REPORT TO THE DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS

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Final Report

April 2004

Monitoring of Cereal Field Margin Options in Agri-environment Schemes

Part 1: Arable Stewardship Pilot Scheme

ADAS

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

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Botanical Assessment of the Arable Stewardship Pilot Scheme, 2003

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Summary

1. The Arable Stewardship Pilot Scheme (ASPS) was established in two pilot areas in England (East Anglia and West Midlands) in 1998 to test a range of options for managing arable land to benefit biodiversity. An ecological evaluation of the scheme had been carried out following field surveys in 1999 and 2000. As part of a wider assessment of the contribution of agri-environment schemes to the Cereal Field Margins Habitat Action Plan, a second assessment was done in 2003 of four field margin options.

2. At 54 farms, vegetation was surveyed in 156 sites managed as conservation headlands (Option 3A), conservation headlands without fertiliser (Option 3B), uncropped wildlife strips (Option 4C), wildlife seed mixtures (Option 5) or normally cropped cereal headlands. At each site, botanical data were collected from 30 randomly located quadrats, soil cores were collected and the site searched for rare arable plant species. Additional soil cores and plant community data were collected at the loci of rare plant species. Data were analysed using ordination methods, Analysis of Variance and *t*-tests.

3. In total, 257 plant taxa were recorded, including crop and other sown species. Most were common species of arable land. As expected, the 'static' Options 4C and 5 differed markedly from the cereal headland options (Options 3A and 3B) and normally cropped headlands, having high cover and diversity of naturally regenerated species, particularly perennials.

4. Paired comparisons between Option 3A and normally cropped sites on the same farm showed that Option 3A sites had more dicotyledons and annuals but there was no difference in monocotyledons, perennials or pernicious weeds. The difference between Option 3A and normally cropped headlands was in the abundance rather than the identity of these species. At the scheme level, Option 3A was therefore successful, although variation was high between individual sites. At Option 3A sites where none of the permitted herbicides had been applied, there was a tendency for perennials to be slightly more prevalent.

5. Option 3B sites were only present at a few farms but tended to have a greater abundance of all species groups than Option 3A sites. Option 3B therefore appeared to confer additional benefits but with perhaps some risk of encouraging pernicious weed species.

6. At Option 4C sites, perennials increased substantially between 1999 and 2003, from 12% to 60% cover, and annuals declined. *Cirsium arvense* and *C. vulgare* were examples of increasing species. These changes might be of concern for the conservation of annual dicotyledons, although it is not known at what stage equilibrium might be reached. Option 4C appears to be most beneficial in the initial years of establishment. Contrary to expectations however, monocotyledon cover did not increase. Soil properties had not changed since 1999. The same cultivation regime tended to be applied at all sites on a farm so the opportunity to maximise diversity between sites was not realised. Non-compliance was a problem at some sites.

7. A range of cover types in different mixtures had been sown at Option 5 sites, but Brassicas, cereals and maize were most commonly sown. Changes between

1999 and 2003 were similar in direction and magnitude to those in Option 4C sites, with a build up of perennials and a decrease in annuals, despite the presence of the sown species.

8. There were 20 records of seven species of rare arable plants in East Anglia, plus 6 incidental records from other sites. This is broadly comparable with the previous survey. Records were from all margin types, including normally cropped headlands, and from seven National Vegetation Classification communities. Species newly recorded in 2003 were *Bromus secalinus* and *Iberis amara*. Option 4C sites were most likely to contain rare species but populations at most had declined compared to 1999. There were fewer records at Option 5 sites than in the previous survey. Annual plant populations fluctuate from year to year but some might have declined as a result of perennial vegetation increasing in Options 4C and 5.

9. Food plant species of butterfly larvae and bumblebees were much more abundant in Options 4C and 5 than in Option 3A or normally cropped headlands. These were most abundant in Option 4C sites, although bumblebee food plants increased between 1999 and 2003 at Option 5 sites. Bird and butterfly larva, but not bumblebee, food plants were more prevalent in Option 3A sites than normally cropped headlands. The presence of food plants does not necessarily confer advantage on these faunal groups but there might be potential benefits at all ASPS options.

10. Soil pH was higher in East Anglia (mean 8.1) than West Midlands (mean 6.8), as was extractable K, but extractable Mg was lower. Vegetation also differed between pilot areas, having more grassland characteristics in West Midlands and more annual arable plants in East Anglia. Arable plant conservation might be more easily achievable in East Anglia.

Introduction

Under the UK Biodiversity Action Plan, Cereal Field Margins are identified as a Priority Habitat for conservation (Anon., 1995). Objectives identified in the Habitat Action Plan (HAP) are to maintain, improve and restore, by management, the biodiversity of 15,000 ha of cereal field margins on appropriate soil types in the UK by 2010.

Substantial changes to the arable flora of the UK in the second half of the 20th century resulted from intensive agricultural practices. Annual dicotyledons declined, whereas a relatively small number of nitrophilous species, particularly grass weeds increased (Chancellor, 1975; Chancellor & Froud-Williams, 1984). The abundance and species diversity of arable plants were reduced at individual sites and plant communities associated with light or chalky soils were much reduced in their geographical distribution (Rodwell, 2000; Wilson & King, 2000). Many formerly common arable plants are now nationally scarce. Declines in farmland invertebrates and birds are also associated with the reduction in arable plants (Marshall *et al*., 2003). The aim of the HAP for Cereal Field Margins is to reverse these trends to benefit arable plants and their associated fauna, including farmland birds, mammals and invertebrates.

The Arable Stewardship Pilot Scheme (ASPS) was established in two regions (the East Anglia and West Midlands pilot areas) of England in 1998 as a preliminary to the countrywide introduction in 2002 of a range of management options for arable land. Agri-environment schemes such as the ASPS are seen as the main vehicle for achieving the objectives of the Cereal Field Margins HAP. Management options available to farmers in the ASPS included overwinter stubbles and spring fallow, undersown cereals and grass leys, conservation headlands, sown, naturally regenerated or cultivated field margins and wildlife seed mixtures (MAFF, 1998).

An ecological evaluation of the ASPS was carried out during the first three years of the scheme (ADAS *et al*., 2001). In this, the benefits of the scheme to biodiversity were assessed, by relating field survey data to the agreement status of farms and the management options in place. Taxa studied were higher plants, bumblebees, bugs, ground beetles, sawflies, birds and brown hares. In the higher plants module of the project, 294 sites under a range of management options were surveyed. The botanical composition of each option or habitat type was compared with the results of previous research on that habitat. The vegetation that established matched the expectations for most of the management options. Differences between the two pilot areas were also apparent, there being more rapid successional development and more monocotyledons in West Midlands. Soil properties and landscape structure also accounted for variation in the vegetation. In East Anglia, a notable number of records was made of rare arable plant species, but few from West Midlands.

The previous study examined the outcomes of various management options during the initial years of the scheme. With the scheme now closed to new applicants and the first management agreements reaching the end of their five year life, there was an opportunity in 2003 to re-assess some management options five years into the scheme. The aim of the current study was to survey and assess a sample of conservation headlands (Option 3A), conservation headlands without fertiliser (Option 3B), uncropped wildlife strips (Option 4C), wildlife seed mixtures (Option 5) and normally cropped cereal headlands (see Appendix 1 for a description of the ASPS options). Specific objectives were

1. to compare plant species composition between the management options and with normally cropped headlands
2. to assess the incidence of rare or declining arable plants
3. to determine how vegetation at the (static) Option 4C and Option 5 sites had changed since the first survey and
4. to assess the relationships with soil properties and management practices.

Methods

Site selection

All sites were selected from the same sample of farms as in the previous surveys of 1999 and 2000 (Critchley *et al.*, 2001a; in revision). This original sample comprised the 37 farms in East Anglia and 38 in West Midlands that had ASPS management agreements in place in 1999. The current sample was drawn from the 54 farms that had management agreements for one or more of the four field margin options.

A site was defined as a single field margin. In the 1999/2000 survey, sites were selected using proportionate random sampling, such that the number of sites selected on a farm was in proportion to the number of sites of that type on the farm. This ensured that the sample was representative of the statistical population of sites under each management option. Up to 20 sites of each type per pilot area were selected, depending on availability.

Option 3A and 3B sites can move around the farm each year with the cereal crop rotation. Therefore, new samples of these were selected for the 2003 survey. A random sample of sites was drawn for each option but with the same number being selected on each farm as in the previous survey. No Option 3B sites were selected from West Midlands because the uptake there was low. Option 4C and 5 sites are static and the same sites were surveyed in 2003 as previously. Normally cropped cereal headlands had not been included in the previous survey. One site was selected from each of 20 farms in each pilot area. Farms were selected randomly but with some subsequent adjustment of the sample to ensure that normally cropped sites were evenly distributed amongst farms with the various options. This adjustment was done objectively with no reference to any other characteristics of the farms. To accommodate the requirements of the bumblebee survey, the normally cropped site was matched as closely as possible to an Option 4C or 5 site sampled on the same farm (if present).

A number of Option 4C and 5 sites could not be resurveyed because they were not being managed according to the Option 4C prescriptions or were no longer present (eight and three Option 4C in East Anglia and West Midlands respectively and two Option 5 from each pilot area). One control site in East Anglia was rejected because the Option 5 site on that farm could not be re-located. This resulted in 156 sites being available for analysis (Table 1).

Table 1. Number of sites (number of farms in parentheses) surveyed and available for analysis.

Option	ASPS Code	East Anglia	West Midlands	Total
Conservation headland	3A	20 (13)	20 (13)	40
No-fertiliser conservation headland	3B	20 (5)	-	20
Uncropped wildlife strip	4C	11 (10)	13 (7)	24
Wildlife seed mixture	5	16 (12)	17 (14)	33
Normally cropped cereal headland	-	19 (19)	20 (20)	39
Total		86	70	156

Field survey

Main survey

The main vegetation surveys followed the same method as the 1999/2000 surveys, with minor modifications. In each field margin site, a 100 m long sampling zone had been randomly located, but not within 10 m of either end of the margin. Sampling zones in Option 4C and 5 sites were re-located from site maps. In the new Option 3A and 3B and normally cropped sites sampling zones were established in the same way as the previous survey. Some Option 5 sites were small blocks rather than field margin strips; in the previous survey the sampling zone in these was 50 m long and extended up to 32 m into the field. In the 2003 survey, the sampling zone was restricted to a maximum of 12 m into the field because the aim was to assess field margins only.

In the sampling zone, thirty 0.5 m × 0.5 m nested quadrats were randomly positioned. To obtain top cover estimates, a single pinhit per quadrat was recorded, by lowering a pin vertically in the corner of the quadrat and noting the first hit of plant species, bare ground or litter. The presence of all additional plant species rooted in the quadrat (or bare ground or litter) was recorded cumulatively from the nested cells in the quadrat (12.5 × 12.5 cm; 25 × 25 cm; 50 × 50 cm). Plants with less than two true leaves were recorded as 'seedlings', and mosses and liverworts grouped as 'bryophytes'. Plant species nomenclature is after Stace (1997).

Soil samples were collected from 3 randomly selected quadrats per site. Ten evenly-distributed cores of depth 0-15 cm were collected per quadrat, and bulked to provide one sample per site. Soil samples were analysed at Direct Laboratory Services Ltd., Wolverhampton using standard techniques (MAFF, 1986) for pH, extractable phosphorus (P), potassium (K) and magnesium (Mg) and a hand texture assessment done.

Information on management practices was also collected for the ASPS sites. Resources did not allow for formal data collection, but information was obtained from farmers wherever possible during or near to the field visits. Information was sought on use of permitted herbicides in Options 3A and 3B, cultivation timing, frequency and depth and herbicide use in Option 4C and cutting timing, frequency and removal of cuttings in Option 5. These data were useful for interpreting the survey results but were not sufficiently complete for formal analysis.

Rare species

Each site was searched systematically for rare annual arable plant species by walking in a systematic zigzag pattern at a slow to moderate pace. Species that were the object of survey were those identified by Wilson (1999) as being likely to occur in one or other of the two pilot areas, and whose national status was known to be rare or scarce. These numbered 35 in total, and were either UK BAP priority species or species of conservation concern (Anon., 1995), other Red Data Book and nationally scarce species (Stewart *et al*., 1994) or other species thought to be scarce but whose status was not well known (Appendix 2). The number of individuals of any rare species found was estimated for the site on a log scale. Casual observations of rare species were also recorded if they were noticed elsewhere on the selected farms. A similar search for rare plants had been carried out during the 1999/2000 surveys.

The species composition of the surrounding vegetation was also recorded. At the main locus of the species in a site, three 2 m x 2 m quadrats were positioned 2 m apart and parallel to the field boundary. Plant species present in each quadrat were recorded and their percentage cover estimated. The grid reference of each rare species locus was recorded for future reference.

Ten soil cores were collected from the central quadrat (avoiding damage to the rare plants), bulked and analysed as for the main survey.

Data analysis

All data were input from field forms to Microsoft Excel software and imported to Microsoft Access. All data were validated by comparing hardcopy outputs from Access with the original field forms.

Comparisons between field margin types

Variation in species composition between sites of all five field margin types was determined using Detrended Correspondence Analysis (DCA) (Hill, 1979). A preliminary DCA showed a unimodal response of species along the first axis, confirming that this was the appropriate method to use (ter Braak & Šmilauer, 1998). Analysis was carried out on log-transformed species frequencies (out of 30 quadrats) for each site, including sown species and crop volunteers but not unidentified seedlings or bryophytes. All multivariate analyses were done using Canoco V.4.02 software (ter Braak & Šmilauer, 1998).

Differences between field margin types were also determined using Analysis of Variance (ANOVA) on a range of plant community variables derived from species groups. Species groups were dicotyledons, monocotyledons, obligate annuals and perennials (excluding crop species), food plants of farmland birds, butterfly larvae and bumblebees and pernicious weeds. Bird and butterfly larva food plants were those identified by Smart *et al*. (2000). Lists of plant species at which bumblebees have been observed foraging have been compiled previously by Fussell & Corbet (1992, 1993) and Carvell *et al*. (2001). However, these lists are extensive and include species that might not be particularly favoured by bumblebees (Claire Carvell, pers. comm.). Instead, therefore, a list was compiled by CEH of plant species observed during the 2003 bumblebee surveys of ASPS sites to be visited by foraging bumblebees (Appendix 3).

Eight pernicious weeds were specified, namely *Alopecurus myosuroides*, *Anisantha sterilis*, *Avena fatua*, *Cirsium arvense*, *Elytrigia repens*, *Galium aparine*, *Rumex crispus* and *R. obtusifolius*. Total species richness 0.25 m^{-2} and the number of species of each group were calculated for each site as the mean from 30 quadrats. Total plant cover and cover values for each group were calculated as the percentage of pinhits per site. Cover values were transformed to arcsine$\sqrt{x}$. Variables were analysed by an ANOVA model incorporating pilot area and management option. Option 3B was excluded because it was only sampled from East Anglia. The same model was used to compare soil properties between options and pilot areas. Analyses were done using Statistica V5.5 (Statsoft, Inc., 1999).

Conservation headlands and normally cropped headlands

Options 3A and 3B were compared with the normally cropped headlands to assess the effectiveness of the reduced inputs in conservation headlands. Species composition was compared between the three types of cereal headland management using Principle Components Analysis (PCA) since a preliminary DCA indicated a linear response of species along the first ordination axes (ter Braak & Šmilauer, 1998). Analysis was performed on the same log-transformed species frequencies as for the DCA of all margin types.

Differences between Option 3A and normally cropped cereal headlands were also assessed by paired comparisons between sites on the same farm. There were 19 farms (nine in East Anglia and 10 in West Midlands) with both Option 3A and normally cropped headlands. Where more than one Option 3A site had been sampled on a farm, one was randomly selected. The community variables described above were analysed using paired *t*-tests.

Uncropped wildlife strips in 1999 and 2003

Change in species composition at Option 4C sites between 1999 and 2003 was analysed using PCA on log-transformed species frequency data from the previous (Critchley *et al*., 2001a; in revision) and current surveys together. One site from West Midlands could not be matched with data from the 1999 survey and so was omitted, leaving 23 sites for analysis.

Changes in the community variables between 1999 and 2003 were analysed using repeated-measures ANOVA, which included year as the repeated measure and pilot area as a factor. Although the 12 sites from West Midlands had been sampled from only six farms, exploratory analysis showed that the sample was not strongly biased by any particular farm and this could be discounted in the analysis.

The change in frequency of a small number of key widespread species was also analysed using the same model. These were the perennials or biennials *Cirsium arvense*, *C. vulgare*, *Rumex obtusifolius* and *Senecio jacobea*, the annual grass weeds *Anisantha sterilis* and *Alopecurus myosuroides* and the annual dicotyledons *Stellaria media* and *Polygonum aviculare*.

Soil samples had also been collected from these sites during the 1999 survey, using the same field sampling and laboratory analysis methods. The 1999 samples had been analysed for individual quadrats, so mean values were calculated for each site. Changes in soil properties between 1999 and 2003 at Option 4C sites were analysed using the same ANOVA model as the plant community variables.

The relationship between species composition in 2003 and soil properties was analysed using Redundancy Analysis (RDA). Soil properties (texture classes, pH and extractable P, K and Mg) were included as environmental variables; log-transformed species frequency data were as described above. Soil variables were added to the model using forward selection and the significance of their relationship with species tested in turn using 199 Monte Carlo permutations. Only significant soil variables (at the 5% level) were included in the final model.

Wildlife seed mixtures in 1999 and 2003

Wildlife seed mixtures are regularly resown, so changes in species composition are dictated mainly by the species sown. However, it was of interest to investigate whether there was any overall change in the type of species present that might indicate underlying trends independent of year to year management. Changes in community variables between 1999 and 2003 were analysed using the repeated-measures ANOVA model. One site from East Anglia could not be matched with 1999 survey data and was omitted, leaving 32 sites for analysis (15 from East Anglia and 17 from West Midlands). Change in soil properties was also analysed as for Option 4C. One site had missing soils data for 1999 and was omitted.

Phytosociological associations of rare plant species

Data from the three quadrats at each rare species locus were used to identify the National Vegetation Classification (NVC) (Rodwell, 2000) plant community in which the rare species was located. Species frequency (presence in up to three quadrats) was used to calculate similarity coefficients with NVC communities using SIMIL software (Dring, 1996). Crop species and those obviously sown at Option 5 sites (e.g. *Phacelia tanacetifolia*) were omitted. Loci were allocated to the community with the highest coefficient. If the top coefficients were closely similar the classification was checked by reference to quadrat data and the published NVC tables and descriptions.

Results

In total, 257 plant taxa were recorded (including crop species). The most widespread naturally-regenerated species were *Galium aparine* (57% of sites), *Polygonum aviculare* (55%), *Poa trivialis* (54%), *Poa annua* (49%), and *Cirsium arvense*, *Fallopia convolvulus* and *Veronica persica* (all 48%). Plant species recorded in the survey are listed in Appendix 4 (including English names).

Comparisons between field margin types

There was a clear difference in species composition between Options 4C and 5 and the cereal headland field margins (Options 3A and 3B and normally cropped headlands), these two groups being separated along the first two ordination axes from the DCA (Figure 1a). Perennials and biennials were associated more with Options 4C and 5, for example *Cirsium arvense*, *Ranunculus repens* and *Urtica dioica*. In contrast, annual arable plants such as *Alopecurus myosuroides*, *Veronica arvensis* and *Viola arvensis* and the sown cereals were associated with Options 3A, 3B and normally cropped headlands (Figure 1b).

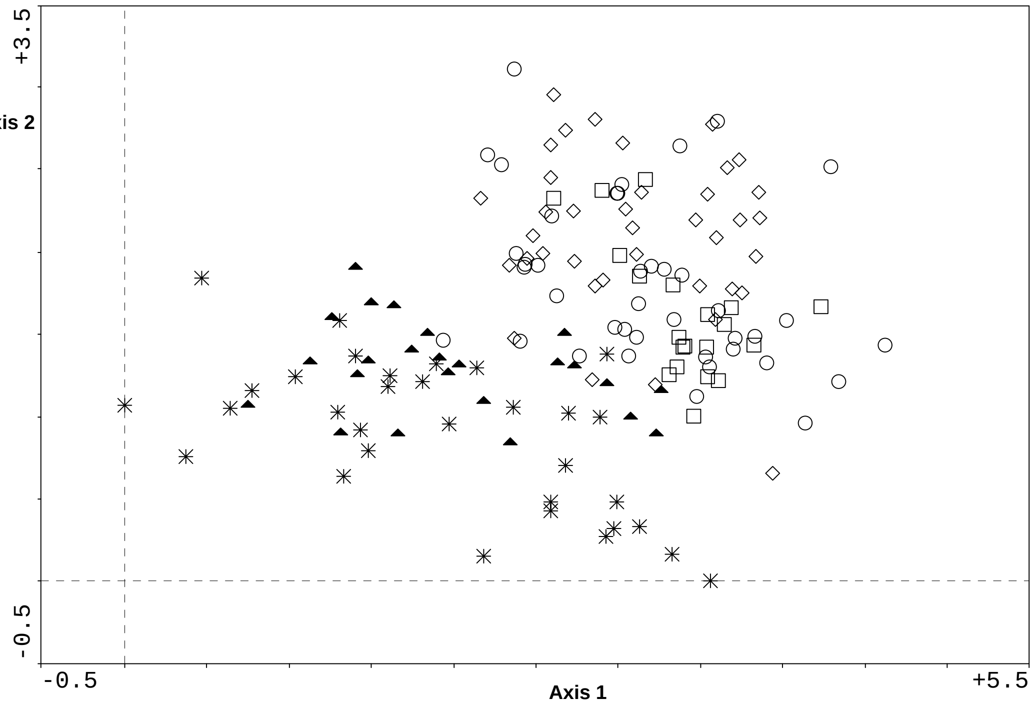
The other main source of variation in species composition was related to the pilot areas, these being separated along axes 1 and 3 (Figure 2a). Perennial species normally found in grassland were more associated with West Midlands, for example *Holcus lanatus*, *Agrostis stolonifera* and *Phleum pratense*. In contrast, annual arable plants occurred more in East Anglia, examples being *Sinapis arvensis*, *Alopecurus myosuroides* and *Chenopodium album* (Figure 2b).

There were significant differences between field margin types for all cover components (Table 2). Options 4C and 5 had greater cover of dicotyledons, monocotyledons and perennials than Option 3A and normally cropped headlands (excluding the crop itself), cover being less than 5% in the latter two. The same pattern was evident in the richness of these species groups (Table 3). Differences were particularly marked for perennial cover and richness. Perennial cover was *c*. 60% in Options 4C and 5 but less than 2% in Option 3A and normally cropped headlands. Perennial species richness ($0.25m^{-2}$) was *c*. 3.5 and 0.5 respectively for the two groups of sites. Annual cover showed the same pattern but there was no difference between field margin types in species richness of annuals.

Overall cover of dicotyledons, monocotyledons and perennials was greater in West Midlands than East Anglia. Perennial species richness was also higher in West Midlands. Significant interactions showed that there was some variation in how options differed between pilot areas; these are elucidated below in the analyses of specific options.

There was more than twice as much cover of bird food plant species in Option 3A and normally cropped headlands than in Options 4C and 5. However, the cereal crop itself is classified as a bird food plant and accounted for much of this difference. Despite this, the number of bird food plant species was lowest in normally cropped cereal headlands. The number of species was also slightly higher in West Midlands than East Anglia.

(a)



(b)

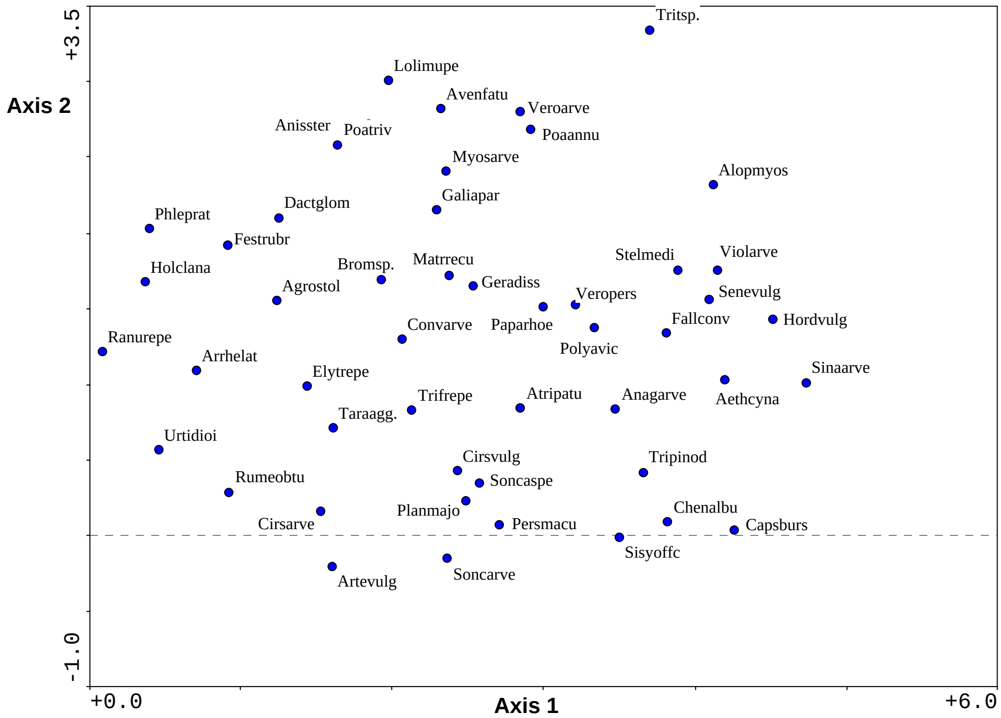
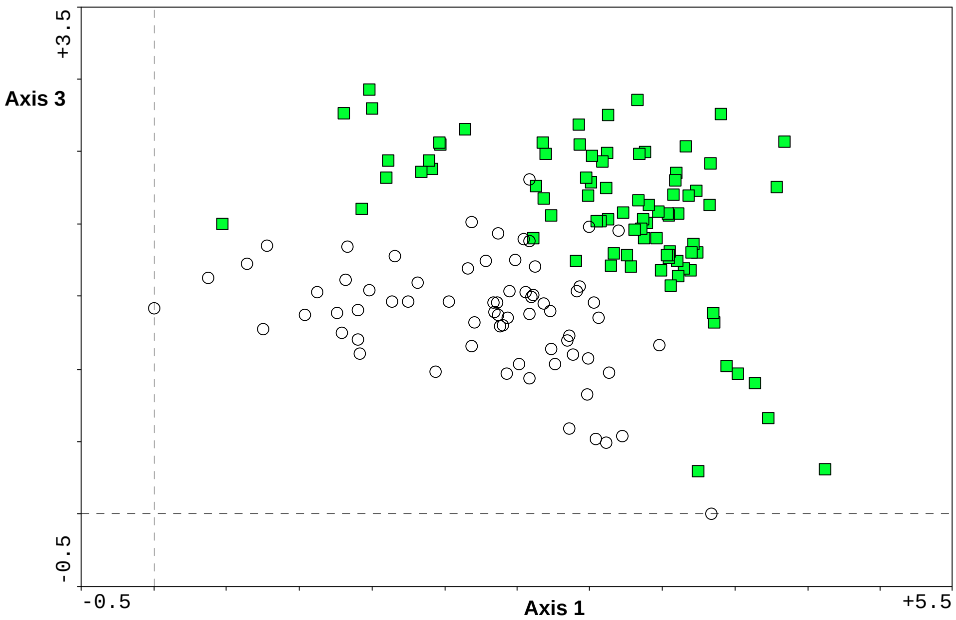


Figure 1. Scatter plots of axes 1 and 2 from DCA ordination of all field margin types. (a) sites: Options 3A (open circles), 3B (open squares), 4C (filled triangles) and 5 (stars) and normally cropped headlands (open diamonds). (b) species: only those with minimum weight of 10 shown for clarity; for species codes see Appendix 5.

(a)



(b)

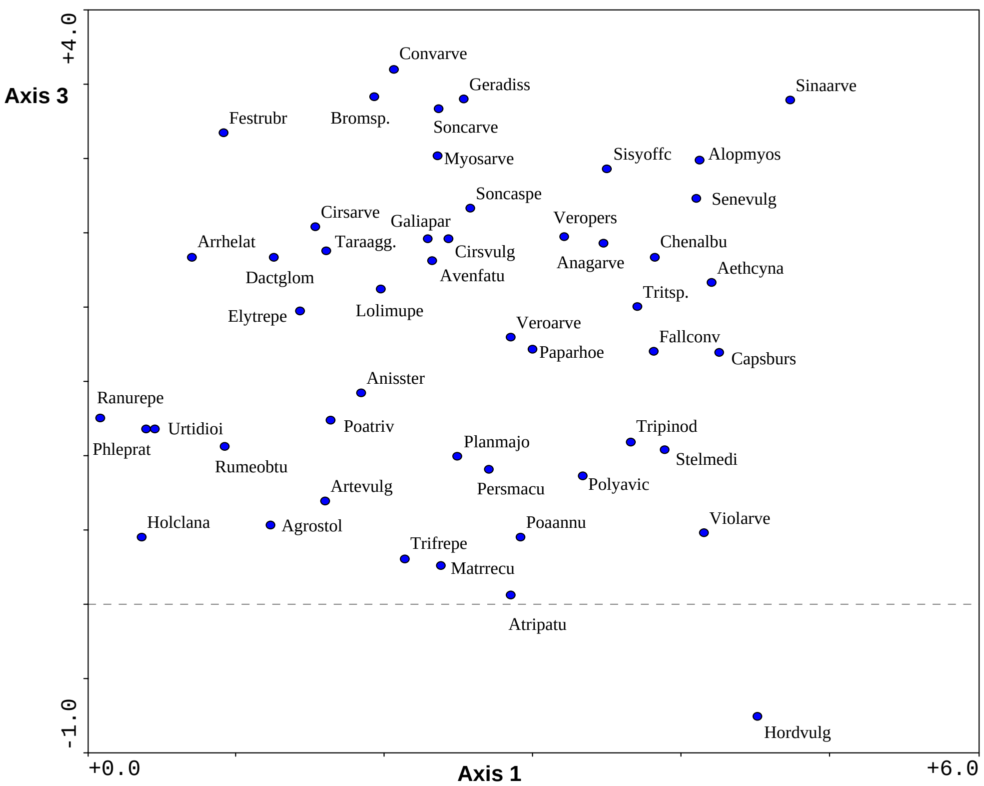


Figure 2. Scatter plots of axes 1 and 3 from DCA ordination of all field margin types. (a) sites: East Anglia (closed squares) and West Midlands (open circles) pilot areas. (b) species: only those with minimum weight of 10 shown for clarity; for species codes see Appendix 5.

Table 2. Total plant cover and cover of (non-crop) dicotyledons, monocotyledons, annuals, perennials, farmland bird food plants, butterfly larva food plants, bumblebee food plants and pernicious weeds for each field margin type and the East Anglia (EA) and West Midlands (WM) pilot areas. Data are backtransformed means with standard errors in parentheses, with ANOVA results for pilot area (pa), option (opt), their interaction (pa × opt); * $P < 0.05$; ** $P < 0.01$;*** $P < 0.001$; ns = not significant. Backtransformed standard errors have two (asymmetrical) values, which are + and – respectively. Option 3B not included in ANOVA or EA summary statistics.

		Option				Pilot area		ANOVA results		
Variable	**3B**[1]	**C**	**3A**	**4C**	**5**	**EA**	**WM**	**pa**	**opt**	**pa × opt**
n	20	39	40	24	33	66	70	$F_{(1,128)}$	$F_{(3,128)}$	$F_{(3,128)}$
plant cover	95.4 (1.36, 1.53)	96.4 (1.46, 1.86)	98.3 (0.67, 0.80)	95.9 (2.00, 2.61)	90.6 (3.43, 4.05)	95.5 (1.44, 1.75)	96.2 (1.09, 1.27)	ns	*	**
dicots	1.9 (1.11, 0.88)	0.4 (0.26, 0.19)	2.2 (0.79, 0.70)	44.1 (7.39, 7.26)	46.0 (5.00, 5.05)	9.3 (2.91, 2.55)	17.1 (3.68, 3.39)	*	**	ns
monocots	0.4 (0.45, 0.28)	1.8 (0.70, 0.61)	3.3 (1.44, 1.19)	41.7 (7.66, 7.46)	21.2 (4.83, 4.46)	6.8 (2.49, 2.08)	15.0 (2.73, 2.61)	*	**	ns
annuals	2.3 (2.37, 1.53)	1.0 (0.64, 0.49)	1.3 (0.70, 0.57)	7.0 (3.98, 3.18)	11.6 (3.75, 3.23)	2.9 (0.94, 0.81)	5.3 (1.83, 1.57)	ns	***	ns
perennials	0.3 (0.27, 0.19)	0.5 (0.35, 0.27)	1.3 (0.63, 0.50)	61.1 (7.53, 7.81)	60.2 (7.76, 8.13)	10.1 (3.75, 3.27)	25.4 (5.39, 4.95)	***	***	ns
bird food	92.5 (1.69, 1.88)	93.4 (2.23, 2.70)	94.3 (1.52, 1.68)	39.3 (4.03, 4.92)	45.9 (4.90, 4.76)	79.4 (4.41, 4.79)	74.0 (3.34, 3.58)	ns	***	***
butterfly food	0.2 (0.24, 0.14)	0.4 (0.25, 0.19)	2.2 (1.11, 0.87)	30.1 (6.60, 6.21)	13.8 (3.55, 3.14)	2.7 (1.25, 0.99)	11.3 (2.38, 2.12)	***	***	ns
bumblebee food	0.6 (0.50, 0.35)	0.1 (0.09, 0.05)	0.2 (0.17, 0.12)	22.0 (4.45, 4.07)	26.4 (4.15, 3.95)	4.7 (1.64, 1.44)	6.7 (1.85, 1.68)	ns	***	ns
weeds	0.7 (0.52, 0.37)	0.4 (0.28, 0.21)	1.1 (0.47, 0.37)	16.1 (3.84, 3.50)	20.4 (3.66, 3.43)	4.3 (1.29, 1.16)	6.7 (1.69, 1.47)	ns	***	ns

[1] East Anglia only.

Table 3. Species richness per 0.25m^2 and numbers of (non-crop) dicotyledons, monocotyledons, annuals, perennials, farmland bird food plants, butterfly larva food plants, bumblebee food plants and pernicious weeds for each field margin type and the East Anglia (EA) and West Midlands (WM) pilot areas. Data are means with standard errors in parentheses, with ANOVA results for pilot area (pa), option (opt), their interaction (pa × opt); * $P < 0.05$; ** $P < 0.01$;*** $P < 0.001$; ns = not significant. Option 3B not included in ANOVA or EA summary statistics.

	Option					**Pilot area**		**ANOVA results**		
Variable	**3B**[1]	**C**	**3A**	**4C**	**5**	**EA**	**WM**	**pa**	**opt**	**pa × opt**
n	20	39	40	24	33	66	70	$F_{(1,128)}$	$F_{(3,128)}$	$F_{(3,128)}$
species richness	6.55 (2.662)	2.98 (1.273)	4.50 (1.995)	7.52 (2.105)	6.96 (3.405)	4.91 (2.873)	5.46 (2.915)	ns	***	**
dicots	4.77 (2.570)	0.95 (0.846)	2.19 (1.532)	4.72 (2.454)	4.48 (2.962)	2.92 (2.383)	2.75 (2.687)	ns	***	***
monocots	0.60 (0.429)	0.69 (0.660)	0.96 (0.916)	2.46 (1.067)	1.63 (1.150)	1.03 (1.212)	1.58 (0.897)	**	***	**
annuals	4.86 (2.056)	2.06 (0.841)	3.10 (1.506)	2.86 (2.430)	2.43 (3.106)	1.97 (1.952)	2.56 (2.254)	ns	ns	***
perennials	0.63 (0.519)	0.36 (0.478)	0.60 (0.782)	3.59 (1.415)	3.43 (1.850)	1.39 (1.884)	2.08 (1.881)	**	***	ns
bird food	3.06 (1.471)	1.65 (0.678)	2.53 (1.216)	2.90 (0.947)	3.18 (1.469)	2.11 (1.023)	2.86 (1.348)	***	***	ns
butterfly food	0.63 (0.500)	0.31 (0.419)	0.73 (0.765)	1.61 (0.660)	1.15 (0.809)	0.56 (0.729)	1.15 (0.785)	***	***	ns
bumblebee food	1.03 (0.844)	0.27 (0.321)	0.47 (0.523)	1.66 (0.879)	1.74 (0.944)	1.01 (0.969)	0.86 (0.924)	ns	***	ns
weeds	0.45 (0.319)	0.24 (0.226)	0.31 (0.324)	1.17 (0.723)	1.02 (0.529)	0.58 (0.591)	0.65 (0.617)	ns	***	ns

[1] East Anglia only.

Butterfly food plants had highest cover (30 %) and number of species (1.6) in Option 4c, followed by Option 5 and Option 3A, and with least in normally cropped headlands (0.5% cover and 0.3 species $0.25m^{-2}$). There were also significant differences between pilot areas, with greater cover and species numbers in West Midlands.

There was a substantial difference in cover of bumblebee food plants in Options 4C and 5 (*c*. 25%) compared to Option 3A and normally cropped headlands (<0.5%). Numbers of bumblebee food plants were also significantly higher in Options 4C and 5 but there were no differences between the two pilot areas.

There was significantly higher cover and number of species of pernicious weeds in Options 4C and 5 compared to Option 3A and normally cropped headlands. Cover ranged from 20% in Option 5 to less than 0.5% in normally cropped headlands. However, there was considerable variation between sites, particularly in Options 4C and 5. There was no significant difference between pilot areas.

Three-quarters of the sites in East Anglia were silty clay loam (Table 4). The remainder were also loams of various types, apart from four sites on clay. Half of the West Midlands sites were sandy loam or sandy silt loam. Sites on sandy and organic or peaty soils were confined to West Midlands. Soil pH was significantly higher in East Anglia (mean 8.1) than West Midlands (6.8) (Table 5). All but one site in East Anglia had pH greater than 8.0. Extractable P did not differ between pilot areas (overall mean of 31 mg l^{-1}). Extractable K was significantly higher in East Anglia, being 202 mg l^{-1} compared to 146 mg l^{-1} in West Midlands. Extractable Mg was substantially higher in West Midlands (mean 105 mg l^{-1}) than East Anglia (mean 48 mg l^{-1}). Variability of extractable P, K and Mg was high between sites, ranges being 6-102, 40-427 and 16-578 mgl^{-1} respectively. No differences were detected between field margin types for any soil properties.

Table 4. Number of sites in each pilot area by soil texture classes.

Texture	East Anglia	West Midlands	Total
Clay loam	4	6	10
Clay	1	-	1
Loamy sand	-	16	16
Organic loamy sand	-	1	1
Organic sandy loam	-	1	1
Peat	-	5	5
Sandy clay loam	2	1	3
Sandy loam	1	23	24
Sandy silt loam	10	12	22
Silty clay	3	-	3
Silty clay loam	63	4	67
Silty loam	2	1	3
Total	86	70	156

Table 5. Soil properties in each pilot area. Extractable P, K and Mg in mg l^{-1}. Data are means with standard errors in parentheses, with ANOVA results for pilot area (pa), option (opt), their interaction (pa × opt); * $P < 0.05$; ** $P < 0.01$;*** $P < 0.001$; ns = not significant.

	East Anglia	**West Midlands**	**All**	**pa**	**opt**	**pa × opt**
n	66	70	136	$F_{(1,128)}$	$F_{(3,128)}$	$F_{(3,128)}$
pH	8.11 (0.228)	6.77 (0.603)	7.42 (0.817)	***	ns	ns
P	29.1 (15.98)	32.7 (18.99)	31.0 (17.62)	ns	ns	ns
K	202.2 (71.72)	146.0 (79.18)	173.3 (80.49)	***	ns	ns
Mg	48.2 (21.15)	105.2 (93.67)	77.8 (74.17)	***	ns	ns

Conservation headlands and normally cropped headlands

The species composition of Options 3A and 3B and normally cropped headlands did not differ markedly, the sites not being obviously separated in plots from the PCA (Figure 3a). However, there were differences in species composition between the two pilot areas. The majority of sites from East Anglia were separated from the West Midlands sites along the first two PCA axes, although some sites (of all three field margin types) from East Anglia did occupy the West Midlands ordination space (Figure 3b).

The main source of variation was in the abundance of a wide range of (mostly annual) species in the sites. Sites with high values on axis 1 tended to have a wide range of species and those with low values had fewer species and with lower frequencies (Figure 3c). Sites with most species were Option 3B; no normally cropped headlands were of this type. However, there was considerable variation among sites of each field margin type. There was also a distinctive group of species that were mainly perennials of eutrophic conditions, such as *Rumex obtusifolius*, *Urtica dioica* and *Elytrigia repens*, but relatively few sites were associated with this group. Wheat and barley sites were separated along the second axis.

Option 3A sites had significantly greater cover and species richness of annuals and dicotyledons than normally cropped headlands (Table 6). Total species richness was also higher in Option 3A sites. However, the differences were relatively small and mean cover values for Option 3A sites were less than 5% and total species richness (0.25 m^{-2}) only *c*. 4.5. Crop cover was slightly higher in normally cropped headlands. No differences were detected for monocotyledons, perennials or pernicious weeds. However, variation in monocotyledon cover and richness was high among Option 3A sites and perennial cover was approaching zero in most normally cropped headlands. Option 3A sites also had more bird food plant species than normally cropped headlands and greater cover and number of species of butterfly larva food plants. In contrast, there was no significant difference between the two field margin types in either the cover or number of bumblebee food plant species. No differences were detected between the two headland types in any soil properties.

Fig. 3(a)

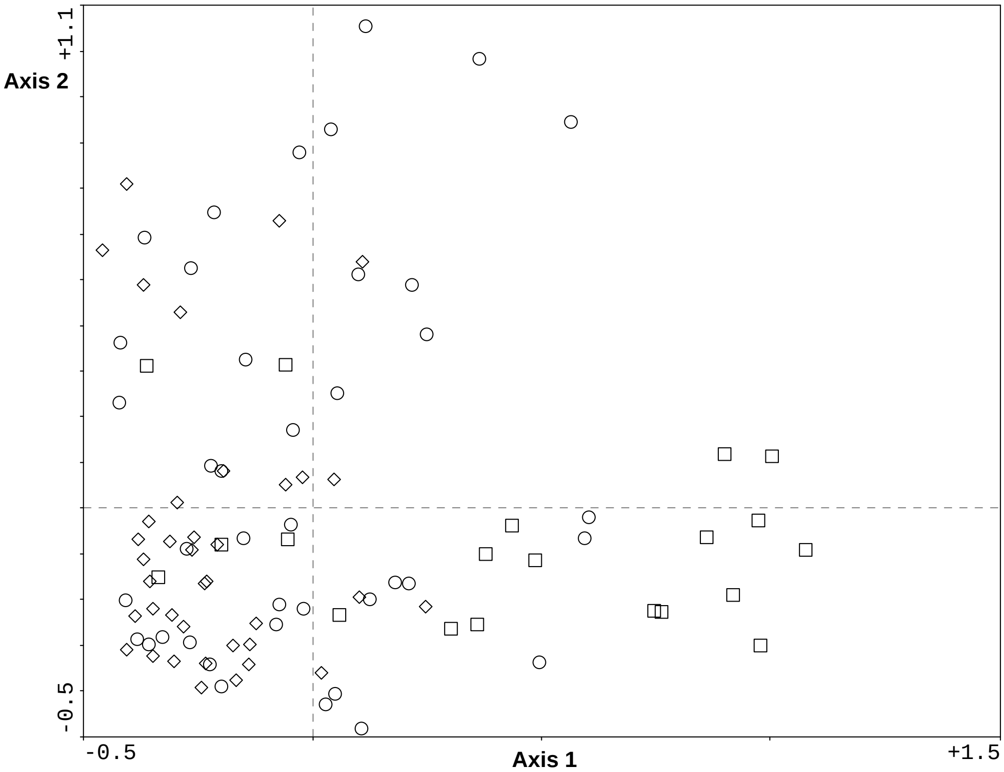
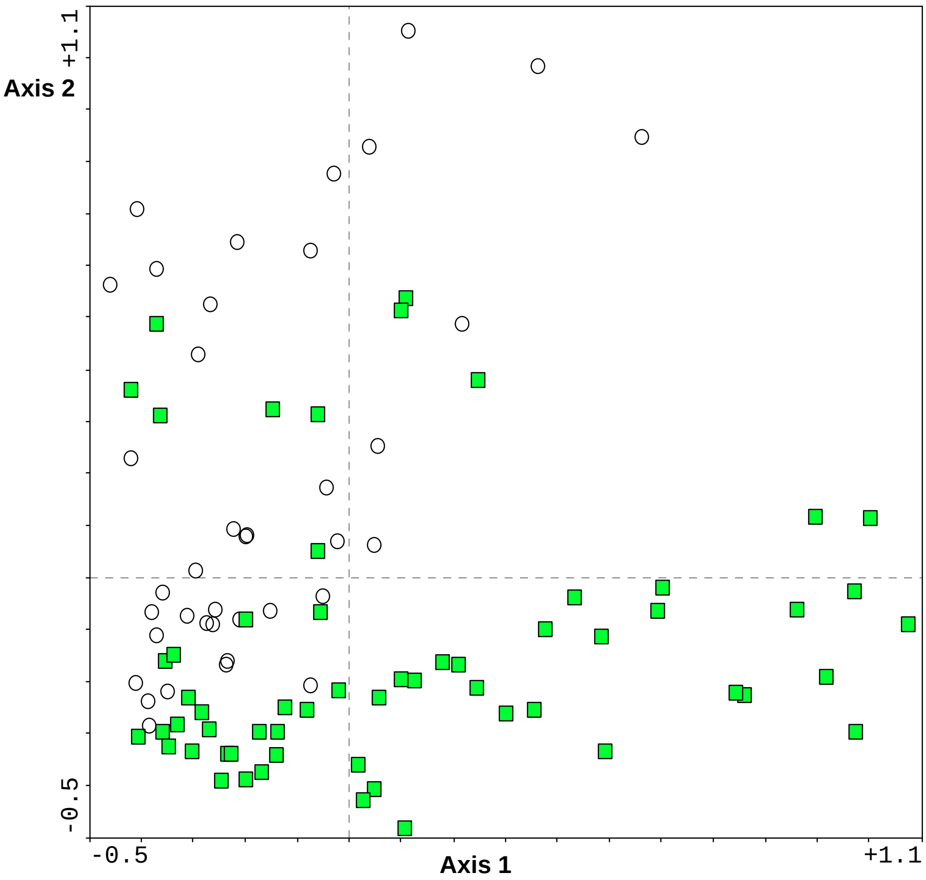


Fig 3(b)



(c)

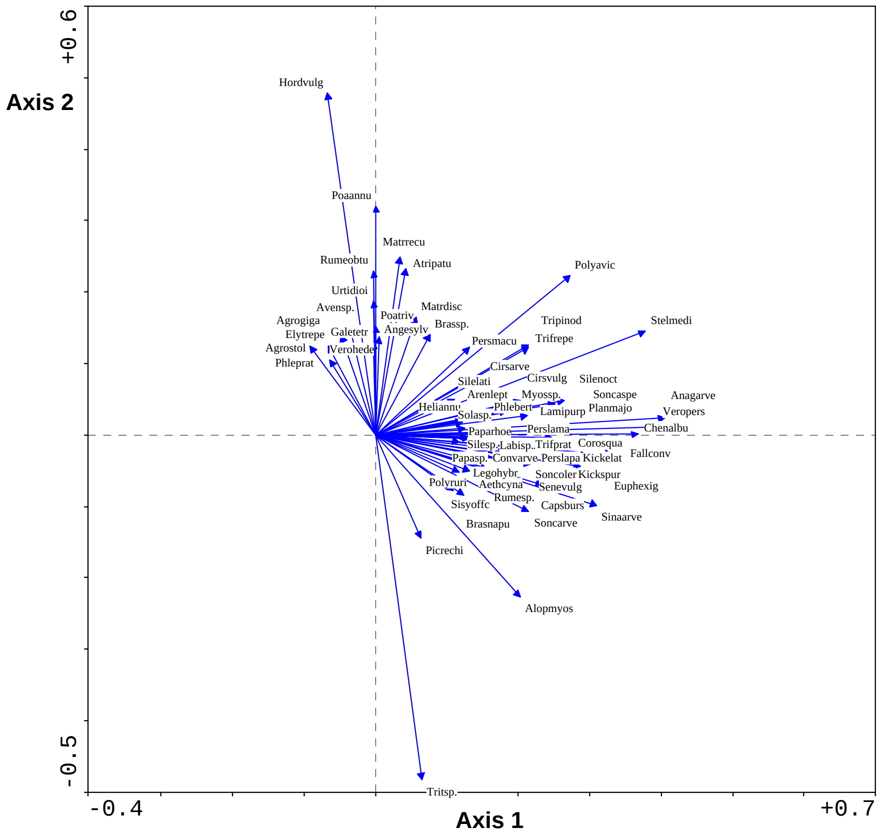


Figure 3. Scatter plots of axes 1 and 2 from PCA of conservation headlands and normally cropped headlands. (a) sites: Options 3A (open circles), 3B (open squares) and normally cropped headlands (open diamonds). (b) sites: East Anglia (closed squares) and West Midlands (open circles) pilot areas. (c) species: only those with minimum fit of 5 shown for clarity; for species codes see Appendix 5.

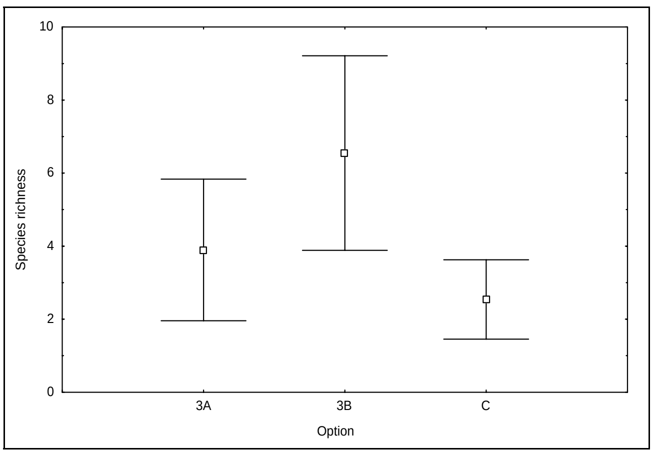


Figure 4. Mean species richness (with standard deviations) in Option 3A and 3B and normally cropped headlands in East Anglia (*n* = 20, 20 and 19 sites respectively).

Option 3B sites were only present on a small number of farms, and 75% of the sample had to be drawn from only two farms. Although the confounding effect of farm precluded formal statistical analyses, some informative trends were evident in the data. Comparison of all Option 3A, 3B and normally cropped sites in East Anglia showed a consistent trend of decreasing species richness from 3B to 3A and to normally cropped headlands (Figure 4). This was evident for all species groups including bird, butterfly larva and bumblebee food plants and pernicious weeds. Cover of bumblebee food plants showed the same trend and cover of dicotyledons appeared to be higher in Option 3B sites than the others.

One farm with eight Option 3B sites was organic so none of the permitted herbicides had been applied. In comparison with other Option 3B sites, these tended to have higher species richness. However, species richness at the remaining Option 3B sites still tended to be higher than at Option 3A sites.

Table 6. Paired comparisons within farms of Option 3A and normally cropped headlands (C) of total cover and number of species per $0.25m^2$ of all species and of crop, monocotyledons, dicotyledons, annuals, perennials, farmland bird food plants, butterfly larva food plants, bumblebee food plants and pernicious weeds. Data are means with standard errors in parentheses and paired *t*-test results; * $P < 0.05$; ** $P < 0.01$;*** $P < 0.001$; ns = not significant (n = 19 sites). Backtransformed standard errors have two (asymmetrical) values, which are + and – respectively.

Variable	**Cover** 3A	C		**Numbers** 3A	C	
All species	99.0 (0.57, 0.79)	98.9 (0.63, 0.91)	ns	4.59 (2.071)	3.02 (1.139)	***
Crop	89.1 (2.69, 3.02)	95.1 (1.79, 2.17)	*	-	-	-
Dicotyledons	2.2 (0.82, 0.69)	0.3 (0.31, 0.20)	**	2.17 (1.625)	0.99 (0.957)	**
Monocotyledons	3.8 (2.10, 1.66)	1.8 (0.91, 0.71)	ns	1.05 (1.005)	0.71 (0.622)	ns
Annuals	3.6 (1.41, 1.21)	0.7 (0.60, 0.41)	*	2.17 (1.639)	1.19 (0.903)	**
Perennials	1.1 (0.71, 0.54)	0.7 (0.56, 0.40)	ns	0.58 (0.590)	0.36 (0.381)	ns
Bird food	95.8 (1.26, 1.47)	97.3 (1.17, 1.53)	ns	2.63 (1.348)	1.74 (0.658)	**
Butterfly food	2.7 (1.62, 1.25)	0.2 (0.29, 0.18)	**	0.72 (0.703)	0.35 (0.492)	*
Bumblebee food	0.1 (0.20, 0.11)	0.4 (0.12, 0.10)	ns	0.31 (0.335)	0.88 (1.508)	ns
Weeds	1.2 (0.69, 0.55)	0.5 (0.36, 0.28)	ns	0.33 (0.348)	0.31 (0.273)	ns

Herbicides permitted within the scheme prescriptions had been applied at eighteen of the 32 farms from which Option 3A or 3B sites had been sampled. Amidosulfuron (post-emergence herbicide for species such as *Galium aparine*) was used most frequently (Table 7).

In the sub-sample used for the paired comparisons with normally cropped headlands, there tended to be higher cover and species richness of perennials (Figure 5a) at Option 3A sites where no herbicide had been applied compared to Option 3A sites with herbicide application and normally cropped headlands. In addition, the number of bird food plant species tended to be highest in Option 3A sites without herbicide and lowest in normally cropped headlands (Figure 5b). The cover of bumblebee food plants also tended to be higher in Option 3A sites without herbicide.

Table 7. Herbicides applied at Option 3A or 3B sites (*n* = no. of farms).

Product	***n***	**Active ingredient**	**Application**
Eagle	12	Amidosulfuron (sulfonylurea)	Post-emergence for *G. aparine* etc.
Avadex	4	Tri-allate (thiocarbamate)	Soil acting for grass weeds
Topik	4	Clodinafop-propargyl	Annual grass weeds in cereals
Pursuit	1	Amidosulfuron (sulfonylurea)	Post-emergence for *G. aparine* etc.
Cheetah	1	Fenoxaprop-P-ethyl (phenoxypropionic acid)	For use in wheat
Panther	1	Diflufenican & isoproturon	Contact & residual herbicide
IPU	1	Isoproturon	Residual urea herbicide
Starane 2	1	Fluroxypyr (aryloxyalkanoic acid)	Post-emergence dicots
Unknown	5		
None	12		

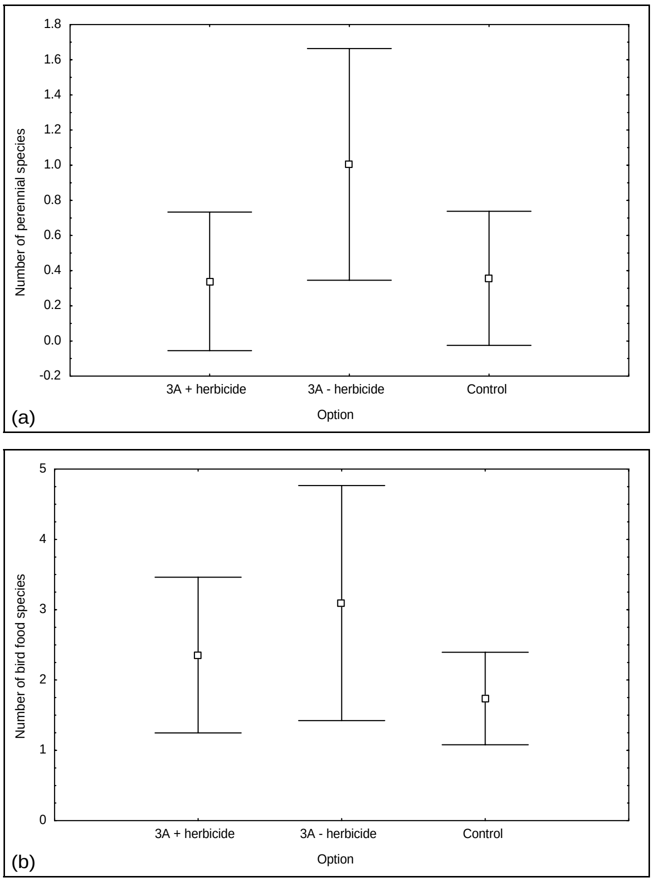


Figure 5. Numbers of (a) perennial and (b) bird food plant species at Option 3A sites where herbicide had been applied, where no herbicide had been applied and normally cropped headlands. Data are means with standard deviations; *n* = 12, 7 and 19 respectively.

Uncropped wildlife strips in 1999 and 2003

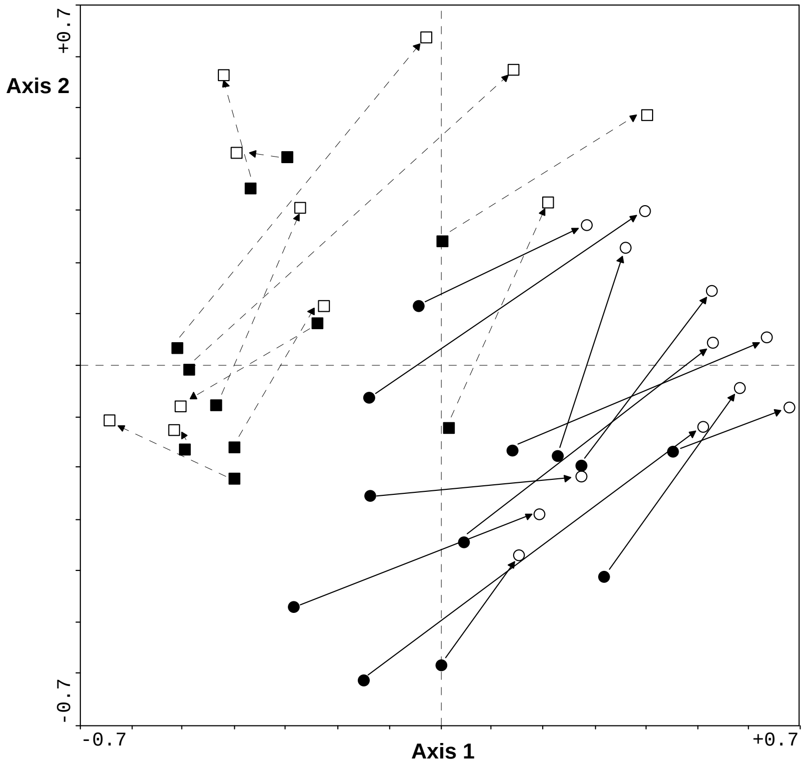
The species composition of all sites in West Midlands underwent a similar transition from 1999 to 2003. This was evident from the PCA plot of axes 1 and 2 in which the sites had similar trajectories over time (Figure 6a). Six (out of 11) sites from East Anglia also had this trajectory. Comparison with the species plot of axes 1 and 2 showed that the change was primarily a shift from communities comprised mainly of annuals to those where perennials were much more prominent (Figure 6b). There were no clear differences in soil properties or cultivation regime that might explain why five East Anglian sites did not follow this trend. Pilot area also accounted for some variation in species composition, with only one site from East Anglia in 1999 occupying the same ordination space as the West Midlands sites.

Sites from East Anglia also showed a consistent trajectory against axes 2 and 3, towards species associated with grassland or hedgebanks, most of which were perennials (Figure 7a). Examples were the perennials *Knautia arvensis*, *Convolvulus arvensis* and *Glechoma hederacea* as well as *Bromus* sp. (Figure 7b). All but two sites showed this change in species composition. There was some tendency for West Midlands sites also to move in this direction, but the pattern was less consistent.

These patterns of change were confirmed by the ANOVA results. There were significant increases in *Cirsium arvense* ($F_{(1,21)} = 19.2$, $P < 0.001$) and *C. vulgare* ($F_{(1,21)} = 7.2$, $P < 0.05$) and a decline in *Stellaria media* ($F_{(1,21)} = 6.7$, $P < 0.05$). Total plant cover and cover of perennials increased significantly between 1999 and 2003 (the latter from 12 % to 60%), whereas annual cover declined (from 53% to 22%) (Table 8). Cover of crop volunteers also declined although it was only at a low level in 1999. Numbers of perennials also increased from *c*. 1.5 to 3.6 species 0.25 m^{-2}. Monocotyledon numbers also increased and those of volunteers declined. A significant interaction between year and pilot area indicated a decline in numbers of annual species primarily in West Midlands (Figure 8a). Dicotyledon richness was similar in both pilot areas in 1999 but it increased in East Anglia and decreased in West Midlands, as denoted by the significant interaction (Figure 8b). Total species richness showed the same effect. Annual cover and species richness were significantly higher in East Anglia, whereas perennial cover and species richness were higher in West Midlands.

Cover and numbers of bird food plant species did not change between 1999 and 2003, but were higher in West Midlands than East Anglia. Bird food plant species with highest cover values were *Cirsium arvense* and *Holcus lanatus*, which together accounted for about one third of the cover of all bird food plant species (25 species in total). However, the cover and numbers of butterfly larva food plants increased (cover from 13% to 28% and numbers from 1.1 to 1.6 species 0.25 m^{-2}); numbers were also higher West Midlands. *Arrhenatherum elatius*, *Holcus lanatus* and *Dactylis glomerata* were the butterfly larva food plants with highest cover values (eight species in total). No changes were detected in the cover or numbers of bumblebee food plant species, although species numbers showed an increasing trend just outside the limits of statistical significance ($P = 0.07$). Numbers of weed species also increased from 0.6 to 1.2, but no change in their cover was detected.

(a)



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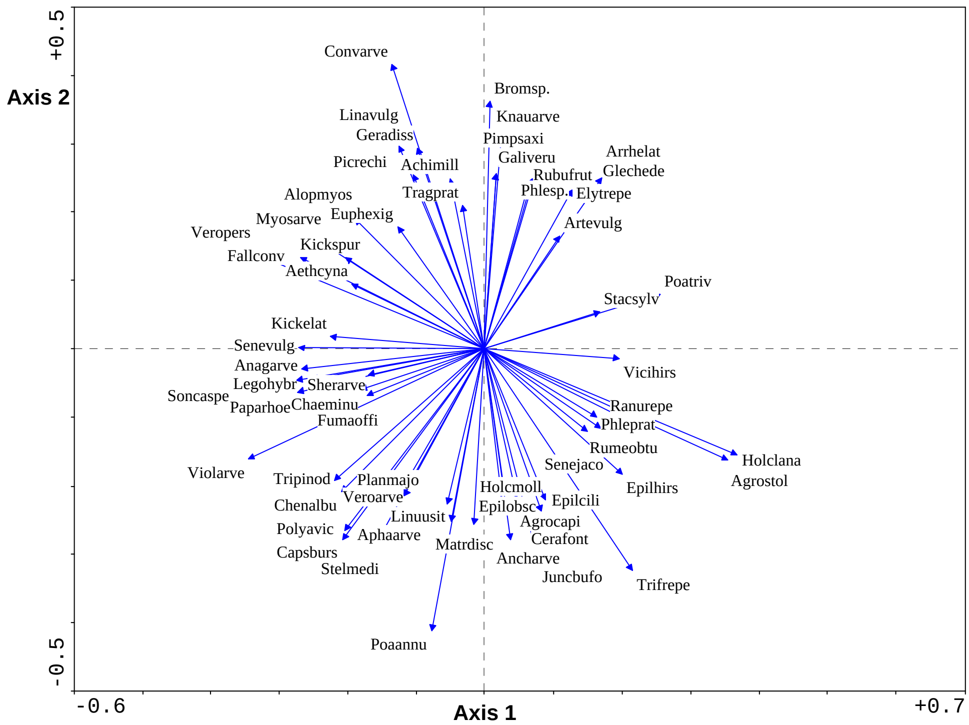
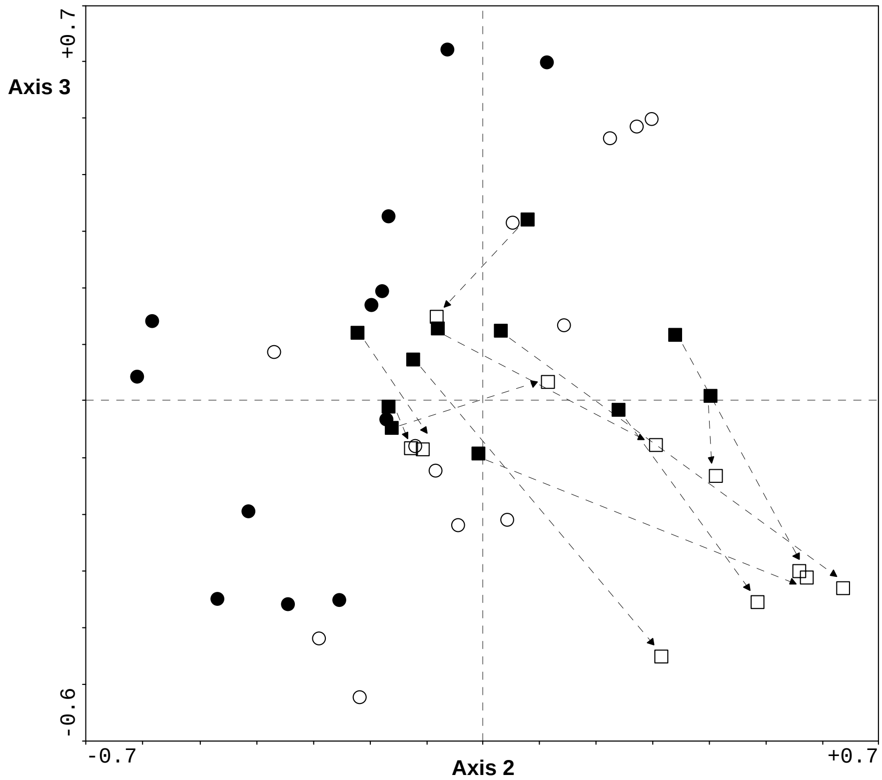


Figure 6. Scatter plot along axes 1and 2 from PCA of Option 4C sites in 1999 and 2003. (a) sites: 1999 (closed symbols) and 2003 (open symbols) from East Anglia (squares) and West Midlands (circles). Trajectories of individual sites shown by dotted arrows (East Anglia) and solid arrows (West Midlands). (b) species: only those with minimum fit of 13 shown for clarity; for species codes see Appendix 5.

(a)



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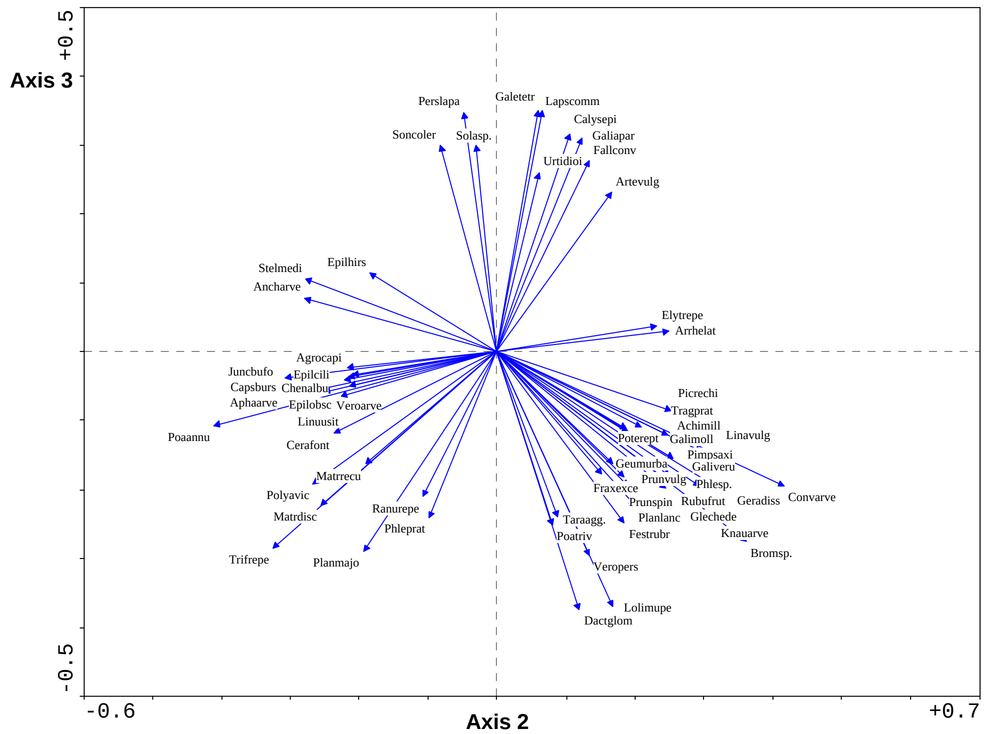


Figure 7. Scatter plot along axes 2 and 3 from PCA of Option 4C sites in 1999 and 2003. (a) sites: 1999 (closed symbols) and 2003 (open symbols) from East Anglia (squares) and West Midlands (circles). Trajectories of individual sites from East Anglia shown by dotted arrows. (b) species: only those with minimum fit of 13 shown for clarity; for species codes see Appendix 5.

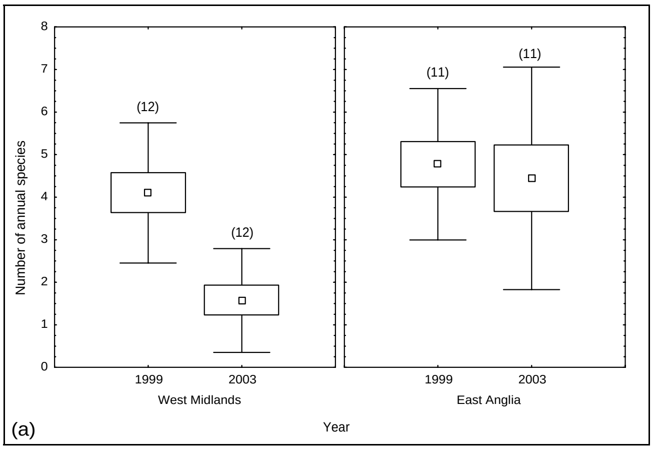
Table 8. Cover and numbers of species per $0.25m^2$ of all species and of volunteers, dicotyledons, monocotyledons, annuals, perennials, farmland bird food plants, butterfly larva food plants, bumblebee food plants and pernicious weeds in Option 4C sites in 1999 and 2003. Data are means with standard errors in parentheses. Cover data are backtransformed; backtransformed standard errors have two (asymmetrical) values, which are + and – respectively. ANOVA results are for year (y), pilot area (pa) and their interaction (y × pa); * $P < 0.05$; ** $P < 0.01$;*** $P < 0.001$; ns = not significant (n = 23).

	1999	**2003**	**y**	**pa**	**y x pa**
Cover					
All species	83.7 (4.57, 5.16)	95.5 (2.15, 2.18)	*	ns	ns
Volunteers	0.7 (0.54, 0.40)	0.00 (0.06, 0.02)	*	ns	ns
Dicotyledons	36.5 (7.05, 6.68)	46.5 (7.29, 7.22)	ns	ns	ns
Monocotyledons	32.9 (6.43, 6.12)	38.9 (7.31, 7.16)	ns	ns	ns
Annuals	52.8 (7.04, 7.09)	22.1 (6.69, 6.03)	**	*	ns
Perennials	12.1 (4.33, 3.75)	60.0 (7.77, 8.13)	***	**	ns
Bird food	32.8 (6.52, 6.30)	38.4 (5.11, 5.08)	ns	*	ns
Butterfly food	12.7 (3.89, 3.49)	28.0 (6.39, 5.97)	*	ns	ns
Bumblebee food	15.1 (5.99, 5.08)	23.2 (4.52, 4.23)	ns	ns	ns
Weeds	9.0 (3.32, 2.79)	16.6 (3.96, 3.68)	ns	ns	ns
Numbers					
All species	7.46 (1.957)	7.64 (2.065)	ns	ns	**
Volunteers	0.26 (0.343)	0.03 (0.067)	**	ns	ns
Dicotyledons	4.97 (1.805)	4.88 (2.384)	ns	*	**
Monocotyledons	1.68 (0.970)	2.41 (1.064)	**	ns	ns
Annuals	4.42 (1.707)	2.94 (2.449)	**	*	*
Perennials	1.54 (0.949)	3.59 (1.447)	***	*	ns
Bird food	2.84 (1.088)	2.95 (0.938)	ns	*	ns
Butterfly food	1.11 (0.377)	1.59 (0.450)	**	**	ns
Bumblebee food	1.36 (0.742)	1.70 (0.504)	ns	ns	ns
Weeds	0.63 (0.385)	1.21 (0.718)	**	ns	ns

The same cultivation regime tended to have been applied at all sites on a farm. At most farms the sites were cultivated annually, but at one the cultivation was less often than prescribed by the scheme (Table 9). Sites were cultivated in the spring (January to March) at the majority of farms. Autumn cultivations tended to be in October. Depth of cultivations ranged from 2 – 9 cm.

Trends in the data suggested that cultivation depth might have some effect on the vegetation. Numbers of dicotyledon species tended to be higher with deep cultivations in both pilot areas and, in West Midlands, monocotyledon cover appeared to be lower. Also in West Midlands, annual species richness and cover also tended to be higher with deeper cultivations. These trends should be interpreted with caution, because of the confounding effects of farm and cultivation type. No pattern was evident in relation to cultivation timing.

Herbicide use was recorded at only one farm, being glyphosate application to control *Cirsium* spp. Cutting to control *Avena fatua* or *Cirsium* spp. was done at one farm each.



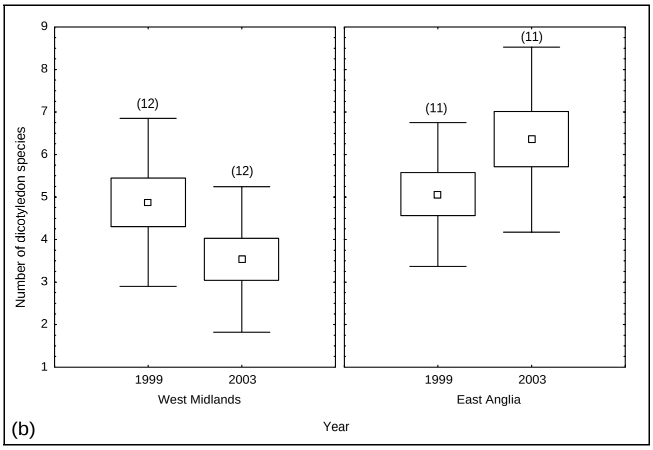


Figure 8. Interaction between year and pilot area at Option 4C sites for numbers of (a) annual and (b) dicotyledon species. Data are means, standard errors (boxes) and standard deviations (bars); data labels are *n*.

Table 9. Number of Option 4C sites by cultivation frequency, timing and depth.

Frequency		**Timing**		**Depth (cm)**	
Annual	11	Spring	10	2-3	3
Biennial	2	Autumn	3	4-6	5
Less frequent	1	Summer[1]	2	6-9	7
Unknown	3	Unknown	2	Unknown	2

[1] July or 'late summer/early autumn'

No change in any soil properties was detected between 1999 and 2003. Differences between pilot areas were consistent with those found for all margin types. Soil pH ($F_{(1,21)}$ = 48.7, $P < 0.001$) and extractable K ($F_{(1,21)}$ = 5.5, $P < 0.05$) were higher in East Anglia and extractable Mg ($F_{(1,21)}$ = 5.2, $P < 0.05$) was higher in West Midlands (Table 10). No interaction terms (year x pilot area) were significant.

In the RDA of 2003 species and soils data, only soil pH (F = 3.12, $P < 0.01$) and peat texture (F = 1.97, $P < 0.05$) were significantly related to species. There were only three sites with peaty soil, but examples of species associated with this were *Galeopsis tetrahit*, *Phalaris arundinacea*, *Phragmites australis* and *Glyceria maxima*, reflecting high prevailing soil moisture content. Examples of species associated with high soil pH were *Sonchus asper* and *Veronica persica*, whereas *Bromus hordeaceus* and *Arctium minus* were associated with low pH values.

Table 10. Soil properties at Option 4C sites in 1999 and 2003 (n = 23).

	1999		2003	
	EA	**WM**	**EA**	**WM**
pH	7.9 (0.32)	6.7 (0.54)	8.1 (0.22)	6.7 (0.69)
P	31 (22.1)	27 (13.8)	29 (19.9)	26 (14.4)
K	230 (76.2)	154 (84.3)	227 (73.8)	171 (79.8)
Mg	59 (38.1)	107 (69.2)	56 (29.6)	102 (55.3)

Wildlife seed mixtures in 1999 and 2003

A range of cover types had been sown in 2003, but about half of the sites had a mixture of more than one cover type. Brassicas were most commonly sown (14 sites), with cereals (7), maize (6), buckwheat (4), borage (3), grass/legumes (3), teasel (2) and *Phacelia* (1) also sown. However, at almost one third of sites (10) it was not clear what had been sown because the cover was predominantly grasses or naturally regenerated species or cover had not yet established following cultivation.

Table 11. Cover and numbers of species per $0.25m^2$ of all species, volunteers, dicotyledons, monocotyledons, annuals, perennials, farmland bird food plants, butterfly larva food plants, bumblebee food plants and pernicious weeds in Option 5 sites in 1999 and 2003. Data are means with standard errors in parentheses. Cover data are backtransformed; backtransformed standard errors have two (asymmetrical) values, which are + and – respectively. ANOVA results are for year (y), pilot area (pa) and their interaction (y × pa); * $P < 0.05$; ** $P < 0.01$;*** $P < 0.001$; ns = not significant (n = 32).

	1999	**2003**	**y**	**pa**	**y x pa**
Cover					
All species	86.2 (2.52, 2.80)	91.1 (3.40, 4.11)	ns	*	ns
Volunteers	15.0 (4.92, 4.33)	2.9 (1.78, 1.34)	**	ns	ns
Dicotyledons	31.0 (6.83, 6.35)	46.0 (5.30, 5.15)	ns	ns	ns
Monocotyledons	21.0 (4.82, 4.44)	21.9 (4.98, 4.60)	ns	ns	ns
Annuals	47.0 (6.69, 6.64)	12.8 (4.87, 4.24)	***	ns	ns
Perennials	13.8 (5.32, 4.63)	61.6 (7.79, 8.20)	***	ns	ns
Bird food	50.0 (4.99, 4.99)	45.9 (5.00, 4.95)	ns	ns	ns
Butterfly food	11.6 (4.32, 3.66)	14.7 (3.63, 3.23)	ns	**	*
Bumblebee food	10.1 (3.82, 3.32)	26.3 (4.24, 4.03)	**	ns	ns
Weeds	4.2 (1.85, 1.49)	20.4 (3.74, 3.58)	***	ns	ns
Numbers					
All species	7.71 (2.878)	6.96 (2.459)	ns	ns	ns
Volunteers	1.06 (0.875)	0.50 (0.603)	**	ns	ns
Dicotyledons	4.73 (2.420)	4.45 (3.003)	ns	ns	ns
Monocotyledons	1.59 (0.856)	1.67 (1.147)	ns	ns	ns
Annuals	4.34 (2.468)	2.39 (3.143)	***	ns	ns
Perennials	1.56 (1.338)	3.48 (1.859)	***	ns	ns
Bird food	3.53 (1.494)	3.17 (1.491)	ns	ns	ns
Butterfly food	1.08 (0.801)	1.18 (0.796)	ns	*	*
Bumblebee food	1.33 (0.893)	1.71 (0.940)	ns	ns	ns
Weeds	0.61 (0.444)	1.01 (0.533)	**	ns	**

Annual cover and species richness declined significantly between 1999 and 2003, whereas cover and numbers of perennial species increased (Table 11). The magnitude of change was similar to that in Option 4C sites. Cover and numbers of volunteers also declined, although these were already at low levels in 1999. No change in the abundance of dicotyledons or monocotyledons was detected. However, variation was high between sites in the abundance of different species groups. Total plant cover was greater in West Midlands than East Anglia. Changes in the frequency of individual species reflected these patterns. *Cirsium arvense* ($F_{(1,30)} = 30.5$, $P < 0.001$) and *C. vulgare* ($F_{(1,30)} = 5.1$, $P < 0.05$) increased, whereas *Stellaria media* ($F_{(1,30)} = 9.0$, $P < 0.01$), *Polygonum aviculare* ($F_{(1,30)} = 6.0$, $P < 0.05$) and *Alopecurus myosuroides* decreased (the latter was present in East Anglia only; year x pilot area interaction $F_{(1,30)} = 16.6$, $P < 0.001$). *Rumex obtusifolius* also increased, but in West Midlands only (interaction $F_{(1,30)} = 5.5$, $P < 0.05$).

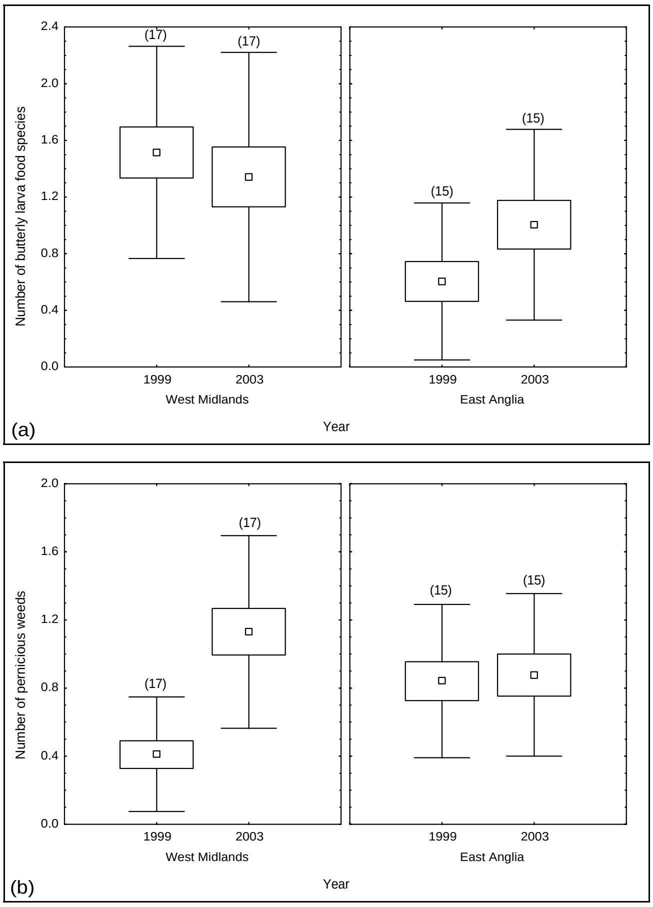


Figure 9. Interaction between year and pilot area at Option 5 sites for numbers of (a) butterfly larva food plants and (b) pernicious weeds. Data are means, standard errors (boxes) and standard deviations (bars); data labels are *n*.

There were more cover and numbers of species (Figure 9a) of butterfly larva food plants in West Midlands than East Anglia. In addition, the significant interactions between year and pilot area were due to these increasing in East Anglia between 1999 and 2003. *Elytrigia repens* accounted for almost one third of the cover of butterfly larva food plants. In contrast, bird food plant species did not vary significantly between pilot areas or over time, whereas cover of bumblebee food plants increased from 10% to 36%. *Cirsium arvense* was the bird food plant species with greatest cover, the highest value being 47% at one site. Cover of pernicious weeds increased in both study areas; the number of species also increased but this was primarily in West Midlands, as denoted by the significant interaction (Figure 9b).

Of the seventeen farms from which Option 5 sites had been sampled, about half had new cover sown shortly before the 2003 survey. The effect of recent sowing would therefore mask any effects of cutting regimes at these farms. Of the remainder, sites were cut annually on six farms and every other year on two farms. Cutting was usually done in February or March at four farms and in summer or autumn at the remainder. There was one instance of cutting in July under a derogation for thistle control. In most cases, cuttings were left *in situ* rather than being removed.

Trends in the data suggested that annuals and dicotyledons were more frequent at sites cut in the spring, although variation between these sites was high. As expected, there tended to be more perennial and monocotyledon species and total plant cover at sites sown less often than annually.

No change was detected in any soil properties between 1999 and 2003. Differences between pilot areas showed the same patterns as Option 4C sites and all field margin types collectively (Table 12). Soil pH ($F_{(1,29)}$ = 53.6, P < 0.001) and extractable K ($F_{(1,29)}$ = 4.7, P < 0.05) were higher in East Anglia and extractable Mg ($F_{(1,29)}$ = 7.8, P < 0.01) was higher in West Midlands. There were no significant interactions.

Table 12. Soil properties at Option 5 sites in 1999 and 2003 (n = 31).

	1999		**2003**	
	EA	**WM**	**EA**	**WM**
pH	8.0 (0.26)	6.8 (0.73)	8.1 (0.22)	6.8 (0.60)
P	22 (12.8)	34 (19.4)	25 (20.3)	33 (16.9)
K	215 (79.8)	170 (79.3)	220 (86.8)	154 (82.9)
Mg	59 (25.1)	138 (106.0)	54 (26.6)	126 (92.8)

Rare arable plants

Seven rare arable plant species were recorded from 20 sites, there being 26 records in total, all of which were in the East Anglia pilot area (Table 13). This included two records of *Iberis amara*, which although not on the target list, has been included as a notable record. Most records were from Option 3B sites, but these were all from one farm under organic management, where every record bar one was of *Silene noctiflora*. Rare species were recorded from nearly half of the Option 4C and 3B sites and from nearly a quarter of all sites sampled. There was only one rare species record from an Option 5 site but two from normally cropped headlands. Six were incidental records from sites near to those sampled in the main survey. These sites included grass verges, arable fields and a sterile strip between an Option 4C and the crop.

Summary data for each species recorded are presented in Appendix 6, including information on soils and plant communities. Autecological data for rare arable plant species are often lacking and these data will be useful to aid the conservation management of these species.

The population size of rare species ranged from one individual to between 100 and 1000, with most in the range of 2-20 individuals (Figure 10). No species apart from *Silene noctiflora* had populations greater than 11-20.

Table 13. Number of sites (percentage of the 2003 sample in parentheses) with rare plant species records in each field margin type in East Anglia. C = normally cropped headlands; other = casual records from other sites.

n	**3A** 20	**3B** 20	**4C** 11	**5** 15	**C** 19	**Total** 85	**Other**	**Overall total**
Bromus secalinus					1	1	1	2
Fumaria parviflora			1			1		1
Iberis amara			1			1	1	2
Papaver hybridum	1		1			2	3	5
Polygonum rurivagum		1	1			2		2
Scandix pecten-veneris			1			1		1
Silene noctiflora	2	8		1	1	12	1	13
Total	3 (15)	9 (45)	5 (45)	1 (7)	2 (11)	20 (24)	6	26

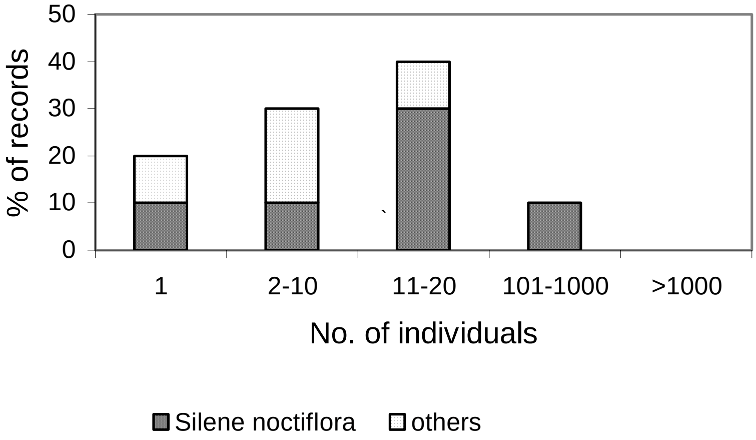


Figure 10. Frequency distribution of population sizes of rare plants recorded from survey sites in East Anglia (*n* = 20 records).

Rare species were recorded from similar numbers of Option 3A, 3B and 4C sites in 1999 and 2003. However, a greater percentage of Option 4C sites had records in 2003 as fewer were surveyed than in 1999 when records were from 26% of sites. Fewer Option 5 sites had records in 2003 compared to 1999 (5 records from 18 sites). However, at Option 4C and 5 sites that were visited in both surveys, there were eight rare plant records (four at each option) in 1999 that were not made again in 2003 (Table 14). Only four records were made in both surveys but for three of these (all at Option 4C sites) the population had declined substantially in 2003. On the other hand, two rare species were recorded in Option 4C in 2003 that had not been found in 1999.

There was no consistent link between changing population size and the varying trends noted above in the plant species composition of Option 4C sites.

Table 14. Population sizes of rare species at Option 4C and 5 sites with records in 1999 or 2003.

Species	Option	1999	2003
Fumaria parviflora	4C	101-1000	1
Iberis amara	4C	0	11-100
Papaver argemone	4C	2-10	0
Papaver argemone	5	1	0
Papaver hybridum	4C	0	11-100
Papaver hybridum	5	0	2-10[1]
Papaver hybridum	5	11-100	0
Polygonum rurivagum	4C	11-100	2-10
Scandix pecten-veneris	4C	101-1000	2-10
Silene gallica	4C	2-10	0
Silene noctiflora	4C	11-100	0
Silene noctiflora	4C	11-100	0
Silene noctiflora	5	11-100	11-100
Silene noctiflora	5	11-100	0
Silene noctiflora	5	11-100	0

[1]Present in adjacent field boundary but not in sampled margin

A comparison of mean values within each farm of sites containing rare species with the normally cropped sites on these farms (excluding normally cropped sites with rare species) showed that soil extractable K was significantly lower at sites with rare species than the normally cropped headlands ($F_{(1,17)} = 5.18$, $P < 0.05$). The same trend was evident for soil extractable P, but there was no significant difference. *Bromus secalinus* was recorded from a site with fairly high level of extractable P (47 mg l^{-1}). *Scandix pecten-veneris* was in a site with relatively low pH (7.2) compared to the whole sample from East Anglia.

Rare species were recorded from seven different NVC communities (Table 15). Eight records were from the OV15a sub-community, which is an annual community dominated by small species, typically found in cereal crops on base-rich soils in south-east Britain (Rodwell, 2000). A characteristic is the presence of *Kickxia* spp. and *Euphorbia exigua*. Others with several records were OV16, which is found on light, well-drained calcareous soils and is characterised by the presence of *Silene noctiflora*, and OV8, which is a weed community of heavily textured and fertile loams and clays and characterised by *Alopecurus myosuroides*. The most species-rich communities had more than 20 species per 4 m^2, which were the loci of *Fumaria parviflora* and *Iberis amara* in Option 4C sites (both OV15a community). In contrast, normally cropped headlands and Option 3A sites with rare species had fewer than ten species per 4 m^2.

The most frequent associate species (i.e. those that tended to occur at rare species loci) are also nationally common and widespread (Table 16). Only *Silene noctiflora*, *Papaver hybridum* and *Polygonum rurivagum* had more than one record and the latter pair only two records apiece so the relationships are only tentative. However, *Papaver rhoeas* tended to occur more with *Papaver hybridum* than the other species, whereas *Alopecurus myosuroides* tended to occur with *Polygonum rurivagum*. Other species with a more restricted national distribution that occurred at three or more rare species loci included *Euphorbia exigua* (6 loci), *Persicaria lapathifolia* (5), *Kickxia spuria* (5), *Legousia hybrida* (5), *Sherardia arvensis* (4), *Fumaria officinalis* (3), *Persicaria maculosa* (3), *Chaenorhinum minus* (3), *Kickxia elatine* (3) and *Descurainia sophia* (3).

Table 15. NVC communities in which each rare species locus was recorded. Two communities are allocated to loci if co-efficients are closely similar. Opt. = option; C = normally cropped sites; Coef. = co-efficients from SIMIL analysis.

Species	Opt.	Code	Community (sub-community)	Coef.
Bromus secalinus	C	OV8	*Veronica persica – Alopecurus myosuroides*	0.281
Fumaria parviflora	4C	OV15a	*Anagallis arvensis – Veronica persica* (*Stellaria media – Convolvulus arvensis*)	0.350
Iberis amara	4C	OV15a	*Anagallis arvensis – Veronica persica* (*Stellaria media – Convolvulus arvensis*)	0.423
Papaver hybridum	3A	OV16	*Papaver rhoeas – Silene noctiflora*	0.279
Papaver hybridum	4C	OV15a	*Anagallis arvensis – Veronica persica* (*Stellaria media – Convolvulus arvensis*)	0.425
Polygonum rurivagum	3B	OV15a	*Anagallis arvensis – Veronica persica* (*Stellaria media – Convolvulus arvensis*)	0.403
Polygonum rurivagum	4C	OV10b	*Poa annua – Senecio vulgaris* (*Polygonum aviculare – Matricaria perforata*)	0.426
Scandix pecten-veneris	4C	OV8	*Veronica persica – Alopecurus myosuroides*	0.397
Silene noctiflora	3A	OV16	*Papaver rhoeas – Silene noctiflora*	0.279
Silene noctiflora	3A	OV16	*Papaver rhoeas – Silene noctiflora*	0.208
Silene noctiflora	3B	OV15a/ OV16	*Anagallis arvensis – Veronica persica* (*Stellaria media – Convolvulus arvensis*)/ *Papaver rhoeas – Silene noctiflora*	0.360/ 0.360
Silene noctiflora	3B	OV15a	*Anagallis arvensis – Veronica persica* (*Stellaria media – Convolvulus arvensis*)	0.382
Silene noctiflora	3B	OV16	*Papaver rhoeas – Silene noctiflora*	0.361
Silene noctiflora	3B	OV33/ OV10b	*Polygonum lapathifolium – Poa annua/* *Poa annua – Senecio vulgaris* (*Polygonum aviculare – Matricaria perforata*)	0.341/ 0.339
Silene noctiflora	3B	OV15a	*Anagallis arvensis – Veronica persica* (*Stellaria media – Convolvulus arvensis*)	0.432
Silene noctiflora	3B	OV15a	*Anagallis arvensis – Veronica persica* (*Stellaria media – Convolvulus arvensis*)	0.452
Silene noctiflora	3B	OV8	*Veronica persica – Alopecurus myosuroides*	0.356
Silene noctiflora	3B	OV8/ OV12a	*Veronica persica – Alopecurus myosuroides*/ *Poa annua – Myosotis arvensis* (typical sub-community)	0.444/ 0.420
Silene noctiflora	5	OV7	*Veronica persica – Veronica polita*	0.245
Silene noctiflora	C	OV16	*Papaver rhoeas – Silene noctiflora*	0.226

Table 16. Species recorded at ≥50% of rare arable plant loci. Data are % of loci with average frequency out of three quadrats in parentheses. Blocks separate species that tend to be associated with all, *Silene noctiflora*, *Papaver hybridum* and *Polygonum rurivagum* loci respectively. Occurrence of the three key rare species also shown.

Species	**All (20)**	***Silene* (12)**	***Papaver* (2)**	***Polygonum* (2)**
Chenopodium album	90 (III)	100 (III)	50 (II)	100 (III)
Fallopia convolvulus	90 (III)	92 (III)	50 (II)	100 (III)
Polygonum aviculare	70 (III)	50 (II)	100 (II)	100 (III)
Triticum sp.	70 (III)	83 (III)	50 (III)	50 (III)
Veronica persica	65 (II)	67 (III)	50 (I)	100 (III)
Stellaria media	60 (III)	67 (III)	0 (-)	100 (III)
Tripleurospermum inodorum	60 (II)	50 (II)	100 (III)	50 (I)
Cirsium arvense	55 (II)	50 (II)	50 (II)	50 (I)
Cirsium vulgare	55 (II)	42 (II)	100 (II)	50 (II)
Anagallis arvensis	50 (III)	58 (III)	0 (-)	50 (III)
Aethusa cynapium	50 (III)	50 (III)	100 (III)	100 (II)
Viola arvensis	50 (II)	42 (I)	50 (II)	50 (II)
Sinapis arvensis	45 (II)	58 (II)	0 (-)	50 (III)
Galium aparine	45 (II)	50 (II)	0 (-)	50 (I)
Papaver rhoeas	30 (II)	17 (II)	100 (II)	0 (-)
Alopecurus myosuroides	45 (II)	42 (III)	0 (-)	100 (I)
Silene noctiflora	70 (II)	100 (II)	50 (I)	50 (I)
Papaver hybridum	15 (II)	8 (I)	100 (II)	0 (-)
Polygonum rurivagum	10 (I)	0 (-)	0 (-)	100 (I)

Discussion

In general, the vegetation of all four management options sampled comprised common plant species of arable land but with some less widespread species occurring, usually at low frequency, at some sites. There were marked differences in the overall composition of the vegetation between the cereal field headland options (Options 3A and 3B) and the ‘static’ Options 4C and 5. Apart from the obvious presence or otherwise of the cereal crop itself, the Options 4C and 5 sites had greater abundance of naturally regenerated species and particularly of perennial species. This reflected the reduced herbicide inputs and absence of competition from the crop in comparison with the conservation headland options.

Conservation headlands

The previous survey of ASPS options showed that Options 3A and 3B had achieved their intended objective of promoting annual dicotyledonous species (Critchley *et al*., 2001a; in revision). The current survey in the East Anglia pilot area confirmed this and provided a useful additional comparison between conservation headlands and normally cropped headlands not under scheme agreement but on the same farms. The differences between Option 3A sites and normally cropped headlands were confined to annuals and dicotyledons, with no overall difference in perennials and monocotyledons, or in pernicious weed species. Differences were mainly in the amount of non-crop vegetation as distinct from its species composition. This suggests that the Option 3A was successful because there was a greater abundance of the target species groups than would otherwise be expected under normal crop management but without encouraging the less desirable or more problematic species. However, there was high variation between sites. Some Option 3A sites had sparse non-crop plant cover whereas some normally cropped headlands had notable amounts. The Option 3A prescription was successful at the whole scheme level, but not necessarily at all sites. Some variation in Option 3A sites appeared to be explained by herbicide use. If herbicides (permitted under the prescriptions) had not been applied, there appeared to be a greater risk of perennials establishing. Therefore, there it might be advantageous to crop production if the permitted herbicides were applied as a matter of course. Option 3B appeared to confer the intended additional benefits (Kleijn & Van der Voort, 1997) over Option 3A, particularly in the increased abundance of dicotyledons. However, only a small number of farms had Option 3B agreements. On one of these, the Option 3B sites were subjected to the additional restrictions conferred by organic status, the effect of which was a greater abundance of perennials. There also appeared to be an increased risk from pernicious weeds at Option 3B sites.

Uncropped wildlife strips and wildlife seed mixtures

There was a substantial increase in the perennial component of the vegetation of Option 4C and 5 sites since the previous survey in 1999, largely at the expense of annuals. These sites were in their first year of establishment at the time of the first survey. At Option 5 sites, the sampling in 2003 was concentrated in the field margin, whereas it extended further into the field at some sites in 1999. Annual dicotyledonous species are more abundant near the edges of fields (Wilson & Aebischer, 1995). This might account for some of the apparent change in abundance of annuals at Option 5 sites. However, in a Defra-funded experiment, perennials also increased in uncropped wildlife strips over a three-year period under a variety of annual cultivation regimes at three geographically distinctive sites (Project BD1613; Critchley *et al*., 2001b). This indicates that successional replacement of annuals by perennials could be a universal effect in uncropped wildlife strips. The main benefits to annual arable plants are therefore in the first years following establishment. It is not known whether the relative proportions of annuals and perennials would continue to change over a longer period of time, nor at what proportions an equilibrium might be reached. In the experiment, there was also an underlying increase in the abundance of monocotyledons. However, in the ASPS there was no increase in cover of monocotyledons over the five years covered by the surveys, although the number of species did increase. This is encouraging because development of vegetation dominated by grasses would be counter to the aims of this management option. The soil properties of both Options 4C and 5 were remarkably consistent between the two surveys. As well as providing some reassurance of the robustness of the sampling and analysis methods, this suggests that the soil properties measured are likely to be stable under these types of management. In the Defra experiment, the season and depth of cultivation applied in a given year had a major effect on the species composition in that year. Because of this, diversity between sites would be achieved easily by cultivating sites across a farm at different times and depths in a given year. However, in the ASPS the same cultivations tended to be applied at all sites on a farm, so missing this opportunity to maximise spatial diversity. In the ASPS sample, there appeared to be some benefit of deeper cultivation. However, the effect of cultivation depth was strongly site-specific in the Defra experiment and so this trend might have been attributable to other confounding between-farm effects in the ASPS survey. Most Option 4C sites were cultivated annually, but Option 5 sites that were cultivated less frequently tended to have more perennials and monocotyledons. Annual cultivation will be more beneficial for the target annual dicotyledonous arable plants. The apparently high rate of non-compliance, especially with Option 4C is of concern. Sites were rejected from the sample mostly because they had not been cultivated recently. The reasons for this non-compliance are not clear, but are possibly due to a lack of understanding or attention to the requirements of the prescriptions on the part of the participating farmers.

Rare arable plants

Taking into account the wider range of ASPS options and larger number of sites surveyed in 1999-2000 than in 2003, the numbers of records made of rare species in East Anglia were broadly comparable between the two surveys. However, there were substantially fewer records from Option 5 sites in 2003 and most populations recorded at Option 4C and 5 sites were much smaller in 2003. This occurred across a range of species. Rare arable plant populations can fluctuate markedly from year to year, and firm conclusions are difficult to make from just two surveys (Rich, 1997). However, it is possible that the rare plant populations might have been reduced as a result of competition from the increase in perennials, at Option 4C and 5 sites. Despite this, rare species were still most likely to occur at Option 4C sites in 2003. This could be a combined effect of spatial targeting of this management option and benefits of the management itself. Option 3B was also beneficial, although most sites were on one farm. New records for the 2003 survey were *Bromus secalinus* and *Iberis amara*. Records were not all from ASPS sites however, which shows that rare species can persist under a range of site conditions. West Midlands is not noted for rare arable species, and none was recorded in the 2003 survey.

Although the majority of records were from OV15a and OV16 NVC communities, rare species were not restricted to these and the remainder were found in a range of weed communities and on different soil types. Rare species tended to occur in plant communities mostly comprised of common species. However, some associate species might be good indicators of the potential locations of rare species. The best indicators would be those with relatively restricted distributions, such as those highlighted above. A systematic analysis of rare plant records using predetermined cut-off levels of associates' frequencies and their national distributions could produce a more definitive list of indicators to help to target sites for rare arable plant conservation.

Weeds

The presence of pernicious arable weeds in field margins managed under the ASPS might be of concern to farmers. However, this would only be justified if they interfered directly with crop yields or harvesting, if they spread from non-cropped areas into adjoining crops or if they persisted at sites scheduled to be cropped in future years. Pernicious weeds would be detrimental in Options 3A or 3B because they would compete directly with the cereal crop, reducing yields and delaying ripening. Although there was some indication that weeds might be more prevalent at Option 3B and 3A sites, there was no significant difference in weed abundance between Option 3A sites and normally cropped headlands. At the general scheme level therefore, pernicious weeds did not appear to be problematical in Option 3A sites. Under Options 4C and 5, pernicious weeds were much more abundant and had increased since the previous survey, albeit with considerable variation between sites. This was particularly the case in Option 5 sites. Control of some weeds is permitted, using herbicide or cutting and this was done at some farms. This suggests that weeds were of concern to some farmers. Thistles appeared to be of most concern, presumably on account of their wind dispersal capability and the persistence of *Cirsium arvense* rhizomes.

Food plants

The presence of food plants might infer some benefit to particular groups of fauna but this benefit would only be realised if certain conditions were met. Food plants can only be exploited if their spatial and temporal availability coincided with the needs of the dependent species. Measurement of parameters such as flowering abundance, seed production or local climate would be necessary to provide an accurate estimate of potential benefit. Even if they did coincide, there would be no guarantee of the food plants being utilised. A particular plant species might provide a potential food source in one ASPS option but not in another. For example, cereal crops are potential food for granivorous birds. In cereal headlands (including conservation headlands), the value would only be realised for some species if grain was spilt during harvest, a practice that is uncommon under efficient agricultural production. In contrast, cereals could be sown at Option 5 sites, where they would be deliberately left to shed seed and are likely to benefit granivores. Although general lists of food plant species can give some indication of the potential value of the different ASPS options for birds, butterflies and bumblebees, a more realistic assessment would require separate lists of potentially beneficial plant species to be compiled for each management option by detailed reference to the published literature. Such an analysis is outside the scope of the current project. A further issue is that sites under ASPS agreements would only contribute to survival or increase of the animal populations if the food plants were limiting to their success; if the food plant was not a scarce resource then animals might simply move to ASPS sites from other suitable sites. Within these caveats, some indication of the potential benefit of the different options was obtained. Options 4C and 5 had substantially more potential food plants for butterfly larvae and bumblebees than Option 3A or normally cropped headlands, reflecting differences in overall abundance of non-crop species. Option 4C sites tended to have greatest abundance of these food plants, although bumblebee food plants had increased in Option 5 sites between 1999 and 2003. Comparison of bird food plants was complicated by the presence of cereal crops in some field margin types. A more meaningful comparison was made between Option 3A and normally cropped headlands, which showed Option 3A to have more bird food plants. Butterfly larva food plants, but not bumblebee food plants, were also more prevalent in Option 3A. All the ASPS options therefore appeared to have potential benefits for the three faunal groups.

Regions

Differences in vegetation between East Anglia and West Midlands were consistent with those reported from the earlier survey, and also from a countrywide survey of set-aside land (Critchley & Fowbert, 2000). In West Midlands, vegetation cover was often more complete and had a larger component of perennials and monocotyledons than East Anglia. In contrast, annual arable plants were more strongly associated with East Anglia. These differences became more marked over time in the Option 4C sites, as annuals and dicotyledons declined more in West Midlands. This reflects the tendency for arable sites to develop more grassland characteristics in West Midlands, whereas in East Anglia the vegetation remains in an earlier successional state for longer. This is probably the result of regional differences in climate and landscape structure as well as the variation in soil properties noted. A consequence of this was that bird and butterfly larval food plants tended to be more prevalent in West Midlands although there were no differences for bumblebee food plants. This contrasts with the greater suitability of East Anglia for annual arable plants, including the rare species. At a regional level, therefore, the ASPS options in West Midlands might have more benefit for farmland birds and butterflies, whereas there are more opportunities to benefit populations of annual arable plants, including rare species, in East Anglia.

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Appendix 1. Description of the four ASPS management options surveyed.

Code	Option	Summary of management prescriptions
3A	conservation headland	• On a 10-12m wide cereal headland, no control of broad-leaved weeds except using amidosulfuron up to 31 March • Grass weeds controlled using specified graminicides only • No insecticide applied between 15 March and harvest
3B	conservation headland with no fertiliser	• Conservation headland managed as above • No organic or inorganic fertiliser applied after harvest of previous crop
4C	uncropped wildlife strip	• Boundary strip averaging at least 6m wide managed for 5 years • Cultivated once a year or every other year in spring (100-150mm depth by tine, disc or plough) or autumn (75-100mm depth by tine) • No other inputs except selective control of serious weeds
5	wildlife seed mixture	• Site-specific seed mixture sown to provide wildlife benefits, e.g. small-grained cereals, teasel, kale, fodder beet, parsnip, chicory, sunflower, millet or quinoa

Appendix 2. Rare annual arable plants targeted for survey, from Wilson (1999).

UK BAP Priority Species	
Centaurea cyanus	Cornflower
Filago lutescens	Red-tipped Cudweed
Filago pyramidata	Broad-leaved Cudweed
Galeopsis angustifolia	Red Hemp-nettle
Galium tricornutum	Corn Cleavers
Scandix pecten-veneris	Shepherd’s Needle
Silene gallica	Small-flowered Catchfly
Torilis arvensis	Spreading Hedge-parsley
UK BAP Species of Conservation Concern	
Adonis annua	Pheasant’s Eye
Ajuga chamaepitys	Ground-pine
Euphorbia platyphyllos	Broad-leaved Spurge
Hypochoeris glabra	Smooth Cat’s-ear
Lithospermum arvense	Corn Gromwell
Lythrum hyssopifolia	Grass Poly
Petroselinum segetum	Corn Parsley
Ranunculus arvensis	Corn Buttercup
Valerianella dentata	Narrow-fruited Corn-salad
Other Red Data Book and Nationally Scarce species	
Apera interrupta	Dense Silky-bent
Apera spica-venti	Loose Silky-bent
Fumaria densiflora	Dense-flowered Fumitory
Fumaria parviflora	Fine-leaved Fumitory
Fumaria vaillantii	Few-flowered Fumitory
Galium spurium	False Cleavers
Lathyrus aphaca	Yellow Vetchling
Polygonum rurivagum	Cornfield Knotgrass
Vicia parviflora	Slender Tare
Other species	
Agrostemma githago	Corncockle
Anthemis arvensis	Corn Chamomile
Bromus arvensis	Field Brome
Bromus secalinus	Rye Brome
Myosurus minimus	Mousetail
Papaver argemone	Prickly Poppy
Papaver hybridum	Rough Poppy
Ranunculus parviflorus	Small-flowered Buttercup
Silene noctiflora	Night-flowering Catchfly

Appendix 3. Plant taxa classified as farmland bird, butterfly larva or bumblebee food plants. Bird and butterfly plants from Smart *et al*., 2000; bumblebee plants from CEH observations at ASPS sites.

Taxa	Bird	Butterfly larva	Bumblebee
Agrostis capillaris		✓	
Alliaria petiolata		✓	
Anchusa arvensis			✓
Anthoxanthum odoratum		✓	
Arctium agg.	✓		
Arctium lappa	✓		
Arctium minus	✓		✓
Arrhenatherum elatius		✓	
Artemisia vulgaris	✓		
Avena fatua	✓		
Avena sativa	✓		
Avena sp.	✓		
Ballota nigra			✓
Barbarea vulgaris		✓	
Beta sp.	✓		
Beta vulgaris ssp. *vulgaris*	✓		
Borago officinalis			✓
Brachypodium sylvaticum		✓	
Brassica napus	✓		✓
Brassica napus ssp. *oleifera*	✓		✓
Brassica nigra	✓		
Brassica oleracea	✓		
Brassica oleracea var. *capitata*	✓		
Brassica oleracea var. *viridis*	✓		
Brassica rapa	✓		
Brassica rapa ssp. *rapa*	✓		
Brassica sp.	✓		
Calystegia sepium			✓
Capsella bursa-pastoris	✓	✓	
Carduus nutans			✓
Centaurea nigra			✓
Centaurea scabiosa			✓
Cerastium fontanum	✓		
Cerastium glomeratum	✓		
Chamerion angustifolium			✓
Chenopodium album	✓		
Chenopodium ficifolium	✓		
Cirsium arvense	✓		✓
Cirsium palustre	✓		✓
Cirsium sp.			✓
Cirsium vulgare	✓		✓
Convolvulus arvensis			✓
Crataegus monogyna	✓		
Cynosurus cristatus		✓	
Dactylis glomerata		✓	
Deschampsia cespitosa		✓	
Dipsacus fullonum			✓
Elytrigia repens		✓	
Epilobium hirsutum			✓
Festuca arundinacea	✓		
Festuca pratensis	✓	✓	

Festuca rubra	✓			
Festuca sp.	✓			
Galeopsis tetrahit				✓
Hedera helix	✓			
Helianthus annuus	✓			✓
Holcus lanatus	✓	✓		
Holcus lanatus/mollis	✓	✓		
Holcus mollis	✓	✓		
Hordeum vulgare/distichon	✓			
Kickxia spuria				✓
Knautia arvensis				✓
Lamium purpureum				✓
Lathyrus pratensis		✓		
Linaria vulgaris				✓
Lolium multiflorum/perenne	✓	✓		
Lotus corniculatus		✓		✓
Lotus pedunculatus		✓		
Malva sylvestris				✓
Medicago lupulina		✓		✓
Medicago sativa				✓
Melilotus officinalis				✓
Melilotus sp.				✓
Onobrychis viciifolia				✓
Papaver rhoeas				✓
Persicaria hydropiper	✓			
Persicaria lapathifolia	✓			✓
Persicaria lapathifolia/maculosa	✓			✓
Persicaria maculosa	✓			✓
Phacelia tanacetifolia				✓
Picris echioides				✓
Poa annua	✓	✓		
Poa pratensis	✓			
Poa trivialis	✓			
Polygonum aviculare	✓			
Polygonum rurivagum	✓			
Potentilla anserina		✓		
Potentilla reptans		✓		
Prunus spinosa	✓			
Raphanus raphanistrum		✓		
Reseda lutea		✓		✓
Reseda luteola				✓
Rosa sp.	✓			
Rubus fruticosus	✓			✓
Rumex acetosa	✓	✓		
Rumex acetosella	✓	✓		
Rumex conglomeratus	✓			
Rumex crispus	✓			
Rumex obtusifolius	✓			
Rumex sanguineus	✓			
Rumex sp.	✓			
Senecio erucifolius	✓			
Senecio jacobaea	✓			✓
Senecio vulgaris	✓			✓
Sinapis alba	✓			
Sinapis alba/arvensis	✓			
Sinapis arvensis	✓			
Sisymbrium officinale		✓		
Sonchus arvensis	✓			✓

Sonchus asper	✓		
Sonchus oleraceus	✓		
Sonchus sp.	✓		
Spergula arvensis	✓		
Stachys sylvatica			✓
Stellaria holostea	✓		
Stellaria media	✓		
Taraxacum officinale agg.	✓		
Trifolium arvense	✓		
Trifolium dubium	✓	✓	
Trifolium pratense	✓	✓	✓
Trifolium repens	✓	✓	✓
Tripleurospermum inodorum			✓
Triticum sp.	✓		
Urtica dioica	✓	✓	
Urtica urens		✓	
Vicia hirsuta	✓		
Vicia sativa	✓		
Vicia sp.	✓		
Vicia tetrasperma	✓		
Viola arvensis			✓
Zea mays	✓		

Appendix 4. Occurrence of species (% of sites) from quadrat records of Options 3A, 3B, 4C, 5 and normally cropped headlands.

Latin name	English Name	All	3A	3B	4C	5	C
	bare ground	98.7	100	100	100	90.9	100
	litter	97.4	95.0	100	100	93.9	97.4
	seedling	86.5	87.5	100	83.3	93.9	71.8
	moss	59.4	70.0	40.0	62.5	57.6	56.4
	tree seedling	1.3	5.0	-	-	-	-
	rock	0.6	-	5.0	-	-	-
Crops, crop volunteers & sown species							
Triticum sp.	Wheat	60.0	75.0	90.0	25.0	24.2	79.5
Hordeum vulgare/distichon	Barley	16.8	30.0	10.0	8.3	9.1	17.9
Brassica napus	Rape	8.4	10.0	10.0	-	21.2	-
Avena sp.	Oat	5.2	10.0	-	4.2	3.0	5.1
Zea mays	Maize	5.2	-	-	-	24.2	-
Phacelia tanacetifolia	Phacelia	3.9	-	-	-	18.2	-
Brassica oleracea var. *viridis*	Kale	3.2	-	-	-	15.2	-
Fagopyrum esculentum	Buckwheat	3.2	-	-	-	12.1	2.6
Solanum tuberosum	Potato	1.9	2.5	-	-	3.0	2.6
Borago officinalis	Borage	1.9	-	-	-	9.1	-
Dipsacus fullonum	Wild Teasel	1.9	-	-	-	9.1	-
Helianthus annuus	Sunflower	1.3	-	5.0	-	3.0	-
Beta sp.	Beet	0.6	-	-	-	3.0	-
Brassica napus ssp. *oleifera*	Oil-seed rape	0.6	-	-	-	3.0	-
Brassica oleracea var. *capitata*	Cabbage	0.6	-	-	-	3.0	-
Brassica rapa ssp. *rapa*	Turnip	0.6	-	-	-	3.0	-
Linum usitatissimum	Flax	0.6	-	-	-	3.0	-
Beta vulgaris ssp. *vulgaris*	Root Beet	0.6	-	-	-	-	2.6
Monocotyledons							
Poa trivialis	Rough Meadow-grass	54.2	45.0	55.0	87.5	54.5	41.0
Poa annua	Annual Meadow-grass	49.0	55.0	55.0	50.0	33.3	51.3
Elytrigia repens	Common Couch	43.9	32.5	20.0	66.7	69.7	30.8
Lolium multiflorum/perenne	Ryegrass	35.5	37.5	10.0	62.5	36.4	28.2
Alopecurus myosuroides	Black-grass	34.8	35.0	70.0	37.5	15.2	30.8
Agrostis stolonifera	Creeping Bent	31.6	27.5	-	54.2	51.5	20.5
Anisantha sterilis	Barren Brome	25.8	25.0	5.0	54.2	21.2	23.1
Dactylis glomerata	Cock's-foot	25.2	15.0	25.0	50.0	36.4	10.3
Holcus lanatus	Yorkshire-fog	23.9	22.5	-	50.0	39.4	7.7
Arrhenatherum elatius	False Oat-grass	21.3	10.0	-	54.2	36.4	10.3
Festuca rubra	Red Fescue	16.8	7.5	10.0	25.0	36.4	7.7
Avena fatua	Wild-oat	15.5	17.5	5.0	25.0	9.1	17.9
Phleum pratense	Timothy	14.8	12.5	-	29.2	21.2	10.3
Bromus sp.	Brome	11.0	2.5	5.0	29.2	15.2	7.7
Bromus hordeaceus	Soft-brome	6.5	7.5	-	8.3	6.1	7.7
Bromus commutatus	Meadow Brome	5.2	15.0	-	-	-	5.1
Phleum sp.	Cat's-tail	3.9	-	-	12.5	6.1	-
Juncus bufonius	Toad Rush	3.9	-	-	8.3	12.1	-
Anthoxanthum odoratum	Sweet Vernal-grass	3.2	5.0	-	-	6.1	2.6
Agrostis gigantea/stolonifera	Bent-grass	2.6	2.5	-	8.3	-	7.7
Holcus mollis	Creeping Soft-grass	2.6	-	-	-	12.1	-
Agrostis sp.	Bent-grass	1.9	5.0	-	-	-	2.6

Phleum bertolonii	Smaller Cat's-tail	1.9	-	5.0	-	6.1	-
Cynosurus cristatus	Crested Dog's-tail	1.9	-	-	8.3	3.0	-
Juncus inflexus	Hard Rush	1.9	-	-	4.2	6.1	-
Phalaris arundinacea	Reed Canary-grass	1.9	-	-	4.2	6.1	-
Carex hirta	Hairy Sedge	1.9	-	-	-	9.1	-
Agrostis capillaris/stolonifera	Bent-grass	1.3	-	-	8.3	-	-
Glyceria maxima	Reed Sweet-grass	1.3	-	-	4.2	3.0	-
Deschampsia cespitosa	Tufted Hair-grass	1.3	-	-	-	6.1	-
Juncus acutiflorus	Sharp-flowered Rush	1.3	-	-	-	6.1	-
Juncus effusus	Soft-rush	1.3	-	-	-	6.1	-
Poaceae sp.[1]	unidentified grass	1.3	-	-	-	6.1	-
Festuca arundinacea	Tall Fescue	0.6	2.5	-	-	-	-
Holcus lanatus/mollis	Soft-grass	0.6	2.5	-	-	-	-
Agrostis gigantea	Black Bent	0.6	-	-	4.2	-	-
Brachypodium sylvaticum	False Brome	0.6	-	-	4.2	-	-
Phragmites australis	Common Reed	0.6	-	-	4.2	-	-
Vulpia sp.	Fescue	0.6	-	-	4.2	-	-
Carex pendula	Pendulous Sedge	0.6	-	-	-	3.0	-
Festuca pratensis	Meadow Fescue	0.6	-	-	-	3.0	-
Poa pratensis	Smooth Meadow-grass	0.6	-	-	-	3.0	-
Dicotyledons							
Galium aparine	Cleavers	56.8	55.0	75.0	87.5	42.4	41.0
Polygonum aviculare	Knotgrass	54.8	62.5	70.0	54.2	39.4	51.3
Fallopia convolvulus	Black-bindweed	48.4	57.5	75.0	58.3	21.2	41.0
Veronica persica	Common Field-speedwell	48.4	37.5	90.0	54.2	51.5	30.8
Cirsium arvense	Creeping Thistle	48.4	20.0	35.0	79.2	93.9	25.6
Cirsium vulgare	Spear Thistle	45.2	37.5	30.0	70.8	72.7	20.5
Viola arvensis	Field Pansy	44.5	52.5	65.0	41.7	24.2	43.6
Chenopodium album	Fat-hen	43.9	40.0	60.0	45.8	57.6	25.6
Tripleurospermum inodorum	Scentless Mayweed	35.5	45.0	45.0	29.2	36.4	23.1
Sonchus asper	Prickly Sow-thistle	34.8	32.5	30.0	70.8	51.5	2.6
Stellaria media	Common Chickweed	32.9	47.5	85.0	25.0	15.2	10.3
Anagallis arvensis ssp. *arvensis*	Scarlet Pimpernel	31.0	22.5	70.0	50.0	33.3	5.1
Urtica dioica	Common Nettle	28.4	22.5	5.0	54.2	54.5	7.7
Senecio vulgaris	Groundsel	25.2	30.0	60.0	29.2	15.2	7.7
Rumex obtusifolius	Broad-leaved Dock	25.2	17.5	-	45.8	63.6	-
Aethusa cynapium	Fool's Parsley	23.9	35.0	25.0	29.2	12.1	17.9
Plantago major	Greater Plantain	23.2	7.5	30.0	45.8	39.4	7.7
Sonchus arvensis	Perennial Sow-thistle	21.3	10.0	35.0	37.5	39.4	-
Persicaria maculosa	Redshank	20.6	17.5	15.0	37.5	27.3	10.3
Veronica arvensis	Wall Speedwell	18.7	12.5	30.0	25.0	18.2	15.4
Papaver rhoeas	Common Poppy	18.7	25.0	25.0	41.7	9.1	2.6
Taraxacum agg.	Dandelion	18.1	2.5	10.0	45.8	36.4	5.1
Trifolium repens	White Clover	17.4	15.0	20.0	29.2	27.3	2.6
Atriplex patula	Common Orache	16.8	17.5	10.0	16.7	21.2	15.4
Capsella bursa-pastoris	Shepherd's-purse	16.8	15.0	35.0	33.3	12.1	2.6
Sisymbrium officinale	Hedge Mustard	14.8	17.5	15.0	25.0	21.2	-
Geranium dissectum	Cut-leaved Crane's-bill	14.8	10.0	15.0	33.3	15.2	7.7
Ranunculus repens	Creeping Buttercup	14.8	2.5	5.0	33.3	39.4	-
Sinapis arvensis	Charlock	14.2	12.5	40.0	12.5	12.1	5.1
Convolvulus arvensis	Field Bindweed	14.2	5.0	20.0	33.3	21.2	2.6
Lapsana communis	Nipplewort	12.9	20.0	5.0	20.8	15.2	2.6
Myosotis arvensis	Field Forget-me-not	12.3	10.0	15.0	29.2	15.2	-
Silene latifolia	White Campion	11.6	12.5	10.0	20.8	12.1	5.1
Matricaria recutita	Scented Mayweed	11.6	12.5	5.0	29.2	6.1	7.7
Picris echioides	Bristly Oxtongue	11.0	10.0	20.0	12.5	12.1	5.1

Artemisia vulgaris	Mugwort	11.0	5.0	-	25.0	24.2	2.6
Epilobium hirsutum	Great Willowherb	11.0	-	5.0	25.0	27.3	2.6
Cerastium fontanum	Common Mouse-ear	10.3	5.0	5.0	25.0	15.2	5.1
Heracleum sphondylium	Hogweed	10.3	5.0	5.0	20.8	24.2	-
Arctium minus	Lesser Burdock	9.0	5.0	-	29.2	15.2	-
Rubus fruticosus	Bramble	9.0	5.0	-	16.7	15.2	7.7
Senecio jacobaea	Ragwort	9.0	-	-	29.2	21.2	-
Matricaria discoidea	Pineappleweed	7.7	7.5	15.0	16.7	3.0	2.6
Glechoma hederacea	Ground-ivy	7.7	5.0	-	20.8	15.2	-
Kickxia elatine	Sharp-leaved Fluellen	7.1	2.5	20.0	16.7	6.1	-
Persicaria lapathifolia	Pale Persicaria	7.7	2.5	15.0	12.5	9.1	5.1
Epilobium sp.	Willowherb	7.1	-	5.0	80.3	21.2	2.6
Kickxia spuria	Round-leaved Fluellen	6.5	2.5	15.0	16.7	3.0	2.6
Lamium purpureum	Red Dead-nettle	5.8	7.5	15.0	4.2	6.1	-
Euphorbia exigua	Dwarf Spurge	5.8	5.0	30.0	4.2	-	-
Aphanes arvensis	Parsley-piert	5.8	5.0	10.0	4.2	6.1	5.1
Coronopus squamatus	Swine-cress	5.8	2.5	20.0	12.5	3.0	-
Veronica sp.	Speedwell	5.2	5.0	-	4.2	12.1	2.6
Silene noctiflora	Night-flowering Catchfly	5.2	2.5	30.0	-	-	2.6
Arenaria serpyllifolia[2]	Thyme-leaved Sandwort	4.5	2.5	10.0	8.3	3.0	2.6
Achillea millefolium	Yarrow	5.2	2.5	-	12.5	12.1	-
Fumaria officinalis	Common Fumitory	5.2	2.5	-	8.3	9.1	5.1
Fraxinus excelsior	Ash	5.2	-	15.0	8.3	6.1	2.6
Trifolium pratense	Red Clover	4.5	5.0	20.0	4.2	-	-
Rumex crispus	Curled Dock	4.5	2.5	5.0	8.3	9.1	-
Linaria vulgaris	Common Toadflax	4.5	-	-	20.8	6.1	-
Calystegia sepium	Hedge Bindweed	4.5	-	-	12.5	12.1	-
Anchusa arvensis	Bugloss	4.5	-	-	8.3	12.1	2.6
Epilobium montanum	Broad-leaved Willowherb	4.5	-	-	4.2	15.2	2.6
Raphanus raphanistrum	Wild Radish	3.9	5.0	-	-	9.1	2.6
Galeopsis tetrahit	Common Hemp-nettle	3.9	2.5	-	16.7	3.0	-
Gallium mollugo	Hedge Bedstraw	3.9	2.5	-	8.3	9.1	-
Stachys sylvatica	Hedge Woundwort	3.9	-	-	12.5	9.1	-
Chamerion angustifolium	Rosebay Willowherb	3.9	-	-	4.2	15.2	-
Epilobium ciliatum	American Willowherb	3.9	-	-	4.2	15.2	-
Vicia hirsuta	Hairy Tare	3.2	5.0	-	8.3	3.0	-
Legousia hybrida	Venus's-looking-glass	3.2	2.5	5.0	8.3	3.0	-
Reseda lutea	Wild Mignonette	3.2	2.5	-	16.7	-	-
Myosotis sp.	Forget-me-not	3.2	-	10.0	4.2	3.0	2.6
Lamium album	White Dead-nettle	3.2	-	-	16.7	3.0	-
Prunus spinosa	Blackthorn	3.2	-	-	12.5	6.1	-
Medicago sativa ssp. *sativa*	Lucerne	3.2	-	-	-	15.2	-
Acer pseudoplatanus	Sycamore	2.6	5.0	10.0	4.2	-	-
Solanum nigrum	Black Nightshade	2.6	2.5	-	8.3	3.0	-
Brassica sp.[3]	Cabbage	2.6	2.5	-	-	9.1	-
Euphorbia helioscopia	Sun Spurge	2.6	2.5	-	-	6.1	2.6
Apiaceae sp.	unidentified umbellifer	2.6	-	5.0	4.2	6.1	-
Knautia arvensis	Field Scabious	2.6	-	-	16.7	-	-
Lactuca serriola	Prickly Lettuce	2.6	-	-	12.5	3.0	-
Plantago lanceolata	Ribwort Plantain	2.6	-	-	12.5	3.0	-
Vicia sativa	Common Vetch	2.6	-	-	12.5	3.0	-
Epilobium parviflorum	Hoary Willowherb	2.6	-	-	8.3		-
Sherardia arvensis	Field Madder	2.6	-	-	8.3	3.0	-
Sinapis alba	White Mustard	2.6	-	-	4.2	9.1	-
Geranium molle	Dove's-foot Crane's-bill	2.6	-	-	4.2	9.1	-
Spergula arvensis	Corn Spurrey	2.6	-	-	4.2	9.1	-
Acer campestre	Field maple	1.9	7.5	-	-	-	-
Ranunculus sp.	Buttercup	1.9	2.5	5.0	4.2	-	-

Sonchus sp.	Sow-thistle	1.9	2.5	5.0	4.2	-	-
Angelica sylvestris	Wild Angelica	1.9	2.5	-	4.2	3.0	-
Geranium pusillum	Small-flowered Crane's-bill	1.9	2.5	-	4.2	3.0	-
Crataegus monogyna	Hawthorn	1.9	2.5	-	-	3.0	2.6
Sonchus oleraceus	Smooth Sow-thistle	1.9	-	15.0	-	-	-
Brassicaceae sp.	unidentified crucifer	1.9	-	5.0	8.3	-	-
Quercus sp.	Oak	1.9	-	5.0	-	6.1	-
Solanum sp.	Nightshade	1.9	-	5.0	-	6.1	-
Prunella vulgaris	Selfheal	1.9	-	-	8.3	3.0	-
Carduus nutans	Musk Thistle	1.9	-	-	4.2	6.1	-
Epilobium tetragonum	Square-stalked Willowherb	1.9	-	-	4.2	6.1	-
Lotus corniculatus	Common Bird's-foot-trefoil	1.9	-	-	4.2	6.1	-
Lotus pedunculatus	Greater Bird's-foot-trefoil	1.9	-	-	4.2	6.1	-
Medicago lupulina	Black Medick	1.9	-	-	4.2	6.1	-
Potentilla reptans	Creeping Cinquefoil	1.9	-	-	4.2	6.1	-
Scrophularia auriculata	Water Figwort	1.9	-	-	4.2	6.1	-
Silene dioica	Red Campion	1.9	-	-	-	6.1	2.6
Anthemis cotula	Stinking Chamomile	1.3	5.0	-	-	-	-
Veronica polita	Grey Field-speedwell	1.3	5.0	-	-	-	-
Trifolium dubium	Lesser Trefoil	1.3	2.5	-	-	-	2.6
Rumex sp.	Dock	1.3	2.5	5.0	-	-	-
Rumex acetosa	Common Sorrel	1.3	2.5	-	4.2	-	-
Veronica hederifolia	Ivy-leaved Speedwell	1.3	2.5	-	4.2	-	-
Atriplex sp.	Orache	1.3	2.5	-	-	3.0	-
Hedera helix	Ivy	1.3	2.5	-	-	3.0	-
Urtica urens	Small Nettle	1.3	2.5	-	-	3.0	-
Persicaria lapathifolia/maculosa	Knotweed/Redshank	1.3	-	10.0	-	-	-
Lamiaceae sp.	unidentified dead-nettle	1.3	-	5.0	4.2	-	-
Silene sp.	Campion	1.3	-	5.0	4.2	-	-
Chaenorhinum minus	Small Toadflax	1.3	-	-	8.3	-	-
Galium verum	Lady's Bedstraw	1.3	-	-	8.3	-	-
Geum urbanum	Wood Avens	1.3	-	-	8.3	-	-
Rumex acetosella	Sheep's Sorrel	1.3	-	-	8.3	-	-
Tragopogon pratensis	Goat's-beard	1.3	-	-	8.3	-	-
Ballota nigra	Black Horehound	1.3	-	-	4.2	3.0	-
Centaurea scabiosa	Greater Knapweed	1.3	-	-	4.2	3.0	-
Crepis capillaris	Smooth Hawk's-beard	1.3	-	-	4.2	3.0	-
Geranium sp.	Crane's-bill	1.3	-	-	4.2	3.0	-
Silene vulgaris	Bladder Campion	1.3	-	-	4.2	3.0	-
Sagina apetala	Annual Pearlwort	1.3	-	-	4.2	3.0	-
Pimpinella saxifraga	Burnet-saxifrage	1.3	-	-	4.2	-	-
Conyza canadensis	Canadian Fleabane	1.3	-	-	-	6.1	-
Gnaphalium uliginosum	Marsh Cudweed	1.3	-	-	-	6.1	-
Papaver dubium	Long-headed Poppy	1.3	-	-	-	6.1	-
Potentilla anserina	Silverweed	1.3	-	-	-	6.1	-
Reseda luteola	Weld	1.3	-	-	-	6.1	-
Brassica nigra	Black Mustard	0.6	2.5	-	-	-	-
Clematis vitalba	Traveller's-joy	0.6	2.5	-	-	-	-
Coronopus didymus	Lesser Swine-cress	0.6	2.5	-	-	-	-
Descurainia sophia	Flixweed	0.6	2.5	-	-	-	-
Geranium pyrenaicum	Hedgerow Crane's-bill	0.6	2.5	-	-	-	-
Stachys sp.	Woundwort	0.6	2.5	-	-	-	-

Alliaria petiolata	Garlic Mustard	0.6	-	5.0	-	-	-
Arenaria sp.	Sandwort	0.6	-	5.0	-	-	-
Odontites vernus	Red Bartsia	0.6	-	5.0	-	-	-
Papaver sp.	Poppy	0.6	-	5.0	-	-	-
Polygonum rurivagum	Cornfield Knotgrass	0.6	-	5.0	-	-	-
Rumex sanguineus	Wood Dock	0.6	-	5.0	-	-	-
Bryonia dioica	White Bryony	0.6	-	-	4.2	-	-
Crepis vesicaria	Beaked Hawks'-beard	0.6	-	-	4.2	-	-
Geranium dissectum/molle	Crane's-bill	0.6	-	-	4.2	-	-
Hieracium sp.	Hawkweed	0.6	-	-	4.2	-	-
Hypochaeris radicata	Cat's-ear	0.6	-	-	4.2	-	-
Lathyrus sp.	Pea	0.6	-	-	4.2	-	-
Leontodon sp.	Hawkbit	0.6	-	-	4.2	-	-
Ranunculus acris	Meadow Buttercup	0.6	-	-	4.2	-	-
Rosa sp.	Rose	0.6	-	-	4.2	-	-
Salix cinerea	Grey Willow	0.6	-	-	4.2	-	-
Sanguisorba minor	Salad Burnet	0.6	-	-	4.2	-	-
Valeriana officinalis	Common Valerian	0.6	-	-	4.2	-	-
Vicia tetrasperma	Smooth Tare	0.6	-	-	4.2	-	-
Aphanes sp.	Parsley-piert	0.6	-	-	-	3.0	-
Barbarea vulgaris	Winter-cress	0.6	-	-	-	3.0	-
Castanea sativa	Sweet Chestnut	0.6	-	-	-	3.0	-
Centaurea nigra	Common Knapweed	0.6	-	-	-	3.0	-
Cichorium intybus	Chicory	0.6	-	-	-	3.0	-
Cirsium palustre	Marsh Thistle	0.6	-	-	-	3.0	-
Corylus avellana	Hazel	0.6	-	-	-	3.0	-
Erigeron acer	Blue Fleabane	0.6	-	-	-	3.0	-
Erodium cicutarium	Common Stork's-bill	0.6	-	-	-	3.0	-
Eupatorium cannabinum	Hemp-agrimony	0.6	-	-	-	3.0	-
Geranium robertianum	Herb-robert	0.6	-	-	-	3.0	-
Hypericum tetrapterum	Square-stalked St. John's-wort	0.6	-	-	-	3.0	-
Lactuca sp.	Lettuce	0.6	-	-	-	3.0	-
Lamium amplexicaule	Henbit Dead-nettle	0.6	-	-	-	3.0	-
Lathyrus pratensis	Meadow Vetchling	0.6	-	-	-	3.0	-
Malva sp.	Mallow	0.6	-	-	-	3.0	-
Malva sylvestris	Common Mallow	0.6	-	-	-	3.0	-
Melilotus officinalis	Ribbed Melilot	0.6	-	-	-	3.0	-
Mentha aquatica	Water Mint	0.6	-	-	-	3.0	-
Myosotis discolor	Changing Forget-me-not	0.6	-	-	-	3.0	-
Polygonum sp.	Knotgrass	0.6	-	-	-	3.0	-
Populus sp.	Poplar	0.6	-	-	-	3.0	-
Rumex conglomeratus	Clustered Dock	0.6	-	-	-	3.0	-
Stachys palustris	Marsh Woundwort	0.6	-	-	-	3.0	-
Trifolium arvense	Hare's-foot Clover	0.6	-	-	-	3.0	-
Tussilago farfara	Colt's-foot	0.6	-	-	-	3.0	-
Ulmus procera	English Elm	0.6	-	-	-	3.0	-
Euphorbia sp.	Spurge	0.6	-	-	-	-	2.6
Pastinaca sativa	Parsnip	0.6	-	-	-	-	2.6
Salix fragilis	Crack-willow	0.6	-	-	-	-	2.6
Other species							
Equisetum arvense	Field Horsetail	9.7	5.0	5.0	12.5	24.2	2.6
Dryopteris sp.	Buckler-fern	0.6	-	-	-	3.0	-
Pinus sp.	Pine	0.6	-	-	-	3.0	-

[1]Possibly a cultivated species
[2]Includes *Arenaria serpyllifolia* ssp. *leptoclados*
[3]Maybe cultivated or wild species

Appendix 5. Codes used for plant species in ordination plots.

Achimill	*Achillea millefolium*	Legohybr	*Legousia hybrida*
Aethcyna	*Aethusa cynapium*	Linavulg	*Linaria vulgaris*
Agrocapi	*Agrostis capillaris*	Linuusit	*Linum usitatissimum*
Agrogiga	*Agrostis gigantea/stolonifera*	Lolimupe	*Lolium multiflorum/perenne*
Agrostol	*Agrostis stolonifera*	Matrdisc	*Matricaria discoidea*
Alopmyos	*Alopecurus myosuroides*	Matrrecu	*Matricaria recutita*
Anagarve	*Anagallis arvensis*	Myosarve	*Myosotis arvensis*
Ancharve	*Anchusa arvensis*	Myossp.	*Myosotis sp.*
Angesylv	*Angelica sylvestris*	Paparhoe	*Papaver rhoeas*
Anisster	*Anisantha sterilis*	Papasp.	*Papaver sp.*
Aphaarve	*Aphanes arvensis*	Perslama	*Persicaria lapathifolia/maculosa*
Arenlept	*Arenaria serpyllifolia ssp leptoclados*	Perslapa	*Persicaria lapathifolia*
Arrhelat	*Arrhenatherum elatius*	Persmacu	*Persicaria maculosa*
Artevulg	*Artemisia vulgaris*	Phlebert	*Phleum bertolonii*
Atripatu	*Atriplex patula*	Phleprat	*Phleum pratense*
Avenfatu	*Avena fatua*	Phlesp.	*Phleum sp.*
Avensp.	*Avena sp.*	Picrechi	*Picris echioides*
Brasnapu	*Brassica napus*	Pimpsaxi	*Pimpinella saxifraga*
Brassp.	*Brassica sp.*	Planlanc	*Plantago lanceolata*
Bromsp.	*Bromus sp.*	Planmajo	*Plantago major*
Calysepi	*Calystegia sepium*	Poaannu	*Poa annua*
Capsburs	*Capsella bursa-pastoris*	Poatriv	*Poa trivialis*
Cerafont	*Cerastium fontanum*	Polyavic	*Polygonum aviculare*
Chaeminu	*Chaenorhinum minus*	Polyruri	*Polygonum rurivagum*
Chenalbu	*Chenopodium album*	Poterept	*Potentilla reptans*
Cirsarve	*Cirsium arvense*	Prunspin	*Prunus spinosa*
Cirsvulg	*Cirsium vulgare*	Prunvulg	*Prunella vulgaris*
Convarve	*Convolvulus arvensis*	Ranurepe	*Ranunculus repens*
Corosqua	*Coronopus squamatus*	Rubufrut	*Rubus fruticosus*
Dactglom	*Dactylis glomerata*	Rumeobtu	*Rumex obtusifolius*
Elytrepe	*Elytrigia repens*	Rumesp.	*Rumex sp.*
Epilcili	*Epilobium ciliatum*	Senejaco	*Senecio jacobaea*
Epilhirs	*Epilobium hirsutum*	Senevulg	*Senecio vulgaris*
Epilobsc	*Epilobium obscurum*	Sherarve	*Sherardia arvensis*
Euphexig	*Euphorbia exigua*	Silelati	*Silene latifolia*
Fallconv	*Fallopia convolvulus*	Silenoct	*Silene noctiflora*
Festrubr	*Festuca rubra*	Silesp.	*Silene sp.*
Fraxexce	*Fraxinus excelsior*	Sinaarve	*Sinapis arvensis*
Fumaoffi	*Fumaria officinalis*	Sisyoffc	*Sisymbrium officinale*
Galetetr	*Galeopsis tetrahit*	Solasp.	*Solanum sp.*
Galiapar	*Galium aparine*	Soncarve	*Sonchus arvensis*
Galimoll	*Galium mollugo*	Soncaspe	*Sonchus asper*
Galiveru	*Galium verum*	Soncoler	*Sonchus oleraceus*
Geradiss	*Geranium dissectum*	Stacsylv	*Stachys sylvatica*
Geumurba	*Geum urbanum*	Stelmedi	*Stellaria media*
Glechede	*Glechoma hederacea*	Taraagg.	*Taraxacum officinale agg.*

Heliannu	*Helianthus annuus*	Tragprat	*Tragopogon pratensis*
Holclana	*Holcus lanatus*	Trifprat	*Trifolium pratense*
Holcmoll	*Holcus mollis*	Trifrepe	*Trifolium repens*
Hordvulg	*Hordeum vulgare/distichon*	Tripinod	*Tripleurospermum inodorum*
Juncbufo	*Juncus bufonius*	Tritsp.	*Triticum sp.*
Kickelat	*Kickxia elatine*	Urtidioi	*Urtica dioica*
Kickspur	*Kickxia spuria*	Veroarve	*Veronica arvensis*
Knauarve	*Knautia arvensis*	Verohede	*Veronica hederifolia*
Labisp.	*Labiate sp.*	Veropers	*Veronica persica*
Lamipurp	*Lamium purpureum*	Vicihirs	*Vicia hirsuta*
Lapscomm	*Lapsana communis*	Violarve	*Viola arvensis*

Appendix 6. Summary data for each rare species.

Species: *Bromus secalinus* **No. of records:** 1

Grid ref.	Date	Field margin type	Soil texture	NVC	No. of individs
TL 75 50	07/07/03	normally cropped cereal headland	ZCL	OV8	2-10

Community data (means from three 4m^2 quadrats):

	Total	Dicots	Monocots	Annuals	Perennials
Cover	92.7	4.7	0.7	5.2	0.3
Richness	9.00	5.7	1.3	6.3	0.7

Soil properties:

pH	P (mg l^{-1})	K (mg l^{-1})	Mg (mg l^{-1})
8.0	47	145	53

Species: *Fumaria parviflora* **No. of records:** 1

Grid ref.	Date	Field margin type	Soil texture	NVC	No. of individs
TL 39 36	10/07/03	uncropped wildlife strip	ZCL	OV15a	1

Community data (means from three 4m^2 quadrats):

	Total	Dicots	Monocots	Annuals	Perennials
Cover	51.2	33.8	15.8	17.7	20.0
Richness	22.0	15.7	4.3	10.7	7.7

Soil properties:

pH	P (mg l^{-1})	K (mg l^{-1})	Mg (mg l^{-1})
8.3	21	113	15

Species: *Iberis amara* **No. of records:** 1

Grid ref.	Date	Field margin type	Soil texture	NVC	No. of individs
TL 29 40	26/07/03	uncropped wildlife strip	ZCL	OV15a	11-100

Community data (means from three 4m^2 quadrats):

	Total	Dicots	Monocots	Annuals	Perennials
Cover	44.7	4.8	0.7	26.5	9.5
Richness	20.7	19.0	6.7	13.7	3.3

Soil properties:

pH	P (mg l^{-1})	K (mg l^{-1})	Mg (mg l^{-1})
8.4	16	93	21

Species: *Papaver hybridum* **No. of records:** 2

Grid ref.	Date	Field margin type	Soil texture	NVC	No. of individs
TL 65 60	11/07/03	conservation headland	ZCL	OV16	2-10
TL 29 39	25/07/03	uncropped wildlife strip	ZCL	OV15a	11-100

Community data (means from three 4m^2 quadrats per site):

	Total	Dicots	Monocots	Annuals	Perennials
Cover	49.7-101.5	5.7-49.2	0-0.3	4.2-44.5	0.2-4.7
Richness	10.7-16.3	8.0-15.3	0-0.7	7.3-12.3	0.3-3.0

Soil properties (range):

pH	P (mg l^{-1})	K (mg l^{-1})	Mg (mg l^{-1})
8.3-8.4	11-30	96-170	17-37

Species: *Polygonum rurivagum* **No. of records:** 2

Grid ref.	Date	Field margin type	Soil texture	NVC	No. of individs
TL 84 60	16/04/03	no-fertiliser conservation headland	ZCL	OV15a	1
TL 81 56	30/07/03	uncropped wildlife strip	CL	OV10b	2-10

Community data (means from three 4m^2 quadrats):

	Total	Dicots	Monocots	Annuals	Perennials
Cover	67.0-105.8	6.3-103.7	0.2-1.7	5.3-100.2	0.5-5.2
Richness	11.7-15.0	10.3-12.7	0.3-0.3	9.7-10.7	1.0-1.0

Soil properties (range):

pH	P (mg l^{-1})	K (mg l^{-1})	Mg (mg l^{-1})
7.6-8.3	12-41	150-179	41-41

Species: *Scandix pecten-veneris* **No. of records:** 1

Grid ref.	Date	Field margin type	Soil texture	NVC	No. of individs
TL 81 56	30/07/03	uncropped wildlife strip	ZCL	OV8	2-10

Community data (means from three $4m^2$ quadrats):

	Total	Dicots	Monocots	Annuals	Perennials
Cover	101.7	86.0	8.3	93.0	8.2
Richness	16.0	12.7	1.0	12.7	2.3

Soil properties:

pH	P (mg l^{-1})	K (mg l^{-1})	Mg (mg l^{-1})
7.2	31	153	40

Species: *Silene noctiflora* **No. of records:** 12

Grid ref.	Date	Field margin type	Soil texture	NVC	No. of individs
TL 65 60	11/07/03	conservation headland	SZL	OV16	11-100
TL 84 60	15/07/03	normally cropped cereal headland	SZL	OV16	101-1000
TL 65 60	11/07/03	conservation headland	ZCL	OV16	2-10
TL 64 60	15/07/03	wildlife seed mixture	SZL	OV7	11-100
TL 84 59	11/07/03	no-fertiliser conservation headland	ZCL	OV15a/ OV16	11-100
TL 84 60	16/07/03	no-fertiliser conservation headland	ZCL	OV15a	101-1000
TL 84 60	16/07/03	no-fertiliser conservation headland	ZCL	OV16	11-100
TL 84 60	16/07/03	no-fertiliser conservation headland	ZCL	OV10b/ OV33	1
TL 84 60	17/07/03	no-fertiliser conservation headland	ZC	OV15a	1-10
TL 84 60	17/07/03	no-fertiliser conservation headland	ZCL	OV15a	11-100
TL 84 59	17/07/03	no-fertiliser conservation headland	ZCL	OV8	11-100
TL 84 59	17/07/03	no-fertiliser conservation headland	ZL	OV8/ OV12a	101-1000

Community data (means from three 4m^2 quadrats per site):

	Total	Dicots	Monocots	Annuals	Perennials
Cover	64.5-104.0	5.0-55.3	0-1.3	3.0-62.0	0-2.6
Richness	8.3-17.0	7.0-15.7	0-2.7	4.7-13.3	0.3-3.7

Soil properties (range):

pH	P (mg l^{-1})	K (mg l^{-1})	Mg (mg l^{-1})
7.7-8.4	12-27	77-440	22-70

Project Reference MA01017

Monitoring of Cereal Field Margin Options in Agri-Environment Schemes
Part 1: Arable Stewardship Pilot Scheme: Bumblebee Monitoring

Final report

NERC Centre for Ecology and Hydrology
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Providing foraging resources for bumblebees in contrasting intensively farmed landscapes

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Key-words: habitat creation; restoration; field margins; conservation headlands; seed mixtures; pollen and nectar resources

Abstract

Habitat loss and the intensification of farming practices have caused severe declines in the range and abundance of many bumblebee species in the UK. This study examines the long-term effectiveness of four different management strategies to enhance and restore bumblebee foraging habitat on arable field margins in two regions with markedly contrasting landscape structure, farming systems and amount of semi-natural habitat. Bumblebees were monitored on 120 field margins in July and August, together with estimates of flower abundance and the vegetation composition. There were no differences in the abundance and diversity of the bumblebee assemblage between the two regions, despite a greater abundance of flowers and flowering species on the lighter soils of the West Midlands. Very few bumblebees were recorded on intensively managed cereal field margins due to the lack of dicot species. Conservation headlands supported a significantly greater number of flowering dicots, but the majority of these were annuals which did not provide good forage for bumblebees. From an agronomic and ecological perspective, the removal of the field margin from the cropping system was the best strategy for providing foraging habitat for bumblebees. Non-crop habitat resulting from natural regeneration provided good foraging habitat for bumblebee species, but most of the key forage species were pernicious weeds of agriculture (*Cirsium* sp.). Sowing non-crop field margins with wildlife seed mixtures had the potential for providing the best foraging habitat for bumblebees provided preferential forage species were introduced (e.g. *Trifolium pratense*). Further research is required to refine and target this management prescription for bumblebee conservation in the wider countryside.

1. Introduction

In recent years many bumblebee (*Bombus*) species have shown serious declines in abundance and marked contractions in geographic range both in Europe and North America (e.g. Williams, 1982; Rasmont, 1995; Banaszak, 1996; Buchmann and Nabhan, 1996; Westrich 1996). In the UK, three species have become extinct and a further five have become so restricted in their distribution that they have been placed on the UK Biodiversity Action Plan (UKBAP) (Anon., 1995) as priorities for conservation. The primary cause of these declines is thought to be the post-war intensification of agriculture (Osborne and Corbet, 1994). Traditional mixed livestock and arable farming has declined to be replaced with simplified cropping patterns which are applied to increasingly consolidated parcels of land. This has caused the loss and fragmentation of essential foraging and nesting habitats for bumblebees, such as species-rich hay meadows, field headlands and hedgerows. This is coupled with the increasingly intensive management of each land parcel, including the greater usage of fertilisers and insecticides, and shorter fallow periods. The net result has been the significant decline in abundance of a number of highly preferential bumblebee forage plants in the UK Countryside, especially members of the Fabaceae and Lamiaceae (Carvell et al., 2001).

Bumblebees provide an essential pollination service for both semi-natural and agricultural ecosystems (Corbett et al. 1991; Kevan and Baker, 1983; Free, 1993). In order to maintain this service they require suitable sites for nesting and hibernation, and a continuous supply of pollen and nectar resources throughout the spring and summer months (Steffan-Dwenter and Tscharntke, 2001). Declines in the abundance and diversity of bumblebees may therefore have serious implications for plant community composition, the conservation of small, fragmented populations of native plant species (Kwak et al., 1991; Steffan-Dwenter and Tscharntke, 1999), and the yield of many entomophilous crops (Holm, 1966; Willmer et al., 1994). It is therefore essential to maintain and restore suitable habitats for bumblebees and other pollinators in agricultural landscapes. Indeed, this has been recently recognised as a globally important issue by the launch of the International Pollinator Initiative in 2000 (http://www.biodiv.org/doc/meetings/sbstta/sbstta-07/official/sbstta-07-09-add1-en.pdf).

Recent changes to European agri-environmental policy recognise the need to conserve and enhance biodiversity in intensively managed agricultural landscapes (Bignal, 1998). With this in mind, it is becoming increasingly important to develop practical, cost-effective prescriptions to manage farmland for the benefit of wildlife. In the UK, this policy is delivered nationwide through the Countryside Stewardship Scheme (Defra, 2002). The prescriptions available for habitat restoration and management on arable land were developed primarily from an experimental agri-environmental scheme (the Arable Stewardship Pilot Scheme (ASPS)) which was established in 1998 (MAFF, 1998). The scheme offered opportunities and financial incentives to maintain and restore wildlife habitats on intensively managed arable land by following a number of prescribed methods, including within whole-field habitat enhancement (over winter stubbles and spring fallow, undersown cereals and grass leys), and habitat creation at the edge of the field. The ASPS examined two contrasting field margin management philosophies: namely the enhancement of biodiversity within the crop through the reduction in the use of herbicides and pesticides at the field edge (conservation headland), compared with the removal of the field margin from cropping followed by targeted habitat creation, either by sowing a seed mixture or allowing natural regeneration from the seed bank.

Conservation headlands encourage the survival of broad-leaved annuals and their associated insects (Critchley et al., *in press*). However, annual plants, with some exceptions, do not provide a good supply of nectar. Nectar-rich perennial and biennial species are the favoured forage for bumblebees (Fussell & Corbet 1992). The effectiveness of conservation headlands for providing bumblebee foraging habitat has been examined in the field, but the results have been inconclusive. Significantly higher numbers of bumblebees visited the non-crop, naturally regenerated field margins compared with the conservation headlands (Kells, Holland and Goulson, 2001). However, a more recent study found no significant difference in the abundance of bumblebees between both habitat types (Meek et al., 2002a).

Non-crop field margins sown with tussocky grass species provide suitable habitat for animals for which a dense, sheltered vegetation structure is important, such as hibernating carabid and staphylinid beetles, spiders, small mammals, nesting bumblebees and certain breeding birds (Smith *et al* 1993; Marshall and Moonen 1998; Thomas *et al* 1992; Svensson et al, 2000; Collins et al., 2003a&b; Kells and Goulson, 2003). Similarly, sowing non-crop field margins with perennial wildflowers can enhance the number of nectar- and pollen-feeding invertebrates, including butterflies, bumblebees, honeybees and hoverflies (e.g. Lagerlöf et al., 1992; Feber et al., 1996; Carvell et al., *in press*), especially if the margin occupies a sunny, sheltered position (e.g. Dover, 1996, Pywell et al., *in press*). However, most of these studies have focused on a single location where geographic factors, such as the size of the local species pool and individual populations, may have a strong influence on the results. Furthermore, most studies have been conducted on newly created habitats in the early stages of succession.

In this study we examined the long-term effectiveness of both crop and non-crop ASPS field margin options in providing foraging habitat for bumblebees on a large number of sites situated in two contrasting landscape types. In order to achieve this we will test the following hypotheses:

H1: *Regional effects on bumblebees*: the abundance and diversity of bumblebees is greater in the more enclosed, mixed farming region of the West Midlands, compared with the open, intensive arable region of East Anglia;

H2: *Value of conservation headlands*: bumblebee richness and abundance are significantly higher on conservation headlands compared with equivalent margins under conventional cereal production;

H3: *Value of non-cropped habitats*: richness and abundance of bumblebees are higher on non-cropped margin habitats compared with equivalent areas cropped with cereals;

H4: *Value of sown non-crop habitats*: field margins sown with dicot seed mixtures provide better foraging habitat for bumblebees than naturally regenerated margins or conservation headlands.

The results are discussed in the context of (i) the ecological role of the different habitats in bumblebee conservation, and (ii) the implications for future agri-environment scheme policies aimed at the enhancement and creation of habitat for bumblebees on farmland.

2. Methods

2.1. Site selection

In 1998 the Arable Stewardship Pilot Scheme (ASPS) was established in two regions of the UK with markedly contrasting soil types, topography and farming systems (Fig. 1). The East Anglian Pilot Area was situated the south-eastern lowlands of England on calcareous heavy soils and loams. The region is characterised by large, open fields supporting predominantly intensive arable farming. There is comparatively little remnant semi-natural habitat. In contrast, the West Midlands Pilot Area was situated in the central midlands of England on soils with a light to medium texture. This region is characterised by smaller, enclosed fields supporting more mixed and varied farming systems. More semi-natural habitat has survived in this region.

The sample comprised 19 farms in East Anglia and 17 farms in the West Midlands which had ASPS management agreements in place in 1999. In the summer of 2003 bumblebees were monitored on a number of field margin 'sites' on each farm where ASPS options had been implemented. Sample field margins were selected using proportionate random sampling, such that the number of sites selected on a farm was in proportion to the number of sites of that type on the farm. This ensured that the sample was representative of the statistical population of sites under each management option. Three ASPS options were sampled for bumblebees (Table 1):

conservation headland with no fertilisers (3b) (16 sites), naturally regenerated field margins (4c) (18 sites) and field margins sown with a wildlife seed mixture (5) (28 sites). These were selected on the basis of uptake and their potential value as foraging habitat for bumblebees. The non-crop margin options (4c and 5) remained static from 1999. However, the conservation headland option (3b) can move around the farm each year with the cereal crop rotation. Therefore, new samples of these were selected for the 2003 survey. A paired approach was adopted in which bumblebee numbers were estimated from both the targeted option and, at the same time, from a nearby, conventionally managed cereal field margin with the similar aspect and boundary type. This acted as a control treatment. It was possible to pair a very high proportion (97%) of the ASPS options with a cereal control margin in this way. Bumblebees were recorded on a total 75 option sites in the East Anglia and 45 option sites in the West Midlands.

2.2. Bumblebee monitoring

Bumblebees were recorded on the sample ASPS options in July and again in August. At each field margin site, a 100 m long sampling zone was randomly located, but not within 10 m of either end of the margin. On each visit, foraging bumblebees were counted along linear transects of 100 × 6 m cited along the centre line of options established in strips (Banaszak 1980). For options established as blocks which were less than 100 m in length, bumblebees were counted along two parallel transects of 50 × 6 m. The crop edge and hedge base were avoided. A note was made of the plant species on which each bumblebee was foraging. *B. terrestris* and *B. lucorum* were collectively recorded, as workers of these species cannot be reliably distinguished in the field (Prŷs-Jones & Corbet, 1991). Similarly, the different castes (queen, worker or male) of *B. lapidarius* were distinguished, but for other species, in which workers and males are difficult to separate, all individuals were recorded together. The cuckoo bumblebees (*Psithyrus* spp.), which are brood parasites of 'true' *Bombus* species, were counted together as a group for analysis, but honeybees and solitary species were not noted. Walks were carried out between 10.00 and 17.00 when weather conformed to Butterfly Monitoring Scheme (BMS) rules (temperature above 13°C with at least 60% clear sky, or 17°C in any sky conditions. No count at all if raining). The shade (ambient) temperature, percentage sunshine and wind speed were recorded at the end of each transect walk.

2.3 Vegetation survey

Vegetation sampling was undertaken in the same sampling zone as that of the bumblebee counts, but encompassed the full width of the field margin (4 m to 12 m) rather than a 6 m width along the centre line. In the sampling zone, twenty 0.5 × 0.5 m quadrats were randomly positioned. The presence of all vascular plant species rooted in the quadrat was recorded in each quadrat. Plant species nomenclature follows Stace (1997).

2.4 Flower survey

Following each bumblebee walk, the flowering component of the vegetation along each transect was recorded to give a measure of the forage resource availability. All flowering plants were recorded in the field (122 species). The approximate abundance of single flowers and multi-flowered stems for groups such as umbellifers, labiates and vetches were scored using a simple floristic index (Carvell et al., *in press*): 1. Rare (approx. 1 – 25 flowers); 2. Occasional (approx. 26 - 200 flowers); 3. Frequent (approx. 201 - 1000 flowers); 4. Abundant (approx. 1001+ flowers); 5. Super-abundant (more than 5000 flowers). These flower abundance scores were later combined into 18 broad groups to allow analysis: Convolvulaceae (Bindweeds); Boraginaceae (Borages); bramble/Rosaceae; Caryophyllaceae; Chenopodiaceae (Fat hens); Asteraceae (Thistles/daisies) red/purple; Asteraceae (Thistles/daisies) yellow/white; Geraniaceae (Cranesbills); Brassicaceae (Crucifers); Onagraceae (Epilobiums); Lamiaceae (Dead nettles); Fabaceae (legumes) red/purple;

Fabaceae (legumes) yellow/white; polygonaceae; scrophulariaceae; Apiaceae (Umbellifers) and small-flowered annuals.

2.5 Statistical analysis

A detrended correspondence analysis (DCA) (Hill, 1979) on logarithmic transformed plant frequency data was used to determine the variation in the plant communities between the 120 transects. There was a unimodal response of species along the first axis, confirming that this was the appropriate method to use. DCA was undertaken using Canoco (version 4.5) software (ter Braak & Šmilauer, 1998).

Differences between field margin types were further investigated by comparing a range of plant group variables. These comprised both species number (richness) and cumulative frequency from the 20 quadrats for crop, dicotyledons, monocotyledons, annuals and perennials (excluding crop species). In addition, the flower counts from each visit were combined to describe differences in forage resources between sites in terms of overall number of flowering plants (flower richness) and total flower abundance.

Counts of individual bumblebee species from the July and August visits were summed for each site. In addition, the summary groupings of total bumblebee number and species richness, and the functional grouping of short- and long-tongued species (Prŷs-Jones & Corbet, 1991) were calculated for each site. Logarithmic transformation of all the count data was undertaken prior to analysis to normalise residual variation.

Overall differences in the plant groups, forage resources, and both individual and summary bumblebee variables between the two pilot areas were examined using two-sample t-tests. Differences between the individual field margin options and the paired conventional cereal field margin controls were examined using two-way Analysis of Variance (ANOVA) with site and treatment as factors. Finally, differences between the three field margin treatments (3b, 4c and 5) were examined using a one-way ANOVA with Tukey's Honest Significant difference test. Prior to this analysis the effect of site was removed by subtracting the count or scores for the control from that of the paired margin treatment.

The relationship between logarithmic bumblebee abundance and environmental factors, such as flower abundance scores, was investigated using forward stepwise regression analysis. During the model-fitting process, Alpha-to-enter and Alpha-to-remove were set at 0.15, and only final models in which all variables were significant ($P \leq 0.05$) were accepted. All analyses were performed using Minitab 13 statistical software (Ryan, Joiner & Ryan, 2000).

3. Results

Across all 120 sites a total of 1376 true bumblebees representing seven species were recorded. These included *Bombus ruderarius* recorded on one transect in East Anglia, which is a species not commonly seen on farmland. In addition, 58 individuals of bumblebee brood parasites (*Psithyrus* sp.) were recorded.

3.1 Variation in plant communities between treatments

During the survey a total of 234 plant species (including crops) were recorded. These are listed in the Appendix. The DCA indicated that the first two ordination axes accounted for 12.8% of the variation in the vegetation data between the sites. There was clear separation of the different field margin types (Fig. 2). The crop and non-crop field margin habitats clearly separated along axis 1 (Fig. 2a). The conventionally managed cereal field margin had the lowest axis 1 scores (0 to 3). There was considerable overlap with the ordination space occupied by the conservation headland sites (3b). The non-crop field margin options (4c and 5) were generally well separated from the crop and conservation headlands along axis 1, with scores of 2 to 4. The option 5 sites had the most extreme axis 1 scores. There was also some separation of the naturally regenerated margins (4c) and those sown with a wildlife seed mixture (5) along axis 2. The option 5 sites had a wider range of axis 2 scores (0 to 4) compared with option 4c (2 to 4).

Species with large weights in the DCA which were associated with the conventionally managed cereal field margins and conservation headlands were crop species, such as *Triticum aestivum* (Fig. 2b), together with the most frequent annual weed species of cereal fields: monocotyledons *Alopecurus myosuroides, Poa annua, Anisantha sterilis;* and dicotyledons *Galium aparine, Fallopia convolvulus, Veronica persica, Polygonum aviculare, Chenopodium album* and *Tripleurospermum inodorum.* Species associated with the naturally regenerated and sown field margins (4c and 5) were perennial monocots, such as *Dactylis glomerata, Holcus lanatus, Poa trivialis, Festuca rubra* and *Arrhenatherum elatius*, together with perennial dicots, *Cirsium arvense, Cirsium vulgare, Carduus nutans, Urtica dioica Rumex obtusifolius* and *Plantago major.*

The greatest number of preferential bumblebee forage plants (shown in bold on Fig. 2b) was associated with the non-crop field margin options (4c and 5). Several of these species, such as *C. vulgare* and *C. nutans* were associated with the cultivated natural regeneration margins (4c). Whereas others, such as *Trifolium pratense, Lotus corniculatus* and *Phacelia tanacetifolia* were introduced to sites in the wildlife seed mixtures (option 5).

3.2 Differences between the Pilot Areas

There were relatively few differences in the overall field margin vegetation composition, regardless of treatment, between the two pilot areas (Table 2). Field margins in the West Midlands contained on average more species per 100 m (18.19±1.55) compared with East Anglia (14.39±1.28), but these differences were not quite significant (P=0.06). However, margins in the West Midlands did contain significantly more monocot species than East Anglia (4.79±0.39

compared with 3.19±0.35), and significantly more perennial species (8.77±1.06 compared with 4.87±0.74). Similarly, the cumulative frequency of both monocots and perennials was significantly higher in the West Midlands compared with East Anglia. In addition, the total abundance of dicot flowers and the number of flowering dicot species were both significantly greater in the West Midlands (10.82±1.21 and 9.07±0.90 respectively) compared with East Anglia (6.32±0.82 and 6.37±0.65) (Table 2). However, despite these significant differences in the vegetation and forage resource, there were few differences in the abundance and richness of bumblebees between the two pilot areas. Only *Bombus pratorum* was significantly more abundant in the West Midlands (0.31±0.12 per 100 m) compared with E. Anglia (0.01±0.01).

3.3 Conservation Headlands

There were a large number of significant differences in the vegetation composition of the conservation headlands (option 3b) compared with the conventionally managed cereal field margins (control) (Table 3). Conservation headlands contained on average more species per 100 m (15.38±1.87) compared with the control (7.46±0.98). This was primarily due to the significantly greater number of dicot species present on conservation headlands (12.23±1.80) compared with the controls (3.85±0.74). The majority of these species were annuals. Dicots, annuals and perennials also had a much greater cumulative frequency in the conservation headland compared with the control. It follows that the conservation headlands also supported a significantly greater abundance of dicot flowers and richness of flowering plants compared with the cereal control. However, there were no significant differences in either the abundance or species richness of any individual bumblebee species or functional grouping between the conservation headlands and the control.

3.4 Habitat creation by natural regeneration

The non-crop, naturally regenerated field margin vegetation (option 4c) contained on average four times the number of species (29.75±1.45) compared with the cereal field margin control (7.00±0.99) (Table 4). Much of this difference was due to the greater number of dicot species on the 4c margins. There was an approximately equal split between annual and perennial species. A similar pattern was repeated for cumulative frequency of these species groups. The number and frequency of crop species was significantly higher on the control compared with the 4c margins. Flowering dicots were also significantly more abundant on the 4c margins in the July and August period compared with the controls (Table 4). The diversity of the forage resource was also significantly greater, with four times the number of flowering species on the 4c margins (12.75±1.30) compared to the control (3.25±0.78). With the exception of *Bombus pratorum*, all bumblebee species were significantly more abundant on the naturally regenerated margins compared with the conventional cereal field margins (Table 4). Overall, there was a mean of 18.31 (±5.22) bumblebees recorded per 100 m in July and August on the 4c margins compared with 0.19 (±0.14) on the control margins. Similarly, 2.75 (±0.34) bumblebee species were present on the 4c margins compared with 0.19 (±0.14) on the controls.

3.5 Habitat creation by sowing wildlife seed mixtures

The non-crop field margins sown with a wildlife seed mixture (option 5) contained more than twice the number of species (23.23±1.93) than the conventionally managed cereal field margin (9.83±1.26) (Table 5). Moreover, the option 5 margins contained a significantly greater number and cumulative frequency of monocots, dicots and perennials. There were no differences in the number and frequency of annuals between the two margin types. Flowering dicots were also significantly more abundant and diverse (12.00±0.94) on the sown margins compared with the cereal controls

(4.57±0.76) (Table 5). With the exception of *Bombus hortorum*, all bumblebee species were significantly more abundant on the margins sown with the wildlife seed mixtures compared with the conventional cereal field margins (Table 5). Overall, there was a mean of 28.61 (±6.56) bumblebees recorded per 100 m in July and August on the option 5 margins compared with just 0.29 (±0.13) on the control margins. Similarly, 3.00 (±0.30) species were recorded on the 4c margins compared with 0.25 (±0.10) on the controls.

3.6 Comparison of crop and non-crop habitat creation

Bumblebee abundance per 100 m (0.21±0.08) and species richness (0.19±0.07) was very low on the conventionally managed cereal field margin controls (Fig. 3). A small number of bumblebees were recorded on the conservation headlands (3b) (1.31±0.95). In contrast, a comparatively large number (18.29±4.90) and richness (3.65±0.48) of bumblebees was recorded on the non-crop, natural regeneration margins. However, the greatest abundance (37.79±8.64) and richness (4.11±0.46) of bumblebees were found on the non-crop field margins created by sowing a wildlife seed mixture.

After allowing for site effects, there were a large number of significant differences in the vegetation composition, forage resources, and bumblebee abundance and richness between the different field margin types (Table 6). The naturally regenerated field margins (4c) contained significantly more plant species (22.29±1.85) compared with either the field margins sown with a wildlife seed mixture (5) (12.04±2.10) or the conservation headlands (3b) (7.92±2.10). The non-crop margins (4c and 5) had significantly greater number and cumulative frequency of monocot and perennials species than the conservation headland. Furthermore, the natural regeneration margins contained a significantly higher number and frequency of dicots than either the conservation headlands or the wildlife seed mixtures. Finally, the natural regeneration margins had a significantly greater number and frequency of annuals than the margins sown with wildlife seed mixtures. There were also significant differences in the bumblebee forage resource between the margin types (Table 6). The naturally regenerated margins contained a significantly greater abundance and richness of dicot flowers in July and August than the conservation headland, but not the margins sown with wildlife seed mixtures.

Significantly greater numbers of *B. terrestris/lucorum* and *B. pascuorum* were recorded on the non-crop field margins (options 4c and 5) compared with the conservation headland (3b). Similarly, significantly higher numbers of *B. lapidarius* were recorded on the non-crop margins sown with wildlife seed mixtures compared with the conservation headlands. There were significantly greater numbers of all bumblebees recorded on the wildlife seed mixture margins (37.46±8.62) and natural regeneration margins (18.13±5.19) compared with the conservation headlands (1.62±1.16). There was a similar pattern for the richness of bumblebee species, with more than 2.5 species recorded on average on the non-crop margins compared with 0.5 species on the conservation headland.

3.7 Forage plant preferences

During the study a total of 1434 foraging bumblebees (including *Psithyrus* sp.) were observed visiting 49 flowering plants. The plant species receiving the most foraging visits varied between the different field margin types, reflecting the relative abundance of those species flowering on each margin treatment (Fig. 4). However, *Cirsium arvense* and *C. vulgare* together accounted for a significant proportion of the foraging visits in all margins. The conventionally managed crop and conservation headlands provided the most limited range of forage plants. Annual dicot weeds, such as *Viola arvensis*, accounted for half of the foraging visits (6) in the crop. Over 80% of the foraging visits in the conservation headland were to *Cirsium* sp. Dicots of the Asteraceae family, such as *Cirsium* spp., *Carduus nutans* and *Sonchus arvensis*, accounted for over 70% of the foraging visits on the non-crop margins produced by natural regeneration. The non-crop margins sown with wildlife seed mixtures provided the greatest range of forage species. On these margins, sown forage species (*Trifolium pratense*, *T. hybridum*, *Lotus corniculatus,* and *Phacelia tanacetifloia*) accounted for a significant proportion (28%) of foraging visits.

The short-tongued species group *B. terrestris/lucorum* showed a preference for foraging on *Cirsium arvense* followed by *C. vulgare* and *Phacelia tanacetifolia* (Fig. 5). These three species accounted for 56% of visits. *B. lapidarius* has an intermediate tongue length and showed marked preference for foraging on *C. arvense* (37% of visits), followed by *Trifolium hybridum*, *Sonchus arvensis* and *C. vulgare*. The most abundant long-tongued species was *B. pascuorum*. This species showed a preference for foraging on *T. pratense* and *C. vulgare*, together accounting for 50% of the visits. The other long-tongued species, *B. hortorum*, also showed a strong preference for *T. pratense* (33%), followed by *C. vulgare* .

Stepwise multiple regression analyses allowed the above relationships to be examined in more detail (Table 7). All of the multiple regression models were highly significant, and with the exception of two species recorded in low numbers (*B. pratorum* and *B. hortorum*), most had a high degree of explanatory power, with R^2 values in excess of 65%. The results highlight the importance of the red/purple-flowered legume group (Fabaceae) in explaining the abundance of most bumblebee species with the exception of *B.terrestris/lucorum* and *B. pratorum*. Similarly, the yellow/white-flowered legumes were positively associated with the abundance of all species except *B. terrestris/lucorum* and *Psithyrus* sp. Total flower abundance, red/purple legumes and thistles\daisies (Asteraceae) were the most important variables in explaining the total numbers of bumblebees. Small-flowered annuals had a strong negative effect. Red/purple thistles\daisies, borages, bindweeds and yellow/white legumes were all important in explaining variation in bumblebee species richness between sites. There was a strong positive association borage and total flower abundance in explaining the numbers of the short-tongued generalists *B.terrestris/lucorum*. Similarly, both red/purple thistles\daisies and legumes were important in explaining the abundance of *B. lapidarius*. Total flower abundance and yellow/white legumes were associated with large numbers of *B. pratorum*. Red/purple legumes and thistles\daisies were significantly correlated with the abundance of *B. pascuorum*. Finally, legume flowers were important in explaining the abundance of *B.hortorum*.

4. Discussion

4.1 The bumblebee assemblage on farmland

This study confirmed the relatively impoverished nature of the bumblebee assemblage present within these two intensively farmed landscapes of lowland Britain. Six of the bumblebee species recorded belonged to the widespread lowland group defined by Williams (1982). Of these, 78% of the sample was classified as short-tongued, generalist species (*B. terrestris, B. lucorum, B. lapidarius* and *B. pratorum*) and the remaining 22% were long-tongued species (*B. pascuorum, B. hortorum*). This latter group has undergone the most dramatic declines in geographic range and abundance in recent years, and is considered the most vulnerable. Indeed most of the threatened UK BAP listed bumblebees are long-tongued species. Many of these species are associated with extensive areas of unimproved, flower-rich habitat supporting large numbers of flowers with long corollas, especially those belonging to the plant families Lamiaceae and Fabaceae. (Falks, 1981). A recent analysis of change in the UK flora based on Countryside Survey found that more than 70% of bumblebee forage plants declined, and nearly 30% had shown significant declines between 1978 and 1998 (Carvell et al., 2001). Amongst these were a number of highly preferential forage plants for long-tongued bumblebees (e.g. *Trifolium pratense*, *Lotus corniculatus*).

However, in this study recorded small numbers of the Nationally Scarce, long-tongued species *Bombus ruderatus* on one transect in East Anglia. Others were also noted close to transects in the same area. This species was formerly widespread in southern Britain, but has undergone dramatic declines so that there were fewer than 10 confirmed post-1980 sites. The BAP for this species requires the enhancement of existing populations and re-introduction at other suitable localities so that by 2010 there are 20 viable populations within the historic range. Our results suggest that habitat creation under the Arable Stewardship Pilot Scheme maybe making an important contribution towards this policy objective.

4.2 Creation and enhancement of bumblebee foraging habitat on farmland

The observed effects of field margin type on the abundance of foraging bumblebees can largely be explained by the availability of suitable flowers. In the last 40-50 years many plant species associated with lowland farmed landscapes have shown marked contractions in geographic range and severe declines in abundance (Wilson et al., 1999; Smart et al., 2000; Preston et al., 2002). The impoverished flora of arable land now typically comprises a small number of species which can tolerate modern, intensive farming practices, including autumn sowing, the frequent use of selective herbicides, high rates of fertiliser application and efficient seed cleaning (Robinson and Sutherland, 2002). The majority of these species, such as *Galium aparaine, Polygonum aviculare* and *Alopecurus myosuroides*, do not provide suitable forage for bumblebees. Intensively managed cereal field margins have also been shown to provide poor habitat for other nectar-feeding invertebrates, such as butterflies (Pywell et al. *in press*), as well as other groups, such as carabids, spiders and harvestmen (Meek et al., 2002b).

The restricted use of herbicide, and in some cases fertiliser, at the field edge has been shown to encourage the survival of annual dicots and their associated insects (Critchley et al., *in press*). However, many arable plant communities have become impoverished following years of intensive management, and, with few exceptions (e.g. *Viola arvensis*), they do not provide a good forage for bumblebees (Fussell & Corbet 1992). These factors probably explain the lack of a positive effect of conservation headlands on bumblebee abundance.

There are good agronomic and ecological arguments for removing the edges of fields from arable cropping. These areas are typically less fertile, and more prone to drought and shading than other parts of the field. As such they typically produce lower yields (Boatman, 1992; Cook and Ingle, 1997), and often require greater inputs of pesticide and fertiliser for a lower economic return (de Snoo and Chaney, 1999). In addition, field edges often harbour populations of pernicious weeds (e.g. *Anisantha sterilis, Galium aparine* and *E. repens*) which can spread into the crop and prove difficult to control (Marshall and Moonen, 2002). The vegetation community which develops on arable field margins by natural succession following removal from cropping will be dependant on the management history, the surrounding vegetation, and the composition and size of the seed bank (Firbank et al., 1993). The development of very diverse vegetation is likely to be constrained by the high residual soil fertility, increasingly impoverished species pool in arable landscapes, together with evidence that the overall size of the seed bank in arable soils has declined markedly in recent years (Robinson and Sutherland, 2003). Nevertheless, relatively diverse plant communities with an average of 29.7(±1.4) species per 100 m were recorded on the field margins following 5 years of succession. The management prescription for these naturally regenerated margins requires shallow (100-150 mm) cultivation in the spring or autumn of every year or every other year (MAFF, 1998). This type of management will tend to encourage the dominance of widespread perennial grasses and forbs which were originally present at the field edge and in the hedge bottom, and regenerate by vegetative means (e.g. *Cirsium arvense, Trifolium repens, Elytrigia repens*), or have a biennial life history (e.g. *Cirsium vulgare, Carduus nutans*). However, the frequent cultivation prevents the plant communities from became increasingly dominated by grassland species as was found for non-rotational setaside land (Firbank et al., 2003). It is the abundance of perennial and biennial thistle species which primarily accounts for the greater numbers of foraging bumblebees found in this field margin type compared with the conventionally cropped margins or conservation headland. However, the value of this habitat for foraging bees proved to be very variable, and most of the key forage plants it produced were pernicious weeds (*Cirsium* sp.) which require control under the

Weeds Act (1959). Indeed, studies have shown that where a field margins contains such undesirable plant species at the outset, these are likely to increase under natural regeneration (West et al., 1997; Smith et al., 1999).

Introducing species to field margins by sowing a wildlife seed mixture offers the opportunity for directing vegetation succession and therefore achieving a more targeted habitat restoration for bumblebees. Other studies have demonstrated that carefully designed wildflower seed mixtures can be very successful in supplying forage resources for a range of pollinating insects, including butterflies (Feber et al., 1996; Pywell et al., *in press*) and bumblebees (Carreck et al., 1999; Bäckman and Tiainen, 2002; Carvell et al., *in press*). The resultant dicot-rich vegetation is also good habitat for a wide range of other invertebrate groups (Meek et al., 2002b). Furthermore, sowing a field margin with perennial species will provide a barrier against the spread of pernicious weeds from the field edge into the crop (Marshall and Moonen, 2002). However, not all of the species sown in the wildlife seed mixture option were suitable forage plants for bumblebees, and some (e.g. *Zea mays*) may have had a negative impact by suppressing the abundance of unsown forage species.

The potential value of targeted habitat creation for bumblebees by sowing mixtures of preferential forage species has been recognised. In 2001 Defra announced revised prescriptions for wildlife enhancement on arable farmland which included a specific pollen and nectar seed mixture comprising legumes, such as *Trifolium pratense* and *L. corniculatus* (option WM2, Defra, 2001). Further research is required to test the effectiveness of this prescription in providing forage for bumblebees. However, preliminary results suggest that this approach might be very effective, with an average of 222.5 (±60.2) bumblebees recorded per 100 m in July and August of 2003 on equivalent field margins managed under this prescription (B. Meek, *pers comm.*).

4.3 Implications for bumblebee conservation in the wider countryside

The conservation measures required to sustain bumblebee populations within intensively managed landscapes are complex and poorly understood at present. They are likely to require the provision of suitable habitats for all life-cycle stages, including a season-long succession of nectar and pollen resources, together with mating, nesting and hibernation sites. This study has only focused on the effectiveness of management prescriptions in providing late-summer forage resources. More work is required to determine the importance of other factors, such as the quality of nesting and hibernation sites, on bumblebee population fitness. Indeed, most studies of bumblebees, including this one, make the assumption that an abundance of workers is positively correlated with the success of bumblebee colonies. Empirical measurements of colony density (Chapman, Wang and Bourke, *in press*) and fitness (Goulson et al., 2002) are now possible, and would be a more effective means of measuring the success of habitat restoration and enhancement. Finally, there have been very few studies of the responses of insect pollinators to habitat change at the landscape scale (Bronstein, 1995; Debinski & Holt, 2000; Steffan-Dewenter et al., 2002). These studies suggest that bumblebees may respond to spatial and temporal changes in resource supply at scales greater than a single farm, and that habitat restoration measures may need to be targeted at the regional, rather than the local level. Future research is therefore required to determine how the quantity and spatial distribution of habitats influences the fitness and dynamics of bumblebee populations in the whole landscape.

5. Conclusions

To return to the original hypotheses:

H1: *Regional effects on bumblebees*: despite a significantly greater abundance of dicot flowers and flowering species on the lighter soils of the West Midlands, there were no significant differences in the abundance or richness of bumblebee species recorded on the field margins between the two pilot areas;

H2: *Value of conservation headlands*: restrictions to herbicide and fertiliser application on conservation headlands resulted in a significantly greater number of non-crop plant species, especially dicots, together with a greater abundance and richness of flowering dicots. However, the majority of these species were annuals which did not provide good forage for bumblebees. This resulted in no significant differences in bumblebee abundance or richness between conservation headlands or conventional cereal field margins;

H3: *Value of non-cropped habitats*: removing the field margin from the cropping system and allowing vegetation to develop by natural regeneration provided good foraging habitat for bumblebee species compared with conventionally cropped margins. However, the value of this habitat proved to be very variable, and most of the key forage plants it produced were pernicious weeds (*Cirsium* sp.) which require control under the Weeds Act (1959);

H4: *Value of sown non-crop habitats*: sowing non-crop field margins with wildlife seed mixtures had the potential for providing the best foraging habitat for bumblebees in intensively managed arable landscapes provided preferential forage species (e.g. *Trifolium pratense, Lotus corniculatus*, *Borago officinalis*) are included in the mixture.

This study has demonstrated the value of different habitat for providing forage for bumblebee populations in the late summer. However, the provision of pollen and nectar in spring and early-summer, together with suitable nesting and hibernation habitat are required for the effective conservation of bumblebee populations in the wider countryside. Further work is required to define and test the effectiveness of agri-environment management prescriptions which will provide these essential habitats.

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Table 1
Sample size for the two Arable Stewardship Scheme Pilot Areas and options recorded in 2003

	East Anglia	West Midlands	Total
Conventional cereal field margin	36	22	58
3b (Conservation headland)	13	3	16
4c (Natural regeneration margin)	11	7	18
5 (Wildlife seed mixture margin)	15	13	28
Total	75	45	120

Table 2
Differences in the vegetation composition, forage resources, and bumblebee abundance and species richness between the two Pilot Areas.

	East Anglia (n=75)		West Midlands (n=45)		t-test	P-value
Vegetation - species number						
All species	14.39	±1.28	18.19	±1.55	-1.90	0.061ns
Crop	0.80	±0.08	0.93	±0.12	-1.09	0.279ns
Monocotyledons	3.19	±0.35	4.79	±0.39	**-3.09**	**0.003****
Dicotyledons	10.42	±1.11	12.53	±1.38	-1.19	0.236ns
Annuals	8.59	±0.79	8.49	±0.86	-0.08	0.934ns
Perennials	4.87	±0.74	8.77	±1.06	**-3.02**	**0.003****
Vegetation - cumulative frequency						
Crop	67.75	±5.58	61.05	±7.76	0.70	0.485ns
Monocotyledons	102.54	±14.32	145.23	±14.11	**-2.12**	**0.036***
Dicotyledons	253.91	±30.26	271.98	±41.20	-0.35	0.725ns
Annuals	219.50	±26.30	189.19	±29.47	0.77	0.445ns
Perennials	132.93	±22.71	227.09	±30.64	**-2.47**	**0.016***
Forage resource						
Total flower abundance	6.32	±0.82	10.82	±1.21	**-3.07**	**0.003****
Total flower richness	6.37	±0.65	9.07	±0.90	**-2.41**	**0.018***
Bumblebees						
B. terrestris/lucorum	1.49	±0.41	3.62	±1.02	-1.79	0.055ns
B. lapidarius	8.03	±2.62	3.96	±1.41	0.47	0.637ns
B. pratorum	0.01	±0.01	0.31	±0.12	**-2.52**	**0.015***
B. pascuorum	1.68	±0.61	2.93	±1.06	-1.10	0.277ns
B. hortorum	0.55	±0.33	0.16	±0.10	0.65	0.515ns
Psithyrus spp.	0.61	±0.21	0.27	±0.20	1.44	0.152ns
Short-tongued species	9.53	±2.90	7.89	±2.13	-0.57	0.567ns
Long-tongued species	2.23	±0.88	3.09	±1.12	-0.92	0.360ns
Total bumblebees	12.37	±3.70	11.24	±2.92	-0.68	0.498ns
Richness bumblebees	1.45	±0.25	2.04	±0.38	-1.30	0.199ns

Significant differences are given in bold. Bumblebee count data were log transformed prior to analysis, untransformed means (± se) per 100 m are presented for clarity. Ns = no significant difference; *** P≤0.001; ** P≤0.01; * P≤0.05.

Table 3
Differences in the vegetation composition, forage resources, and bumblebee abundance and species richness between conventionally managed cereal field margins and conservation headlands (3b).

	Cereal field margin (n=13)		Conservation headland (3b) (n=13)		ANOVA $F_{1,12}$	P
Vegetation - species number						
All species	7.46	±0.98	15.38	±1.87	**14.30**	**0.003****
Crop	1.08	±0.14	1.00	±0.11	0.19	0.673ns
Monocotyledons	2.54	±0.53	2.15	±0.37	0.62	0.445ns
Dicotyledons	3.85	±0.74	12.23	±1.80	**22.15**	**0.001*****
Annuals	5.08	±0.84	10.92	±1.35	**11.55**	**0.005****
Perennials	1.31	±0.36	3.46	±0.89	**6.85**	**0.023***
Vegetation - cumulative frequency						
Crop	93.85	±7.91	87.31	±9.07	0.25	0.626ns
Monocotyledons	53.85	±14.91	67.31	±15.06	1.16	0.303ns
Dicotyledons	83.85	±21.06	356.15	±66.09	**19.80**	**0.001*****
Annuals	107.69	±19.44	337.31	±53.67	**14.00**	**0.003****
Perennials	30.00	±12.30	86.15	±24.86	**4.73**	**0.05***
Forage resource						
Total flower abundance	2.15	±0.63	7.25	±1.92	**7.43**	**0.018***
Total flower richness	2.69	±0.55	6.62	±1.41	**7.26**	**0.020***
Bumblebees						
B. terrestris/lucorum	0.00	±0.00	0.15	±0.15	1.00	0.500ns
B. lapidarius	0.00	±0.00	1.31	±0.93	3.40	0.107ns
B. pascuorum	0.00	±0.00	0.15	±0.10	2.18	0.165ns
Short-tongued species	0.00	±0.00	1.46	±1.08	2.97	0.111ns
Long-tongued species	0.00	±0.00	0.15	±0.10	2.18	0.165ns
Total bumblebees	0.00	±0.00	1.62	±1.16	3.10	0.104ns
Richness bumblebees	0.00	±0.00	0.46	±0.27	2.96	0.111ns

Significant differences are given in bold. Bumblebee count data were log transformed prior to analysis, untransformed means (± se) per 100 m are presented for clarity. Ns = no significant difference; *** P≤0.001; ** P≤0.01; * P≤0.05.

Table 4
Differences in the vegetation composition, forage resources, and bumblebee abundance and species richness between conventionally managed cereal field margins and naturally regenerated field margins (4c).

	Cereal field margin (n=16)		Nat. regeneration margin (4c) (n=16)		ANOVA $F_{1,15}$	P
Vegetation - species number						
All species	7.00	±0.99	29.75	±1.45	**144.66**	**<0.001*****
Crop	1.00	±0.00	0.06	±0.06	**169.00**	**<0.001*****
Monocotyledons	3.21	±0.66	6.56	±0.66	**13.59**	**0.003****
Dicotyledons	2.79	±0.54	23.19	±1.33	**167.78**	**<0.001*****
Annuals	4.07	±0.56	15.56	±1.62	**34.06**	**<0.001*****
Perennials	1.80	±0.55	14.13	±1.41	**63.94**	**<0.001*****
Vegetation - cumulative frequency						
Crop	92.86	±7.14	0.63	±0.63	**167.31**	**<0.001*****
Monocotyledons	64.64	±16.70	237.50	±25.45	**45.36**	**<0.001*****
Dicotyledons	37.86	±10.52	546.25	±49.75	**108.60**	**<0.001*****
Annuals	67.33	±11.43	394.69	±71.12	**19.09**	**0.001*****
Perennials	33.67	±13.81	388.44	±42.11	**73.07**	**<0.001*****
Forage resource						
Total flower abundance	2.78	±0.90	15.06	±1.92	**36.07**	**<0.001*****
Total flower richness	3.25	±0.78	12.75	±1.30	**39.53**	**<0.001*****
Bumblebees						
B. terrestris/lucorum	0.13	±0.09	4.00	±2.01	**16.82**	**0.001*****
B. lapidarius	0.00	±0.00	9.56	±4.57	**17.07**	**0.001*****
B. pratorum	0.00	±0.00	0.06	±0.06	1.00	0.333ns
B. pascuorum	0.06	±0.06	3.38	±1.29	**21.43**	**<0.001*****
B. hortorum	0.00	±0.00	0.31	±0.15	**4.69**	**0.047***
Psithyrus spp.	0.00	±0.00	1.00	±0.48	**5.50**	**0.033***
Short-tongued species	0.13	±0.09	13.63	±5.10	**28.23**	**<0.001*****
Long-tongued species	0.06	±0.06	3.69	±1.41	**22.37**	**<0.001*****
Total bumblebees	0.19	±0.14	18.31	±5.22	**73.18**	**<0.001*****
Richness bumblebees	0.19	±0.14	2.75	±0.34	**60.76**	**<0.001*****

Significant differences are given in bold. Bumblebee count data were log transformed prior to analysis, untransformed means (± se) per 100 m are presented for clarity. Ns = no significant difference; *** P≤0.001; ** P≤0.01; * P≤0.05.

Table 5
Differences in the vegetation composition, forage resources, and bumblebee abundance and species richness between conventionally managed cereal field margins and field margins sown with wildlife seed mixtures (5).

	Cereal field margin (n=28)		Wildlife seed mix margin (5) (n=28)		ANOVA $F_{1,27}$	P
Vegetation - species number						
All species	9.83	±1.26	23.23	±1.93	**32.87**	**<0.001*** **
Crop	1.00	±0.09	0.96	±0.23	0.03	0.874ns
Monocotyledons	2.46	±0.42	5.27	±0.58	**20.33**	**<0.001*** **
Dicotyledons	6.38	±1.10	17.12	±1.71	**28.55**	**<0.001*** **
Annuals	6.33	±0.85	10.08	±1.39	2.96	0.099ns
Perennials	2.50	±0.52	12.19	±1.30	**45.69**	**<0.001*** **
Vegetation - cumulative frequency						
Crop	91.46	±5.78	39.81	±10.03	**12.30**	**0.002** **
Monocotyledons	67.29	±12.10	179.23	±23.93	**14.16**	**0.001*** **
Dicotyledons	109.17	±17.60	418.46	±55.15	**44.86**	**<0.001*** **
Annuals	128.96	±14.97	254.62	±48.99	3.03	0.096ns
Perennials	47.50	±10.15	341.73	±40.83	**44.76**	**<0.001*** **
Forage resource						
Total flower abundance	4.03	±0.79	14.29	±1.37	**54.06**	**<0.001*** **
Total flower richness	4.57	±0.76	12.00	±0.94	**45.21**	**<0.001*** **
Bumblebees						
B. terrestris/lucorum	0.18	±0.09	7.00	±1.20	**49.97**	**<0.001*** **
B. lapidarius	0.11	±0.08	21.18	±6.10	**63.22**	**<0.001*** **
B. pratorum	0.00	±0.00	0.43	±0.18	**6.45**	**0.017* **
B. pascuorum	0.04	±0.04	6.86	±1.99	**37.82**	**<0.001*** **
B. hortorum	0.00	±0.00	1.43	±0.87	3.60	0.069ns
Psithyrus spp.	0.00	±0.00	0.89	±0.40	**8.98**	**0.006** **
Short-tongued species	0.29	±0.13	28.61	±6.56	**93.27**	**<0.001*** **
Long-tongued species	0.04	±0.04	8.29	±2.55	**36.08**	**<0.001*** **
Total bumblebees	0.32	±0.14	37.79	±8.64	**106.24**	**<0.001*** **
Richness bumblebees	0.25	±0.10	3.00	±0.30	**90.39**	**<0.001*** **

Significant differences are given in bold. Bumblebee count data were log transformed prior to analysis, untransformed means (± se) per 100 m are presented for clarity. Ns = no significant difference; *** P≤0.001; ** P≤0.01; * P≤0.05.

Table 6

Differences in the vegetation composition, forage resources, and bumblebee abundance and species richness between conservation headlands (3b), naturally regenerated field margins (4c) and field margins sown with wildlife seed mixtures (5). Site effects were removed by subtracting the value from the paired conventionally managed cereal field margin prior to analysis.

	Conservation headland (3b) (n=13)		**Nat. regeneration margin (4c) (n=16)**		**Wildlife seed mix margin (n=28)**		**ANOVA $F_{2,54}$**	**P**
Vegetation - species number								
All species	7.92a	±2.10	22.29b	±1.85	12.04a	±2.10	**10.14**	**<0.001*****
Crop	-0.08ab	±0.18	-0.93b	±0.07	-0.04a	±0.27	**4.22**	**0.021***
Monocotyledons	-0.38a	±0.49	3.43b	±0.93	3.00b	±0.67	**6.89**	**0.002****
Dicotyledons	8.38a	±1.78	19.86b	±1.53	9.22a	±1.73	**11.73**	**<0.001*****
Annuals	5.85ab	±1.72	11.07b	±1.90	2.30a	±1.34	**7.77**	**0.001*****
Perennials	2.15a	±0.82	12.14b	±1.52	9.78b	±1.45	**11.07**	**<0.001*****
Vegetation - cumulative frequency								
Crop	-6.54a	±13.09	-92.14b	±7.12	-48.91ab	±13.95	**8.65**	**0.001*****
Monocotyledons	13.46a	±12.50	188.21b	±27.95	110.44b	±29.35	**8.05**	**0.001*****
Dicotyledons	272.31a	±61.20	498.21b	±47.81	246.52a	±36.81	**8.33**	**0.001*****
Annuals	229.62ab	±61.36	321.43b	±73.57	67.39a	±38.69	**6.09**	**0.004****
Perennials	56.15a	±25.82	364.29b	±42.62	288.04b	±43.05	**12.06**	**<0.001*****
Forage resource								
Total flower abundance	5.08a	±1.86	12.28b	±2.04	10.27ab	±1.40	**3.52**	**0.036***
Total flower richness	3.92a	±1.46	9.50b	±1.51	7.43ab	±1.10	**3.37**	**0.042***
Bumblebees								
B. terrestris/lucorum	0.15a	±0.15	3.88b	±1.95	6.82b	±1.20	**11.39**	**<0.001*****
B. lapidarius	1.31a	±0.93	9.56ab	±4.57	21.07b	±6.09	**8.42**	**0.001*****
B. pratorum	0.00	±0.00	0.06	±0.06	0.43	±0.18	2.76	0.073ns
B. pascuorum	0.15a	±0.10	3.31b	±1.30	6.82b	±1.99	**8.58**	**0.001*****
B. hortorum	0.00	±0.00	0.31	±0.15	1.43	±0.87	1.13	0.331ns
Psithyrus spp.	0.00	±0.00	1.00	±0.48	0.89	±0.40	2.10	0.133ns
Short-tongued species	1.46a	±1.08	13.50b	±5.09	28.32b	±6.55	**13.08**	**<0.001*****
Long-tongued species	0.15a	±0.10	3.63b	±1.42	8.25b	±2.55	**8.91**	**<0.001*****
Total bumblebees	1.62a	±1.16	18.13b	±5.19	37.46b	±8.62	**16.75**	**<0.001*****
Richness bumblebees	0.46a	±0.27	2.56b	±0.33	2.75b	±0.29	**14.07**	**<0.001*****

Bumblebee count data were log transformed prior to analysis. Untransformed means (± se) per 100 m are presented for clarity. Significant differences are given in bold. Means with the same letter are not significantly different (P≤0.05) following Tukey's Honest Significant difference test. Ns = no significant difference; *** P≤0.001; ** P≤0.01; * P≤0.05.

Table 7
Summary of stepwise multiple regression models showing the habitat characteristics influencing bumblebee numbers on the different field margin options. Numbers presented are regression co-efficients. *** P≤0.001; ** P≤0.01; * P≤0.05.

	B. terrestris/lucorum	***B. lapidarius***	***B. pratorum***	***B. pascuorum***	***B. hortorum***	***Psithyrus* spp.**	**Short-tongued species**	**Long-tongued species**	**Total bumblebees**	**Richness bumblebees**
Convolvulaceae (Bindweeds)						0.147***				0.64***
Boraginaceae (Borages)	0.122***			0.055*		0.050**	0.078*	0.055*	0.097*	0.36***
Caryophyllaceae									-0.193*	
Chenopodiaceae (Fat hens)		0.120*								
Asteraceae (Thistles/daisies) red/purple		0.137***		0.072***		0.038***	0.093**	0.076***	0.084**	0.348***
Asteraceae (Thistles/daisies) yellow/white						-0.059***			-0.059*	
Geraniaceae (Cranesbills)	-0.078*					-0.081*				
Brassicaceae (Crucifers)						-0.119***				
Onagraceae (Epilobiums)				0.083***				0.080***		0.261**
Lamiaceae (Dead nettles)		-0.193**					0.123*			
Fabaceae (legumes) red/purple		0.279***		0.293***	0.074*	0.070**	0.257***	0.296***	0.275***	0.330*
Fabaceae (legumes) yellow/white		0.115**	0.074***	0.063*	0.059**			0.083**		0.332**
Small-flowered annuals	-0.092***						-0.109***		-0.013***	
Apiaceae (Umbellifers)							-0.232*			
Others	-0.070*						-0.108**		-0.099*	
Total flower abundance	0.045***		0.062***				0.059***		0.078***	0.040*
Total flower richness						0.021***				
F ratio	**42.36**	**44.04**	**22.97**	**43.25**	**13.62**	**17.90**	**45.36**	**41.64**	**54.30**	**46.55**
d.f.	**5,114**	**5,114**	**2,117**	**5,114**	**2,117**	**8,111**	**8,111**	**5,114**	**8,111**	**7,112**
Significance	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
R^2(%)	**65.0**	**65.9**	**28.0**	**65.5**	**18.9**	**56.3**	**76.6**	**64.6**	**79.6**	**74.4**

Fig. 1. A map showing the location of the two Arable Stewardship Scheme Pilot Areas

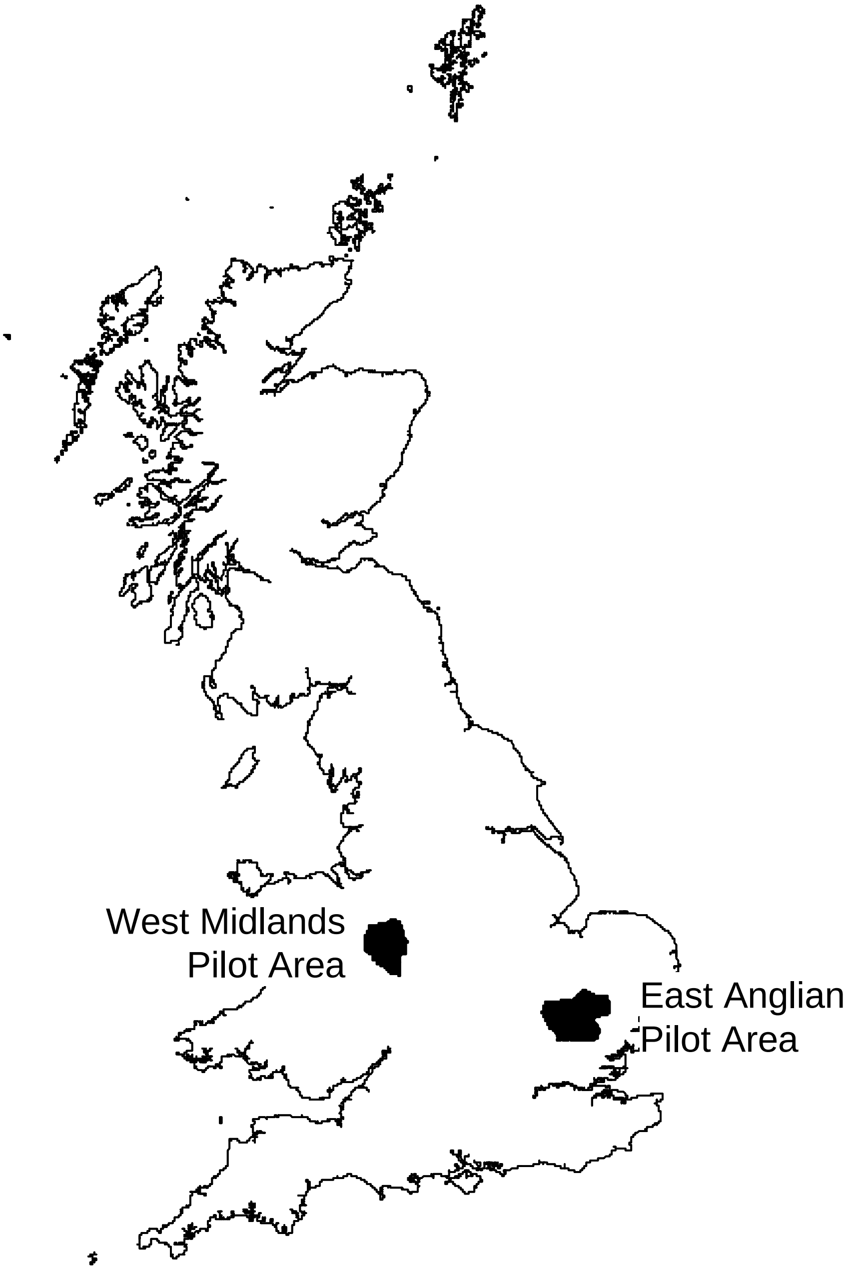
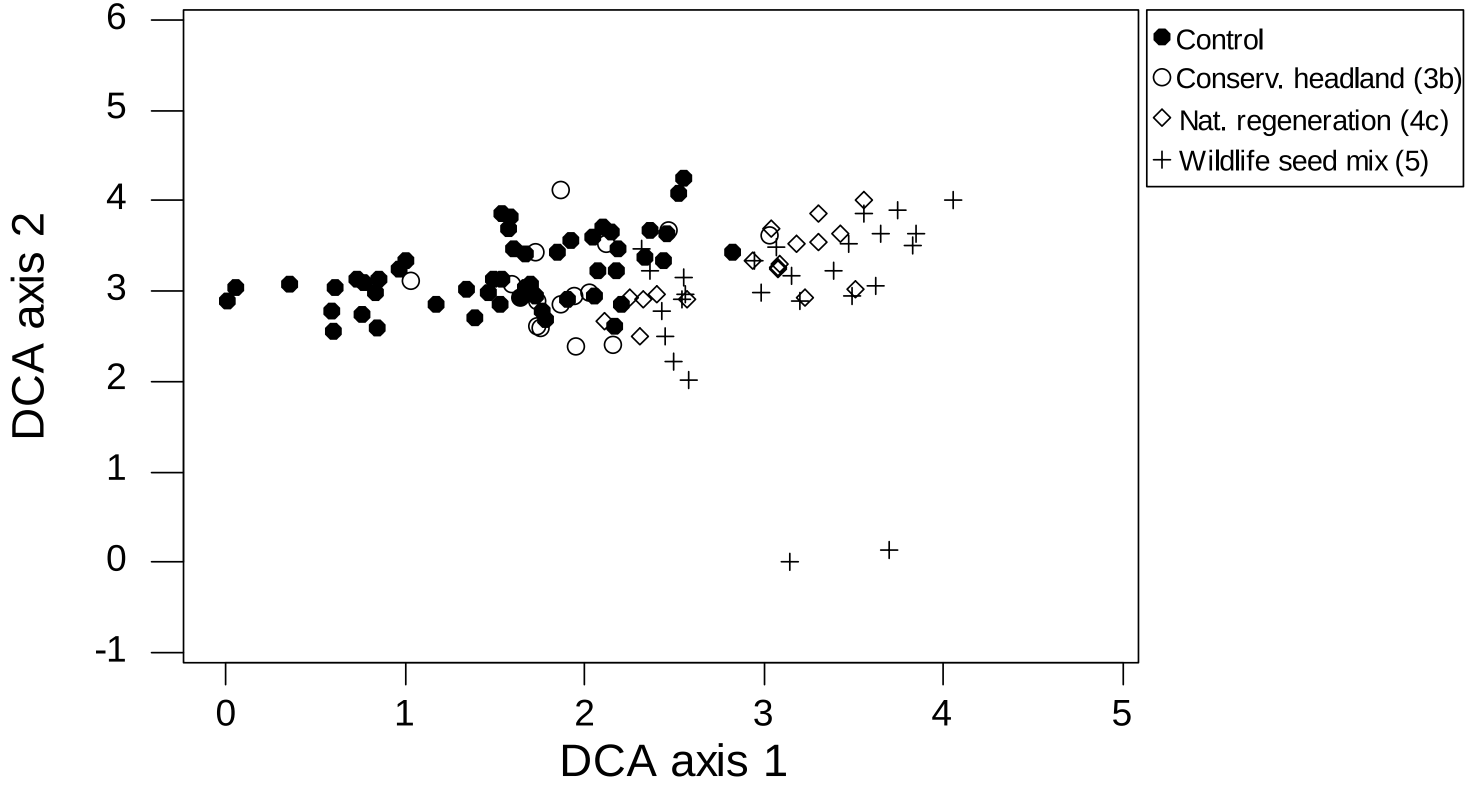


Fig. 2. Scatter plots of axes 1 and 2 from detrended correspondence analysis (DCA) of all field margin types. (a) sites; (b) species: only those with a minimum weight of >55 in the analysis are shown for clarity, together with the ten most preferential bumblebee forage plants (in bold). Overlapping species labels have been moved slightly for clarity.

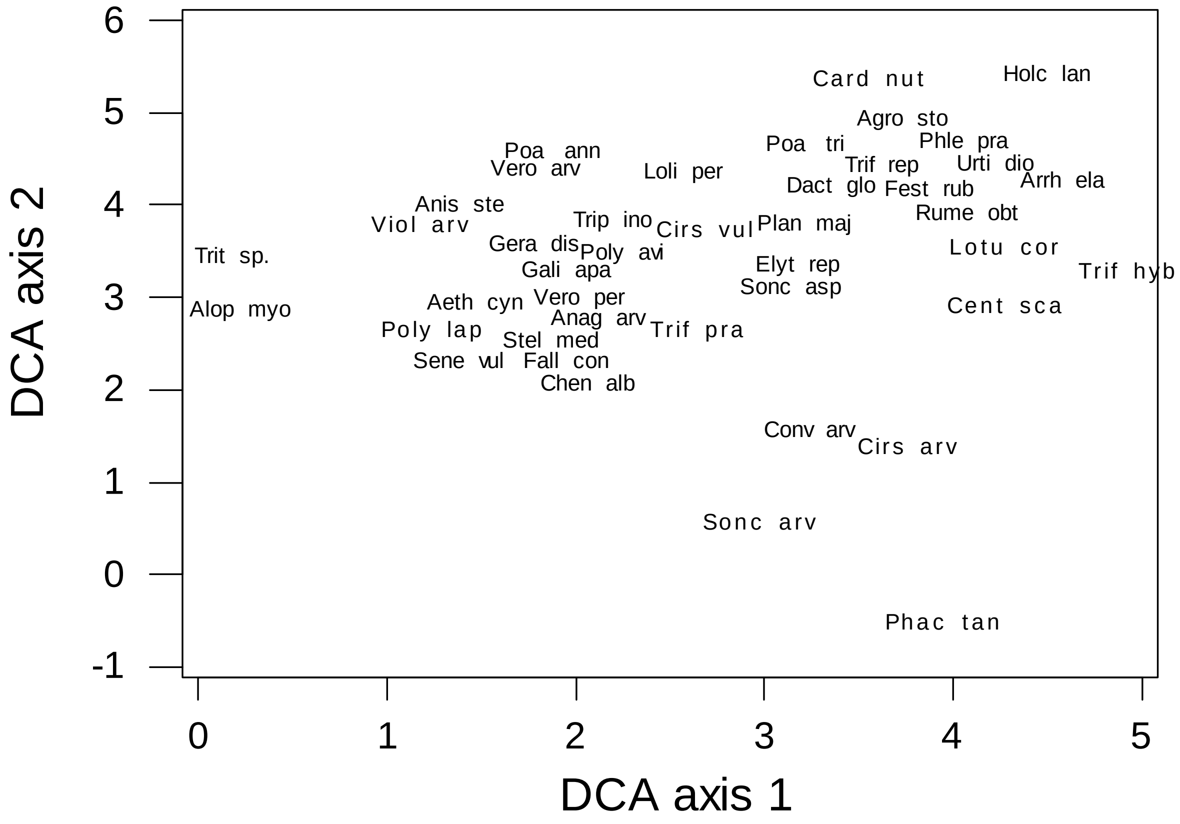
Abbreviations of species names: *Poa ann = Poa annua, Poa tri = Poa trivialis, Agro sto = Agrostis stolonifera, Dact glo = Dactylis glomerata, Elyt rep = Elytrigia repens, Alop myo = Alopecurus myosuroides, Loli per = Lolium perenne/multiflorum, Arrh ela = Arrhenatherum elatius, Holc lan = Holcus lanatus, Fest rub = Festuca rubra, Phle pra = Phleum pratense, Anis ste = Anisantha sterilis, Cirs arv = Cirsium arvense, Vero per = Veronica persica, Fall con = Fallopia convolvulus, Poly avi = Polygonum aviculare, Viol arv = Viola arvensis, Gali apa = Galium aparine, Anag arv = Anagallis arvensis, Chen alb = Chenopodium album, Stel med = Stellaria media, Cirs vul = Cirsium vulgare, Sonc asp = Sonchus asper, Rume obt = Rumex obtusifolius, Urti dio = Urtica dioica, Plan maj = Plantago major, Trif rep = Trifolium repens, Trip ino = Tripleurospermum inodorum, Gera dis = Geranium dissectum, Conv arv = Convolvulus arvensis, Aeth cyn = Aethusa cynapium, Sonc arv = Sonchus arvensis, Sene vul = Senecio vulgaris, Trif pra = Trifolium pratense, Vero arv = Veronica arvensis, Lotu cor = Lotus corniculatus, Phac tan = Phacelia tanacetifolia, Trif hyb = Trifolium hybridum, Cent sca = Centaurea scabiosa, Card nut = Carduus nutans, Poly lap = Polygonum lapathifolia, Trit sp. = Triticum aestivum*

(a)



6
5
4
3
2
1
0
-1
DCA axis 2
0
1
2
3
4
5
DCA axis 1
Control
Conserv. headland (3b)
Nat. regeneration (4c)
Wildlife seed mix (5)

(b)



Card nut
Holc lan
Agro sto
Phle pra
Poa tri
Poa ann
Vero arv
Loli per
Trif rep
Urti dio
Dact glo
Fest rub
Arrh ela
Anis ste
Rume obt
Viol arv
Trip ino
Cirs vul
Plan maj
Gera dis
Poly avi
Lotu cor
Trit sp.
Gali apa
Elyt rep
Trif hyb
Sonc asp
Aeth cyn
Vero per
Alop myo
Cent sca
Anag arv
Poly lap
Trif pra
Stel med
Sene vul
Fall con
Chen alb
Conv arv
Cirs arv
Sonc arv
Phac tan
6
5
4
3
2
1
0
-1
0
1
2
3
4
5
DCA axis 2
DCA axis 1

Fig. 3. Comparison of bumblebee abundance and species richness per 100m on the different AS options and the cereal field margin control.

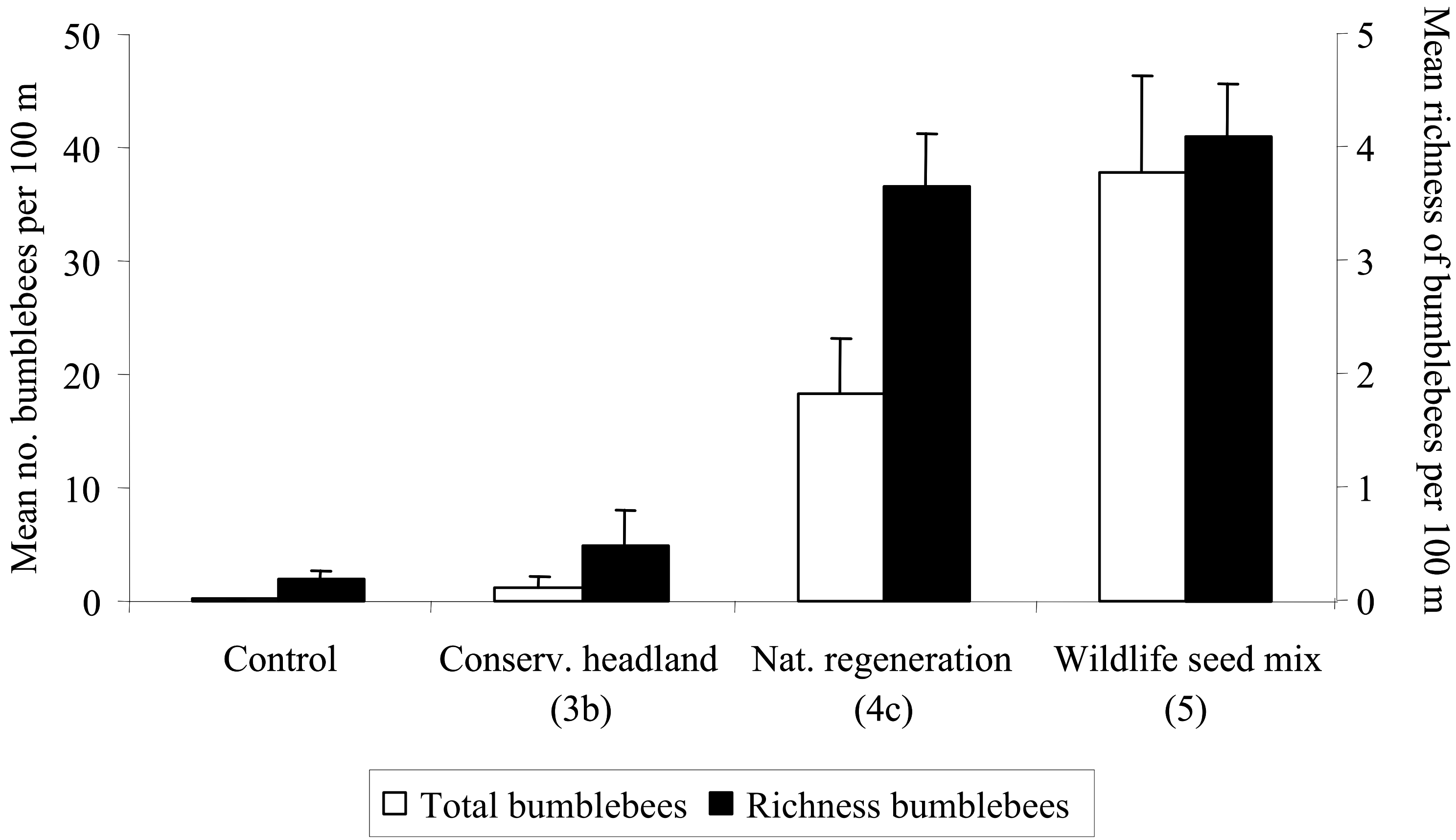


Fig. 4. Flower preferences of foraging bumblebees (all species) across the 4 field margin types sampled in this study.

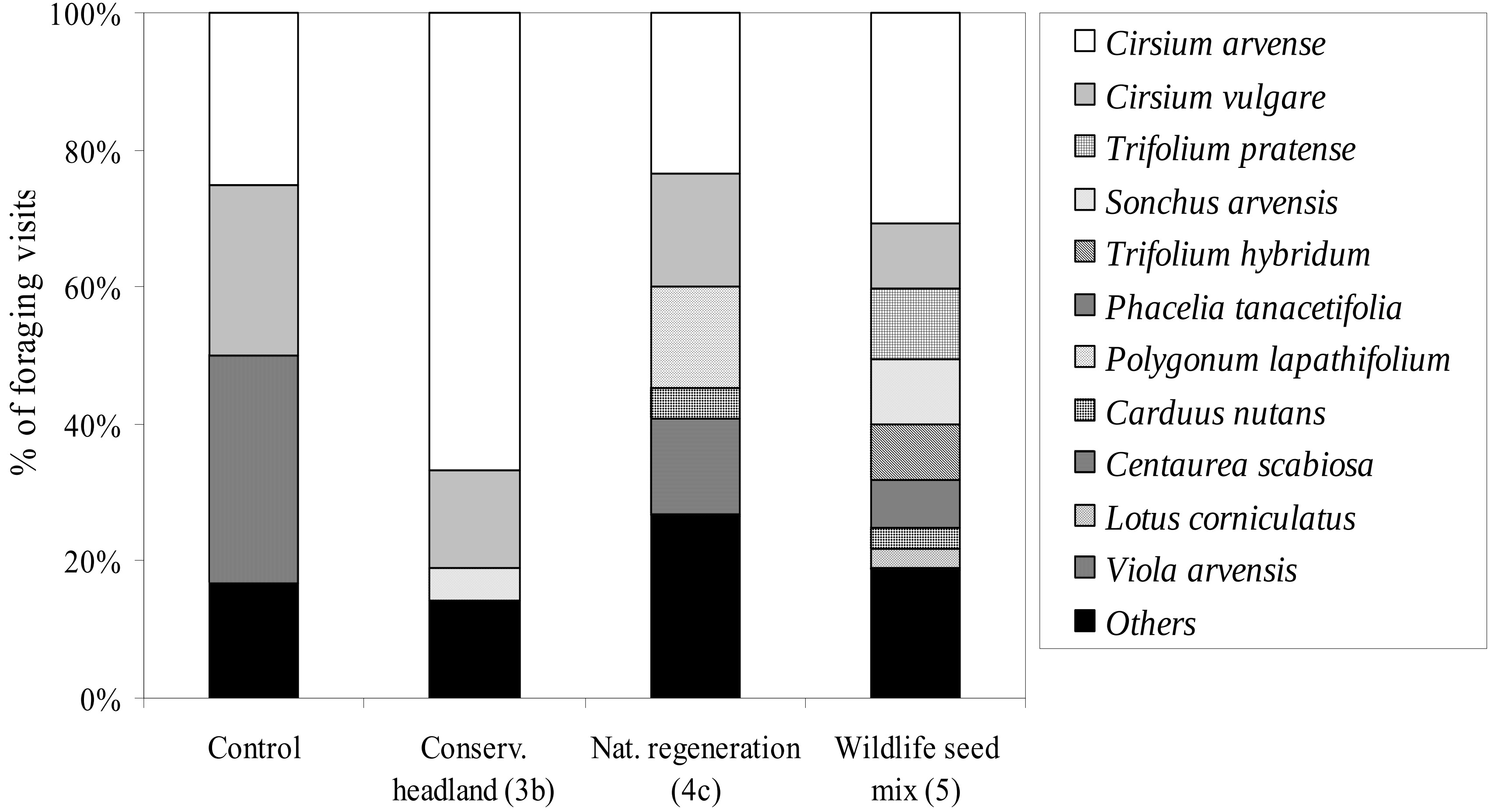
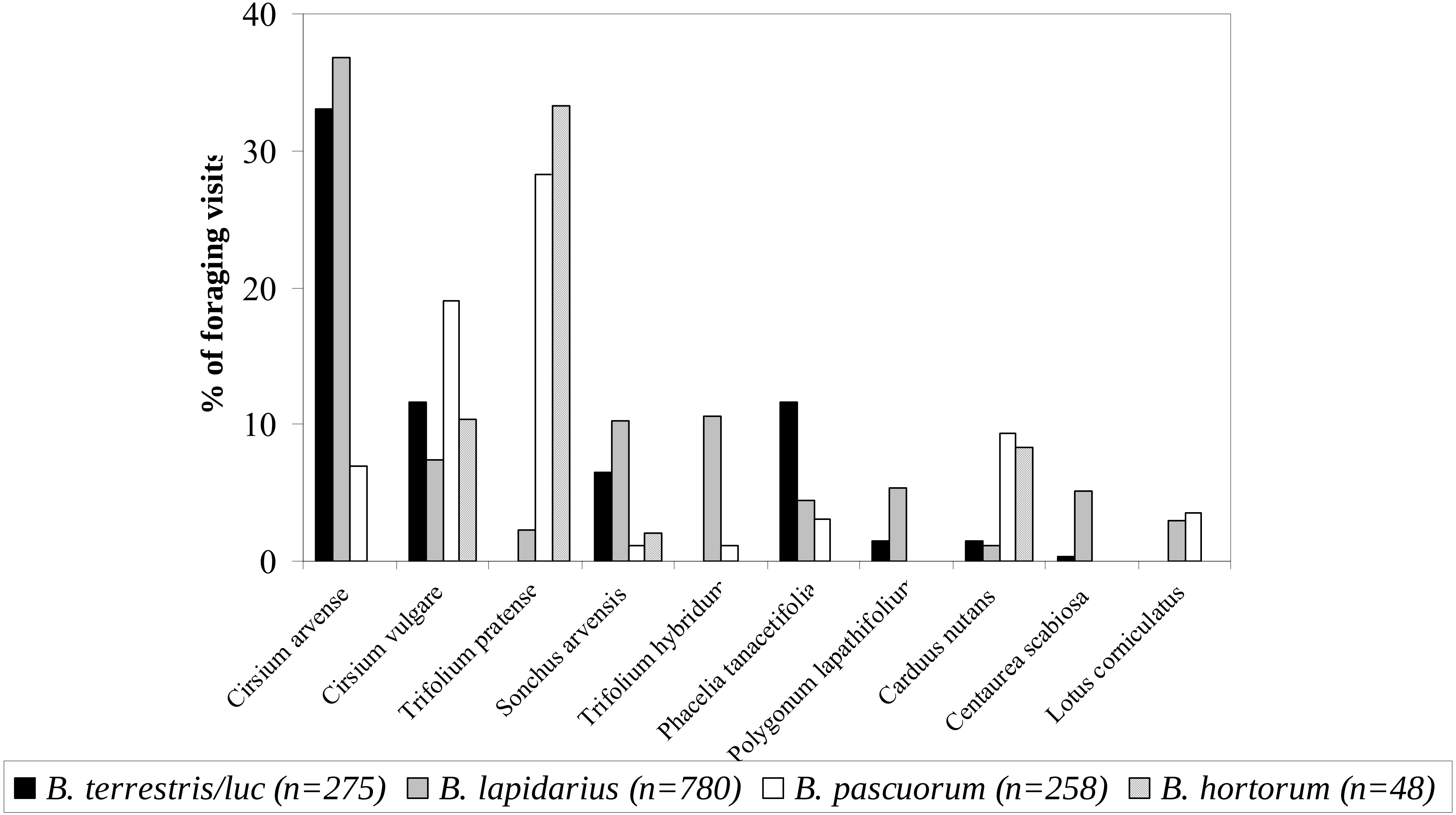


Fig. 5. Pattern of flower visitation of the three most abundant bumblebee species.



Appendix

Mean % frequency of all species recorded in the different field margin types

	Cereal field margin	Conservation headland (3b)	Nat. regeneration margin (4c)	Wildlife seed mix margin (5)
Monocotyledons				
Poa annua	14.0	31.3	6.8	12.4
Poa trivialis	7.9	6.6	27.6	18.3
Agrostis stolonifera	4.4	4.4	28.8	13.9
Dactylis glomerata	1.0	5.0	28.5	13.3
Elytrigia repens	3.1	2.2	17.9	20.9
Alopecurus myosuroides	9.1	10.9	16.8	5.0
Lolium perenne/multiflorum	5.7	3.1	21.5	7.6
Arrhenatherum elatius	0.3	1.3	25.6	6.1
Holcus lanatus	0.5	0.6	22.1	6.5
Festuca rubra	0.6	7.5	9.1	12.4
Phleum pratense	1.5	0.0	11.8	13.0
Anisantha sterilis	5.1	0.9	7.9	2.8
Bromus sp.	0.5	0.3	8.8	1.3
Phleum sp.	0.0	0.0	3.2	5.7
Avena fatua	1.8	0.0	5.6	0.9
Festuca arundinacea	0.0	0.0	0.0	3.7
Juncus bufonius	0.0	0.0	0.3	3.0
Bromus commutatus	2.9	0.3	0.0	0.0
Carex hirta	0.0	0.0	0.0	3.1
Cynosurus cristatus	0.0	0.0	0.0	2.8
Juncus effusus	0.0	0.0	0.0	2.4
Bromus hordeaceus	1.4	0.0	0.3	0.6
Holcus mollis	0.4	0.0	0.0	1.3
Deschampsia cespitosa	0.0	0.0	0.0	1.5
Agrostis stolonifera/capillaris	0.0	0.0	1.5	0.0
Phalaris arundinacea	0.0	0.0	0.0	1.1
Gramineae sp.	0.0	0.0	0.0	0.9
Phleum bertolonii	0.0	0.0	0.0	0.9
Glyceria maxima	0.0	0.3	0.6	0.0
Agrostis gigantea/stolonifera	0.9	0.0	0.0	0.0
Brachypodium sylvaticum	0.0	0.0	0.9	0.0
Juncus acutiflorus	0.0	0.0	0.0	0.7
Anthoxanthum odoratum	0.0	0.0	0.0	0.6
Vulpia sp.	0.0	0.0	0.3	0.0
Juncus inflexus	0.0	0.0	0.0	0.2
Vulpia bromoides	0.1	0.0	0.0	0.0
Poa pratensis	0.0	0.0	0.0	0.0
Dicotyledons				
Cirsium arvense	0.8	7.5	36.8	44.8
Veronica persica	6.7	27.8	27.9	18.5
Fallopia convolvulus	7.5	23.4	21.2	8.7
Polygonum aviculare	6.6	17.2	21.2	11.1
Viola arvensis	11.8	14.7	14.7	8.0
Galium aparine	4.2	20.6	15.0	5.2
Anagallis arvensis	0.3	20.6	13.2	10.7
Chenopodium album	2.9	10.0	7.9	18.9
Stellaria media	0.7	21.9	5.9	5.9
Cirsium vulgare	2.7	3.4	14.1	11.5

	Cereal field margin	Conservation headland (3b)	Nat. regeneration margin (4c)	Wildlife seed mix margin (5)
Sonchus asper	0.1	2.8	16.2	11.1
Rumex obtusifolius	0.1	2.5	10.3	14.3
Urtica dioica	0.5	1.9	11.2	13.5
Plantago major	0.2	5.6	12.1	8.5
Trifolium repens	0.1	6.6	9.4	9.3
Tripleurospermum inodorum	1.9	1.3	15.3	4.8
Geranium dissectum	5.1	1.3	12.4	4.1
Papaver rhoeas	0.4	4.7	15.6	1.3
Convolvulus arvensis	0.8	1.3	11.5	6.9
Picris echioides	0.0	3.8	11.2	2.8
Myosotis arvensis	0.0	5.9	9.7	1.7
Aethusa cynapium	3.4	3.8	7.6	2.4
Sonchus arvensis	0.0	1.6	4.4	10.4
Persicaria maculosa	0.5	0.9	10.9	3.3
Matricaria recutita	0.9	6.3	5.9	2.6
Artemisia vulgaris	0.9	0.6	8.2	5.4
Senecio vulgaris	1.9	6.3	4.4	2.2
Capsella bursa-pastoris	0.5	3.8	4.7	5.6
Equisetum arvense	0.8	0.0	6.5	6.5
Epilobium hirsutum	0.0	0.9	6.5	6.1
Trifolium pratense	0.0	4.1	2.4	5.6
Veronica arvensis	1.4	6.6	0.6	2.4
Sinapis arvensis	0.4	2.2	6.5	1.7
Heracleum sphondylium	0.5	3.4	2.9	2.6
Persicaria lapathifolia	0.0	2.8	2.4	4.3
Sherardia arvensis	0.0	0.0	7.4	1.7
Fumaria officinalis	1.5	0.0	3.8	3.1
Ranunculus repens	0.0	0.0	4.4	3.9
Senecio jacobaea	0.0	0.9	5.9	1.3
Lotus corniculatus	0.0	0.0	0.9	7.2
Taraxacum officinale agg.	0.2	0.3	5.3	2.2
Sisymbrium officinale	2.9	0.6	1.5	2.6
Cerastium fontanum	0.3	2.5	3.2	1.3
Phacelia tanacetifolia	0.0	0.0	0.0	6.9
Lamium purpureum	0.1	0.0	3.5	3.1
Glechoma hederacea	0.0	1.3	3.8	1.3
Polygonum persicaria	0.2	5.9	0.0	0.0
Fraxinus excelsior	0.7	2.5	1.5	0.7
Kickxia elatine	0.1	0.0	4.7	0.6
Galium mollugo	0.0	0.3	4.1	0.7
Atriplex patula	1.9	0.0	0.9	2.4
Anchusa arvensis	0.0	0.0	0.3	4.6
Medicago lupulina	0.0	0.0	0.3	4.6
Euphorbia exigua	0.0	2.2	2.4	0.4
Kickxia spuria	0.2	0.6	3.5	0.6
Calystegia sepium	0.1	0.0	4.4	0.4
Spergula arvensis	0.0	0.9	0.3	3.5
Sonchus oleraceus	0.7	0.6	0.9	2.4
Arctium minus	0.1	1.3	2.6	0.6
Achillea millefolium	0.0	0.0	1.2	3.3
Epilobium parviflorum	0.0	0.0	4.1	0.2
Epilobium ciliatum	0.0	0.0	0.0	4.1
Galeopsis tetrahit	0.0	0.0	3.8	0.2

	Cereal field margin	Conservation headland (3b)	Nat. regeneration margin (4c)	Wildlife seed mix margin (5)
Silene latifolia	0.2	0.9	2.1	0.6
Arenaria serpyllifolia ssp. lept	0.0	3.4	0.3	0.0
Linaria vulgaris	0.0	0.0	3.5	0.2
Legousia hybrida	0.0	3.1	0.6	0.0
Medicago sativa	0.0	0.0	0.0	3.7
Lapsana communis	0.5	0.0	1.8	1.3
Lotus pedunculatus	0.0	0.0	0.3	3.1
Plantago lanceolata	0.0	0.0	2.6	0.7
Epilobium obscurum	0.0	0.6	2.4	0.0
Geranium molle	0.2	0.0	0.0	2.8
Hypochaeris radicata	0.0	0.0	2.9	0.0
Prunus spinosa	0.0	0.0	2.4	0.4
Rubus fruticosus	0.0	0.0	1.2	1.5
Myosotis sp.	0.0	0.0	2.6	0.0
Epilobium sp.	0.1	1.3	0.9	0.4
Aphanes arvensis	0.0	1.9	0.3	0.4
Reseda luteola	0.0	0.0	0.3	2.2
Ranunculus sp.	0.0	2.2	0.3	0.0
Gnaphalium uliginosum	0.0	0.0	0.0	2.4
Chaenorhinum minus	0.0	0.0	2.4	0.0
Vicia hirsuta	0.0	0.0	2.4	0.0
Rumex crispus	0.0	0.0	0.6	1.7
Fagopyrum esculentum	0.2	0.0	0.0	2.0
Sinapis alba	0.2	0.0	0.0	2.0
Trifolium hybridum	0.0	0.0	0.0	2.2
Centaurea scabiosa	0.0	0.0	1.5	0.7
Chamerion angustifolium	0.0	0.0	1.5	0.7
Geum urbanum	0.0	0.0	2.1	0.0
Quercus sp.	0.6	0.9	0.0	0.4
Rumex sp.	0.0	1.9	0.0	0.0
Silene noctiflora	0.0	0.0	0.0	1.9
Geranium sp.	0.0	0.0	1.2	0.6
Epilobium montanum	0.0	0.0	0.6	1.1
Epilobium tetragonum	0.0	0.0	0.6	1.1
Veronica sp.	0.0	0.0	0.6	1.1
Cirsium palustre	0.0	0.0	0.0	1.7
Solanum nigrum	0.0	0.0	0.0	1.7
Coronopus squamatus	0.0	0.0	1.5	0.2
Matricaria discoidea	0.2	0.0	0.9	0.6
Carduus nutans	0.0	0.0	0.9	0.7
Stachys sylvatica	0.0	0.0	0.3	1.3
Knautia arvensis	0.0	0.0	0.6	0.9
Potentilla anserina	0.0	0.0	0.0	1.5
Rumex acetosella	0.0	0.0	1.5	0.0
Vicia sativa	0.0	0.0	1.5	0.0
Lamium album	0.0	0.0	1.2	0.2
Scrophularia auriculata	0.0	0.0	0.6	0.7
Rumex cripus	0.0	0.3	0.6	0.4
Dipsacus fullonum	0.0	1.3	0.0	0.0
Umbelliferae sp.	0.0	1.3	0.0	0.0
Geranium dissectum\molle	0.0	0.0	1.2	0.0
Reseda lutea	0.0	0.0	1.2	0.0
Vicia tetrasperma	0.0	0.0	1.2	0.0

	Cereal field margin	Conservation headland (3b)	Nat. regeneration margin (4c)	Wildlife seed mix margin (5)
Lathyrus pratensis	0.0	0.0	0.0	1.1
Silene dioica	0.1	0.0	0.0	0.9
Aphanes sp.	0.0	0.0	0.0	0.9
Onobrychis viciifolia	0.0	0.0	0.0	0.9
Silene sp.	0.0	0.0	0.9	0.0
Sonchus sp.	0.0	0.0	0.9	0.0
Alliaria petiolata	0.5	0.3	0.0	0.0
Lactuca serriola	0.0	0.0	0.6	0.2
Prunella vulgaris	0.0	0.0	0.6	0.2
Raphanus raphanistrum	0.4	0.0	0.0	0.4
Silene vulgaris	0.0	0.0	0.0	0.7
Polygonum lapathifolia	0.1	0.6	0.0	0.0
Sagina apetala	0.0	0.0	0.3	0.4
Urtica urens	0.0	0.0	0.3	0.4
Ligustrum ovalifolium	0.0	0.0	0.6	0.0
Hypericum tetrapterum	0.0	0.0	0.0	0.6
Stachys palustris	0.0	0.0	0.0	0.6
Angelica sylvestris	0.0	0.0	0.3	0.2
Geranium pusillum	0.0	0.0	0.3	0.2
Labiate sp.	0.0	0.0	0.3	0.2
Potentilla reptans	0.0	0.0	0.3	0.2
Crepis capillaris	0.1	0.0	0.3	0.0
Conyza canadensis	0.0	0.0	0.0	0.4
Lamium amplexicaule	0.0	0.0	0.0	0.4
Malva sylvestris	0.0	0.0	0.0	0.4
Papaver dubium	0.0	0.0	0.0	0.4
Solanum sp.	0.0	0.0	0.0	0.4
Barbarea vulgaris	0.0	0.3	0.0	0.0
Acer pseudoplatanus	0.0	0.0	0.3	0.0
Anthriscus sylvestris	0.0	0.0	0.3	0.0
Bryonia dioica	0.0	0.0	0.3	0.0
Crepis vesicaria	0.0	0.0	0.3	0.0
Lathyrus sp.	0.0	0.0	0.3	0.0
Pimpinella saxifraga	0.0	0.0	0.3	0.0
Rosa sp.	0.0	0.0	0.3	0.0
Salix cinerea	0.0	0.0	0.3	0.0
Sanguisorba minor Ssp. minor	0.0	0.0	0.3	0.0
Senecio erucifolius	0.3	0.0	0.0	0.0
Tragopogon pratensis	0.0	0.0	0.3	0.0
Valeriana officinalis	0.0	0.0	0.3	0.0
Euphorbia helioscopia	0.1	0.0	0.0	0.2
Castanea sativa	0.0	0.0	0.0	0.2
Centaurea nigra	0.0	0.0	0.0	0.2
Chenopodium polyspermum	0.0	0.0	0.0	0.2
Cichorium intybus	0.0	0.0	0.0	0.2
Corylus avellana	0.0	0.0	0.0	0.2
Dryopteris sp.	0.0	0.0	0.0	0.2
Erigeron acer	0.0	0.0	0.0	0.2
Erodium cicutarium	0.0	0.0	0.0	0.2
Lactuca sp.	0.0	0.0	0.0	0.2
Linum usitatissimum	0.0	0.0	0.0	0.2
Pinus sp.	0.0	0.0	0.0	0.2
Polygonum sp.	0.0	0.0	0.0	0.2

	Cereal field margin	Conservation headland (3b)	Nat. regeneration margin (4c)	Wildlife seed mix margin (5)
Rumex conglomeratus	0.0	0.0	0.0	0.2
Trifolium arvense	0.0	0.0	0.0	0.2
Acer sp.	0.1	0.0	0.0	0.0
Trifolium dubium	0.1	0.0	0.0	0.0
Cirsium acanthoides	0.0	0.0	0.0	0.0
Crataegus monogyna	0.0	0.0	0.0	0.0
Cruciferae sp.	0.0	0.0	0.0	0.0
Galium verum	0.0	0.0	0.0	0.0
Odontites vernus	0.0	0.0	0.0	0.0
Crops, crop volunteers & sown species				
Triticum aestivum	76.4	68.8	0.9	19.1
Hordeum sp.	17.9	20.6	0.0	3.0
Zea mays	0.0	0.0	0.0	8.7
Brassica oleracea var. viridis	0.0	0.0	0.0	8.1
Avena sp.	2.1	0.3	0.0	3.7
Milium sp.	0.0	0.0	0.0	5.9
Chenopodium quinoa	0.0	0.0	0.0	5.4
Brassica napus	0.0	0.0	0.0	3.0
Vicia faba	1.8	0.0	0.0	0.0
Brassica napus Ssp. oleifera	0.0	0.0	0.0	1.7
Borago officinalis	0.0	0.0	0.0	1.3
Fagopyrum esculentum	0.0	0.0	0.0	1.3
Brassica sp.	0.0	0.0	0.0	0.7
Brassica rapa ssp. rapa	0.0	0.0	0.0	0.6
Solanum tuberosum	0.5	0.0	0.0	0.0
Beta sp.	0.0	0.0	0.0	0.2

Conclusions and Recommendations

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Conclusions

1. Differences in the vegetation communities between East Anglia and West Midlands pilot areas were consistent with those noted previously. The vegetation of the West Midlands tended to have more grassland characteristics.
2. There were no significant differences in the abundance and diversity of the bumblebee assemblage nor in the abundance of bumblebee foodplants between the two pilot areas. There was, however, a greater abundance of flowers and flowering species on the lighter soils of the West Midlands.
3. The proportion of sites in East Anglia containing rare arable plants was similar to the 1999 survey, but in Option 4C and 5 sites the populations tended to be smaller in 2003.
4. A rare bumblebee species (*Bombus ruderatus*) was recorded on a single Option 5 site in East Anglia in 2003. This was not recorded in the 1999 survey.
5. As expected, the vegetation of the static Options 4C and 5 was markedly different from the cereal headland Options 3A and 3B. In general, the scheme objectives were met for Options 3A and 3B. The benefits for annual arable plants had been met at Options 4C and 5 in the first year of establishment but this value declined by the fourth year.
6. Very few bumblebees were recorded on intensively managed cereal field margins due to the lack of dicot species. Option 3B supported a significantly greater number of flowering dicots, but the majority of these were annuals which did not provide good forage for bumblebees.
7. Option 3A worked well at the whole scheme level, having more of the target annuals and dicotyledons than normally cropped headlands but without also encouraging problematical grass or perennial weeds. However, individual sites varied in the abundance of annual arable plants that they contained. Option 3B appeared to confer additional benefits although assessment was hindered by uptake being limited to relatively few farms.
8. Option 4C continued to support a wide range of annual arable plants but perennials had increased markedly since the 1999 survey and their value for rare arable plants declined. Contrary to expectations, there had been no overall increase in abundance of monocotyledons since 1999. Non-compliance was a problem at some Option 4C sites. Many plant species present were potential food sources for farmland birds and butterfly larvae. This option generally provided good foraging habitat for bumblebee species, but most of the key forage species were pernicious weeds of agriculture (*Cirsium* sp.).
9. Perennials increased at Option 5 sites. Although rare arable plants were present at several sites in 1999, they declined by 2003, possibly as a result of increasing competition from perennials. Establishment of sown species was poor in some cases. This option typically provide the best foraging habitat for bumblebees of all those monitored.

Recommendations

Wider objectives of Arable Stewardship

1. Although this study focussed on plants and bumblebees, objectives also need to take into account those for birds, butterflies and other groups.

Arable plant conservation

2. The focus of arable plant conservation should be on assemblages of species that are declining nationally as well as on rare species. Uncropped wildlife strips have the best potential but conservation headlands and wildlife seed mixtures can also be beneficial.
3. Uncropped wildlife strips should be targeted in areas of known arable plant interest. Farmers should be encouraged to vary the cultivation regime during any given year to optimise between-site diversity. The introduction of a 'break year' could be considered, during which normal cropping is carried out to enable control of perennials.
4. Conservation headlands are best targeted in areas of known arable plant interest because their value for bumblebees is low. Farmers should be encouraged to adopt no-fertiliser conservation headlands except where pernicious weeds are present.
5. Wildlife seed mixture sites could be rotated to allow control of perennials during the cropped phase. Alternatively, perennials could be controlled before re-sowing Option 5 cover by applying herbicide (e.g. glyphosate) in late summer (August/September) by which time most annuals will have senesced. Herbicide would, however, need to be applied before germination of winter annuals.

Bumblebee conservation

6. Sowing non-crop field margins with wildlife seed mixtures has the potential for providing the best summer foraging habitat for bumblebees, so long as preferential forage species were introduced (e.g. *Trifolium pratense*). However, the provision of pollen and nectar in spring and early-summer, together with suitable nesting and hibernation habitat are required for the effective conservation of bumblebee populations in the wider countryside. Further work is required to define and test the effectiveness of agri-environment management prescriptions which will provide all of these essential habitats.

Targeting restoration

7. Rare and vulnerable arable plants and bumblebees had a localised distribution in both Pilot Areas. Site objectives could take this into account by targeting the options suitable for arable plants in the appropriate locations and targeting those for bumblebees elsewhere. Conservation of annual arable plants should be targeted on light or chalky soils, and other areas where rare species are known to occur.

Monitoring

8. Rare arable plant and bumblebee populations recorded in this and the previous survey could be re-surveyed annually to confirm status and long-term trends.

Success rates

9. It would be useful to identify reasons for variation between conservation headland sites. Individual sites where non-crop vegetation is sparse or absent could be identified by Project Officers and past herbicide use and other management discussed with farmers.
10. The reasons for non-compliance at Option 4C sites could be identified via Project Officers and measures taken to ensure all agreements are adhered to.
11. Management prescriptions could explicitly require re-sowing of wildlife seed mixture sites if sown species fail to establish.