Title: Small areas of wildflower grassland in urban areas support significant species richness and abundance of pollinating insects

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Research involving Human Participants and/or Animals:

This research has included the collection of invertebrates for study. Where possible all identifications of species were made in the field, although some specimens were collected via alcohol and verified by the appropriate county recorder for the taxa. Very small numbers of individuals were killed as part of this research, and only to verify uncommon or confusion species.

This is a comparative study of the pollination systems of a restored urban grassland and includes observations of solitary bees and hoverflies, both significantly understudied groups in the UK.

Abstract

1. Diversity of invertebrate pollinators is essential in supporting flowering plant species richness, including agricultural crops. In the UK, losses are reported for bees, hoverflies, butterflies and moths. Urban green spaces are essential refugia for these groups, and restoration of these areas can improve pollinator diversity through improved floral resources.

2. Our research aimed to compare two differently managed areas of urban amenity grassland for their insect pollinators, with transect surveys of butterflies, bumblebees, solitary bees and hoverflies.

3. Our results revealed that even in an urban matrix, a small area of wildflower meadow had significantly higher insect abundance and species richness than a comparable amenity grassland. Both abundance and species richness of pollinating insects was positively related to floral species richness.

4. The wildflower grassland supported a number of notable solitary bee species, and numerous hoverflies, although visitation by solitary bees was confined to only a small number of flowering plants, exhibiting visitation specialisation, however many of these plant species were not visited by other taxa.

Keywords: Pollinators, Solitary bees, Hoverflies, Grassland Restoration, Wildflower Meadows.

Introduction

The services provided by pollinating animals globally are estimated at €153 billion a year (Gallai *et al.,* 2009), and are thought to enable the production of 35% of all crops (Kleijn *et al.,* 2007). UK pollination services are valued at around £400 million yearly (POST, 2010). Aside from these considerable contributions to crop production, pollinating animals are estimated to provide services to approximately 88% of all flowering plants globally (Ollerton *et al.,* 2011).

Several insect orders contain floral visitors, but three of these are regarded as the most significant contributors to pollination. Wild bees (Order: Hymenoptera) are often considered the most important of these groups. With a total of 25,000 described species, they feed on flowers all life stages, and the females of many species have specific morphological structures for carrying pollen (Winfree *et al.*, 2011). Many flies (Order: Diptera) also play a vital role in plant pollination (Orford *et al.*, 2015), most notably the family Syrphidae (Larson, Kevan & Inouye, 2001), more commonly known as the hoverflies. Whilst as larvae they exploit various feeding strategies, as adults all 6000 species feed on nectar and pollen (Larson *et al.*, 2001; Rader *et al.,* 2016). Many families of butterflies (Order: Lepidoptera) are also important pollinators. Whilst less frequent flower visitors in some systems, there is evidence that they fly further than bees and thus may transfer pollen over longer distances (Winfree *et al.*, 2011).

Global populations, and species richness of pollinating insects have been decreasing at an alarming rate over the last fifty years or so, with well-studied groups such as honeybees and bumblebees best evidenced as in decline (Goulson *et al.,* 2015; Potts *et al.*, 2010a). The result is a warning from experts of a 'pollination crisis', in which the losses of key pollinators become detrimental to human populations (Gross, 2008; Holden, 2006). UK monitoring data has revealed significant declines in bumblebees (Carvell *et al.,* 2006; Goulson *et al.,* 2008), honeybees (Potts *et al.,* 2010b), hoverflies (Beismeijer *et al.,* 2006), moths (Fox *et al.,* 2013) and butterflies (Thomas *et al.,* 2004). Analysis of monitoring data in both the UK and the Netherlands revealed that for both hoverfly species and solitary bees, declines were strongest in specialist species (Beismeijer *et al.,* 2006).

Declines in bee populations are thought not to be driven by one stressor alone, instead by a combination of factors including habitat and floral resource losses, parasites and pesticides (Goulson *et al.,* 2015). Using landscape analysis, Steffan-Dewenter *et al.* (2002) revealed a significant positive relationship between semi-natural habitat cover and wild bee species richness and abundance, with this relationship being even stronger for solitary bees specifically. Within the UK, it is thought that losses in key habitats such as wildflower meadows have played a significant role in changing bee populations (Carvell *et al.,* 2006; Goulson *et al.,* 2008; Potts *et al.,* 2010b). Research into the dispersal of solitary bee species has revealed limited ranges for some species, with smaller species having lower dispersal abilities (Gathmann & Tscharntke, 2002; Zurbuchen *et al.,* 2010). These results have relevance for fragmented landscapes such as urban or agricultural areas, where habitat patches may be few and far between.

Despite a focus in the media and literature on social bee groups such as bumblebees and honey bees, most bee species globally are not social like bumblebees and honeybees (Michener, 2007). In the UK alone, around 220 of the c. 270 species of bees are solitary (National Bee Unit, 2017). Whilst honey bees are often regarded as the most important providers of crop pollination, there is a growing consensus that wild insects play a crucial role (Breeze *et al.,* 2011). Research into the importance of groups such as solitary bees and hoverflies is however limited, most likely due to the specialist identification skills required for some of these taxa (Brown & Paxton, 2009; Murray *et al.,*2009).

Though less regular visitors to flowers than honeybees (Albrecht *et al.,* 2012), solitary bees are more species rich, and shown to be more effective pollinators, with individuals depositing pollen on 71.3% of visits, compared with a figure of 34% for honeybees (Woodcock *et al.,* 2013). Conversely, hoverflies are thought to be less effective pollinators (Jauker *et al.,* 2011), but more frequent (King *et al.,* 2013), and less specialised visitors (Cowgill *et al.,* 1993). Unsurprisingly, the general consensus is that more diverse pollinator communities will support more diverse plant communities (Albrecht *et al.,* 2012; Fontaine *et al.,* 2005).

This research aims to highlight the benefits of floral enhancement and reduced cutting regimes in urban amenity grasslands for pollinator populations. Two adjacent and differently managed areas of amenity grassland in an urban area were surveyed for invertebrate floral visitors, and the relationships between increased floral resources and invertebrate species richness and abundance is explored. We highlight the importance of even small flowering habitats in intensive urban areas for invertebrate populations including hoverflies, butterflies, solitary, bumble and honeybees.

Research Hypotheses

The following hypotheses were tested:

1. There will be significantly greater floral resource abundance and species richness of flowering plants in the wildflower meadow compared to the amenity grassland.

2. There will be a significantly greater abundance and species richness of pollinating insects in the wildflower meadow compared to the amenity grassland.

3. There will be a relationship between floral species richness and abundance, and pollinator species richness and abundance.

Study Site

Woolfall Heath Meadow in the Knowsley borough of Liverpool, Merseyside (Grid Ref: SJ 43392 92520), was selected as the study site. The site consists of 6 main habitat types; unimproved species rich grassland, semi-improved grassland, woodland (including planted trees), scrub, running water and bare earth (Knowsley Council, 2014a). The site is situated in a suburban area of the city close to part of the M57. The site is surrounded by network of major roads and both commercial and residential buildings, as well as several other urban green spaces.

Site History

Local charity 'Landlife' began trialling experimental plots and ultimately sowing soils around the Knowsley area of Liverpool, Merseyside in the early 1990's (Gilbert & Anderson, 1998). Woolfall Heath, was chosen as a site for creative conservation, a process by which simplified habitats (i.e. not attempting to mimic semi-natural communities) are created using a small number of species. Between

350 and 400 mm of the fertile top layer of sandy soil was removed from a 1.7 ha area of the approximately 4 ha site in 1993. A total of 20 wildflower species were sown over the late 90s. In 2000 the area was surveyed; all sown species were present and a further 61 species of higher plant had naturally colonized. In the interim between sowing and surveying the site was not cut, and continued not to be for 15 years after its creation. A once annual late summer mow then commenced (Price, 2012; Putwain, 2016).

In the south end there remains an area of amenity grassland, which like the wildflower meadow is managed by the local council. This area is frequently mown, approximately once every two weeks. Preliminary site visits in 2016 suggested that it intermittently has some flowering plants, notably *Ranunculus repens*, *Taraxacum agg.* and *Trifolium repens*; the species identified by Hicks *et al.* (2016) as potentially providing almost all sources of pollen and nectar in spring, yet often considered weeds and removed through intensive mowing regimes of amenity green spaces. The entire site is bordered by woodland containing flowering woody species also known to be important floral resources for pollinating insects such as *Prunus* and *Salix spp.*

Methods

Data Collection

Based on preliminary site visits, it was decided that five 30m x 2m belt transects would be used in each of the two habitats in order to cover a reasonable representation of total site area whilst being as time efficient as possible. To maximize the total ground covered, the recommendations of Wheater *et al.,* (2011) were also incorporated and triangular walks were employed. These were split into three equal sections. At the start of each transect the surveyor walked 10 m at a 45° angle to the their left or right, then turned 90° in the opposite direction for 10 m before doing the same one final time.

Transect start points were chosen each time to cover a section through the middle and each of the four corners of both habitats. The habitat area surveyed first and the transect area to start in was alternated each visit to avoid always surveying the same area at similar times of the day. Transects were walked on two occasions each survey visit – once to list species of plants in flower and count number of floral units and again to count the number of both species and individuals of bees, butterflies and hoverflies, as well as to note visitation details.

Both habitats were surveyed four times a month in 2017 from April to July, approximately once every 5-9 days to coincide with recommendations from the UKBMS (2013). Visits were carried out when conditions were in accordance with UKBMS: between 13-17°C and at least 60% sun, above 17°C in any weather aside from precipitation and wind speeds always below 5 on the Beaufort scale (UKBMS, 2013).

To ensure both the amenity grassland and wildflower meadow were surveyed for pollinators under similar conditions, once one habitat had been completed the other was started immediately, unless the weather changed considerably, in which case surveying the second habitat was delayed until weather conditions were approximate to those of the first habitat survey.

For the plant transect walks abundance was measured by counting the number of floral units. A floral unit was defined by the criteria outlined by Carvell *et al*. (2006). Plant species identifications were made in the field where possible using a wildflower key (Rose, 2006). Photographs and notes were taken and where identification was uncertain, botanists from Manchester Metropolitan University were consulted to verify identification. A full site list survey was also carried out to obtain a more accurate estimation of overall total flowering plant species richness.

For pollinator walks only insects deemed to be collecting pollen or feeding from nectar were recorded. Transects were walked at the same slow pace advised by Tarrant *et al.* (2012) of three m/minute. Each transect therefore took approximately 10 minutes and total survey time in each habitat was around 50 minutes per visit. Insects were netted where necessary to aid identification. Where identifications could not be confidently made in the field, specimens of bees and hoverflies were placed in collecting pots and examined microscopically at World Museum Liverpool where expert entomologists were consulted to verify identifications. As most butterfly species can be reliably identified in the field, voucher specimens were not taken. If identification was uncertain the advice of the UKBMS was followed and individuals were assumed to be the most likely common species (UKBMS, 2013).

Data analysis

Data analysis was conducted in R version 3.4.1 (R Core Team, 2017). Data were assed for normality using the Shapiro-Wilk test. Differences in insect abundance and richness between the two treatment sites was assessed using a non-parametric Wilcoxon test. Predictors were assessed for collinearity. Flower richness and abundance were strongly correlated ($r = 0.781$, $p = < 0.001$). Flower richness was used as main predictor of insect richness and abundance as this showed the strongest correlation. Linear mixed effect models (LME) using the package nlme (Pinheiro *et al*., 2017) and generalized linear mixed effect model (GLMM) with a Poisson distribution in package lme4 (Bates *et al*., 2015) were used to examine the effect of flower abundance and richness on both insect abundance and richness and to take into account for repeated sampling of the transects. The best fitting model was selected based on the assessment of validation plots and R2 values.

Following the protocol of other studies which have examined the relationship between insects and characteristics of their environment (McFredrick & Buhn, 2005; Derraik, *et al*., 2010; Noordijk *et al*., 2010) a series of linear regression analyses were conducted in R (R Studio, 2017) to quantify the strength of the associations between abundance and species richness of flowers and pollinating insects. In this case the data for each transect per habitat was used rather than the single figures generated from each survey visit for the matched pair's tests. This was done to increase the available data set and more acutely demonstrate if there were any statistically significant relationships. Data for both habitats combined and each habitat separately were analysed. Only results were sufficient data was deemed to have been collected and a strong relationship was inferred between abundance and species richness of flowers and insects were included in the results and discussion sections. Observation records for the meadow habitat were also used to calculate the overall proportion of the different taxa recorded. Bees were split into two separate groups - bumble bees and solitary bees.

Information on all species of bees, butterflies and hoverflies recorded in both habitats was then compiled for interpretation, including geographic distribution, habitat association, flight period, nest/larval requirements and conservation status. For bees, information on whether they are considered generalists (polylectic) or specialists (oligolectic) species in relation to pollen collection was also included. To permit an assessment of whether species recorded were common or not, conservation status according to information from the relevant recording society was utilized, alongside information on geographic distribution and habitat associations.

Plant-Pollinator Relationship

To assess the plant-pollinator relationships across the study sites, network diagrams were created using the SNA package in R (Butts, 2008). Individual taxonomic groups were also separated out to aid interpretation.

Results

Summary Data

Over the course of the study 45 species of flowering plant species and 412 observations of 63 species of pollinating insects were recorded during 5 months of site visits. A total of four surveys were conducted each month from April to July.

Effects of Differing Management

There was a highly significant difference between the total abundance of floral units in the amenity grassland and wildflower meadow (W = 2, n = 16, p = < 0.001). The wildflower meadow had a greater number of total floral units in all but the first survey in May.

Significant differences in both insect richness and abundance was observed between the two treatment sites; with the highest values observed in the Meadow site (Abundance: W = 827.500, p = <0.001, Richness: W = 861.500, p = <0.001, Figure 1A and 1B).

Effects of Floral Species Richness

There was a highly significant difference between the species richness of flowering plant species in the amenity grassland and wildflower meadow (W = 0; n = 16; p = < 0.001).

A significant positive effect of floral richness was found for both insect abundance (LME: $\beta \pm$ se, 1.7 $\pm$ 0.08, t154 = 20.21, p = <0.001, Figure 2A) and richness (LME: 0.95 $\pm$ 0.05, t154 = 17.81, P<0.001, Figure 2B). The positive effect of floral richness remained significant when split into the two sites for both insect abundance (Meadow: 1.66 $\pm$ 0.14, t74 = 12.18, p = <0.001; Amenity: 0.43 $\pm$ 0.09, t74=4.66, p = <0.001) and for insect richness (Meadow: 0.85$\pm$ 0.08, t74 = 10.14, p = <0.001; Amenity: 0.43 $\pm$ 0.09, t74=4.66, p = <0.001).

Plant-Pollinator Relationships

The most frequently visited floral resource throughout the study was *Knautia arvensis,* a generalist flowering species commonly visited by a range of taxa. This species had a total of 124 observations, over twice that of the next most visited species *Taraxacum agg.*, which was also the floral resource with the highest species richness observed throughout this study (Table 2).

Plant-pollinator relationships were also investigated using network diagrams (Figures 3, 4 & 5). As expected, bumblebees (*Bombus spp.*) were core in this network, however did not visit all flowers in the habitats. Species within the solitary bees were observed visiting species unvisited by other taxa (Figure 3).

When displayed alone, social and solitary bees displayed differences in terms of their levels of visitation specialisation. Bumblebees (*Bombus spp.*) showed almost no specialisation, whereas solitary bee species tended towards visiting specific plants. There were also much less visitations from solitary bees over the course of the study.

Discussion

Effects of Differing Management

Differences in Floral Resources

There was both a statistically significant greater abundance and species richness of flowering plants in the wildflower meadow compared to the amenity grassland. Somewhat unsurprisingly, the difference in flowering plant species was much less marked in spring. For the first three surveys both habitats had the same number of flowering species. *Primula veris* was the only wildflower species in the meadow habitat for the first three surveys. *P. veris* accounted for most flower visits by both butterfly species and bumble bees, *Bombus pascuorum* and was also the only species visited by the bumblebee *Bombus hortorum*; the species with the longest tongue of all UK bumblebees and known to prefer bell shaped flowers with deep corollas (Falk, 2015). Most observed visits during April (23 of 32 observations) were to *Taraxacum agg.*, supporting evidence that this plant is an important nectar and pollen source in early spring (Hicks *et al*., 2016).

It was not until late May that there was a notable difference between the two habitats in terms of both flowering plant abundance and species richness. The amenity grassland had only gained a single plant species by this stage, *Ranunculus repens*, which was only visited by a single insect during spring. This was in stark contrast to the wildflower meadow where eight other species had flowered by the end of May. The corresponding higher abundance of floral units in the wildflower meadow was not entirely due to its greater number of species however, but certainly, at least in early spring, was in part a likely result of the intensive mowing regime in the amenity grassland. During an interim in mowing during the final survey in April and the first survey in May, the amenity grassland had just twenty fewer floral units and over 1.5 times more floral units respectively. It is likely that if mowing frequency were reduced, the abundance of floral units would be closer that of the wildflower meadow during much of spring surveying.

Differences in Insect Visitors

As hypothesized there was a significantly higher abundance and species richness of pollinating insects in the wildflower meadow (Figure 1). The pattern however very much reflected that of flowering plants, with a very noticeable widening gap in the number and species of pollinating insects between the two habitats not occurring until the second half of May. It has already been evidenced that flower abundance is an important determinant of pollinating insect diversity (Hicks *et al.,* 2016).

Linear modelling demonstrated that flower species richness had a significant positive association with both insect abundance and species richness (Figure 2). Many pollinating insects have very different floral preferences (Johnson & Steiner, 2000), and indeed this was evidenced by the network analysis done in this study (Figures 3, 4 & 5). Whilst some species and taxa generally visited a range of flowering species, others showed preferences for specific species. This was most obvious in the case of solitary bees, for which almost half of records were to *Taraxacum agg.*, with *Knautia arvensis* and *Ranunculus acris* accounting for a further 30%. Indeed, one species, *Andrena marginata*, was only ever observed on *K. arvensis* during transect walks. Whilst none of the hoverfly species showed any definitive preference, it was notable that 20% of the flowers species recorded accounted for over 60% of records and one species, *R. acris*, had 75% of records for the genus *Cheilosia*.

The assumption that amenity grasslands provide less resources than sown wildflower meadows ignores the importance of their role in early spring. Whilst the top pollen producers investigated by Hicks *et al*. (2016) were all wildflower species, they were also species that do not bloom until at least late spring. Of these high pollen producers *Taraxacum agg.* was the only species in flower at Woolfall Heath in spring. Whilst it potentially has lower quality pollen compared to other flowering species, this has only been demonstrated in the case of social bees – *Bombus spp.* (Genissel *et al.,* 2002; Moerman *et al*., 2015), and the honey bee *Apis mellifera* (Loper & Berdel, 1980). Alongside *Trifolium pratense*, it has been demonstrated as a vital source of early pollen and nectar (Larson *et al*., 2014). Certainly, as expected, 'weeds' formed a significant resource in spring for both hoverflies and solitary bees. Notably, *Taraxacum agg.*, accounted for over half of the observed vistations (Table 2).

Plant-Pollinator Relationships

Analysis of visitation data across the two sites revealed that the most important floral resource was *K. arvensis* (Table 2). Visualisation of the plant-pollinator networks revealed unsurprisingly that social bees (*Bombus spp.*) were more generalist visitors to the plants across the sites, whereas solitary bees were generally only see visiting a small number of plant species, particularly Dandelion (*Taraxacum agg.*). Hoverflies were also an interesting group in terms of visitation preferences, with some species visiting a range of species, and others just visiting one or two specific species.

Rare and Notable Species

Andrena marginata was undoubtedly the most intriguing observation of the study. Modern records suggest it is confined to south England north to Oxfordshire, with a scattering of records in Norfolk and South Wales, and a cluster of sites in the Scottish Highlands (NBN, 2017) It is restricted to scabious rich sites, typically with Field Scabious (*Knautia arvensis*) and Small Scabious (*Scabiosa columbaria*) in southern sites and Devils-bit Scabious (*Succisa pratensis*) in its northern range (Falk, 2015). The observation in this study appears to be the only recorded siting of this species for the vice county, and the closest historical biological record seems to be a single record from North Wales, dating back to 1939 (NBN, 2017). To date, it appears to have been unrecorded in the entire north-west of England.

The most perplexing aspect of this species' occurrence at Woolfall Heath, is perhaps how it arrived there, given solitary bees' known limits in dispersal (Zurbuchen *et al.,* 2010). It has been suggested that its variation in floral selection may also correspond to genetic differences between northern and southern populations and an autecological study is currently underway (Edwards, pers. comm.). Despite the northern location of Woolfall Heath Meadow, it was observed on Field Scabious initially. In August however, when Devils-bit was also in flower it was only observed foraging on Devils-bit Scabious, and not observed at all on Field Scabious, despite it still being abundant. This observation is interesting as prior knowledge of this species suggests it generally forages on Devils-bit or Field Scabious, not both (Falk, 2017). It is likely that further research into this under-recorded species is needed in order to understand its visitation preferences.

Andrena humilis, another species of conservation concern, was also recorded during transect walks. Whilst more widespread than *A. marginata*, it is generally confined to the southern half of Great Britain, with its north-west England occurrence largely restricted to Cumbria. Whilst it is more diverse in its floral choices it does forage for pollen exclusively from yellow Asteraceae, notably *Hypochaeris radicata* and *Hieracium pilosella*, as well as similar looking species including *Taraxacum* agg (Falk, 2015). It was recorded on *Taraxacum agg.* in the amenity grassland and *Senecio jacobaea* in the meadow.

One other notable species was recorded not on transect walks but upon exiting the wildflower meadow on the final survey in July. Once regarded as a species of south England, *Bombus rupestris* has expanded its range in recent years, but remains scarce in northern England (Falk, 2015). During summer individuals have a definite preference for weeds species, with both males and females using thistles, ragwort and brambles for nectar; although it is known to visit Devils-bit scabious where available also. It has been established that there is a positive correlation between the occurrence of cuckoo bumble bees and their host. *B. lapidarius* (BWARS, 2016; Falk, 2015), which was by far the most commonly recorded species on site.

Common Bumblebees

The high abundance of *Bombus lapidarius* is almost certainly explained by various aspects of its ecology. Bumble bees are one of a relatively few known invertebrate groups known to display facultative endothermy, in which body temperature is raised above ambient temperature by elevating metabolism (Dzialowski *et al*., 2014). Consequently, they can tolerate lower environmental temperatures than most other invertebrates. *B. lapidarius,* again like other common bumble bees, is polylectic, collecting both pollen and nectar from a wide range of flowers, and nests underground, often in old mammal nests. These factors are almost certainly why some bumble bees are so common and widespread, including in urban locations, having the capacity to utilize a range of flowers and thus able to forage in gardens and parks, as well as being able to utilize a variety of underground holes for nesting sites.

It is unsurprising that as hypothesized, and in line with many other studies of sown wildflower sites, that the pollinating insect fauna in this study was dominated by common bumblebees. One aspect of their ecology needs to be considered however when evaluating urban sown wildflower sites for other taxon groups. A well-established bumble bee nest can contain as many as 400 bees (Bumblebee Conservation Trust, no date) in underground holes, whereas solitary bees do not form colonies, and whilst can form large aggregations, many are known to nest singly, and often require light, bare or sparsely vegetated soils, with many nesting predominantly on south facing slopes. This encompasses the nesting behaviour of many of the genus *Andrena* and family Halictidae. Members of the family Megachilidae are predominantly aerial nesters in holes and cavities. Thus, availability of suitable nesting sites may contribute to the dominance of bumble bees. Butterflies and hoverflies also frequently have specific requirements for egg-laying and larvae development. Butterflies generally have specific larval food plant requirements, and hoverflies display a wide range of larval microhabitat, ranging from specialist food plants, the presence of dead wood or waterbodies, through to the presence of other invertebrate groups. These issues support the proposal by Dennis *et al.* (2003; 2006; 2013), that a resource-based approach to the conservation of invertebrates is more likely to be successful than traditional habitat focused methods.

Amongst those species with less specialist requirements there was a mix of habitat associations represented by the pollinating insect assemblage recorded. Although most species were ones associated with open biotopes, there was a diverse mix of specific habitat requirements from ones associated with tall sward and scrub, to others associated with short sward and bare ground. Amongst the bare ground species, factors including soil base status, humidity and type are all known to impact the suitability of sites for these species (Gregory & Wright, 2005) Consideration should therefore certainly be given not only to the provision of range of floral resources, but a range of other resources, notably nesting sites and larval microhabitats if the intention of creating urban wildflower sites is to promote the conservation of a wide diversity of pollinating insect species.

Conclusions

Despite the small size of the wildflower meadow area in this study, and its positioning within an urban matrix, this study revealed a relatively high number of pollinating invertebrate species, including many solitary bee species, one of which had not previously been recorded in the area. Our research revealed that although both floral species richness and abundance of floral units were significantly linked with invertebrate species richness and abundance, floral species richness had the strongest relationship with both. It was noted that frequency of mowing had an impact on the floral units present in the amenity area, and as a result the invertebrates. We suggest that urban grasslands be cut less frequently, particularly in spring when nectar resources are most importance for pollinating insects. Weedy species such as dandelion are especially important, with benefits for solitary bees and hoverflies particularly. Urban wildflower sowing is recommended, as it can be highly beneficial, even in fragmented, urban areas.

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Ethical Conflict of Interest Statement

I testify on behalf of all co-authors in relation to our article submitted to the Journal of Insect Conservation:

1) this material has not been published in whole or in part elsewhere;
2) the manuscript is not currently being considered for publication in another journal;
3) all authors have been personally and actively involved in substantive work leading to the manuscript and will hold themselves jointly and individually responsible for its content.

E Coulthard – Corresponding Author.

Declaration of Authorship

Author Contributions: AL and LH conceived and designed the study as part of LH's masters thesis. LH carried out the field work. DN analysed the data. EC wrote the manuscript and advised on the project; other authors provided editorial advice.

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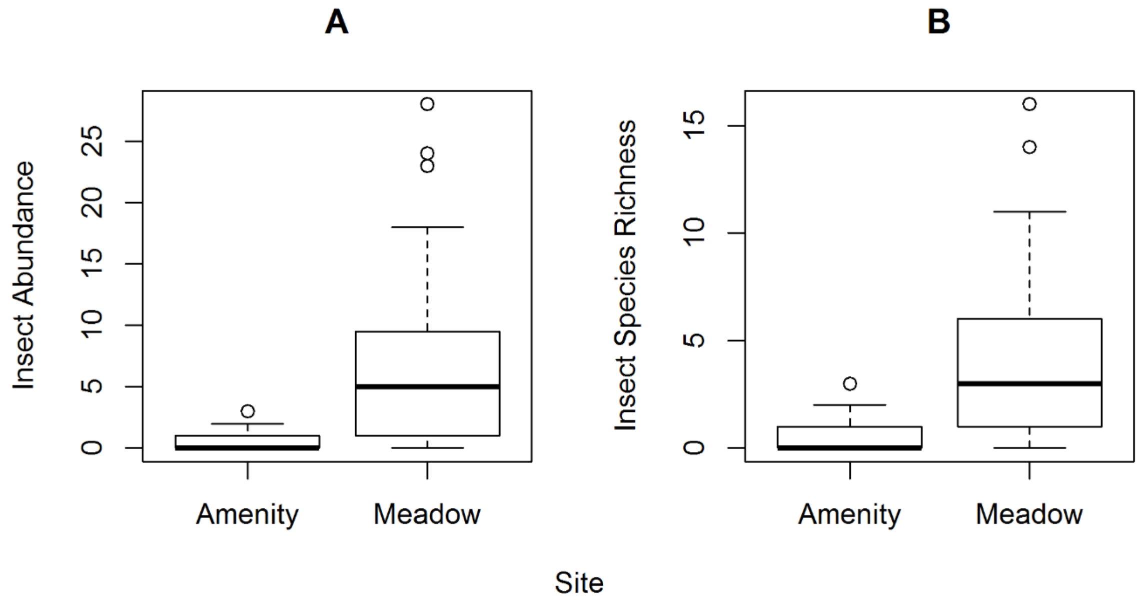
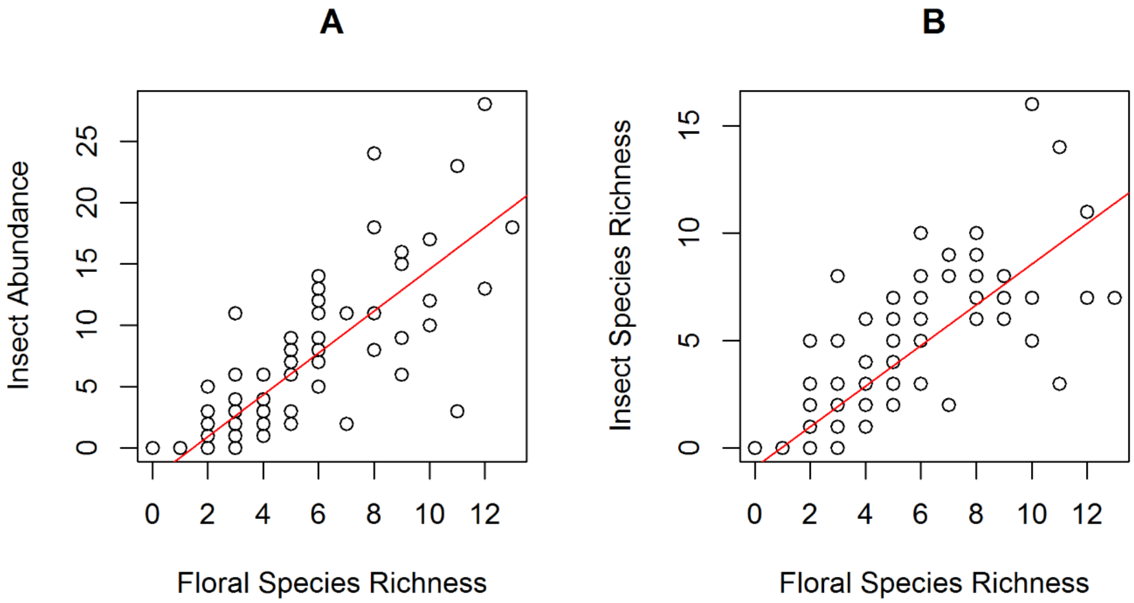

A
B
Insect Abundance
Insect Species Richness
0
5
10
15
20
25
Amenity
Meadow
Site

Figure 1


A
Insect Abundance
0
5
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25
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2
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Floral Species Richness
B
Insect Species Richness
0
5
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Floral Species Richness

Figure 2

Figures

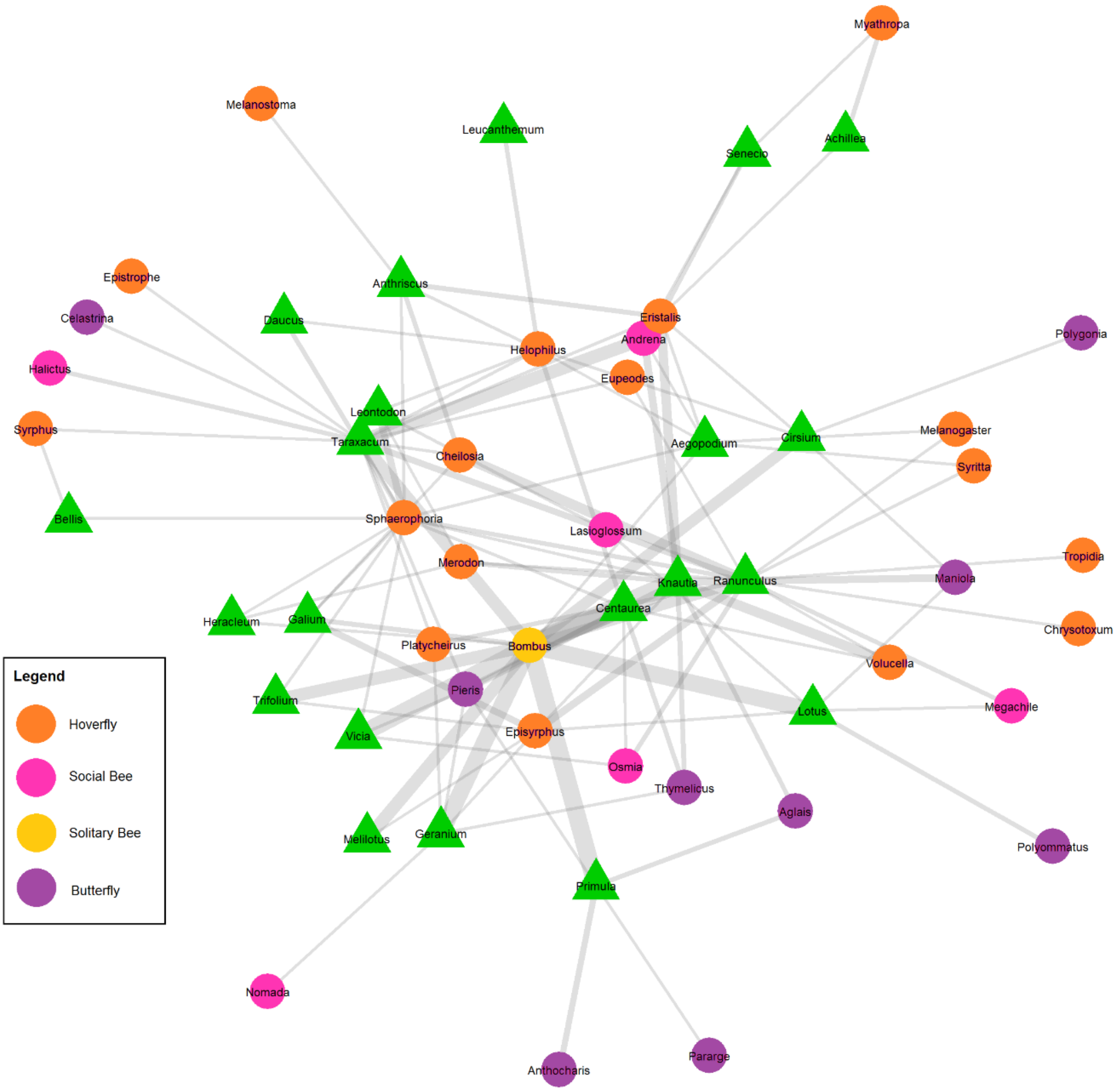
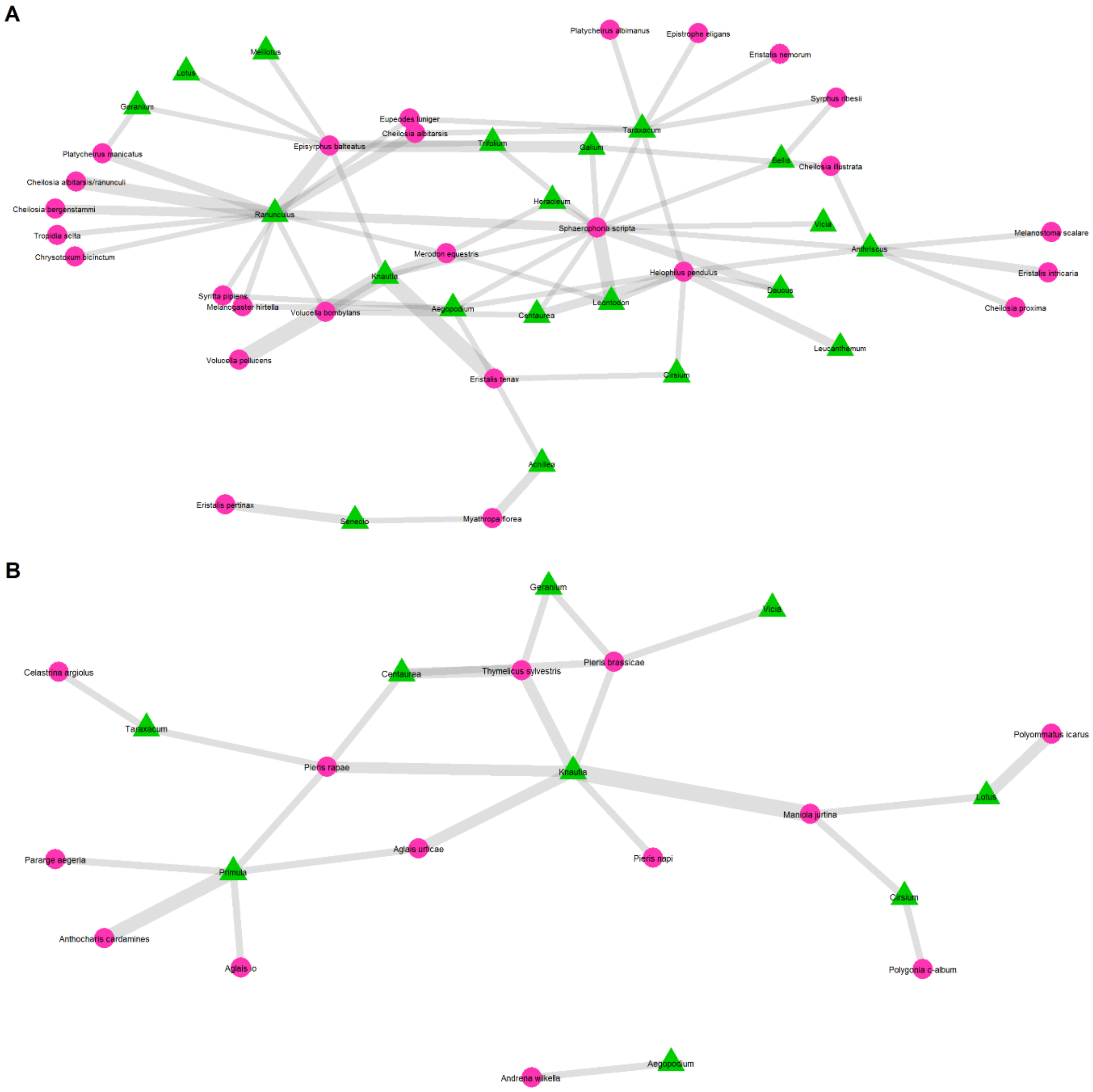


Figure 3


A
Platycheirus albimanus
Epistrophe eligans
Eristalis nemorum
Syrphus ribesii
Melilotus
Lotus
Geranium
Eupeodes luniger
Cheilosia albitarsis
Taraxacum
Episyrphus balteatus
Trifolium
Galium
Bellis
Cheilosia illustrata
Platycheirus manicatus
Cheilosia albitarsis/ranunculi
Cheilosia bergenstammi
Ranunculus
Heracleum
Vicia
Sphaerophoria scripta
Tropidia scita
Chrysotoxum bicinctum
Merodon equestris
Anthriscus
Melanostoma scalare
Knautia
Helophilus pendulus
Eristalis intricaria
Syritta pipiens
Melanogaster hirtella
Daucus
Volucella bombylans
Aegopodium
Centaurea
Leontodon
Cheilosia proxima
Leucanthemum
Volucella pellucens
Eristalis tenax
Cirsium
Achillea
Eristalis pertinax
Senecio
Myathropa florea
B
Geranium
Vicia
Celastrina argiolus
Centaurea
Thymelicus sylvestris
Pieris brassicae
Taraxacum
Polyommatus icarus
Pieris rapae
Knautia
Maniola jurtina
Lotus
Parage aegeria
Aglais urticae
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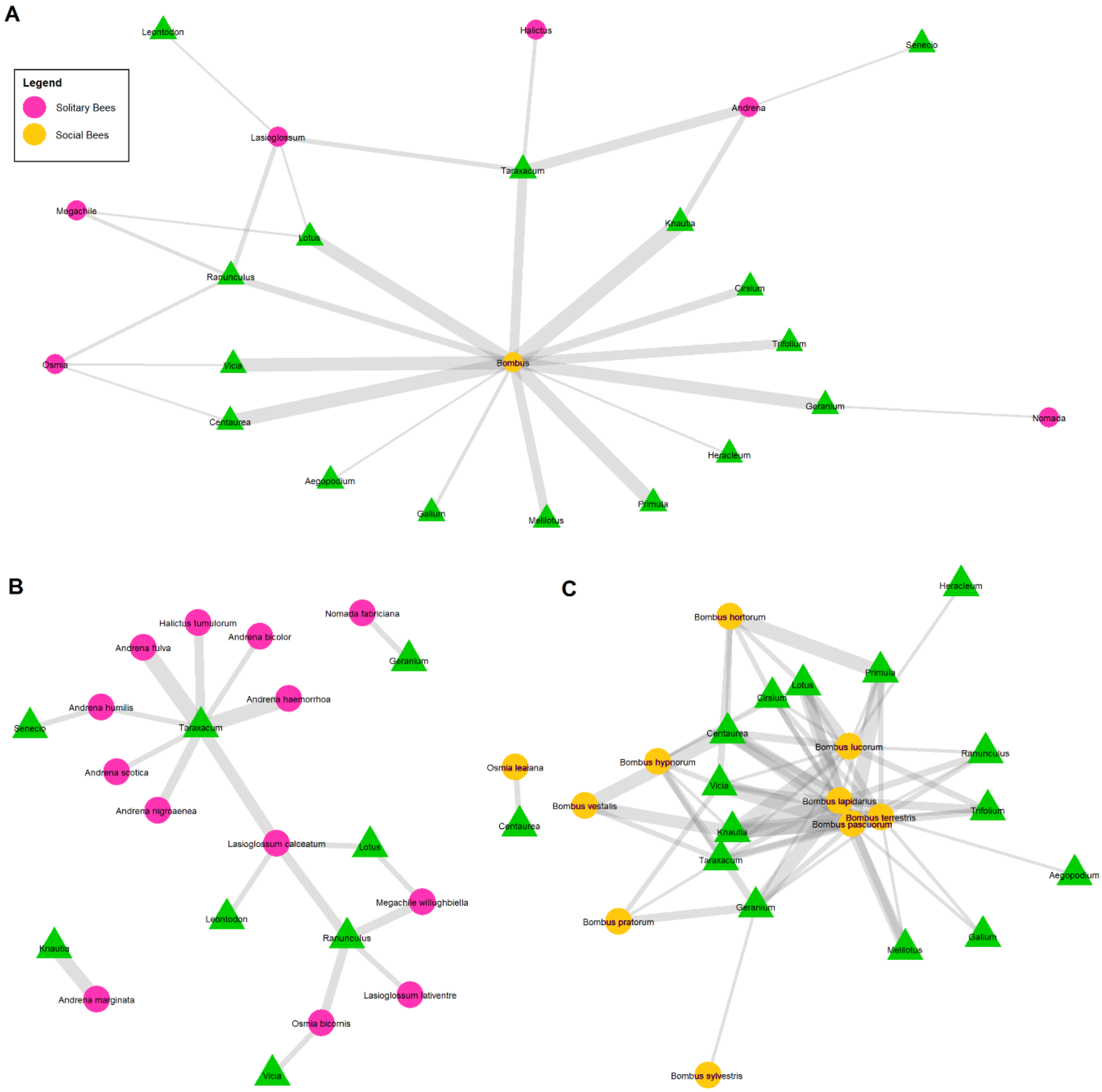
Primula
Cirsium
Anthocharis cardamines
Aglais io
Polygonia c-album
Andrena wilkella
Aegopodium

Figure 4



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606 Figure 5

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Figure Legends

Figure 1: Difference in insect abundance (A) and species richness (B) between the two treatment sites.

Figure 2: Relationship between floral richness and both insect abundance (A; LME: $\beta \pm$ se, 1.7 ± 0.08, t_{154} = 20.21, $p = <0.001$) and species richness (B; LME: 0.95 ± 0.05, t_{154} = 17.81, $p = <0.001$, Figure 2B) across both treatment areas

Figure 3: Plant-pollinator visitation network diagram for all pollinator and plant genera observed throughout the study. Coloured circles are invertebrate genera, green triangles are plants. Width of lines indicates frequency of visitation observations.

Figure 4: Plant-pollinator visitation network diagram for A) hoverflies and B) butterflies. Pink circles are invertebrate taxa, green triangles are plants. Width of lines indicates frequency of visitation observations.

Figure 5: Plant-pollinator visitation network diagram for A) all bee species, B) social bee species, and C) solitary bees. Coloured circles are invertebrate taxa, green triangles are plants. Width of lines indicates frequency of visitation observations.

Tables

Table 1

		Amenity Grassland		Meadow		Combined	
Taxa	**Subtaxa (Bees only)**	**Total Obs.**	**Species Richness**	**Total Obs.**	**Species Richness**	**Total Obs.**	**Species Richness**
Bees	*Social*	18	6	201	9	350	10
	Solitary	12	7	28	12	41	14
	All Bees	30	13	229	27	391	24
Butterflies		1	1	33	11	33	11
Hoverflies		12	4	107	22	129	25
Totals		43	18	369	56	554	62

Table 2

Flowering Plant Species	Total Visitations	No. Species (confirmed ID)	No. Taxa (solitary bees, social bees, hoverflies, butterflies)	Dominant Visiting Taxa
Knautia arvensis	124	21	4	Social bees
Taraxacum agg.	52	25	4	Solitary bees
Primula veris	51	10	2	Social bees
Ranunculus acris	41	21	3	Hoverfly
Lotus corniculatus	40	11	4	Social bees
Geranium pratense	39	14	3	Social bees
Centaurea nigra	34	14	4	Social bees
Vicia sp.	21	3	2	Social bees
Vicia sepium	20	9	3	Social bees
Cirsium arvense	17	12	3	Social bees
Melilotus officinalis	15	4	2	Social bees
Trifolium repens	13	6	2	Social bees
Aegopodium podagraria	12	9	4	Hoverfly
Anthriscus sylvestris	9	7	1	Hoverfly
Galium verum	8	6	2	Hoverfly
Centaurea scabiosa	7	2	1	Social bees
Leontodon hispidus	7	4	3	Hoverfly
Senecio jacobaea	5	4	3	Hoverfly
Achillea millefolium	4	2	1	Hoverfly
Bellis perennis	3	2	1	Hoverfly
Daucus carota	3	2	1	Hoverfly
Heracleum sphondylium	3	3	2	Hoverfly
Leucanthemum vulgare	2	1	1	Hoverfly
Ranunculus repens	2	2	2	Bees
Trifolium pratense	2	1	1	Social bees

Table Titles

Table I: Summary of insect species richness and abundance across the two sites, with separation by taxa and totals. The results of the chi-squared are also shown.

Table 2: Floral resource importance for both habitats. Plant species ranked by total visitations, and listing the number of species identified, number of taxa, and the most frequently visiting taxa.