Urban Ecosyst (2017) 20:425–434
DOI 10.1007/s11252-016-0604-7

An assessment of bumblebee (Bombus spp) land use and floral preference in UK gardens and allotments cultivated for food

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Published online: 8 October 2016

Abstract There is increasing interest in the value of domestic gardens for supporting biodiversity. While it is well established that bumblebees exploit urban green spaces, this is the first study to explore the land use and floral preferences of the UK's seven most common bumblebees in gardens and allotments cultivated for food. A citizen science survey was carried out at 38 sites, between 1st June and 30th September 2013. At the landscape scale, bumblebee abundance and species richness was not significantly correlated with surrounding land use characteristics (both $p > 0.05$). *Bombus pratorum* was the only species to show correlations with surrounding land use, demonstrating a positive relationship with built areas and gardens and allotments, and a negative correlation with greenspace and agriculture. At the local site-level scale, bumblebee abundance was negatively correlated with areas cultivated for vegetables and fruits, and positively correlated with areas cultivated for flowers, although neither correlation was statistically significant ($p = 0.070$ and $p = 0.051$ respectively). Bumblebee species richness was not correlated with either land use ($p > 0.05$). All bumblebee species were negatively correlated with areas cultivated for vegetables and fruit, bare ground and hard paving. Several flowering plants were visited by all bumblebee species, although relative preferences varied between bumblebee species. Results emphasise the importance of including floral resources within garden and allotment areas cultivated for food, and the need for a mosaic of different flowering plants to cater for varying floral preferences demonstrated by bumblebee species.

Keywords Garden · Allotment · Bombus · Bumblebee, land use · Floral resources

Introduction

There have been global declines in populations of insect pollinators, including the honeybee (*Apis mellifera*) and bumblebees (*Bombus* spp) – a trend which has been well documented across Europe and North America (FAO 2008; Goulson et al. 2008; UNEP 2010; Potts et al. 2010). This is of concern because bees play an essential ecological role as pollinators of a large number of wild flowers and crops (Klein et al. 2007), including those that are commonly cultivated in domestic, community and roof-top gardens and allotments (Matteson and Langellotto 2009).

The main driver of insect pollinator decline is thought to be habitat loss, as a result of agricultural intensification and increasing urbanisation (Goulson et al. 2008; Winfree et al. 2009; Potts et al. 2010). Pollinator species richness has been found to decline with increasing intensification of agricultural practices (Kremen et al. 2002; Steffan-Dewenter 2003), and levels of urbanisation (Hernandez et al. 2009; Bates et al. 2011). However, some studies have indicated that urban habitats can actually support high bee species richness (Saure

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1996; *Frankie* et al. 2009*;* Baldock et al. 2015), and certain taxa such as bumblebees have been found to demonstrate a positive response to urbanisation (Carré et al. 2009; Bates et al. 2011).

The value of well managed urban green spaces for native biodiversity is therefore becoming increasingly recognised (Goddard et al. 2010). Although the number of urban bee studies has increased in recent years, urban areas remain understudied (Baldock et al. 2015). Consequently, little is known about the diversity and abundance of bees in domestic gardens and allotments (Hernandez et al. 2009; Matteson and Langellotto 2009) or the variables that influence their presence and diversity (Shwartz et al. 2013).

Domestic gardens are private spaces surrounding dwellings, which comprise a range of features such as lawns, flower beds and vegetable patches. Allotments are areas reserved for horticulture where plots are let to individuals for growing vegetables and flowers. These spaces have high spatial heterogeneity as a result of varying land use, management and plant cultivation at small spatial scales (Thompson et al. 2003). As a result they can provide bees with a wide diversity of forage (Loram et al. 2007; Frankie et al. 2009). They have also been found to support high densities of bumblebee nests compared to agricultural land (Osborne et al. 2008b; Ahrné et al. 2009) and higher bumblebee abundance and species richness than parks and cemeteries because gardeners often employ techniques that enhance pollinator habitats (Anderson et al. 2007).

There is great potential for domestic gardens, which account for between 21 and 27 % of the land in UK cities (Loram et al. 2007), to be managed for conservation. Despite this, many gardening recommendations in popular literature are based on assumptions or informal observation rather than empirical data (Garbuzov and Ratnieks 2013). There is also a lack of understanding about how to support and encourage bee populations in gardens and allotments (Frankie et al. 2009). This is especially true of areas cultivated for food, as the majority of advice about enhancing floral provision focuses on the addition of flowers to ornamental borders. As food cultivation is becoming an increasingly common practice in gardens and allotments in industrialised countries (Lawson 2005), the effect this has on the presence of bees warrants investigation, especially as evidence suggests that increasing intensity of garden management reduces bumblebee species richness (Smith et al. 2006).

The aim of this study was to explore the presence and foraging activity of the UK's seven most common bumblebee species in gardens and in allotments cultivated for food. We hypothesised that bumblebee abundance, bumblebee species richness and the individual bumblebee species would 1) be positively correlated with built areas and gardens and allotments in the surrounding landscape, 2) be positively correlated with the cultivation of flowers within allotment and garden survey sites and that 3) bumblebees would demonstrate relative preferences in the flowering plants they visited both overall and between species.

Materials and methods

Study design

A citizen science approach was used to gather information about the presence of the UK's seven most common bumblebee species in garden spaces and allotments used for food cultivation. This enabled us to gather data from a wide variety of locations across the UK (Fig. 1). A total of 121 participants were contacted through Garden Organic, a UK charity promoting organic growing. These participants were selected because they cultivated their gardens or allotments for food (growing vegetables and/or fruits), and had experience of bumblebee identification, having previously taken part in a Garden Organic bumblebee survey. These participants were therefore ideally placed for completing this survey as they were confident in participating in citizen science projects, and were familiar with the seven species of bumblebee we asked them to monitor. Results were received from 38 participants (representing 31 % of those contacted).

Participants were provided with instructions, recording forms and a bumblebee identification field guide which contained images and descriptions of the species that formed part of the study. The species surveyed, which are often referred to as the 'big seven', were *B. terrestris and B. lucorum* (the Buff-tailed Bumblebee and White-tailed Bumblebee, which were grouped because of the difficulty separating the species in the field), *B. hortorum* (Garden Bumblebee), *B. pratorum* (Early Bumblebee), *B. pascuorum* (Common Carder Bee), *B. lapidarius* (Red-tailed Bumblebee), and *B. hypnorum* (Tree Bumblebee). These species were selected as they are the most common bumblebee species in the UK and account for the majority of sightings (Goulson 2010). With the exception of *B. terrestris/lucorum,* they are also distinct enough in appearance to be readily identified.

Bumblebee survey

The survey was undertaken from 1st June 2013 to 30th September 2013. This period was selected to capture the peak activity of the survey species (Prys-Jones and Corbet 2011). Participants were instructed to select a survey site (3 m × 3 m, rising to 3 m above the ground), which was representative of the areas cultivated for food in their garden or allotment. They were asked to make a note of, or mark out, its location so that they could return to it each week during the survey period. Participants were instructed to observe and record the bumblebees entering the survey site once a week, during a 10 min

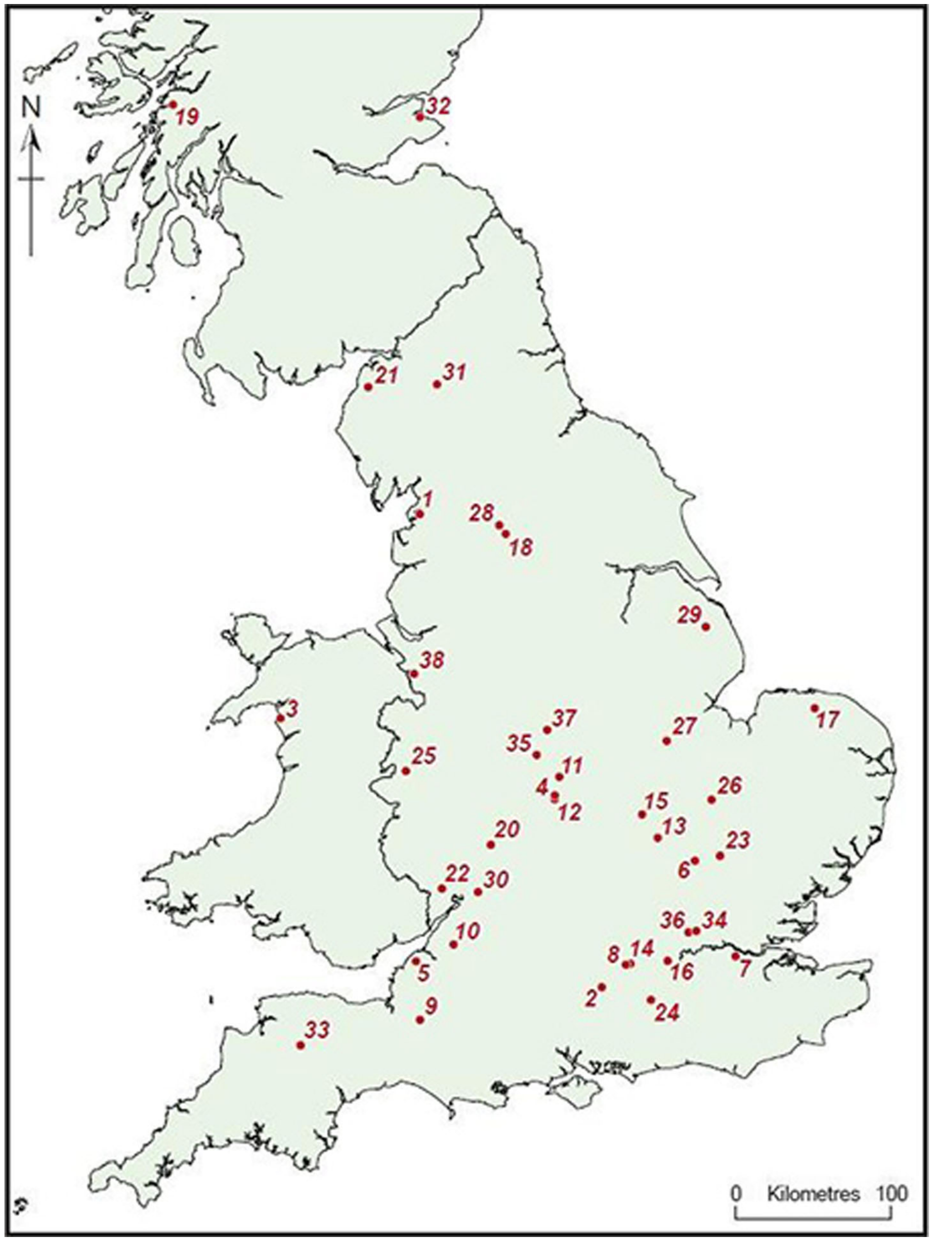


Fig. 1 Locations of the 38 UK gardens and allotments surveyed for bumblebees

period, when there was sunshine or scattered cloud, and the temperature was above 15 °C.

Participants were asked to record the total number of each species of bumblebee observed. In addition, they were asked to record which flowering plant species each bumblebee visited and the number of visits made to flowers on that plant. Participants were asked to record visits to all flowering plants, including ornamental flowers, fruits, vegetables, herbs and weeds. For each of the flowering plants visited, they were asked to estimate the number of floral units of that species within the survey site, using the following scale: 1 = 1 flower; 2 = 2–10 flowers; 3 = 11–50 flowers; 4 = 51–100 flowers; 5 = over 100 flowers. One floral unit was defined as a collection of flowers that a bumblebee could walk around when foraging, without the need for flight. At the end of the season, participants submitted their data either by mail or via an online form. Since bumblebee tongue length affects floral preferences, the tongue lengths of the survey species were characterised as long, medium or short, using descriptions in Prys-Jones and Corbet (2011).

Landscape scale characteristics

The latitude of survey sites was determined from the garden and allotment addresses provided by participants. The land use characteristics within 2500 m of the midpoint of each garden or allotment were categorised using digital data from the Ordnance Survey MasterMap dataset (accessed through

EDINA Digimap in February 2014), and analysed with the ArcGIS 10.1 (ESRI Redlands, USA) geographical information system (GIS). This radius was selected because bumblebee species may travel kilometres from their nest sites to forage within the surrounding landscape. For example, field studies have reported *B. terrestris* workers to forage at least 1.5 km (Osborne et al. 2008a) and 2.2 km (Kreyer et al. 2004) from their nests.

Based on previous work by Bates et al. (2011) and Ahrné et al. (2009), five broad land use types were defined and attributes from several OS MasterMap fields were grouped to represent each category. The five categories (and their OS MasterMap fields) were: Built (manmade buildings, glasshouses, roads, rail, manmade tracks and paths), Gardens and Allotments (multiple make general surface - which was comprised of lawns, vegetable/flower beds, trees, garages/sheds/greenhouses, paving), Greenspace and Agriculture (natural land, rough grassland, scrub, rock, boulders, natural tracks and paths), Trees (coniferous trees, non-coniferous trees, orchards), and Water (tidal water, inland water, marsh reeds, saltmarsh). A small percentage of the areas remained unclassified (mean 0.4 % of the landscape) as the MasterMap data included unclassified areas and minor gaps in the data.

Site-level characteristics

Participants were asked to provide details about site-level characteristics by estimating the percentage ground cover dedicated to each of the following land use types within their survey site: vegetable and fruit cultivation, cultivated flowers, hard paving, lawn, trees, shrubs/hedges, waste ground/rough habitat, water and bare soil. Participants were also asked to score their gardening practices on a scale ranging from one to five, with one representing frequent management with synthetic chemicals, and five being exclusively organic.

Statistical analysis

For the purposes of analysis the *B. terrestris/lucorum* group was treated as one species. Thus analyses considered six species groups. Analysis was based on standard correlation and regression techniques as described below, and carried out using Minitab 17, Minitab Inc. Redundancy Analysis ordination was carried out in Canoco 5.

Weighted regression was conducted to investigate the effect of time on the abundance of each bumblebee species, total bumblebee abundance and bumblebee species richness (the number of bumblebee species) using mean values on week number (weights in regression = number of recorders). Correlation analysis was used to investigate the relationships between latitude and the abundance of each bumblebee species, total bumblebee abundance and bumblebee species richness.

Redundancy Analysis ordination (RDA) was carried out to compare the abundances of the six species groups with the land use characteristics within 2500 m of the survey sites, and with the land use characteristics within the 3 m × 3 m survey sites. Total bumblebee abundance and species richness were compared to the same land use characteristics at each scale using Pearson correlations, data were checked for normality prior to analysis and no significant deviation was detected.

To identify which flowering plants were preferred by bumblebees, flower abundance categories were converted to the midpoint of their range and summed across each plant species. Similarly, the total number of bumblebees feeding on each plant species was summed. The log (x + 1) number of bumblebees was then regressed on log (x + 1) flower abundance ($R^2 = 64.2$ %, $p < 0.001$), using only those flower species/cultivars ($n = 94$) with at least 3 records, and standardised residuals stored. A cut-off of +1.645 (i.e. the expected 95th percentile) for the standardised residuals was used to identify plant species on which bumblebee feeding was greater than expected given its flower abundance.

Preferences relative to overall feeding patterns were estimated for individual bumblebee species. This involved regressing the number of feeding records of the bumblebee species on the total number of bumblebee feeding records for each plant species. Again standardised residuals of +1.645 were used as a cut-off point to identify relative preferences. This process was repeated for each bumblebee species and was restricted to the same plant species as for total abundance.

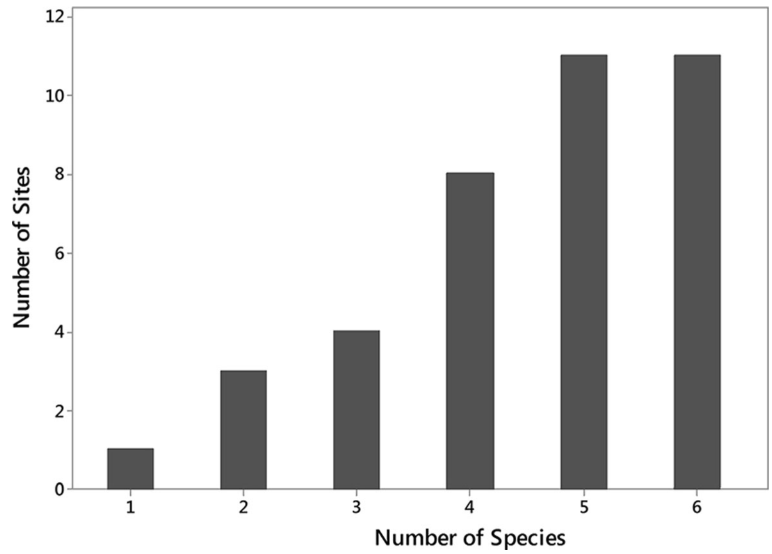
Results

Bumblebee surveys

The majority of participants (34, 89 %) surveyed gardens, while the remaining four participants surveyed allotments. Participants' survey sites were located across the United Kingdom – the majority were located in England, two were in Scotland and one was in Wales (Fig. 1). The 38 participants submitted data from a total of 363 survey occasions undertaken between June and September 2013. The majority of survey sites (57 %) were visited by five or six of the six bumblebee species groups monitored (Fig. 2).

A total of 2621 individual bumblebees were observed (Table 1). *B. terrestris/lucorum* was the mostly frequently observed species group, accounting for 50 % of sightings and was the only species group present at all 38 sites. All other species were relatively common, being present at the majority of survey sites, and accounting for 7 to 16 % of observations. Between 3 and 16 (mean 9.6) weekly observations were made by each participant. There were significant reductions in

Fig. 2 Frequency distribution of bumblebee species richness across the 38 UK survey sites



species richness ($p < 0.05$), and in the number of both *B. pratorum* ($p < 0.001$) and *B. hypnorum* ($p < 0.05$) as the season progressed (Fig. 3).

Landscape scale characteristics

Latitude was not found to have a significant effect on the abundance of each bumblebee species, total bumblebee abundance, or bumblebee species richness (all $p > 0.05$). Land use characteristics within 2500 m of survey sites were not significantly correlated with total bumblebee abundance or bumblebee species richness (both $p > 0.05$).

The first two axes of RDA explained 16.3 % (13.0 % and 3.3 % respectively) of the relationship between bumblebee species abundances and surrounding land use characteristics (Fig. 4). The more important first axis may be considered to be a gradient from open green spaces to urban areas and gardens and allotments; the second axis is difficult to interpret. Most species had short vectors indicating the lack of a relationship with surrounding land use characteristics, although the vector for *B. pratorum* was close to (and hence positively correlated with) vectors for built areas, and gardens and allotments, and opposed to (and hence negatively correlated with) the vector for greenspace and agriculture.

Table 1 Presence of the bumblebees surveyed in 38 UK gardens and allotments cultivated for food

	Number (%) of sites with species present (n = 38)	Number (% of total) of bumblebees recorded
B. terrestris/ lucorum	38 (100 %)	1313 (50 %)
B. hortorum	25 (68 %)	300 (11 %)
B. pratorum	22 (58 %)	169 (6 %)
B. pascuorum	32 (84 %)	406 (16 %)
B. lapidarius	32 (84 %)	239 (9 %)
B. hypnorum	23 (61 %)	194 (7 %)
		2621

Site-level characteristics

The majority of participants (33, 87 %) rated their garden management practices as organic (4 or 5 on the scale), and so the range was not sufficient to allow further investigation into the effects of management practices. The most common land use within the survey sites was food growing (mean 42 % of the area), followed by the cultivation of flowers (mean 26 % of the area).

Total bumblebee abundance was positively correlated with the percentage of the survey site used for cultivated flowers, and negatively correlated with percentage of the survey site used for food production, although neither correlation was statistically significant ($p = 0.051$ and $p = 0.070$ respectively). Correlations between bumblebee species richness and the percentage of the survey site used for flower cultivation and food production were not significant (both $p > 0.05$).

The first two axes of RDA explained 15.9 % (10.2 % and 5.7 % respectively) of the relationship between bumblebee species abundances and site-level land use characteristics (Fig. 5). The first axis can be interpreted as a gradient from heavily managed sites to those containing more woody species; the second axis as a gradient from flower rich gardens to those dominated by lawns and vegetable production. Vectors for all bumblebee species were opposed to (and hence negatively correlated with) vectors for fruit and vegetable cultivation, bare ground and hard paving. Vectors for *B. lapidarius* and *B. pratorum* were also close to (and hence positively correlated with) vectors for flowers and waste ground.

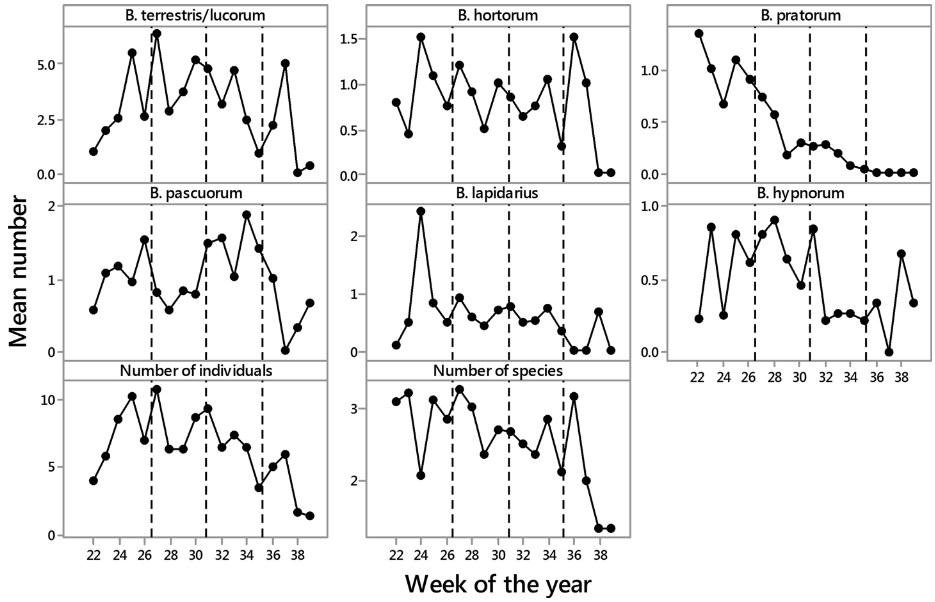


Fig. 3 Plots between weeks 22 and 39 (1st June and 29th September 2013) showing mean numbers per location of each bumblebee species, mean bumblebee abundance and mean number of species

Floral preferences

There were 12,105 observations of bumblebees visiting 164 flowering plant species. The majority of bumblebee visits were made to a relatively small proportion of the flowers available, with 51 % of bumblebee visits being made to 37 plant species (24 % of the plants surveyed), which accounted for 10 % of the floral units available. A small selection of plant species were visited by all six bumblebee species groups, including Meadow Cranesbill (*Geranium pratense*), Blackberry (*Rubus fruticosus*), Borage (*Borago officinalis*) and Lavender (*Lavandula angustifolia*).

Regression analysis identified 32 plant species where differences in feeding preferences could be detected (Table 2). The plant species which were relatively preferred by bumblebees overall were Meadow Cranesbill (*Geranium pratense*), Green Alkanet (*Pentaglottis sempervirens*), Sage (*Salvia officinalis*),

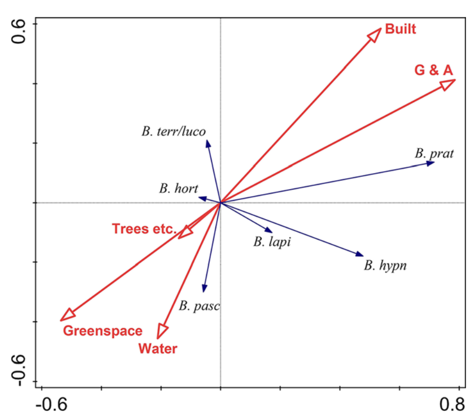


Fig. 4 RDA biplot examining relationship between bumblebee abundances and land use characteristics within 2500 m. Most species had short vectors indicating the lack of a relationship with surrounding land use characteristics, although *B. pratorum* was positively correlated with built areas, and gardens and allotments, and negatively correlated with greenspace and agriculture. Species abbreviations: *B. terr/luco* = *B. terrestris/lucorum group, B. hort* = *B. hortorum, B. prat* = *B. pratorum, B. pasc* = *B. pascuorum, B. lap* = *B. lapidarius, B. hyp* = *B. hypnorum.* Land use abbreviations: Built = built areas, G & A = gardens and allotments, Greenspace = greenspace and agriculture, Trees etc. = trees/ woodlands/ orchards, and Water = water

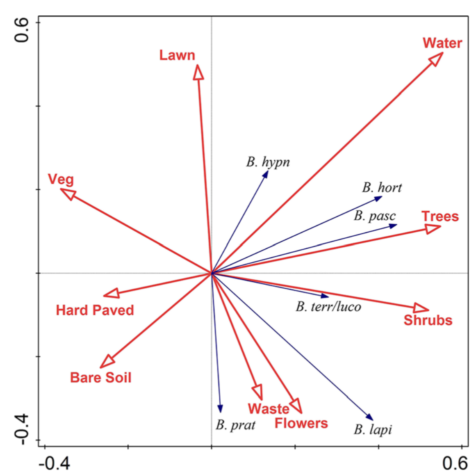


Fig. 5 RDA biplot examining relationship between bumblebee abundances and land use characteristics within the 3 m × 3 m survey sites in gardens and allotments. All species were negatively correlated with fruit and vegetable cultivation, bare ground and hard paving, and *B. lapidarius* and *B. pratorum* were positively correlated with cultivated flowers and waste ground. Species abbreviations: *B. terr/luco* = *B. terrestris/lucorum group, B. hort* = *B. hortorum, B. prat* = *B. pratorum, B. pasc* = *B. pascuorum, B. lap* = *B. lapidarius, B. hyp* = *B. hypnorum.* Land use abbreviations: Veg = vegetable and fruit cultivation, Flowers = cultivated flowers, Hard paved = hard paved, Lawn = lawn, Trees = non-crop trees, Shrubs = shrubs and hedges, Waste = waste ground/ rough habitat, Water = water, and Bare soil = bare soil

Table 2 Standardised residuals for floral preferences of bumblebees relative to the overall mean. Standardised residuals of +1.645 were used as a cut-off to identify relative preferences and these are shown in bold. Tongue length categories: Lt = Long tongue, Mt. = Medium tongue, St = Short tongue

Plant species	All bumblebees	*B. terrestris/ lucorum*	*B. hortorum*	*B. pratorum*	*B. pascuorum*	*B. lapidarius*	*B. hypnorum*
		(St)	(Lt)	(St)	(Lt)	(Mt)	(St)
Meadow Cranesbill (*Geranium pratense*)	**3.08**	0.01	0.18	**2.47**	**2.72**	**3.05**	0.21
Green Alkanet (*Pentaglottis sempervirens*)	**2.66**	-0.55	-1.19	1.59	1.36	**2.16**	**3.75**
Sage (*Salvia officinalis*)	**2.49**	-0.14	-1.12	-0.81	**2.79**	-1.00	-0.89
Mallow (*Lavatera* spp)	**2.17**	**2.09**	1.00	**2.00**	1.02	1.17	-0.32
Marjoram (*Origanum vulgare*)	**1.70**	1.57	1.46	-0.87	1.26	0.18	**2.48**
Blackberry (*Rubus fruticosus*)	1.43	0.93	-0.26	**2.55**	0.66	0.46	**2.32**
Oriental Poppy (*Papaver orientale*)	1.30	1.25	**1.98**	-0.07	-0.45	-0.39	-0.22
Opium Poppy (*Papaver somniferum*)	1.24	**1.68**	1.06	-0.30	-0.29	0.65	-0.42
Borage (*Borago officinalis*)	1.04	0.54	0.74	**2.13**	1.61	**1.82**	1.47
Perennial Cornflower (*Centaurea montana*)	0.99	-0.81	-0.66	-0.38	0.80	**2.11**	-0.50
Cornflower (*Centaurea cyanus*)	0.92	0.52	0.29	**2.21**	-1.16	1.59	0.65
Russian Comfrey (*Symphytum x uplandicum*)	0.89	1.12	-1.02	**2.37**	-1.33	0.50	0.76
Foxglove (*Digitalis purpurea*)	0.86	0.80	**1.90**	-1.14	1.35	-1.28	0.29
Common Bugle (*Ajuga reptans*)	0.78	0.19	**1.96**	-0.77	0.92	1.13	-0.85
Geranium ‘Rozeanne’ (*Geranium* ‘Rozeanne’ Gerwat)	0.77	1.19	-0.98	1.51	-1.92	**1.85**	1.03
Small Globe Thistle (*Echinops ritro*)	0.73	1.20	-1.09	-0.78	-1.41	**1.70**	-0.34
Red Campion (*Silene dioica*)	0.72	0.32	**2.49**	-1.04	-0.44	-1.19	-1.09
Common Snowberry (*Symphoricarpos albus*)	0.53	-0.20	-1.06	**1.90**	-1.36	-0.95	**2.26**
Clover (*Trifolium* spp)	0.50	-0.13	-0.71	0.84	0.55	**1.68**	-0.54
Bear’s Breeches (*Acanthus mollis*)	0.43	-1.96	-0.45	-0.18	**1.67**	-0.48	-0.32
Sedum (*Sedum* spp)	0.37	0.92	0.06	0.39	-0.59	**1.76**	-1.20
White Campion (*Silene latifolia* subsp. *Alba*)	0.37	-2.00	**1.98**	0.66	-0.63	-0.50	-0.34
Poached Egg Plant (*Limnanthes douglasii*)	0.22	0.26	-1.42	**2.02**	-0.08	1.62	-1.14
Lavender (*Lavandula angustifolia*)	0.21	0.15	0.90	-0.39	1.27	0.16	**1.72**
Larkspur (*Delphinium* spp)	0.14	-2.05	**1.85**	-0.76	0.95	-0.96	-0.02
Raspberry (*Rubus idaeus*)	0.08	-0.69	0.30	**1.93**	-0.25	-1.43	**2.50**
Rock crane’s-bill (*Geranium phaeum*)	0.04	0.53	-1.21	**2.20**	-1.56	-1.07	-0.96
Broad bean (*Vicia faba*)	-0.13	-1.26	-1.52	**1.69**	1.24	-0.35	0.78
Hollyhock (*Alcea rosea*)	-0.23	-1.79	**1.88**	-0.77	0.00	-0.21	-0.85
Field Scabious (*Knautia arvensis*)	-0.41	-1.58	**1.75**	-0.77	0.15	-0.97	-0.85
Honeywort (*Cerinthe major* ‘Purpurascens’)	-0.48	-0.79	-1.38	**1.74**	-0.28	1.38	-1.10
Montbretia (*Crocosmia* spp)	-0.68	-0.96	-0.92	-0.62	-0.26	-0.85	**1.70**

Mallow (*Lavatera spp*), and Marjoram (*Origanum vulgare*). Relative preferences varied between bumblebee species.

Discussion

Our results indicate that the bumblebee species surveyed are frequent visitors to spaces cultivated for food in UK gardens and allotments. The majority of survey sites were visited by five or six of the six bumblebee species groups surveyed, indicating that these common species are fairly ubiquitous within these spaces. The number of bumblebee sightings, and the presence of each bumblebee species varied through the season, probably as a result of phenological differences in the bumblebee species studied.

In contrast to expectation, bumblebee abundance and species richness were not correlated with surrounding land use characteristics. A similar study of Swedish allotments also reported landscape to have limited on bumblebee abundance, but did find bumblebee species richness to be negatively correlated with increasing proportions of built areas/impervious surfaces (Ahrné et al. 2009). If our study had surveyed all 25 UK bumblebee species a similar pattern may have emerged, as evidence suggests that urban areas generally contain fewer floral specialists and rare species (Frankie et al. 2009; Hernandez et al. 2009; Bates et al. 2011). In particular, the rare species of bumblebee in the UK have been found to be less generalist/polylectic than the common species which are able to exploit the wide range of floral resources available in gardens (Goulson et al. 2005).

Bombus pratorum was the only species to show correlations with the surrounding land use characteristics, demonstrating a positive relationship with built areas, gardens and allotments, and a negative relationship with greenspace and agriculture. This species appears to be becoming increasingly urbanised due to its intolerance of agriculture (Benton 2000), and our results suggest urban green spaces are important habitats for this species. This could be because *B. pratorum* is a small species with a short foraging distance. It also often nests in cavities and bird boxes (Prys-Jones and Corbet 2011; Lye et al. 2012) and these features are common in urban areas and gardens.

Many studies have suggested that local factors such as site management, flower abundance and plant diversity have a greater effect on bee presence than surrounding landscape (Ahrné et al. 2009; Frankie et al. 2009; Pardee and Philpott 2014). Our results indicate that bumblebee abundance is negatively correlated with increasing proportions of food cultivation, and all bumblebee species demonstrated a negative response to this local land use. Bumblebee abundance was positively correlated with increasing flower cultivation. This is supported by other studies which have reported bumblebee abundance to be positively related to the proportion of flowering plants (Ahrné et al. 2009), as well as floral abundance and plant diversity (Hennig and Ghazoul 2012).

Bumblebee species richness however was not affected by site-level land use, again possibly because the survey was limited to the most common bumblebee species. Other studies have reported an increase in bee species richness with increasing floral diversity (Smith et al. 2006) and floral area (Matteson and Langellotto 2010), and a reduction in bumblebee species richness with increasing intensity of garden management (Smith et al. 2006). This highlights the need for further detailed assessments of garden management practices, also called for by Shwartz et al. (2013).

Our results suggest the importance of including flowers in areas cultivated for food, in order to maximise floral resource availability within these areas. This message is likely to become increasingly important if food production continues to grow in popularity in domestic gardens and allotments. This does not necessarily need to be at the expense of production in vegetable patches or allotments, as bumblebees demonstrated relative preferences for several herbs, fruits and vegetables. The provision of floral resources may also contribute to improved yields of insect pollinated crops. Recent research by Potter and LeBuhn (2015) found that tomato pollination in gardens was positively correlated with floral resource density within survey gardens, as an indirect effect of increased abundance of bees or increased visitation rates.

Although 164 plant species were visited during this study, the majority of visits were made to a relatively small number of flowering plants. Half of all bumblebee visits were made to 37 plant species representing only 10 % of the available floral units. Similar figures were reported by Ahrné et al. (2009), where although 168 plant species were visited by bumblebees, half of the visits were made to just 14 plant species. Some of the flowering plant species monitored in this study were visited by all bumblebee species groups studied, including Meadow Cranesbill (*Geranium pratense*), Blackberry (*R. fruticosus*), Borage (*B. officinalis*) and Lavender (*L. angustifolia*). These plants can therefore be recommended as useful species for supporting the UK's common bumblebee species.

As expected, the relative preferences varied between bumblebee species, and the majority of the variation can be explained by the morphological differences in tongue length (Prys-Jones and Corbet 2011). Meadow Cranesbill (*G. pratense*), the most visited flower overall, was especially popular with *B. pratorum, B. lapidarius* and *B. pascorum* (short, medium and long-tongued species respectively), which all showed a significant relative preference for the flower. Many *Geranium* species are known to be popular with bees because their open flowers enable a range of species with varying morphology to access pollen and nectar resources within the flower (Kirk and Howes 2012).

Few weed species were visited by bumblebees during this study, and only four (Thistle (*Cirsium* spp), Red Deadnettle (*Lamium purpureum*), Common Bugle (*Ajuga reptans*) and Clover (*Trifolium* spp)) featured in the list of the 37 most visited plant species. This is probably a result of the intensive weeding practices commonly employed in spaces cultivated for food. As native plants are an important source of forage in the wider landscape, especially in the spring, gardeners may benefit from education about the value of certain flowering weeds, which could be removed after flowering but before seed set.

Although this study did not explore the huge variety of plants available to gardeners, with over 75,000 being listed in the RHS Plant Finder (Armitage 2016), it does highlight some of the more commonly grown plants and how they are used by bumblebees. Although plants such as Meadow Cranesbill (*G. pratense*) had general appeal, many bumblebee species demonstrated relative preferences for other flowers. This emphasises the need for a mosaic of different flowering plants that can cater for the needs of the various bumblebee species in both space and time.

Conclusion

This is the first study to explore the land use and floral preferences of bumblebees in gardens and allotments cultivated for food across the UK. Although bumblebee abundance and species richness was not significantly correlated with surrounding land use characteristics, our results suggest that gardens and allotments are important habitats for *B. pratorum*. Our results also highlight the importance of local site-level land use, as all bumblebee species were negatively correlated with vegetable and fruit cultivation, while total bumblebee abundance was positively correlated with flower cultivation. This emphasises the importance of including flowers in areas cultivated for food, in order to maximise floral resource availability within these areas.

Many gardeners are keen to support pollinators by growing appropriate flowers and there are numerous lists available to guide them in their plant choices. The preferred plants identified in this study generally compared well with popular lists of plants designed to support pollinators (such as Royal Horticultural Society 2016a; 2016b). However, several plant species that bumblebees demonstrated relative preferences for in our study do not feature in the lists. This highlights the need for expanding current lists or creating lists designed to support pollinators in spaces cultivated for food, for which there is limited information available.

Although the survey period covered the flight activity of all the common bumblebee species, future studies would benefit from an earlier start date to capture information about the activity of emerging queens. There is also a need to study all 25 UK bumblebee species, as rarer species are in greater need of conservation support than the common species, which tend to be more generalist, with broader tolerances.

Acknowledgments We thank the Garden Organic members who kindly volunteered their time to collect data for this project. We also thank Stuart Gill for his work carrying out GIS analysis, as well as Barbara Smith, Judith Conroy and two anonymous reviewers for their comments which improved this manuscript. This study was funded by Coventry University.

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