Urban Forestry & Urban Greening 13 (2014) 433–442

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

The grass-free lawn: Management and species choice for optimum ground cover and plant diversity

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ARTICLE INFO

Keywords:
Garden
Grass-free
Lawn
Mowing
Ornamental horticulture

ABSTRACT

In Britain, managed grass lawns provide the most traditional and widespread of garden and landscape practices in use today. Grass lawns are coming under increasing challenge as they tend to support a low level of biodiversity and can require substantial additional inputs to maintain. Here we apply a novel approach to the traditional monocultural lawnscape by replacing grasses entirely with clonal perennial forbs. We monitored changes in plant coverage and species composition over a two year period and here we report the results of a study comparing plant origin (native, non-native and mixed) and mowing regime. This allows us to assess the viability of this construct as an alternative to traditional grass lawns. Grass-free lawns provided a similar level of plant cover to grass lawns. Both the mowing regime and the combination of species used affected this outcome, with native plant species seen to have the highest survival rates, and mowing at 4 cm to produce the greatest amount of ground coverage and plant species diversity within grass-free lawns. Grass-free lawns required over 50 percent less mowing than a traditionally managed grass lawn. Observations suggest that plant forms that exhibited: (a) a relatively fast growth rate, (b) a relatively large individual leaf area, and (c) an average leaf height substantially above the cut to be applied, were unsuitable for use in grass-free lawns. With an equivalent level of ground coverage to grass lawns, increased plant diversity and a reduced need for mowing, the grass-free lawn can be seen as a species diverse, lower input and potentially highly ornamental alternative to the traditional lawn format.

Introduction

For some time the traditional lawn has presented something of a modern day dilemma to those with an interest in the urban landscape. On the one hand the traditional grass lawn contributes substantially to urban green space, a feature increasing seen as valuable to human wellbeing (Tzoulas et al., 2007), and in the socio-economics of the city, lawns are 'consumed' indirectly through their aesthetic appeal and their influence on personal viewpoints and property values (Robbins et al., 2001). On the other hand the grass lawn can be viewed as a biodiversity poor monoculture that displaces indigenous landscape biota and requires large subsidies of chemicals and energy to maintain (Borman et al., 2001; Robbins and Sharp, 2003b; Robbins, 2007), with a deleterious influence in terms of run-off and emissions that may extend considerably beyond its immediate physical location (Schueler, 2000; Robbins and Sharp, 2003a).

This has led to lawn alternatives being promoted as a solution to some of the negative environmental aspects of lawn maintenance (Henderson et al., 1998), particularly in Europe and North America where much of the research on suburban garden lawns has been based. Solutions within private gardens that do not see the complete removal of the lawn in favour of a hard surface have been largely focussed around reducing management intensity and lawn size, replacing it with a mixture of ground covers, shrubs and trees (particularly native species), and allowing for a more meadow-like appearance in remaining lawn covered areas (Daniels, 1995; Scott et al., 1998; Hadden, 2012). In locations beyond NW Europe where grass lawns are sometimes seen as symptomatic of homogenisation and globalisation in urban horticulture, these practices may additionally include the use of indigenous grasses, including other native plant species more suited to local conditions and that require fewer inputs to maintain (Stewart et al., 2009; Simmons et al., 2011; Ignatieva, 2011). Nevertheless, efforts to promote these types of lawn alternatives have not resulted in significant levels of change (Henderson et al., 1998; Feagan and Ripmeester, 1999; Piekielek, 2003). The traditional grass lawn still dominates the urban and suburban landscapes of Canada and America (Vinlovea and Torlaa, 1994; Milesia et al., 2005), and it remains integral to

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http://dx.doi.org/10.1016/j.ufug.2014.04.008
1618-8667/

the British garden, where up to 60% of gardens contain a lawn of some description (Gaston et al., 2005).

A new type of ecological aesthetic has been called for, whereby what looks good is that which does not have negative ecological consequences (Koh, 1988; Robbins et al., 2001). This allows for any landscape that preserves or enhances biodiversity, reduces pollution and the need for additional inputs to be seen as good-looking no matter what its actual appearance may be, yet there is a very low correlation between implementing lawn alternatives and a homeowner's ecological motivations (Purchase, 1997). Clearly the ecological aesthetic does not fulfil the requirements made of the urban lawn, but it does make clear that aesthetics have an important role to play in the relationship between socio-cultural and ecological systems (Picket et al., 2001; Byrne, 2005).

Gardeners may hold the key to unlocking at least part of the dichotomy posed by the lawn, but this seems only likely if they can be persuaded by an acceptable aesthetic that sufficiently maintains some of the traditional characteristics of a lawn and contains easily recognised cues to care, while also incorporating within it an ecological motivation (Nassauer, 1993). Some direct lawn alternatives have been in limited use for some time; chamomile and thyme lawns are traditional British examples (see Smith & Fellowes, 2013 for a review). However the simple replacement of one monoculture by another has not caught the imagination of gardeners at large; nor have they been shown to demonstrate any specific ecological advantage.

There is an opportunity for a lawn format that combines both an environmentally friendly motivation, easily recognised cues to care and is aesthetically pleasing and desirable. We propose that one way to achieve this is to remove both the monoculture and the grass from the lawn. A grass-free polyculture of diverse plant species which can survive and reproduce under the traditional lawn management practice of mowing has yet to be tried as a grass lawn alternative (Smith and Fellowes, 2013). Such a construct would retain traditional cues to care in that it would show the presence of human intention and represent a carefully species selected and managed garden feature; additionally it would also contain within it an ecological motivation, bringing with it an immediate increase in plant diversity and its concomitant insect and animal life. It would go some way to fulfilling the requirement highlighted by Nassauer for a method of improving the ecological quality of urban design, while maintaining the traditional aesthetics of prominent mown areas (Nassauer, 1993). Furthermore, it has the potential to be very visually appealing and be a feature that gardeners may see as highly desirable, since it can bring both flowers and diverse foliage forms to an area of a garden that traditionally would be managed to be a monochrome green.

To ensure sufficient longevity of a grass-free construct, perennial species that display the clonal characteristics of rhizomes, stolons or adventitious roots make a logical choice, particularly since mowing limits opportunities for propagation by seed (Schmid, 1985). For British gardens in particular, it is reasonable to hypothesise that British native species of this type are most likely to be competitively superior to non-natives since they are well adapted to UK conditions.

The aim of this study was to see if such a construct would remain structurally and perennially robust, what species to use, and in what proportions; as well as how often to cut grass-free lawns, what height they should be cut at, if natives would outperform non-natives, and how these factors might influence floral performance. To address these questions we have used three trial groupings of clonal perennial forbs, a native species group, a non-native group and a group of mixed origin. Three mowing regimes selected to be representative of common practice in mowing were applied and comparison made with grass lawns treated in the same manner. The only inputs subsequent to completed planting of the lawns were the application of mowing as required and edge-trimming of lawns to maintain a constant shape and size.

Materials and methods

Study site

The experiment was set up in October 2010 in the Biological Sciences experimental grounds of the University of Reading, Whiteknights Park, Reading, Berkshire, UK (51°26′11.60″ N, 0°56′27.60″ W). The grounds have an open aspect, and are on Hurst 841b soil with a cultivated loamy topsoil (Anon., 2011a). The site has a history of cultivation with Beet, Turnip and *Coreopsis* being grown between 2007 and 2009. It also contains a thriving population of locally common weed species associated with cultivated soil, particularly small nettle (*Urtica urens*), annual meadow grass (*Poa annua*), cudweed (*Gnaphalium uliginosum*), purslane (*Portulaca oleracea*) and groundsel (*Senecio vulgaris*). To reduce weed coverage glyphosate was applied in April 2010 in a 10 ml/l formulation. As the site had been subject to heavy compaction through footfall, it was rotovated to a depth of 0.2 m in June and subsequently had a second glyphosate application in August 2010. These treatments reflect the relatively poor condition of the study site rather than *a priori* predicted requirements for successful planting of the grass-free lawn.

Experimental design

Three trial groups were created from clonal grassland species deemed likely to survive and propagate under the influence of mowing; a native species group, a non-native species group and a mixed species group that contained a mixture in even proportions of all the native and non-native species used. The native group contained native, clonal perennial forb species commonly found throughout the British Isles in managed grasslands, including lawns (Anon., 2010a,b, 2011b). The non-native group was composed in equal proportions of 10 non-native clonal perennial forbs that were sourced on the basis of commercial availability (Table 1). The non-native group represented a compromise in obtaining specific species and/or forms of non-natives that have been reported or observed as growing in lawn type environments. The non-native group included *Mentha pulegium* L. a species at the edge of its range in the UK and where its non-native status is uncertain (Anon., 2010b).

The experimental layout consisted of thirty six 60 cm × 60 cm randomised plots. Each plot contained one of the three plant groups, with plants laid out in a randomised pattern that had been predetermined before planting. Plots had been randomised to account for variations in soil and microclimate. Each individual plot contained 100 plants respectively that had been grown in advance from cuttings where possible and from seed where this was not practicable. Young plants were potted on into 6 cm plugs in September 2010 and grown on in John Innes #2 formula loam-based potting compost for later transplanting.

Before planting each plot had the top 6 cm of soil and any large stones removed. The plug plants were put in place and any gap between plugs was filled in with loose soil from the plot. Plots were hand watered to soil saturation on completion of planting. Following common domestic lawn management practice in the UK, no additional watering was applied at any time after planting.

In April 2011 for comparison of the behaviour of the grass-free plots to an established grass lawn, a further 12 grass plots were added. These were sourced from a part of the University lawn known not to have received any treatment beyond regular mowing for 20+ years. Grass plots were subsequently treated in the same

Table 1
Plant species used and their groups with floral period and characteristics.

NATIVE GROUP			Floral Period														
Species	Common Name	Locale/Origin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Habit	Leaf	Flower
Achillea millefolium	Yarrow	Widespread UK						Dark	Dark	Dark	Dark	Dark	Dark		Semi-erect	Evergreen	White
Bellis perennis	Daisy	Widespread UK	Pale	Pale	Pale	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Rosette	Evergreen	White
Pilosella officinarum	Mouse Ear Hawkweed	Widespread UK					Dark	Dark	Dark	Dark	Dark				Creeping	Evergreen	Yellow
Potentilla reptans	Cinquefoil	Widespread UK						Pale	Dark	Dark	Dark				Creeping	Evergreen	Yellow
Prunella vulgaris	Selfheal	Widespread UK						Dark	Dark	Dark	Dark				Semi-erect	Evergreen*	Violet
Ranunculus repens	Creeping Buttercup	Widespread UK				Pale	Dark	Dark	Dark	Dark	Dark	Dark			Creeping	Evergreen	Yellow
Stellaria graminea	Lesser Stitchwort	Widespread UK					Dark	Dark	Dark	Dark					Semi-erect	Evergreen	White
Trifolium repens	White Clover	Widespread UK					Pale	Dark	Dark	Dark					Creeping	Evergreen*	White
Veronica chamaedrys	Germander Speedwell	Widespread UK			Dark	Dark	Dark	Dark	Dark						Decumbent	Evergreen	Blue
Viola odorata	Sweet Violet	Widespread UK		Pale	Dark	Dark	Dark								Creeping	Evergreen	Violet
NON-NATIVE GROUP																	
Species	Common Name	Locale/Origin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Habit	Leaf	Flower
Diasica integerrima	Twinspur	S. Africa						Pale	Pale	Pale	Pale	Pale	Pale	Pale	Semi-erect	Semi-evergre	Pink
Pilosella aurantiaca	Fox & Cubs	Europe					Pale	Pale	Pale	Pale	Pale	Pale	Pale	Pale	Creeping	Evergreen	Orange
Lindernia grandiflora	Blue Moneywort	SE. North America					Pale	Pale	Pale	Pale	Pale	Pale	Pale		Prostrate	Evergreen*	Violet
Lobelia angulata	Pratia 'Tredwellii'	New Zealand					Pale	Pale	Pale	Pale	Pale	Pale	Pale	Pale	Prostrate	Evergreen*	White
Lobelia oligophylla	Hypsela	Andean S. America					Pale	Pale	Pale	Pale	Pale	Pale	Pale		Prostrate	Evergreen*	Pink
Lobelia pedunculata	Pratia 'County Park'	Australia					Pale	Pale	Pale	Pale	Pale	Pale	Pale	Pale	Prostrate	Evergreen	Blue
Mazus reptans	Creeping Mazus	Himalayas				Pale	Pale	Pale	Pale	Pale		Pale	Pale		Rostellate	Evergreen	Violet
Mentha pulegium	Penny Royal	Europe (UK)						Pale	Pale	Dark	Dark	Pale	Pale	Pale	Semi-erect	Evergreen	Violet
Parochetus communis	Blue Oxalis	S. Africa/Himalayas				Pale	Pale	Pale				Pale	Pale	Pale	Creeping	Evergreen*	Blue
Phuopsis stylosa	Crosswort	Europe						Pale	Pale	Pale	Pale	Pale	Pale		Semi-erect	Evergreen	Pink

* May be deciduous below 0˚C

Floral period: http://www.ecoflora.co.uk (Published data shown as: Dark shading. Observed data: Pale shading.)

Accepted species names (2012): http://www.theplantlist.org/

manner as the grass-free plots. Temperature at ground level on the plots was continually recorded using a Tinytag Extra TGX-3580 data logger.

Method

Each of the plant groups had three treatments continuously applied starting in April 2011. Treatment one was a monthly mowing to 4 cm in height, applied, weather depending, on the same day each month irrespective of the height the plot. This was deemed the minimum frequency of cutting a lawn might expect and to be suitable as a reference treatment, since growth beyond a month is likely to produce a low meadow-like appearance rather than a lawn (Thompson et al., 2004). Two further mowing treatments were implemented based on how lawns are cut in response to the increasing height of a lawn. Treatment two was a low cut, where plots were mown on attaining an overall 3 cm in height and cut back to 2 cm, and treatment three a medium cut, where plots were mown on attaining 6 cm in height and cut back to 4 cm. Height was measured using a falling plate meter of 5 g (Barnhart, 1998; Rayburn and Lozier, 2003). These two responsively cut treatments were designed to remove approximately the top 1⁄3 of the plant material in each plot so as to maintain the viability of the plants being cut (Jacques and Edmond, 1952; Crider, 1955).

Mowing was initiated when 75% of plots in each group had attained the designated cutting height and was applied using a Bosch Rotak 43Li cordless rotary mower beginning in April 2011. Biomass was collected by the mower and removed and dried for a minimum of four days at 70 °C. After mowing plots were edge trimmed back to their original size. Species presence based on original planting position was recorded five days after the initial cut in April 2011 using a fixed point clear acrylic quadrat and recorded again in the same manner in October 2011. Five days was deemed a sufficient recovery period subsequent to mowing. This process was repeated in March 2012 and again in October 2012 in response to the start and finish of seasonal growth. In addition flower number by species was recorded in each plot before each application of mowing. Both biomass and flower number data were collected for later additional analysis.

Data analysis

To identify any influence of the species groupings and treatments on individual component species within plots, comparisons of treatments were made using a general linear model with repeated measures ANOVA in MINITAB (Minitab, 2012). Where data sets did not follow a normal distribution prior to ANOVA data was transformed using either log(n + 1), sin or arcsine square root transformations to meet the assumptions of the terms. Interactions were analysed using a *post hoc* Tukey test. Changes to proportional cover of species and bare soil found in lawns in November 2012 used a two-way ANOVA based on original planting groups for grass-free lawns and a one-way ANOVA for grass lawns. To correct for multiple comparisons (*i.e.* to reduce the likelihood of Type I errors) a Bonferroni correction was applied, where P = 0.0042 was considered the significance threshold.

Results

Establishment

The first ground frost on the plots occurred one day after planting on 26 October 2010. A second ground frost occurred three weeks later and was followed by the coldest December for 100 years (Anon., 2011c). The lowest recorded air temperature above the experimental plots between planting in October and the first application of mowing in April 2011 was −10.5 °C.

Table 2
Change in mean (±SE) proportional cover by species in all three trial groups between Oct 2010 and April 2011.

Species	Mixed group	Native group	Non-native group
Achillea millefolium	+0.56 (0.05)	+0.30 (0.01)	na
Bellis perennis	+0.01 (0.02)	−0.04 (0.01)	na
Diascia integerrima	−0.09 (0.00)	na	−0.05 (0.01)
Lindernia grandiflora	−0.10 (0.00)	na	−0.10 (0.00)
Lobelia angulata	−0.09 (0.01)	na	−0.07 (0.02)
Lobelia oligophylla	−0.10 (0.00)	na	−0.10 (0.00)
Lobelia pedunculata	−0.10 (0.00)	na	−0.10 (0.00)
Mazus reptans	−0.06 (0.01)	na	−0.01 (0.01)
Mentha pulegium	−0.02 (0.01)	na	+0.24 (0.01)
Parochetus communis	−0.09 (0.00)	na	−0.03 (0.01)
Phuopsis stylosa	−0.04 (0.01)	na	+0.07 (0.02)
Pilosella aurantiaca	−0.06 (0.01)	na	+0.09 (0.02)
Pilosella officinarum	−0.07 (0.01)	−0.09 (0.00)	na
Potentilla reptans	−0.06 (0.01)	−0.07 (0.00)	na
Prunella vulgaris	−0.03 (0.01)	−0.07 (0.01)	na
Ranunculus repens	+0.04 (0.02)	−0.01 (0.01)	na
Stellaria graminea	0.00 (0.02)	−0.06 (0.01)	na
Trifolium repens	+0.43 (0.03)	+0.22 (0.02)	na
Veronica chamaedrys	−0.07 (0.01)	−0.09 (0.00)	na
Viola odorata	−0.09 (0.00)	−0.09 (0.00)	na
Bare soil	+0.01 (0.00)	0.00 (0.00)	+0.06 (0.01)

Effect of winter

In April 2011 all plots were surveyed to determine changes in plant cover that had occurred over the winter period (Table 2). In the mixed group all non-native species had substantially reduced cover, with two species *Lindernia grandiflora* (Nutt.) and *Lobelia oligophylla* (Wedd.) found to be extinct. The winter growth of native species in the mixed group acted to compensate for the loss of non-native species cover with total mean coverage remaining above 98%. Native species *Achillea millefolium* L. and *Trifolium repens* L. clearly showed winter growth within the mixed group and had both increased cover by more than 400% respectively. Winter growth was also observed in the native group, where both *Achillea* and *Trifolium* showed an increase in cover, both by over 200%. The same high level of overall winter cover seen in the mixed group was also maintained in the native group. In the non-native group cover was reduced for all but three species, *M. pulegium*, *Pilosella aurantiaca* L. and *Phuopsis stylosa* (Trin.); each increased in cover by more than 60%. The amount of bare soil, which has an influence on first season lawn aesthetics, was significantly higher in the non-native group (Fig. 3) compared to both mixed and native groups (Figs. 1 and 2), which were not seen to be significantly different from each other ($F_{2,35}$ = 27.94, P < 0.001).

Frequency of mowing

In 2011 monthly cut lawns required mowing eight times each and (although at different times) both the 2 cm and 4 cm lawns each required mowing nine times. In 2012 monthly cut lawns required mowing seven times each and (again with different timings) both the 4 cm and 2 cm lawns each required mowing eleven times. By comparison, over the same period the University turf lawn adjacent to the experimental ground was mown by grounds maintenance staff a total of 29 times in 2011 and 26 times in 2012.

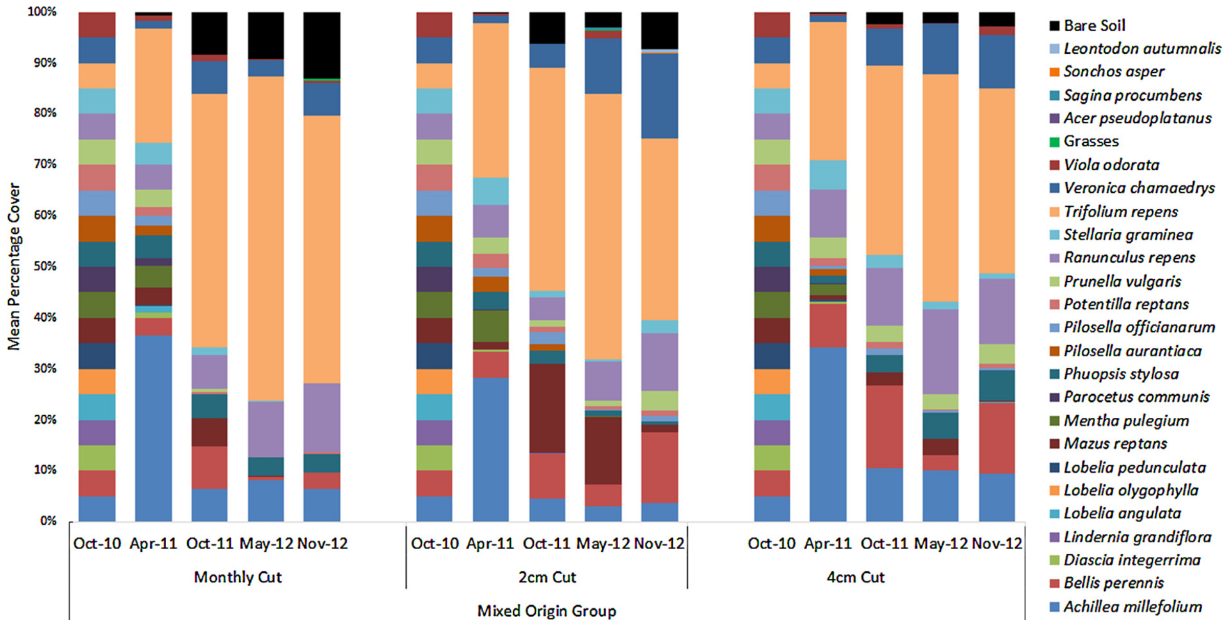

Fig. 1. Mean change in cover by species in the mixed origin group between Oct 2010 and Nov 2012.

Influence of group and cut

Individual species response to the group and the treatment was seen to vary with species (Table 3). In April 2011 after the initial winter period, the composition of the mixed group was seen to have changed, with a reduced number of non-native species (Fig. 1). With the exception of *Mazus reptans* (N.E.Br.) and *Diascia integerrima* (E. May.), all the non-native species that had become extinct or had coverage reduced to 2% or less in mixed species lawns were also seen to lose cover in the non-native group. Subsequently the structural behaviour over time of the mixed group had strong similarities to the native group (Fig. 2). The winter period reduction in species number in the mixed group meant it was not possible to clearly determine the influence that species number might have on the behaviour within groups. The dominant species in both the mixed and native groups was *T. repens* L. and its proportional cover was not significantly different within treatments in either group. The composite structuring over time of both the mixed and native groups to the mowing treatments applied showed strong similarities. Although individual species showed differing and sometimes significantly different amounts of cover within the mixed and native groups and within the treatments over time, the overall pattern of behaviour remained similar for the duration of the experiment. This was particularly evident at the conclusion of the experiment in November 2012. The non-native group lost most of its original species over time under all treatments. The individual species cover produced by the three remaining original species *Mazus, P. aurantiaca* and *Phuopsis* was seen to vary in response to the different treatments. Although there were small individual species variations within treatments, the composite structure

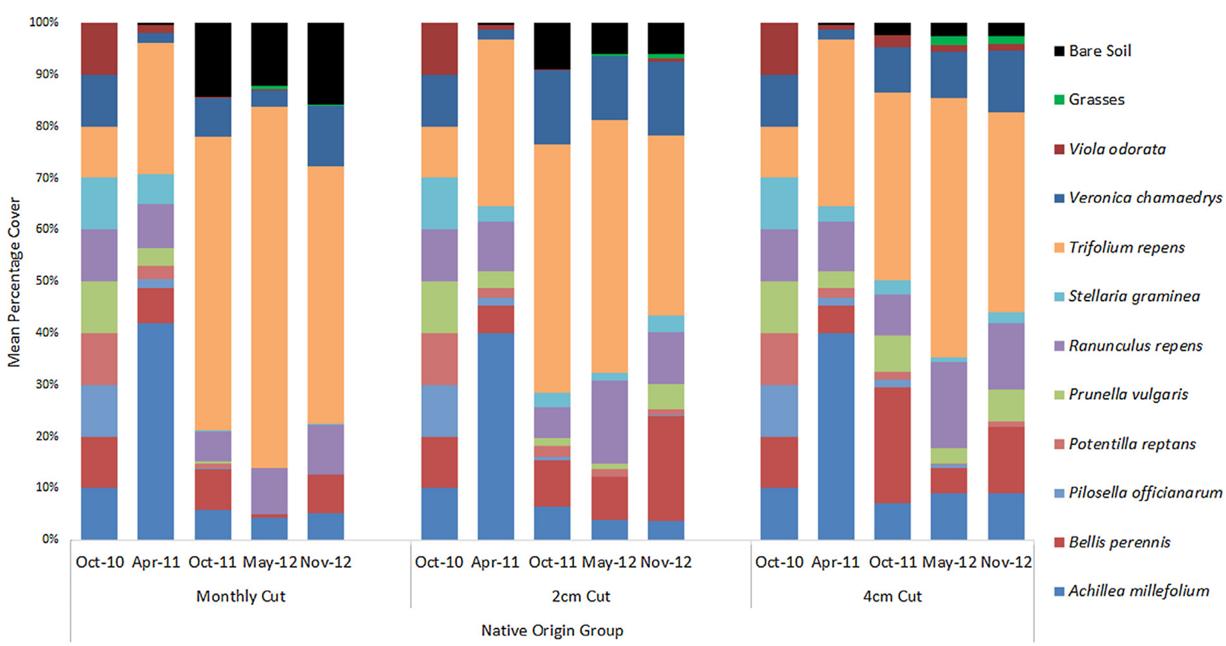

Fig. 2. Mean change in cover by species in the native origin group between Oct 2010 and Nov 2012.

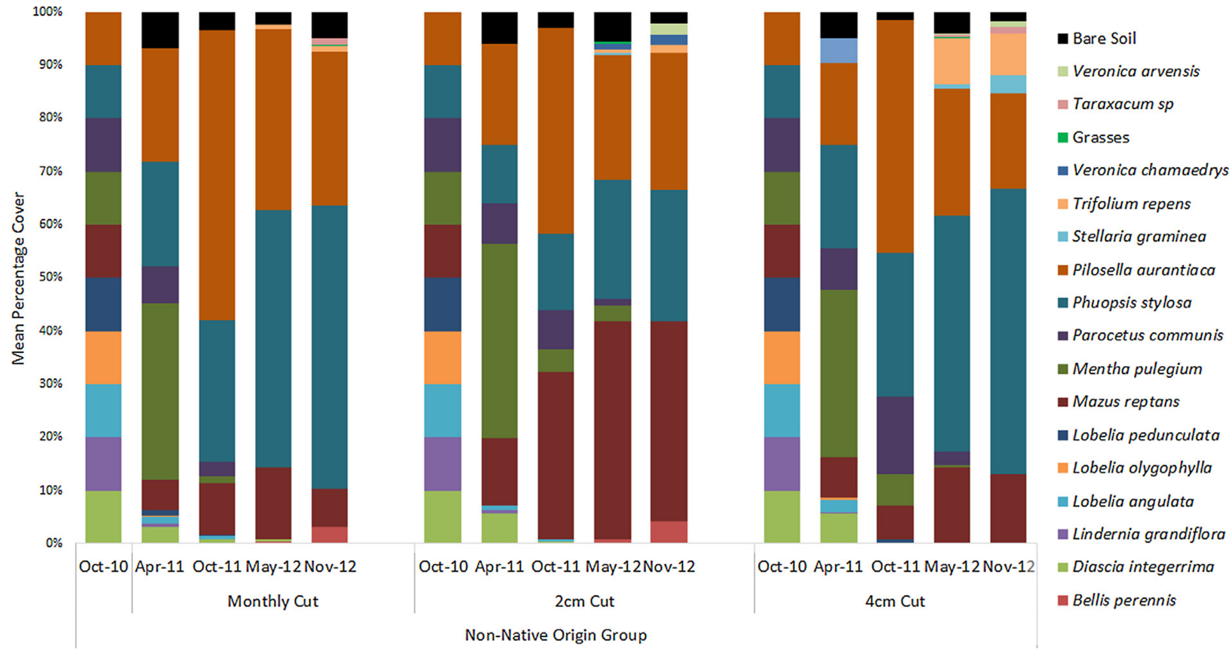

Fig. 3. Mean change in cover by species in the non-native origin group between Oct 2010 and Nov 2012.

over time was similar in the monthly and 4 cm cut lawns (Fig. 3). Both monthly and 4 cm cuts saw greater coverage produced by tall growing *Phuopsis*. Two cm cut lawns saw greater cover produced by prostrate *Mazus*. All of the non-native treatment groups acquired additional indigenous species. Five of the eight acquired species were species used in native group lawns, although the acquired *Trifolium* phenotype was seen to be different from that used in native group lawns and matched that found in the grass lawns. At the end of the experiment the 4 cm cut contained the greatest proportion of cover provided by acquired species, this was mostly produced by *T. repens*.

Table 3
Repeated measures ANOVA, showing the influence of group and cut on the change in proportional cover of surviving species in original groups between Oct 2010 and Nov 2012.

Species	Group	Cut	Group*cut
Achillea millefolium	<0.001 $F_{1,23}=20.67$	0.005 $F_{2,23}=7.19$	ns
Bellis perennis	ns	<0.001 $F_{2,23}=13.85$	ns
Mazus reptans	<0.001 $F_{1,23}=77.06$	<0.001 $F_{2,23}=19.13$	0.003 $F_{2,23}=8.08$
Phuopsis stylosa	<0.001 $F_{1,23}=354.29$	<0.001 $F_{2,23}=39.00$	ns
Pilosella aurantiaca	<0.001 $F_{1,23}=191.41$	ns	ns
Prunella vulgaris	0.007 $F_{1,23}=9.19$	<0.001 $F_{2,23}=34.36$	ns
Ranunculus repens	ns	ns	ns
Stellaria graminea	ns	ns	ns
Trifolium repens	ns	0.004 $F_{2,23}=7.67$	ns
Veronica chamaedrys	ns	ns	ns
Viola odorata	<0.001 $F_{1,23}=16.04$	ns	ns
Empty space	<0.001 $F_{2,35}=14.26$	<0.001 $F_{2,35}=32.98$	ns

Bare soil and surviving species number

There were significant differences in the amount of bare soil under different mowing regimes in both the mixed and native groups ($F_{2,47}=22.07$, $P<0.001$; $F_{2,47}=29.15$, $P<0.001$). There was a clear pattern, with monthly cuts producing the greatest amount of bare soil and 4 cm cuts the least, 2 cm cuts produced an intermediate value (Table 4). The pattern was not found in the non-native group ($F_{2,47}=1.41$ $P=0.425$). Grass lawns also showed greater amounts of bare soil in monthly cuts, but the differences between cuts were also not significant ($F_{2,47}=3.72$, $P=0.067$).

Compared to monthly cut lawns, the 2 cm and 4 cm cuts had significantly higher original species survival rates in both the mixed and native groups (Table 4). The lower percentage of remaining species seen in the mixed group is representative of the loss of many of the original non-native constituents. Overall British natives had significantly higher survival rates. Species survival in the non-native group was not seen to be influenced by the mowing regime, with all cuts retaining only three of the original species.

The acquired species seen to occur in grass-free lawns were either species that were original to the experiment or grasses or other species with wind borne seeds. That grasses were recorded in plots is not surprising since adjacent on two sides to the experimental ground is the University of Reading British grasses collection. Observation showed that grasses occurred most frequently in lawns closest to the collection. Local weed species common to the experimental grounds did not appear in any of the lawns and mosses were also not recorded.

Grass lawns

The grass lawns used for comparison with grass-free lawns showed grass cover fluctuated with season, and treatments showed no clear common pattern (Fig. 4). Repeated measures ANOVA showed both the year ($F_{1,23}=9.43$, $P=0.015$) and the individual plots ($F_{10,23}=14.30$, $P<0.001$) as significant influences on grass cover. The cut applied showed no significant influence ($F_{2,23} = 3.31$, $P = 0.079$) and there was no interaction between the year or cut ($F_{2,23} = 0.67$, $P = 0.53$). Although proportional coverage of grass cover had reduced in all treatments by November 2012 this is deemed an unreliable indicator of overall behaviour due to the high variability of grass cover observed over time.

Discussion

In this study we sought to determine whether an ornamental grass-free lawn would be perennially robust by surviving beyond two years and what influences, if any, the origin of the species used and the different mowing regimes would have on its internal structuring and ground coverage over time.

Unlike turf lawns which are started using broadcast seed the grass-free lawn required the initial use of young plants. Autumn planting of perennials is a familiar and common practice within horticulture in the United Kingdom; the soil is usually warm enough for plants to establish before the onset of winter and all the species used were thought to be hardy in an average British winter (RHS hardiness rating H4). The unusually early ground frosts and low temperatures that occurred in the autumn of 2010 are likely to have had a significant influence on the establishment of the plants used. The winter that followed also included the coldest December for 100 years, with air temperatures on the experimental grounds recorded at $-10.5\,^{\circ}$C (RHS hardiness rating H5). The influence of poor establishment and the unusually harsh winter were reflected in species survival rates (Table 2). Species unable to establish themselves, either due to plant size differences, the environmental conditions or to competition within lawns from more environmentally robust species, were seen to become extinct or be reduced in number and coverage.

Although all the species used were considered hardy, it was those species that showed the capacity for winter growth that had the highest survival rates and the greatest level of cover in spring 2011. This was seen to be the case in all groups. Within this result there is practical horticultural information. Frozen soil followed by a cold winter subsequent to planting of a grass-free lawn is likely to be detrimental to evergreen species that do not exhibit winter growth. The timing of planting should therefore ensure a sufficient period for establishment, and the use of plug plants may be particularly unsuitable if this is not the case. This last point is potentially relevant since the size of the plug plants used at planting may have also been a factor in survival. It was observed that the plug plants that had achieved the least amount of growth prior to planting (*e.g. L. oligophylla* and *Viola odorata* L.) were also seen to have poor survival rates.

Subsequent to the application of mowing, some of the species that had increased cover over the winter period were seen to quickly lose their initial advantage; this was particularly noticeable in *Achillea* in the mixed and native groups (Figs. 1 and 2) and *Mentha* in the non-native group (Fig. 3). This early level of cover in these two species was never recovered, with *Achillea* immediately loosing cover and returning to a level approximating that at planting in both the mixed and native groups, while *Mentha* became extinct in both the mixed and non-native groups. Both of these species are rhizomatous with relatively robust upright flowering stems that are slow to develop to full maturity. The *Mentha* phenotype originally specified (*M. pulegium* 'nana') has a prostrate habit; however the seed supplied did not match specification. This may in part explain its extinction. *D. integerrima*, a rhizomatous species with upright flowering stems, also became extinct in both the mixed and non-native groups. However the *Diascia* was severely affected by the winter prior to the application of mowing and the influence of mowing is not clearly demonstrated. That three rhizomaceous

Table 4
Mean (±SE) percentage of bare soil between Oct 2010 and Nov 2012 and mean (±SE) percentage of originally planted species remaining in grass-free swards in Nov 2012.

Group	Mixed			Native			Non-native			Turf*		
Cut	Monthly	2 cm	4 cm	Monthly	2 cm	4 cm	Monthly	2 cm	4 cm	Monthly	2 cm	4 cm
% bare soil (±SE)	7.9 (1.22)	4.2 (0.93)	1.9 (0.42)	10.7 (1.66)	5.4 (1.12)	1.9 (0.37)	4.4 (0.71)	4.2 (0.70)	3.0 (0.71)	2.4 (0.9)	0.9 (0.7)	1.1 (0.5)
% remaining species (±SE)	35.0 (2.04)	43.75 (5.15)	48.0 (2.38)	52.5 (2.50)	85.0 (2.27)	77.5 (2.50)	30 (0)	30 (0)	30 (0)	na		

* Grass lawn data between May 2011 and November 2012.

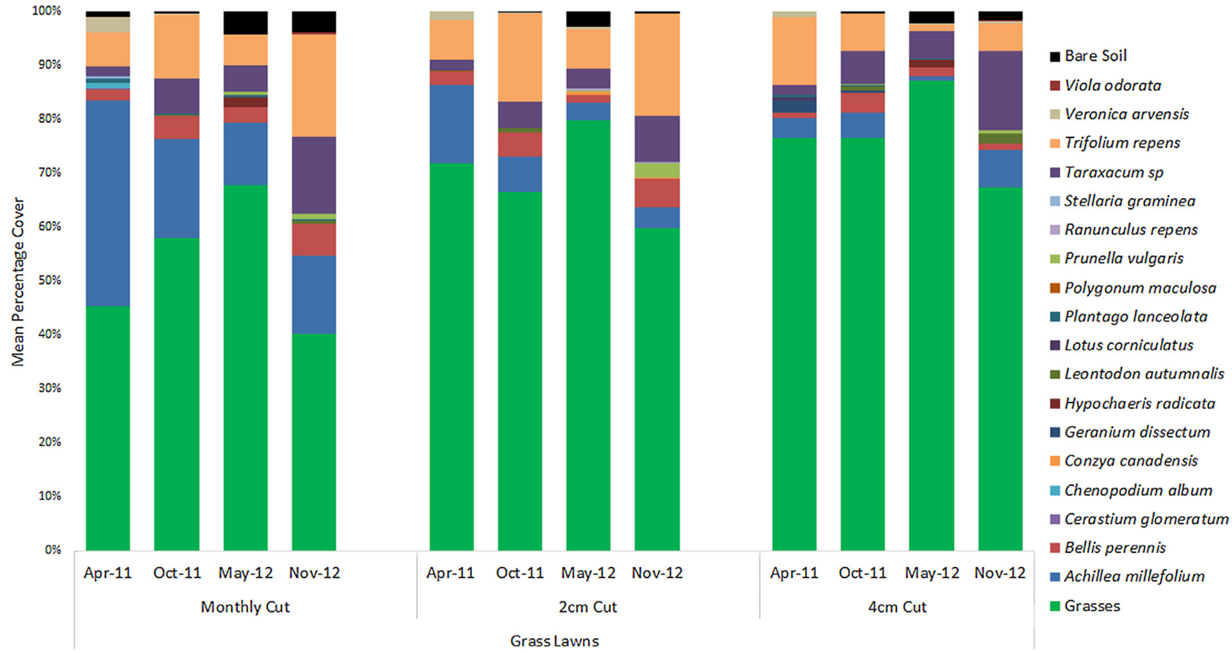

Fig. 4. Mean change in cover by species in grass lawns between May 2011 and November 2012.

species that all show slow to mature flower stems did not either survive or thrive is potentially indicative that these features may not be particularly suited to grass free lawns where mowing is applied with a similar frequency.

In the mixed and native groups *Trifolium* was seen to continue to increase its level of cover subsequent to the application of mowing and under all mowing regimes. This increasing cover persisted until May 2012. A subsequent decrease in cover under all mowing regimes was observed in mixed and native groups in November 2012, suggesting a species specific or life-cycle response rather than a direct response to the mowing treatments, particularly since no unusual environmental conditions were evident. *T. repens* is a short lived perennial that perpetuates itself clonally through stolons; older parts of the plant are commonly seen to die after two to three years. *T. repens* stolon growth is also known to be density dependent, with stolon growth decreasing at high clover density. There may also be a negative density feedback between *T. repens* and its nitrogen-fixing symbiont rhizobium at high densities (Cain et al., 1995). The reduction in *Trifolium* cover seems likely to have been due to a combination of either two or all of these factors.

A particular feature of the *T. repens* used in the study was its phenotype. It was apparent that the phenotype had been misrepresented by the seed supplier. Its vigour, height and leaf size did not match that commonly found in lawns, and although it flowered profusely these characteristics made it particularly unsuitable for use in an ornamental lawn setting. During the experiment the application of mowing was height responsive, and in both the mixed and native lawns it was inevitably the density and height of the *Trifolium* that induced mowing. A smaller and less vigorous variety is likely to have induced mowing less frequently.

Being ornamentally unsuitable due to high vigour and unsightly cut stems, the form of *Trifolium* used offered an insight into the characteristics of plants and their forms that can be considered as unsuitable. The three characteristics that in combination made this particular form of *T. repens* unsuitable were (a) a very fast growth rate relative to the other species used, (b) a large individual leaf area relative to other species used and (c) an average leaf height substantially above the cut to be applied.

Any plant or plant form that has these three characteristics is likely to be unsuitable for use in an ornamental grass-free lawn. The unsuitable fast growth rate applies specifically to the rate at which the individual plant biomass is seen to increase, rather than to the production of flowering stems which are ornamentally desirable. Since the full expression of the remaining two characteristics can be directly influenced by the frequency and intensity of mowing, plants that have these characteristics may be subject to management. It seems prudent to avoid species or cultivars with very fast growth rates and it is likely that the best manner in which to use plants with either of the two other manageable characteristics is to use them sparingly. Species or cultivars that contain all three characteristics should be avoided.

Another feature of the *T. repens* used is that the level of cover it achieved within lawns was significantly influenced by the mowing regime, but not by the other species within the lawns (Table 3). It seems likely that this particular form of *Trifolium* was able to outcompete the other plant species in the lawns and reach the trigger cutting height before any other species, so the mower became the only significant influence on its pattern of cover.

The only other species that was seen to be significantly influenced by the mowing regime alone was *Bellis perennis*. *Bellis* was also the only species that was clearly seen to continually propagate successfully by self-sown seed. This behaviour suggests there may be an opportunity to use seed in grass-free lawns after inception and that clonality may not be the only plant characteristic suitable for grass-free lawns.

The range of results of influences on surviving species (Table 3), shows that mowing has a direct influence on the cover of most of the individual species used and is therefore a useful coverage management tool. It also shows that the combination of species used in a group can have an equivalent level of influence. Species and phenotype selection is therefore equally as important a management tool in this regard, since the choice of plants to include in a grass-free lawn will significantly influence the amount of cover achieved. The data also shows that for some species (*e.g. Veronica chamaedrys* L. and *Viola odorata*), coverage is unlikely to be managed by either method.

An aesthetically meaningful consequence of plant responses to both the species group and the mowing regime is the amount of bare soil that remains visible within a grass-free lawn. Bare soil is aesthetically detrimental in a lawn and it too is significantly related to the plant species used and the cut applied (Table 4).

A pattern can be identified in the occurrence of bare soil in both mixed and native groups, with Monthly cut lawns containing the most and 4 cm cuts the least. Since monthly cutting allowed for extended plant growth relative to the more frequently applied 2 cm and 4 cm cut heights, monthly cut lawns were taller and contained more biomass, largely produced by *Trifolium*. This particular form was able to repeatedly out-complete and exclude the other species by creating a shade canopy that existed for longer between cuts relative to the more frequently cut 2 cm and 4 cm lawns, it also influenced by etiolation the growth architecture of other competing species within the Monthly cut lawns; growth tended to be predominantly upright. A result of this vertical growth was Monthly cuts produced unsightly stems in addition to the greatest amount of bare soil.

Although the increased frequency of mowing in 4 cm and 2 cm lawns reduced the period of canopy shading, this in itself seems unlikely to be a sole condition sufficient to explain the variation in bare soil. The cut height itself is seen to be a clearly significant influence, with only two of the surviving original species not being significantly influenced by it (Table 3). Since a 2 cm cut reduces the amount of vertical space available for growth by half that of a 4 cm cut, it seems likely that the 4 cm cut represents a ‘happy medium’ whereby plant growth is possible for low growing and prostrate species and sufficient for species that have the capacity to grow taller. This is evidenced by the greater numbers of surviving species are also a feature of lawns that have the least amount of bare soil (Table 4).

It also seems probable that a smaller amount of bare soil is not only due to the influence of the frequency of cutting and cut height but also to the greater diversity of plant habit and architecture that increased species number brings and that can be expressed to a greater extent within a 4 cm cut compared to a 2 cm cut.

The most successful species seen to survive within both 2 cm and 4 cm mown lawns were British natives. Since the original species selection was drawn from species known to perennially exist in turf lawns, the results indicate that this selection of British natives represent a highly useful and relevant species pool for grass-free lawns in the UK. Non-native species alone are unlikely to be suitable.

In both the mixed and the native group a Tukey test showed no significant differences between original species survival in 2 cm and 4 cm cut lawns. Since species survival is not significantly different between the two cuts but the amount of bare soil is, bare soil becomes a deciding factor in identifying the most suitable cut height for cover management purposes. For grass free lawns to be aesthetically acceptable the level of bare soil should ideally be equivalent to or less than that found in turf lawns (Table 4). Using this benchmark, only the 4 cm cut can be identified as a suitable cut height.

Unlike grass-free lawns where the mowing treatments were seen to be a highly significant influence on cover, the mowing height applied to turf lawns was not seen to have a significant effect (Fig. 4). The amount of bare soil within turf lawns was also not significantly influenced by the mowing regimes (Table 4). The influence of turf lawn composition and the mowing regime applied on coverage in turf lawns and grass-free lawns are clearly different. This suggests that turf and grass-free lawns require different approaches to cover management.

In this study the experimental design took an approach that was based on traditional British lawn management practice (Anon., 2013). The grass-free lawns were cut when the majority of lawns had reached the height that prompted mowing. This works well for turf lawns and produces the familiar aesthetic results of a planed and height standardised surface. However, grass-free lawns produce a canopy in a fundamentally different manner to turf lawns and cover is subsequently seen to be influenced by different factors. Height is also not uniformly distributed in a grass-free lawn in the format that is commonly seen in turf lawns. Particular taller and faster growing species were seen to be mowing triggers in grass-free lawns rather than the visually generalised overall height that is used in turf. Unlike traditional monoculture type turf lawns the grass-free lawn is a polyculture, an example of an experimental lawn used in our study is shown in Fig. 5. It is a mix of diverse species, each clearly seen to respond in a unique manner to environmental influences, the presence of other species and to the influence of the mower. It may therefore be useful to regard the grass-free lawn not as the single and largely uniform entity ‘lawn’ in the manner of turf lawns but rather a type of lawn with composite mixed species features; horticultural terminology may need to expand to encompass this novel format.

Fig. 5. Experimental four species grass-free lawn.

This study was the first step in examining the potential of grass-free lawns and we used a limited number of wild-type species to determine if grass-free lawns could provide ground coverage in the manner expected of a lawn. The next step is to examine floral performance, since it is both a particular feature of grass-free lawns and is likely to influence lawn biodiversity by the addition of floral resources to a space traditionally managed to be flower-free. By adding to the plant diversity of lawn space grass-free lawns have the potential to be useful tools in the management of greenspace biodiversity, particularly where lawns are purely ornamental. By widening the type of plants to include the use of ornamental varieties with colourful flowers and foliage, grass-free lawns may also have a useful role to play in private gardens as well as public spaces.

Conclusions

This work has shown that grass-free lawns are not only technically feasible, but they are also practically achievable. The experimental grass-free lawns required substantially less mowing than traditional turf lawns and required no additional inputs to maintain. They showed a level of perennial cover similar to that seen in traditional turf lawn and show they can be managed by species selection and mowing. In practice it seems likely that cover management of grass free lawns should begin before the lawn has been laid. Timing the laying of the lawn to allow for good establishment is clearly important as is the selection of plants and the phenotypes to be used. Tall, vigorous and large leaved species and phenotypes should be avoided or used with caution. To ensure the best level of species survival and cover British native species make for the best but not only choice, and when mowing becomes necessary a cut height of 4 cm is most suitable. However the trigger for mowing is likely to be down to the behaviour of a few species only and this seems likely to be a more subjective judgement than a specifically defined height response.

Although mowing can be used effectively as a simple tool for managing cover for most but not all species when combined together in a grass-free lawn, the aesthetics of lawn coverage and not just individual species behaviour are likely to be factors in the timing chosen to apply mowing. When to mow is then a decision that is in part a management necessity, aesthetically subjective and visual effect oriented; it is the type of decision gardeners are particularly familiar with. While it is clear that there is considerable potential for a grass-free lawn in terms of cover and diversity, a reasonable query is whether this construct would be aesthetically useful. We have no doubt that this is the case (Smith & Fellowes, in prep.). Furthermore, our unpublished data shows that grass-free lawns support a significantly greater abundance and diversity of invertebrates, including pollinators (Smith et al. in prep).

With the grass-free lawn shown to be a construct that requires less mowing, is both perennial and manageable and provides coverage similar to that of a traditional turf lawn, it can be recommended as a novel alternative to the traditional turf lawn.

Acknowledgements

We are grateful to the Royal Horticultural Society of Great Britain, the Finnis-Scott Foundation and the Garden Centre Association's Dick Allen Scholarship Fund for supporting this study.

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