RECLAIMING THE LAWN FOR URBAN BIODIVERSITY: REPLACING THE TRADITIONAL GRASS LAWN WITH GRASS-FREE LAWNS CAN GREATLY INCREASE POLLINATOR DIVERSITY AND ABUNDANCE.

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Abstract

Worldwide, pollinating insects are declining in abundance and diversity. In part this is the result of the loss of floral richness and abundance associated with anthropogenic changes in land use. An area of particular concern is the biotic homogenisation of urban areas. To address this the addition of pollinator friendly plants to gardens is an increasingly familiar component of urban wildlife conservation, however the largest area of garden planting the traditional grass lawn, is generally overlooked in this regard.

The use of purposefully created highly floral vegetation as an alternative to traditional turf lawns may contribute to ameliorating the declines observed in urban pollinators by bringing floral resources to an area traditionally managed to be flower-free. To examine the potential of this approach we compared visits made by pollinators (hoverflies, bees, and butterflies) to an ornamental grass-free lawn composed of mowing tolerant flowering forbs with visits to traditional grass-only turf and a commercially available 'flowering lawn' mix of grasses and forbs.

Overall, grass-free lawns were visited by four times as many pollinator species than traditional grass lawns and by almost twice as many as flowering lawns. The frequency of pollinator visits was also greatest on grass-free lawns, with over one hundred visits for every twelve recorded on flower lawns and one on turf. Grass-free lawns fostered the development of a much more complex plant-pollinator web than flower lawns or grass lawns.

We suggest that where suitable, the replacement of traditional grass lawns by grass-free style lawns not only has the potential to bring aesthetic benefits, but also act as a significant resource to help build pollinator abundance and diversity in urban ecosystems through the provision of greater floral richness as an alternative to traditional lawns.

Introduction

Urbanisation is an extreme example of anthropogenic habitat change, and is associated with a considerable loss of biodiversity and ecosystem services. However, while urbanisation has many deleterious ecological consequences, it is here that we can find the greatest density of hobby habitat managers, as garden owners manage their space for a variety of amenity and aesthetic purposes, and increasingly this includes managing gardens for biodiversity (Daniels and Kirkpatrick, 2006, Clayton, 2007, Davies et al., 2009, Fuller et al., 2007, Goddard et al., 2010). An increasingly common purposeful choice when gardening for wildlife is to consider pollinators, particularly bees and butterflies (Fuller et al., 2007, DEFRA, 2011, Salisbury 2017).

This change in gardening emphasis is a response to the recognised recent loss of insect pollinators as a result of agricultural expansion, increased use of insecticides, habitat loss, urbanisation, and biotic homogenisation, and this is considered a global threat to biodiversity and human well-being (Buchmann and Nabhan, 1997, Kearns et al., 1998, Meffe, 1998, Klein et al., 2007, Potts et al., 2010). In the Europe, where populations of pollinators have been well studied, 37-65% of bee species are of conservation concern (Patiny et al., 2009), and in the UK it is thought that almost half of the bumble bee species that have been historically recorded have become extinct or are close to extinction (Cussans et al., 2010). Similarly for butterflies, 71% of species saw population declines in the last twenty years of the twentieth century (Thomas et al., 2004), and this trend continues (Oliver et al., 2016).

However, the most common of greenspace features, the grass lawn (Ignatieva and Stewart, 2009), can be environmentally insensitive (Borman et al., 2001, Robbins, 2007) and is of little value to pollinators. Grass lawns are typically formed of one to three grass species, and are regularly and frequently mown to maintain short turf (Smith & Fellowes, 2013). In the UK grass lawns occupy up to 60% of garden space (Gaston et al., 2005). Current alternatives such as wildflower or species-rich turf and flower lawns are regarded and often marketed as pollinator friendly lawn formats since they specifically contain grasses mixed with flowering plants that are traditionally excluded from intensively managed grass lawns, but their role as a typical well-managed lawn is limited due to their taller meadow style format where plants are much taller than is usual for garden lawns (Smith & Fellowes, 2013).

We developed a novel grass-free lawn (Smith and Fellowes, 2014, 2015a, 2015b), an innovation in specifically designed vegetation suited to the maritime climate of NW Europe that primarily, but not exclusively, uses mowing tolerant clonal perennial forbs in place of grass. It is a format that has recently been referred to as 'Tapestry Lawn' or 'T-lawn' due to the interweaving growth patterns of the plants used.

T-lawns have been shown to provide a similar level of ground cover to traditional grass lawns (Smith & Fellowes, 2015b) and show environmental benefits through a reduced requirement for mowing and management, increasing ground-level insect abundance and diversity (Smith et al., 2015), and offer a plant species rich and highly floral alternative to a traditional green monoculture.

Replacing grasses with forbs requires a trade-off between the resilience and robustness of grasses and the diversity and floral performance of forbs (Smith and Fellowes, 2014), however, where footfall is less frequent grass-free lawns have the potential to be a useful tool in the environmentally friendly management of greenspace. Given that grass-free lawns can have high levels of floral productivity (Smith & Fellowes 2015b), and that pollinators are a guild of key conservation concern, we speculate that grass-free lawns could provide conservation benefits to this group in urban habitats, in addition to their aesthetic benefits.

We therefore address the question of whether grass-free style T-lawns can affect the abundance and diversity of pollinators visiting lawned areas. Here, over a three-month summer period, we compared the differences in the abundance and diversity of bees, butterflies and hoverflies visiting a traditional grass-only lawn, a commercially available flowering lawn mixture (a mix of grasses and wildflower seeds, marketed as a 'flower lawn' and being 'pollinator-friendly'), and grass-free lawns, each mown to their appropriate and recommended lawn height.

Methods and Materials

The study site was located at the University of Reading, Whiteknights campus (UK) at 51°26'11.8''N, 0°56'28.7''W, on Hurst 841b, a seasonally waterlogged silt loam soil (Anon, 2011), 68m above sea level. The bare soil site had remained uncultivated for two years before the experiment, and before the planting of lawns was cleared of unwanted vegetation in September 2012 using a proprietary solution of glyphosate at 1:40 dilution. To maintain vegetation-free space between plots this solution was applied again in June 2013 prior to pollinator sampling using a hand-held partially enclosed targeting wand.

Over two autumn days in early October 2012 eighteen randomised 1.5m² lawn plots, six of each lawn type, were created via seed or plants, with a 0.75m separation between plots. Both grass lawns and commercial flowering lawns were hand sown using seed mixes at twice the recommended rate due to initial poor seed coverage. Grass lawns (multi-purpose lawn seed) contained two grass species (Table 1), while the flowering lawns contained four grass species and ten forb species that also included *Trifolium repens* L, (White clover) a species that was not a listed component but nevertheless occurred in the mix in an unknown proportion (Table 1).

Grass-free lawns were created from a pool of ninety-seven plant components of both native and non-native origin. Sixty-three of these components were wild-type seed grown plant species and thirty-four were either ornamental cultivars, hybrids or forma chosen for their aesthetic appeal and grown from plug plants and cuttings (Table 1). We use the term components here since we used different forms of the same species specifically for aesthetic purposes and visual appeal; an intentional design characteristic of ornamental grass-free lawns. For example, the white clover species *Trifolium repens* used included three cultivars with coloured, patterned, or otherwise unusual leaves and one (unusually for the species) with red-coloured flowers; this represented four components.

Plants were selected to produce a realistic year-long interest full coverage lawn rather than being expected to be specifically floral during only the designated pollinator sampling period, and T-lawns contained species with floral periods ranging from very early in the spring e.g. *Viola odorata* L. (Sweet violet) and to later in the autumn e.g. *Geranium thunbergii* Siebert ex Lindl. & Paxton (Japanese cranesbill), and specifically included aesthetically interesting and widely available varieties with variably coloured foliage and ornamental double floral forms (Smith and Fellowes 2014, 2015a, 2015b).

All plants were initially grown as 7cm pot plants propagated in John Innes #2 formula sterilised loam. Plants used in grass-free lawns had previously been identified as being likely suitable component species or cultivars, and based on earlier work were included in lawns in proportions that reflected the characteristics of their growth and availability (Smith and Fellowes, 2014, 2015a, 2015b).

Grass-free lawns					Flower lawns
Acaena magellanica	*Dianthus deltoides* 'Flashing Light'	*Leptinella squallida* 'Platt's Black'	*Pilosella tardans*	*Trifolium pratense* 'Susan Smith'	*Galium verum*
Acaena microphylla 'Copper Carpet'	*Diascia* 'Lilac Belle'	*Lobelia angulata*	*Polygala vulgaris*	*Trifolium repens* 'Chocolate Splash'	*Leontodon hispidus*
Achillea millefolium	*Erodium castellanum*	*Lobelia chinensis*	*Potentilla neumanniana*	*Trifolium repens* 'Garnet'	*Leucanthemum vulgare*
Ajuga genevensis	*Fragaria vesca* 'Golden Alexandria'	*Lobelia oligophylla*	*Potentilla reptans*	*Trifolium repens* 'Purpurescens'	*Lotus corniculatus*
Ajuga reptans 'Atropurpurea'	*Frankenia thymifolia*	*Lobelia pedunculata* 'Blue Star Creeper'	*Primula elator*	*Trifolium repens* 'Son of William'	*Primula veris*
Ajuga reptans 'Burgundy Glow'	*Gentiana stevenagensis*	*Lobelia pedunculata* 'County Park'	*Primula wanda* (hybrid)	*Veronica chamaedrys*	*Prunella vulgaris*
Ajuga reptans 'Chocolate Chip'	*Geranium albanum*	*Lotus corniculatus*	*Prunella grandiflora*	*Veronica liwanensis*	*Ranunculus acris*
Ajuga reptans 'Pink Elf'	*Geranium pyrenaicum*	*Lotus corniculatus* 'Plenus'	*Prunella vulgaris*	*Veronica officianalis*	*Rumex acetosa*
Ajuga reptans 'Variegata'	*Geranium thunbergii*	*Lysimachia nummularia*	*Ranunculus repens* 'Buttered Popcorn'	*Veronica prostrata* 'Lilac Time'	*Trifolium pratense*
Anthyllis vulneria	*Geranium yoshinoii*	*Mazus reptans*	*Ranunculus repens* 'Gloria Spale'	*Veronica prostrata* 'Mrs Holt'	*Trifolium repens*
Argentina anserina	*Glechoma hederacea* 'Variegata'	*Mentha requenii*	*Ranunculus repens* 'Pleniflorus'	*Veronica repens*	*Agrostis capillaris*
Bellis perennis (Hybrids)	*Gypsophila cerastioides*	*Nierenburgia repens*	*Ranunculus repens* 'Semi Double'	*Veronica spicata nana* 'Blue Carpet'	*Cynosurus cristatus*
Campanula cochlearifolia	*Hieracium maculatum* 'Leopard'	*Oenothera minima*	*Sagina subulata*	*Viola hederacea*	*Festuca rubra litoralis*
Campanula rotundifolia	*Houstonia caerulea*	*Oreganum aureum* 'Crispum'	*Salvia lyrata*	*Viola odorata*	*Phleum pratensis*
Chamaemelum nobile 'Flore Pleno'	*Houstonia caerulea* 'Millards Variety'	*Oxalis magellanica* 'Nelson'	*Selleria radicans*	*Viola riviniana*	
Chrysanthemum weyrichii	*Lathyrus laxiflorus*	*Parochetus communis*	*Taraxacum pseudoroseum*	*Viola sororia*	
Convolvulus augustissimus	*Leontodon saxatilis*	*Phuopsis stylosa*	*Taraxacum rubrifolia*	*Viola stojanowii*	
Coronilla varia	*Leptinella alata*	*Phyteuma scheuchzeri*	*Thymus minima*		Grass Lawn
Cotula hispida	*Leptinella dioica*	*Pilosella aurantiaca*	*Thymus serpyllum*		*Festuca rubra* 'Boreal'
Dianthus arenarius	*Leptinella squallida*	*Pilosella officianarum*	*Trifolium pratense*		*Lolium perenne* 'Evening Shade'

Table 1. Species used in Grass-free, Flowering and Grass-only lawns

As with both the grass-only and commercial flower lawn seed mixes, good initial lawn-like ground coverage was considered a specific and necessary requirement for a lawn format. With natural variation in container grown plant size and development, innate differences between species and their ornamental cultivars, and prior experience of the subsequent variations in plant survival and establishment that can occur in grass-free lawns over the period of a British winter (Smith and Fellowes, 2014), identical replication was not considered a practicable aim; rather each grass-free lawn contained plants from a commonly used set of format relevant species in similar numbers in each lawn (Table 1). Numbers were similar rather than identical since to achieve the required initial ground cover two or more smaller plants which offered essentially poor ground coverage individually might be used in place of one larger plant that provided good ground coverage. Good ground coverage is considered an essential characteristic for any lawn. The number of winter-surviving constituent plant species and their cultivars in each lawn were recorded prior to the start of pollinator sampling in July 2013, with each lawn containing representatives from between 61 and 68 of the original component species, opportunistic weed species were removed as necessary.

A baseline Spring cut (mowing height) of 5cm was applied to all the trial lawns at the beginning of May 2013 before recording began, although prior to this the grass-only lawns had required two earlier cuts earlier in 2013 to maintain and ensure a lawn-type appearance. The subsequent application of mowing was determined by the recommended individual cultural requirements of each of the lawns.

All turf lawns were mown at the same time to 5cm once 75% of all the turf plots had attained 7cm. From and including the first baseline cut, turf lawns were mown a total of eight times during the study. The flowering lawns were mown as per the cultural instructions provided by the supplier (Flowering Lawn Seed Mix, Really Wild Flowers, 2012) and subsequently all mown to 5cm once 75% of the lawns had surpassed 14cm.

Cultural management of grass-free lawns requires lawns to be mown if any part of the lawn reaches approximately 9cm in height or when competition between plants produces clearly detrimental internal shading (Smith and Fellowes, 2015a). This methodology was followed and all lawns were mown at the same time. Including the base line cut both flower lawns and grass-free lawns were mown a total of three times respectively. Height throughout was determined using a 5g falling plate meter and mowing was applied using a Bosch Rotak 43Li cordless rotary mower. Arisings were collected by the mower and removed. After mowing plots were edge-trimmed by hand as necessary to retain their original size.

Monitoring of pollinator activity was restricted to bees (Hymenoptera), butterflies (Lepidoptera) and hoverflies (Diptera: Syrphidae), with species identification made during observations, netting specimens as required. Where necessary keys were used (Stubbs and Falk, 1983, Lewington, 2003, Edwards and Jenner, 2005, Allen, 2012, Else, 2012, Ball et al., 2013). *Bombus pascuorum* and *Bombus lucorum* (Hymenoptera: Apidae) queens were identified to species, while workers were allocated to a separate category B. *pascuorum*/

lucorum due to difficulties in field identification and to facilitate analysis (Scherber et al., 2010).

To allow for variation in weather conditions observations were made beginning on the first suitable day within a designated two-week sampling window starting 2nd July 2013, nine months after the lawns had been created, until 8th October 2013; days were deemed suitable if they were warm and sunny with light winds, allowing pollinator activity. There were four sampling windows each separated by two weeks, and five sample days required within each window, totalling twenty days of observation. Individual plots were randomly selected on the day of observation and each was observed for ten minutes without repeat until all plots had been sampled. This was conducted during the morning and again in the afternoon to produce a twenty-minute observation of each plot on each sample day. Each plot was observed for a total of 400 minutes.

As we A) wished to discover how attractive each lawn type was to pollinators and B) recognised the complexity of monitoring multiple visiting individuals, a pollinator visit was recorded when a pollinator landed on a plant within an observed plot. The pollinator and plant species were recorded. Subsequent visits by the same pollinator with the same plant species were not recorded; if the same pollinator came into contact with a different plant species, this was then recorded as a separate visit. All grass species were grouped as 'grasses.'

Statistical Analysis

Non-parametric Kruskal-Wallis tests suitable for small sample sizes were used to test the effect of treatment on the two response variables 1) the number of pollinator species observed to visit the plots, and 2) the number of pollinator visits observed. For each plot, data was pooled across the 20 observation days resulting in $N = 6$ per each of the three treatments. For each response variable four tests were performed: one for each of the three taxonomic groups, Diptera (Syrphidae), Hymenoptera, and Lepidoptera, and one for all pollinators combined. P-values were adjusted to correct for multiple testing using the Bonferroni method. The software R was used for all statistical analyses (R Core Team, 2016)

Results

Pollinator species

A total of 1228 pollinator contacts were observed, with grass-free lawns receiving 1091 contacts, flowering lawns received 124 contacts, and 13 pollinators contacted grass lawns.

A total of eight Lepidoptera, 15 Hymenoptera and 23 Syrphidae species were recorded across all lawns. A total of 45 pollinator species were recorded on grass-free lawns, 29 on flowering lawns and nine on grass lawns (Fig 1). Floral generalists *Bombus pascuorum* and *Bombus lapidarius* were the most frequent contact pollinator species, particularly on grass-free lawns.

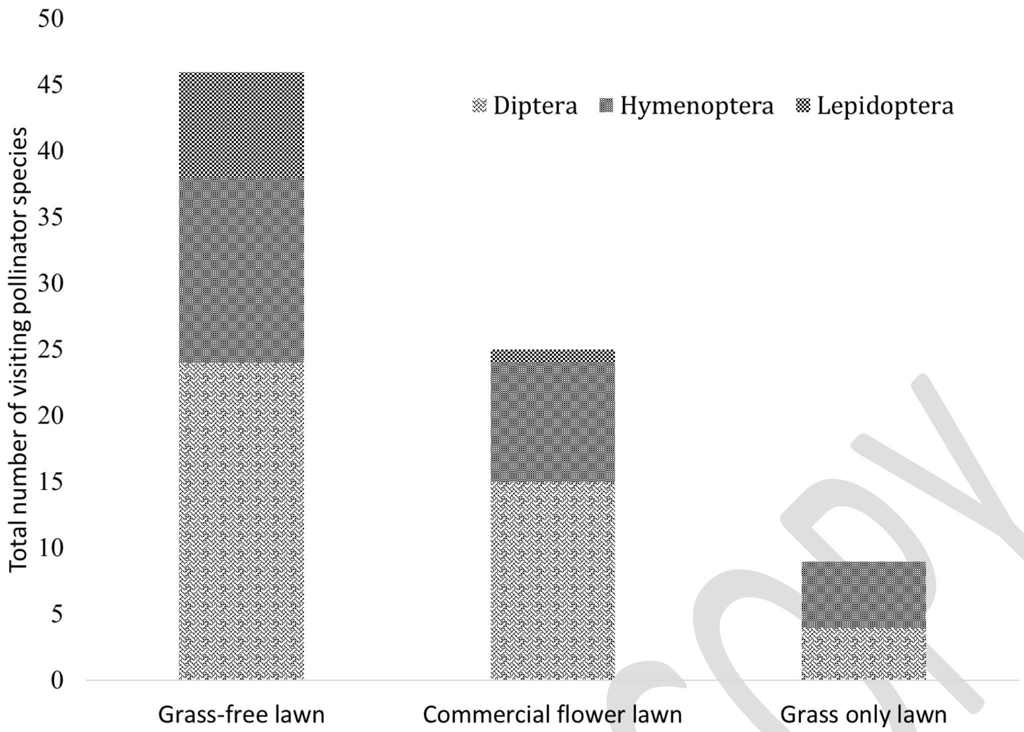

Fig 1. Total number of visiting pollinator species per lawn by type.

Grass-free lawns supported 17 species that were not observed in the other lawn types: eight syrphids, five hymenopterans and four lepidopterans (Fig. 2). Grass-free lawns and the commercial lawns supported an additional 20 species that were not seen in grass lawns: 12 syrphids, four hymenopterans and four lepidopterans. All lawn types had only eight species in common: three syrphids and five hymenopterans. Only a single species was observed in commercial flower lawns and grass lawns but not in grass-free lawns, the hymenopteran *Osmia leaiana*.

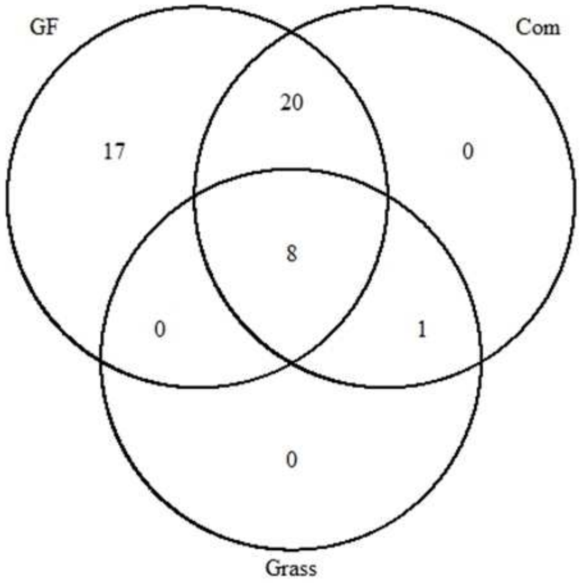

Fig. 2. A Venn diagram showing the overlap of pollinator species in the three lawn types. GF = Grass-free lawn; Com = Commercial flowering lawn; Grass = Grass-only lawn.

The number of pollinator species observed per plot was significantly affected by treatment (p = 0.0028, Table 2) with the number of pollinator species visiting grass-free lawns almost three times higher than the commercial flowering lawns and almost 20 times higher than that found visiting grass lawns (Fig. 3a). The results were qualitatively similar within each of the pollinator taxa (Syrphidae, Hymenoptera, Lepidoptera) with significant effects of lawn type ($p < 0.01$ for each taxon), and with most species observed in grass-free lawns, second-most in flowering lawns and fewest in grass lawns (Table 2, Fig. 3b-d).

Number of pollinator species				*fold-increases in median numbers*	
	Chi-Sq	*d.f.*	*p*	*G to GF*	*Com to GF*
Total number	*14.5*	*2*	*0.0028*	*19.7*	*2.8*
Syrphidae	*13.86*	*2*	*0.0039*	*14.5*	*2.2*
Hymenoptera	*12.74*	*2*	*0.0068*	*9.5*	*2.7*
Lepidoptera	*14.44*	*2*	*0.0029*	*NA*	*5*

Number of pollinator visits				*fold-increases in median numbers*	
	Chi-Sq	*d.f.*	*p*	*G to GF*	*Com to GF*
Total number	*14.27*	*2*	*0.0032*	*124.7*	*9.8*
Syrphidae	*14.68*	*2*	*0.0026*	*51*	*4.4*
Hymenoptera	*12.75*	*2*	*0.0068*	*78.7*	*16.9*
Lepidoptera	*14.36*	*2*	*0.0031*	*NA*	*9.5*

Table 2. Results from Kruskal-Wallis tests exploring the effect of lawn type on the number of pollinator species and on the number of pollinator visits.

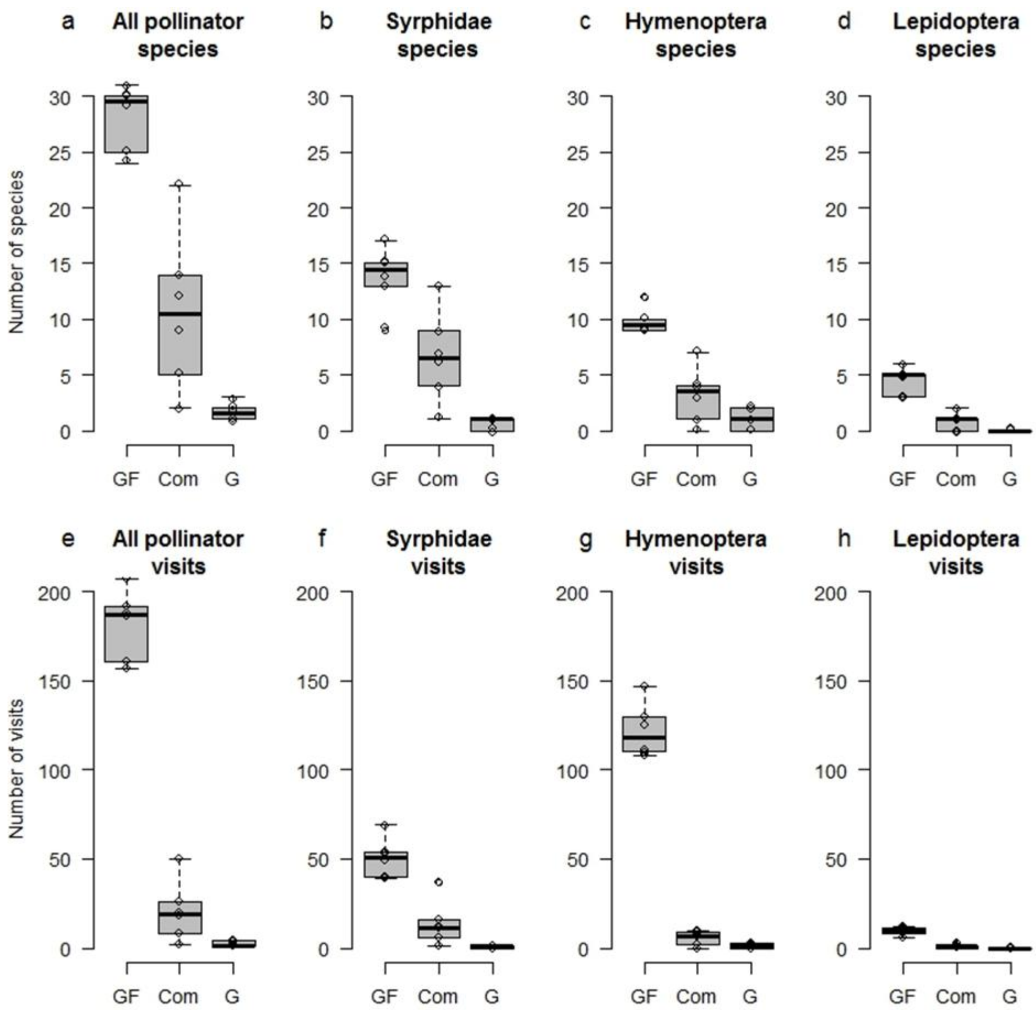

Fig. 3. Number of pollinator species (a-d) and number of pollinator visits (e-h) plotted against lawn type. Box plots show medians, quantiles and outliers, and raw data is shown as small circles (N = 6 per treatment). GF = Grass-free lawn; Com = Commercial flowering lawn; G = Grass lawn.

Pollinator visits

The number of pollinator visits observed per plot was significantly affected by treatment (p = 0.0032, Table 2) with the number of pollinator visits in grass-free lawns almost 10 times higher than flowering lawns and almost 125 times higher than grass lawns (Fig. 3e). The results were qualitatively similar within each pollinator taxon, with significant effects of lawn type ($p < 0.01$ for each taxon), and most species were observed in grass-free lawns, second-most in flowering lawns and the fewest in grass lawns (Table 2, Fig. 3f-h).

Within lawns, component plants were differentially visited by pollinators along a continuum of possible contact types and frequencies (Fig 4). In grass-free lawns this varied from only one individual from a pollinator species visiting only a single plant species (one *Platycheirus manicatus* (Diptera: Syrphidae) made one visit to a single *Gypsophila cerastioides* D.Don plant), and one species of pollinator repeatedly visiting only one species of plant (Harebell

Carpenter Bee *Chelostoma campanularum* (Hymenoptera: Megachilidae) was only recorded visiting *Campanula cochlearifolia* (Lam)), to a single species of pollinator (*Bombus pascuorum)* recorded visiting 24 plant species but showing a strong preference for *Prunella vulgaris* L and *Trifolium pratense* L.

For clarity on plant pollinator interactions plant-pollinator webs are shown in Figs 5a-b.

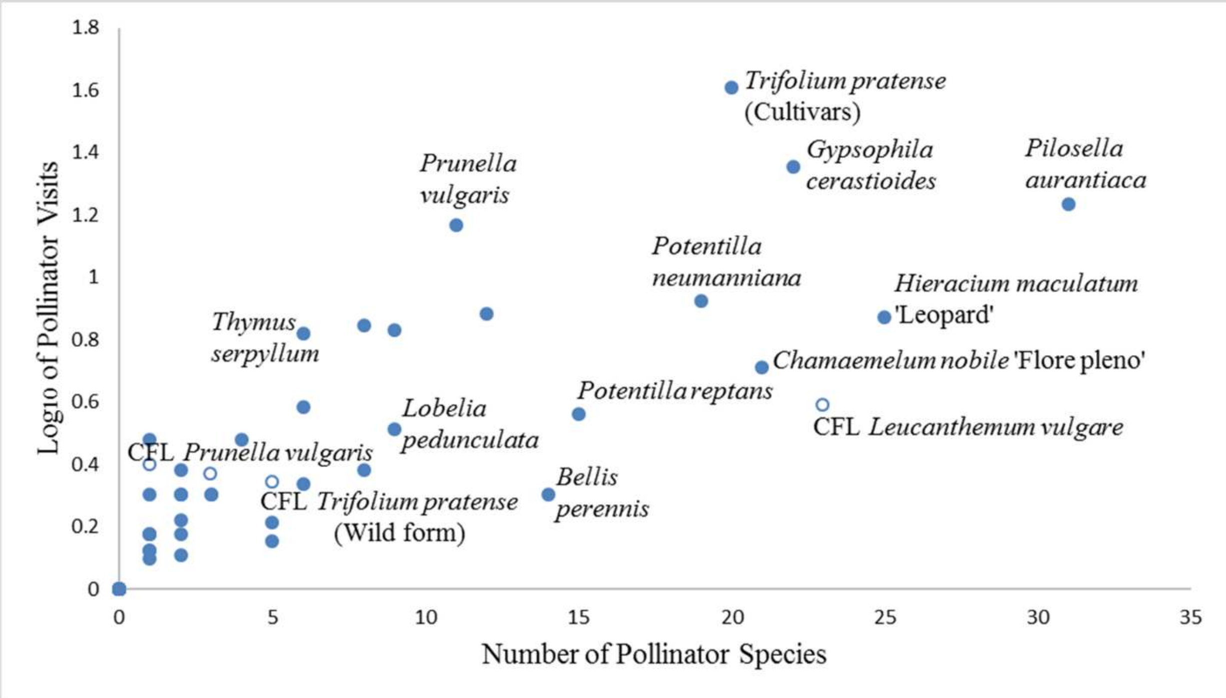

Fig 4. Log^{10} of pollinator visits. Highly visited and format-shared species named. CFL open circles = Commercial Flower Lawn.

Preference for visiting plant species located in grass-free lawns over the same species located in commercial flowering lawns was observed for several pollinator species (Fig 4). The hoverfly *Episyrphus balteatus* (Diptera: Syrphidae) was recorded visiting twenty-one different plant species in grass-free lawns including *Prunella vulgaris* and *Trifolium pratense,* however, it contacted only *Leucanthemum vulgare* (Vaill.) Lam. in flowering lawns despite both *P. vulgaris* and *T. pratense* being present and in-flower. For *Prunella vulgaris* this preference for grass-free lawns-only was observed with three syrphids, six Hymenoptera and one Lepidoptera species. Only *Bombus pascuorum* was found to contact *P. vulgaris* in both lawn types. A similar preference for grass-free lawns was also observed in visits to *T. pratense* with nine syrphids, six hymenoptera and three lepidoptera.

Mowing followed cultural requirements throughout and was observed to reduce the number of pollinator visits immediately post-mowing on all lawns. Management protocols and growth patterns unexpectedly led to both grass-free lawns and flowering lawns being mowed at the same time allowing for a comparison between formats. The influence of mowing on pollinator visits was observed to be greater in flowering lawns since the primary floral resource provided by tall growing *Leucanthemum vulgare* (Vaill.) Lam. (Ox-eye daisy) was removed by the cut (Fig 5).

Most of the plants in grass-free lawns are naturally or responsively low growing and were not as severely affected by the mower. Although tall flowering stems were removed; plants with flowers below the cut height of the mower (e.g. *G. cerastioides*) continued to offer floral resources immediately post-mowing. This was particularly evident during sampling window three when pollinator visits were reduced in commercial flowering lawns but less so in grass-free lawns (Fig 5).

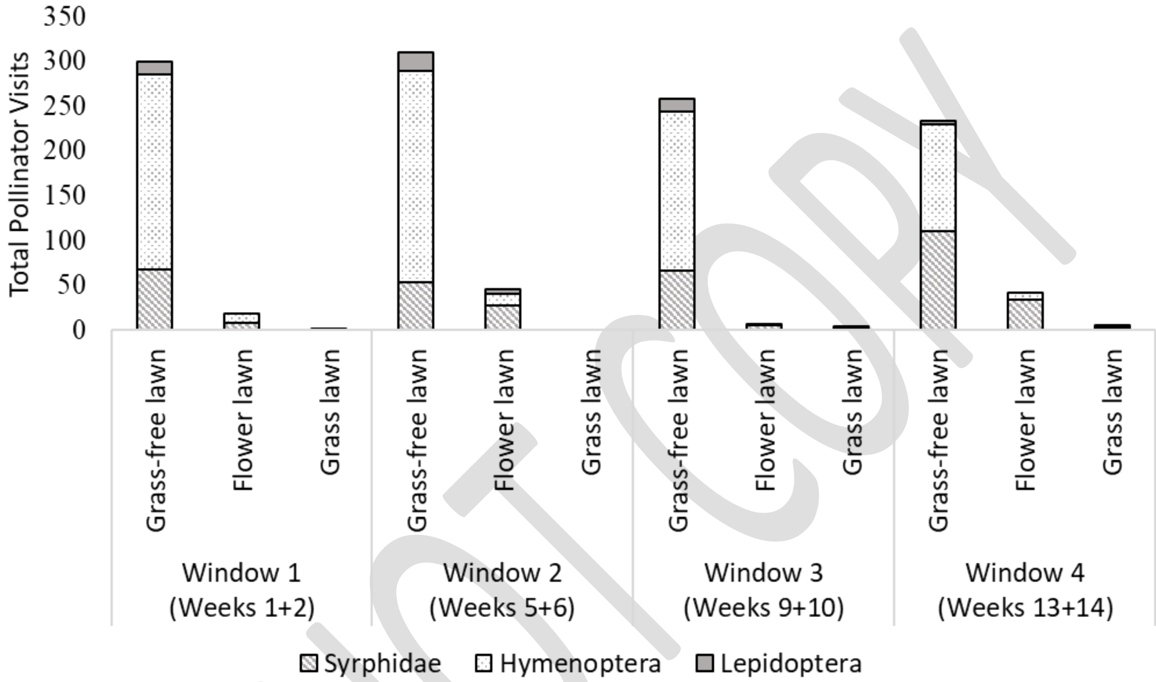

Fig 5. Total pollinator visits recorded over the four sampling period windows.

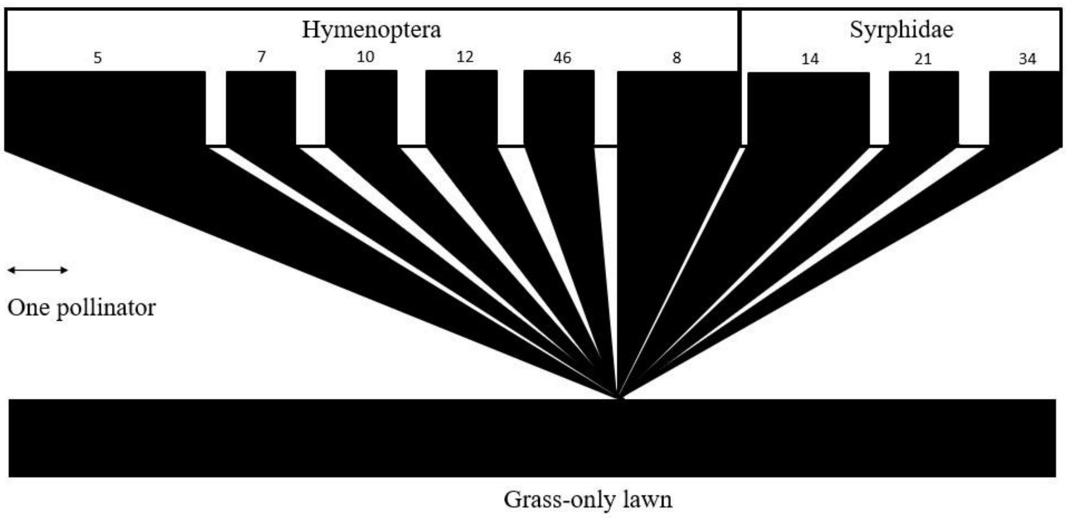

Fig 5a. Plant-Pollinator web for Grass-only lawns.

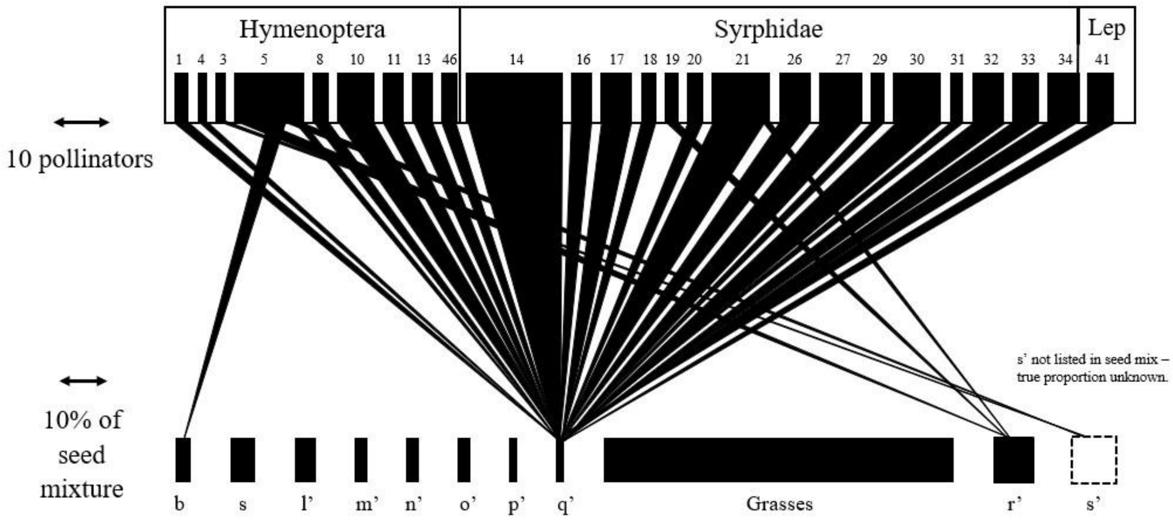

Fig 5b. Plant-Pollinator web for Flowering lawns.

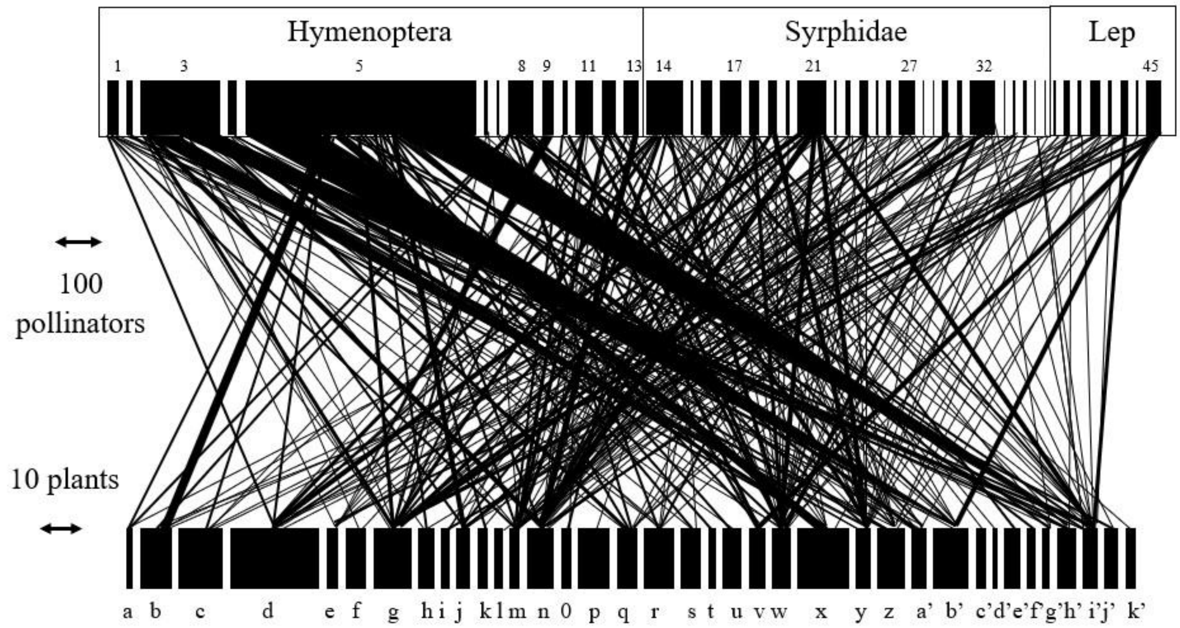

Fig 5c. Plant-Pollinator web for Grass-free lawns. For species of plant and pollinator see appendix.

Discussion

Traditional grass lawns have useful ecosystem service features beyond that of simple ground cover in that they have been found to act as atmospheric nitrogen sinks (Raciti et al., 2008), sequester carbon (Milesi et al., 2005), reduce rainfall run-off velocity and increase run-off initiation time (Schueler, 1987), act as erosion control agents (Lush, 1990), via transpiration act to moderate temperatures (Beard and Johns, 1985), offer both noise and glare abatement (Cook and VanHaverbeke, 1971), and as a component of greenspace may contribute to well-being (Mitchell and Popham, 2007). They also can influence property values and reflect societal norms (Nassauer, 1995, Nassauer et al., 2009). Lawns therefore have considerable value to humans; however, they are of little value to pollinators unless they contain flowering forbs. A lawn format that can retain these service features and be of significant benefit to pollinators would represent a considerable advance in the amenity and ecological value of lawns.

We examined the value to pollinators of experimental lawns composed only of flowering forbs (grass-free lawns), and lawns containing predominantly grasses (a commercial flowering lawn format & grass-only lawns) since no such information is currently available. We recognise that grass-free lawns are likely to be composed from a variety of different format suitable plants and aesthetically interesting cultivars and therefore included as many of these in the trial lawns as was possible to provide an indication on how pollinators may interact with such a construct. This was intended to be informative and not definitive.

Outside of trial grounds we would expect that each grass-free lawn is likely to be different with plant selections based on personal aesthetic preferences, plant availability and predominant local environmental conditions, and that outcomes are therefore likely to be variable with different grass-free and flowering lawn mixes likely to produce differing outcomes. However, our results demonstrate that a lawn composed of forbs-only can receive visits from one and a half times as many pollinator species than that found on a commercial flowering lawn, and five times more than found to contact grass-only lawns; also, that for every pollinator visit made with grass-only lawns eight are made on forbs in commercial flowering lawns and over 84 on plants in grass-free lawns. Pollinator visits on grass lawns were few and clearly unrelated to the act of pollination since no floral resources are available. Evidently, grass-free lawns are exceptionally attractive to pollinators, when compared to the format they can replace.

Commercially available flowering lawns are frequently marketed as being pollinator-friendly and this would appear to be the case when compared with a traditional grass-only lawn. However, only the seasonally in-flower forbs received visits and visits were dominated by a single tall-growing species (Fig 5b), with visits substantially reduced when (due to mowing) this was no longer available (Fig 3). The height that these types of lawn attain prior to mowing may also exceed what most would regard as a low-cut lawn.

Notably, the same species of plant that received many visits in grass-free lawns did not receive a similar number of visits in commercial flowering lawns (Fig 3). This may be interpreted as being indicative of preference between the patches of floral resource available (Fründ et al., 2010), and that pollinators found the grass-free format more attractive or possibly less intimidating (Benoit, A.D. and Kalisz, S., 2020), even when the same plant species were available in the flowering lawns nearby. This preference was seen to be maintained throughout the period of study (Fig 4) with grass-free lawns receiving more visits (Fig 1) from a greater number of pollinating species (Fig 5c).

Since pollination by generalists is thought to predominate in nature (Herrera, 1996, Waser et al., 1996, Olesen, 2000, Herrera, 2005), grass-free lawns may serve as an accessible floral resource for many more pollinating species than is provided for by forb limited (and taller growing) commercial flowering lawn alternatives, in addition to potentially providing for some preferentially nectar specific pollinators as was the case with the Harebell Carpenter bee.

Poor floral resources can be a restricting factor in the populations of bees (Roulston and Goodell, 2011), butterflies (Summerville and Crist, 2001, Öckinger and Smith, 2006) and hoverflies (Kleijn and Van Langevelde, 2006, Meyer et al., 2009). With the of loss of nectar specific plants, biotic homogenisation, and reduction in habitat quality through a reduction in flower abundance and richness being current issues in pollinator ecology, particularly in urban areas (Winfree et al., 2011); grass-free lawns can be seen to usefully contribute to habitat quality and foster greater complexity.

A part of this complexity was facilitated using specifically ornamental non-native plant species in the grass-free species mix. Although the most frequently contacted plant was the British native *T. pratense* (Red clover), the second most frequently contacted was the non-native *G. cerastioides* (Mouse-eared gypsophila), and the greatest number of pollinator species were found visiting the non-native (but UK naturalised) *Pilosella aurantiaca* (L.) F.W.Schultz & Sch.Bip.

In grass-free lawns, the prostrate (and therefore often partially concealed) non-native *Lobelia pedunculata* (R. Br), a species with a relatively low number of visits, was found to receive greater numbers of visits from more pollinator species than high contact natives such as *T. pratense* located in the (native-only) forb component of the commercial flower lawns (Fig 3). This suggests a structural influence in pollinator responses to the formats.

Non-native plants accounted for over forty percent of the pollinator visits within grass-free lawns, encouraging higher pollinator species richness, abundance, and flower visitation (Lopezaraiza–Mikel et al., 2007). In accordance with earlier findings (Memmott and Waser, 2002, Hanley et al., 2014, Salisbury et al.,2015), non-natives have not only an ornamental role, but are also useful components in the plant-pollinator webs they help create. Indeed, while our attempts in gardens to support biodiversity can have unexpected consequences (e.g. with feeding birds; Orros & Fellowes 2012, Orros et al. 2015, Hanmer et al. 2017), the grass-free lawns increases plant diversity, increases general insect diversity (Smith et al. 2015), and here we show that this aesthetically pleasing construct also substantially increases the abundance and diversity of visiting insect pollinators, an internationally declining keystone guild (Brown et al., 2016).

The grass-free lawns in this study had a mix of ornamental cultivars and nativars, and not all were in flower during the summer sampling windows since many of them have an early spring floral period and some a late summer/autumn one. Plants were not specifically selected to produce flowers during the sampling period, but rather to produce an effective and attractive ground covering lawn equivalent (Smith & Fellowes 2015b). These unvisited components potentially extend the floral resource prior to and beyond the period of study, a feature not matched in the same manner by the components of the commercial flower lawn mix that have late spring and summer floral periods. By having several seasons of interest and being highly floral and visually attractive, grass-free lawns would be appropriate for gardens and public spaces, particularly if heavy footfall is not a requirement.

The urban landscape is anthropogenic. Gardens and lawns are a significant component of urban green space (Gaston et al., 2005, Loram et al., 2008) and provide both aesthetic and amenity value to the gardener. Part of that amenity value comes with the recognition that urban gardens may play a key role in conservation through the activities of what we could term ‘citizen conservationists,’ who work to attract a wide diversity of species to their gardens (Fuller et al., 2007, Davies et al., 2009, Orros and Fellowes, 2014). It is widely thought that a great number of small habitats covering a wide range of geographic area can maximize beta diversity (Tscharntke et al., 2002), and since gardens can occupy substantial amounts of space in urban environments and offer a patchwork of green spaces and small habitats, they can usefully contribute to urban conservation. Where the ‘green’ of greenspace is purely ornamental or unutilised grass lawn e.g. front gardens, there now exists a novel opportunity to capture the desire for wildlife-friendly gardening and significantly improve pollinator habitat by increasing flower abundance and richness using grass-free lawns.

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Appendix

Key to pollinator webs

Hymenoptera

1 *Apis mellifera*
2 *Bombus hypnorum*
3 *Bombus lapidarius*
4 *Bombus lucorum*
5 *Bombus pascuorum*
6 *Bombus pratorum*
7 *Bombus terrestris*
8 *Bombus terrestris / lucorum*
9 *Chelostoma campanularum*
10 *Colletes daviesanus*
11 *Lasioglossum calceatum*
12 *Lasioglossum lucozonium*
13 *Lasioglossum morio*

Diptera

14 *Episyrphus balteatus*
15 *Eristalis nemorum*
16 *Eristalis pertinax*
17 *Eristalis tenax*
18 *Eupeodes corollae*
19 *Eupeodes luniger*
20 *Helophilus hybridus*
21 *Helophilus pendulus*
22 *Helophilus trivittatus*
23 *Melanostoma mellinum*
24 *Melanostoma scalare*
25 *Merodon equestris*
26 *Myathropa florea*
27 *Platycheirus albimanus*
28 *Platycheirus manicatus*
29 *Platycheirus scutatus*
30 *Platycheirus tarsalis*
31 *Scaeva pyrastri*
32 *Sphaerophoria scripta*
33 *Syritta Pipens*
34 *Syrphus ribesii*
35 *Syrphus vitripennis*
36 *Volucella pellucens*
37 *Xanthogramma pedissequum*

Lepidoptera

38 *Lycaena phlaeas*
39 *Maniola jurtina*
40 *Ochlodes sylvanus*
41 *Pieris brassicae*
42 *Pieris napi*
43 *Pieris rapae*
44 *Polyommatus icarus*
45 *Thymelicus sylvestris*

Species recorded visiting the commercial lawn formats but not the grass-free lawn

46 *Osmia leaiana* (Hymenoptera)

Grass Free Lawn Plants

a *Achillea millefolium c.f. Aurea*
b *Anthyllis vulneria*
c *Argentina anserina*
d *Bellis perennis* (Ornamental)
e *Campanula cochlearifolia*
f *Campanula rotundifolia*
g *Chamaemelum nobile* 'Flore Pleno'
h *Coronilla varia*
i *Cotula hispida*
j *Erodium castellanum*
k *Gentiana stevenagensis*
l *Geranium albanum*
m *Gypsophila cerastioides*
n *Hieracium maculatum* 'Leopard'
o *Leontodon saxatilis*
p *Lobelia angulata*
q *Lobelia pedunculata* 'Blue Star Creeper'
r *Lobelia pedunculata* 'County Park'
s *Lotus corniculatus*
t *Lotus corniculatus* 'Plenus'
u *Mentha requenii*
v *Phuopsis stylosa*
w *Pilosella aurantiaca*
x *Polygala vulgaris*
y *Potentilla neumanniana*
Z *Potentilla reptans*
a' *Prunella grandiflora*
b' *Prunella vulgaris*
c' *Ranunculus repens* 'Gloria Spale'

d' *Ranunculus repens* 'Pleniflorus'
e' *Sagina subulata*
f' *Salvia lyrata*
g' *Thymus minima*
h' *Thymus serpyllum*
i' *Trifolium pratense*
j' *Trifolium pratense* 'Susan Smith'
k' *Veronica prostrata* 'Lilac Time'

Plant species in the commercial lawns.

l' *Primula veris*
m' *Galium verum*
n' *Ranunculus acris*
o' *Rumex acetosa*
p' *Leontodon hispidus*
q' *Leucanthemum vulgare*
r' *Trifolium pratense*
s' *Trifolium repens*