Landscape context not patch size determines bumblebee density on flower mixtures sown for agri-environment schemes

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Bumblebee declines across Europe have been linked to loss of habitat and forage availability due to agricultural intensification. These declines may have severe ecological and commercial consequences, since bumblebees pollinate a range of wildflowers and crops. In England attempts are being made to reintroduce forage resources through agri-environment schemes, yet there are few data on how the area of forage, or landscape context in which it is provided, affect their success. We investigated the effects of sown forage patches on bumblebees across sites varying in landscape characteristics. Bumblebee densities were higher on sown patches compared to control habitats but did not vary with patch size, i.e. total forager numbers were proportional to patch area. Importantly, the relative response to sown forage patches varied widely across a landscape gradient such that their impact in terms of attracting foraging bumblebees was greatest where the proportion of arable land was highest.

Key-words: *Bombus*, forage plants, pollination

1. INTRODUCTION

Bumblebees (*Bombus* spp.) are important pollinators of a large number of native plant species and some crops (Corbet *et al.* 1991). Recent declines in their abundance in Europe have been linked to habitat loss and alteration resulting from intensified agriculture (Goulson *et al.* 2005). In particular, intensified crop management and reductions in mixed farming have led to the loss, or botanical simplification, of both semi-natural habitats (e.g. flower-rich meadows) and linear habitats (e.g. species-rich hedgerows and margins; Robinson & Sutherland 2002). This has led to a widespread decline in the quality and abundance of forage resources and nesting habitats for bumblebees (Carvell *et al.* 2006).

Reduced pollination services can have detrimental effects on the dynamics and persistence of plant species and communities (Fontaine *et al.* 2006). Whilst diverse pollinator assemblages may be important to the maintenance of these services, bumblebees may be able to compensate for the losses in other pollinator groups. This makes them key species in some agro-ecosystems (Kremen *et al.* 2002, Kremen *et al.* 2007).

The European Union has recognized the need to counteract the negative effects of modern agriculture on the environment, and has introduced agri-environment schemes whereby farmers are paid to manage their land for the benefit of particular habitats and species. England has recently adopted the Environmental Stewardship scheme (www.defra.gov.uk/erdp/schemes/es/default.htm). This includes specific options targeted at pollinators, aiming to enhance the supply of pollen and nectar sources by sowing flower mixtures at field margins. These mixtures can significantly enhance the local density and diversity of foraging bumblebees on arable land (Carvell *et al.* 2004), yet their effects have not been studied with respect to the area of forage or landscape context in which they are provided.

Landscape context, especially the availability of semi-natural habitats, has been recognized as important to bumblebees, and may interact with farming systems to determine local community structure (Tscharntke *et al.* 2005). However, recent work questions the benefit of semi-natural habitat to bumblebee communities within agricultural landscapes (Westphal *et al.* 2003; Kleijn *et al.* 2006). These studies have considered neither the targeted agri-environment scheme options for pollinators being implemented in the UK nor the response of bumblebees to introduced forage resources relative to resources elsewhere in the landscape. Here we investigate the responses of bumblebees to habitat creation in different agricultural landscapes. We test if sown forage patches have a positive effect on forager densities and if the effect is influenced by landscape context.

2. METHODS

We selected eight sites across central and eastern England that represented typical land use for their locations but varied widely in landscape characteristics (table 1). We randomly allocated four treatments to each site: three forage patches of 0.25, 0.5 and 1ha sown with a mixture of 20% legumes (*Trifolium pratense*, *Trifolium hybridum, Lotus corniculatus*) and 80% fine leaved grasses (*Festuca rubra, Poa pratensis, Cynosurus cristatus*) and a control patch representing typical non-crop vegetation for the site. Loss of legumes is suggested as a major driver of declines of longer-tongued bumblebees (Goulson *et al.* 2005) so we expected that these bumblebee species would be most attracted to the sown patches. Each patch was separated by approximately 3km (mean=2.99±0.23km, SE) to reduce bumblebee dispersal between them (Knight *et al*. 2005). Patches were established between autumn 2003 and spring 2004.

A circular sampling zone around each treatment patch (n=32) was extended to a radius of 1km (314 ha) to reflect the scale at which the longer-tongued bumblebees forage (Knight *et al*. 2005). Landscape characteristics for each zone were obtained from the Land Cover Map 2000 (www.ceh.ac.uk/data/lcm), a computer-classified land cover data set derived from satellite-based multi-spectral scanners. We used the proportion of arable cropped fields as an indicator of landscape context because it was negatively correlated with the proportions of grassland, woodland (P<0.001) and urban cover (P<0.05).

Bumblebee activity was recorded monthly from May to September 2005 (five occasions) when all patches were successfully established and flowering. Foraging bumblebees were counted along two fixed 2m×100m transects in the centre of each treatment patch, and the plant species on which they were foraging were noted (Banaszak 1980). In small or irregularly shaped patches we used U-shaped transects to cover an equivalent area (e.g. four 50×2m transects). All social *Bombus* species, cuckoo bees (subgenus *Psithyrus*) and honeybees (*Apis mellifera*) were recorded. For analysis we grouped social *Bombus* species into colour groups (after Fussell & Corbet

1992, but with melanic *Bombus ruderatus* as a separate group), tongue length groups (long >8.5mm, short <8.5mm) and diet breadth groups (defined using Simpson's diversity index, *D*, based on our flower visitation data; mean=3.8, narrow=*D*<3.8, broad=*D*>3.8) (table 2). Transects were carried out between 10.00 and 17.30 during dry weather when ambient temperature was above 13°C with at least 60% clear sky, or 17°C under any sky conditions.

Forage availability on every visit was measured by identifying all flowering dicotyledonous species and scoring their flower abundance in each 2×10m transect section within the following ranges: 1-5; 6–25; 26-200; 201-1000; 1001-4999 and 5000+ flower units (defined as a single flower or an umbel, spike or capitulum on multi-flowered stems). For analysis, flower abundance was expressed as the median value for each range, giving an estimate of the number of flowering units on each sampling visit.

The effects of patches on bee density were tested using a randomized block ANOVA on log transformed mean per transect (across all visits) with site and treatment as factors, and contrasts for effects of treatment type (control vs. sown) and patch size. Differences in flower density (mean number of flowers per transect, per sampling visit) between treatment patches across the landscape sectors were tested by ANOVA and contrasts. The relationship between bee density and % arable across sites was compared between control and sown forage patches allowing for a random site effect using residual maximum likelihood (REML).

3. RESULTS

We observed 6602 bees including nine social bumblebee species and at least three cuckoo bee species. The most common species groups were: *Bombus lapidarius (+B. ruderarius*) 45%, *B. pascuorum (+B. muscorum/humilis)* 31%, *B. terrestris* agg. (+*B. lucorum*) 8%, *B. hortorum* 8%, *B. ruderatus* 0.5% and *B. pratorum* 0.4%.

Bumblebee density was significantly higher on the sown forage treatments than on the control patches (table 2) but did not differ significantly with sown patch size for any species (table 2), suggesting that total bumblebee numbers increased in proportion to patch area. Individual bumblebee species or groups showed variable responses to the sown patches. As expected, the strongest positive response was from the longer-tongued species (Goulson *et al.* 2005), with *B. lapidarius* and *B.*

pascuorum, the most commonly recorded, 15-35 times more abundant on the sown forage patches than control areas. *Psithyrus* spp. and *A. mellifera* did not show a significant response to sown forage patches. The mean density of visited flowers (defined as species that bumblebees visited at least once in the study) was significantly higher on the sown forage patches than the control ($F_{1,23}$=40.9, P<0.001) but did not differ significantly between sown forage patches ($F_{2,14}$=1.01, P=0.39) within or between sites ($F_{7,14}$=1.2, P=0.37).

The effect of landscape context was highly significant in determining the response of bumblebee density to forage patches but did not affect honeybee density which declined in both forage patches and control areas with increasing proportion of arable land (table 3). In general, significantly more bumblebees per transect were found on forage patches in landscapes in which the proportion of arable land was highest. Importantly, the density of narrow diet and longer-tongued species on control patches decreased with increasing proportion of arable land in the habitat surrounding the patches (figure 1). This suggests that non-crop habitats surrounding the patches were poorer for bumblebees as the proportion of arable land increased (e.g. control patch log legume cover r=-0.72 P=0.043). There was no significant correlation between honeybee and bumblebee abundance suggesting little or no competition for forage resources (r=-0.296, P = 0.106). Finally, there was a strong positive correlation between the mean estimated number of flowers of all bumblebee forage plant species and the mean total number of bumblebees per patch (Total *Bombus* spp.=0.61+0.0022×total forage flowers, r=0.74, P<0.001).

4. DISCUSSION

Our analyses suggest that the higher densities of foraging bumblebees attracted to sown forage patches did not vary with patch size but did with landscape context. If at the start of the experiment, patches were isolated (i.e. no shared foragers), bumblebee colonies were randomly distributed within a landscape and bees foraged only on patches, we would expect forager density to decline with increasing patch size. Absence of this trend is consistent with several alternative explanations: a) An ideal free distribution; this would occur if patches were not truly isolated and bumblebees traveled between them, but seems unlikely given the limited foraging ranges described for several species, e.g. *B. pascuorum*, *B. lapidarius* 449-450m (Knight *et al*. 2005). b) Higher colony growth rates near larger patches (more total forage) led to an increase in foragers visiting larger patches, offsetting expected decreases in density. c) Not all foragers within an area visited a patch, but larger patches were encountered more often, thus the proportion of foragers visiting a patch scales with its size.

In common with previous work we found higher numbers of bees on sown forage patches in areas with high levels of agriculture. Westphal *et al.* (2003) concluded that the abundance of mass flowering crops (MFCs), rather than that of semi-natural habitats, was an effective determinant of bumblebee forager density on flowering patches. In contrast, our data suggest that the response to introduced forage patches was driven by a lack of forage resources in the surrounding habitats typified by the control patches (MFCs had flowered earlier in all landscapes). Across our landscape gradient, increasing arable area led to a reduction in both the quantity and quality of semi-natural forage resources for bumblebees. Thus sown patches were relatively more exploited where the availability of resources from semi-natural habitats was limited. The mobility of bumblebees means that they appear able to readily locate and exploit high quality forage patches, at least within the scale at which we sampled.

Although the *Bombus* species assemblages differed across sites, many bumblebees, especially the longer-tongued and narrow diet species, showed a positive response to the sown mixture of legume species. Bumblebees often show strong preferences for certain flowers or plant families (Heinrich 1976). The decline of our sown legume species in the UK countryside may be a principal cause of rarity and decline in some bumblebees (Goulson *et al.* 2005). Our results suggest that restoring forage resources through agri-environment schemes can enhance bumblebee densities and attract large numbers of foraging bumblebees, especially in intensively managed agricultural landscapes. Whilst our results focus on densities of individuals, it is important to realise that this may not reflect impacts on populations *per se*. This requires more direct measurements of either colony density or colony performance, and these form the basis of ongoing work.

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Table 1. Landscape characteristics averaged across all patches (n=4) within sites. ANOVA revealed no significant differences between patch area characteristics within a site for each landscape type (P >0.05).

Site	Arable* % (SE)	Arable range	Grass† % (SE)	Grass range	Woodland % (SE)	Woodland range	Urban % (SE)	Urban range
1	89.7(2.1)	84.6-93.4	8.0 (2.6)	2.9-13.5	0.2 (0.2)	0-0.6	1.8 (0.7)	0.2-3.6
2	81.2 (4.7)	75.2-95.2	15.2 (4.2)	3-21.5	1.7 (0.9)	0-4	1.8 (0.6)	0.9-3.5
3	73.9 (2.7)	66.4-79.4	16.6 (5.4)	5.2-27.9	7.3 (4.2)	0.6-19.7	1.9 (1.4)	0-6.1
4	71.6 (4.0)	63.3-81.0	22.3 (4.9)	15.0-36.2	4.2 (2.3)	0-8.8	0.6 (0.5)	0-2.0
5	67.6 (4.5)	59.2-79.4	18.4 (2.6)	13.1-25.6	8.9 (2.1)	4.7-14	4.7(3.1)	0-13.1
6	34.8 (5.5)	19.9-46.3	30.7 (7.5)	13.9-50.2	20.5 (3.2)	13.0-28.2	11.4 (3.0)	4.4-16.7
7	26.9 (2.7)	22.7-34.7	57.9 (6.4)	39.5-68.4	12.7 (3.8)	7.6-23.8	2.2 (0.7)	0.8-3.9
8	26.5(3.3)	17.4-33.5	55.8 (3.1)	49.3-64.4	10.8(2.8)	6.8-19.2	3.3 (0.7)	2.4-5.2

*includes cereals and mass flowering crops e.g. oilseed rape, field bean, potato.

† includes improved and unimproved grassland, set-aside.

Table 2. Bumblebee forager density on control and forage patches and ANOVA tests for differences between a) control and forage patches and b) sown forage patches. S=short-tongued; L=long-tongued; BD=broad diet and ND=narrow diet. ***P<0.001, *P<0.05.

Bumblebee species or group	Treatment mean (± SE)		*P*-value of contrast	
	Control	Forage patch	control *vs*. forage patches (1 d.f.)	between forage patches (2 d.f)
Bombus spp.	1.78 (0.70)	25.65 (4.30)	<0.001***	0.91
B. hortorum (L, ND)	0.18 (0.11)	2.05 (0.43)	<0.001***	0.25
B. lapidarius (S, ND)	0.83 (0.32)	13.26 (2.25)	<0.001***	0.96
B. pascuorum (L, ND)	0.39 (0.21)	8.75 (1.89)	<0.001***	0.62
B. pratorum (S, BD)	0.05 (0.05)	0.03 (0.01)	0.86	0.66
B. ruderatus (L, ND)	0.04 (0.04)	0.09 (0.05)	0.50	0.93
B. terrestris agg (S, BD)	0.30 (0.12)	1.48 (0.35)	0.016*	0.22
short-tongued *Bombus* spp.	1.18 (0.43)	14.77 (2.47)	<0.001***	0.99
long-tongued *Bombus* spp.	0.60 (0.34)	10.88 (2.01)	<0.001***	0.92
broad diet *Bombus* spp.	0.35 (0.16)	1.50 (0.36)	0.013*	0.25
narrow diet *Bombus* spp.	1.43 (0.56)	24.14 (4.07)	<0.001***	0.87
Psithyrus spp.	0.14 (0.11)	0.30 (0.11)	0.22	0.99
Apis mellifera	0.40 (0.33)	0.92 (0.28)	0.077	0.14

Table 3. Estimated slopes relating bumblebee density to % arable land across sites for control and sown forage patches, with Wald test for differences in slopes. **$P<0.01$, *$P<0.05$.

Bumblebee species or group	Control			Sown			Comparison of slopes	
	Intercept	slope	SE	Intercept	slope	SE	Wald	*P*
Bombus spp.	0.14	-0.0026	0.0051	0.61	0.011	0.037	6.18	0.013*
B. hortorum	-0.76	0.0007	0.0055	-0.48	0.010	0.0045	3.62	0.057
B. lapidarius	-0.20	-0.0011	0.0051	0.44	0.009	0.0040	3.86	0.049*
B. pascuorum	-0.59	0.0001	0.0059	-0.15	0.014	0.0038	4.22	0.04*
B. pratorum	-1.02	0.0018	0.0026	-1.00	0.001	0.0018	0.02	0.88
B. ruderatus	-1.06	0.0023	0.0036	-1.16	0.005	0.0029	0.63	0.43
B. terrestris agg	-0.67	0.0022	0.0063	-0.58	0.009	0.0044	0.9	0.34
broad diet *Bombus* spp.	-0.68	0.0026	0.0062	-0.57	0.009	0.0043	0.87	0.35
narrow diet *Bombus* spp.	0.08	-0.0028	0.0050	0.58	0.011	0.0037	6.82	0.009**
short-tongued *Bombus* spp.	-0.05	-0.0015	0.0051	0.48	0.009	0.0039	4.28	0.039*
long-tongued *Bombus* spp.	-0.33	-0.0019	0.0051	0.01	0.014	0.0035	7.34	0.007**
Psithyrus spp.	-0.53	-0.0047	0.0052	-1.16	0.009	0.0044	7.93	0.005**
Apis mellifera	-0.46	-0.0033	0.0066	0.47	-0.014	0.005	2.17	0.141

Figure 1. Percentage of arable habitat in relation to mean density ($\log_{10}$) of narrow diet bumblebees on transects (2×100m) on sown (▲=0.25ha, ■=0.5ha, ●=1.0ha) and control (○) patches. Fitted line equations, control y=0.077-0.0028 *x;* sown *y*=0.58+0.011 *x*.