Creation and Management of Pollen and Nectar Habitats on Farmland

Syngenta Crop Protection AG

Annual report 2007/8

Richard Pywell, Lucy Hulmes & Bill Meek

NERC Centre for Ecology and Hydrology, Maclean Building, Benson Lane, Crowmarsh Gifford, Wallingford, Oxon, OX10 8BB; e-mail: rfp@ceh.ac.uk

Marek Nowakowski

Wildlife Farming Company, Chesterwood, Alchester Road, Chesterton, Oxon, OX26 1UN

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Wildlife Farming Company
- Proven Wildlife Delivery -

Summary

1. Intensive farming has contributed to the serious declines in the abundance and diversity of bumblebee and butterflies.
2. UK agri-environmental policy aims to conserve and restore bee and butterfly populations by providing foraging habitats on land taken out of production.
3. Recent research suggests that current management prescriptions are failing to provide pollen and nectar habitats of sufficient quality and longevity in the wider countryside.
4. We report the findings of a range of integrated experiments to determine the best means of creating and managing pollen and nectar habitats on arable farmland in the UK.
5. **Experiment 1:** examines the flowering performance and persistence of a range of Red clover varieties managed under different cutting regimes.
6. Over four years the agricultural variety of Red clover Milvus and the wild variety from Somerset were the most persistent. Summer cutting (June) with or without an autumn cut significantly enhanced the cover of Red clover and the abundance of flowers. However, this cutting regime reduced cover and flower abundance of other sown legumes, such as Birdsfoot trefoil. Removal of cut material significantly increased the cover and flower abundance of sown broad-leaved species.
7. **Experiment 2:** investigated the performance of pollen- and nectar-rich broad-leaved species sown with grasses of differing competitive ability.
8. The typical practice of sowing tall and competitive grass species, such as Meadow Fescue, Timothy and Rye grass, significantly reduced the cover legume species. Persistence of sown legumes was significantly better in mixtures sown either without grasses, or with fine-leaved grasses, such as Crested Dogstail. Winter application of the graminicide propyzamide (Kerb Flo, Dow AgroSciences Ltd.) in year 3 reduced competition from grasses, increased cover of sown dicots and undesirable weed species (*Cirsium* sp.).
9. **Experiment 3:** compared the foraging preference of bumblebees and butterflies for a range of annual crop species sown in wild bird seed mixes with perennials sown in pollen and nectar seed mixtures.
10. In year 1 flowers of annual species were much more abundant than those of perennials. In year 2 flower abundance of perennials, such as Red clover and Sweet clover, were similar to the annual species. There were marked differences in the timing of peak flowering between species: Crimson clover flowered in late May, Fodder radish in late June, Borage, Phacelia. Red clover and Sweet clover in late July, Sunflower in late August. Short-tongued bees showed a marked preference for Phacelia and Borage. Long-tongued bees showed a significant preference for Red clover, Crimson clover and Sainfoin.

1. Introduction

Bumblebees (*Bombus* sp.) provide a vitally important pollination service for semi-natural ecosystems (Dicks, Corbet and Pywell, 2002), together with a wide range of crops, and garden plants (Free, 1993). Over the last 25 years there have been significant declines in the diversity of bumblebees, butterflies and other pollinating insects in the UK and Europe (Thomas et al., 2004; Biesmeijer et al., 2006). Intensive agricultural management, loss of habitat and food plants, and increased pesticide use have been cited as important contributing factors to this decline (Carvell et al., 2006; Dennis and Shreeve, 2003; Goulson et al., 2005). The UK agri-environment schemes (AES) seek to mitigate these damaging impacts of modern farming by encouraging extensive management practices within the crop and by creating non-crop habitats for wildlife, typically at the margins of fields (Anon., 2005). The recent BUZZ project examined the effectiveness of a large number of AES management options on a wide range of plants and animals (Pywell et al., 2007). It concluded that the best means of providing foraging habitat for bumblebees and butterflies, in the short-term, was to remove field margins from cropping and to sow a simple, low-cost mixture of pollen- and nectar-rich species. The effectiveness of this management options has been confirmed by the results of national monitoring of the AES (Pywell et al., 2006). However, the abundance of the sown clover species declined significantly after year three under the recommended management of cutting in the autumn each year. It was concluded that more research was required to increase the quality and longevity of this critically important habitat for pollinators.

1.2 *Aims*

The overall aim of this project is to undertake a range of integrated experiments in order to increase the quality and longevity of pollen and nectar habitats created under the agri-environment schemes.

1.2.1 Experiment 1: Performance of Clover Varieties

The aims of this experiment are to determine a) the best performing variety of Red clover in pollen and nectar seed mixtures, b) the optimum cutting management regime to prolong the longevity of this habitat, and c) any positive and negative interactions between cutting regime and clover varieties.

1.2.2 Experiment 2: Pollen and Nectar Seed Mixtures

The aim of this experiment is to develop and test the most effective and reliable pollen and nectar seed mixtures by varying a) the seed rate and competitive ability of companion grasses, and b) the composition of the legume component.

1.2.3 Experiment 3: Pollen and Nectar Preference

The aim of this experiment is to compare the foraging preference of bumblebees and butterflies for a range of annual crop species sown in wild bird seed mixtures with perennials sown in pollen and nectar seed mixtures.

2. Methods

2.1 *Experiment 1: Performance of Clover Varieties*

2.1.1 Experimental treatments

Experiment 1 was sown at Manor Farm, Malton, Yorkshire (Grid ref. SE 770657) on 20 August 2003. Six different pollen and nectar seed mixtures were sown at random in contiguous plots measuring 48 × 6 m with two replicates of each. All seed mixtures contained the same proportion (80%) of four fine-leaved grasses (Table 1). Four of the mixtures contained different varieties of Red clover (*Trifolium pratense*), and the fifth mixture contained Alsike clover (*T. hydridum*). Finally, the Multi-mix contained equal proportions of an early- and a late-flowering variety of Red clover and was equivalent to pollen and nectar seed mixtures sown typically sown under the agri-environment schemes, including Operation Bumblebee farms. All mixtures were sown at 20 kg ha^{-1}. In the first year all plots were cut to a height of 10-15 cm and the herbage removed on 18 April and 25 September 2004 in order to control competition from unsown species. In 2005 each main plot was sub-divided into eight contiguous 6 × 6 m sub-treatment plots and the following cutting regimes were applied at random both with and without removal of cut herbage: A. Cut April, B. Cut June, C. Cut June + October, and D. Cut October. In 2005 cutting was carried out on 20 April, 31 May and 3 October. In 2006 cutting was carried out on 24 April, 6 June and 13 October. Cutting was carried out using a 1.6 m wide Ryetec 1600C rear-mounted flail collector mower (www.ryetec.co.uk). The rear collector box was left open to deposit cut and macerated herbage evenly across the sub-treatment plots as required.

2.1.2 Monitoring

In August of each year the composition of the vegetation community was recorded from three 1 × 1 m quadrats placed at random within each sub-treatment plot (96 in total). In each quadrat the percentage cover of individual broad-leaved (dicot) species was estimated as a vertical projection. The cover of all grasses was summed as a single category. Counts of single flowers and multi-flowered stems of all dicot species were made from three 50 × 50 cm quadrats placed at random in each sub-treatment plot on 9 occasions between May and September 2005, on 7 occasions between May and September 2006, and on 5 occasions between early June and September 2007.

2.1.3 Statistical analysis

Mean percentage cover of individual species was calculated for each treatment and sub-treatment. In addition, mean flower counts for sown species were calculated for treatments and sub-treatments for each visit and in total for each year. The effects of clover variety and seed mixture main treatment, and cutting regime sub-treatments on vegetation composition and flower abundance was investigated using a split-plot analysis of variance (ANOVA). The model had seed mix as the main treatment (tested against the block × seed mix mean square), sub-treatments of cutting date in factorial combination with leaving or removal of cut material, and various seed mix × cutting regime interactions (all tested against the error mean square). Tukey's pairwise comparisons were used to determine differences among individual treatments and sub-treatments. For the purposes of this interim report the three years were analysed separately using Genstat 9 statistical software.

2.2 *Experiment 2: Pollen and Nectar Seed Mixtures*

2.2.1 Experimental treatments

Experiment 2 was sown at the Upton Estate, Warwickshire (Grid ref. SP 365454) on 4 April 2005. It comprised 10 pollen and nectar seed mixtures with varying proportions of grass species with differing competitive abilities sown at random in contiguous 6 × 10 m plots with three replicates (Table 2). All plots were cut to 10-12 cm on 22 June, 12 July and 17 October. Cutting was carried out using a 1.6 m wide rear-mounted flail collector mower. The rear collector box was left open to deposit cut and macerated herbage evenly across the plots. On 15 April 2006 plots containing the Rye grass nurse crop (Treatment 3) were sprayed with the graminicide Fluazifop-P-butyl (as Fusilade Max, Syngenta Crop Protection Ltd.) at 0.5 l ha^{-1} in 200 litres of water ha^{-1} (62.5 g a.i. ha^{-1}). All plots were cut to 15-20 cm and the cut material left *in situ* on April 26 and 19 September 2006. Finally, on 24 November 2006 each plot was split into two 3 × 10 m sub-plots and the graminicide propyzamide (as Kerb Flo, Dow AgroSciences Ltd.) was applied at 2.1 l ha^{-1} (840 g a.i ha^{-1}). It was noted that the grasses had begun to change colour in the treated sub-plots on 8 January 2007. All plots were cut to 15-20 cm 21 April 2007.

2.2.2 Monitoring

In July 2005 the percentage cover of all vascular plant species was recorded in two 1 × 1 m quadrats placed at random in each plot. In July 2006 composition was recorded from three 1 × 1 m random quadrats per plot. Following splitting the plots to apply graminicide in 2007, the composition of each sub-plot was recorded separately from two randomly placed1 × 1 m quadrats. Also, in August and September 2006, and July 2007 transect walks were carried out through each plot to record the abundance and diversity of bumblebees according to the methodology described by Pywell et al. (2006).

2.2.3 Statistical analysis

Mean species number (richness) of vascular plants and percentage cover of sown and unsown species per m^2 was calculated for each treatment in each year. Counts of individual bumblebee and butterfly species from each visit were summed for each treatment plot. In addition, bumblebees were classified into short- and long-tongued feeding guilds according to Goulson et al. (2005). Differences in species number, and percentage cover of sown grasses and dicots between treatments was investigated using analysis of variance (ANOVA) with block and seed mixture in the model. Tukey's pairwise comparisons were used to determine differences among individual treatments. Each year was analysed separately. Differences in the abundance of bumblebees between treatments was investigated using the same ANOVA model. From 2007 onwards the effects of gramininicide application on vegetation composition, flower and bee abundance were examined using a split-plot ANOVA.

Table 1. Details of the clover seed mixtures (kg ha^{-1} and percentage composition) sown in Experiment 1.

Seed mixture	**Crested Dogstail**	**Chewings Fescue**	**Slender Red Fescue**	**Smooth Meadow Grass**		**Birdsfoot Trefoil**	**Sainfoin**	**Alsike Clover**	**Red Clover (var. Britta)**	**Red Clover (var. Milvus)**	**Red Clover (var. Wild Somerset)**	**Red Clover (var.Wild Berkshire)**	**Seed rate (kg ha^{-1})**
1. Britta	**4.8** 24.0%	**5.6** 28.0%	**3.2** 16.0%	**2.4** 12.0%		**1.2** 6.0%	**0.8** 4.0%		**2.0** 10.0%				**20.0**
2. Milvus	**4.8** 24.0%	**5.6** 28.0%	**3.2** 16.0%	**2.4** 12.0%		**1.2** 6.0%	**0.8** 4.0%			**2.0** 10.0%			**20.0**
3. Wild Somerset	**4.8** 24.0%	**5.6** 28.0%	**3.2** 16.0%	**2.4** 12.0%		**1.2** 6.0%	**0.8** 4.0%				**2.0** 10.0%		**20.0**
4. Wild Berkshire	**4.8** 24.0%	**5.6** 28.0%	**3.2** 16.0%	**2.4** 12.0%		**1.2** 6.0%	**0.8** 4.0%					**2.0** 10.0%	**20.0**
5. Alsike	**4.8** 24.0%	**5.6** 28.0%	**3.2** 16.0%	**2.4** 12.0%		**1.2** 6.0%	**0.8** 4.0%	**2.0** 10.0%					**20.0**
6. Multi-mix	**4.8** 24.0%	**5.6** 28.0%	**3.2** 16.0%	**2.4** 12.0%		**1.4** 7.0%		**0.6** 3.0%	**1.0** 5.0%			**1.0** 5.0%	**20.0**

Table 2. Details of the pollen and nectar seed mixtures (kg ha^{-1} and percentage composition) sown in Experiment 2.

Seed mixture	Crested Dogstail	Chewings Fescue	Creeping Red Fescue	Smooth Meadow Grass	Rye Grass	Dwarf Rye Grass	Timothy	Meadow Fescue	Alsike Clover (var. Aurora)	Birdsfoot Trefoil (var. Sans Gabiel)	Sainfoin	Lucerne	Red Clover (var. Essex Wild)	Red Clover (var. Alteaswede (late))	Red Clover (var. Milvus (early))	Seed rate (kg ha^{-1})	Cost (£ ha^{-1})	Grass : forb ratio
a) No grass																		
1. Set aside									**0.5** 10.0%	**1.0** 20.0%	**1.3** 25.0%		**1.0** 20.0%	**0.8** 15.0%	**0.5** 10.0%	**5.0**	**£30**	**0:100**
2. Legume only									**1.0** 10.0%	**2.0** 20.0%	**2.5** 25.0%		**2.0** 20.0%	**1.5** 15.0%	**1.0** 10.0%	**10.0**	**£60**	**0:100**
3. Rye Grass nurse					**16.0** 80.0%				**0.4** 2.0%	**0.8** 4.0%	**1.0** 5.0%		**0.8** 4.0%	**0.6** 3.0%	**0.4** 2.0%	**20.0**	**£60**	**80:20**
b) Short grass																		
4. Fine grass simple	**5.3** 35.0%								**1.0** 6.5%	**2.0** 13.0%	**2.4** 16.3%		**2.0** 13.0%	**1.5** 9.8%	**1.0** 6.5%	**15.0**	**£80**	**35:65**
5. Fine grass complex	**4.0** 20.0%	**6.0** 30.0%	**4.0** 20.0%	**2.0** 10.0%					**0.6** 3.0%	**0.8** 4.0%	**1.6** 8.0%			**1.0** 5.0%		**20.0**	**£90**	**0:100**
c) Tall grass																		
6. Typical ELS	**2.0** 10.0%			**2.0** 10.0%			**3.0** 15.0%	**9.0** 45.0%	**0.4** 2.0%	**0.8** 4.0%	**1.0** 5.0%		**0.8** 4.0%	**0.6** 3.0%	**0.4** 2.0%	**20.0**	**£80**	**80:20**
7. Dwarf Rye Grass	**2.0** 10.0%			**2.0** 10.0%		**9.0** 45.0%	**3.0** 15.0%		**0.4** 2.0%	**0.8** 4.0%	**1.0** 5.0%		**0.8** 4.0%	**0.6** 3.0%	**0.4** 2.0%	**20.0**	**£80**	**80:20**
8. Rye Grass	**2.0** 10.0%			**2.0** 10.0%	**9.0** 45.0%		**3.0** 15.0%		**0.4** 2.0%	**0.8** 4.0%	**1.0** 5.0%		**0.8** 4.0%	**0.6** 3.0%	**0.4** 2.0%	**20.0**	**£80**	**80:20**
9. Lucerne							**1.0** 5.0%	**2.0** 10.0%		**3.0** 15.0%	**6.0** 30.0%	**8.0** 40.0%				**20.0**	**£80**	**15:85**
10. Lucerne & legume							**1.0** 5.0%	**2.0** 10.0%		**2.0** 10.0%	**6.0** 30.0%	**8.0** 40.0%		**1.0** 5.0%		**20.0**	**£80**	**15:85**

2.3 *Experiment 3: Pollen and Nectar Preference*

2.3.1 Experimental treatments

Experiment 3 was sown at the Upton Estate, Warwickshire (Grid ref. SP 365464) on 7 May 2006. The annual species were re-established in the same plots on 25 May 2007. Ten small-seeded crop species typically sown in wild bird seed mixtures (Entry Level Stewardship EF2; Anon., 2005) and three perennial dicots sown in pollen and nectar seed mixtures (EF4) were established in single species stands in 6 × 4 m plots in a randomised block experiment with four replicates (Table 3).

Table 3. Details of the seed mixtures (kg ha^{-1}) sown in Experiment 3.

English name	Latin name	Life history	Sowing rate kg ha^{-1}
Borage	*Borago officinalis*	Annual	25
Buckwheat	*Fagopyrum esculentum*	Annual	62
Chicory	*Cichorium intybus*	Perennial	7
Crimson clover	*Trifolium incarnatum*	Annual	15
Fodder radish	*Raphanus sativus*	Annual	12
Linseed	*Linum usitatissimum*	Annual	49
Lucerne	*Medicago sativa*	Perennial	20
Mustard	*Brassica juncea*	Annual	20
Phacelia	*Phacelia tanacetifolia*	Annual	10
Red clover	*Trifolium pratense*	Perennial	15
Sainfoin	*Onobrychis viciifolia*	Perennial	62
Sunflower	*Helianthus annuus*	Annual	25
Sweet clover	*Melilotus officinalis*	Biennial	15

2.3.2 Monitoring

Transects were walked through each plot to record the abundance and diversity of butterfly and bumblebees species on six occasions between July and September 2006, on six occasions between May and September 2007 according to the methodology described by Meek et al. (2002) and Pywell et al. (2006). In addition, on each visit the percentage cover of flowers of all dicot species was estimated for each plot.

2.3.3 Statistical analysis

Counts of bumblebees and butterflies were summed for all six visits. Mean abundance and species number (richness) were calculated for each treatment. In addition, bumblebees were classified into short- and long-tongued feeding guilds according to Goulson et al. (2005), and the functional classification of ‘mobile’ or ‘immobile’ was applied to each butterfly species according to Warren (1992). Finally, mean abundance of dicot flowers was calculated for each visit. Differences in the abundance and species richness of bumblebees and butterflies between different treatments was investigated using Analysis of Variance (ANOVA) with block and treatment in the model.

3. Results

3.1 *Experiment 1: Performance of Clover Varieties*

3.1.1 Vegetation composition

In 2005 the percentage cover of Birdsfoot trefoil was significantly higher in the seed mixture based on Wild Somerset Red clover compared with those based on the agricultural varieties Britta and Milvus (Table 4). The cover of Alsike clover was significantly higher in the mixture based on Alsike clover compared with all others. Cover of Red clover was highest in the Britta mix, then the mixtures based on Milvus, Wild Berkshire and the Multi-mix, and lowest in the Wild Somerset and Alsike mixes. Cover of grasses was significantly higher in the Wild Somerset mix compared with the Britta, Wild Berkshire and Multi-mix. There were no significant effects of cutting date or herbage disposal technique (leave or remove) on the cover of dicots or grasses in 2005. However, there was a significant interaction between clover variety and cutting date. This reflected the larger than expected increase in cover of Milvus under the June and June and October cutting regimes.

In 2006 the cover of Alsike clover was significantly higher in the Multi-mix compared with all other mixtures (Table 4). Red clover was significantly more abundant in the Milvus mixture compared with all others. Cover of sown dicots was significantly higher in the Milvus mix compared with all others except the Wild Somerset mix. Cover of sown dicots was also significantly higher in this mix compared with the Alsike mix. There were no significant differences in the cover of grasses between seed mixtures. Cover of Alsike clover was highest following cutting in June and October compared with cutting in October alone. Similarly, cutting in June and October resulted in a significantly higher cover of Red clover compared with all other dates. Also, cutting in June resulted in a higher cover than April cutting. Similarly, cutting in June and October resulted in a significantly higher cover of all sown dicots and a lower cover of grasses compared with all other dates. Removal of the cut material significantly increased the cover of Birdsfoot trefoil and all sown dicots. Finally, there was a significant interaction between seed mixture and herbage disposal technique. This reflected an increase in grass cover under herbage removal for the Britta and Wild Somerset mixes, and a decrease for the Milvus and multi-mix mixtures.

In 2007 cover of Birdsfoot trefoil was significantly higher in the Wild Somerset Red seed mix compared with Milvus and Multi-mix (Table 4). Cover of Red clover was significantly higher in the mixture containing Milvus compared with all others. Cover of all sown dicots was significantly higher in the Milvus mix compared with the mixes based on Wild Red from Berkshire, the Alsike and Multi mixes. There were no significant differences in the cover of Alsike clover or grasses between mixtures. Cover of Birdsfoot trefoil was significantly higher following cutting in April or October compared with cutting in June or June and October. In contrast, cover of Red clover was significantly higher following the June and October cut compared with cutting in April or October. Similarly, cutting in June resulted in a higher cover of Red clover than cutting in April. Overall cover of sown dicots was significantly higher following cutting in April or October compared with June. Cutting in October also resulted in a higher cover than June cutting. Cover of grasses was significantly higher following June cutting compared with April or October cutting. Cover of Birdsfoot trefoil and all sown dicots was significantly higher following the removal of cut herbage. Leaving the cut material *in situ* significantly enhanced the cover of grasses. Finally, there were significant interactions between variety and cutting date. This reflected the larger than expected cover of Birdsfoot trefoil in the mixtures based on Britta and Wild Somerset which were cut in April or October. Also, the cover of Red clover under the June and June and October cutting regimes was larger than expected in the mixtures based on Milvus compared to the others.

3.1.2 Flower abundance

In 2005 there were highly significant differences in the abundance of sown dicot flowers between the different seed mixtures (Table 5; Fig. 1a). Abundance was significantly higher in the Alsike seed mix compared with all others. Abundance was also higher in the Wild Somerset and Multi-mix treatments compared with the Wild Berks mix. The abundance of Red clover flowers was significantly higher in the mixtures based on Britta and Milvus compared with those based on Wild Berkshire and Alsike (Fig. 2a). Cutting in October resulted in a significantly higher abundance of dicot flowers compared with cutting in June and October (Fig. 1b). There was no significant effect of cutting date on Red clover flower abundance (Fig. 2b). Similarly, there was no significant effect of herbage disposal technique on flower abundance of sown dicots or Red clover (Figs. 1c & 2c).

In 2006 the abundance of sown dicot flowers was significantly higher in the mixture based on Wild Somerset compared with those based on Alsike clover and the Multi-mix (Table 5; Fig. 1a). The abundance of Red clover flowers was significantly higher in the mixtures based on Milvus and Wild Somerset compared with all others (Fig. 2a). Cutting in April resulted in a significantly higher number of sown dicot flowers compared with cutting in June or June and October (Fig. 1b). In contract, cutting in June and October resulted in significantly more Red clover flowers compared with cutting in April or October alone (Fig. 2b). Finally, removal of cut herbage resulted in significantly more flowers of sown dicots (Fig. 1c). However, there was no significant effect on Red clover flower abundance (Fig. 2c).

In 2007 there were no significant differences in the abundance of sown dicot flowers between seed mixtures (Table 5; Fig. 1a). However, the abundance of Red clover flowers was significantly higher in mixtures based on Milvus and Wild Somerset compared with all others (Fig. 2a). April or October cutting resulted in a significantly higher abundance of dicot flowers compared with June or June and October cutting (Fig. 1b). There was evidence that the abundance of Red clover flowers was higher under October or June and October cutting, but this not significant (Fig. 2b). Removal of the cut material resulted in a significantly higher abundance of dicot flowers compared with leaving the herbage *in situ* (Fig. 1c). There was no overall effect of herbage disposal on abundance of Red clover flowers. There were no significant interactions between variety / seed mix, cutting date or herbage disposal.

Table 4. The effects of a) Clover variety / seed mix, b) Cutting date and c) Herbage disposal technique on the percentage cover of dicots and grasses in 2005 and 2007. Means with the same letter in the same column are not significantly different (P> 0.05).

	Birdsfoot trefoil			**Sainfoin**			**Alsike clover**			**Red clover**			**Sown dicots**			**Grasses**		
a) Variety / seed mix	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
Red clover (var. Britta)	8.9b	19.7	27.75ab	0.0	0.0	0.10	0.4b	0.4b	0.44	72.2a	11.9b	9.67b	81.5	32.1bc	37.96ab	17.1b	50.4	44.50
Red clover (var. Milvus)	8.7b	9.9	14.44b	0.0	0.0	0.00	1.9b	0.0b	0.44	60.1b	62.9a	49.81a	70.7	72.8a	64.69a	27.1ab	24.5	27.98
Red clover (var. Wild Somerset)	27.0a	21.9	31.35a	0.0	0.3	0.17	4.5b	1.7b	0.21	28.3c	29.0b	14.71b	59.8	52.9ab	46.44ab	34.9a	39.6	41.10
Red clover (var. Wild Berkshire)	13.6ab	16.4	20.15ab	0.1	0.3	0.10	8.0b	4.2b	0.42	51.7b	13.0b	6.19b	73.4	34.0bc	26.85b	18.9b	57.9	55.71
Alsike clover	8.4b	17.5	22.17ab	0.1	0.0	0.00	60.9a	1.3b	1.58	2.3c	1.0b	1.35b	71.7	19.8c	25.11b	28.7ab	77.9	71.38
Multi-mix	5.4b	11.2	16.13b	0.0	0.0	0.10	14.2b	11.1a	3.40	57.9b	13.6b	4.56b	77.5	35.9bc	24.19b	18.4b	53.7	53.67
ANOVA $F_{5,5}$	9.84*	2.45ns	6.78*	0.56ns	0.63ns	1.22ns	25.73***	25.02**	3.67ns	298.70***	22.27**	22.34**	3.23ns	18.11**	7.95*	13.66**	3.21ns	2.78ns
b) Cut date																		
Apr	13.1	17.5	29.64a	0.0	0.0	0.00	13.6	2.6	1.08	42.5	16.8c	8.24c	69.2	36.9b	38.96ab	25.5	53.2a	45.17b
Jun	11.1	15.3	9.94b	0.0	0.1	0.14	14.1	2.3	0.25	49.7	23.1b	16.43ab	74.9	40.8b	26.76c	22.9	50.8a	58.22a
Jun + Oct	11.3	16.1	13.54b	0.0	0.1	0.03	17.5	5.5	1.51	46.7	29.5a	21.89a	75.5	51.2a	36.97bc	21.0	42.0b	49.68ab
Oct	12.4	15.5	34.86a	0.1	0.3	0.15	14.7	2.0	1.47	42.8	18.3bc	10.97bc	70.1	36.1b	47.46a	27.4	56.6a	43.15b
ANOVA $F_{3,42}$	0.88ns	0.64ns	42.70***	1.32ns	1.06ns	1.32ns	1.57ns	3.02*	1.52ns	2.76ns	13.46***	11.41***	1.85ns	12.79***	9.57***	1.79ns	12.20***	6.64***
c) Herbage disposal																		
Leave	11.2	14.4	18.83	0.0	0.0	0.10	15.2	2.7	0.78	45.5	20.8	13.07	71.9	37.9	32.78	23.8	51.6	52.95
Remove	12.7	17.8	25.17	0.1	0.2	0.06	14.8	3.5	1.38	45.3	23.1	15.69	73.0	44.6	42.30	24.6	49.8	45.16
ANOVA $F_{1,42}$	2.17ns	7.90**	11.68***	1.07ns	1.75ns	0.28ns	0.05ns	0.80ns	1.54ns	0.00ns	2.19ns	2.15ns	0.20ns	12.00**	11.99***	0.17ns	0.98ns	9.00***
Interactions																		
Cut date × Herbage disposal	1.76ns	3.44*	1.26ns	1.64ns	0.26ns	0.67ns	1.23ns	0.33ns	0.30ns	0.12ns	0.35ns	0.09ns	1.10ns	0.95ns	0.51ns	0.90ns	0.36ns	1.18ns
Variety × Cut date	0.72ns	2.14*	2.57**	1.10ns	0.86ns	1.12ns	1.14ns	0.88ns	1.42ns	3.14**	1.23ns	3.28***	1.57ns	1.12ns	2.35*	1.46ns	0.85ns	1.93*
Variety × Herbage disposal	0.73ns	1.33ns	1.15ns	0.86ns	0.86ns	0.83ns	0.12ns	0.50ns	0.74ns	2.12ns	1.51ns	0.79ns	1.11ns	2.21ns	0.44ns	0.90ns	3.54**	1.58ns

ns = no significant difference; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

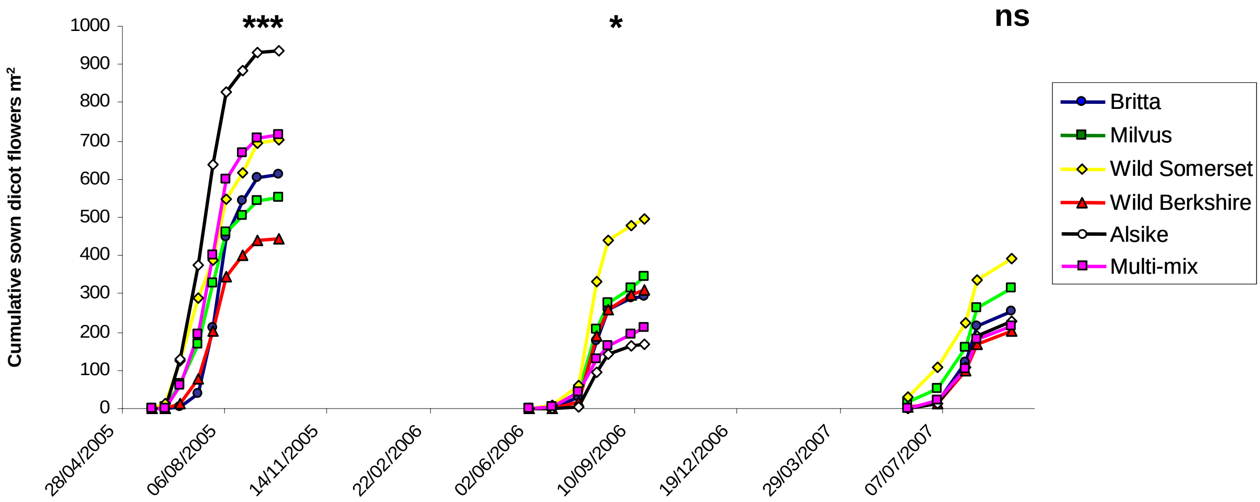
Table 5. The effects of a) Clover variety, b) Cutting date and c) Herbage disposal technique on the cumulative abundance of sown dicot and Red clover flowers per m^{-2} counted between June and September 2005-2007. Means with the same letter in the same column are not significantly different (P> 0.05).

	Flowers of sown dicots m^{-2}			Flowers of Red clover m^{-2}		
a) Variety / seed mix	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
Red clover (var. Britta)	613.5bc	291.6ab	50.6	547.4a	7.2b	7.0b
Red clover (var. Milvus)	553.3bc	343.5ab	62.9	502.8a	125.1a	29.8a
Red clover (var. Wild Somerset)	703.2b	496.3a	78.2	406.5ab	60.0a	28.7a
Red clover (var. Wild Berkshire)	444.2c	308.4ab	40.9	284.8b	14.2b	4.2b
Alsike clover	936.8a	166.1b	45.9	12.7c	2.0b	1.2b
Multi-mix	717.0b	209.2b	42.9	399.6ab	18.7b	4.6b
ANOVA $F_{5,5}$	33.20***	7.08*	3.63ns	28.73***	253.53***	17.17**
b) Cut date						
Apr	675.4ab	342.4a	77.7a	369.8	32.5bc	13.5
Jun	655.2ab	270.9b	26.3b	356.2	42.5ab	14.6
Jun + Oct	629.1b	285.9b	34.9b	343.7	51.1a	20.4
Oct	685.7a	310.8ab	93.6a	366.1	25.3c	21.2
ANOVA $F_{3,42}$	2.80*	4.78**	68.31***	1.35ns	5.85**	3.05*
c) Herbage disposal						
Leave	716.4	282.6	54.9	351.1	33.5	15.6
Remove	731.4	322.4	61.4	366.8	42.3	19.2
ANOVA $F_{1,42}$	0.92ns	7.78**	6.85*	2.47ns	3.55ns	3.07ns
Interactions						
Cut date × Herbage disposal	2.26ns	5.26***	1.13ns	3.87*	1.13ns	0.06ns
Variety × Cut date	3.13**	3.89***	1.55ns	1.72ns	3.19**	1.24ns
Variety × Herbage disposal	1.08ns	0.61ns	0.81ns	0.28ns	2.07ns	0.15ns

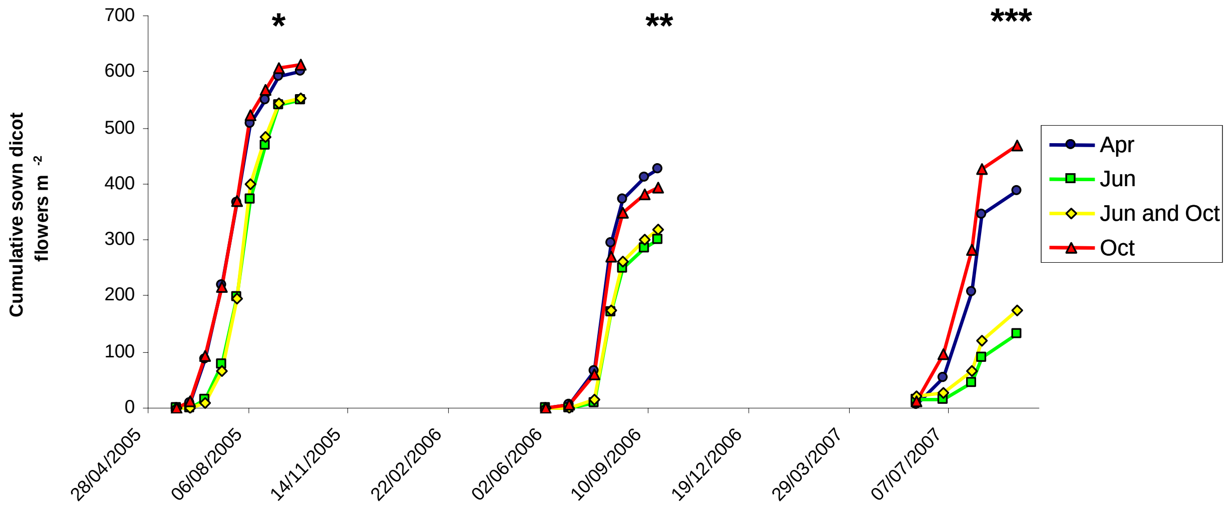
ns = no significant difference; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

Fig. 1. Effects of a) Variety, b) Cutting date and c) Herbage disposal on cumulative abundance of sown dicot flowers per m^{-2} 2005-2007. ns = no significant difference; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

a) Variety



b) Cutting date



c) Herbage disposal

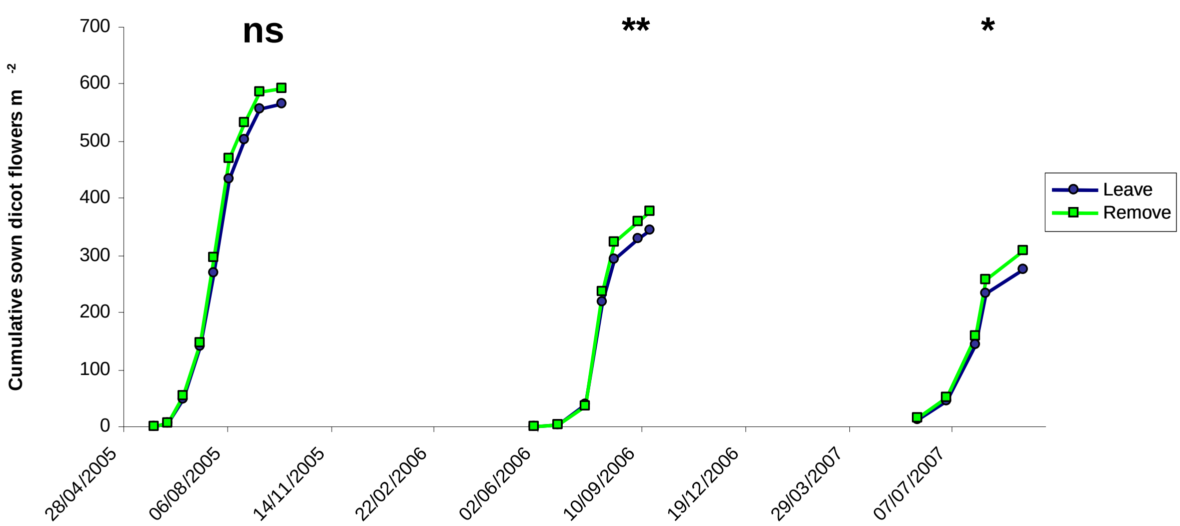
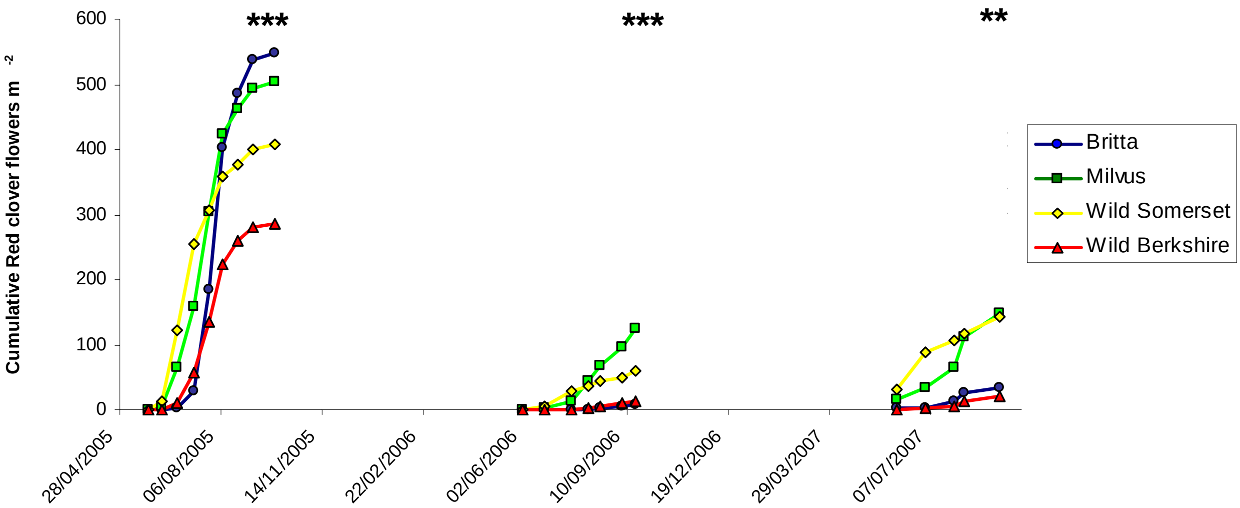
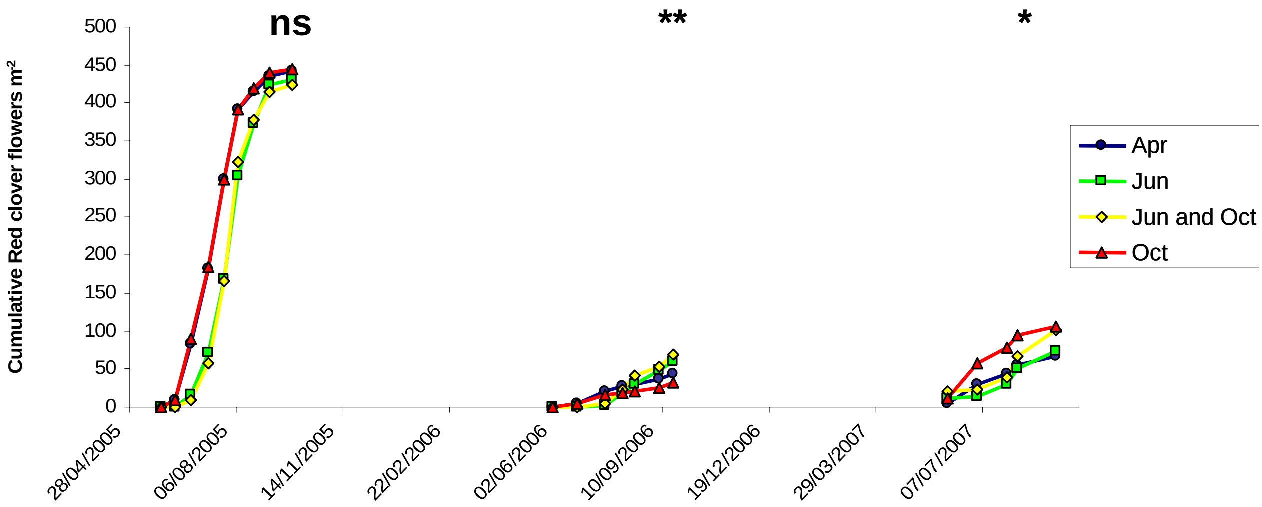


Fig. 2. Effects of a) Variety, b) Cutting date and c) Herbage disposal on cumulative abundance of Red clover flowers per m^{-2} 2005-2007.
significant difference; * = P < 0.05; ** = P < 0.01; *** = P < 0.001

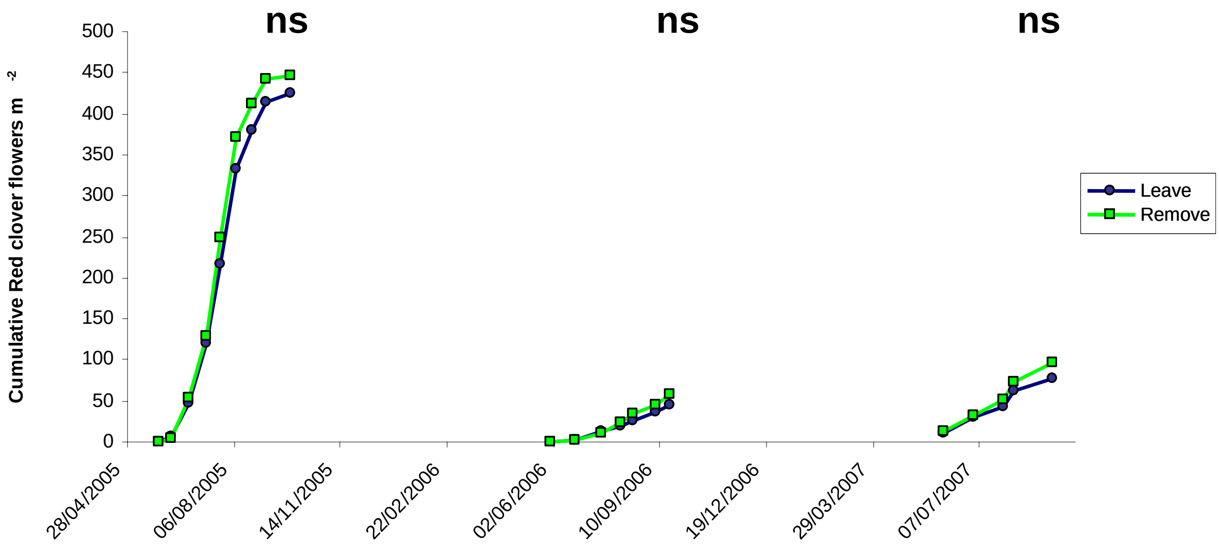
a) Variety



b) Cutting date



c) Herbage disposal



3.2 *Experiment 2: Pollen and Nectar Seed Mixtures*

3.2.1 Vegetation composition

In 2005 there were highly significant differences in species number (richness) between the different seed mixtures (Table 6a). Vegetation resulting from the Dwarf Rye grass mix had a significantly higher species number than the Set-aside, Legume only, Rye Grass Nurse, Fine Grass Simple and Lucerne mixes. Moreover, species number was significantly lower in the Legume only and Lucerne mixes compared with all others except the Typical ELS mix. Percentage cover of sown grasses was significantly higher in the Rye Grass Nurse and Rye Grass seed mixes compared with all others except the Dwarf Rye Grass mix (Fig. 3a). Grass cover was lowest in the Set-aside, Legume Fine Grass Simple Typical ELS, Lucerne and Lucerne and Legumes mixes. There were no significant differences in the overall cover of sown dicots.

In 2006 the cover of bare ground was significantly higher in the Legume only mix compared with the Rye Grass Nurse, Fine Grass Complex, Dwarf Rye Grass, Lucerne, and Lucerne and Legume mixes (Table 6b). Species number was significantly higher in the Set-aside and Typical ELS mixes compared with the Rye Grass Nurse mix. Cover of sown grasses was significantly higher in the Lucerne mix compared with all others except the Dwarf Rye Grass and Rye Grass mixes (Fig. 3b). Cover of grasses was next highest in the Lucerne and Legume and Typical ELS mixes. Cover of sown dicots was highest in the Legume only, Rye Grass Nurse, and Fine grass (Simple and Complex) compared with all others except the Set-aside mix (Fig. 3b). Cover of sown dicots was significantly lower in the Lucerne, and perennial Rye Grass mixes. There were large differences in the ability of different legume species to tolerate competition from grasses. For example, Lucerne appeared to be much less able to tolerate competition than Red clover.

In 2007 there were no significant differences in the percentage cover of bare ground, sown grasses or dicots, or species number (richness) between the ten seed mixtures (Table 6c). This probably reflected the large declines in the cover of sown legumes in all seed mixtures. However, splitting the plots and applying graminicide at random to one half resulted in a significant increase in the cover of bare ground and sown dicot species (Fig. 3c). As expected, it resulted in a significant reduction in cover of sown grasses and species number. There was some evidence that graminicide application resulted in an increase in the cover of undesirable weeds (e.g. *Cirsium* sp., *Rumex* sp.) (13.7% ±2.6 compared with 3.6% ±1.0). However, this was not quite significant at the $P<0.05$ level.

3.2.2 Bumblebee abundance and richness

In 2006 there were no significant differences in the abundance (ANOVA $F_{9,18} = 0.62$ ns) or species number ($F_{9,18} = 0.86$ns) of bumblebees between the seed mixture treatments. Similarly, there were no significant differences in bee abundance ($F_{9,36} = 1.09$ns) between treatments in 2007. However, there was a weakly significant difference in the species number (richness) of bees between treatments ($F_{9,36}$ = 2.25*). Richness was highest in the legume only mix compared with those sown with tall grasses or lucerne. Finally, graminicide application resulted in a significant increase in the abundance of sown dicot flowers (ANOVA $F_{1,2}$ = 30.40*). However, this did not result in a significant increase in the overall abundance ($F_{1,2}$ = 5.33ns) or richness of bees ($F_{1,2}$ = 9.00ns).

Table 6. Effects of seed mixture and graminicide application on bare ground, species number and percentage cover of sown grasses and dicots in a) 2005, b) 2006 and 2007. Means with the same letter in the same column are not significantly different (P> 0.05).

a) 2005

Seed mix	Bare ground		Species number			% cover sown grass			% cover sown dicots	
1. Set aside	1.1	±0.8	12.3	±0.6	**b**	0.2	±0.2	**c**	39.7	±9.1
2. Legume only	0.7	±0.5	12.0	±1.4	**c**	0.0	±0.0	**c**	48.5	±7.0
3. Rye Grass nurse	0.4	±0.2	12.5	±1.1	**b**	28.3	±4.0	**a**	34.8	±4.6
4. Fine grass simple	0.4	±0.3	13.0	±0.8	**b**	1.4	±0.8	**c**	60.0	±7.7
5. Fine grass complex	1.3	±0.5	14.7	±1.5	**ab**	9.2	±1.6	**b**	55.9	±7.1
6. Typical ELS	1.0	±0.7	14.0	±1.1	**abc**	13.8	±6.1	**c**	30.5	±2.8
7. Dwarf Rye Grass	1.2	±0.6	15.5	±1.0	**a**	25.1	±3.1	**ab**	35.2	±3.2
8. Rye Grass	0.6	±0.3	14.5	±0.8	**ab**	32.7	±4.0	**a**	39.8	±4.1
9. Lucerne	0.2	±0.2	11.8	±0.8	**c**	6.5	±1.0	**c**	49.2	±7.5
10. Lucerne & legume	1.5	±0.8	13.2	±1.1	**abc**	7.2	±1.3	**c**	63.5	±7.8
ANOVA $F_{2,18}$	**0.51ns**		**7.24*****			**12.27*****			**1.75ns**	

b) 2006

Seed mix	Bare ground			Species number			% cover sown grass			% cover sown dicots		
1. Set aside	0.7	±0.0	**ab**	9.6	±0.8	**a**	0.9	±1.3	**c**	82.0	±1.5	**ab**
2. Legume only	2.1	±0.5	**a**	7.8	±1.9	**ab**	1.7	±0.5	**c**	93.0	±6.0	**a**
3. Rye Grass nurse	0.0	±0.0	**b**	5.9	±0.6	**b**	7.8	±2.4	**c**	92.7	±3.0	**a**
4. Fine grass simple	0.8	±0.6	**ab**	8.8	±1.2	**ab**	1.7	±0.5	**c**	94.7	±1.7	**a**
5. Fine grass complex	0.0	±0.0	**b**	7.7	±1.0	**ab**	3.2	±0.8	**c**	93.5	±2.6	**a**
6. Typical ELS	0.7	±1.1	**ab**	9.6	±1.6	**a**	33.9	±1.3	**b**	65.4	±2.4	**b**
7. Dwarf Rye Grass	0.0	±0.0	**b**	8.1	±0.8	**ab**	37.6	±3.5	**ab**	60.9	±4.0	**b**
8. Rye Grass	0.6	±0.4	**ab**	7.7	±0.8	**ab**	40.7	±4.3	**ab**	57.9	±4.0	**c**
9. Lucerne	0.0	±0.5	**b**	7.6	±1.4	**ab**	53.5	±3.5	**a**	46.7	±3.7	**c**
10. Lucerne & legume	0.0	±0.0	**b**	7.2	±0.8	**ab**	27.1	±2.7	**b**	75.8	±4.1	**abc**
ANOVA $F_{2,18}$	**3.53***			**2.61***			**30.70*****			**15.44*****		

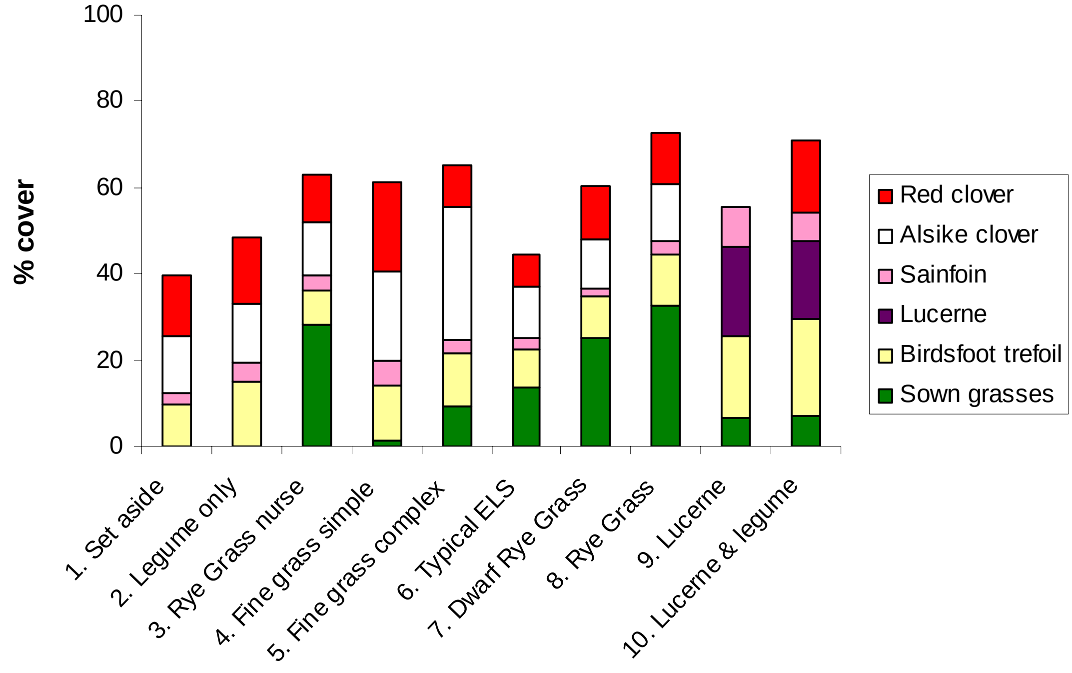
c) 2007

Seed mix	Bare ground			Species number			% cover sown grass			% cover sown dicots		
1. Set aside	4.8	±3.2		8.3	±1.1		21.9	±12.0		45.6	±11.3	
2. Legume only	12.7	±7.8		7.2	±0.9		26.2	±13.3		32.1	±12.7	
3. Rye Grass nurse	11.9	±7.5		7.8	±0.5		5.5	±4.0		51.2	±7.2	
4. Fine grass simple	2.2	±1.2		7.1	±0.9		20.8	±13.2		53.8	±10.8	
5. Fine grass complex	2.2	±1.2		6.3	±1.2		24.4	±15.0		34.4	±11.4	
6. Typical ELS	9.6	±4.4		6.9	±0.2		18.7	±8.2		38.6	±7.8	
7. Dwarf Rye Grass	8.1	±4.5		5.8	±0.7		25.5	±11.9		49.9	±10.0	
8. Rye Grass	10.5	±6.9		6.0	±0.7		23.4	±13.7		43.9	±15.9	
9. Lucerne	23.9	±11.1		6.5	±0.8		36.7	±14.7		27.2	±9.7	
10. Lucerne & legume	15.0	±6.4		5.9	±0.4		30.9	±11.8		21.7	±7.1	
ANOVA $F_{2,18}$	**1.27ns**			**1.13ns**			**1.02ns**			**1.87ns**		
No graminicide	3.8	±1.1		7.3	±0.4		44.5	±4.9		24.0	±3.6	
Graminicide	16.3	±3.5		6.3	±0.3		2.3	±0.6		55.7	±4.1	
ANOVA $F_{1,2}$	**70.61***			**21.24***			**98.24****			**22.57***		

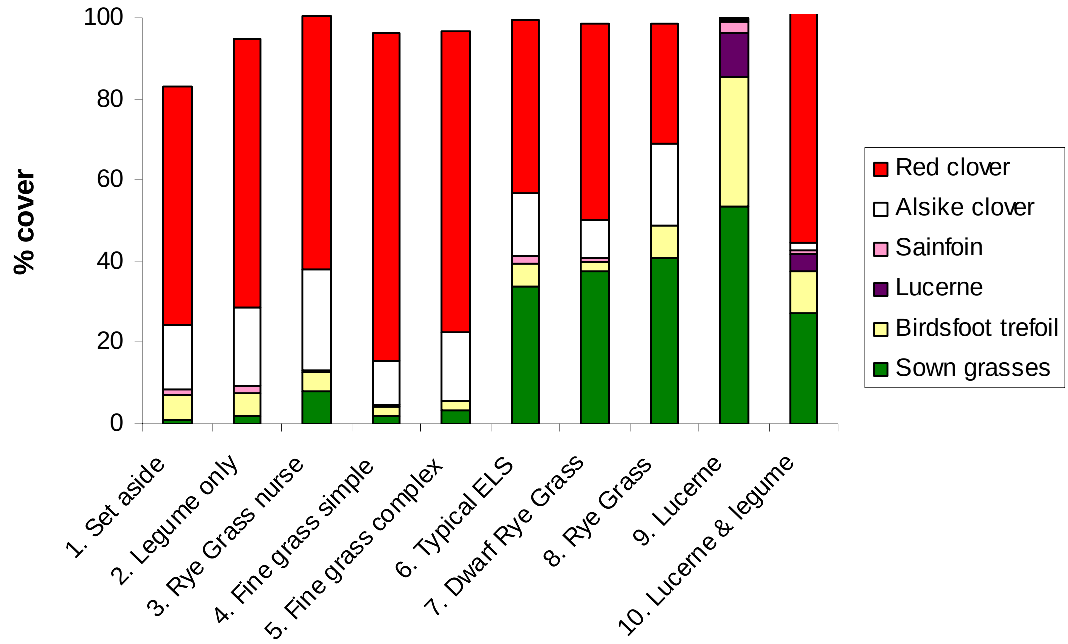
ns = no significant difference; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

Fig. 3. Cover of individual sown species in the 10 seed mixtures a) 2005, b) 2006, c) 2007 (i) without graminicide, and d) 2007 (ii) with graminicide

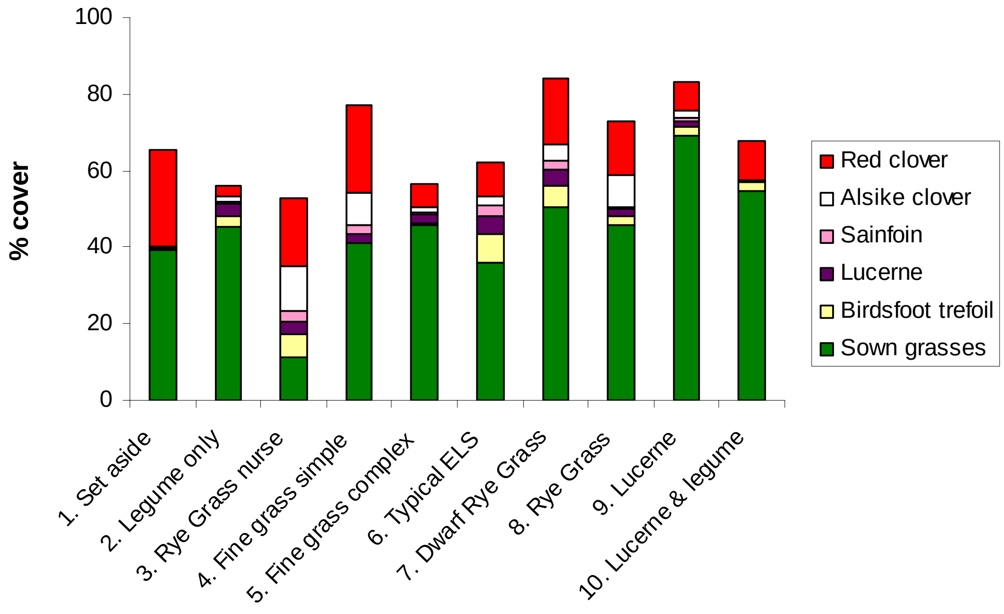
a) 2005



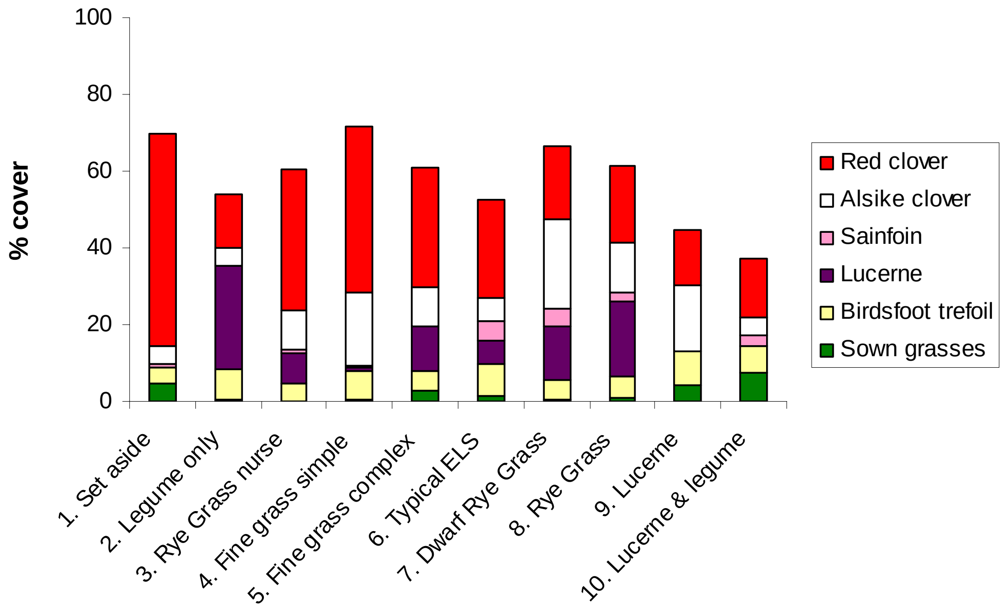
b) 2006



c) 2007 (i) without graminicide



d) 2007 (ii) with graminicide



3.3 *Experiment 3: Pollen and Nectar Preference*

3.3.1 <u>Bumblebee and butterfly abundance</u>

In 2006 bumblebee abundance summed for all visits was significantly higher on plots sown with Phacelia, then Borage, and then Crimson clover and Sunflower compared with all other treatments (Table 7a). Bee species number (richness) was also significantly higher in the Phacelia, Borage Crimson clover and Sunflower plots compared with all others. Short-tongued bees showed a marked preference for plots sown with Phacelia and Borage, followed by Sunflower compared with all other treatments (Fig. 4a; ANOVA $F_{12,36}$=194.37***). Long-tongued bees showed a significant preference for Crimson clover compared with all other species except Borage and Phacelia (Fig. 4a; $F_{12,36}$=6.50***). Also, Borage was preferred to all species except Phacelia, Sainfoin and Sunflower.

Abundance and species number (richness) of butterflies were significantly higher in the plots sown with Lucerne compared to those sown with Borage, Chicory and Sainfoin (Table 7a). Immobile butterfly species showed a marked preference for the Lucerne plots compared with all others except Red clover, Crimson clover and Sweet clover (Fig. 5a; $F_{12,36}$=3.43**). There were no significant differences in the abundance of mobile butterfly species between treatments ($F_{12,36}$=1.45ns).

In 2007 bumblebee abundance was significantly higher in the plots sown with Phacelia compared with all others except Borage (Table 7b). Bee abundance was also significantly higher in the plots sown with Red clover compared those sown with Buckwheat, Chicory, Linseed, Lucerne, and Sweet Clover. Bee species number was significantly higher in plot sown with Borage, Crimson clover, Phacelia, Red clover and Sunflower compared with Mustard. Once again, short-tongued bees showed a marked preference for plots sown with Phacelia and Borage compared with all other treatments (Fig. 4b; ANOVA $F_{12,36}$=42.73***). Long-tongued bees showed a significant preference for Red clover compared with all other species (Fig. 4b; $F_{12,36}$=8.86***). They also showed a strong preference for Sainfoin and Crimson clover.

In 2007 overall numbers of butterflies were very low even compared with 2006. Abundance was significantly higher in the plots sown with Red clover compared those sown with Chicory (Table 7b). There were no other significant differences. There were weakly significant differences in the abundance of mobile butterfly species between treatments (Fig. 5b; $F_{12,36}$= 2.22*), with abundance highest in plots sown with Red clover and Fodder radish. There were no significant differences in the abundance of immobile butterfly species between treatments (Fig. 5b; $F_{12,36}$= 0.71ns).

3.3.2 Flower abundance

In 2006 species with the highest percentage cover of flowers were the annuals Phacelia, Borage, Crimson clover, Sunflower and Buckwheat (Fig. 6a). Flower cover in the perennials (Red clover, Sainfoin and Lucerne) was much lower. Peak flowering of Phacelia and Borage was in late June to mid-July. Crimson clover flowering peaked in mid-July. Sunflower flowered throughout August. Buckwheat continued to flower throughout July and August.

In 2007 more distinctive patterns in flowering phenology were observed between treatments (Fig. 6b). Peak flowering of Crimson clover was early in the season (late-May), followed by peak flowering of Fodder radish in late June. Many important bee forage species had their peak flowering in late July, including Phacelia, Borage, Red clover and Sweet clover. Peak flowering of Sunflower was in late August.

There were highly significant differences in the mean flower abundance between treatments (ANOVA $F_{12, 36} = 28.80$***). Flowers of Fodder radish were the most abundant on average, followed by Buckwheat, Red clover, Phacelia, Borage and Sweet clover. Flowers of Sainfoin, Chicory and Crimson clover were the next most abundant, and those of Mustard, Lucerne, Sunflower and Linseed the least abundant.

Table 7. Bumblebee and butterfly abundance and species number (richness) on the different plant species in a) 2006 and b) 2007. Means with the same letter in the same column are not significantly different (P> 0.05).

a) 2006

Treatment	Total butterflies			Species number butterflies			Total bumblebees			Species number bumblebees		
Borage	0.3	±0.3	**b**	0.3	±0.3	**b**	99.8	±12.1	**b**	3.3	±0.3	**a**
Buckwheat	2.0	±0.4	**ab**	1.5	±0.5	**ab**	1.3	±0.6	**d**	1.0	±0.4	**b**
Chicory	0.8	±0.5	**b**	0.5	±0.3	**b**	0.3	±0.3	**d**	0.3	±0.3	**b**
Crimson clover	3.0	±0.9	**ab**	2.0	±0.4	**ab**	37.3	±2.5	**c**	4.0	±0.0	**a**
Fodder radish	1.0	±0.7	**ab**	0.5	±0.3	**b**	1.5	±1.5	**d**	0.3	±0.3	**b**
Linseed	2.8	±1.0	**ab**	1.3	±0.6	**ab**	0.8	±0.3	**d**	0.8	±0.3	**b**
Lucerne	6.3	±2.7	**a**	3.5	±0.6	**a**	2.5	±0.6	**d**	1.3	±0.3	**b**
Mustard	1.5	±1.0	**ab**	1.0	±0.7	**ab**	0.0	±0.0	**d**	0.0	±0.0	**b**
Phacelia	1.8	±0.9	**ab**	1.5	±0.6	**ab**	134.3	±3.6	**a**	3.5	±0.3	**a**
Red clover	3.3	±0.8	**ab**	2.8	±0.5	**ab**	3.8	±0.8	**d**	1.0	±0.0	**b**
Sainfoin	0.8	±0.8	**b**	0.5	±0.5	**b**	5.5	±1.2	**d**	1.3	±0.3	**b**
Sunflower	2.0	±0.6	**ab**	1.5	±0.3	**ab**	26.3	±5.3	**c**	2.8	±0.5	**a**
Sweet clover	2.5	±1.6	**ab**	2.0	±1.1	**ab**	2.3	±1.4	**d**	0.3	±0.3	**b**
ANOVA $F_{12,36}$	**2.04***			**2.97****			**117.01*****			**25.63*****		

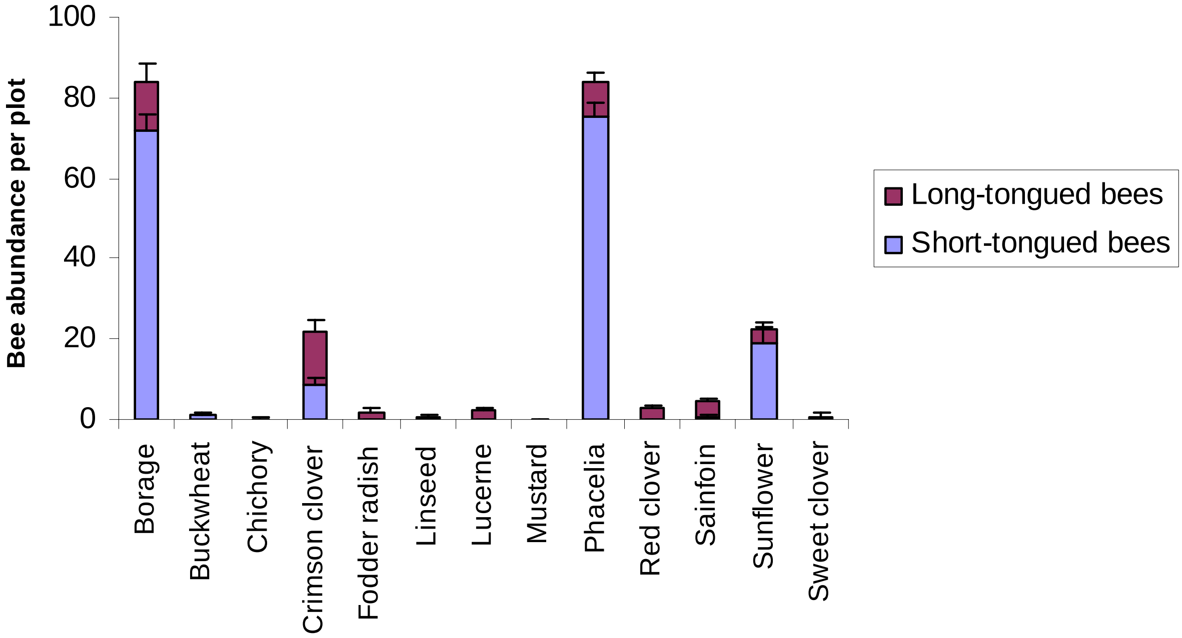
b) 2007

Treatment	Total butterflies			Species number butterflies			Total bumblebees			Species number bumblebees		
Borage	1.3	±0.6	**ab**	1.0	±0.4		32.0	±3.5	**ab**	3.3	±0.3	**a**
Buckwheat	1.0	±0.6	**ab**	0.8	±0.5		5.3	±3.5	**d**	1.5	±0.9	**ab**
Chicory	0.0	±0.0	**b**	0.0	±0.0		5.8	±1.4	**d**	2.3	±0.3	**ab**
Crimson clover	0.8	±0.3	**ab**	0.8	±0.3		10.3	±2.0	**cd**	3.3	±0.5	**a**
Fodder radish	2.3	±0.8	**ab**	1.5	±0.5		9.5	±1.3	**cd**	2.3	±0.3	**ab**
Linseed	0.5	±0.5	**ab**	0.3	±0.3		3.0	±1.7	**d**	1.8	±0.5	**ab**
Lucerne	2.0	±1.2	**ab**	1.5	±0.9		4.8	±1.5	**d**	1.8	±0.5	**ab**
Mustard	0.8	±0.3	**ab**	0.8	±0.3		2.0	±1.7	**d**	0.5	±0.3	**b**
Phacelia	1.5	±0.5	**ab**	1.3	±0.3		38.5	±2.2	**a**	3.3	±0.3	**a**
Red clover	3.3	±1.5	**a**	1.8	±0.6		21.0	±3.0	**bc**	3.0	±0.7	**a**
Sainfoin	0.3	±0.3	**ab**	0.3	±0.3		11.0	±1.2	**cd**	2.0	±0.0	**ab**
Sunflower	0.5	±0.5	**ab**	0.5	±0.5		9.8	±0.8	**cd**	3.0	±0.0	**a**
Sweet clover	0.3	±0.3	**ab**	0.3	±0.3		8.8	±4.2	**d**	2.8	±0.8	**ab**
ANOVA $F_{12,36}$	**2.20***			**1.91ns**			**21.29***			**3.24***		

ns = no significant difference; * = P < 0.05; ** = P < 0.01; *** = P < 0.001

Fig. 4. Abundance of Long- and short-tongued bumblebees on the different plant species in a) 2006 and b) 2007.

a) 2006



b) 2007

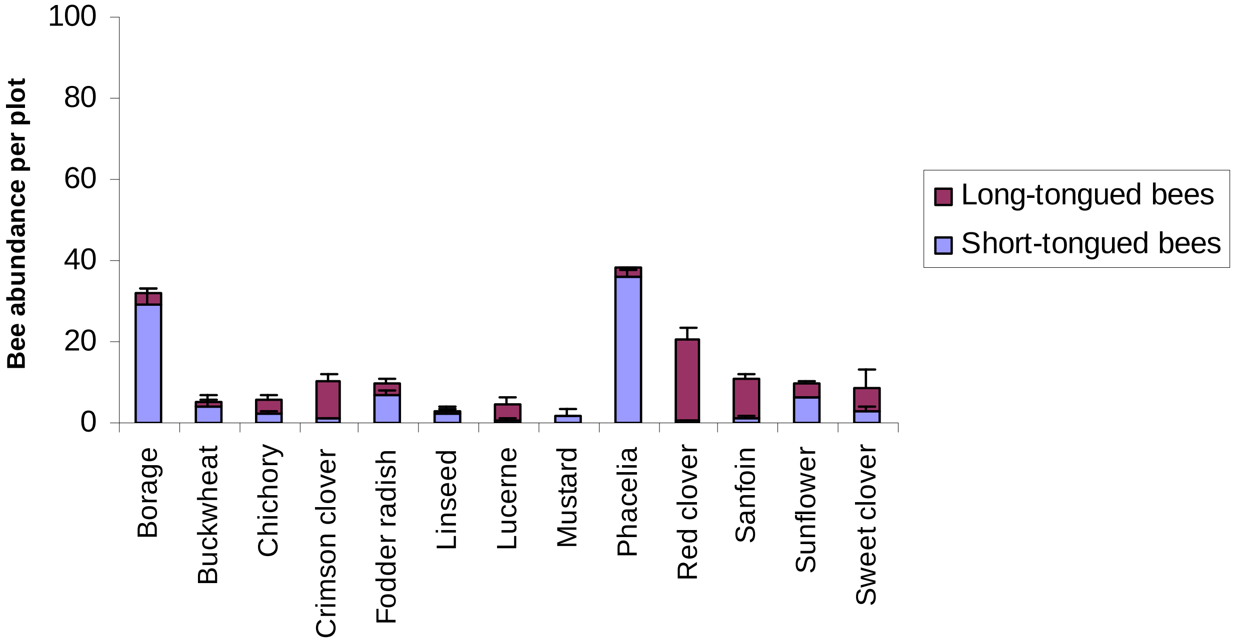
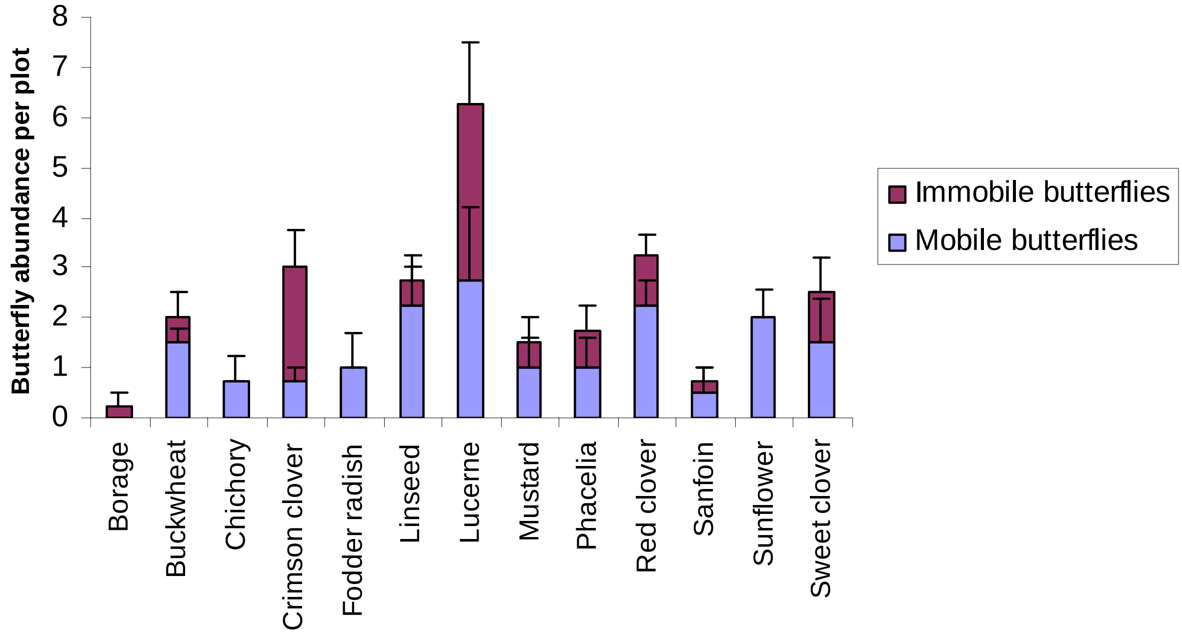


Fig. 5. Abundance of mobile and immobile butterfly species on the different plant species in a)2006 and b)2007.

a) 2006



b) 2007

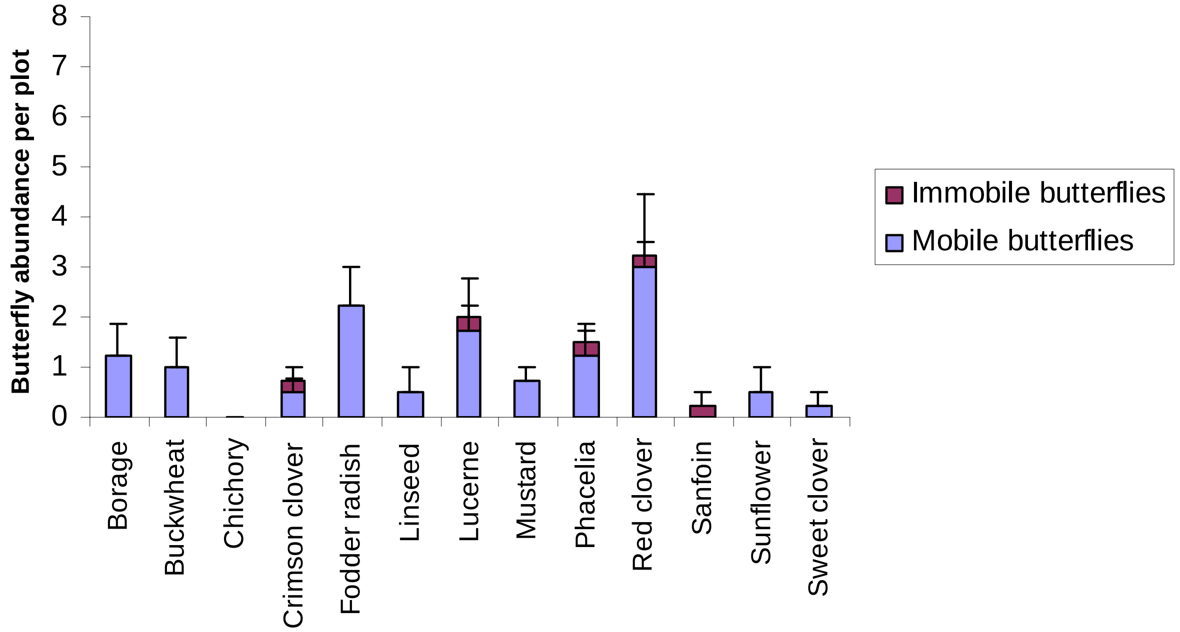
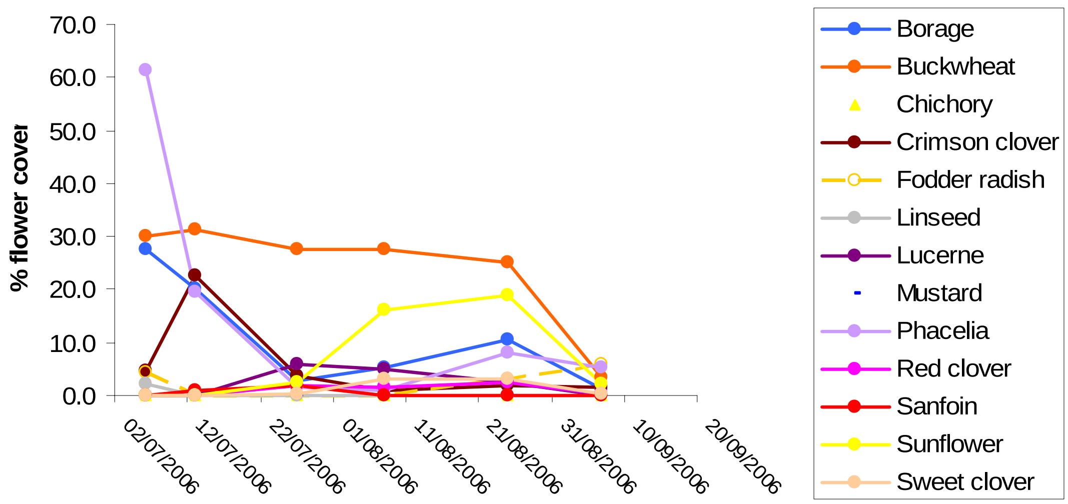
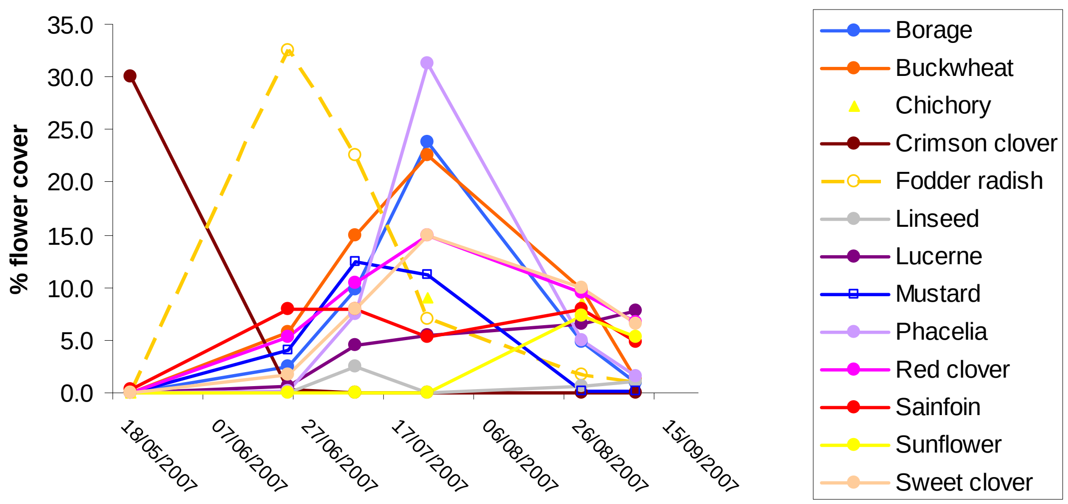


Fig. 6. Flowering phenology of the different plant species in a) 2006 and b) 2007.

a) 2006



b) 2007



4. Discussion

4.1 *Experiment 1: Performance of Clover Varieties*

Red clover is a short-lived perennial in productive grassland systems (Frame, Charlton and Laidlow, 1998). This experiment confirmed that relatively few of the varieties of Red clover tested were persistent beyond year 4 when sown in pollen and nectar seed mixtures on fertile ex-arable soils. Indeed, mean percentage cover of clover fell from a peak of 54% in year 2 to 26% in year 3 and just 17% in year 4. Milvus was the best performing agricultural variety, maintaining a cover of between 50-60% in all three years. This variety has large leaves which forms a dense, competitive canopy enabling it to out-compete the companion grass species. Somerset was the best performing wild variety of clover maintaining a cover of around 28% in years 2 and 3, but falling to 15% in year 4. This has smaller leaves and a relatively lower competitive ability. Nevertheless, the smaller leaves and stoloniferous growth form of this variety probably enable it to persist well in grass swards.

It is good management practice in non-grazed, Red clover swards to cut and mulch regularly during the growing season. In this experiment cutting in June and October significantly increased the cover and flower abundance of Red clover in years 3 and 4. Similarly, cutting in June alone increased clover cover compared with more typical cutting in April or October. Cutting in June removes peak biomass of the competitive grasses, and will encourage branching growth and flower bud formation in clovers. Further research is required to determine the precise mechanism of this observed effect, and if it is an effective means of maintaining sown pollen and nectar species in the longer term. However, there is evidence that timing and frequency of cutting influence the rate of crown deterioration and therefore persistency in Red clovers (Anon., 2002). Also, related studies have shown that cutting in mid- and late-June and delay flowering of clover until after the peak requirements of bumblebee colonies. It is also evident that other sown legume species showed markedly different responses to cutting management. For example, after 4 years of summer cutting the cover of Birdsfoot trefoil was reduced by between 50-60%.

The method of herbage disposal also had important ecological effects on vegetation composition and the provision of pollen and nectar resources. Agricultural varieties of Red clover are vigorous, and have succulent, non-fibrous stem and leaves. There is a danger that the thick residue of cut material may act as a physical barrier to light reaching the underlying plants and may result in smothering, particularly in winter. Plant species will vary greatly in their ability to tolerate the stress induced by this type of shading. This will have indirect effects on plant community composition by altering the competitive balance between species. The removal of cut material resulted in a significant increase in the cover of sown dicots at the expense of grasses, and increased flowering in both years 3 and 4. This probably reflects the instant reduction in competition for space and light compared with the more gradual reduction resulting from leaving the cut material *in situ*. It is also likely that removal resulted in nutrient off-take and reduction in soil fertility (Tallowin et al., 2002).

4.2 *Experiment 2: Pollen and Nectar Seed Mixtures*

Many seed mixtures currently sold for the creation of pollen and nectar habitat under the Agri-environment schemes comprise mixtures of agricultural legumes and tall, competitive grasses, such as Meadow Fescue and Timothy.

This experiment demonstrated that these mixtures did not perform well, with cover of legumes significantly reduced after less than 2 years. This reflects the small seed size and low seedling growth rates of many of the sown legumes, and the lower competitive ability of adult plants compared with tall grasses growing on fertile soils. Persistence of legumes was significantly better in mixtures sown either without grasses, or with just fine-leaved grasses, such as Crested Dogstail, with significantly lower competitive ability.

This was further confirmed by the effectiveness of graminicide application in the winter of year 3 in reducing the cover of grasses and increasing both the cover and flower abundance of sown legumes. However, the increased bare ground also resulted in greater colonisation by undesirable agricultural weed species, such as thistles (*Cirsium* spp.). This probably represents and unacceptable side effect for land managers.

4.3 *Experiment 3: Pollen and Nectar Preference*

The results from the BUZZ project and also Experiment 1 confirmed that many the pollen and nectar seed mixtures sown under the Agri-environment schemes are relatively short lived. Moreover, experience of the BIGBEE project has shown that the re-establishment of this habitat in the same location is severely constrained by competition from sown, fine-leaved grasses emerging from the seed bank which is enhanced by increased nitrogen mineralization (Matt Heard, *pers. comm.*). There are therefore good practical and agronomic reasons for the development of low-cost, annual pollen and nectar seed mixtures which can be readily established on fertile, field margin strips and moved to different locations each year. Previous research has shown that bumblebees generally prefer to forage on native perennial plants rather than annuals (Pywell et al., 2005). However, certain annual crop species, such as Borage and Fodder radish, have been shown to be attractive to bumblebees (Carreck et al., 1999; Carvell et al., 2006). Some of these species have the additional advantage of producing large quantities of small-seeds for farmland birds in the autumn and winter (Stoate, Szczur and Aebischer, 2003). The results from Experiment 3 showed that the flowers of the annual crop species were much more abundant than those of perennials in the first year. The peak flowering period of most species was late July. This is coincident with peak worker abundance for most species of bumblebee. At this time short-tongued bees showed a marked preference for Phacelia and Borage, whereas long-tongued bees showed a significant preference for the perennial legumes Red clover, Crimson clover and Sainfoin. Butterfly numbers were probably too small to draw many meaningful conclusions regarding the value of these habitats. In 2006 immobile butterfly species showed some preference for plots containing the short-lived perennial legume Lucerne. In 2007 mobile butterflies preferred plots containing Red clover. These preliminary results suggest there is some potential for the development of annual pollen and nectar seed mixtures which provide foraging habitat for both short- and long-tongued bees, and potentially widespread butterfly species.

5. References

Anon. (2002) *Clover Management leaflet.* (www.iger.bbsrc.ac.uk/Practice/Publications_&_Leaflets/In%20Clover.pdf)

Anon. (2005) Entry Level Stewardship Handbook. London: Defra.

Biesmeijer, J. C., Roberts, S. P. M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A. P., Potts, S. G., Kleukers, R., Thomas, C. D., Settele, J., & Kunin, W. E. (2006) Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands. Science, 313, 351-354.

Carreck, N.L., Williams, I.H., & Oakley (1999) Enhancing farmland for insect pollinators using flower mixtures. Aspects of Applied Biology, 54, 101-108.

Carvell, C., Roy, D.B., Smart, S.M., Pywell, R.F., Preston, C. & Goulson, D. (2006) Declines in forage availability for bumblebees at a national scale. Biological Conservation, 132, 481-489.

Dennis, R. L. H., & Shreeve, T. G. (2003) Gains and losses of French butterflies: tests of predictions, under-recording and regional extinction data in a new atlas. Biological Conservation, 110:131-139.

Dicks, L.V., Corbet, S.A. & Pywell, R.F. (2002) Compartmentalization in plant-insect flower visitor webs. Journal of Animal Ecology, 71, 32-43.

Frame, J., Charlton, J.F.L, & Laidlow, A.S. (1998) *Temperate Forage Legumes*. Oxford University Press, Oxford.

Free, J.B. (1993) *Insect Pollination of Crops*, 2nd edn. Academic Press, London.

Goulson, D., Hanley, M. E., Darvill, B., Ellis, J. S., & Knight, M. E. (2005) Causes of rarity in bumblebees. Biological Conservation, 122, 1-8.

Meek, W. M., Loxton, R., Sparks, T. H., Pywell, R. F., Pickett, H., Nowakowski, M. (2002) The effect of arable field margin composition on invertebrate biodiversity. Biological Conservation, 106: 259-271.

Pywell, R. F., Warman, E. A., Carvell, C., Sparks, T. H., Dicks, L. V., Bennett, D., Wright, A., Critchley, C. N. R., & Sherwood, A. (2005) Providing foraging resources for bumblebees in intensively farmed landscapes. Biological Conservation, 121, 479-494.

Pywell, R. F., Warman, E. A., Hulmes, L., Hulmes, S., Nuttall, P., Critchley, C. N. R., Sherwood A. (2006) Effectiveness of new agri-environment schemes in providing foraging resources for bumblebees in intensively farmed landscapes. Biological Conservation, 129, 192-206.

Pywell, R.F., Meek, W.M., Carvell, C., Hulmes, L. & Nowakowski, M. (2007) The Buzz project: biodiversity enhancement on arable land under the new agri-environment schemes. Aspects of Applied Biology, 81, 61-68.

Stoate, C., Szczur, J., & Aeibischer, N.J. (2003) Winter use of wild bird cover crops by passerines on farmland in northeast England. Bird Study, 50, 15-21.

Tallowin, J.R.B., Smith, R.E.N., Pywell, R.F., Goodyear, J., Martyn, T. 2002. Use of fertiliser nitrogen and potassium to reduce soil phosphorous availability. In: Frame, J. (Ed.), *Conservation Pays? Reconciling Environmental Benefits with Profitable Grassland Systems.* In: British Grassland Society Occasional Symposium, vol. 36. British Grassland Society, Reading, pp. 163–166.

Thomas, J. A., Telfer, M. G., Roy, D. B., Preston, C. D., Greenwood, J. J. D., Asher, J., Fox, R., Clarke, R. T., Lawton, J.H. (2004) Comparative losses of British butterflies, birds, and plants and the global extinction crisis. Science, 303, 1879-1881.

Warren, M.S. (1992) Butterfly populations. In: Dennis, R.L.H. (Ed.) *The Ecology of Butterflies in Britain*. Oxford University Press, Oxford, pp. 73-92.