropped land arranged in strips improved butterfly diversity and abundance of skylarks and rabbits, but blocks favoured linnets and grey partridge. For a five-year period the mean annual gross margins for the project-managed habitats and grass margins was £399/ha, and this was £192 per annum lower than that of a winter wheat-oilseed rape rotation. This requires extra financial support through agri-environment schemes to help farmers to increase the proportion of uncropped land to enhance biodiversity. Project-managed habitat quality varied between years and sites depending on soil type and weather, but floristically enhanced grass provided the most reliable cover followed by the wild bird seed mixture.

In conclusion, at the 100 ha scale the results showed that, on average across the 28 sites there was no significant effect of habitat management on bird abundance, as both Biodiversity Action Plan species and the Farmland Bird Index continue to decline between 2006 and 2010. However the declining rate on project-managed farms was slower than on farmer-managed farms, but the differences were not statistically significant. If farmland biodiversity is to be encouraged it is essential to provide all the necessary habitat and resources for each group of organisms on

farmland, for example, food, breeding areas, and shelter throughout the year and this requires better use of uncropped land, that is unharvested and managed for biodiversity through agri-environment schemes.

2. SUMMARY

2.1. Introduction

The decline in farmland biodiversity and the link to agricultural changes over the last 40 years is now well documented and accepted. In response, the UK has global, EU and national commitments to reduce or halt the decline in biodiversity. In order to meet these commitments and targets, the UK government has adopted various policies and strategies. The widespread adoption of agri-environment schemes (AES) is seen as the route by which farmland biodiversity can be revived and this objective is being promoted by industry partners in Campaign for the Farmed Environment. Organic farming can also benefit farmland biodiversity, but whether at the farm-scale organic farming is any better than conventional farming with carefully targeted prescriptions for wildlife habitats has never been tested. Overall the majority of UK arable farmers, for sound financial reasons and ease of management, would prefer to encourage biodiversity through targeted management of limited areas of uncropped land rather than by modifying the management of crops which could reduce the prospect of economically sustainable crop production. This has been proven by the poor uptake of within-crop wildlife management options in Environmental Stewardship.

The success of AES may be dependent on how they are implemented in terms of the advice provided, but also on the level of financial support which can influence option uptake. When uptake of the Entry Level Scheme (ELS) was reviewed in 2009 it revealed that the majority of agreement holders had taken up a relatively few simple options. Furthermore, if farmland biodiversity is to be encouraged it is essential to provide all the necessary habitat and resources for each group of organisms, for example, food, breeding areas, and shelter throughout the year and this may require better use of uncropped land than is currently being achieved. Ideally, changes to cropping as well as the creation of suitable habitats may also be required even though this may be uneconomic for the farming businesses without outside financial support. The scale over which these habitats/resources are provided and their structural arrangement may also be important, although this could vary according to the species mobility and requirements of each species. All of this indicates that a range of complex, interacting components may be driving an individual species success. Overall, the best examples of wildlife recovery have been where evidence based advice has been provided and appropriate habitat established and correctly managed over a contiguous area in which the target species is present.

The main aim of the Farm4bio project was to determine whether management of uncropped land for biodiversity on conventional arable farms could achieve significant and measurable increases in biodiversity, that were equivalent to or greater than those attained on organic farms with primarily arable cropping systems. The project also aimed to investigate some, as yet unanswered, fundamental questions regarding the type and scale of habitat enhancement for wildlife namely: 1) are there relationships between the proportion of uncropped land and levels of biodiversity and can thresholds be identified? 2) does active habitat creation compared to simple farm management lead to higher levels of biodiversity? 3) how should this land be arranged in the landscape? Determining when an appropriate level of wildlife for the farm/landscape has been achieved is also a key question. For some Biodiversity Action Plan (BAP) species this has been determined, but for other species, especially those that are common, targets are sometimes vague or unspecified. By working at the 100 ha scale the project was able to learn more about the real practicalities and additional variables of managing for biodiversity on farm.

2.2. Materials and methods

2.2.1. Selection of study sites

In order to select comparable sites for the study a wider selection of 100 ha blocks, 18 in East Anglia and 17 in Wessex, were first monitored in 2006. Monitoring included assessments of plants in three fields and field verges, pollinating insects in the same field verges and birds across the 100 ha. For the imposition of targeted management of uncropped land from year 2, 12 sites in each region were selected for the study, based upon the biodiversity monitoring, the future rotation, the shape of the block and its neighbouring vegetation and landscape features. Any that appeared atypical for the region were avoided. Two primarily arable organic farm sites were selected in each region at the end of 2006 for inclusion into the project in Year 2.

2.2.2. Experimental design

Six treatments were then allocated at random to the 24 sites, with four replicates per treatment, two in each region with an additional two organic blocks per region. The treatments imposed in spring 2007 were:

1. Each block with 6 ha of project-managed uncropped land arranged in strips[1]
2. Each block with 1.5 ha of project-managed uncropped land arranged in strips
3. Each block with 6 ha of project-managed uncropped land arranged in 1-2 blocks[2]
4. Each block with 1.5 ha of project-managed uncropped land arranged in one block
5. Each block with 6 ha of farmer-managed uncropped land
6. Each block with 1.5 ha of farmer-managed uncropped land
7. Organically managed block with 1.5 ha of farmer-managed uncropped land.

The project-managed uncropped land was split into four equal areas comprising:

[1] In general the strips were 24m wide (4 parallel strips x 6m wide)

[2] In general the blocks were at least 48m wide (4 x 12m)

i. Floristically Enhanced Grass mix (FEG) (6 uncompetitive grasses and 8 flowering plant species) to encourage pollinating insects.
ii. Insect Rich Cover (IRC) (triticale and common vetch in 2007, 2008 and 2010; rye and vetch in 2009) to provide invertebrate chick food for breeding farmland birds in summer and seed in winter.
iii. Wild Bird Seed mixture (WBS) (triticale/mustard in spring 2007; triticale/fodder radish/kale/millet/quinoa in spring 2008; fodder radish/kale/rye in spring 2009; triticale/fodder radish/millet in spring 2010) to provide seed for birds in winter. Failure of autumn sowings and abnormally dry spring weather meant that seed mixes had to be adapted to the conditions.
iv. Natural Regeneration (NR) (annual cultivation) to encourage annual arable plants

The farmer-managed blocks included habitat managed for game cover (either maize or a wild bird seed mixture), grass margins and other Environmental Stewardship habitats and cross compliance margins. As the habitats sown in spring 2007 did not fully established that summer, all the 2007 data were amalgamated with 2006 data to create a baseline data set. Treatment data was collected in 2008 to 2010. A suite of biodiversity measurements was conducted on each block each year with some designed to provide a indication of the impact across the 100 ha block (birds, mammals, pollinators) and others of particular uncropped habitats (plants, insects). The block scale measurements were:

a) plants - in the same three fields weeds assessed at 0, 4, 8 and 32m from the crop edge in spring 2006-2009 and plants along the boundaries (hedge, verge and any additional uncropped habitats) in 2007 and 2008;
b) bees, butterflies and hoverflies assessed along the same three field boundaries used for the plants once in July 2006 and thereafter in June and late July/early August every year 2007-2010;
c) birds, three counts during the breeding season (April-June) 2006-2010;
d) mammals, hares, rabbits, deer, foxes and badgers were counted twice in winter 2006/7, 2007/8 and 2008/9.

The assessments made at the habitat scale were:

a) plants and vegetation structure in each project-managed and predominant farmer-managed uncropped land habitats every year,
b) bees, butterflies and hoverflies twice in June and late July/early August 2008-2010 within each project-managed and predominant farmer-managed uncropped habitats;
c) other insects, collected using a modified Vortis suction sampler once in July 2007-2010 within each project-managed and predominant farmer-managed uncropped habitats.

2.2.3. Analysis

It was expected that the different taxa recorded (birds, plants, invertebrates) would respond to the availability and type of uncropped land at contrasting scales. Therefore, variability in the biodiversity was analysed 1) between the 100ha blocks (using Generalised Linear Mixed Models, GLMM) and 2) between plots of sown habitats within the blocks (using Residual Maximum Likelihood, REML). The analysis at the block scale first tested for differences between the treatments assuming the original factorial design with the scale and arrangement of uncropped land included as categorical variables. A second phase of the analysis included input scale and arrangement of uncropped land as continuous variables. Where appropriate, additional co-variates (e.g. % arable in the surrounding 3-km^2 of each site and the boundary to area ratio of the 100-ha site) were included to account for the effect of landscape structure.

For birds, comparisons were made between individual species and between three species groups according to their level of dependency on farmland and their population trajectory in the last 10 years. The groups were: high farmland-dependency species (including skylark), stable or increasing species (such as woodpigeon) and lower farmland-dependent species (such as song thrush).

Because project managed farms also had other areas of uncropped land within the 100 ha block, there were often not clear divisions between the project treatments in terms of the scale of uncropped land. Therefore, a second analysis was done that included the scale and arrangement of uncropped land as a continuous variable.

2.3. Results

2.3.1. Plants

A relationship was found between the amount of uncropped land and plant species richness: more plant species were recorded in the boundaries of farms with a greater percentage of uncropped land. There was a strong correlation between the amount of uncropped land and heterogeneity of uncropped habitats and it is likely that this partly explains the effect on species richness. Approximately one additional species accumulated with every percentage increase in uncropped land. This may have been a consequence of increased recruitment opportunity but it is also likely that the significant correlation between the amount of uncropped land and habitat heterogeneity of field boundaries (r=0.61, P<0.001) was important. Farms with more uncropped land tended to have a wider range of different management options providing more diverse habitats for species with contrasting ecology. Despite the fact that the project farms had additional species sown, there was no significant effect of the treatments on plant diversity on uncropped land when analysed at the

100 ha block scale (including region and year as co-variates). However, an upward temporal trend in species richness on the project farms was observed as the habitats matured.

There were clear differences between the floras recorded in the cropped areas of the field and the uncropped land with greater plant diversity recorded on the latter. The only significant treatment effect on weed communities in the crops was increased diversity on organic farms. Once region was included as a blocking factor, there were no effects of landscape on weeds although distinct weed communities could be identified in particular crop types. Crop choice was a major driver in determining the weed flora, with weeds being most abundant on the grass/legume crops (found predominantly on organic farms), and on uncropped fields and least abundant in cereal crops.

A multivariate analysis revealed significant differences in plant communities recorded on uncropped land between project and farmer-managed sites. Farmer-managed treatments were dominated by grass margins and therefore the plant community was characterised by grassland species including Yorkshire fog (*Holcus lanatus*) and cock's-foot (*Dactylis glomerata*). In contrast, in addition to the sown species on the project-managed habitats the plant communities were characterised by a ruderal, annual community including groundsel (*Senecio vulgaris*) and scarlet pimpernel (*Anagallis arvensis*). This was a result of the annual disturbance of the NR, IRC and WBS that encouraged an understory of weeds growing beneath the sown species. While, particularly on heavy land, this could present a problem by encouraging weeds, such as black-grass (*Alopecurus myosuroides*), many of these species may also have a biodiversity benefit by providing nectar and seed resources.

2.3.2. Invertebrates

The study clearly demonstrated that pollinating insects (wild bees and butterflies) were enhanced by the provision of extra uncropped land and that there was no detectable upper threshold. But at the 100-ha scale the type of management, project versus farmer managed, and the original treatments were not significant factors. Two habitats (FEG and WBS) were clearly the most attractive to invertebrates. The FEG supported the highest densities of wild bees, hoverflies and butterflies seeking oviposition sites (Satyridae) or nectar (Lycaenidae). The density of wild bees was dependent on floral resources and consequently FEG or nectar flower mixes should be a component of every farm's Agri-environment scheme.

Once the increase in overall percentage of uncropped land had been accounted for, the project-sown habitats had an effect on diversity of bees with increased diversity recorded on farms with project-sown habitats. However, these farms also had less bee abundance and diversity along the field margins suggesting that the project treatments may have been drawing in bees from the surrounding landscape.

Fewer bees were recorded along the margins of the organic farms but it was not possible to identify the cause, although they may have been attracted into fields, such as those containing fertility-building legume crops. The proportion of uncropped land had a positive effect on butterfly diversity along the field margins and wild bee abundance and diversity in the uncropped habitats, with no evidence of any threshold for the first two measures but wild bee diversity reached a plateau at 3-5% uncropped, either because of the level of identification was insufficiently sensitive or there was limited opportunity within the wild bee fauna for an increase. There was evidence that wild bees were being attracted to the project-managed habitats from the field margins which has implications for the pollination of wild plants along margins. Butterfly diversity increased when the uncropped land was arranged in strips rather than blocks. For the invertebrates collected by Vortis sampling there was no effect of management type, the proportion of uncropped land or its arrangement, instead they responded at the smaller, habitat scale. The sown species mixtures, especially the wild bird seed, generally supported higher populations than grass margins. As a result there were higher abundances and biomass on project farms. On average project farms were providing approximately twice the biomass of invertebrates per unit area as the farmer managed (control) farms.

The assessments of individual uncropped habitats revealed that wild bees were mainly bumble bees (92%) and almost 90% of these were of three species (*Bombus pascuorum, B. lapidarius and B. pratorum*). The majority (ca. 70%) of the bumble bees were short-tongued and the only abundant long-tongued species, B. *pascuorum*, occurred predominantly in the floristically enhanced grass (FEG). Overall bumble bees and cuckoo bees were 3-8 times more abundant, depending on the time when sampled, in FEG compared to the other habitats. Solitary bees were most abundant in FEG in June, however, they were 10 times more abundant in the game cover in East Anglia than in the game cover elsewhere. The occurrence of butterfly adults was largely dependent on the presence of larval food plants. The Pieridae (whites) which feed on brassicas were twice as abundant in the WBS (which contained fodder radish and kale) and formed 75% of the species composition compared to the other habitats. Those with grass hosts, especially Satyridae (browns), were most abundant in FEG and grass margins. Butterflies seeking the nectar provided by the sown species were 25-50% more abundant in the FEG compared to the other sown habitats and FEG also attracted the most Lycaenidae (hairstreaks, coppers and blues). Hoverflies were most abundant in FEG and grass margins in June, but by July occurred in similar numbers in all habitats except grass margins where they were 50% lower than in the other uncropped habitats. There were at least four times as many hoverflies in most habitats in Wessex compared to East Anglia in July.

In the Vortis suction samples, the natural enemies of pests formed almost 40% of the species composition with the majority being parasitoids. In contrast, pests only formed a maximum of 32%, these being highest in natural regeneration and lowest in grass margins. The wild bird seed contained the greatest density of invertebrates and pests, and because the pests are consumed by birds, farmland bird chick-food and grey partridge chick-food indices were also highest in this habitat. The biomass of farmland bird chick-food was five times larger in East Anglia compared to Wessex. The abundance of natural enemies was relatively similar across all uncropped habitats, only varying by approximately 25%.

2.3.3. Birds

The study provided important evidence of a scaled effect of habitat provision on the abundance of birds associated with English arable farmland. The strongest and most detectable effect on bird abundance was the gross area cover of uncropped land.

The analysis which controlled for the % area of uncropped land present, showed a significant increase in bird abundance for linnet on farms where the uncropped land was project-managed rather than farmer-managed. Similar, but non-significant trends were also seen for skylark and yellowhammer.

In the regression analysis for individual species, significant effects of uncropped land were detected for linnet, yellowhammer, skylark and lapwing. The effect of organic farms was significant for lapwing, woodpigeon and rook and this suggests that the organic rotation, with grassland content, was a dominant and confounding factor. There was a non-significant positive effect of total uncropped land for 17 out of 21 species.

Using GLMM statistical analyses, for the continuous variable '% area uncropped land', a significant relationship with uncropped land was identified for the three most abundant species present, linnet, yellowhammer and skylark (using the larger dataset and especially on conventional farms; their abundance provided sufficient analytical power to detect a relationship that also appeared to be present in other species but fell short of statistical significance), and for Biodiversity Action Plan (BAP) and Farmland Bird Index (FBI) species as combined groups.

The effect of organic farms compared to conventional farms was significant and positive for lapwing, skylark, woodpigeon, rook and goldfinch. Among groups of species, the response to % area uncropped land was strongest amongst high dependency, declining species. No specific threshold was identified for uncropped land and the relationship was strongest on conventional farmland. Instead, an area of uncropped land below 3% supported significantly lower densities of skylark, linnet and yellowhammer than areas of 10% or more, for which abundance was roughly

60% higher. Among the other high farmland-dependency, declining species (kestrel, lapwing, grey partridge, yellow wagtail, corn bunting and reed bunting), no individually significant effects of uncropped land were detected. However, collectively all showed a positive relationship with uncropped land and with the area of grass margins present, that was in contrast to the lower dependency species (such as song thrush and house sparrow). These percentages of uncropped land are averages for 'average' types of uncropped land and do not account for habitat quality or composition – as is likely to be the case on the majority of farmland locations where wildlife habitat management is not closely supervised. Under such a scenario, the curves suggest disproportionately low bird densities at percentages below 3%. Yellowhammer was also significantly associated with the presence of wild bird seed (WBS).

The effect of perimeter-to-area ratio (which quantifies the 'blockiness' of the uncropped land) was not statistically significant for any species, except for skylark and linnet, and to a lesser extent, grey partridge when in combination with other variables (grey partridge had a preference for larger blocks rather than narrower strips). For skylark, a larger relative edge effect was significant (typical of strips rather than blocks) and probably related to availability of bare ground. For linnet, higher abundance was correlated with larger blocks of contiguous habitat. For other species, including yellowhammer, there was no significant effect of patch size, patch number or perimeter-to-area ratio.

2.3.4. Mammals

The data on hares and rabbits (which were recorded in 2008 and 2009) were only analysed at the 100 ha block scale using the two phase analysis. The effect of keepering was added to the analytical model. Only a small number of significant effects were identified by the models. Hares were more abundant in 2008 than in 2009 (16.4 vs. 11.3 hares / 100 ha) and on organic compared to conventional farms (32.6 vs. 10.7) and rabbits were more abundant on sites with a higher perimeter to area (P / A) ratio (preferring uncropped land arranged in strips because their burrows are located along the margins of annually cultivated fields).

2.3.5. Economics

For a five-year period the mean annual economic gross margins for the habitats, comprised of the Environmental Stewardship payments less the costs of seeds, fertiliser and sprays, were as follows: 4m grass margins (£381), FEG (£433), biennial WBS (£407), annual NR (£388) and WBS/IRC replaced annually (£386). The mean annual economic gross margin for the four project-managed habitats was positive (£398), but in comparison, over four years and based upon national farm business survey, the average annual gross margin for a winter wheat and oilseed rape rotation was £591. The FEG had the highest gross margin and was the easiest to establish and manage, but at present at present this option is not available in ELS.

2.4. Discussion

One of the main objectives of the project was to see whether enhanced management of conventional farms could increase their diversity up to a level seen in organic arable farms. At the 100 ha scale the results showed that, on average across the 28 sites there was no significant affect of habitat management on bird abundance, as both Biodiversity Action Plan species and the Farmland Bird Index continue to decline between 2006 and 2010. However the declining rate on project-managed farms was slower than on farmer-managed farms, but the differences were not statistically significant. Moreover, it may take longer than the period available for a response to be detectable, as found with other investigations appraising the impact of ELS. If farmland biodiversity is to be encouraged it is essential to provide all the necessary habitat and resources for each group of organisms on farmland, for example, food, breeding areas, and shelter throughout the year and this requires better use of uncropped land, that is unharvested and managed for biodiversity through agri-environment schemes.

Overall the differences between the organic and conventional farms were relatively small with significantly enhanced numbers of weeds in fields, five bird species (lapwing, skylark, woodpigeon, rook and goldfinch) and hares on the organic farms. The differences for birds and hares were attributed to the organic rotation that included, on average, a higher grassland component and weedier arable crops. The impact of the project- compared to farmer-managed was restricted to differences in plant species composition and linnets. On farmer-managed farms the plant community was grass focussed because grass margins were the main type of uncropped land, whereas on the project-managed farms annual weeds prevailed in the natural regeneration and annually sown mixes. However, natural regeneration was unsuitable for heavier soils where it encouraged pernicious weeds such as black-grass, and this option is best targeted at sites with light soil types or where there are known populations of rare arable flowers. There was an upward trend over time in plant diversity in the project-managed perennial habitats. Linnets were more abundant on project-managed farms. There were more noticeable and local differences between habitat types, especially for invertebrates. Project-managed habitats encouraged individual groups of invertebrates, for example the FEG attracted wild bees and the WBS contained more invertebrate chick-food. Overall, project-managed habitats had twice as much farmland bird chick-food compared to farmer-managed habitats.

2.4.1. How much uncropped land?

The proportion of uncropped land was positively related to the abundance of wild bees and butterfly diversity, and for 17 of the 21 bird species (5 significantly so) and bird functional groups. There was also an increase in the number of bee groups between 0-3 and 3-5% uncropped land, but no increase beyond this, either because individual species were not identified or because there was limited opportunity for recruitment. Wild bee abundance increased positively with uncropped land at the expense of the margins, indicating redistribution may have been occurring and this merits further investigation to ensure pollination of hedgerows plants is not being compromised by the planting of areas super-rich in floral resources. Butterfly diversity also increased with the proportion of uncropped land and there was no detectable threshold to their enhancement. Grass margins and wild bird seed mixes or game cover comprised a large proportion of the additional uncropped land and this explains the response because the larvae of many species feed on grasses or brassicas.

The Farm4Bio study provided important evidence of a scaled effect of habitat provision on the abundance of birds associated with arable farmland. The strongest and most detectable effect on bird abundance was the gross area cover of un-cropped land. Sites with <5% area (especially <3%) of un-cropped land were relatively under-populated; sites with >10% held significantly higher densities of key species. A rate close to or <5% un-cropped land may be inadequate for population stabilisation under circumstances where un-cropped land *is not* closely managed for biodiversity. Extra provision of specific resources for birds, such as winter bird food, may enable farms to stabilise bird populations without increasing the % uncropped land above 5% but this would need further study. Species considered to be of higher farmland-dependency were the most responsive to the availability of uncropped land, especially the more abundant skylark, linnet and yellowhammer. Collectively, these species represent a range of life-history strategies and ecological requirements that encompass traits found in the other less abundant but declining species present. For example, they represent both open nesting and boundary nesting species, obligate seed-eating species and more generalist seed and invertebrate feeding species. Managing farmland for these three species would to some degree attend to the basic habitat structural requirements of the other high farmland-dependency species that are important to the Farmland Bird Index (FBI) trend. Other species also showed a positive response to the proportion of uncropped land, such as woodland species (e.g., song thrush and dunnock) and urban species (e.g., house sparrow), but these species would preferentially require the provision of surrogate woodland (hedgerows or shade) or urban (buildings) habitats.

2.4.2. Spatial arrangement of uncropped land

The spatial arrangement of uncropped land had very little impact apart from a few exceptions. Butterfly diversity was higher when the uncropped land was in strips. This may be expected because butterflies prefer sheltered areas next to hedgerows which facilitate dispersal and make a more favourable habitat for breeding. There was a weak response by birds, with skylark, linnet and to a lesser extent grey partridge showed differing responses to habitat arranged as blocks or strips.

2.4.3. Economics

All the habitats potentially had lower gross margins than would be achieved by cropping the land over the project's duration. Indeed the Environmental Stewardship payments alone were less than the average gross margin of wheat and oilseed rape. This, however, may overestimate the discrepancy because agri-environment options are often established on less productive land and require a lower fixed cost structure. These figures are therefore only a relatively crude example of the relative economic margins but still any increase in the proportion of uncropped land requires extra financial support through agri-environment schemes to help farmers to increase the proportion of uncropped land. This needs further investigation and may need increasing to maintain their competiveness when crop values are high.

In summary, the quantity of uncropped land was found to be the primary driver for biodiversity and especially farmland birds. However, this study showed that management of uncropped land was unable to reverse the declining trend for both Biodiversity Action Plan species and the Farmland Bird Index within the project's duration. Maximising the availability of uncropped land will positively affect the carrying capacity of conventional arable farmland when measured at a scale of resolution that is consistent with many national and regional bird monitoring schemes, not just in the UK. The quality of uncropped land was important for some groups, notably wild bees and farmland bird invertebrate chick-food. It is also essential to provide all the necessary habitat and resources for each group of organisms, for example, food, breeding areas, and shelter throughout the year and this requires better use of uncropped land through agri-environment schemes, and this was clearly demonstrated in the Farm4bio project.

3. TECHNICAL DETAIL

3.1. Introduction

The decline in farmland biodiversity and the link to intensive agriculture over the last 40 years is now well documented and accepted by policy makers.

There is strong evidence of a decline in farmland birds (Fuller *et al.,* 1995; Siriwardena *et al.*, 1998; Donald *et al*., 2001) and this is considered to be most severe in the more intensively farmed areas (Donald *et al*., 2001). In the UK between 1970 and 1990 the abundance of 18 species of farmland bird had declined and the range of 28 species had constricted (Fuller *et al*., 1995). These declines have been attributed to the intensive farming (Chamberlain *et al*., 2000) which has led to a loss of nesting, foraging and escape cover, whilst an increase in pesticide usage has reduced plant and invertebrate food supplies (Campbell *et al*., 1997; Wilson *et al*., 1999; Robinson & Sutherland, 2002; Holland, 2004). Predation by mammalian and avian predators has also been implicated (Stoate & Szczur, 2001). Many of the agri-environment schemes in the UK have options designed to provide resources for farmland birds including seed provision in winter, invertebrates in summer and nesting habitat.

There is some evidence that invertebrate abundance and diversity has also declined on farmland since the late 1960s (Heydemann & Meyer, 1983; Fox *et al*., 2006; Basedow, 2002; Aebischer, 1991) while their range is also contracting (Holland, 2002). Species dominance has also changed (Croy, 1987; Körner, 1990) upsetting the balance of the agroecosystem. The decline of invertebrate populations is considered to have been caused by changes in farming systems but especially the introduction and widespread use of insecticides, molluscicides and herbicides. The former two may cause direct mortality or reduce populations through indirect effects (Sotherton & Holland, 2002). Herbicides act indirectly by removing foliage and seeds used by phytophagous and polyphagous species, but also by changing the microclimate and degree of physical protection from predators (Freemark & Boutin, 1995).

Invertebrates perform a number of indispensable functions on farmland. They are an essential dietary component for most farmland bird species because they provide the protein that is essential for chick growth and development, whilst also supplying the necessary energy to resist chilling (Potts, 1986; Liukkonen-Anttila *et al*., 1996, Southwood & Cross, 2002). Many species of invertebrate also assist with pest control and are a key component of integrated pest management (Kogan, 1998). Polyphagous predators, pest-specific predators and parasitoids have all been identified as contributing to bio-control in arable crops (Wratten & Powell, 1991; Holland & Thomas, 1997; Symondson *et al*., 2002; Powell & Pickett, 2003). Invertebrates also pollinate crops and wildflowers and can influence crop yields (Corbet, 1987). AES options that aim to encourage invertebrates have been developed and tested and these include beetle banks and flower-rich habitats.

The abundance of plants that provide food resources and cover for higher organisms (Marshall *et al*. 2003) has declined across farmland over the last 40 years. This has been documented in the published atlas of the British flora (Preston *et al.,* 2002), where arable weeds dominate the list of the least successful species. Additionally hedgerows have been removed or have become degraded (Petit *et al*., 2003). Further evidence that arable weeds within crops have declined as herbicides have become more effective and their use more widespread is provided by Potts et al. (2010) and Sutcliffe & Kay (2000). Options designed specifically to encourage annual arable plants are available within UK AES options and others may also encourage these plants (e.g. wild bird seed mixtures, low input crops)

Overall there is evidence that the impact of intensive farming is widespread, affecting wildlife through the disruption of the food chain. The best evidence for this comes from the research on the grey partridge in which the link between food supplies and chick survival and chick survival and bird populations has been demonstrated (Potts, 1986; Potts & Aebischer, 1995). There is now more evidence that indirect effects are partly or wholly responsible for the population decline in other bird species (Boatman *et al*., 2004). This might be expected given that the diets of farmland songbirds are relatively similar to each other (Wilson *et al.*, 1999; Holland et al., 2006).

In response to these declines the UK had global, EU and national commitments to reduce or halt the decline in biodiversity by 2010 (recently revised to 2020). In order to meet these commitments and targets, the UK government adopted various policies and strategies. The widespread adoption of agri-environment schemes was seen as the route by which farmland biodiversity could be revived (Anon, 2009). The importance of halting the decline in biodiversity has been recognised by the NFU who have initiated the Campaign for the Farmed Environment which is aimed at encouraging greater farmer participation in environmental issues and greater uptake of key biodiversity AES options and the recognition of additional voluntary measures. These policies are based on the premise that habitats must be improved across the wider agricultural landscape to achieve benefits to national populations. This could involve extensification of farming systems (e.g. organic or less-intensive crop management) termed land sharing and/or taking land out of production for wildlife habitats (e.g. agri-environment schemes), termed land sparing (Green et al., 2005). While organic farming can benefit farmland biodiversity (Hole et al., 2005), organic arable crops are best produced on mixed farms, but this may not be achievable in many areas because the necessary infrastructure for livestock farming has been eroded and the skills lost. Furthermore, whether organic farming is any better for biodiversity than conventional farming with carefully targeted prescriptions for wildlife habitats has never been tested at the farm-scale (Hole et al., 2005). A variety of extensive farming approaches have been trialled mostly at the plot-scale (Holland et al., 1994) and although benefits to biodiversity were achieved it was the changes in cropping and tillage that were most influential (Berry et al., 2005). The benefits of implementing integrated farming or extrapolation to larger scales beyond the plot or farm has not been tried. Overall, the majority of UK arable farmers, for sound financial reasons and ease of management, would prefer to encourage biodiversity through targeted management of limited areas of uncropped land, rather than by modifying the management of crops which could reduce the prospect of economically sustainable crop production. This has been confirmed by the poor uptake of within-crop wildlife management options in Environmental Stewardship (Boatman et al., 2007). Theoretical models comparing the extensive approach (land sharing) with that of the AES approach (land sparing) also indicate that the latter may be the best option, although this cannot be confirmed until we have more realistic information on the density-yield functions for individual species (Green et al., 2005).

The success of agri-environment schemes (AES) may be dependent on how they are implemented in terms of reward for each option and the advice provided. A review of Entry Level Scheme (ELS) uptake revealed that the majority of agreement holders had taken up a relatively few simple options making use of existing features or management already in place (Boatman et al., 2007), yet if farmland biodiversity is to be encouraged it is essential to provide all the necessary habitat and resources for each target group of organisms, for example, food, breeding areas and shelter, throughout the year. Ideally, this may involve changes to cropping as well as the creation of suitable habitats (Stoate, 2009). Furthermore, the scale over which these resources are provided and their structural arrangement may also be important, although this could vary according to the species mobility and its requirements. All of which indicate that a range of complex, interacting components may be driving the success of both individual species and the ecosystem. The use of biodiversity indicators comprised of many species (e.g. farmland bird index) further complicates interpretation. At present, farmland birds continue to decline in England despite the widespread uptake of ELS (70% of holdings), but there may be many explanations as a consequence of the birds temporal and spatial dynamics. National scale monitoring may be too insensitive to detect habitat manipulation at the farm-scale, or more time may be needed to detect national changes. There is, however, evidence that when optimum habitat management is put in place bird numbers can respond over a relatively short period (3 years) (Stoate & Szczur, 2001). Overall the best examples of wildlife recovery have been where evidence-based advice has been provided and appropriate habitat established and correctly managed over a contiguous area in which the target species is present (Peach et al., 2001).

For some species, habitat management alone may not be sufficient and predator control may be required to improve breeding success and/or survival (Stoate & Szczur, 2001). Again variation may be expected between species with some being more vulnerable than others (Martin, 1993). It maybe that the impact of predation can be reduced through the management or creation of habitats to specifically reduce nest predation and there is some evidence to support this approach (Evans, 2004; White et al., 2008).

The selection of AES options was largely determined by features or management already in place, such as mitigating spray drift into water courses using grass margins (Boatman et al., 2007). In addition, as crop values rise the payments from AES become less attractive and consequently farmers may not enter into the schemes or renew agreements. Moreover, they may be become more reluctant to take land out of production or adopt options that require the most effort, although these are the most valuable options for wildlife (e.g. wildflower and wild bird seed mixtures).

In summary, if AES are to be implemented in the most cost effective way whilst also maximising their value for biodiversity, then a greater understanding of the relationship between the proportion of land taken out of production and the benefits to biodiversity is needed. This would enable farmers and policy makers to target the allocation of uncropped land more effectively. There may be thresholds of habitat proportion that must be exceeded if species are to colonise and survive. In addition, there is a body of evidence indicating the composition of the surrounding landscape exerts an influence on biodiversity and thereby the ecosystem services they provide (Bergman et al., 2004; Tscharntke et al., 2005; Holzschuh et al., 2007).

At a more local scale there is a need to understand how the distribution of uncropped land on individual holdings may influence biodiversity. Ecology theory indicates that there may be benefits from having interconnected habitats facilitating movement and a greater proportion of linear habitats may also encourage the edge dependent species (Dover, 1996). For territorial birds and those with restricted nest site opportunities, this also increases the chance that habitat will be created within their foraging range. Evidence from studies on pesticide effects revealed that where parent birds had to travel further to forage as a consequence of insecticide spraying, there was an increased risk of predation and chilling and thereby lower nest survival (Redondo & Castro, 1992). On the other hand, larger blocks of habitat are considered to be more stable, as populations within them are greater and there is less chance of extinction (Diamond, 1975). They may also support a wider range of species. However, if uncropped land is placed in larger patches these will be more isolated from each other compared to where many smaller ones are established.

Finally the provision of advice is also influential. At present the ELS does not include on-farm advice, farmers make their own decisions about which options to adopt, whereas HLS includes on-farm guidance, and higher quality options such as FEG. The two different approaches may have a profound impact not only on the choice of options that are selected but also the subsequent impact on biodiversity.

The main aim of the Farm4bio project was to determine whether management of uncropped land for biodiversity on conventional arable farms could achieve significant and measurable increases in biodiversity, that are equivalent to or greater than those attained on organic farms with primarily arable cropping systems. The Farm4bio project also aimed to investigate some as yet unanswered fundamental questions regarding the type and scale of habitat enhancement for biodiversity namely:

1. Are there relationships between the proportion of uncropped land and levels of biodiversity?
2. Does active management compared to farm management lead to higher levels of biodiversity?
3. How should this land be arranged in the landscape?

The research focussed on biodiversity that is known to be under threat on farmland whilst also including taxa for each component of the food chain.

3.2. Materials and methods

3.2.1. Experimental design

An extensive experimental approach was devised that would allow each of the three main objectives to be tested. A study site size of 100 ha (1 km^2) was selected as this was considered an appropriate scale over which to investigate the impact on mobile organisms such as farmland birds and pollinating insects. Farms were selected that had predominantly winter cropping as these offer the greatest challenge to biodiversity.

The study sites were selected by utilising the consortium's extensive network of associated farmer members (TAG, Game & Wildlife Conservation Trust and Rothamsted Research Association). To ensure that study areas selected had a similar landscape structure, cropping and initial levels of biodiversity, 35 study areas were selected in year 1 (18 in East Anglia & 17 in Wessex) and a reduced sampling programme conducted on each. Measurements that created instant data (e.g. hares, birds and insects assessed by transect counts) were conducted so that the study areas could be rapidly appraised. From these, 24 areas were selected for the study to be conducted in years 2-5 by the project committee and treatments were allocated in a statistically randomised basis. Sites selected were those that contained the key target species, had an appropriate square structure that was not heavily influenced by adjacent features (woodland), an appropriate future rotation and a willingness of the farmers to continue implementing the proposed treatments if selected. A further four 100 ha sites, with similar attributes to those above, on arable organic farms were added to the project in 2007 to provide a basis for a comparison with the 24 'conventional' farms.

Seven treatments (Figure 1) were devised that had either 1.5 or 6.0 ha (i.e. 1.5 and 6%) of land specifically managed for biodiversity, distributed either in strips or blocks and these were compared to farmer-managed farms with 1.5 or 6.0 ha of uncropped land within the 100 ha study area and with organic farms. After the baseline year, two replicates of each treatment (1-6) were allocated randomly to sites in two regions (East Anglia and Wessex). For various reasons three farms selected to be project-managed did not establish the treatments thus reducing replication to three farms for treatments 1 and 4, instead acting as extra replicates for farm managed treatments, 5 and 6.

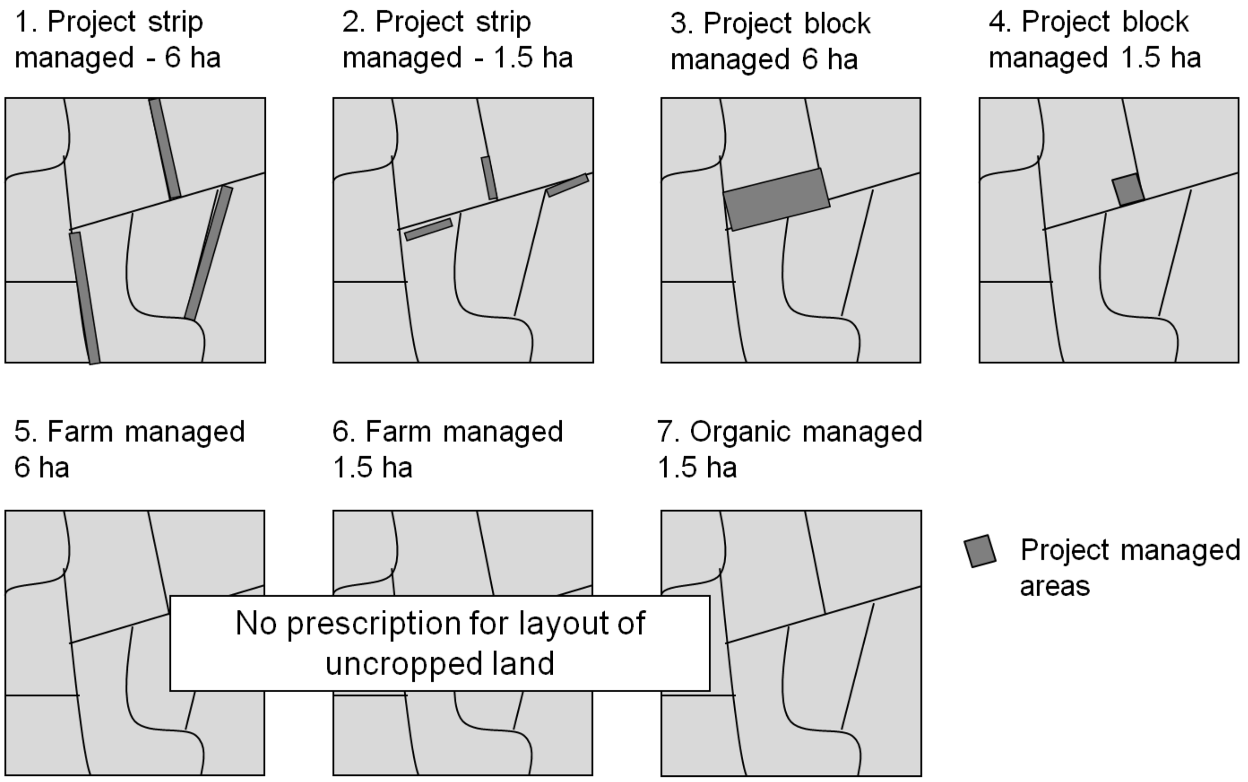


Figure 1. Experimental design showing arrangement of the project-managed areas for each treatment.

In treatments 1-4 the farmers were asked to establish four habitats designed to provide the key resources for farmland birds, invertebrates and plants. The habitats were: Wild Bird Seed (WBS), Insect Rich Cover (IRC), Floristically Enhanced Grass (FEG) and annual Natural Regeneration (NR). Where seeds were sown then the same seed mixture provided by the same supplier was used across all sites. The habitats were first sown in spring 2007, however, establishment was either slow or poor and consequently the data from 2007 was added to the baseline information from 2006. In some years the covers failed because of exceptionally dry spring weather and had to be resown. In the farmer-managed treatments they had one or more of the following: uncropped habitats funded through Environmental Stewardship (usually grass margins), game cover (usually maize) and set-aside in the early years.

The seed mixtures were as follows:

Floristically Enhanced Grass Mix – Perennial (sown spring 2007)

5% common bentgrass	(*Agrostis capillaris*)
5% crested dogstail	(*Cynosurus cristatus*)
5% small timothy	(*Phleum pratense*)
20% sheeps fescue	(*Festuca ovina*)
20% red fescue	(*Festuca rubra*)
34% smooth meadow grass	(*Poa pratensis*)
1% late red clover	(*Trifolium pretense*)
1% alsike clover	(*Trifolium hybridum*)
1% bird's-foot trefoil	(*Lotus corniculatus*)
3% sainfoin	(*Onobrychis viciifolia*)
2% common vetch	(*Vicia sativa*)
1% yellow trefoil/black medic	(*Medicago lupulina*)
1% lesser knapweed	(*Centaurea nigra*)
1% yarrow	(*Achillea millifolium*)

Sowing rate 20kg per ha

Wild bird Seed

2007 (spring sown)

30 kg triticale	(× *Triticosecale*)
2 kg mustard	(*Brassica oleracea*)

Sowing rate 32 kg per ha

2008 (spring sown)

2 kg fodder radish	(*Raphanus sativus*)
3 kg millet	(*Panicum miliaceum*)
0.25 kg quinoa	(*Chenopodium quinoa*)
0.25 kale	(*Brassica oleracea var. Acephala*)

Sowing rate 5.5 kg per ha

2009 (sown autumn 2008)

1 kg kale	
1 kg fodder rape	
30 kg rye	(Secale cereale)

For failed areas (sown spring 2009)

35 kg triticale

1.5 kg fodder radish

3 kg millet

0.65 kg kale

Sowing rate 40.15 kg per ha

2010 (spring sown)

20 kg triticale

2 kg fodder radish

3 kg millet

Sowing rate 25 kg per ha

Failure of autumn sowings and abnormally dry spring weather meant that seed mixes had to be adapted to the conditions.

<u>Insect Rich Cover</u> – annual autumn sown (spring sown if autumn sowings failed)

15 kg triticale

10 kg common vetch (*Vicia sativa*)

Sowing rate 25 kg/ha in 2007, increased to 35 kg/ha thereafter.

In 2009 rye was used instead of triticale because of poor germination with triticale.

3.2.2. Biodiversity measurements

A suite of biodiversity measurements were conducted on each block with some designed to provide an indication of the impact across the 100 ha block (birds, mammals, pollinators) and others of particular habitats (plants, insects) (Table 1).

Table 1. Timing and number of assessments of plants, invertebrates, birds and mammals. (FEG=Floristically Enhanced Grass; IRC= Insect Rich Cover; WBS=Wild Bird Seed; NR=Natural Regeneration; E=East Anglia region; W=Wessex region)

	Fields	No. transects	Total reps/habitat	No. assessments/year									
				2006		2007		2008		2009		2010	
Plants				E	W	E	W	E	W	E	W	E	W
Boundary	3	1		1	1	1	1						
Margins	3	3	12	1	1	1	1	1					
Verge	3	3	12	1	1	1	1	1					
Centre	3	4	16	1	1	1	1	1	1	1	1		
Project uncropped land						1	1	1	1	1	1	1	1
FEG	1-2		12			1	1	1	1	1	1	1	1
IRC	1-2		12			1	1	1	1	1	1	1	1
WBS	1-2		12			1	1	1	1	1	1	1	1
NR	1-2		12			1	1	1	1	1	1	1	1
Farm uncropped land													
Habitat 1	2		12			1	1	1	1	1	1	1	1
Habitat 2	2		12			1	1	1	1	1	1	1	1
Habitat 3	2		12			1	1	1	1	1	1	1	1
Habitat 4	2		12			1	1	1	1	1	1	1	1
Pollinators													
Boundary /Margins	3	1	1	1	1	1	1	1	2	2	2	2	2
Project uncropped land													
FEG	1-2	2	2			1	1	2	2	2	2	2	2
IRC	1-2	2	2			1	1	2	2	2	2	2	2
WBS	1-2	2	2			1	1	2	2	2	2	2	2
NR	1-2	2	2			1	1	2	2	2	2	2	2
Farm uncropped land													
Habitat 1	1-2	2	2			1	1	2	2	2	2	2	2
Habitat 2	1-2	2	2			1	1	2	2	2	2	2	2
Habitat 3	1-2	2	2			1	1	2	2	2	2	2	2
Habitat 4	1-2	2	2			1	1	2	2	2	2	2	2
Vortis													
Project uncropped land													
FEG	1-2	2	4			1	1	1	1	1	1	1	1
IRC	1-2	2	4			1	1	1	1	1	1	1	1
WBS	1-2	2	4			1	1	1	1	1	1	1	1
NR	1-2	2	4			1	1	1	1	1	1	1	1
Farm uncropped land													
Habitat 1	1-4	2	4			1	1	1	1	1	1	1	1
Habitat 2	1-4	2	4			1	1	1	1	1	1	1	1
Habitat 3	1-4	2	4			1	1	1	1	1	1	1	1
Habitat 4	1-4	2	4			1	1	1	1	1	1	1	1
Birds	All			3	3	3	3	3	3	3	3	3	3
Mammals	All			2	2	2	2	2	2	2	2		

Plants

The vegetation was assessed in four plant habitats:

1. Cropped field
2. Verge: defined as the area immediately adjacent to the hedge, ditch or fence, including 2m cross compliance area.
3. Hedgerow: trees and shrubs along field boundary where present.
4. Uncropped field margin or block: defined as an area of land that would otherwise be cropped with a width of at least 4m and with vegetation distinct from the verge.

1. Cropped field (weeds)

Weeds were assessed in April of 2006 (except organic farms), 2007, 2008 & 2009. For each farm, three fields were selected including a winter cereal, winter broad-leaf crop (usually oilseed rape) and a spring crop (where this was present). The crop species were recorded. The same fields were used every year with the exception of a few occasions where a field did not have a crop sown. The method used was similar to that used in the Farm-Scale Evaluation of GM crops (Heard *et al.,* 2003) Four transects were marked out at intervals of 33m perpendicular to the field boundary (the south facing side of the field was always used). Weeds were assessed in $0.5m^2$ quadrats positioned at 0, 4, 8 and 32m from the crop edge along each transect using a three-point scoring system for each species present in the quadrat: 1= species present (1-3 plants), 2 = minor constituent (3-10 plants), 3 = major constituent (could include an estimate of cover).

2. Verge

In 2006 & 2007 (2007 & 2008 on organic farms), the vegetation in the verge along the field boundaries used for the weed transects was assessed. Four $0.5m^2$ quadrats were used in each of the three intervals between the positions of the cropped field transects (a total of 12 quadrats along approx. 100m). The species present in each quadrat were recorded with a note made of any dominant species. Because the organic farms were not assessed in 2006, this protocol was done in 2007 & 2008 on these farms

In 2007 & 2008, the vegetation in the verges bordering areas of newly sown habitats on farms with treatments 1-4 was assessed in the same way using 12 quadrats positioned along a 100-m length of field boundary. This was done to provide data on possible sources of colonisation of the newly sown habitats. In order to maintain equal sample number between the treatments, 12 quadrats were also assessed along an additional verge on farms with treatments 5-7.

3. Hedgerow

In 2006 & 2007 (2007 & 2008 on organic farms), the vegetation in the hedgerows was assessed, the dominant woody species (making up >20% of the canopy) in any hedgerow or wood bordering the field was recorded along a 10m length at either end of the 100-m used for the verge quadrats.

4. Uncropped land

In June / July of 2006 & 2007, the vegetation in any uncropped land along the boundaries of the fields used for the weed assessments was assessed (NB these were areas floristically distinct from the verge). Four 0.5m^2 quadrats were positioned in each interval between the cropped field (weed) transects (a total of 12 quadrats along approx. 100m). The species present in each quadrat were recorded with a note made of any dominant species. On a number of farms, the field margin included areas that had been managed differently (for example, a grass margin bordering a cultivated strip). Where this was the case, and each separate area had a width of >4m, 12 quadrats were used in each area. Because the organic farms were not assessed in 2006, this protocol was done in 2007 & 2008.

In June / July of 2007, 2008, 2009 & 2010 the vegetation in twelve 0.5m^2 quadrats positioned along a 100-m transect was assessed in each of the project-managed habitats on farms with treatments 1-4. The species present in each quadrat were recorded with a note made of any dominant species. In addition, falling disc measurements were made in alternate quadrats to assess vegetation height. Where the habitats were established in two separate margins or blocks, 6 quadrats were assessed and three falling disc measurements taken in each area.

In order to maintain an equal sample number between the treatments, the vegetation in 48 equivalent quadrats on uncropped land was assessed on farms with the farmer-managed treatments 5-7. Four transects were marked out on margins or blocks with uncropped land (in addition to those assessed in 2006 & 2007, described above). The four transects were allocated to the different types of uncropped land according to the proportion of uncropped land that they occupied (e.g. if grass margins represented 50% of uncropped land then two transects were allocated). The vegetation was assessed in twelve 0.5m^2 quadrats along the transect in the same way as for the farms with project-managed habitats. Equivalent falling disc measurements were also made.

Invertebrates

Two methods (Transects and Vortis sampling) were chosen that would measure:

1. invertebrates of conservation concern (bumble bees and butterflies);
2. the abundance of those invertebrates delivering the key ecosystem services (pollination and biological control);

3. invertebrate food availability for farmland birds.

1. Transect walks

The standardised butterfly transect method (Pollard & Yates, 1993) was adopted to determine the abundance and diversity of pollinating insects (bees, butterflies and hoverflies) in each habitat type that was assessed. This involved recording all bees, butterflies and hoverflies along a pre-marked 100-m transect. Two approaches were taken, one that provided a measure of pollinator abundance at a farm-scale and the other that would enable the success of the project-managed habitats to be evaluated against farmer-managed habitats.

Taxa identified

Owing to the difficulty in identifying bees and hoverflies to species on the wing, the following groups were identified.

- Bumble bees
    - black body, red tail — *Bombus lapidarius*
    - brown/ginger all over — *B. pascuorum*
    - yellow bands & red tail — *B. pratorum*
    - 2 yellow bands & white tail — *B. terrestris* or *B. lucorum*
    - 3 yellow bands & white tail (long body & head) — *B. hortorum*
    - cuckoo bees as a group — subgenus *Psithyrus* species
- Solitary bees as a group
- Honey bees — *Apis mellifera*
- Butterflies identified to species
- Hoverflies
    - *Episyrphus balteatus*
    - Other yellow and black species as a group
    - Bee and wasp mimics as a group
    - Dark plain species as a group

Farm-scale assessments

Assessments were conducted twice, once early season (mid-May to mid-June) and once late season (early August), as weather conditions allowed. At each site, a 100 m transect was marked out along a field margin bordering each of three fields, containing, where possible, a winter cereal crop, a winter broad-leaved crop and a spring crop, as chosen for the vegetation assessments. The three transects at one site were walked on the same day, the order being chosen at random, since time of day affects flight activity. Walks were carried out from 10.00h – 17.30h, ideally when weather conformed to Butterfly Monitoring Scheme standards (temperature above 13^{o}C when there was at least 60% clear sky or above 17^{o}C in any sky conditions, apart from heavy rain). The time of day for each transect walk, shade temperature, percentage cloud cover and wind speed (using Beaufort scale) were recorded. The transect was walked at an even pace, covering approximately 15-20 m per minute. Whilst walking along the crop edge, the following were scored: hoverflies within 1 m of the field boundary, bees within 2 m of the field boundary, and butterflies within 5 m of the field boundary. This included margin, verge and boundary vegetation if they fell within the appropriate distance. Each individual butterfly which came within 5 m in front of the recorder was scored. Bees were only scored if they were actively foraging (or nest-searching queens) within 2 m ahead of the recorder and not if they just flew straight past. Hoverflies were only scored if they were sitting on flowers or hovering close to flowers within 1 m ahead of the recorder. Notes were made of the plant species on which bees and hoverflies were foraging

Habitat-scale assessments

The habitats were only sufficiently developed by mid-summer in 2007 and were therefore only assessed in early August. In the following years assessments were conducted twice, once early in the season (mid-May to mid-June) and once late season (early August), as weather conditions allowed. A total of eight 100-m long transects were sampled on all farms. On the project-managed farms (treatments 1-2) where there was more than one strip containing the sown habitats then a transect was assessed within each of the 4 managed habitat types in two fields (allocated randomly). On farms with project-managed blocks (treatments 3 & 4) two transects were assessed in each managed habitat type, at either end of the block or if two or more blocks per farm, one transect per treatment and block (allocated randomly). On farms with farmer-managed strips (treatments, 5-7) two transects in each uncropped habitat type, each in a different field (allocated randomly) were assessed. If more than one uncropped habitat type was present per farm then the transects were allocated in proportion to the area occupied by each habitat type. For example, if there were equal proportions of two habitats the transects were allocated evenly.

2. Vortis sampling

A Vortis sampler with a modified nozzle was used to sample invertebrates both on the ground and vegetation reflecting invertebrate availability for farmland birds and species that contribute to biological control. Sampling was done once at the time of peak aphid numbers in late June/early July when natural enemies of pests and invertebrates important for bird food were abundant. The modified nozzle was attached to a flexible hose and consequently could be placed over the vegetation. A standard Vortis nozzle would have been inappropriate for sampling taller vegetation. The uncropped habitats on each farm were sampled. For each sample, the nozzle was placed over the vegetation and held for 5 seconds in each of 15 sub-sampling points, spaced at least 1 pace apart sampling a total area of 0.47 m^2.

On project-managed farms with strips (treatments 1 and 2) two samples were taken in each managed habitat type, in each of two different fields. On project-managed farms with blocks (treatments 3 and 4) four samples were taken in each managed habitat type, two at either end of the block.

On farmer-managed farms four samples were taken from uncropped habitats in proportion to their relative abundance of each uncropped habitat type. Whenever possible the same margins were used each year.

All invertebrate samples were collected in plastic bags and frozen the same day. The samples were then sorted to remove excessive vegetation and the remaining contents stored in alcohol. The invertebrates listed in the Appendix were identified within each sample under a microscope.

Birds

Birds were counted at each of 28 farm sites, during five annual (2006 and 2010), breeding season assessments, each comprised of three visits (April, May and June). Each visit involved a whole-area search of approximately four hours duration, in which all birds seen or heard were recorded onto large-scale site-maps. No counts were conducted in wind conditions greater than Beaufort Force 4 (light breeze) or in persistent heavy rain as these conditions can strongly reduce the efficiency and accuracy of counting. Birds flying directly over a site were not used in the analysis (e.g. gull *Larus* species). Birds flying but foraging over the site were included in the analysis (e.g. Barn Swallow *Hirundo rustica*). For consistency and to avoid double counting, birds were recorded in the location in which they were first seen or heard and care was taken to avoid recording the same individuals twice. Each record of a single bird or a single group of birds was termed a 'registration'.

Mammals

The numbers of hares and other mammals (foxes, badgers, deer and rabbits) were surveyed across the whole of each study area in November/December and January/February starting autumn 2006 and finishing spring 2009. The survey was based upon fixed point counts across each study area with the aim to observe a high proportion of the area, making the most of farm tracks for vehicular access.

Each farm was visited during daylight prior to the first count and a route selected that could be driven using farm tracks so that each field was visited. For each field viewing points were selected that enabled a high proportion of the field to be seen and the proportion seen estimated.

Surveys were conducted no sooner than one hour after sunset and completed before midnight. Hares and other mammals were sought using a powerful handheld spotlight and identified using binoculars. Records were made of cropping in each field, date, time and weather conditions during the survey.

3.2.3. Data analysis

It was expected that different taxa would respond to the availability of uncropped land at contrasting scales. Therefore two separate analyses were done: 1) Generalised Linear Mixed models (GLMM) to test for the effect of the scale and arrangement of uncropped land on abundance and diversity of plants, pollinators and birds at the scale of the 100 ha block and 2) Residual Maximum Likelihood (REML) analysis of differences in the abundance and diversity of invertebrates at the scale of habitat plots within the 100 ha blocks.

1) Analysis at 100 ha block scale

The analysis at the block scale was divided into two phases. Firstly, the original treatments (1-7) were included in the GLMM analysis as categorical variables after first correcting for the effect of year and region; ‘site’ was included as a random effect in all models described below. A normal distribution was assumed for number of plant species, poisson distribution for pollinator counts and either poisson or negative binomial distribution for bird counts (according to the best fit). The treatments were not fully established until 2008 so the analytical period was 2008-2010. For birds only, a log-area offset variable was added to models to account for small differences in site-area, and to convert abundances to densities. Landscape structure was also expected to influence the occurrence of organisms at the farm scale. Therefore, the percentage area of arable land (% arable) occurring in the surrounding 3-km^2 of each site and the boundary to area ratio (BAR) within each block indicating field size were also included as co-variates in the models.

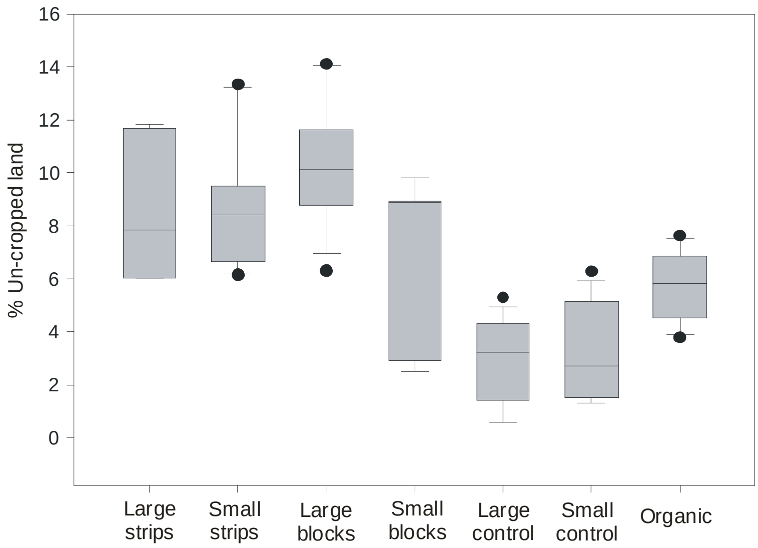


Figure 2. Variability in measured percentage of uncropped land, averaged over 2007-2010, in the 100 ha blocks for farms in the 7 treatments. Farms with blocks or strips were project-managed and control and organic farms were farmer-managed. The outer whiskers are the 10^{th} and 90^{th} percentiles and the filled circles are outliers.

Because project-managed farms also had other areas of (effectively farmer-managed) uncropped land within the 100 ha block, there were not clear divisions between the project treatments in terms of the scale of uncropped land (Figure 2). Therefore, a second analysis was done that included the scale and arrangement of uncropped land as continuous variables using the same distributions for the response variables as described above. A continuous variable for arrangement of uncropped land was calculated as the total perimeter of each patch of uncropped land / total area of uncropped land (P/A). ‘Strippier’ sites had a larger P/A ratio. Basic models included the following components: Count = year + region + % area of uncropped land + P/A + % arable + BAR (boundary/area ratio). Finally the *additional* effect of project-sown habitats was tested by including ‘plus or minus project habitats’ as an additional categorical variable. Since it was valid to use these general metrics of uncropped land before the treatments properly established, the analytical period was extended to include 2007 to 2010 (for improved analytical power) for the bird analysis, while the 2008-2010 data were retained to be comparable to the first analysis and combined test of birds, invertebrates and plants within established patches of uncropped land (established from 2008 onwards).

Two additional analyses were done at the 100 ha block scale for the bird data. Firstly, using GLMM, the additional effects of more detailed explanatory data on the proportion of crops and quality of the uncropped land were tested. These variables included the area of margins, the area of different crop types, the area of semi-natural habitats (such as patches of scrub, tracks and pond fringing vegetation), the area of winter bird cover, and the area of floristically enhanced grassland (e.g., grass-flower margins). Secondly, analyses were done to look for contrasts between trends across years, since 2006, between sites with project-managed uncropped land versus sites with farmer-managed uncropped land, the expectation being that project-managed uncropped land would perform the better of the two.

Finally, the plant data were analysed using Canonical Correspondence Analysis (CCA) to investigate differences in communities between project and farmer-managed farms.

2) Analysis at habitat plot scale

Measurements of pollinators were made along three field boundaries and in each uncropped habitat at each study site. However, besides the field boundaries only the four project-managed uncropped habitats, grass margins and game cover were sampled sufficiently to allow data from all sites and years to be compared using REML. Data were analysed separately for each sampling occasion owing to differences in phenology, especially butterflies, where not all species would be present on each sampling occasion. The model below was used. The random part takes into account the inherent variation between regions, farms, fields and years. The fixed part tests for differences between the regions, treatments and their interaction.
Random= region and its interaction with farm, nested within field nested with year
Fixed=region, habitat and their interaction

Measurements of invertebrates using a Vortis sampler were conducted in each uncropped habitat at each study sites. However, only the four project-managed uncropped habitats, grass margins and game cover were sampled sufficiently to allow data from all sites and years to be compared using REML. Because there was more than one sample per habitat, sample was added to the random model in the following way:
Random= region and its interaction with farm, nested within field nested with year nested within the interaction between habitat and sample
Fixed= region, habitat and their interaction

3.2.4. Economics and farmer attitudes to growing wildlife crops

The costs associated with establishing and maintaining the four project-managed habitats and grass margins were determined and the gross margins calculated. These were compared to the gross margins for winter wheat and oilseed rape during the projects years taken from the Farm Business surveys (Lang, 2009, 2010; Wilson & Cherry, 2010).

All the farmers who had planted covers as part of the Farm4bio project were visited in February 2009 by John Holland and Jim Orson in order to canvas their opinions on the ease of management and their success.

3.3. Results

3.3.1. Crops and uncropped land

The uncropped land on the 28 farms varied from less than 2% to 18% (Figure 2). The uncropped land on the farmer-managed farms, including the organic farms, was predominantly grass margins but areas of floristically enhance grassland, wild bird seed, pollen and nectar mixes and game cover (mainly maize) were also present. On the project-managed farms the uncropped land included the four project designed habitats, plus varying amounts of farmer-managed areas. The cropping on the farms was predominantly winter cereals. On the three assessed fields, over four years (2006-2009) 52% were planted with winter cereals, 18% with autumn-sown broad-leaved crops (mainly oilseed rape), 19% with spring sown crops, 6% with grass and/or legumes, and 4% were uncropped.

3.3.2. Plants

During the project, 14,760 0.5 m^2 quadrats were assessed and the species present recorded. In total, 277 species were identified; of these, about 25% were only recorded once or twice. There were 273 species recorded in the uncropped land indicating that only four species were found exclusively in the crop (two were crop volunteers). Eight species occurred on uncropped land on every farm: barren brome (*Anisantha sterilis*), tall oat grass (*Arrhenatherum elatius*), cock's-foot (*Dactylis glomerata*), red fescue (*Festuca rubra*), cleavers (*Galium aparine*), hogweed *(Heracleum sphondylium*), bramble (*Rubus fructicosus*) and stinging nettle *(Urtica dioica*). There were 140 species recorded in the cropped area of the fields. The following 10 species occurred in crops on at least 20 of the farms: cleavers, groundsel (*Senecio vulgaris*), common field-speedwell (*Veronica persica*), field pansy (*Viola arvensis*), annual meadow grass (*Poa annua*), charlock (*Sinapis arvensis*), shepherd's-purse (*Capsella bursa-pastoris*), barren brome, cut-leaved cranesbill (*Geranium dissectum*) and scentless mayweed (*Tripleurospermum inodorum*).

A number of species that are of interest because they are rare or declining in arable habitats were recorded: small toadflax (*Chaenorhinum minus*), corn marigold (*Chrysanthemum segetum*), sharp-leaved fluellen (*Kickxia elatine*), round-leaved fluellen (*Kickxia spuria*), prickly poppy (*Papaver argemone*), shepherd's-needle (*Scandix pecten-veneris*), corn spurrey (*Spergula arvensis*) and slender tare (*Vicia parviflora).*

To determine whether there was a peak flowering period and whether there may be a "hungry gap" in terms of floral resources for pollinating insects, the number of species flowering in each month was determined for the 75 most frequently recorded species found on uncropped land and within fields. Most species were in flower during July, declining by month before and afterwards (Figure

3). The period of flowering for FEG showed a similar peak, starting in April and finishing in September with all eight species flowering in July. This coincides with the demand for floral-resources which is highest mid to late summer, but some resources should be available April-September.

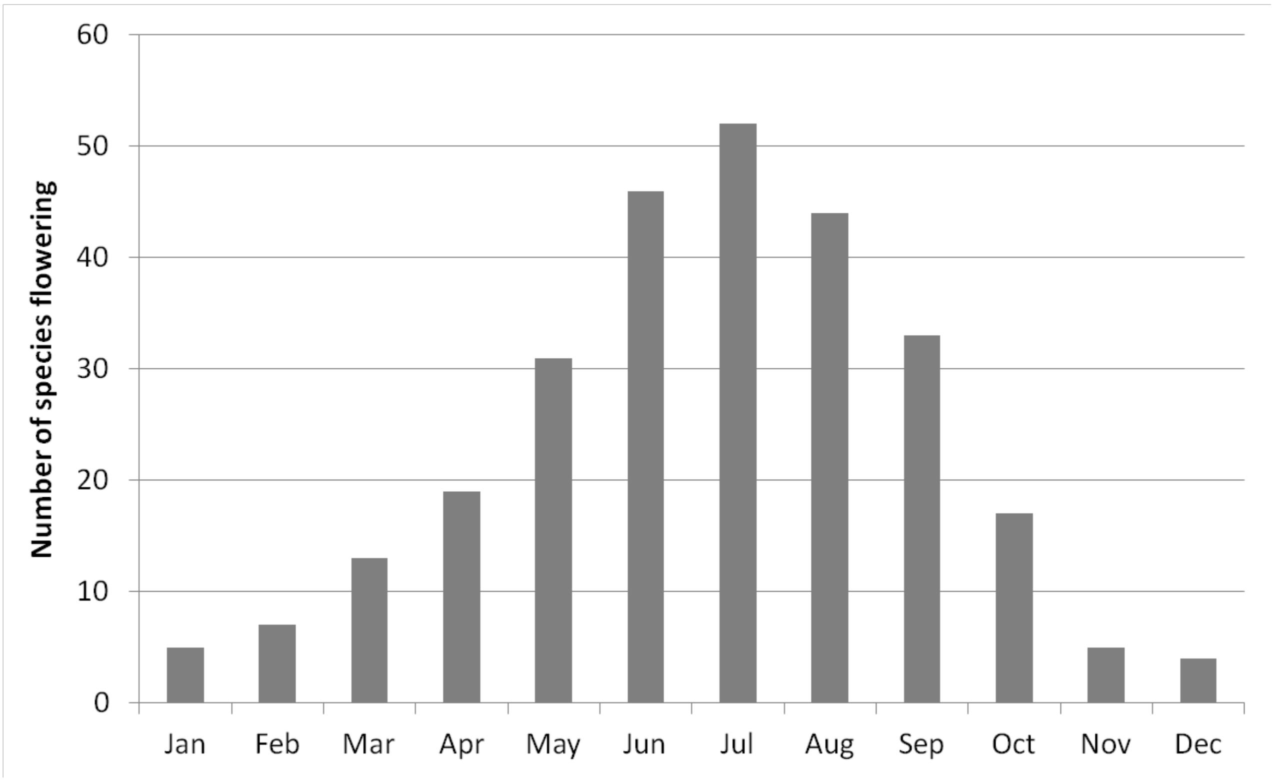


Figure 3. Number of species in flower each month for the 75 most frequently recorded plant species on uncropped land and within fields.

Phase 1 of the analysis at the 100 ha block scale, retaining the original treatments as categorical variables, indicated that there were large differences between years and regions in terms of the numbers of species recorded in the uncropped and cropped areas of the fields with significantly higher species richness in East Anglia in both habitats (Table 2,Figure 4). Organic farms had higher weed species richness in the crops but similar numbers of species in the margins indicating that herbicide spray drift was not damaging. There were no further treatment differences between the project and control farms. However, the number of species recorded on project-managed farms did increase in 2008, 2009 and 2010 as a result of the sown species mixes (Figure 4), although the differences between project and farmer-managed farms were not significant once year and region were included as co-variates in the GLMM analysis.

Far more weeds were present in the grassland crops (which included legumes and/or grasses) and in the uncropped fields, than there were in the other cropped fields (estimated 48 plants m^{-2} (grass), 66 plants m^{-2} (uncropped), 14-28 plants m^{-2} (other crops)). The grass/legume crops tended to be most frequent on the organic farms. Cropping also affected the predominant species such as black-grass, cleavers and annual meadow grass which were most common in winter cereals, whilst charlock and cut-leaved cranesbill were most abundant in autumn-sown broad-leaved crops. Similarly, spring-emerging weeds such as black bindweed (*Fallopia convolvulus*) and fool's parsley (*Aethusa cynapium*) were commonest in the spring-sown crops (see Lutman *et al.*, 2009).

Table 2. Step-wise GLMM analysis (using identity link function) for plant species richness (average values appear in parentheses). In each year, 48 quadrats were assessed in each farm both for the uncropped and cropped habitats. Cropped habitats (weeds) were not assessed in 2010.

Plant species richness	Year (2008, 09, 10)	Region (SE, SW)	Organic (+/-)	Project treatments
Uncropped land	* (38.8, 39.2, 43.5)	*** (51.5, 29.5)	NS	NS
Cropped field	** (14.2, 16.7)	*** (20.9, 10.0)	** (22.4, 14.3)	NS

Although there were no significant differences in the numbers of plant species recorded on uncropped land between the treatments, project-managed and farmer-managed farms had contrasting plant communities even when the sown species were removed from the analysis. These differences in communities were analysed using Redundancy Analysis on the data from a single year, 2008, excluding sown species and seedlings of trees and shrubs and including region as a covariate. Farmer-managed field margins were largely grass strips and this was reflected in the plant list on these farms that were dominated by grassland species (Figure 5a). In contrast, the annual disturbance, particularly of the natural regeneration treatment but also of the WBS and IRC, promoted a community dominated by annuals. As a result the uncropped land on project-managed farms contained a large number of species that can potentially be crop weeds (Figure 5b). Many of these, particularly spring germinating species, can play a beneficial role by providing resources for birds and invertebrates. However, this needs to balance with the potential build-up of problem weeds such as black-grass that were particularly abundant on farms with heavier soils.

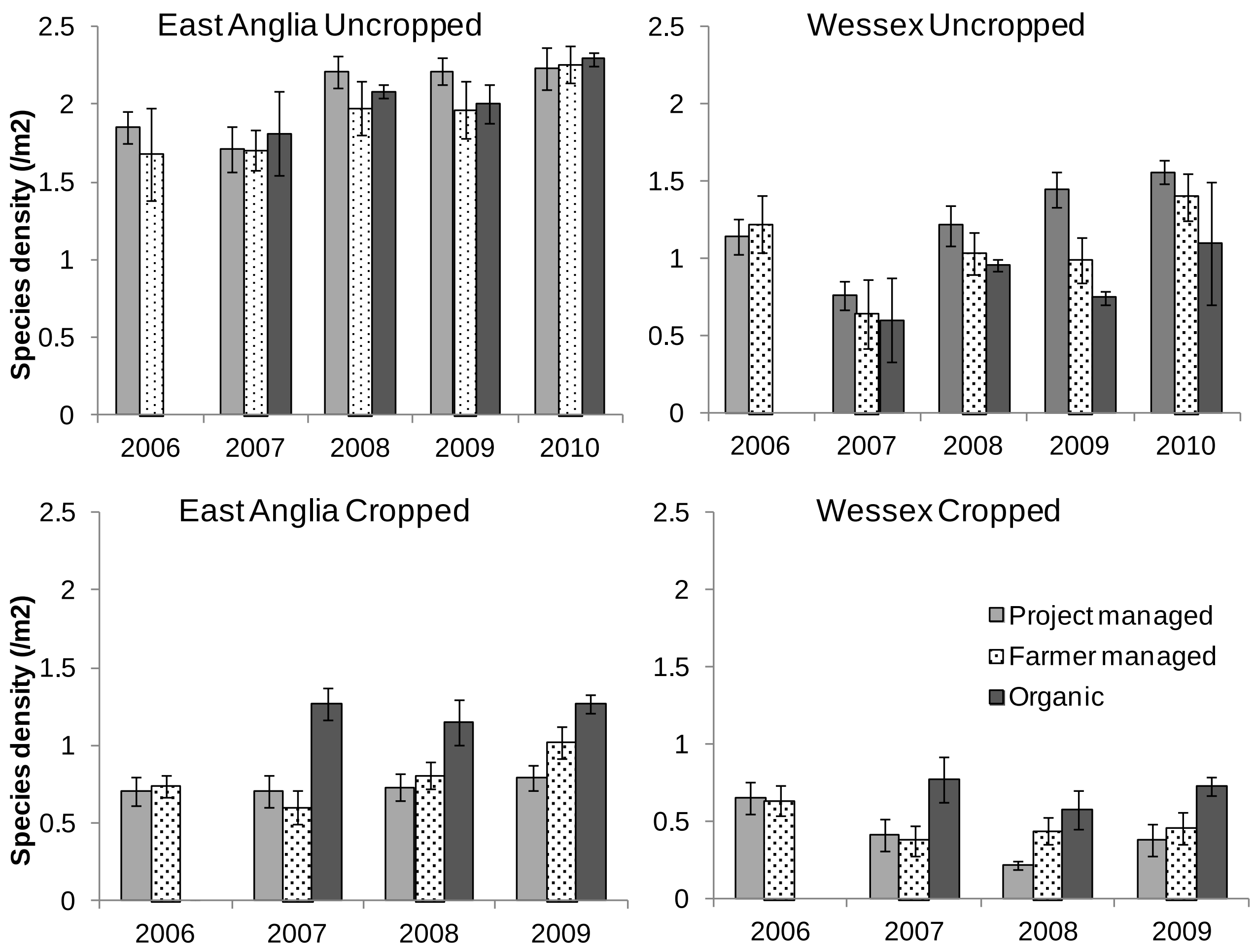
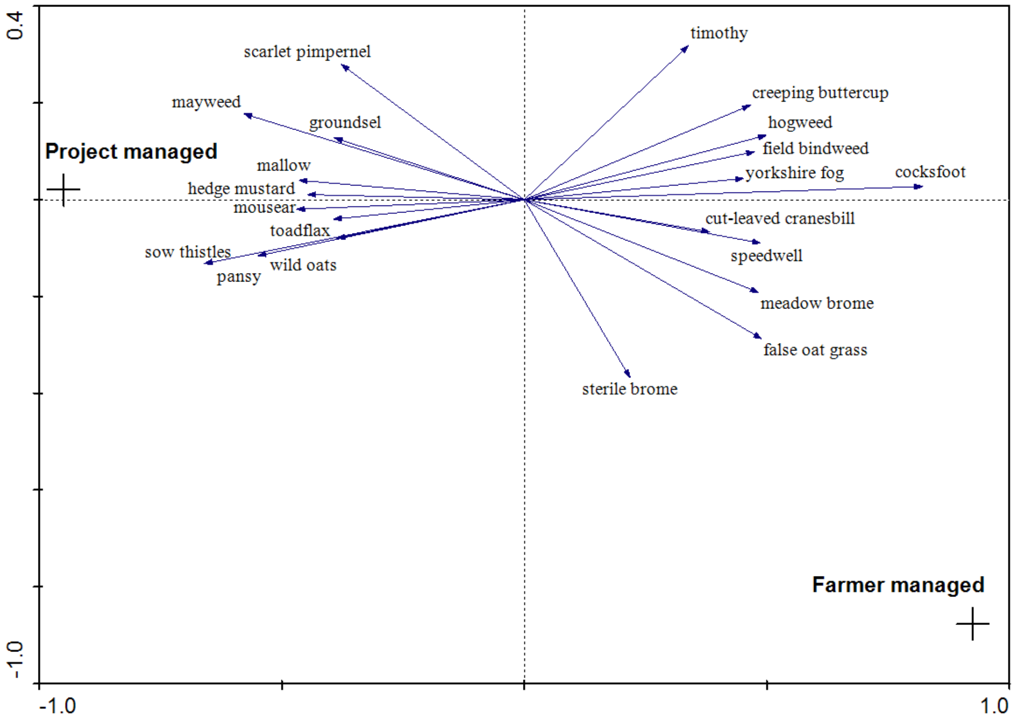


Figure 4. Plant species density in uncropped and cropped habitats. Error bars = standard error of means. Only baseline margins were assessed in 2006 (no records from organic farms) and habitat establishment was poor in 2007. Cropped habitats (weeds) were not assessed in 2010.

a)



b)

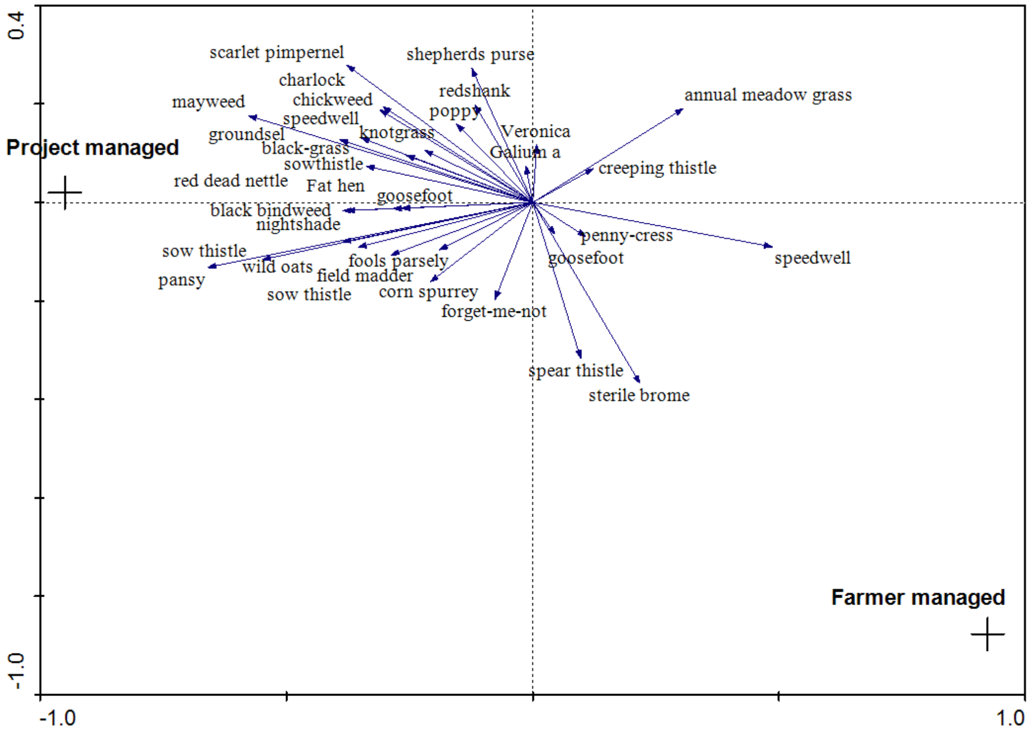


Figure 5. Redundancy analysis of plant communities recorded on uncropped land in 2008 excluding sown species and including region as a covariate. The ordination was performed for all species but only a sub set are presented in each figure: a) only 21 species with highest loading presented; farmer-managed farms are dominated by grassland species. b) All weed species recorded on uncropped land presented; most are more abundant on project-managed farms.

When the area of uncropped land was input into the model as a continuous variable, it explained a proportion of the variability in numbers of plant species recorded on uncropped land ($P<0.05$). This may be explained by the strong correlation between uncropped land area and heterogeneity (calculated as a Shannon diversity index of different habitats), $r=0.66$, $P<0.001$ – farms with more uncropped land were likely to have more diverse habitats. There was no effect on the number of plant species found in the cropped area of the fields and no effects of the landscape variables on plant species richness in either habitat.

3.3.3. Invertebrates

1) Analysis at 100 ha block scale

Pollinators

There were significant differences in all the insect groups recorded on the transect walks between years and regions (Table 3). Generally higher abundance and diversity of insects was recorded in Wessex than East Anglia, despite the lower plant species richness. When the treatments were included as categorical variables, the only significant result was that fewer bees were recorded along the field margins (those assessed in 2007) on organic farms when compared to conventional. This was because the bees were foraging on the organic grass/legume leys in the field centres rather than the field margins where the transects were located. When the scale and arrangement of uncropped land were included as continuous variables, the percentage uncropped land was significantly correlated with butterfly diversity in the baseline margins and bee abundance and diversity recorded on the project habitats or equivalent areas of uncropped land on conventional farms (Table 4, Figure 6). This is evidence that farms with more uncropped land are able to support larger, more diverse populations of pollinators. The relationships were linear for wild bee abundance and butterfly diversity with no suggestion of upper or lower thresholds, however, wild bee diversity did not increase beyond 3-5% uncropped land. Greater butterfly diversity was recorded on farms where the uncropped land was arranged in strips (a high P/A ratio) as opposed to blocks.

Table 3. Mixed effects GLMM using Poisson distribution (log link) for density (m^{-2}) and diversity (Shannon index) for bees, butterflies and hoverflies. Site code entered as random variable in all cases. Numbers in brackets are arithmetic means for 2008, 2009, 2010 (years), SE, SW (Regions) and organic vs. conventional. Suffix b = recorded on baseline margins, h = recorded on habitats (or equivalent uncropped land on control farms), 1 = first recording date, 2 = second recording date.

Variable	Year (2008, 09, 10)	Region (SE, SW)	+/- Organic
Bee diversity,^{1,b}	*(1.8, 2.1, 1.6)	* (2.1, 1.5)	
Hoverfly density^{1,b}	***(3.8, 1.7,1.9)		
Butterfly density^{1,b}	***(0.7, 2.0, 0.9)	**(0.6, 1.7)	
Butterfly diversity^{1,b}	***(0.6, 1.6, 0.9)		
Bee density^{2,b}		* (3.2, 5.3)	* (2.4, 4.5)
Hoverfly density^{2,b}	***(7.5, 5.6, 15.5)		
Butterfly density^{2,b}	***(2.2, 5.3, 3.3)	***(1.6, 5.6)	
Butterfly diversity^{2,b}	***(1.8, 3.7, 2.6)	*(2.3, 3.1)	
Butterfly density^{1,h}	***(0.1, 0.3, 0.2)		
Butterfly diversity^{1,h}	***(0.4, 0.8, 0.7)	*(0.5, 0.8)	
Hoverfly density^{2,h}	***(9.7, 19.3, 41.3)	**(40.9, 6.0)	
Butterfly density^{2,h}	***(0.7, 1.9, 1.2)		

Table 4. Mixed effects model using Poisson distribution (log link) for density (m^{-2}) and diversity (Shannon index) for insects recorded on transect walks along field boundaries with scale and arrangement of uncropped land included as continuous variables. Year, region, % arable, BAR all included as co-variates. Site code entered as random variable in all cases. Numbers in brackets are arithmetic means for farms with or without project sown habitats. Suffix b = recorded along field boundaries, h = recorded on habitats (or equivalent uncropped land on control farms), 1 = first recording date, 2 = second recording date.

Variable	% uncropped land	Perimeter/Area (P/A)	+/- project habitats + -
Bee density^{1,b}			*(2.3, 3.3)
Bee diversity^{1,b}			*(1.6, 2.0)
Butterfly diversity^{1,b}	**(+ive)		
Bee density^{1,h}	***(+ive)		
Bee diversity^{1,h}	***(+ive)		*(0.6, 0.5)
Butterfly diversity^{2,h}		**(+ive)	

Once the increase in overall percentage of uncropped land had been accounted for, the project-sown habitats had an additional effect on diversity of bees with increased diversity recorded on farms with project-sown habitats. However, these farms also had less bee abundance and diversity along the field margins (Table 4) suggesting that the project treatments may have been drawing in bees from the surrounding landscape. There was no effect of the wider landscape variables, the proportion of arable land and BAR, on the counts of insects recorded on the transect walks.

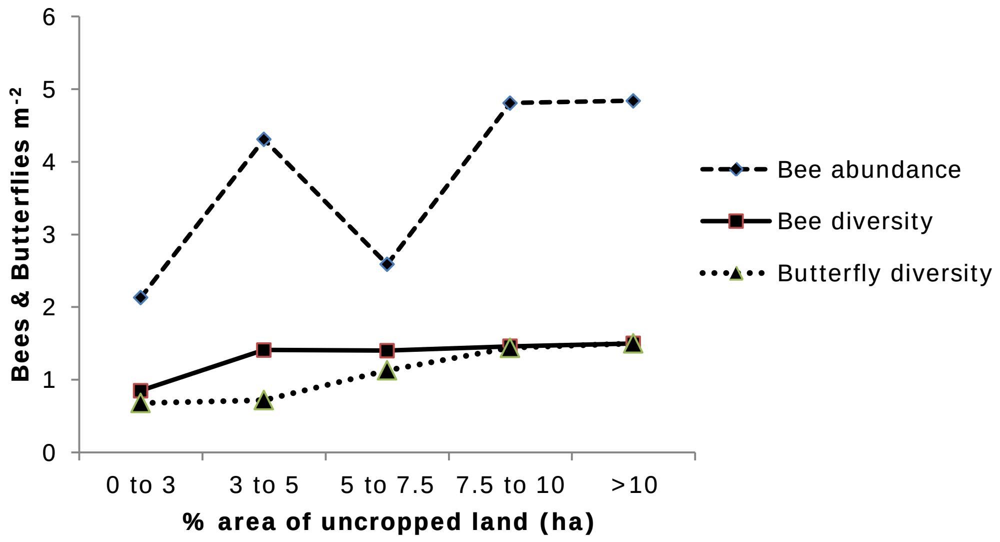
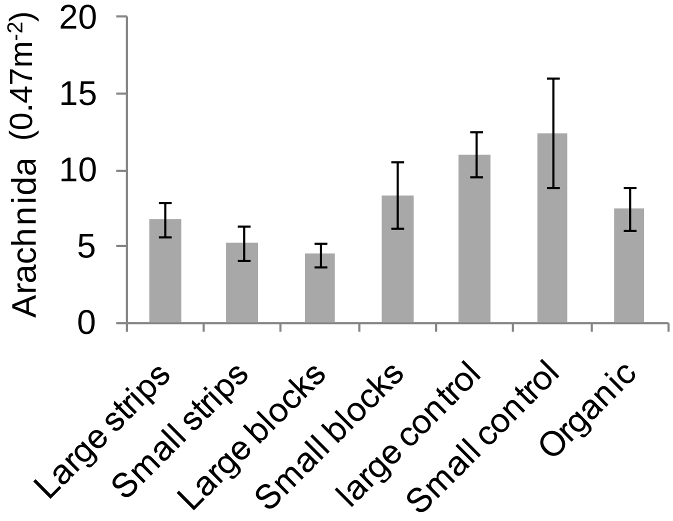


Figure 6. Increase in density of wild bees and diversity of wild bees and butterflies recorded on project habitats, or equivalent areas on uncropped land on control farms, with increasing percentage of uncropped land in the block.

Vortis samples

Phase 1 of the analysis at the 100 ha block scale, using invertebrate groups caught in the Vortis samples, identified consistent effects of year and region for all groups (Table 5). Fewer individuals were caught in 2008 and higher abundance was recorded in East Anglia. There was a significant effect of organic systems on the total number of chick-food items, once the effect of year and region had been accounted for with fewer individuals counted on organic farms. This is due to the large effect of the project-sown habitats (see below) which were only sown on conventional farms. There were two additional effects of the project treatment structure when entered as a categorical variable. Firstly, Arachnida were more abundant on farmer-managed farms, suggesting that they favoured grass margins and, secondly, more Coleoptera were found on project-managed farms where habitats were in blocks (Figure 7). The habitat scale analysis (see below) identified pest species attracted to the Brassicas in the wild bird seed as a possible driver of this effect.



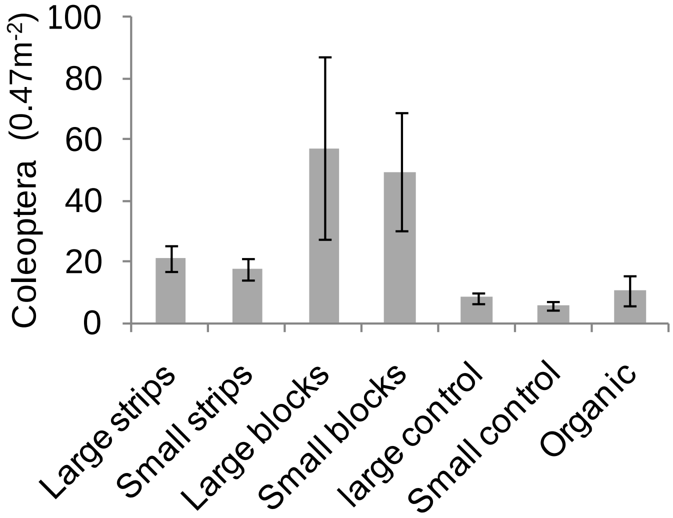


Figure 7. Effect of treatment structure on abundance of Arachnida and Coleoptera when analysed at the 100 ha block scale.

In contrast to the counts of pollinators, there was no effect of either percentage uncropped land or the arrangement of uncropped land on invertebrate groups caught in the Vortis samples when these variables were entered as continuous variables in Phase 2 of the analysis. This suggests that the populations of these species are responding to management at the scale of the habitat plots as opposed to relying on provision of habitat elsewhere on the farm. This is supported by the fact that most Vortis groups responded significantly to the presence of project-sown habitats. The sown species mixtures, especially the wild bird seed, generally supported higher populations than grass margins which resulted in higher abundances and biomass on project farms when analysed at the 100 ha block scale (Figure 8). When averaged over the whole farm, project farms were providing approximately twice the biomass of invertebrates per m^2 as the farmer-managed (control) farms.

Table 5. Mixed effects GLMM using Poisson distribution (log link) for density (0.47 m^{-2}) and biomass (mg 0.47m^{-2}) of invertebrates caught in Vortis samples. Site code entered as random variable in all cases. Numbers in brackets are arithmetic means for 2008, 2009, 2010 (years), SE, SW (Regions) and organic vs. conventional.

Variable	Year (2008,09,10)	Region (SE, SW)	Organic (+/-)	Project treatments
Total numbers	***(129.5, 232.7, 218.9)	**(231.1, 156.2)		
Predators	***(10.4, 15.8, 17.5)			
Parasitoids	***(45.8, 76.3, 63.1)	***(78.8, 44.6)		
Key chick food numbers	***(27.1, 52.3, 61.9)	**(64.8, 29.4)		
All chick food numbers	***(53.4, 90.7, 88.0)		*(88.5, 40.9)	
Pests	***(22.5, 48.6, 55.8)	**(59.4, 25.3)		
Arachnida	***(4.4, 9.4, 11.0)			* (> on farmer-managed farms)
Coleoptera	***(11.6, 31.2, 24.0)	*(34.0, 10.5)		* (> on farms with project blocks)
Diptera	**(44.0, 62.3, 51.3)			
Hemiptera	***(23.1, 51.0, 66.9)	*(54.7, 39.3)		
Hymenoptera	***(46.0, 76.7, 63.4)	***(79.2, 44.9)		
Lepidoptera	***(0.2, 1.3, 1.2)	***(1.5. 0.3)		
Neuroptera		***(0.2, 0.1)		
Orthoptera	**(0.01, 0.03)			
Total biomass	***(442, 1853, 2492)	***(2624, 567.8)		
Key chick food biomass	***(44.6, 209.3, 272.5)			
All chick food biomass	***(419, 1763, 2397)	***(2541, 512)		
Grey partridge chick food index	***(0.33, 1.16, 0.90)	**(1.0, 0.6)		

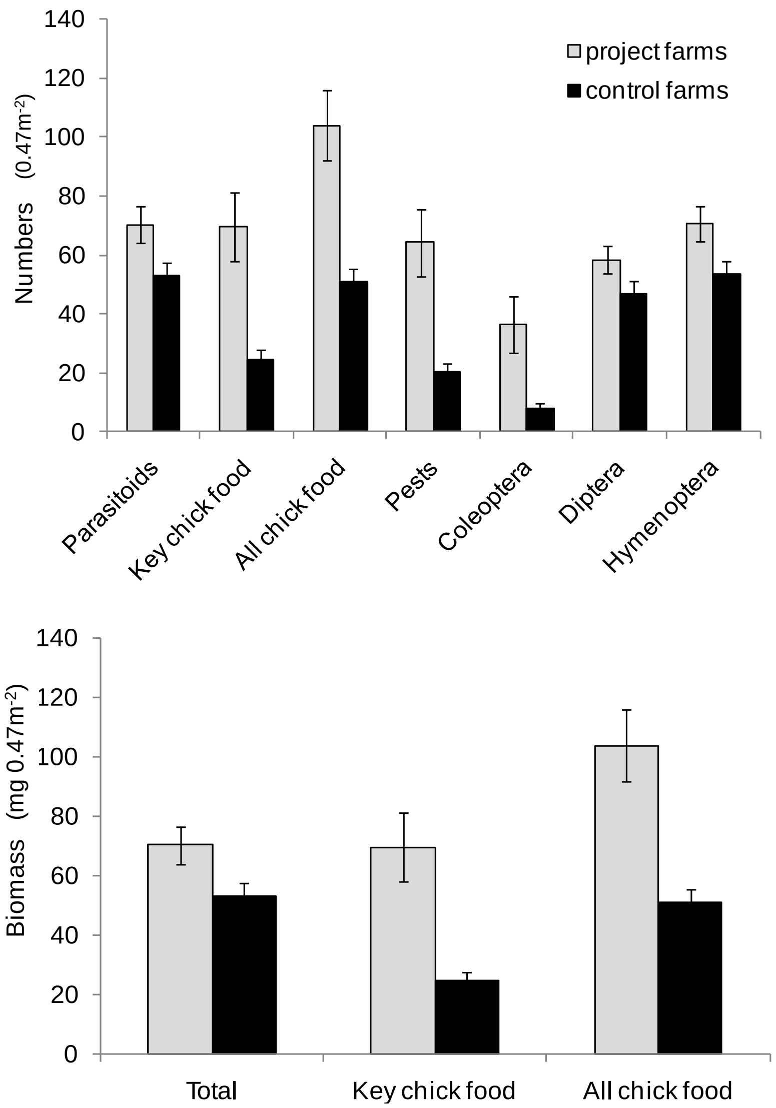


Figure 8. Effect of presence of sown project treatments on total, key chick food and all chick food biomass recorded in Vortis samples averaged over uncropped areas sampled in the 100 ha blocks. All effects were significant in the GLMM once year, region and percentage uncropped land had been accounted for.

2) Analysis at habitat plot scale

1. Transects

The wild bees were comprised largely of bumble bees, these forming at least 92% of wild bees recorded in the boundaries and uncropped habitats (Figure 9). There were three predominant bumble bee species (*B. pascuorum, lapidarius and pratorum*), the remaining species and cuckoo bees each forming less than 10% of the species composition. There was some variation in the species composition between habitats with more *B. pratorum* occurring along the boundaries and in the IRC and game cover, but few in the WBS. Most solitary bees were found in the game cover and natural regeneration. The majority (ca. 70%) of the bumble bees were short-tongued, only *B. terrestris/lucorum* and *B. pascuorum* are long-tongued. *Bombus terrestris/lucorum* formed the greatest proportion of the species composition in IRC and *B. pascuorum* the greatest proportion in

FEG indicating that these long-tongued bees were preferentially attracted to habitats that provided some flowers with longer corollas.

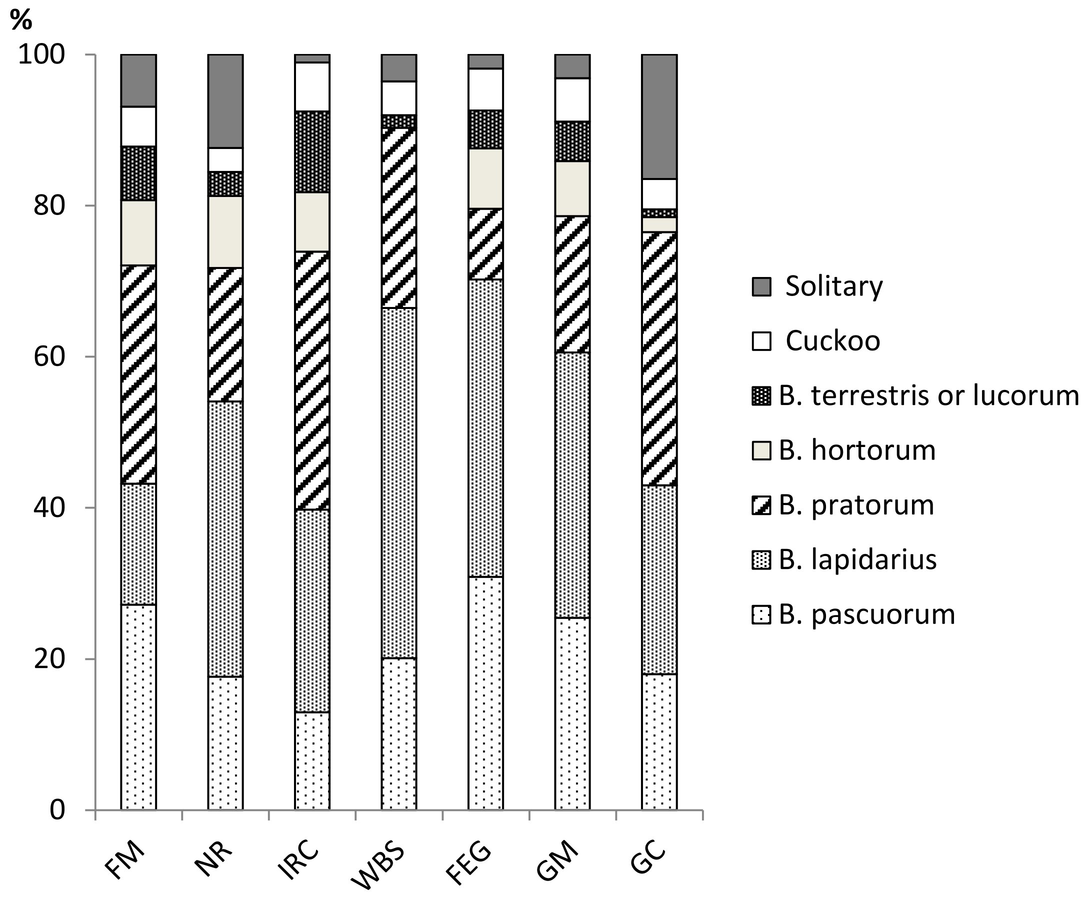


Figure 9. Proportion of wild bee taxa in each uncropped habitat. Mean values for all sites between 2008-10. (FM=field margin; NR=Natural Regeneration; IRC= Insect Rich Cover; WBS=Wild bird seed; FEG=Floristically Enhanced Grass; GM=Grass Margin; GC=Game Cover)

Of the hoverfly groups, the aphid predator *E. balteatus* was most abundant along the boundaries and IRC (Figure 10). Other yellow and black species were especially abundant in the FEG, grass margins and game cover. Bee and wasp mimics abounded in the natural regeneration.

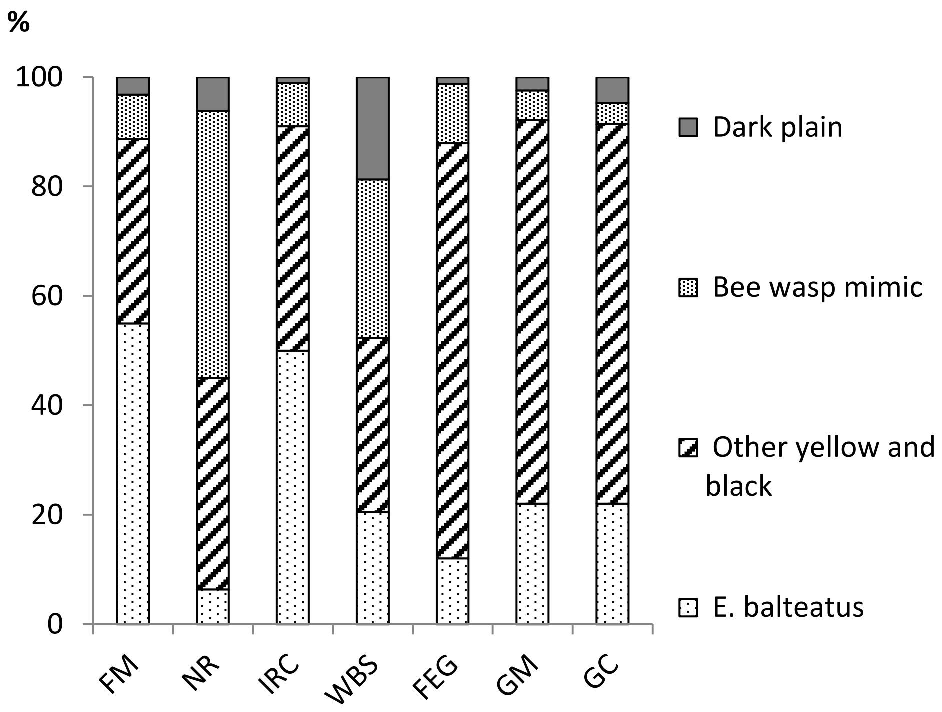


Figure 10. Proportion of hoverfly groups in each uncropped habitat. Mean values for all sites between 2008-10. (FM=field margin; NR=Natural Regeneration; IRC= Insect Rich Cover; WBS=Wild bird Seed; FEG=Floristically Enhanced Grass; GM=Grass Margin; GC=Game Cover)

The Pieridae (whites: Large white - Brimstone) were the predominant butterfly family, with small and large white butterflies forming between 25 and 75% of the total species composition (Figure 11). These two species were most abundant in the WBS and least so in the FEG and grass margins. Lycaenidae (hairstreaks, coppers and blues: Small copper – Brown argus) were rare (<6%) except in FEG where they formed 18% of the species composition. Nymphalidae (Vanessids and Fritillaries: Small tortoiseshell – Painted lady) were relatively abundant in most habitats (11-33%) with most occurring in natural regeneration. Only three species of Hesperiidae were found (Dingy – Small Essex skipper) and these only formed a small proportion of the species composition (<6%). Satyridae (browns: Meadow brown – Small heath) were most abundant in the grass margins (45%) and least so in WBS (4%).

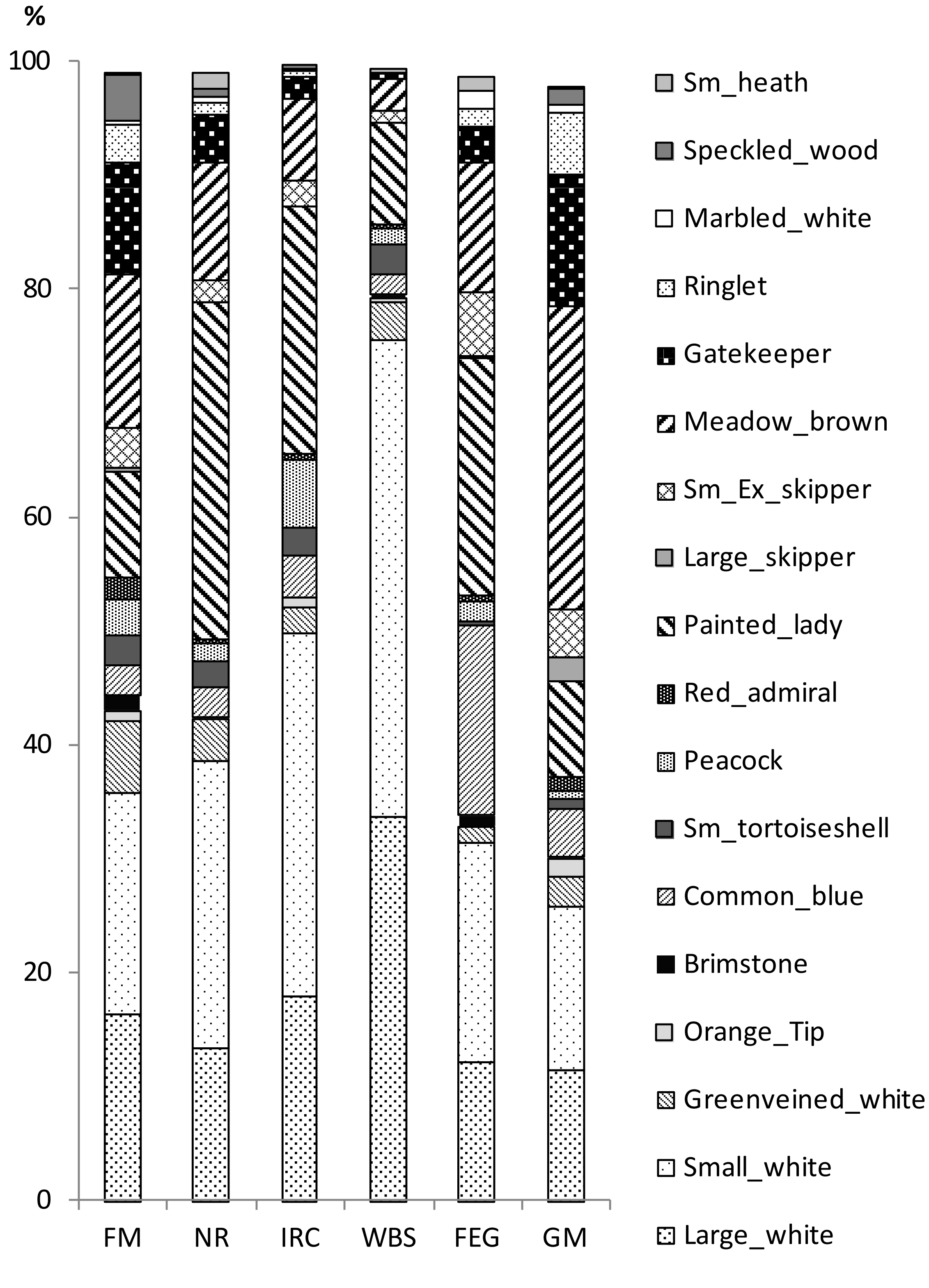


Figure 11. Proportion of butterfly species in each uncropped habitat. Mean values for all sites between 2008-10. (FM-Field Margin (margin, verge & boundary); NR=Natural Regeneration; IRC= Insect Rich Cover; WBS=Wild Bird Seed; FEG=Floristically Enhanced Grass; GM=Grass Margin; GC=Game Cover)

The data for the habitats established on uncropped land for which there was replication between farms and years was analysed using REML. On the first sampling occasion in June there was no interaction effect for habitat and region for any variable and there were only differences between regions for two variables. The abundance of wild bees, hoverflies and butterflies differed significantly between the habitats as did some taxa or groups (Table 6). Wild bee and bumble bee abundance and species richness of wild bees were three times as abundant in the floristically enhanced grassland (FEG) compared to the other habitats (Figure 12a,b). Likewise, cuckoo and solitary bees were most abundant in FEG and least so in IRC and game cover (Figure 12c). The total number of butterflies was highest in the wild bird seed and lowest in the game cover (Figure 12d). The Shannon index for butterflies was highest in the wild bird seed and insect rich cover and especially low in the natural regeneration (Figure 12e). The butterflies whose larvae feed upon grasses were at least twice as abundant in grass margins as on other vegetation (Figure 12f). Those butterfly species whose adults would be expected to make use of nectar provided by the sown wild flowers were highest in the floristically enhanced grass, grass margins and wild bird seed. Satyrid butterflies (Whites), which were largely comprised of species that feed upon brassicas, were at least twice as abundant in WBS, which included fodder radish and kale, compared to any other habitat. Hoverflies were twice as abundant in the FEG and almost twice as abundant in the grass margins compared to the other habitats (Figure 12g). *Episyrphus balteatus* which is an important aphid predator was only present in very low numbers but reflected trends for total hoverflies in habitat selection (Figure 12g).

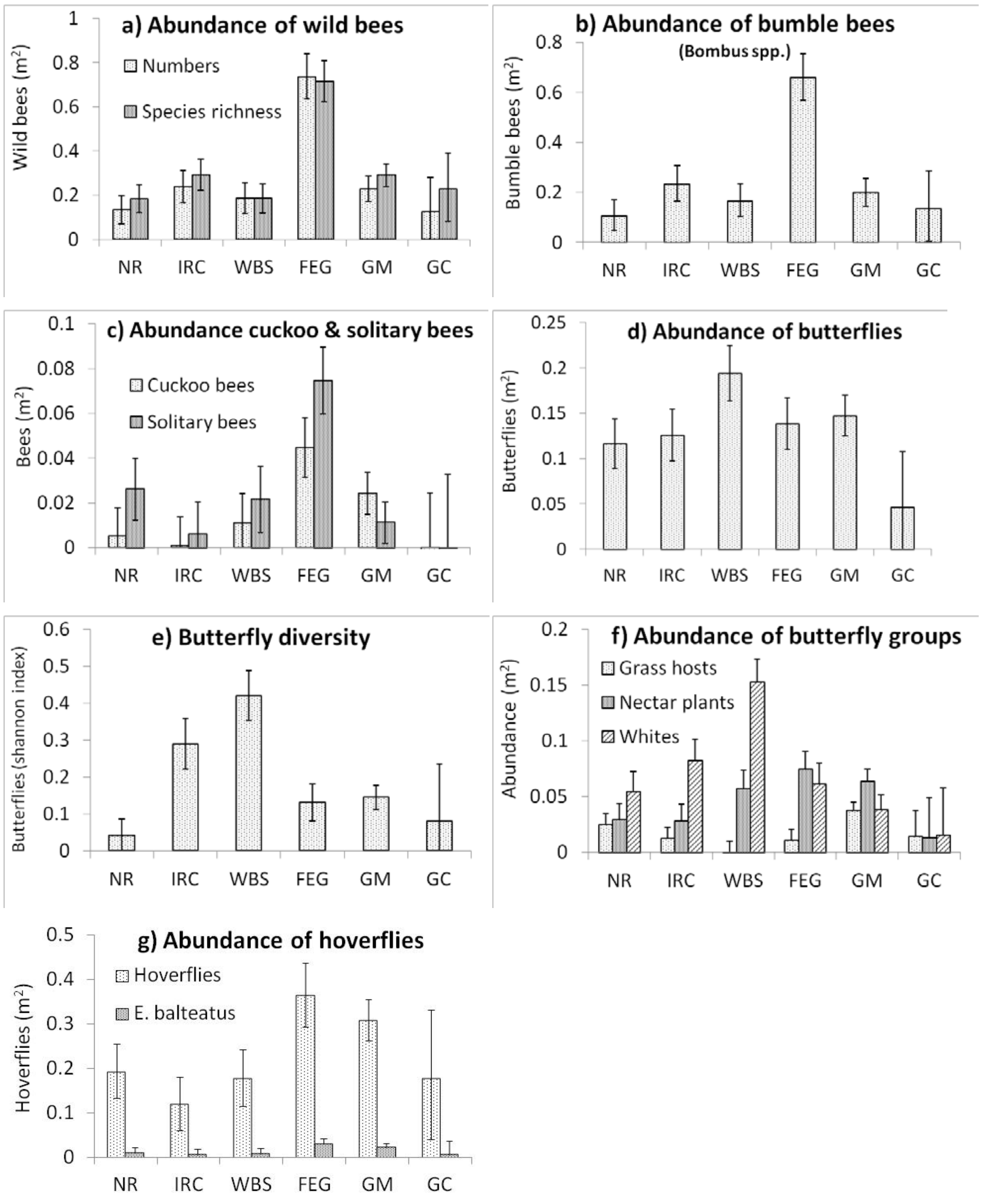


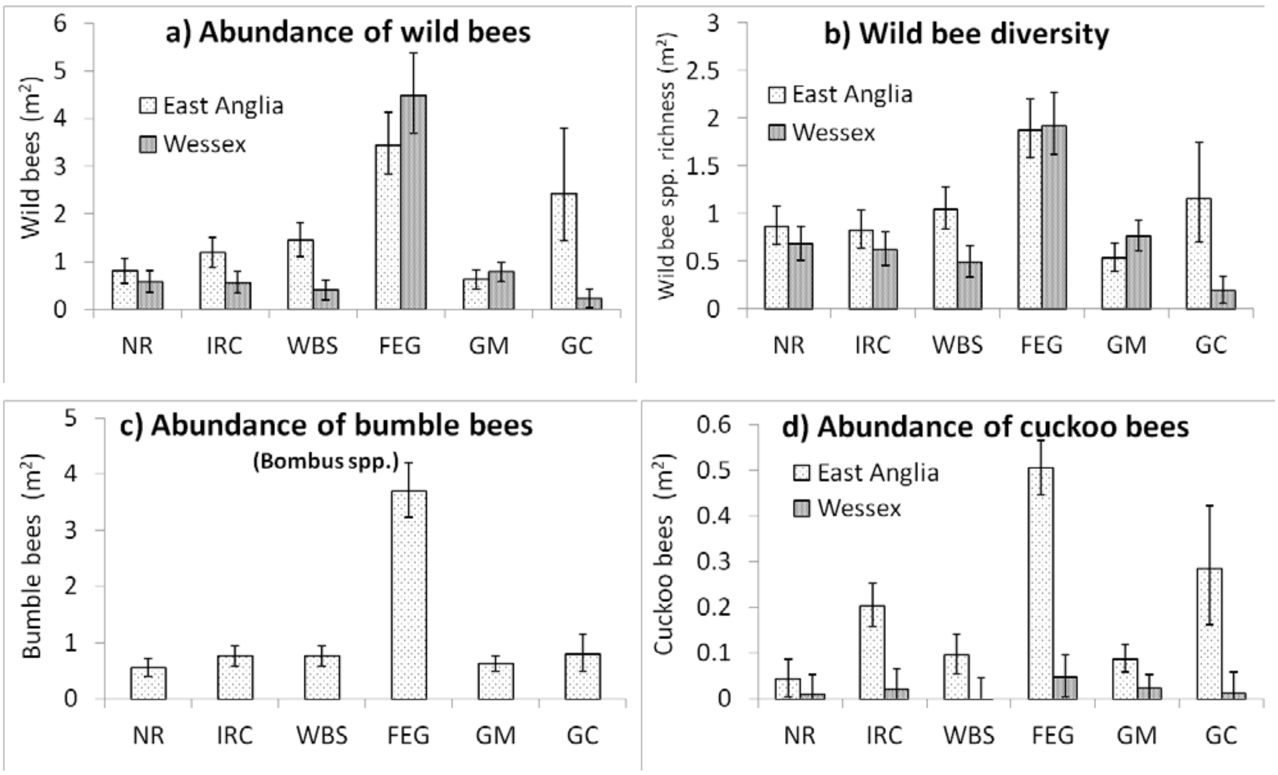
Figure 12 a-g. Invertebrate group mean values with standard errors for each habitat type from transect counts conducted in June. Means are predicted values from the REML analysis back-transformed. (NR=Natural Regeneration; IRC=Insect Rich Cover; WBS=Wild Bird Seed; FEG=Floristically Enhanced Grass; GM=Grass Margin; GC=Game Cover)

On the second sampling occasion there were more interaction effects between habitat and region but predominantly for wild bees and hoverflies (Table 6). Wild bees were more abundant in IRC, WBS and especially game cover in the East Anglian region compared to Wessex (Figure 13a). FEG supported the most wild bees in both regions and especially in the Wessex region, where there were almost eight times as many compared to the other habitats. The number of bee taxa (bumble bees to species, cuckoo bees and solitary bees as groups) followed a similar trend to abundance (Figure 13b). The density of bumble bees (excluding cuckoo bees) was at least seven times greater in the FEG compared to other habitats (Figure 13c). Likewise cuckoo bees were most abundant in FEG and approximately twice as numerous as in IRC or game cover (Figure 13d). In contrast, solitary bees were more than five times as abundant in game cover than natural regeneration and ten times more compared to the other habitats (Figure 13e). The density of butterflies was 25% higher in FEG and WBS compared to the other habitats between which there was little difference (Figure 13f). Butterfly diversity was greatest in FEG, grass margins and game cover (Figure 13f). The occurrence of butterfly adults was largely dependent on the larval food plants. The whites were twice as abundant in the WBS compared to the other habitats except game cover which had 30% fewer. (Figure 13g). Those with grass hosts were most abundant in FEG and grass margins. Butterflies seeking the nectar provided by sown species were 25-50% more abundant in the FEG compared to the other habitats (Figure 13h). Hoverflies and *E. balteatus* in particular were at least four times more abundant in the Wessex region compared to East Anglia, except in the game cover where they were equal (Figure 13i & j). Hoverfly numbers were highly variable as indicated by the large standard errors. Although they were lowest in grass margins abundance was largely similar in all other habitats, except in East Anglia where they were especially high in the game cover.

Table 6. Results of analyses comparing habitats, regions and their interaction on insects observed along transects in June and August.

(Significance values: ***=P<0.001; **=P<0.01; *=P<0.05)

	June		August		
Wild bees	Habitat type	Region	Habitat type	Region	Interaction
Total wild bees	***		***		***
Species richness	***		***		*
Bumble bees (Bombus spp.)	***		***		
Cuckoo bees	*		***	***	***
Solitary bees	**		***	***	***
Butterflies					
Total butterflies	*		***		
Diversity (Shannon)	***	***	***		
Whites	***		***		
Grass feeding	*	*	***		
Use sown flowers	*		***		**
Hoverflies					
Total hoverflies	**		***	***	***
Episyrphus balteatus			*	*	***



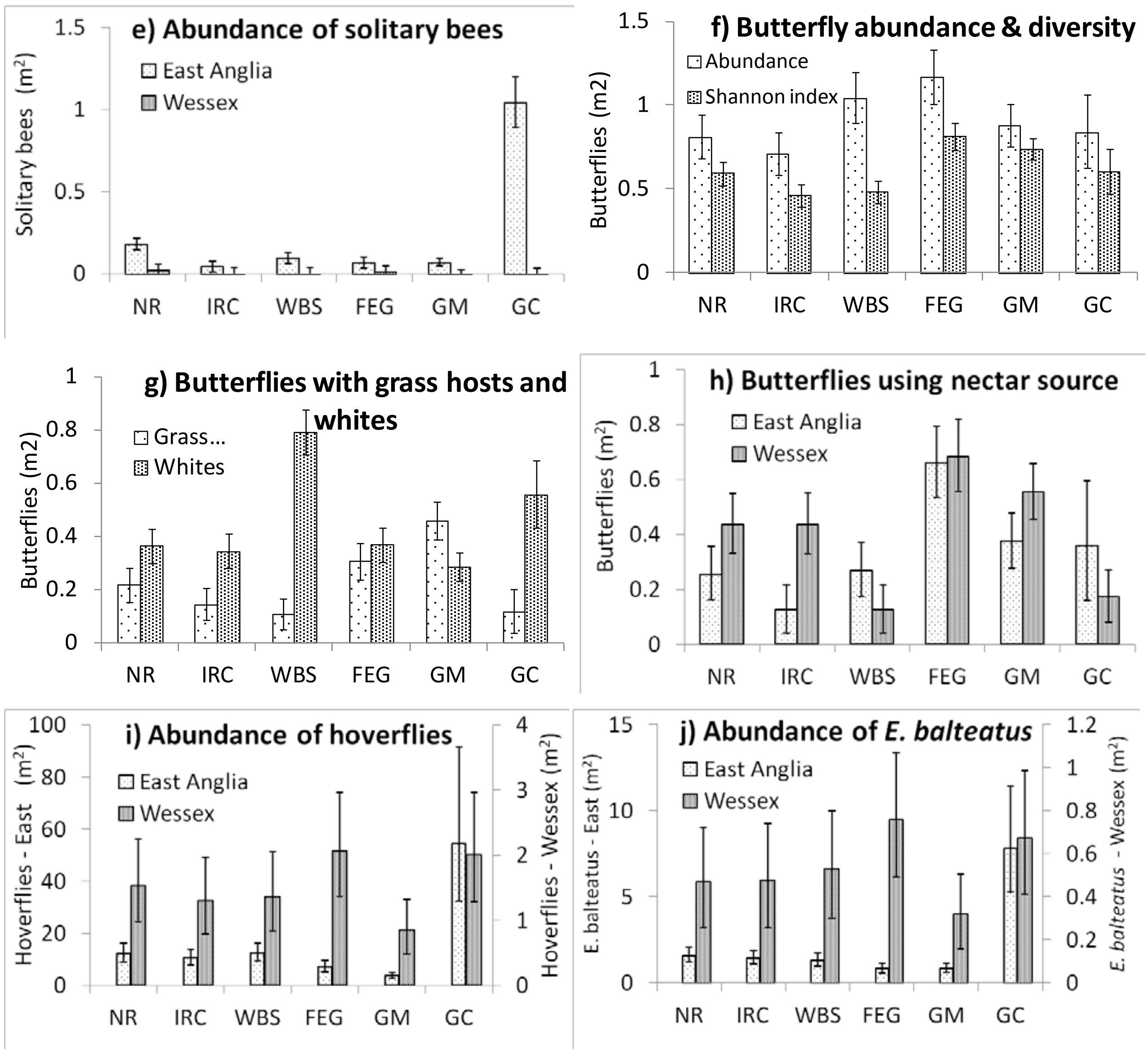


Figure 13 a-j. Invertebrate group mean values with standard errors for each habitat type from transect counts conducted in July/August. Means are predicted values from the REML analysis back-transformed. (NR=Natural Regeneration; IRC=Insect Rich Cover; WBS=Wild Bird Seed; FEG=Floristically Enhanced Grass; GM=Grass Margin; GC=Game Cover)

2. Vortis

The natural enemies of pests formed almost 40% of the species composition with the majority being Parasitica (parasitoids) (Figure 14). In contrast, pests only formed a maximum of 32%, these being greatest in natural regeneration and least in grass margins.

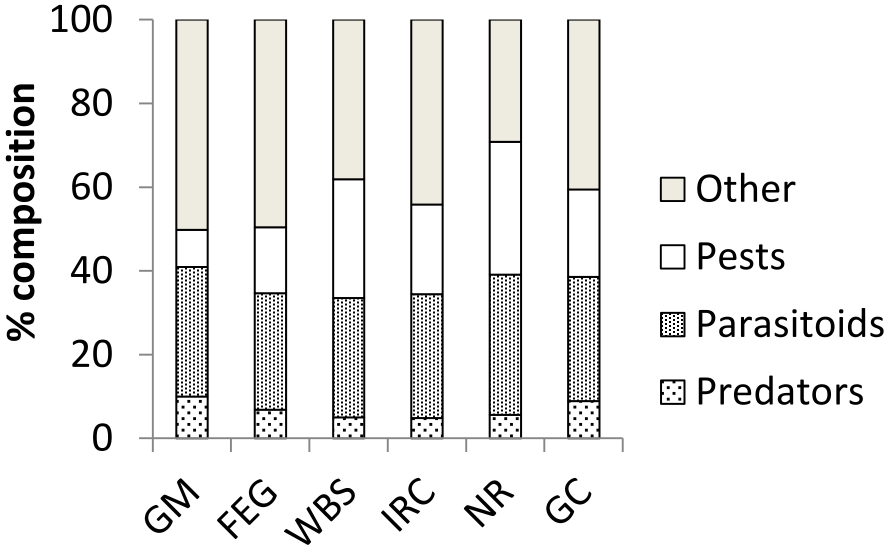


Figure 14. Proportion of beneficial predators and parasitoids, pests and other invertebrates in each uncropped habitat. Mean values for all sites between 2008-10.
(GM=Grass Margin; FEG=Floristically Enhanced Grass; WBS=Wild Bird Seed; IRC= Insect Rich Cover; NR=Natural Regeneration; GC=Game Cover)

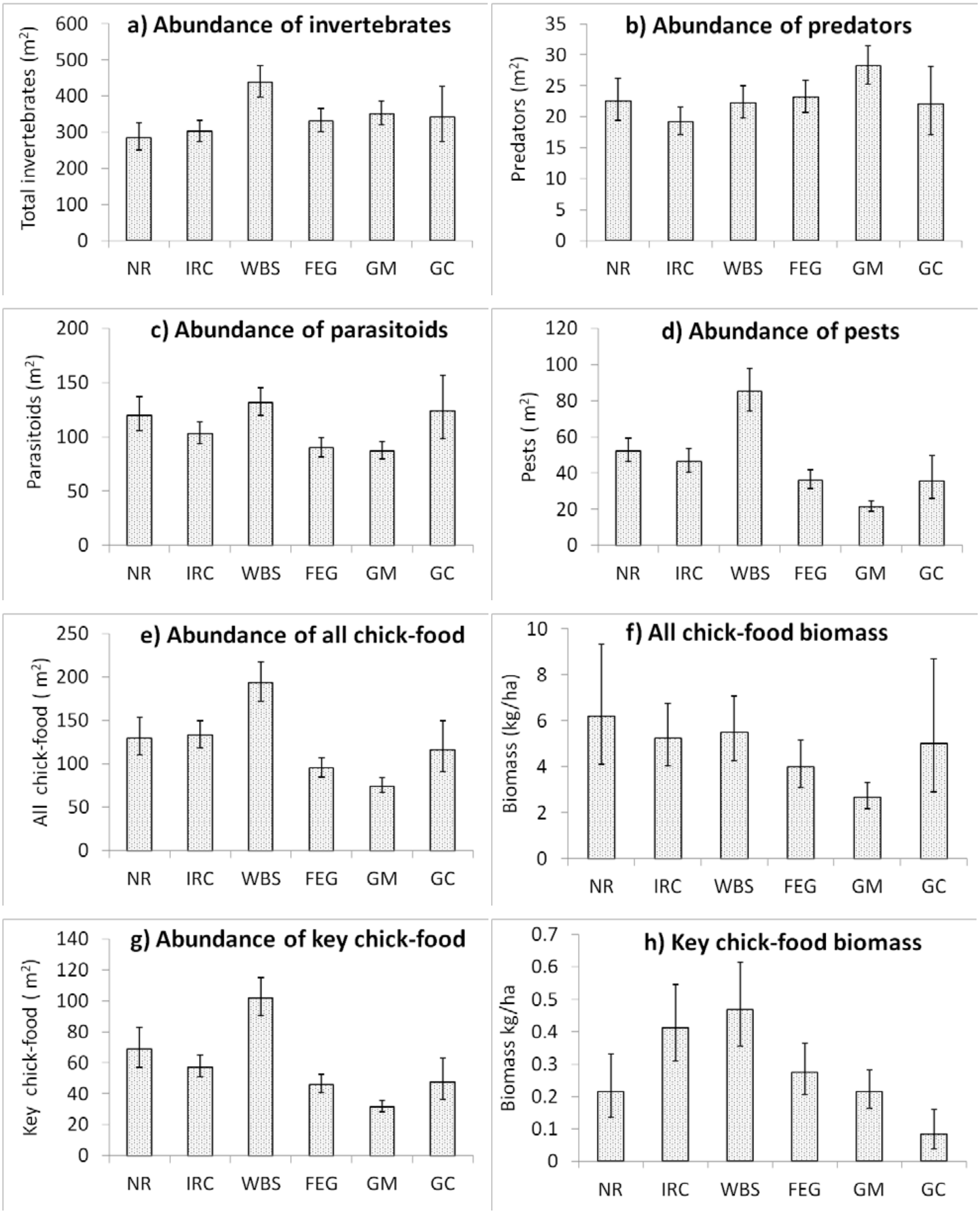
There was no interaction effect for habitat and region except for Arachnida (Table 7). The abundance of groups and invertebrate families differed significantly between the habitats except for total biomass and the two measures of chick-food biomass. The total biomass and chick-food biomass were 4.7 times and 5.4 greater, respectively in East Anglia as compared to Wessex. For all other measures for which there was a region effect, numbers were higher in East Anglia compared to Wessex. Invertebrate density was *ca*. 25% higher in the WBS and relatively similar in the other habitats (Figure 15a). There were 30% more predators in grass margins compared to IRC, but otherwise little variation between habitats (Figure 15b). Parasitoids were more abundant in the annual compared to perennial habitats (Figure 15c). Pests were more than twice as abundant in WBS compared to other habitats and four times more abundant than in grass margins (Figure 15d). The same trend was found for the numbers of chick-food (Figure 15e) and key chick-food invertebrates because many pests are also dietary items for birds, but biomass of these groups was not significantly different between habitats (Figure 15g). The total biomass of chick-food was relatively similar in all habitats, except grass margins where it was lower (Figure 15f). The key chick-food biomass was greatest in IRC and WBS and smallest in game cover (Figure 15h). The grey partridge chick-food index reached the level (0.7) required to maintain a population of grey partridge in the WBS and game cover, and was at least 30% lower in the remaining habitats (Figure 15i).

Arachnida were most abundant in NR, intermediate in IRC and lowest in the remaining habitats these being on the whole similar, except for grass margins in East Anglia where they were higher (Figure 15j). WBS supported the highest densities of Coleoptera, primarily pest species, with NR having 37% fewer and the other habitats >50% less than WBS (Figure 15k). Grass margins had fewest Coleoptera. Diptera were ca. 20% more abundant in IRC, WBS and game cover compared to FEG and grass margins (Figure 15l). Hemiptera showed less variation between habitats, except game cover in which they were in their smallest numbers (Figure 15m). Hymenoptera were up to 25% less abundant in the perennial compared to annual habitats (Figure 15n). Most Lepidoptera occurred in WBS, FEG and the grass margins and least in game cover (Figure 15o).

There were no significant effects on bird invertebrate food abundance for any of the categories sampled from patches of uncropped land, either in univariate or multivariate models. For Yellowhammer and for Corn Bunting 'chick food' was close to significance in univariate tests (F = 2.9, $p < 0.09$ and F = 3.0, $p < 0.07$) but not when controlling for '% area uncropped land'.

Table 7. Results of analyses comparing habitats, regions and their interaction on insects collect using a Vortis suction sampler in July.
(Significance values: ***=P<0.001; **=P<0.01; *=P<0.05)

	Habitat	Region	Interaction
Total invertebrates	***	***	
Total biomass		***	
Predators	*		
Parasitoids	***	***	
Pests	***	***	
All Chick-food	***	**	
All Chick-food biomass		***	
Key Chick-food	***	***	
Key Chick-food biomass			
Grey partridge chick-food index	***	***	
Arachnida	***	**	**
Coleoptera	***	**	
Diptera	***		
Hemiptera	*	***	
Hymenoptera	***	***	
Lepidoptera	**	***	


a) Abundance of invertebrates
Total invertebrates (m2)
600
500
400
300
200
100
0
NR
IRC
WBS
FEG
GM
GC
b) Abundance of predators
Predators (m2)
35
30
25
20
15
10
5
0
NR
IRC
WBS
FEG
GM
GC
c) Abundance of parasitoids
Parasitoids (m2)
200
150
100
50
0
NR
IRC
WBS
FEG
GM
GC
d) Abundance of pests
Pests (m2)
120
100
80
60
40
20
0
NR
IRC
WBS
FEG
GM
GC
e) Abundance of all chick-food
All chick-food (m2)
250
200
150
100
50
0
NR
IRC
WBS
FEG
GM
GC
f) All chick-food biomass
Biomass (kg/ha)
10
8
6
4
2
0
NR
IRC
WBS
FEG
GM
GC
g) Abundance of key chick-food
Key chick-food (m2)
140
120
100
80
60
40
20
0
NR
IRC
WBS
FEG
GM
GC
h) Key chick-food biomass
Biomass kg/ha
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
NR
IRC
WBS
FEG
GM
GC

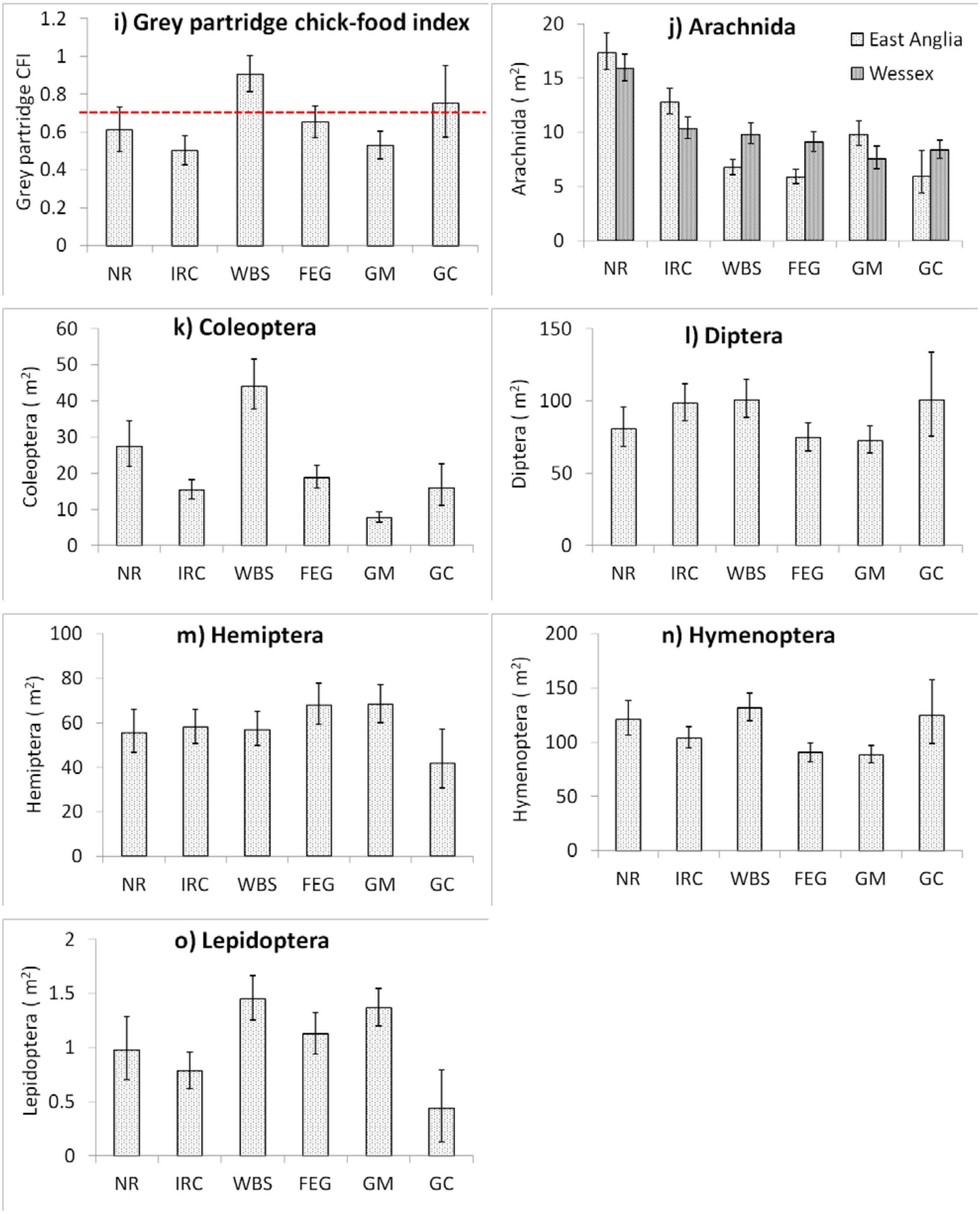


Figure 15 a-o. Abundance or biomass of invertebrate groups in six different habitats determined from Vortis suction sampling. Means are predicted values from the REML analysis back-transformed. (NR=Natural Regeneration; IRC=Insect Rich Cover; WBS=Wild Bird Seed; FEG=Floristically Enhanced Grass; GM=Grass Margin; GC=Game Cover)

In summary, the type of management, project versus farmer-managed, had no impact on pollinators at the 100-ha scales. Fewer bees were recorded along the margins of the organic farms possibly because they were attracted into neighbouring clover ley fields. The proportion of uncropped land had a positive effect on butterfly diversity along the field margins and wild bee abundance and diversity in the uncropped habitats. However, there was evidence that wild bees were being attracted to the project-managed habitats from the field margins. Butterfly diversity increased when the uncropped land was arranged in strips rather than blocks. For the invertebrates collected by Vortis sampling there was no effect of management type, the proportion of uncropped land or its arrangement, instead they responded at the habitat scale.

The assessments of individual uncropped habitats revealed that bumble bees and cuckoo bees were 3-8 times more abundant, depending on the time when sampled, in FEG compared to the other habitats. The occurrence of butterfly adults was largely dependent on the larval food plants. The Pieridae (whites) which feed on brassicas were twice as abundant in the WBS whereas those with grass hosts, especially Satyridae (browns), were most abundant in FEG and grass margins. Butterflies seeking the nectar provided by the sown species were 25-50% more abundant in the FEG compared to the other habitats. Hoverflies were most abundant in FEG and grass margins in June, but by July occurred in similar numbers in all habitats except grass margins where they were 50% lower. There were at least four times as many hoverflies in most habitats in Wessex compared to East Anglia in July.

In the Vortis suction samples, the natural enemies of pests formed almost 40% of the species composition with the majority being parasitoids. In contrast, pests only formed a maximum of 32% these being highest in natural regeneration and lowest in grass margins. WBS contained the greatest density of invertebrates and pests, and because the pests are consumed by birds, the chick-food and grey partridge chick-food index were also highest in this habitat. The biomass of chick-food was five times higher in East Anglia compared to Wessex. The abundance of natural enemies was relatively similar only varying by approximately 25% across all habitats.

3.3.4. Birds

Phase 1: Responses to the treatments and area of uncropped land accounting for site characteristics

a) *Treatments*: The results of the basic model regression analysis of the experimental treatments across all sites found significant effects for Stock Dove (treatment 3 (project-managed, large blocks); $p < 0.05$) and Linnet (both treatment 3 and 7(organic); $p < 0.01$), and for Rook and Goldfinch (both treatment 7; $p < 0.05$) (see Figure 1 for details of treatments). Overall, eight species and two combined species groups ‘BAP’ and ‘FBI species’ were recorded at their highest density on treatment 7 (organic farms), and although the differences between treatments were generally not statistically significant, selection for treatment 7 was the most consistent result.

b) Total area of uncropped land: When substituting the categorical variable 'treatment' with the continuous variable '% area uncropped land', there were positive, statistically significant effects detected for Lapwing, Greenfinch, Linnet and Yellowhammer (Table 8). Among species groups, for high dependency species the proportion of positive to negative effects (whether significant or not) was significant for both periods 2007-2010 and 2008-2010 (Binomial test, $p < 0.04$, n =9; Table 8). Stable or increasing species varied according to the inclusion or not of the 2007 data (Binomial test: 2007-2010, $p < 0.001$, n =7; 2008-2010: $p < 0.45$; Table 8). For lower dependency species though there were more negatives than positives, there was no significant effect of % area uncropped land (Table 8). Overall, a positive effect was detected for 17 of 21 species (Binomial test, $p < 0.006$) for the period 2007 to 2010 but for only 11 of 21 species for 2008 to 2010 (Table 8). So the response to % area uncropped land was strongest amongst declining species.

Among individual species, for the 2007-2010 period, significant effects of uncropped land were detected for linnet (Likelihood ratio (LR), $\chi^2 = 9.3$, $p < 0.003$) and yellowhammer (LR, $\chi^2 = 10.9$, $p < 0.002$), and for BAP and FBI species as combined groups (LR, $\chi^2 = 15.9$, $p < 0.001$ and LR, $\chi^2 = 6.8$, $p < 0.01$ respectively), and approaching significance for skylark (LR, $\chi^2 = 3.01$, $p < 0.08$) but see below. For the 2008 to 2010 period, the relationship for skylarks was not significant but remained significant for linnet, yellowhammer and the declining, high dependency group, and lapwing (Table 8). However, the effect of organic farms was significant for lapwing (LR, $\chi^2 = 4.84$, $p < 0.01$), woodpigeon (LR, $\chi^2 = 5.84$, $p < 0.01$) and rook (LR, $\chi^2 = 4.8$, $p < 0.03$), but for lapwing the effect of % area uncropped land dropped out, suggesting that the organic rotation, with grassland content, was a dominant and confounding factor. There was a significant positive effect of organic farms for 5 out of 21 species. This positive effect may well be associated with the much higher proportion of fields on these farms sown with grass and/or legumes and a more diverse weed flora in the arable crops. Generally, a positive response towards % area uncropped land was strongest on conventional farms. Thus when controlling for the effect of organic farms, the relationship between bird abundance and % area uncropped land was slightly stronger for BAP and FBI species (LR, $\chi^2 = 16.0$, $p < 0.0002$ and LR, $\chi^2 = 14.2$, $p < 0.0003$ respectively, 2007-2010) and for skylark the relationship became significant (LR: $\chi^2 = 6.0$, $p < 0.02$, 2007-2010) i.e. for conventional farms. Consequently, the influence of uncropped land on birds was greater on conventional farms.

Table 8. A summary of the results of regression analyses examining effect on bird abundance at the site level, i.e., per 100 ha. In a) a basic model examines the effects of the total percentage area of uncropped land available on farms between 2007– 2010 and between 2008 to 2010, controlling for year effects (Year), regional effects (Region) and site differences (random effect not shown) as well as the percentage of arable land present in the surrounding 3 km ('% arable' as a landscape variable) and the 'boundary-to-area ratio' of hedges (BAR) as a relative measure of hedgerow length. In b), the analysis examines effects of farm management as the difference between sites with project versus farmer-managed uncropped land (MNG, where '+' is positive for project-managed sites) and whether sites were conventionally or organically managed (ORG, where '+' is positive for organically-managed farms). This is combined with effects of cropped and non-cropped habitats as major crop types (winter cereals (WC), spring cereals (SC), oilseed rape (OSR), pulses (peas and beans) and grassland and according to the content of managed areas of uncropped land (Winter bird seed (WBS), natural regeneration grass margins (Grass) and floristically enhanced grass (FEG)). Notation: + positive effect and – negative effect, with the superscript * $p < 0.05$, ** $p < 0.01$ and ***$p < 0.001$. Parenthesis = relationships where p =< 0.07. All blanks are non-significant results where $p > 0.07$ except for the uncropped land columns. In these columns, the levels of probability are shown at or below $p = 0.1$, for help with comparative interpretations discussed in the main text. All models incorporate Poisson or negative binomial (log-link) error terms according to that giving the best fit (columns 'Best model fit' where ideally values should approach '1'). EA = an effect for East Anglia region only.

	a) Model explanatory variables							b) Model explanatory variables									
			Total area of uncropped land †				Model fit	Farm type		Crops				Margins			Model fit
Species	Year	Region	2007 - 2010	2008- 2010	%arable	BAR		MNG	ORG	WC	SC	OSR	Pulse	Grass	WBS	FEG	
Declining populations and of high farmland dependency																	
Kestrel		*	+	+			0.56							+**			0.48
Grey Partridge			-	-			0.99							+* EA			0.99
Lapwing	***		$+^{0.06}$	+*			1.58		+**		+**		+*				0.76
Skylark	*		$+^{0.08}$	$+^{0.10}$	+*		0.98		+**	-*							0.98
Yellow Wagtail		**	+	+			0.68										0.53
Linnet	**		+**	+**			0.97										0.97
Yellowhammer			+**	+**		+*	0.99							+*	+**		0.99
Reed Bunting	*		+	+			1.67							$+^{(*)}$ EA			1.46
Corn Bunting			+	+			0.49							+**			0.49
Combined			+***	+**			*1.07*										
Declining populations of low to medium farmland dependency																	
Song Thrush	***		-	-			0.98										0.86
Dunnock			+	-			0.99										0.99
Starling	**	*	-*	-			1.67	-(*)		-*							0.82
H. Sparrow			+	+			0.88										0.88
Bullfinch			-	-			0.85										0.85
Combined			*ns*	*ns*			*0.97*										*1.01*
Stable or increasing populations																	
Woodpigeon	***	**	+	+			0.98		+**		$+^{(*)}$	+*	$+^{(*)}$				0.98
Stock Dove	***	***	+	+			0.86										1.06
Rook	*		+	-			0.90		+*	+*							0.90
Jackdaw	***		+	-			0.90										0.88
Whitethroat		**	+	-			0.94										0.94
Greenfinch	***	**	+*	-			1.03										1.03
Goldfinch			+	-	+*		1.01		+*								1.00
Combined			+**	*ns*			*0.99*										*0.99*
FBI species	***	*	+*	+			0.99		+**								0.98

The relationship between bird densities and the % area of uncropped land is illustrated in Figure 16. At this scale (100 ha) farms with an area of uncropped land below 5% supported significantly lower densities of birds than those with areas of 10% or more among the declining, farm-dependent species. These differences were significant for skylark (LR, $\chi^2 = 3.84$, $p < 0.05$), linnet (LR, $\chi^2 = 7.30$, $p < 0.0001$), yellowhammer (LR, $\chi^2 = 4.04$, $p < 0.006$); and for BAP species and FBI species (LR, $\chi^2 = 11.6$, $p < 0.001$ and $\chi^2 = 45.6$, $p < 0.001$ respectively), and they were significant for the declining, high dependency species too (LR, $\chi^2 = 11.3$, $p < 0.001$), but not the low dependency, stable or increasing species (Figure 16).

c) *Between crop types or types of uncropped habitat*: At this scale of measurement (~100 ha) there were relatively few significant effects on the abundance of species analysed. Notably, grass margins were positive and significant for five declining, high dependency species (kestrel, grey partridge (one region only), yellowhammer and corn bunting, with reed bunting close to significant in one region only; Table 8). Lapwing was significantly and positively associated with the area of spring cereals (Table 8) which when entered into models weakened the effect of uncropped land ($p < 0.08$) for this species. Among crops, winter cereals were generally negative for bird abundance (lapwing, starling and rook and all BAP species). Oilseed rape was positive for wood pigeon (and reed bunting too but not significantly). Among the additional habitats provided on project-managed farms, only “wild bird seed” was significant for yellowhammer (Table 8). Ecologically these differences do fit with the food and nesting requirements of these species, e.g. grey partridge make use of tussocky-grass field margins for nesting, lapwings typically nest in spring crops, kestrel will hunt along field margins and wood pigeon feed in oilseed rape and confirm the robustness of the data.

d) *Effects of management and time:* When controlling for the % area of uncropped land present, there was no significant difference in bird abundances between farms where the uncropped land was project-managed rather than farmer-managed except for linnet (Figure 17). In univariate tests, using the basic model plus only one other variable – ‘management’, the relationship with linnet was significant ($p < 0.01$), but only when controlling for the ‘% area of uncropped land’. There was some indication that the rate of decline of Biodiversity Action Plan species and the Farmland Bird Index on project-managed farms was slower than on farmer-managed farms between 2006 and 2010, but the differences were not statistically significant (Figure 18).

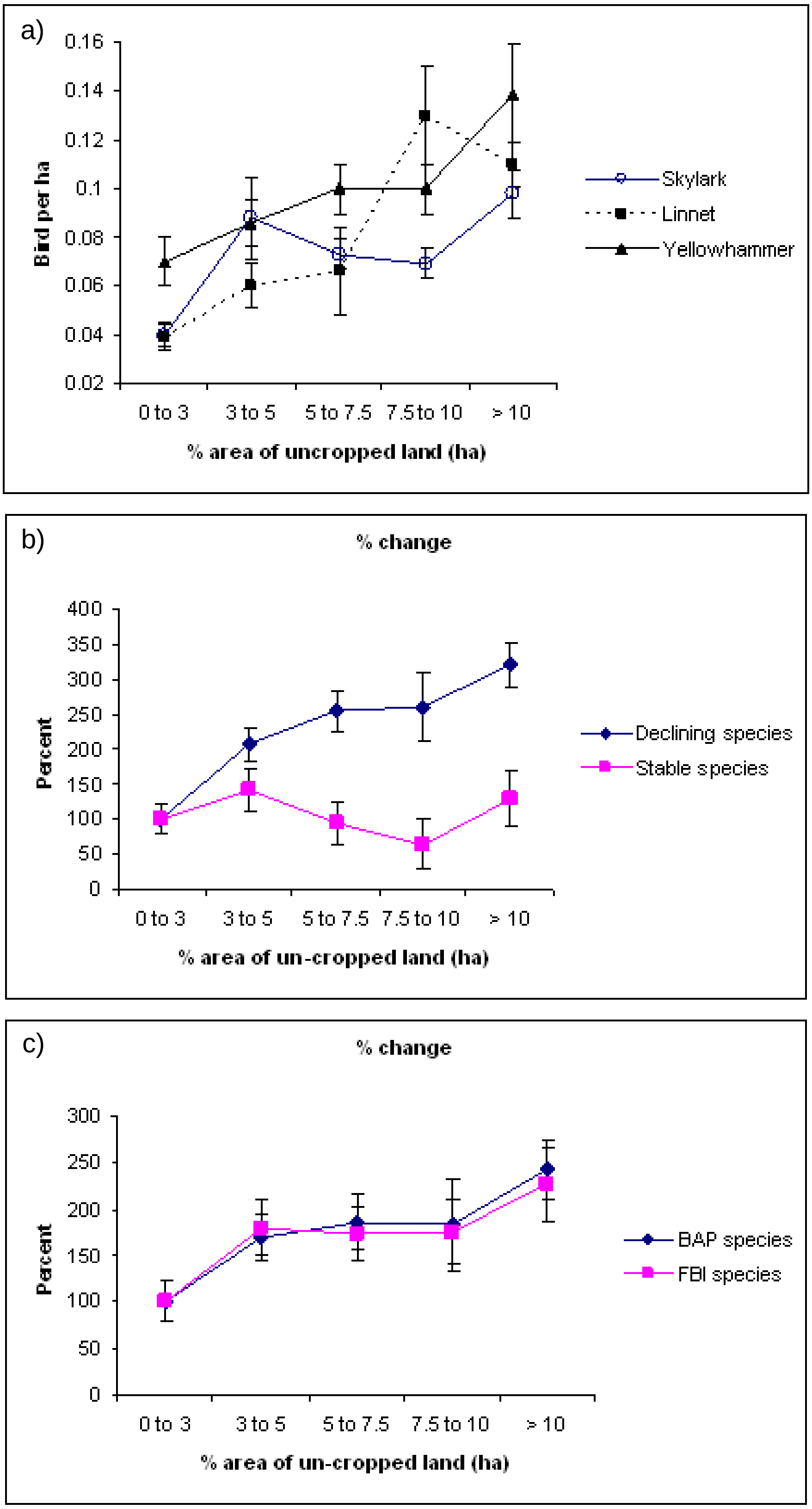


Figure 16. Relationship between site-level densities of bird species or bird species groups in relation to five categories of the percentage area of uncropped land present. In (a) actual densities are shown for three species of conservation concern on arable farmland in England (± SE). In (b) and in (c), for combined-species groups, the percentage differences in density (averaged across species) is calculated relative to the first category (0-3%), 'anchored' at 100 (± SE). Species contributing to the BAP (i.e., Biodiversity Action Plan), FBI (i.e., Farmland Bird Index), 'declining (i.e., declining, high dependency)' and 'stable (i.e., stable or increasing)' groups are defined in the methods and in Table 8.

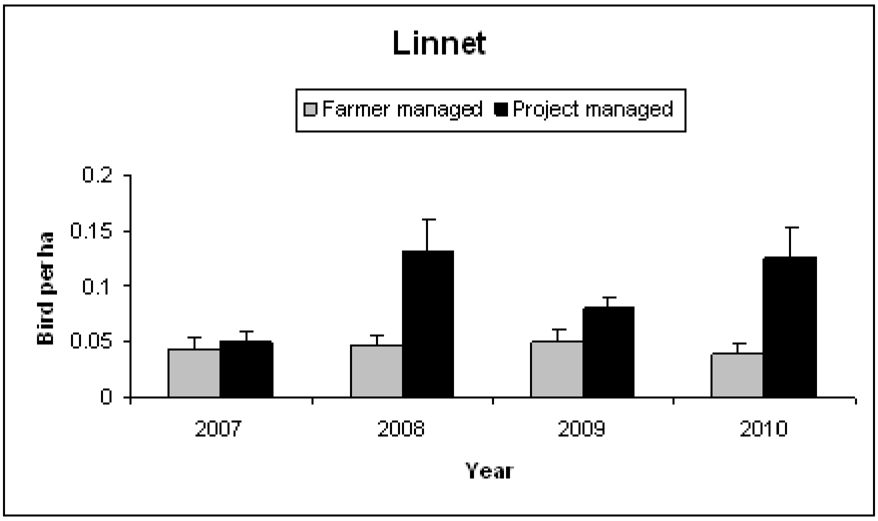
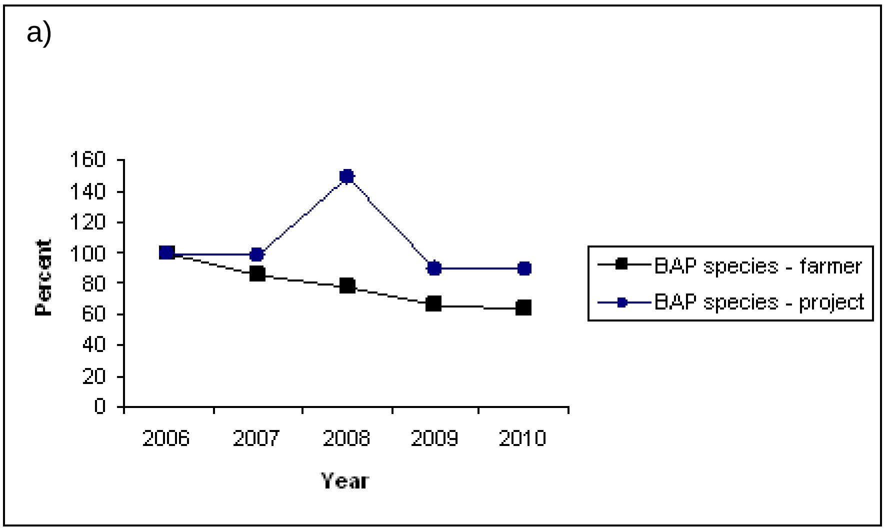


Figure 17. Mean densities for Linnet on farms where uncropped land was farmer-managed and farms were uncropped land was project-managed. (error bars = SE).



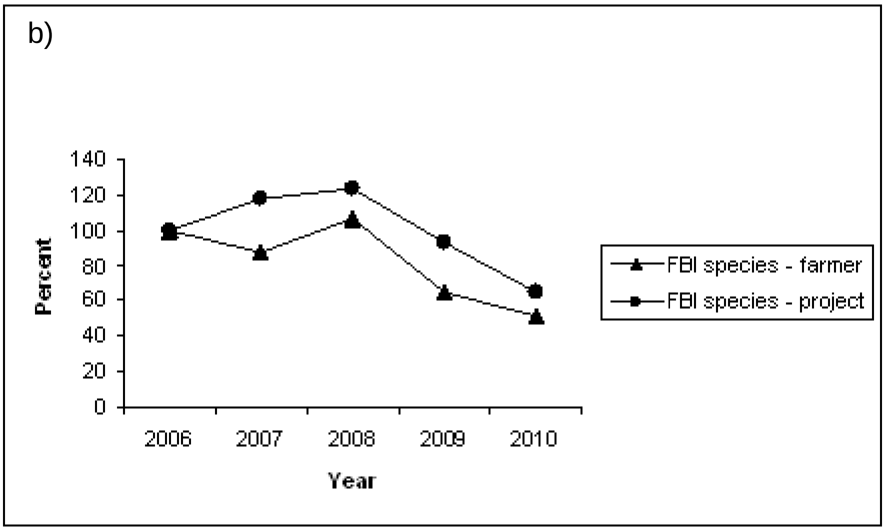


Figure 18 a & b. Trends from 2006 to 2010 showing the percentage change in mean bird densities (per ha) calculated relative to 2006 for a) BAP (Biodiversity Action Plan) species and b) FBI (Farmland Bird Index) species. The data show trends for farms where uncropped land was farmer-managed (labelled 'farmer') and farms were uncropped land was project-managed (labelled 'project').

Phase 2: analysis of configuration (blocks and strips)

The effect of perimeter-to-area ratio was only statistically significant for skylark and linnet. For skylark, the '% area of uncropped land' and the perimeter-to-area ratio of uncropped land in combination, *were both positive and highly significant* in combined models (Poisson error: F = 10.2, $p < 0.003$; F = 8.6, $p < 0.005$) suggesting that the % area of uncropped was important when controlling for relative perimeter length and that a larger relative edge effect (typically strips rather than blocks) was important for a given area of uncropped land. For linnet, in contrast to skylark, the perimeter to area ratio was significantly negative (negative binomial error: F = 5.8, $p < 0.01$) when controlling for % area uncropped land (F = 7.5, $p < 0.008$) indicating that this species was recorded at higher abundance where larger blocks of contiguous habitat were available. For linnet, there was a non-significant negative association with the number of patches of uncropped land, which is further suggestive of 'preferences' towards a 'blockier' arrangement.

For other species, including yellowhammer and despite a good sample size, there was no significant effect of patch size, patch number or perimeter-to-area ratio. For lapwings, mean patch size was positive when substituted for % area cover of uncropped land, but the two variables are correlated (r = 0.392, p = 0.001, n = 81).

Species richness and diversity

There were no significant effects of bird species richness or diversity (Shannon diversity index) in relation to any of the environmental variables measured or indeed between sites (test with normal errors: p range 0.84 to 0.12).

3.3.5. Mammals

The data on hares and rabbits (which were recorded in 2008 and 2009) were only analysed at the 100 ha block scale using the two phase analysis. The model structure described in section 3.2.3 was used with the additional co-variate of + / - keepering. Only a small number of significant effects of the explanatory variables were identified by the models. Hares were more abundant in 2008 (16.4 vs. 11.3 hares / 100 ha) and on organic compared to conventional farms (32.6 vs. 10.7), probably because there were grass fields present, and rabbits were more abundant on sites with a higher P / A ratio (preferring uncropped land arranged in strips).

3.3.6. Economics and farmer attitudes to wildlife crops

Gross margin analysis

Calculating the economic implications of introducing uncropped habitats is dependent on many assumptions unless precise information on costs (including opportunity costs) and crop losses are recorded in individual circumstances. Hence this section is based on a relatively simple approach of gross margin analysis with some reference to published data on crop yields on winter wheat headlands.

Enterprise gross margins take into account directly attributable income less directly attributable costs. This typically means for arable crops the income from the crop/ha less the costs/ha of seeds, fertilisers and sprays. The use of fertilisers and sprays in the cover crops are minimal in order to comply with grant requirements and is usually restricted to the use of glyphosate prior to the establishment of the cover crop and also for its destruction. The current approximate cost of 360 g ae/l glyphosate is £2.00/l and it is assumed in these calculations that 4.0 l/ha is used prior to the establishment of a habitat and 4.0 l/ha is used to destroy the habitat. These doses may be in excess of those used in practice.

Directly attributable income from the uncropped habitats is the payment from the Entry Level Scheme and Higher Level Scheme. Payments that were relevant during the duration of the Farm4bio project from Environmental Stewardship are based on one point being equivalent to £1. Floristically Enhanced Grassland in Higher Level Scheme receives greater funding (485 points/ha) than nectar flower mix or the wild bird seed (450 points/ha) in Entry Level Scheme. Grass margins and natural regeneration for rare plants receive 400 points/ha in the Entry Level Scheme. These payments are made on condition they are managed according to the scheme’s requirements.

The gross margins for the uncropped habitats are hence this level of income/ha less the amount spent of glyphosate at establishment and for habitat destruction less seed costs. Seed costs for the mixtures used in Farm4bio are currently £200/ha for FEG and £70/ha for grass margins, WBS and IRC. The mean annual gross margin for the four project-managed habitats over 5 years was £398. These gross margins are compared with those of winter wheat and winter oilseed rape in the Farm Business Survey (Lang, 2009; 2010; Wilson & Cherry, 2010) results (Table 9).

Hence, the mean gross margins for the covers are less than those of winter oilseed rape and particularly winter wheat and for a winter wheat-oilseed rape rotation (£591). This may be especially so at the higher product prices received for the 2011 harvest. However, it should be born in mind that typically the covers are grown on headlands or parts of the farm where the yields of field crops are lower and/or where the efficiency of large machinery is compromised. Yield of winter wheat adjacent to field boundary hedges or woods vary but could be 1.5-3.5 t/ha lower at 2 m from crop edge when compared to 20 m from the crop edge on the North or East side of a hedge and 1-1.5 t/ha lower on the South or West side of a hedge. This scale of losses would almost negate the financial advantage of winter wheat in Table 8. However, in some cases, yield losses on headlands do not occur (Cook & Ingle, 1997).

Table 9. Environmental Scheme (ES) funding/ha and Gross Margins/ha for natural regeneration, sown covers, winter wheat and oilseed rape; 2006-2010. Floristically enhanced grass (FEG), wild bird seed (WBS) and insect rich cover (IRC), natural regeneration (NR) for rare arable plants, Environmental Stewardship (ES).

		Gross margin £/ha					
	ES funding £/ha	2006	2007	2008	2009	2010	Mean gross margin
FEG	485	277	485	485	485	477[1]	433
WBS/IRC	450	364	364	364	364	364	386
WBS biennial	450	364	450	364	450	364	407
Annual NR	400	384	384	384	384	384	388
Grass margin 4m	400	322	400	400	400	392[1]	381
Winter wheat	-	810	788	679	477	-	689[2]
Winter oilseed rape	-	444	445	606	475	-	493[2]

[1] Includes cost of glyphosate for cover destruction

[2]Based upon 4 years data

Although the areas of covers are limited and inconvenient, machinery input is typically less than that for field crops and can often be done when other farm operations are not being carried out or cannot be carried out. The expensive harvesting operation is avoided. However, unless machinery and labour complements are reduced due to the introduction of the covers then the reduction in their costs on a whole farm basis will be limited.

Experience from Farm4bio suggest that typically arable farms can establish and manage the covers with existing equipment, provided that the width of the covers match those of the farm machinery.

Farmer survey

All the farmers who had planted covers as part of the Farm4bio project were visited in February 2009 by John Holland and Jim Orson in order to canvas their opinions on the ease of management and their success. The main conclusions were:

- With only one exception the most successful cover on the farms for both ease of management and perceived value to biodiversity was the floristically enhance grassland mix (FEG). It was very slow to establish in the first year.
- The most disappointing cover was the natural regeneration. It comprised pernicious weeds, particularly on the clay soils. Obviously, years of chemical weed control has denuded the soil seed bank of what are now described as rare annual plants of particular value to biodiversity. However, one farm noted that owls were commonly seen to hunt over the natural regeneration strip.

- There was also general agreement that a triticale or rye mixed with kale or fodder radish sown annually would provide winter feed and habitat. There was some concern that if this was the only alternative to the floristically enhanced grassland there would be a shortage of floral food resource early in the spring although the understory of annual weeds in an autumn sown triticale/rye/kale/fodder radish could meet this purpose. There was agreement that fodder radish was easier to establish than kale, but the latter is more suitable for longer term mixes and is attractive to a wide range of bird species.
- A few farmers suggested that *Phacelia* would provide an early summer floral food source.
- Most farmers preferred spring rather than autumn as the time to establish sown covers. This was to do with available time, damage to covers by slugs and birds in the autumn/winter and also the belief that it was best to sow when growth is accelerating. The farmers on clay soils were not so definite on the preferred time of establishment with one stating that autumn sowing was preferred.
- There was general agreement that the more permanent covers (to last at least 3-4 years) should be sown in awkward areas for machinery (provided that the vegetation to be replaced has a low value to biodiversity), whilst the ‘annual’ covers should be sown where convenient for machinery. There was also a stated preference for perennial covers to feed birds in the winter and to provide a spring/early summer source of food if these could be developed.
- There was a general agreement that strips at the edge of fields was the most convenient place to establish ‘annual’ covers (often to “square off” the cropped area) unless there were small fields which could be devoted entirely to biodiversity enhancement. However, one farmer preferred blocks of around 2 hectares in size. Some considered that relatively narrow strips at field edges had a less negative impact on the landscape and were more valuable to biodiversity. One farmer was adamant that layout should be determined by specific ‘biodiversity’ targets of the farm.
- The farmers considered that field edge strips will also be important to act as a buffer for spray (and slug pellet) drift and fertiliser application. The floristically enhanced grassland would also reduce movement of soil out of the field.
- Some farmers said that establishment of the field edge strips would be easier if they were sown at the same time as the rest of the field. This would reduce machinery transport to and from the field and meant that cultivation would be easier and would result in better covers. It would also partly overcome the issue that farmers will naturally give preference to sowing the crops rather than the covers. The lower priority given to sowing covers for biodiversity means that seed mixtures should comprise robust species that can be sown before, at the same time or shortly after the main field crops.
- Most farms had access to machinery to establish covers although one or two had sown the seed with a spreader on a quad bike. The regulations governing the width of covers sown

under Stewardship Schemes should be sufficiently flexible to allow the available farm machinery to be used. Width of covers was more of an issue when they needed to be ploughed, killed by glyphosate (concern over drift) or required fertiliser or a pesticide application. There was agreement that the covers needed to be ‘farmed’ to maximise their value but the farmers were aware of the implications of using pesticides and fertilisers at the edge of fields.

- It was suggested by some farmers that where floral strips are present then insecticides need not always be applied to the adjacent crop within 24m because natural pest control would prevail in this area. This would also help prevent drift into the floral strip.
- There was a general agreement that the covers were best moved around the farm because establishment was more assured in ‘clean’ ground and growth of ‘annual’ covers would be improved by the presence of residual nitrogen from the previous crop. However, some farmers considered that moving covers around the edges of different fields should be done in a way as to provide ‘wildlife’ corridors and some liked the idea of ‘complimentary’ strips sown side by side. One farmer suggested that vetches provided residual nitrogen to following ‘annual’ covers where a succession of such covers was necessary. Vetches established well on some farms.
- Weeds were a significant issue, particularly perennials (thistles and to a lesser extent docks) and some annual weeds (ragwort and willowherb). The issue of perennial weeds was a major reason why farmers preferred to establish covers on ‘clean’ ground rather than follow another cover crop.
- In some cases it was alleged that the covers encouraged slugs that then moved into the adjacent crop.
- Some farmers were concerned that seed rates of the covers were too low and did not take into account losses to slugs and birds. Where the objective was to produce a seed crop for birds, farming this as a crop to maximise yield and therefore using conventional seed rates and agrochemicals would make more sense. This would be easiest if located adjacent to a conventional crop managed in the same way.
- Some preferred to have straight crops of, say, kale or fodder radish and rye or triticale rather than sow the mix. Some were critical of commercial seed mixes. They considered them to be unnecessarily complex and lacking information on the purpose of the various components. This, in their view, provided a barrier to their adoption.
- Nearly all farms said that the main aim of their co-operation with the project was to increase biodiversity with shooting interests as a secondary reason. Most questioned the value of the countryside stewardship grass only field edge strips.

3.4. Discussion

3.4.1. Plants

The differences in plant species richness at the farm level between conventionally managed and organic farms, observed in this study, concur with those previously reported in the literature. Organic farms did not have greater plant species richness in uncropped margins or verges agreeing with a previous study using ten pairs of organic and conventional farms (Gibson et al., 2007) and indicating that herbicide spray drift was not causing damage. The only habitat in the Gibson study that had higher species richness was within the cropped field, a conclusion supported by the Farm4Bio data. Although it is now well established that the lack of herbicides in organic systems increase the opportunity space for a wider range of species, leading to a higher α (field scale) diversity, it has also been found that the more limited range of crops grown can lead to lower β diversity at the landscape scale (Hawes et al., 2010).

Plant species richness was always lower in the cropped area of the field than the uncropped margins and crops had a distinct weed community (Marshall 2009) characterised by annual plants. The period of planting (winter/spring), the type of crop (cereal / broad-leaved crop / grass) had a clear impact on the flora. Weeds were least common in the cereals and were most abundant in the grass/legume crops and in the few fields that were uncropped. It should be noted that many of the more floristically diverse grass/legume fields were on the organic farms. The species recorded on the 28 farms included a number of species that are rare or declining (Still, 2007). With exception of slender tare (*Vicia parviflora*) that was found in a margin on an organic farm, all of these records were associated with recently disturbed ground (either on the edge of crops or in NR or WBS) and generally found on farms with lighter soils. For example, small toadflax (*Chaenorhinum minus*), prickly poppy (*Papaver agemone*) and round-leaved fluellen (*Kickxia spuria*) were all found on the chalk site at Royston in East Anglia. These, and other, declining species are relatively uncompetitive with the crop and rely on the transitional habitat at the crop edge where herbicide and fertiliser inputs tend to be lower (Fried et al., 2009). Alternatively, they can be encouraged by appropriate management of field margins. This will involve natural regeneration of annually disturbed ground and can also encourage pernicious weeds (as was observed in this project); these options therefore tend to be unpopular with farmers (see comments by farmers in Section 3.3.6). They are, therefore, best targeted at light land sites that are known to have rich arable plant communities (Wilson, 2007).

Contrary to previous studies (Gabriel et al., 2005; Gaba, 2010), there was no effect of landscape structure, measured as percentage arable in the landscape or length of hedges, on plant species richness either in the cropped fields or uncropped margins. It is likely that no effect of landscape was observed because the differences between Farm4Bio sites in terms of landscape complexity were of a smaller order compared to other studies where a relationship was found. This concurs with the results of Marshall (2009) who also found no effect of landscape on weed diversity. The important drivers of variability in species richness were, therefore, crop choice and management and the types of uncropped land present on the farm. The presence of the project sown treatments did not significantly increase plant species richness at the farm scale. However, when the percentage of uncropped land was included as a continuous variable, there was a positive relationship with plant species richness on uncropped land. It is likely that this was a result of greater habitat heterogeneity on farms with more uncropped land. Specifically, they were more likely to include areas that had been recently disturbed and colonised by annuals and wind-blown species (such as ragwort and willowherbs) as opposed to just grass margins (Critchley et al., 2006). This effect was observed on the project-managed farms where the annual mixes, WBS ad IRC, often had an understory of annual weeds. Many of these spring annuals (for example, fat hen (*Chenopodium album*)) provide a useful function in terms of supporting invertebrate communities that can be fed on by birds in the summer particularly when the mix was sown in the spring (Marshall et al., 2003).

3.4.2. Pollinating insects

Wild bees

Only the six commonest bumble bee species were found and of these the majority (70%) were short-tongued species as found in previous studies of agri-environment options (Pywell et al., 2005; Carvell et al., 2007). The three commonest species were *Bombus pascuorum*, *B. lapidarius* and *B. pratorum*, the first two also being the commonest species found by Carvell et al. (2007). The reasons behind the declines in bumble bees in recent decades remain uncertain, but is most likely a consequence of intensive land-use (Tscharntke et al. 2005; Kremen et al. 2007) leading to a loss of suitable forage plants in agricultural areas (Carvell et al., 2007; Hendrickx et al., 2007) or secondly the destruction and fragmentation of natural or semi-natural habitats that provide a source of bees (Steffan-Dewenter & Westphal, 2008).

When the flowering period of the 75 most frequently recorded species was examined (Figure 3) there was a clear peak flowering period (June to August) which coincides with the peak in bumble bee worker activity (Prys-Jones & Corbett, 1991). The main flowering period for the FEG coincided with this peak explaining in part why the FEG contained high numbers of wild bees. Either side of this period the number of flowering species declined to <10 from November to February and were comprised of annuals. Bumble bee queens are active in March and as late as October. Early in the year (March-May) flowering hedgerow shrubs and annuals are flowering providing the resources for emerging queen bees. Consequently, to ensure sufficient floral resources are available when needed, a range of perennial shrubby species (hedgerows), forbs (wildflower and legume mixes) and early and late flowering annuals are needed on each farm.

In this study, the abundance and diversity of bees increased positively with the proportion of uncropped land and especially on the project-managed farms. However bee diversity reached a maximum at 3-5% uncropped land. This was probably a result of a combination of factors. Firstly the level of identification may not have been sufficiently sensitive, bees were not identified to species just to six bumble bee colour groups, cuckoo and solitary bees thus restricting the potential to detect increases. Secondly there may be limited potential for increase because the farmland fauna has become impoverished, with only six bumble bee species being widespread. The management approach (project versus farmer-managed) did not have a significant impact on pollinators. This was because this level of analysis used an average across the habitats and even though the FEG was attractive to bees other habitats were less attractive. Even so, there was evidence that provision of extra floral resources provided by the FEG across a farm benefited bee diversity at this scale. A positive response to the proportion of uncropped land within a 500m radius has also been found for the diversity and breeding success of cavity nesting bees (Holzschuh et al., 2010). Bee species richness has been shown to be determined by the diversity of nectar sources (Bosch et al., 1997; Potts et al., 2003) although in this study it was probably the provision of extra floral resources (flowering plant density) that was responsible because plant diversity was similar in the different management approaches. In addition, there were differences in the species composition between the project and farmer-managed blocks but further analyses are needed to examine the impact of these on the pollinator community.

Pollinating insects may change their foraging behaviour in response to the way floral resources are provided in the landscape, for example, following corridors of uncropped land in order to reach preferred habitats (Haddad et al., 2003) or focussing on nearby less preferred floral resource in preference to more desirable but distant sources (Steffan-Dewenter et al. 2001). There was evidence that the bees in this study were being attracted into the project-managed areas at the expense of the margins. Similarly, there were fewer bees along the margins on the organic farms because the bees were attracted away from the margins and onto the clover leys. Such changes in behaviour have implications for the pollination and seed production of wild plants occurring on uncropped land, such as hedgerows, much of which is insect pollinated (Jacobs et al., 2009).

There was clear evidence from the transect counts that bumble bees and cuckoo bees responded strongly to the provision of flowers which would be expected given their requirement for nectar and pollen and that appropriate flowers with longer corollas were attracting the longer tongued species. Overall, wild bees were eight times more abundant in FEG compared to the other habitats in July/August and this is in agreement with previous studies in which grass margins, natural regeneration and conservation headlands all contained fewer bees than wildflower mixes (Carvell et al., 2007). Similarly, bumble bee abundance for this same time of year was seven times higher in wildflower margins than grass margins, and two times higher in pollen and nectar mixes than wildflower margins (Pywell et al., 2006) increasing to 3 - 10 times higher depending on the year (Carvell et al., 2007). Pollen and nectar mixes comprised of legumes, trefoils and vetches have some benefits over wildflower mixes: they are more attractive to bees and are often easier to establish. However, their nectar is less available to other insects and they have shorter lifespan compared to FEG, typically four years if sown without grass, less if sown with grasses (Carvell et al., 2007). FEG also supports grass feeding invertebrates including grasshoppers and crickets, butterfly and moth larvae and a wide range of bugs.

Wild bees were also found in the other habitats established in this project, but in much lower numbers, sometimes eight times lower, and there was no evidence that inclusion of vetch in the IRC was preferentially attracting extra wild bees. Likewise in other studies comparing different agri-environment options, the abundance of wild bees was higher in WBS than NR, although species richness was the same (Pywell et al., 2005). Despite the lower abundances, the floral resources provided by the other habitats are still valuable additions because they provide resources outside of the main flowering period (June- August, Figure 3). Some annual weeds can provide floral resources for foraging queens as they are capable of flowering throughout the year, e.g. common field speedwell (*Veronica persica*), groundsel (*Senecio vulgaris*), chickweed (*Stellaria media*) and shepherd’s purse (*Capsella bursa-pastoris*), but natural regeneration had little attraction for wild bees during the summer in this and other studies (Carvell et al., 2007). Overall, a combination of habitats are needed that includes FEG, pollen and nectar mixes and ones with annual weeds to ensure a steady supply of floral resources for the period when pollinators are foraging. The plant species is also important as plants vary considerably in the amounts of nectar and pollen produced and in its accessibility to pollinators. In East Anglia on the second sampling occasion high numbers of solitary bees were found in the game cover, perhaps because there was appropriate bare ground for underground nesting species such as the mining bees.

Overall there would appear to be benefits to bees of establishing flower-rich habitats on farmland, but the plant species to be sown need to be carefully chosen so that they provide appropriate flower types for a broad range of bee species. They should also flower at a time when natural occurring resources are low thus improving colony survival but not pulling bees away from pollinating the natural flora. It may also be necessary to provide additional nesting sites on farms lacking appropriate habitats, although, whether nest sites are a limiting factor in the UK remains uncertain. There was very low uptake of artificial nests by bumble bees in agricultural areas in Scotland either because this approach was unsuitable or that nesting habitats were not limiting (Lye et al., 2011).

Butterflies

How the uncropped land was managed had no direct impact on the abundance and diversity of butterflies. However, butterfly diversity increased positively with the proportion of uncropped land and because this occurred only in the margin transects this indicated a true increase and not just relocation. Butterfly diversity was also higher where the uncropped land was arranged in strips rather than blocks, probably because the strips benefitted more from the shelter provided by hedgerows and they facilitated greater dispersal across the farm. Shelter is known to be important for butterflies on farmland (Dover, 1996, Dover et al., 1997). The heterogeneity of the landscape at a farm-scale had a positive effect on butterfly diversity (Weibull et al., 2000) and this was attributed to the higher levels of shelter provided by the more heterogenous landscapes. The response by individual species to landscape composition may also differ according to the provision of host plants and their mobility. There may also be critical thresholds for the amount of habitat required but this threshold may be lower for more mobile species (Bergman et al., 2004).

The type of farming system (conventional or organic) had no impact on butterfly abundance or diversity in this study, although previous studies have shown higher numbers on organic farms (Feber et al., 1997) and also no effect when landscape composition was taken into account, organic farms often having greater landscape heterogeneity than conventional farms (Weibull et al., 2000). Further investigations revealed that organic farming only benefitted butterflies when the surrounding landscape was relatively homogeneous (Rundlof & Smith, 2006). Overall the abundance of butterflies was largely dictated by their larval food plants. Those with grass hosts (e.g. meadow brown) being more abundant in grass margins and FEG and the whites (e.g. small and large whites) in WBS as their larvae feed on brassicas, this is in contrast to previous studies in which the abundance of whites was found to be dependent on the presence of legumes (Pywell et al., 2004).There was also evidence for the other butterfly species that they were utilising the nectar produced by their preferred plant species when these were included in the sown mix.

Hoverflies

Neither the treatments nor the landscape composition had an impact on the adult hoverflies when considered at the 100 ha block-scale. This may be because they are highly mobile and consequently able to move in or out of the 100 ha study areas in a short time, although species richness and abundance have been reported to be influenced by landscape composition within a 0.5-1 km scale (Haenke et al., 2009). Alternatively, although adult hoverflies feed on nectar and may benefit from flower-rich habitats they also seek out oviposition sites that have an abundance of aphids for their larvae to feed on. Thus the abundance of aphids within fields is an important driver. On the earlier sampling occasion they were found predominantly in the perennial habitats, either because they were utilising the floral resources provided by earlier flowering hedgerow plants such as white campion (*Silene alba*) and ground elder (*Aegopodium podgraria*) (Cowgill et al., 1993) or prey present in the boundaries. Many aphid species overwinter on grasses and consequently they contain higher densities at this time compared to the other habitats. Later in the year hoverflies were more abundant in the game cover and least so in the grass margins, however, these preferences were not explained by the abundance of prey. The Vortis sampling collected Hemiptera (which include aphids) but these were no higher in game cover compared to the other habitats. The game cover may have provided an abundance of their preferred flowering annual weeds such as sowthistles (*Sonchus* spp.), thistles (*Cirsium* spp.), scentless mayweed (*Matricaria perforata*) and fool's parsley (*Aethusa cynapium*) (Cowgill et al., 1993).

Hoverflies, including the species that is known to predate on cereal aphids, *E. balteatus* were more abundant in Wessex than East Anglia. This species overwinters either in more southerly latitudes (Mediterranean) or within the UK (Hondelmann et al., 2005). The higher densities found in southern England may be closer to migratory pathways. Similarly, in Germany the species was more abundant in southern compared to northern regions (Tenhumburg & Poehling, 1995). Alternatively, the differences may have been due to differences in the landscape composition, because *E. balteatus* was more abundant in heterogeneous landscapes (Krause & Poehling, 1996). The lack of any response to the treatments or proportion of uncropped land may also be attributed to the surrounding landscapes. Hoverflies responded positively in Germany to the provision sown flower strips but more so in homogeneous landscapes that otherwise lacked floral resources (Haenke et al., 2009) but it remains unknown whether floral resources are limiting in UK landscapes that have fields surrounded by hedgerows or ditches. The lack of a response in this study may indicate in UK arable landscapes there are sufficient resources for hoverflies or that the resources provided by the project-managed habitats were inadequate to influence hoverfly abundance or diversity. In semi-natural grassland hoverfly diversity was determined by species richness of flowering plants, area of grassland habitat, and landscape diversity. In contrast, hoverfly density depended on factors related to resource quantity, such as the amount of pollen and nectar resources for adults and the amount of larval macrohabitats in the surrounding matrix (Meyer et al., 2009).

3.4.3. Vortis sampling

There were few effects of the treatments on invertebrates captured using the Vortis sampler. Fewer chick food items were found on organic farms, but this was because the project-managed habitats contained high levels and these were not established on the organic farms. More spiders were found on the farmer-managed farms, probably because they favoured the grass margins. More Coleoptera were found in the blocks as opposed to strips on project-managed farms, probably because coleopteran pest species were more attracted to the blocks. The proportion of uncropped land and its arrangement had little impact on the abundance of invertebrates captured, instead they responded at a local scale to the provision of different habitat types. Some of the invertebrate groups are capable of moving across the landscape either actively or passively on wind currents, but these results suggest this has little impact. Overall, the study demonstrated that the biomass of invertebrates when averaged across the 100ha study area could be doubled by appropriate management of the uncropped land.

The individual habitats also varied in their invertebrate composition and density. The density of invertebrates was greatest in the WBS, with pest species forming a large proportion, however, there was no difference in the total biomass between habitats. There was considerable difference in the biomass of invertebrates between the regions including the chick-food insects alone that were higher in East Anglia than Wessex. This has implications for the productivity of farmlands birds whose chicks have an invertebrate diet (i.e. all farmland birds except linnet, doves and pigeons). There is currently, however, only one measure by which we can predict whether sufficient invertebrate food is available in a habitat and that is the grey partridge chick-food index. This was also higher for East Anglia but there was no interaction effect. These findings would suggest that more effort is needed to provide habitats rich in invertebrate food for farmland birds in Wessex than East Anglia and that the WBS, the best performing habitat, can provide this. If farmland birds are to use such habitats, besides having sufficient invertebrates, the vegetation structure must also allow access to the invertebrates (see Clarke et al., 2007 and Douglas *et al.* 2009). The seed mixture chosen for the IRC (cereals and vetch) was designed to provide invertebrates and access for birds and although the numbers of chick-food and their biomass were not especially enhanced, the key chick-food biomass was higher than the other habitats except the WBS. In the WBS, it was the addition of brassicas that was most likely to have increased the chick-food invertebrates as previous research by GWCT has shown these support the most chick-food insects (Holland et al., 2010).

The habitats all supported relatively similar densities of natural enemies, predators and parasitoids, with grass margins containing more predators and WBS and game cover more parasitoids. Likewise, in the SAFFIE project there were 20% more predatory beetles in grass margins compared to FEG (Woodcock et al., 2008). Parasitoids were generally more abundant in the annual habitats, either because they contained more hosts or perhaps the simpler flower structures of the annual weeds in these habitats permitted easier access to their nectar. Increasing nectar supplies for parasitoids has been shown to increase their fecundity and longevity in laboratory studies (e.g Idris. & Grafius, 1995) but the choice of sown plants is important if pest species are not to be encouraged (Winkler et al., 2010). These findings indicate that there may be benefits for pest control by diversifying the range of wildlife habitats on farm to ensure a diversity of beneficial invertebrates. These aspects are explored further in the sister project IFO126 funded by Defra.

Arachnida were most abundant in natural regeneration probably because they prefer more habitats with variation in the vegetation structure which this habitat would have provided with bare ground and patches of vegetation. Coleoptera were most abundant in the WBS, primarily because this supported coleopteran pest species that formed a large proportion of the species composition. The more mobile Diptera and Hymenoptera showed less variation between habitats but preferred the annual ones whereas Hemiptera, which was formed of grass feedings bugs, preferred the perennial habitats. The density of Lepidoptera was very low compared to the other taxa and was made up of grass or brassica feeding larvae, these predominating in the grassy habitats or WBS respectively.

3.4.4. Birds

After virtually two decades of private and government-funded research into farmland birds across Europe, there have been considerable successes in identifying both habitat-related and demographic constraints on populations of some species (Siriwardena et al., 2000; Ausden & Hirons, 2002; Bro et al., 2000; Vickery et al., 2004; Siriwardena et al., 2006). Despite this, the stabilization of national populations of declining species has proved frustratingly elusive, as populations in England, as in many other countries in western Europe, have continued to decline (Pain & Pienkowski, 1997; Donald et al., 2001; Voříšěk et al., 2010). This decline contrasts with some small-scale studies, on single farms, that have demonstrated some successes in reversing declining populations of birds by applying methods apparently similar to those used in national agri-environment schemes (e.g., Peach et al., 2001; Stoate, 2002; Henderson et al., 2009; Hinsley et al., 2010). The difference between small scale intensive sites and national or regional scale monitoring is most probably due to unintentional biases in the application and management of wildlife prescriptions or habitats; sites benefiting from close and continuous professional advice contrast with those across the wider farming spectrum, where both habitat quality and quantity are more likely to become ‘diluted’ in their effect. Unquestionably, the continuing decline in national bird population trends implies habitat related inadequacy at the larger geographic scale. Identifying these inadequacies is imperative in the light of varying commodity prices and up-surging global demands for food and energy.

Main effect

In the present study we provide important evidence of a scaled effect of habitat provision on the abundance of birds associated with English arable farmland, at a resolution comparable with annual bird monitoring schemes for farmland. Based on a sample of farm sites that were representative of typical cereal-based rotations in lowland England (Table 8), the strongest and most detectable effect on bird abundance was the gross area cover of uncropped land. No specific threshold was identified. Instead the clearest distinction was between farms with less than 3% uncropped land present and farms with 10% or more cover of uncropped land present. The sites with less than 3% of uncropped land were associated with significantly lower populations farmland-dependent bird species, especially for three species: skylark, linnet and yellowhammer for which abundance was roughly 60% higher on farms with 10% uncropped land or more (the data could not resolve differences within the 5% to 8% range of cover of uncropped land). This was not to say that field size or the composition of the habitat was un-important (for invertebrates and wild plants in the same study habitat composition was very significant), only that for birds at this particular scale of resolution the absolute availability of 'average' uncropped land on 'average' arable farmland was the strongest and most detectable correlate among the variables measured. The same could not be said of other potentially important and accurately measured variables, such as relative hedgerow length, the difference in crop types present or crop area, the length of field margins present, the floral or invertebrate content of specific patches of uncropped land present, the spatial deployment of uncropped land as either strips or blocks, inter-patch complexity, the land use characteristics of the surrounding countryside (woodland, grassland, arable land and urban components) or predator control, although each of these variables (except predator control) was a significant component for one or other bird species. At this scale of measurement no confounding, surrogate variables were detected and therefore the relationship between birds and uncropped land was most likely genuine. This conclusion is consistent with predictions for the high dependency species in particular, and shows some consistency also with previously published information (Gillings et al., 2005; discussed below).

Proportion of uncropped land

A significant relationship with uncropped land was identified for the three most abundant species present, linnet, yellowhammer and skylark (using the larger dataset and especially on conventional farms). Their abundance provided sufficient analytical power to detect a relationship that was also present in other species but fell short of statistical significance. Among the other declining, high-dependency species (kestrel, lapwing, grey partridge, yellow wagtail, corn bunting and reed bunting) no individually significant effect of uncropped land was detected, but collectively they showed a consistent positive relationship that was not found among the lower dependency species, such as, song thrush, dunnock and house sparrow. It is conceivable that management activities pertinent to the requirements of skylark, linnet and yellowhammer would go some way to improving conditions for the other species among the high dependency group too, since coincidentally, these three species represent a broad range of ecological traits that are shared, collectively, by the other high-dependency farmland species. The range of traits include: open 'field' nesting (skylark) and grass-margin/boundary-nesting species (linnet and yellowhammer), territorially-dispersed species (skylark and yellowhammer) and typically aggregated species (linnet), obligate seed-eaters (linnet) and facultative seed-eaters/insectivores (skylark and yellowhammer), species requiring winter seed provision (linnet and yellowhammer) versus one that is less dependent on it (skylark); and those with preferences for smaller weed-seeds (linnet) versus larger grass seeds (yellowhammer).

Spatial arrangement of uncropped land

Part of the remit of the present study was to look into effects of the spatial arrangement of uncropped land on biodiversity, in this case bird abundance. The theory was that, because birds arrange themselves according to conspecifics, patches of habitat distributed around the farm would optimise the birds' access to uncropped land and thus support a higher density of birds overall. There is evidence that many farmland birds, when breeding, choose to move over areas of less than 300-400 m from the nest site (Green, 1984; Donald et al., 2002; Field & Anderson, 2004; Stoate et al., 1998; Peach et al., 2001; Brickle & Peach, 2004), such that for optimising breeding densities, foraging resources have to be distributed in such a way that birds from all locations on a farm can access resources over those sort of maximum distances. At the 100-ha scale of measure in the present study the spatial arrangement was not as critical to birds as the gross availability of uncropped land *per se*. That said, the spatial arrangement of uncropped land was significance for one highly territorial and spatially over dispersed species when breeding and foraging (skylark), and in contrast, one species that forages by roaming over larger distances, often in aggregations of individuals (linnet). In addition, in some model combinations the perimeter-to-area ratio of uncropped land was also significant for grey partridge.

For grey partridge, an effect of uncropped land on the species' occurrence was detectable only when larger blocks of habitat were present and when the perimeter area was relatively small (thus large blocks rather than narrower strips). As an open-field species this is consistent with its known ecology (Potts, 1986) but suggest that much of the linear configuration of modern farmland (margins, edges, strips) may not be optimal; perhaps, for example, by exacerbating the impacts of predation? For skylarks, the '% area of uncropped land' and the perimeter-to-area ratio of uncropped land were both highly significant positive effects ($p < 0.002$) suggesting that the gross area of uncropped was important especially when controlling for the positive effects of a larger relative edge effect (i.e., typical of approx 24m strips rather than approx 48m blocks). Our expectation was that skylarks would be associated mainly with a blockier configuration since we are used to them being associated with expansive open habitats. But skylarks are strongly territorial and spatially dispersed in summer, and so long as the patches of uncropped land do not sit close to hedges or woodland, they could fulfil the same role as larger contiguous patches but offer a larger edge effect and bare ground component (Henderson et al., 2001). In contrast, linnets are semi-colonial breeding birds that are not strongly territorial. They are not central-place foragers but instead may travel considerable distances to track ephemeral weed seed resources (Moorcroft et al., 2002). This species was strongly associated with the gross '% area of uncropped land' from basic models (Table 8). In contrast to skylarks, the ratio of 'perimeter length to patch area' for uncropped land was significantly negative ($p < 0.01$) indicating that this species was recorded at higher abundance where large blocks of contiguous habitat were available.

In summary, depending on the species, both blocks and strips were associated with higher densities of birds. We suggest, if habitats are arranged and connected so as to optimise access for populations of territorially dispersed species then the roaming species will find and utilise those same habitats if, ultimately, their overall proportional availability is maintained.

Quantification

Our expectations were that on current conventional farmland a higher proportion of uncropped land (unharvested and managed for biodiversity) would indeed raise the carrying capacity of the farmland, particularly for the more dependent species, since the loss of uncropped land is one accepted characteristic of modern agriculture (e.g., Chamberlain et al., 2000). This expectation was reached, and it is also important to note that the declining, high-dependency species were the most responsive group (Figure 16b). These being the species in most need of conservation effort, as well as influencing the trajectory of the Farmland Bird Index (Figure 16c). Although there were some non-significant trends of temporal effects for birds, we did not detect any significant temporal effects of uncropped land, even on the project-managed sites where habitat quality was expected to improve over the first 3 years. Far stronger relationships were detected for invertebrates and plant species richness that were measured at the patch level at the same sites. For birds, the project-managed areas of uncropped land were only one component of the total area of uncropped land available, thus probably weakening their influence and overall quality. Instead for birds the total area of uncropped land was the dominant effect. Densities of skylark, linnet and yellowhammer on farms with less than 3% uncropped land (Figure 16a) were 50% to 60% lower than national mean estimates of densities from the national monitoring scheme in the UK (the BTO/RSPB/JNCC Breeding Bird Survey or ‘BBS’) between 2006 and 2010, using not dissimilar methods (i.e., 0.04, 0.04 and 0.07 birds per ha respectively for skylark, linnet and yellowhammer in the present study compared to 0.1 (CI = 0.04 - 0.15), 0.11 (0.014 - 0.143) and 0.14 (0.1 - 0.25) birds per ha for the BBS. The years 2006 to 2010 were a period of further decline for the farmland bird index in England by around 10% (5% between 2008 and 2009; Defra, 2011a). During this period, uncropped land (including set-aside) fell from 9.8% in 2002 to 2.8% in 2010 (Defra, 2011b). Under similar farming circumstances, it seems unlikely that mean rates of uncropped land occupying substantially less than 5% of the cropped area (at 3% for example) would contribute to future stable or increasing population of birds unless, with all things being relative, the ambient rate of uncropped for a given area of farmland was actually less than 3% and closer to zero.

In an earlier study, Gillings et al. (2005) showed that the proportion of availability of over-winter stubbles (some of which was ‘set-aside’ and a component of uncropped land in the present study) could explain some of the variation in the summer population trajectories for several declining farmland bird species. In particular, skylark populations declined by only 4% in kilometre squares with over 10 ha (>10%) stubbles present compared to squares with less than 10 ha (<10%) winter stubbles (20% decline), and squares with no stubbles present (34% decline). Over a nine year period from 1997 to 2004 populations in the >10% category also began to stabilise and marginally increase. In the present study, the differential between 5% and >10% uncropped land (which excluded stubbles) for skylark, linnet and yellowhammer and for the Farmland Bird Index species combined was between 16% and 34% higher for the over 10% category. Notionally, an increase from 5% to 10% should therefore be sufficient to shift a regional or national population in a positive direction, with the rate of 10% uncropped land being of the right order of magnitude to stabilise bird populations in the wider countryside under farming circumstances where the majority of uncropped land is not closely managed or monitored. However, this is dependent on the status quo, ie., it is a relative change and is thus relative to whatever are the current average levels of uncropped land provision. This figure is not easy to determine for the wide farming community – but may sit at around 5% (see below).

UK government bodies responsible for land management, farming and advisory organisations are collaborating in the Campaign for Farming Environment to encourage farmers to maintain the existing area of uncropped land as was present at the start of the campaign (179,000 ha in 2008/9) and to double the uptake of key options by 2012 (e.g. field margins, wildflower strips for pollinators and winter food resources for wildlife) to 80,000 ha (CFE, 2011). This is in addition to the semi-natural habitats, such as hedgerows, pond edges and woodlands. In practice, the allocation of land for non-farming purposes will always be minimised except where land owners, on their own volition, accept the intrinsic value of wildlife or natural landscapes. In circumstances where the habitats are closely managed and monitored, lower rates of uncropped land may be acceptable and effective, as in the ‘Higher Level Scheme in England in areas that are targeted for the scheme to increase environmental benefits. The HLS scheme however, is competitive and limits the number of farmers that can subscribe. To affect large scale, regional or national population increases in birds such as skylark, linnet and yellowhammer, as many farmers as possible will need to contribute to habitat provision, and then both logistically and financially the quality of uncropped land cannot be closely monitored. In such circumstances, though the evidence suggests that while *all contributions are better than none*, if current rates of uncropped land are around 5%, then this may verge on the inadequate for population stabilisation at present levels, potentially leading to lower population equlibria for the most farmland dependent species.

Although we found no consistent relationships between birds at the 100 ha scale and either plant or invertebrate species richness, diversity or abundance this was almost certainly due to the different scales of measure (non-bird taxa being sampled closer to the patch level or within crops) and the fact that birds may have been responding as much to variations in unmeasured winter food resources (e.g. in the WBS) as summer provisions (Gillings et al., 2005; Siriwardena et al., 2008). Furthermore, summer provision will have most likely influenced breeding success, which was not measured, and subsequent redistribution of offspring through the landscape would preclude any impact in the following year on local populations. Many other farmland bird studies have shown relationships between birds and individual habitats or resources (e.g., Potts, 1986; Robinson & Sutherland 1999; Henderson et al., 2000a; Henderson et al., 2000b; Moorcroft et al., 2002; Donald, 2002; Henderson et al., 2004; Henderson et al., 2009). The design of the present study was more to investigate habitat scale rather than the mechanistic effects of resource abundance. As such, the effects of uncropped land could operate either through winter resources (Buckingham et al., 1999; Peach et al., 1999; Gillings et al., 2005; Siriwardena et al., 2008) and/or in summer (eg., Potts, 1986; Browne et al., 2000; Henderson et al., 2009) since both types of uncropped land (summer grass/flower margins and winter bird cover) were included in the study and neither could be eliminated as having no effect.

3.4.5. General conclusions

Effect of management

The main aim of the project was to determine whether management of uncropped land for biodiversity on conventional arable farms could achieve significant and measurable increases in biodiversity, that were equivalent to or greater than those attained on organic farms with primarily arable cropping systems. The results showed that at the 100 ha scale, on average across the 28 sites there was no significant effect of habitat management on bird abundance, as both Biodiversity Action Plan species and the Farmland Bird Index continue to decline between 2006 and 2010. However the declining rate on project-managed farms was slower than on farmer-managed farms, but the differences were not statistically significant. Moreover, it may take longer than the period available for a response to be detectable, as found with other investigations appraising the impact of ELS (Davey et al., 2010). If farmland biodiversity is to be encouraged it is essential to provide all the necessary habitat and resources for each group of organisms on farmland, for example, food, breeding areas, and shelter throughout the year and this requires better use of uncropped land, that is unharvested and managed for biodiversity through agri-environment schemes.

The floristic content of the uncropped land on the organic farms did not differ from that on the conventional farms and the percentage of uncropped land on the organic farms approximated to the mean percentage for all farms. There were significantly enhanced numbers of weeds in fields, some bird species and hares on the organic farms. However, there were fewer bees on the field margins of the organic farms and no effects were detected on butterflies and hoverflies. The main driver for differences in biodiversity in the project, as outlined in the previous sections, was the percentage uncropped land, but this cannot be the cause of the increased abundance of some of the species recorded. The major difference in the landscapes of the organic and conventional arable farms seems to lie in the fertility-building fields of grass/legumes which were substantial constituents of the cropping on the organic farms but not on the conventional ones. These fields seem to provide resources for some bird species, some insects and mammals, that are not provided by conventional farms.

The impact of the project management was more local, expressed as differences between habitat types. Thus, on farmer-managed farms the plant community was grass focussed because grass margins were the main type of uncropped land. Whereas on the project-managed farms annual flowering weeds prevailed and there was an upward trend over time in plant diversity in the project-managed perennial habitats. Similarly, particular project-managed habitats encouraged individual groups of invertebrates, for example the FEG attracted wild bees and the WBS contained more invertebrate chick-food. For birds and mammals the measurements were at the 100-ha scale, however, localised use of individual habitats is likely to have occurred as demonstrated in the preference of birds for particular seed mixes (Stoate & Parish, 2001; Henderson et al., 2004).

How much uncropped land?

The proportion of uncropped land was positively related to the abundance of wild bees and butterfly diversity, some bird species and functional groups of birds. There was also an increase in the number of bee groups between 0-3 and 3-5% uncropped land, but no increase beyond this, either because individual species were not identified or because there was limited opportunity for recruitment. Wild bee abundance increased positively with uncropped land at the expense of the margins, indicating redistribution may have been occurring and this merits further investigation to ensure pollination of hedgerows plants is not being compromised by the planting of areas super-rich in floral resources. Butterfly diversity also increased with the proportion of uncropped land. Grass margins and wild bird seed mixes or game cover comprised a large proportion of the additional uncropped land and this explains the response because the larvae of many species feed on grasses or brassicas. The main effect on the abundance of birds was the gross proportionate availability of uncropped land, the relationship being strongest on conventional farmland. Sites with <5% area (especially <3%) of un-cropped land were relatively under-populated; sites with >10% held significantly higher densities of key species. A rate close to or <5% un-cropped land may be inadequate for population stabilisation under circumstances where un-cropped land *is not* closely managed for biodiversity. However if there was extra provision of specific resources for birds, such as winter bird food, this may enable farms to stabilise bird populations without increasing the % uncropped land above 5%. Species considered to be of higher farmland-dependency were the most responsive to the availability of uncropped land, especially the more abundant skylark, linnet and yellowhammer. Their abundance provided sufficient analytical power to detect a relationship that was also present in other species but fell short of statistical significance. Less dependent species, such as woodland species (e.g., song thrush and dunnock) or urban species (e.g., house sparrow) were detected as being responsive to the availability of uncropped land, but these species would preferentially require the provision of surrogate woodland (hedgerows or shade) or urban (buildings) habitats. Though based on a smaller sample size, organic farmland was especially significant (relative to conventional) for densities of lapwing, wood pigeon, skylark and rook, probably reflecting the mixed rotation that included, on average, a higher grassland component and weedier arable crops.

Spatial arrangement of uncropped land

Of the pollinating insects, only butterflies responded to the spatial arrangement; diversity was higher when the uncropped land was in strips. This may be expected because butterflies prefer sheltered areas next to hedgerows, these facilitating dispersal and making more favourable habitat for breeding. For birds, there was generally a weak response to the spatial arrangement of uncropped land, though skylark, linnet and to a lesser extent grey partridge show differing response to habitat arranged as blocks or strips. Overall, this study shows that maximising the availability of uncropped land would positively affect the carrying capacity of conventional arable farmland for these species. The study used a scale of resolution that is consistent with pan-european bird monitoring schemes (Anon, 2010). Varying the content, composition and spatial arrangement of habitat on farm will contribute to a variety of resources that will support different species not least by providing resilience in the form of foraging and breeding options (Benton et al., 2003). Sample sizes were low for lapwing and kestrel that range over larger areas of habitat than 100 ha, and for these species a more expansive landscape approach is needed with `vision' extending well beyond the individual farm-scale.

Economics

Over a five-year period all of the habitats produced a gross margin of £381-433/ha, but this was lower than a rotation of winter wheat and oilseed rape grown on productive land (£594/ha). But the comparison may look better on less productive land when the yield potential and/or the difficulty in management of the location of these habitats are taken into account. The FEG had the highest gross margin and was the easiest to establish and manage, although at present this option is not available in ELS. A nectar flower mixture may be established in ELS and attracts 450 points and wildflowers may be incorporated in some buffer options, but there is no extra payment. The 6m buffer options that encourages the establishment of grass margins attract 400 points, but there is a requirement to cut half of this every year and cuttings should be removed yet there is no extra payment for this compared to a 4m grass margin. Overall the payments failed to match the gross margins for the crops unless the land taken out of production had a lower yield potential and/or was a difficult site for efficient crop and machinery management. These findings showed that there is considerable variation in the cost of establishing and managing each agri-environment option and scheme payments are not compensating adequately for the costs involved and any increase in the proportion of uncropped land requires extra financial support through agri-environment schemes to help farmers to increase the proportion of uncropped land.

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Appendix. List of invertebrates identified in the Vortis samples.

ARACHNIDA	Araneae	Linyphiidae	
		Thomisidae	
		Lycosidae	
		Others	
			Juveniles
	Opiliones		
ORTHOPTERA			Adults
			Nymphs
DERMAPTERA			
HEMIPTERA	Homoptera	Aphididae	
		Psyllidae	
		Cicadellidae	
		Delphacidae	
		Cercopidae	
	Heteroptera	Anthocoridae	
		Nabidae	
		Others	
NEUROPTERA			Adult
			Larvae
LEPIDOPTERA			Adult
			Larvae
HYMENOPTERA	Symphyta		Adults
			Larvae
	Parasitica		
		Formicidae	
	Aculeata		Bombus spp
			Apis mellifera
COLEOPTERA		Carabidae	Acupalpus meridianus
			Amara aulica
			Amara familiaris
			Anchomenus dorsalis
			Aspidion flavipes
			Badister bipustulatus
			Bembidion genei
			Bembidion guttula
			Bembidion lampros
			Bembidion lunulatum
			Bembidion quadrimaculatum
			Bembidion obtusus

			Demietrias atricapillus
			Dromius linearis
			Dromius longiceps
			Leistus spinibarbis
			Metabletus foveatus
			Microlestes maurus
			Notiophilus bigutattus
			Lionychus quadrillum
			Microlestus maurus
			Trechus quad.
			Larvae
		Staphylinidae	Aleocholrinae
			Mycetophorus
			Paederus spp.
			Philonthus spp.
			Tachyporus hypnorum
			Tachyporus chysomelinus
			Tachyporus obtusus
			Tachyporus nitidulus
			Tachyporus formosus
			Tachyporus spp
			Stenus spp
			Adult unknown
			Larvae
		Elateridae	
		Cantharidae	
		Nitidulidae	Adult
			Larvae
		Oedemera	
		Coccinellidae	Adults
			Larvae
		Chrysomelidae	Halticini
			Others
			Larvae
		Curculionidae	Ceutorhynchus spp
			C. picitarsis
			C. Assimilis
			C. Pallidactylus
			C. napi
			Apion spp
			Sitona spp

			Others
DIPTERA			Adults
			Larvae
	Nematocera	Tipulidae	Adults
		Cecidomyiidae	Sitodiplosis mosellana
			Contarinia tritici
		Others	
	Brachycera	Empididae	Adults
		Dolichopodidae	Adults
		Others	
		Syrphidae	Adults
			Larvae
		Other Aschiza	
		Opomyzidae	Opomyza florum
			Others
		Chloropidae	Oscinella frit
			Chlorops pumilionis
		Other Acalyptera	
			Others
		Muscidae	Delia coarctata
			Others
		Scatophagidae	
		Other Calyptera	
MECOPTERA	Panorpa		
EPHEMEROPTERA			
Other INSECTS			