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ORIGINAL PAPER

Adding ecological value to the urban lawnscape. Insect abundance and diversity in grass-free lawns

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Abstract Insect diversity may be declining even more rapidly than in plants and vertebrates, particularly in areas where indigenous habitats are replaced by an anthropogenic one. The most common component of anthropogenic greenspace is the ornamental lawn. Intensively managed and offering limited habitat opportunities for both plants and insects, lawns are biodiversity poor and ecologically insensitive. An alternative lawn format that positively influences biodiversity and reduces management requirements would be a useful tool in eco-friendly urban greenspace management. In investigating the potential for a forb-only alternative to the grass lawn we sampled both trial grassfree lawn formats and turf lawns to identify any influence that lawn composition and grass-free lawn specific mowing regimes might have on the abundance and diversity of insect families. In addition to the mowing regimes, both the composition and origin of lawn flora were found to significantly influence insect abundance and diversity and these factors rarely interacted. Native-only and mixed origin grass-free lawns hosted greater numbers of adult insects than found in turf and an equivalent diversity of insect families, however the mowing regime applied was distinct from traditional turf lawn management by being substantially less intensive and our results suggest that there is the potential for even greater abundance and diversity via the grass-free format that may offer additional resources to insectivorous garden species such as birds. When the composition of grass-free lawns included native forbs the diversity of insect families was found be sufficiently different from turf lawns to form distinct assemblages and in so doing contribute to beta diversity within urban greenspace. In sum, grass-free lawns may be a useful and aesthetically appropriate tool for adding value to the generally biodiversity poor urban lawnscape.

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Introduction

Insects dominate terrestrial ecosystems and can contribute via pollination, decomposition and soil aeration to ecosystem services, they are also primary consumers and important to many food webs (Seastedt and Crossley 1984). Current assessments indicate that insect diversity may be declining even more rapidly than in plants and vertebrates (Thomas et al. 2004), and urbanisation via the conversion of natural habitat to anthropogenic habitat is influential on this decline (Davis 1978; Pyle et al. 1981; McIntyre, 2000). A prime determinant of insect assemblages is vegetation (Schaffers et al. 2008), and urban greenspace worldwide is dominated by the grass lawn (Ignatieva and Stewart 2009). Lawns are an anthropogenic construct that is traditionally maintained to an aesthetic standard by intensive management; they are usually species poor and many conventional lawn management practices can be ecologically insensitive (Borman et al. 2001). There is a pressing need for an aesthetically suitable alternative to the traditional turf lawn that ameliorates these practices and contributes to, rather than detracts from, urban biodiversity. Being omnipresent it has been suggested that knowledge of insect assemblages through their diversity and abundance can aid in the planning and management of biodiversity reserves on a variety of landscape scales (Pyle et al. 1981; Kremen et al. 1993; Cassola and Pearson 2000). Here we use insect abundance and the diversity of insect families to assess the potential value of a grass-free lawn alternative as a tool for the management of insect biodiversity in urban greenspace.

Grass-free lawns are a recent innovation in urban horticulture in the UK whereby grasses are replaced by mowing tolerant clonal perennial forbs (Smith and Fellowes 2013). As such they are an example of designed vegetation (Dunnet and Hitchmough 2004; Hitchmough 2008) and are created to be both aesthetically pleasing and ecologically sensitive; they have the potential to be implemented as a species rich, low maintenance and highly floral ground cover alternative to the traditional turf lawn (Smith and Fellowes 2014a, b, c). Intentionally replacing grass dominated turf with a polyculture of forbs both native and non-native, and introducing floral resources to an area traditionally managed to be flower-free is likely to influence local arthropod assemblages (Isaacs et al. 2008). However, the biodiversity benefits of replacing one lawnscape construct with another are unclear. If grass-free lawns can contribute to insect abundance and diversity in urban greenspace they may offer a useful and aesthetically appropriate tool for the management of what has until now been an ecologically insensitive but never-the-less ubiquitous landscape feature.

In natural ecosystems biodiversity is widely accepted to influence the stability and functioning of communities at multiple trophic levels (Hooper et al. 2005), with plant diversity regarded as being strongly influential on the structure and dynamics of animal communities (Elton 1958; Hutchinson 1959; Murdoch et al. 1972). Increases in plant diversity in natural ecosystems have been repeatedly observed to support greater arthropod diversity (Siemann et al. 1998; Scherber et al. 2010), suggesting that arthropod diversity is in the most part limited by the feeding niches available to herbivorous arthropods, and that increases in plant diversity directly increase arthropod consumer diversity (Knops et al. 1999; Haddad et al. 2010). The strength of this linkage has indicated that the plant species composition of vegetation can be a useful predictor of arthropod assemblages (Schaffers et al. 2008), and by inference that manipulation of vegetation may influence arthropod populations (Isaacs et al. 2008).

The vegetation within urban environments tends to be highly manipulated; it is also highly diverse, widely fragmented and often includes a rich variety of non-native species (Pyšek 1998; Sukopp 1990; Zerbe et al. 2003). With a highly heterogeneous landscape and a wide variability in the composition of urban vegetation the abundance and richness of arthropods has not been widely investigated (McIntyre 2000), although arthropod populations are thought to be influenced by the rural to urban gradient, ongoing human activity and land usage, in addition to the wide variability in density, complexity and diversity of vegetation found within the urban matrix (Davis 1978; McIntyre et al. 2001; Raupp et al. 2010).

Within the UK approximately a quarter of this urban matrix is composed of gardens and approximately sixty percent of garden space is covered by lawns (Jo and McPherson 1995; Gaston et al. 2005). Although almost all British lawns are primarily composed of native grass species, plant diversity in UK gardens is prevalently based around the use of ornamental non-native species (Thompson et al. 2003; Smith et al. 2006b). However, gardens have been found to positively influence local biodiversity (Smith et al. 2006a; Davies et al. 2009; Goddard et al. 2010), with suburban gardens being described as potentially the best urban nature reserves (Owen and Owen 1975). Gardens have been found to host a wide variety of arthropods (Owen 1983; Smith et al. 2006a; Owen 2010), with the contrived plant diversity found within the patchwork of suburban residential and public landscapes potentially important for the maintenance of urban biodiversity and ecosystem functioning (Raupp et al. 2010).

However both lawns and the use of non-native plants are currently contentious and globalised issues (Borman et al. 2001; Robbins and Sharp 2003; Ignatieva and Stewart 2009). Lawns represent a highly standardised synanthropic habitat (Müller 1990), and lawns with the highest traditional aesthetic value are those with the lowest species richness. Beyond NW Europe the grasses used in creating lawns may also be non-native, and non-native species of both grasses and forbs, especially those considered to be invasive, are thought to detrimentally influence some native phytophagous insect populations via a variety of mechanisms (Tallamy 2004), although this continues to be an area of considerable debate (Hooper et al. 2005; Thompson 2014).

Since grass-free lawns rely on mowing tolerant clonal plants the choice of British native species is limited by Britain's depauperate flora (Goodwin 1975). This limitation and aesthetic considerations are likely to see non-natives included in grass-free lawn formats, particularly since the use of greater species numbers may help maintain the structural stability of grass-free lawns (Smith and Fellowes 2014a, b, c) and increased plant species diversity may buffer against environmental instability (Isbell et al. 2011). Along with the likely use of non-natives, grass-free lawns also require a mowing regime that suits the novel forb-only format. Earlier work has determined that grass-free lawns can reduce the need for mowing by up to two-thirds when compared to traditional turf lawn management (Smith and Fellowes 2014b), and this reduction in itself may positively influence insect diversity through reduced levels of disturbance (Helden and Leather 2004).

Previous research on the influence of mowing on invertebrate populations has focussed largely on tall grasslands and meadows, with mowing usually applied at no more than three times per annum (Morris and Lakhani 1979; Morris 1981; Humbert et al. 2010). The timing of application and the frequency of mowing were found to be influential on invertebrate populations, and vertical structure also found to influence population size (Morris 2000). Although dependent on the initial structure of the plant community being examined, the land use timescale and the regime applied (Stampfli and Zeiter 1999; Zechmeister et al. 2003), mowing has been repeatedly observed to positively influence plant species richness (Parr and Way 1988; Ryser et al. 1995; Moog et al. 2002), however the diversity of invertebrates is generally found to be negatively influenced by mowing, with a reduction in the number of taxa, and mowing found to increase mortality and deplete resources for grassland invertebrates. In using mowing as a management tool with ecological purpose there is inevitably a trade-off between plant and invertebrate diversity (Fenner and Palmer 1998; Helden and Leather 2004; Cizek et al. 2012).

With the influence that novel grass-free lawn composition and management may have on arthropods unknown the objectives of this study were to (a) describe the insect families found in trial grass-free and turf lawns, and (b) determine if plant species groupings and/or three potential grass-free lawn management regimes influenced insect populations and diversity. This information may prove useful when used to inform decisions on the implementation of grass-free lawns in the future.

Method and materials

Study site

The grass-free lawn management experiment was located the University of Reading, Berkshire, UK (51°26′11.60″N, 0°56′27.60″W) on Hurst 841b soil with a cultivated loamy topsoil (Anon 2011a). The experimental site was bound by adjacent lawn turf (site access point), other native grass-free lawn trials, bare soil and mixed vegetable cultivation. The University's British Grasses Collection was also nearby. A satellite image of the experimental area taken in 2013 and modified to show the site during 2011 is shown in the on-line supplement. All experimental lawn plots were separated by bare soil and continually maintained to be plant-free by hand weeding.

Experimental design

Three plant groupings were used; native, non-native and mixed species. The native group was composed in equal proportions of ten clonal perennial forb species found in managed British grassland including lawns (Anon 2010a, b, 2011b), and the non-native group contained ten clonal perennial species in equal proportions selected from commercially available plants reported to occur in temperate lawns outside the UK. A mixture in equal proportions of all the native and non-native species made up the mixed species group (Table 1). Examples of the three types of grass-free lawns used are shown in the on-line supplement. Turf plots were sourced from a part of the University turf lawn known not to have received any treatment beyond regular mowing for 20+ years and used for comparison. Cover in all turf plots was dominated by grasses (min 60 %) although *Achillea millefolium* L., *Bellis perennis* L., *Taraxacum* sp. and *Trifolium repens* L. were forbs common to all turf plots in varying proportions. Ten other forb species both annual and perennial were also identified in turf, however occurrence was inconsistent between plots and represented by only a few individuals across all plots.

Thirty six 60 cm × 60 cm grass-free plots and twelve turf plots of the same size were used in a six by eight plot grid pattern with plots and treatments spatially randomised. At planting each grass-free plot contained 100 plug plants in a predetermined randomised pattern and were planted out in late October 2010. Due to unusual conditions (early ground frosts) (Anon 2011c), the lifting and subsequent planting of turf plots did not occur until early April 2011. Delayed planting is likely to have retarded the initial growth and height

Table 1 Native and non-native constituent species of trial grass-free lawns

Species	Common name
Native group	
Achillea millefolium	Yarrow
Bellis perennis	Daisy
Pilosella officinarum	Mouse-ear hawkweed
Potentilla reptans	Cinquefoil
Prunella vulgaris	Selfheal
Ranunculus repens	Creeping buttercup
Stellaria graminea	Lesser stitchwort
Trifolium repens	White clover
Veronica chamaedrys	Germander speedwell
Viola odorata	Sweet violet
Non-native group	
Diascia integerrima	Twinspur
Lindernia grandiflora	Blue moneywort
Lobelia angulata	Pratia 'Tredwellii'
Lobelia oligophylla	Hypsela
Lobelia pedunculata	Pratia 'County park'
Mazus reptans	Creeping mazus
Mentha pulegium	Penny royal
Parochetus communis	Blue oxalis
Phuopsis stylosa	Crosswort
Pilosella aurantiaca	Fox and cubs

achieved by plants in turf plots, it will also have introduced disturbance to any initial insect community. However insect sampling commenced 3 months after planting, a period thought sufficient for the influence of the delay to be negligible.

Three mowing treatments were applied to the trial lawns starting late April 2011. A monthly cut that was mown on a calendar basis and cut back to 4 cm in height, a low cut where plots were mown on attaining an overall 3 cm in height and cut back to 2 cm, and a medium cut where plots were mown on attaining 6 cm and cut back to 4 cm. Height was measured using a falling plate meter of 5 g (Barnhart 1998; Rayburn and Lozier 2003). Mowing was applied when the cut height had been reached in 75 % of the grass-free plots in each treatment group using a Bosch Rotak 43Li cordless rotary mower. Arisings were collected by the mower and removed. After mowing plots were edge trimmed back to their original size.

Invertebrate sampling

Starting in the first week of July 2011 sampling was undertaken every 14 days between 10 am and 1 pm using a 'Vortis' insect suction sampler (Burkard Manufacturing Ltd) applied for 10 seconds at each application to four points in each plot that were equidistant from the edge of the plot and from each other. Vortis sampling was used in preference to traps and netting due to the ongoing mowing applied to the lawns. All plots were sampled seven times over the summer period. When inclement weather prevented sampling (two occasions) collections were made on the first subsequent available day. Sampling was undertaken prior to mowing on days that both activities coincided. Samples were initially preserved by freezing on the day of sampling before being later separated, sorted and transferred to 70 % alcohol prior to analysis. Due to the poor condition of the Lepidoptera specimens these remain at an order level classification. With the exception of Coccoidae that was identified to superfamily due to the current uncertainties in taxonomic consensus, all adult insects were identified to family. All specimens were identified using binocular dissecting microscopes (7×–45×), with reference to Insects of Britain & Northern Europe (Chinery 1993) and interactive on-line keys (Dallwitz and Watson 2003 onwards). Diversity was determined using the Shannon Diversity Index (Shannon 2001).

Data Analysis

The response variables analysed were (a) the number of insects, (b) the number of insect families, (c) the diversity of insects, and (d) these three variables within the four most abundant orders. The experimental and sampling design were highly standardised and sample means were relatively large, this allowed for data to be analysed using General Linear Model ANOVA (Minitab 2012). Data was Log transformed as necessary to meet the assumptions of the terms, except when comparing Shannon diversity where a Johnson SU transformation was applied to normalise the data. On the second sampling date an ant nest in one mixed group 2 cm cut plot was apparent, 145 individuals were collected from one plot skewing an otherwise normal distribution. For the purposes of analysis this plot was treated as a plot where ants were present and given a nominal value of one individual. *Post hoc* Tukey tests were applied to identify significant differences within analysed groups. Sørensen's quotient of Similarity was calculated for families using $Qs = \frac{2c}{a+b}$ (Sørensen 1948), where a = total number of species in sample set one, b = total number of species in sample set two, and c = the number of species common to both sample sets.

Results

During the sampling period all monthly cut lawns were mown three times and all 2 and 4 cm cut lawns were mown four times each, by comparison the nearby University lawn was mown eleven times during the same period. A total of 8,912 adult insects across eight orders were collected, comprising 2,026 Diptera, 1,583 Hemiptera, 2,814 Coleoptera, 2,429 Hymenoptera, 6 Lepidoptera, 46 Thysanoptera, 7 Dermaptera, and 1 Neuroptera. Within order insect families are shown in Table 2. Inclusive of Lepidoptera and Coccoidae as representative of one family each, a total of 71 families were identified, 58 families were found in native lawns, 55 in mixed lawns, 47 in non-native lawns and 54 in turf. Also collected were 1,825 non-adult insect forms including nymphs, juveniles and pupae across all orders listed, including one Orthopteran nymph.

The number of all individual insects, the number of insect families and insect diversity found in lawns was significantly influenced by lawn composition and by mowing regime (Table 3), an interaction between composition and mowing regime was only apparent in Diptera, with monthly cut mixed and native grass-free lawns containing substantially greater numbers of individuals. Overall the number of adult insects found in lawns was significantly greater in native and mixed species grass-free lawns than in either turf or non-native lawns. Non-native lawns contained the fewest insects. Insect numbers were found to

Table 2 Insect families within order showing percentage occurrence in trial lawns by type

Order	Family	Lawn type				Order	Family	Lawn type			
		Native	Mixed	Non-native	Turf			Native	Mixed	Non-native	Turf
Diptera	Agromyzidae	18	15	8	26	Hymenoptera	Apidae	1	0	0	0
	Anthomyiidae	0	1	0	0		Bethylidae	5	4	1	0
	Bibionidae	1	2	1	1		Braconidae	80	81	45	79
	Calliphoridae	0	0	0	1		Ceraphronidae	10	4	2	2
	Camillidae	25	20	7	14		Cynipidae	11	15	7	19
	Cecidomyiidae	35	30	23	55		Diapriidae	25	21	20	31
	Chloropidae	10	8	1	27		Dryinidae	0	0	1	2
	Diastatidae	1	1	1	0		Encyrtidae	12	14	4	7
	Dolichopodidae	1	0	0	0		Eulophidae	20	20	10	30
	Drosophilidae	49	39	18	17		Eurytomidae	0	0	0	6
	Empididae	5	6	4	1		Formicoidae	60	60	45	58
	Ephydridae	18	8	5	6		Ichneumonidae	19	17	4	5
	Heleomyzidae	4	4	2	6		Mymaridae	33	29	15	18
	Lonchopteridae	50	43	13	23		Platygastridae	23	33	15	30
	Otitidae	2	0	0	0		Proctotrupidae	7	6	2	10
	Phoridae	19	12	10	24		Pteromalidae	19	17	4	31
	Psilidae	5	1	0	0		Torymidae	0	0	1	0
	Sarcophagidae	2	0	0	0		Vespidae	0	1	0	0
	Sciaridae	51	51	26	49						
	Sepsidae	1	1	1	0						
	Sphaeroceridae	60	71	52	55						
	Tipulidae	0	0	0	1	Lepidoptera	–	2	1	0	2

Table 2 continued

Order	Family	Lawn type				Order	Family	Lawn type			
		Native	Mixed	Non-native	Turf			Native	Mixed	Non-native	Turf
Neuroptera	Hemerobiidae	1	0	0	0	Thysanoptera	Phlaeothripidae	6	7	4	23
Dermaptera	Forficulidae	4	2	2	0		Thripidae	0	1	0	4

Order	Family	Lawn type			
		Native	Mixed	Non-native	Turf
Coleoptera	Anobiidae	1	1	0	2
	Brentidae	39	45	6	10
	Byrrhidae	0	0	1	2
	Carabidae	11	18	15	12
	Chrysomelidae	95	90	67	50
	Coccinellidae	2	5	2	6
	Cryptophagidae	1	1	0	0
	Curculionidae	69	75	44	42
	Dytiscidae	0	0	0	1
	Hydrophilidae	4	8	0	7
	Latridiidae	5	5	4	2
	Nitidulidae	4	4	0	1
	Ptiliidae	19	26	27	17
	Staphylinidae	60	52	43	90

Table 2 continued

Order	Family	Lawn type			
		Native	Mixed	Non-native	Turf
Hemiptera	Anthocoridae	5	5	1	1
	Aphididae	74	73	68	81
	Cicadellidae	30	32	31	49
	Coccoidae	27	25	19	8
	Delphacidae	4	2	1	33
	Lygaeidae	4	1	0	1
	Miridae	7	7	2	0
	Nabidae	0	1	0	0
	Piesmatidae	1	0	0	0
	Psyllidae	0	0	0	4
	Tingidae	0	0	0	17
	Triozidae	1	0	0	1

Coccoidae is a superfamily and Lepidoptera families are omitted be greatest in monthly mown lawns and least in lawns cut to 2 cm (Fig. 1A). This distinct pattern was repeated across the four largest orders of insects found in lawns (Diptera, Hemiptera, Coleoptera and Hymenoptera), although there was no difference in Hymenoptera numbers in 2 and 4 cm cut non-native lawns.

There was no significant difference in the number of insect families found in native, mixed species and turf lawns. Six families of insect were exclusively found in native grass-free lawns, three in mixed species grass-free lawns and six in turf (Table 2), although over half of these unique families were represented by one occurrence only in lawns. The smallest number of families was found in non-native lawns (Fig. 1B), where there was one occurrence of one exclusive family (Torymidae). Overall there was no significant difference on the number of families found in monthly and 4 cm cut lawns. Two cm cut lawns always had the fewest families and this pattern was consistently replicated within the four largest orders.

A significantly lower level of overall insect diversity was found in non-native lawns, and lawns cut to 2 cm, all other lawn types and mowing regimes contained similar levels of overall diversity (Fig. 1C). However within order diversity varied dependent on composition and mowing regime. Diversity was consistently lower in non-native lawns in all of the four largest orders. Diversity in Diptera and Coleoptera was greatest in mixed and native grass-free lawns and in Hymenoptera there was no difference between mixed and native grass-free lawns and turf. Hemiptera were significantly more diverse in turf, particularly when monthly cut, but showed no difference between 2 and 4 cm cuts. Monthly and 4 cm mowing regimes contained similar levels of diversity in Coleoptera and Hymenoptera, and Diptera diversity closely followed the intensity of mowing with monthly cuts containing the greatest and 2 cm cuts the least.

Both native and mixed grass-free lawns shared 45 insect families with turf, however the total number of unshared families also showed that native and mixed grass-free lawns and turf are also the two most dissimilar (Table 4). Of the four lawn types native and mixed grass-free lawns were the most similar, sharing the most families and having the least number of different families between them.

Discussion

When managed in the same way both insect number and diversity in grass-free lawns and turf lawns were found to be directly influenced by both the lawn type and the mowing regime applied (Table 3). In common with previous studies (Samways et al. 1996; Keane and Crawley 2002; Tallamy et al. 2010), the exclusive use of non-native forbs was found to poorly contribute to local insect abundance or diversity when compared to the inclusive use of native forbs or turf (Fig. 1), and only one unique family was identified (Table 2). However, since turf is traditionally mown more frequently than was used in this investigation there is scope for further study in this area.

The composition of the local vegetation is also likely to have influenced the acquisition of insect families by all lawn types (Andow 1991; Agrawal et al. 2006). This may have been advantageous to turf lawns and lawns with native components rather than non-native lawns, since the local landscape turf was the source of the experimental turf lawns and was observed to include of six of the trial native forb species; *A. millefolium, B. perennis, P. vulgaris, R. repens, T. repens* and *V. odorata*.

In addition to the relatively low number of individuals and diversity found in non-native lawns, all lawn types cut to 2 cm also consistently had fewer insects, fewer families and

Table 3 Results of ANOVA showing influence of lawn type and mowing regime on the number of individual adult insects, insect families and insect diversity; test statistic (*F* values) and significance (*P* values) shown

		All insects	Diptera	Hemiptera	Coleoptera	Hymenoptera
Number of adult insects	Lawn type	$P < 0.001$ $F_{3,47} = 28.65$	$P < 0.001$ $F_{3,47} = 27.46$	$P = 0.006$ $F_{3,47} = 4.89$	$P < 0.001$ $F_{3,47} = 31.54$	$P < 0.001$ $F_{3,47} = 9.16$
	Mowing regime	$P < 0.001$ $F_{2,47} = 60.18$	$P < 0.001$ $F_{2,47} = 36.55$	$P < 0.001$ $F_{2,47} = 28.06$	$P < 0.001$ $F_{2,47} = 56.7$	$P = 0.002$ $F_{2,47} = 7.42$
Insect families	Lawn type	$P < 0.001$ $F_{3,47} = 31.31$	$P < 0.001$ $F_{3,47} = 24.7$	$P < 0.001$ $F_{3,47} = 7.03$	$P < 0.001$ $F_{3,47} = 23.37$	$P < 0.001$ $F_{3,47} = 17.57$
	Mowing regime	$P < 0.001$ $F_{2,47} = 42.64$	$P < 0.001$ $F_{2,47} = 17.85$	$P < 0.001$ $F_{2,47} = 9.05$	$P < 0.001$ $F_{2,47} = 22.88$	$P = 0.001$ $F_{2,47} = 8.96$
Shannon diversity	Lawn type	$P < 0.001$ $F_{3,47} = 22.65$	$P < 0.001$ $F_{3,47} = 32.43$	$P < 0.001$ $F_{3,47} = 11.03$	$P < 0.001$ $F_{3,47} = 13.6$	$P < 0.001$ $F_{3,47} = 19.0$
	Mowing regime	$P < 0.001$ $F_{2,47} = 14.61$	$P < 0.001$ $F_{2,47} = 16.52$	$P = 0.001$ $F_{2,47} = 8.87$	$P < 0.001$ $F_{2,47} = 14.0$	$P = 0.014$ $F_{2,47} = 4.79$

The four largest orders of insects found in lawns are shown individually

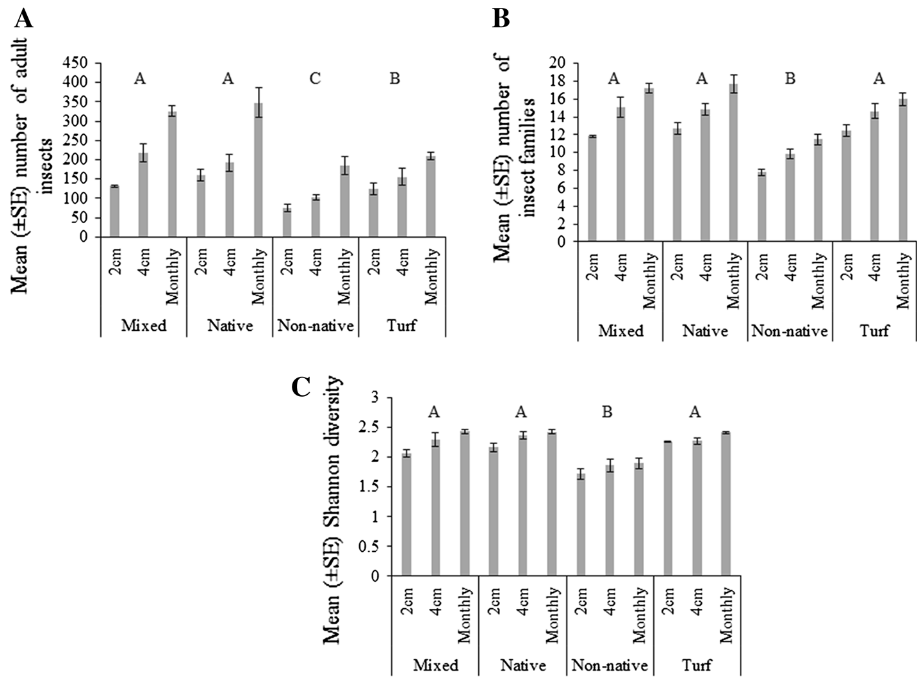

Fig. 1 **A** Mean (±SE) number of adult insects, **B** Insect families and **C** Shannon diversity of insect families, found in trial lawns by type. Lawn types that do not share a letter are significantly different

Table 4 Sørensen quotient of similarity for insect families between lawns by type

Lawn type	Native	Mixed	Non-native	Turf
Native	–	0.902	0.838	0.803
Mixed	0.902	–	0.862	0.825
Non-native	0.838	0.862	–	0.811
Turf	0.803	0.825	0.811	–

lower levels of insect diversity when compared to the other mowing regimes applied to lawns of the same type (Fig. 1). This suggests that both the non-native only lawn format and the 2 cm mowing regime are the least effective management conditions when aiming for the highest levels of lawn insect population and diversity.

The greatest abundance of insects and the highest level of diversity was found in monthly mown lawns of all types; these were the least frequently mown and resulted in the tallest vegetation. This finding agrees with earlier grassland studies where tall vegetation is found to provide greater resource opportunities (Morris 1981, 2000), however from a practical perspective monthly cutting does not seem likely to be an appropriate mowing regime since grass-free lawns are principally designed with specific aesthetic considerations and outcomes in mind. Mowing monthly may, depending on the environmental conditions, be either too frequent or too infrequent, it also does not take into consideration the overall appearance of the lawn which is a key factor for an aesthetic construct. The most aesthetically useful mowing regime has been shown to be a 4 cm cut, with the best outcomes likely if mowing is applied when any part of the lawn reaches approximately 9 cm rather than the 6 cm responsive cut applied here (Smith and Fellowes 2014a, b). This regime may potentially reduce the need for mowing even further and if it does so seems likely, on the basis of these results, to influence both insect abundance and diversity in a positive manner.

The mean Shannon diversity of insect families within the experimental 4 cm cut regime in both native and mixed grass-free lawns and turf was not found to be significantly different and neither were the total numbers of insects. This suggests that while the identity of many of the individual families may vary with lawn type, that all of the three lawn types may produce similar levels of family diversity and insect abundance when mown in this way.

Although all lawns had insect families in common, there were also clear dissimilarities between lawns with some families occurring more frequently within lawn types, particularly turf, e.g., Chloropidae, Phlaeothripidae, and Tingidae (Table 2). This seems to be an indication of the particular feeding niches of individual families and characterises the different lawn type insect assemblages (Schaffers et al. 2008). Using Sørensen's quotient of similarity (Sørensen 1948) where higher values indicate greater similarity, the greatest dissimilarity amongst lawns was found between native grass-free lawn and turf, and the greatest similarity found between native and mixed grass-free lawns (Table 4). This differentiation between both native and mixed forbs and turf has implications for the use of grass-free lawns in the wider urban landscape, particularly where intensively managed grass based lawns currently dominate and diversity maybe low.

Since for aesthetic purposes turf lawns are mown more frequently than is required by the grass-free format, it is unlikely that the reduced frequency of a grass-free mowing regime will be applied to them. This immediately increases the likelihood that less frequently mown grass-free lawns will contain a greater abundance of insects, which would be beneficial to parasitoids and to higher tropic level insectivorous predators such as birds, and contain both richer and more diverse insect assemblages than their turf counterparts and therefore act to increase diversity within an often intensively managed environment of low biodiversity value. When the composition of grass-free lawns includes native clonal perennial forbs they are seen to be sufficiently different from turf lawns to provide feeding niches for differing insect assemblages and in so doing increase overall diversity (gamma) and contribute to the beta diversity in urban greenspace (Sattler et al. 2011). However, the small scale addition of native plants alone to urban gardens has been shown to be insufficient to increase beneficial insect richness (Matteson and Langellotto 2011), larger scale additions are thought to be more useful, particularly if they include the use of non-natives to extend the seasonal availability of pollen and nectar resources. Here the scale and use of lawns that has previously proved to be problematic in managing biodiversity may prove to be advantageous.

Additional research on the grass-free lawn format has indicated that in part due to local environmental suitability that best aesthetic outcomes can occur in plant species rich grass-free lawns that contain mostly (but not exclusively) natives, and that a 4 cm mowing regime helps maintain plant diversity (Smith and Fellowes 2014a), a feature important in maintaining ecosystem service (Isbell et al. 2011). Both of these management features are ornamentally and aesthetically relevant, concur with the diversity outcomes identified and improve the usual trade-off between plant and insect diversity. This new development in environmental horticulture is both relevant and timely and has the potential to be a useful management tool in improving the biodiversity of urban lawnscapes.

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