

The grass-free lawn: floral performance and management implications

Article

Accepted Version

Creative Commons: Attribution-Noncommercial-No Derivative Works 4.0

Smith, L. S. and Fellowes, M. D. E. (2015) The grass-free lawn: floral performance and management implications. *Urban Forestry & Urban Greening*, 14 (3). pp. 490-499. ISSN 1618-8667 doi: <https://doi.org/10.1016/j.ufug.2015.04.010> Available at <http://centaur.reading.ac.uk/45984/>

It is advisable to refer to the publisher's version if you intend to cite from the work.

Published version at: <http://dx.doi.org/10.1016/j.ufug.2015.04.010>

To link to this article DOI: <http://dx.doi.org/10.1016/j.ufug.2015.04.010>

Publisher: Elsevier

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other copyright holders. Terms and conditions for use of this material are defined in the [End User Agreement](#).

www.reading.ac.uk/centaur

CentAUR

Central Archive at the University of Reading

Reading's research outputs online



1 The grass-free lawn: floral performance
2 and management implications.

3
4 Lionel S Smith & Mark D E Fellowes

5
6 School of Biological Sciences, University of Reading, Whiteknights,
7 Reading RG6 6AS, UK

8

9

10 Abstract

11 Grass lawns are a ubiquitous feature of urban green-space throughout much of the temperate world.
12 Species poor and intensively managed, lawns are ecologically impoverished, however
13 environmentally aware lawn owners are reluctant to implement alternatives due to aesthetic concerns.
14 Developing an alternative lawn format which is both biodiversity friendly and aesthetically pleasing is
15 an imperative for urban greening.

16 We suggest that such an alternative can be provided by replacing the grass lawn by a forb-based mix.
17 To advance this, we tested the floral performance of three groups of clonal perennial forbs (native,
18 non-native and mixed), each maintained using standard lawn management mowing regimes.

19 Our findings show that both the frequency of mowing and the height at which mowing is applied
20 influence floral performance and lawn aesthetics. Species origin was found to influence floral
21 productivity, floral visibility and floral variety within grass-free lawns, with native species providing
22 the greatest floral performance. The behaviour and management of grass lawns was not found to be a
23 suitable analogue for the management of grass-free lawns and grass-free lawns are sufficiently
24 different from grass lawns to require an entirely original management approach. We suggest that the
25 grass-free lawn can provide an aesthetically and environmentally relevant replacement for the
26 ubiquitous and ecologically-poor grass lawn.

27 Key Words: Lawn Alternative; Floral Performance; Mowing; Environmental Horticulture; Gardening.

28

29

30 INTRODUCTION

31 Originally composed of a mixture wild grasses and mowing tolerant wildflowers native to the
32 relatively moist and mild maritime climate of NW Europe, the pedigree of the lawn can be
33 traced back nearly a thousand years (Fort, 2000;Smith and Fellowes, 2013). During this time
34 continuous social and economic changes combined with greater general access to improving
35 horticultural technology have seen the ornamental lawn extend its original range, moving
36 from private country estates and parks and into the urban landscape (Macinnis, 2009). This
37 journey transformed the lawn. Although a climatically suited mixture of grasses and forbs is
38 still commonly found throughout lawns in NW Europe (Fogelfors, 1983;Müller,
39 1990;Godefroid, 2001;Thompson et al., 2004), horticultural and aesthetic refinements have
40 been applied to it. The aesthetically refined lawn has taken on very particular characteristics
41 that separate it from its original mixed species composition. The refined or ‘perfect’ lawn is a
42 low, evenly planed, grass-only format that is required to be a rich green monotone in colour
43 without mottling or spoil that should be dense and soft of texture (Steinberg, 2007;Slater,
44 2007). Only very few grass species can meet these requirements and the perfect lawn is
45 inevitably a species poor monoculture. However this refined composition has produced an
46 aesthetic that is much admired; so much so that it has been widely adopted beyond its point
47 of origin and the lawn is now the most common component of urban greenspace worldwide
48 (Stewart et al., 2009;Ignatieva and Stewart, 2009).

49 Even though it is widely implemented, the monocultural nature of the perfect lawn is not
50 without its critics (Robbins, 2007). Changing perceptions of the urban environment and a
51 new green zeitgeist in gardening now see eco-friendly characteristics, native plants, wildlife
52 and sustainability being included in decisions made by landscapers and gardeners (Helfand et
53 al., 2006;Clayton, 2007;Gaston et al., 2007;Kiesling, 2010). This has led to lawns and their
54 management being seen as ecologically insensitive, with refined lawns being perceived as

55 'green deserts'(Allen et al., 2010), and described as 'industrial lawns' due to the high level of
56 inputs required to maintain the refined aesthetic (Borman et al., 2001).

57 Intensively maintaining greenspace to be species poor does not fit comfortably within the
58 trend for greener gardening and alternatives to the refined lawn format are suggested by many
59 garden authors, gardening organisations and local authorities (Marinelli, 1993;Daniels,
60 1995;Ryall and Hatherell, 2003;Thomas, 2010;Anon, 2011a;Brown, 2011). Alternatives can
61 include lawns composed of regionally indigenous grasses (Simmons et al., 2011), species
62 enriched lawns (Cook, 1993) and single forb species replacements (Smith and Fellowes,
63 2013), but more commonly the suggestion is for the lawn to be replaced entirely, usually with
64 a variety of herbs, shrubs and trees, (Hadden, 2012), often with the condition of being native
65 seen as a positive feature in replacement species choices (McMahan, 2006).

66 However where the use of lawn alternatives has been investigated (primarily in North
67 America), alternatives are not found to be widely adopted, and there is little correlation
68 between a lawn owners choice of alternatives and their environmental motivations
69 (Henderson, 1998;Feagan, 2001); alternatives tend to be implemented on the basis of
70 aesthetic improvement (Purchase, 1997). This is in large part due to cultural norms found in
71 North America where the lawn has particular symbolic value (Feagan and Ripmeester,
72 1999;Robbins, 2003;Steinberg, 2007), but is also indicative of the social dimensions in urban
73 ecology (Pickett et al., 2001) and the role of aesthetics in lawn space management (Byrne,
74 2005;Piekielek, 2003). For a lawn alternative to sit comfortably within the green paradigm
75 and be socially agreeable it would require both an ecological motivation, be aesthetically
76 relevant and socially acceptable (Nassauer et al., 2009).

77

78 A new alternative approach to lawns that retains many of the traditional lawn features but
79 removes both the grass and the monoculture has been trialled at the University of Reading,

80 Berkshire, UK. By showing human intention through careful species selection, retaining the
81 traditional low visual aspect and neatness of a lawn by the application of mowing, and
82 providing a level of cover equivalent to that found in traditional grass lawns, the grass-free
83 lawn keeps some of the key characteristics of the ornamental lawn template, although the
84 requirement for mowing is significantly reduced (Smith and Fellowes, 2014a). Composed of
85 mowing tolerant clonal perennial forbs, the grass-free lawn has greater plant species diversity
86 at inception and by the use of a mixture of species that all have the capacity to produce
87 flowers, grass-free lawns bring floral performance to a space not traditionally managed for
88 flowers. Although not intended for sport or amenity use the increase in plant diversity and
89 floral resource found in a grass-free lawn may fit better within the green zeitgeist than the use
90 of the traditional monoculture, and also be aesthetically pleasing; a feature that has the
91 potential to positively influence its societal acceptability (Nassauer, 1995).

92
93 With the exception of its initial and subsequent annual or biannual application in wildflower
94 meadows and prairie (Jefferson, 2007;Wade, 2012), the use of repeated mowing is not
95 traditionally associated with floral management. The influence that different types of mowing
96 regimes and plant species selection will have on the floral performance of grass-free lawns
97 has yet to be reported on. In a preceding paper we identified that mowing can influence the
98 amount of ground cover and plant species survival in grass-free lawns (Smith and Fellowes,
99 2014a), this has implications for the application of mowing to grass-free lawns for the
100 purposes of floral display. For a grass-free lawn to be maintained as a lawn rather than a low
101 meadow it must be mown more frequently. Mowing will inevitably influence floral visibility
102 by the repeated removal of flowers, and the height at which the cut is applied and interactions
103 between the plants used are also likely to influence the outcome. A mowing regime that

104 results in the greatest level of plant and floral diversity and visual performance can be
105 considered to be the optimum management approach.

106 To determine this approach while we examined the influence of three mowing regimes on
107 ground coverage and species survival in native, non-native, mixed species and turf lawns, we
108 concurrently examined the biomass production and floral performance. Biomass was
109 recorded to compare the productivity of grass-free lawns with unrefined grass lawns under
110 the different mowing regimes and to identify any biomass related behaviour in the floral
111 performance of the lawns.

112 METHOD

113 Experimental Design

114 As described in greater detail in our preceding paper (Smith and Fellowes, 2014a), three
115 groups of clonal perennial forbs were created from species deemed likely to survive and
116 reproduce in a mown environment; a native species group, a non-native group and a mixed
117 species group. The native group was composed in equal proportions of ten species commonly
118 found in managed grasslands and lawns throughout the UK. The non-native group contained
119 ten species of non-natives also in equal proportion that had been sourced on the basis of
120 commercial availability (Table 1). The mixed group consisted of all the native and non-native
121 species in equal proportion. All species selected had the potential to produce clearly visible,
122 distinct and colourful flowers. For the purposes of comparison grass lawn plots were sourced
123 from a section of the university's lawn that was known not to have received any lawn
124 management treatments beyond regular mowing for a period of over twenty years.

125 The layout of the experiment consisted of thirty six 60cm² randomised grass-free plots and
126 twelve grass lawn plots. Each grass-free plot contained one hundred plants that had been

127 either propagated via cuttings or from seed where cuttings were impractical. Visual examples
128 of all groups cut at 4cm in May 2011 are shown in Fig 1.

129

130 Three mowing treatments were applied to designated plots continuously over two years from
131 April 2011. The period of mowing the lawns was bound by the start and end of the growing
132 season in both years. Treatments were either a) a monthly cut where plots were cut down to
133 4cm on the same date of each month (weather depending) irrespective of plant height
134 achieved within plots, b) a low cut where lawns were cut back to 2cm having achieved an
135 average 3cm in height, c) a medium cut where lawns were cut back to 4cm having reached an
136 average 6cm in height. Treatments were designed to remove no more than approximately $\frac{1}{3}$
137 of the plant material produced in order to maintain the viability of the plants being cut. The
138 average height achieved by vegetation within plots was determined by using a falling plate
139 meter of 5g (Barnhart, 1998;Rayburn, 2003).

140

141 Mowing was applied to a treatment group when 75% of the plots had reached the designated
142 cut height and was applied using a Bosch Rotak 43Li cordless rotary mower. Total biomass
143 was collected by the mower and then dried for a minimum of four days at 70°C. Subsequent
144 to mowing, plots were hand trimmed back to their original size. In addition to biomass, the
145 floral characteristics of each plot were also recorded: both flower number and calculated
146 overall floral visibility.

147 Flower number. Open and clearly visible flowers of each constituent species were recorded in
148 each plot prior to mowing. *Viola odorata*. flowers were recorded in March although the plots
149 did not require subsequent mowing. Since flowers in a lawn are generally viewed from head
150 height, only flowers that were clearly and individually distinguishable at this height were
151 recorded. In practice the smallest flowers of any of the constituent species that could be

152 clearly distinguished in this manner were those of *Stellaria graminea*, with flowers of
153 approximately 5mm diameter and all flowers were therefore individually countable.

154 When counting flower number a floral cluster composed of many small individual flowers
155 smaller than 5mm was recorded as a single flower rather than as many individual tiny
156 flowers; larger visibly discrete flowers of 5mm and over were individually counted.

157 Floral visibility. Perception of how flower filled a space appears to be is influenced by both
158 the number and the size of the flowers observed within that space. When compared directly, a
159 few large flowers are seen to inhabit more visual space and therefore be more visible than the
160 same number of smaller flowers. Using only the measure of flower number to determine
161 floral performance does not accurately portray the visual effectiveness of a space where floral
162 visibility is a desirable feature; a measure of flower size in addition to flower number is
163 required to compare the visibility of different floral forms.

164 Flower shape and size varies between species, with larger single flowers (e.g. *Ranunculus*
165 *repens*) and tight grouping of many small flowers (e.g. *Trifolium repens*) having a greater
166 visual area than small individual or ungrouped flowers (e.g. *S. graminea*). Previous work on
167 flower size has used the size of the corolla as a measure of flower size (Sargent et al., 2007),
168 however from head height the small individual flowers of species that are in tight groups or
169 tightly clustered in inflorescences are difficult to distinguish. This was the case *Achillea*
170 *millefolium*, *Bellis perennis*, *Mentha pulegium*, *Phuopsis stylosa*, *Prunella vulgaris* and
171 *Trifolium repens*.

172 To provide for a useful method of comparison the flowers of *S. graminea* were used as a
173 flower size reference species. The recorded flowers of all species were allocated a value
174 representative of their size in relation to a single 5mm diameter *S. graminea* flower with a
175 floral area of 19.6 mm². For example, a larger flower with a 10mm diameter has a floral area

176 of 78.5 mm² and is therefore approximately equivalent to four *S. graminea* flowers. This
177 method was modified for use in the field to allow the use of a hole template that measured
178 diameters in whole millimetres. Stellaria equivalent values had been determined for each
179 species by rounding to the nearest whole number the mean obtained by measuring the
180 diameter of twenty flower heads taken randomly from the experimental plots. Where flowers
181 did not occur in sufficient numbers in plots as occurred with *A. millefolium*, additional
182 measurements were taken from plants growing in regularly mown turf adjacent to the
183 experimental grounds. This was used to determine the Stellaria equivalent values shown in
184 Table 1. The modified method used for determining whole number Stellaria values is given in
185 further detail in the appendix.

186 For comparative purposes the number of flowers per species was multiplied by their Stellaria
187 equivalent value to determine an approximate floral area and act as a measure of floral
188 visibility. The floral visibility of individual lawns (Visibility) was the total in Stellaria
189 equivalents (Stellarias) of all the species found within it. To directly compare the visibility of
190 each group and treatment visibility per cut (VpC) was used as an indicator of how floriferous
191 each treatment and group appeared when averaged over time.

192 Data analysis

193 Comparisons of treatments between and within lawns were made using a general linear
194 model with repeated measures ANOVA in MINITAB (Minitab., 2012). Where data sets did
195 not follow a normal distribution prior to ANOVA data was transformed using either
196 Log(n+1), sin or arcsine square root transformations that met the assumptions of the terms.

197 Environmental Conditions

198 Autumn planting in the UK is common horticultural practice as soil temperature is usually
199 sufficient to allow for root growth before the onset of winter (HTA, 2014). In line with
200 common practice the grass-free lawns were planted out in October 2010. However
201 immediately subsequent to planting unseasonal low temperatures were experienced at the
202 experimental site, and were followed by an unusually severe winter that was recorded by the
203 UK Meteorological Office as the worst British winter for 100 years (Anon, 2011b). The
204 lowest temperature recorded at the experimental grounds was -10.5°C (RHS hardiness rating
205 H5). At the start of the first growing season in April 2011 the proportions of individual
206 species within all groups was observed to have changed, particularly within the non-native
207 group (Smith and Fellowes, 2014a). This initial winter period restructuring within groups
208 influenced subsequent outcomes. The second growing season in 2012 was recorded by the
209 UK Meteorological Office as the wettest British summer for 100 years (Anon, 2012).

210 RESULTS

211 Mowing (Cut)

212 2012 had a shorter growing season compared to 2011. In 2011 monthly cut lawns required
213 mowing eight times and although at different times both height sensitive treatments required
214 mowing nine times each. In 2012 monthly cut lawns were cut seven times and also at
215 different times both height sensitive treatments were cut eleven times each. By comparison
216 the University of Reading's turf lawn next to the experimental site was mown by grounds
217 staff 29 times in 2011 and 26 times in 2012.

218 Biomass

219 The total biomass produced by grass-free lawns in both years was substantially greater than
220 that produced by grass lawns over the same period in both mixed and native lawns. Non-

221 native lawns produced a similar amount of biomass to grass lawns over the two year period
222 (Table 2).

223 Biomass production was not seen to be constant in grass-free lawns and varied between years
224 and between the temporal and height sensitive treatments. In 2011 monthly cut grass-free
225 lawns produced significantly greater amounts of biomass than that produced in height
226 sensitive treatments, with approximately a third greater produced in monthly cuts in all three
227 grass-free groups.

228 In 2012 monthly cuts continued to produce significantly greater amounts of biomass in all
229 grass-free groups, although the amount was substantially reduced compared to 2011. A
230 reduction in biomass production in 2012 was also observed in all height sensitive treatments
231 in all grass-free groups. With the exception of the 4cm cut this reduction was not observed in
232 grass lawns

233 In 2012 height sensitive treated grass-free lawns were mown twice more than in 2011 and
234 biomass was significantly reduced in all treatments. Total biomass within grass-free groups
235 only was seen to be influenced by the year, group and the cut applied (Table 4). If the
236 monthly cut lawns are withheld from the analysis since they have a different frequency of
237 application and only the 2cm and 4cm lawns cut with the same frequency are examined, the
238 two responsive mowing regimes are not seen to be a significantly different in their influence
239 on biomass production ($F_{1,47} = 0.67$, $P = 0.424$). Both the year ($F_{1,47} = 67.4$, $P < 0.001$) and
240 the group ($F_{2,47} = 98.07$, $P < 0.001$) remain as significant influences on these two treatments.

241 In grass lawns annual biomass remained similar in all treatments over both years, although a
242 significant reduction was apparent in 4cm cut lawns in 2012. No specific influences on
243 annual biomass were identified however biomass per cut was influenced by both the year, the

244 cut applied, and an interaction between them with height specific cuts producing less biomass
245 in year two (Table 3).

246 Flower Number

247 In 2011 flower number was greatest in lawns that produced the most biomass (Table 2), in all
248 groups this was monthly cut lawns (Fig 2). Treatments applied in response to increasing
249 height had been cut once more than monthly cuts and produced significantly fewer flowers.
250 No relationship between the two responsive cut heights and flower production within grass-
251 free groups was identified.

252 In 2012 even though monthly cut lawns had been cut once less than in 2011, in all monthly
253 cut grass-free groups a reduced mean number of flowers was recorded, significantly so in
254 both the mixed and non-native groups. Compared to 2011, biomass, frequency of mowing
255 and floral production was reduced in all monthly cut grass-free groups (Table 2). In height
256 sensitive treatments there was divergent behaviour between the mixed and native groups and
257 the non-native group. In the mixed and native groups the frequency of mowing had increased
258 and biomass had reduced, however flower numbers were not significantly different between
259 years. In the non-native group which had also received a reduced frequency of mowing and
260 shown a decrease in biomass, flower numbers had significantly increased.

261 In monthly cut lawns within the mixed and native groups the diversity of floral performance
262 had substantially reduced between years and flower production was primarily from one
263 species – *T. repens* (Fig 2). This reflected the changes to the component structure of monthly
264 cut lawns, where the less frequent mowing was observed to favour a vigorous and tall
265 growing *Trifolium* cultivar at the expense of shorter and less vigorous species. In height
266 responsive treatments in the same groups although floral diversity had also reduced this had

267 not occurred to the same degree, and floral contributions were made by greater numbers of
268 species, particularly in the 4cm native group.

269 In non-native lawns the highly floriferous and prostrate species *Mazus reptans* produced
270 fewer flowers in taller growing monthly cut lawns and substantially more flowers in the
271 height responsive cuts, particularly the lowest cut 2cm lawns where its prostrate form was
272 seen to be advantageous in avoiding the blade of the mower.

273 Flower number in grass lawns was not seen to be significantly different between treatments in
274 2011 and ranged between 85% and 95% less than that found in grass-free lawns. In 2012
275 flower number had increased in monthly and 2cm cut grass lawns. This was seen to be due to
276 an expansion in cover of taller growing *A. millefolium* in monthly cut lawns and a notably
277 prostrate form of *B. perennis* in the 2cm cut lawns. Flower numbers in grass lawns in 2012
278 remained broadly in a similar range to 2011.

279 Flowers per unit biomass were calculated to determine if managing biomass via the different
280 mowing regimes might prove be a useful tool in managing floral display. In grass-free lawns
281 over the two year period this figure was found to be highly variable between treatments and
282 groups, particularly in the first year after planting (Table 4).

283

284 Visibility

285 Here visibility is the number of flowers recorded multiplied by their *Stellaria* equivalent
286 value and is measured in *Stellarias*. It is used to provide a generalised but useful measure of
287 the petalled area of lawns.

288 Increased mean visibility in 2012 made all mixed and native lawns appear more floriferous
289 compared to 2011; however this increase was only significant in 4cm cut lawns in both

290 groups (Fig 3). All treatments in mixed and native groups showed at least double the
291 visibility found in the same treatments within the non-native group, indicating the visual
292 usefulness of species with larger flowers. Mean visibility in both the mixed and native groups
293 was not seen to be influenced by either the year or by the treatment applied (Table 3).
294 Visibility in all non-native lawns significantly increased between 2011 and 2012. This was
295 seen to be influenced by the year and an interaction between the year and the cut. This
296 coincided with an increase in *M. reptans* cover and flower number, and to a second year
297 invasion by native species with larger flowers. Visibility in grass lawns also increased in all
298 treatments although this was only significant in monthly cuts (Table 2).

299 Visibility per Cut (VpC) was seen to be greatest in mixed and native monthly cut lawns in
300 both years (Table 2). VpC in 2cm and 4cm cut mixed and native lawns varied slightly but not
301 significantly between years even though there was an increased frequency of cutting applied
302 in 2012. The 4cm cut native group showed the highest level of VpC in both 2011 and 2012.

303 Non-native group VpC was significantly greater in 2012 than in 2011 in all treatments. The
304 significant differences in VpC between treatments in 2011 remained consistent in 2012
305 (Table 2), with the year the only significant influence on VpC in the non-native group (Table
306 3). *M. reptans* was observed to increase its mean area of coverage and floral productivity
307 during this period. In grass lawns VpC increased in monthly and 2cm cut lawns in 2012 but
308 no significant influences were identified (Table 3).

309 DISCUSSION

310 From planting out in 2010, the lawns had two years to develop and this time period falls
311 within the horticultural definition of perennial. This is a relatively short period of continuous
312 development for a long term horticultural feature; however the aim of the study was to
313 discover any significant differences in the initial perennial behaviour of the grass-free lawns

314 in comparison to grass lawns when managed in the same way, and prior to any forms of
315 additional aesthetic intervention that might be applied to an ornamental feature.

316 From the start of the first growing season all the grass-free lawns underwent changes that
317 were seen to be influenced by the treatments applied, the species grouping and to a lesser
318 extent the year (Table 4). This was reflected in the changes in biomass produced and the
319 differences in overall floral performance both in flower number and floral visibility (Table 2).
320 In the first year after planting, all grass-free groups with a monthly cut produced most
321 biomass, most flowers and had the greatest amount of petalled area. For a grass-free lawn this
322 would initially appear to be the ideal management regime if floral visibility were to be the
323 only aesthetic consideration. However, monthly mowing produced taller more meadow-like
324 lawns, it saw a reduction over time in the number of species that were seen to flower (Fig 2),
325 there were also fewer species and greater amounts of bare soil visible within lawns (Smith
326 and Fellowes, 2014a), and post-mowing the monthly cut lawns were aesthetically poor with
327 many cut stems clearly visible.

328 The influence of monthly mowing on lawn component species and their visual performance
329 was most evident in the second year with lawns visually dominated by one species only in all
330 groups (Fig 3). This reflected the changes to the component structure of monthly cut lawns,
331 where the less frequent mowing was observed to favour a vigorous and tall growing *Trifolium*
332 cultivar at the expense of shorter and less vigorous species.

333 Remarkably in both years respectively the two height sensitive mowing regimes applied
334 required the same number of total cuts for all grass-free groups, and also in both years the
335 amount of total biomass collected from lawns cut to 2cm was not significantly different from
336 the total biomass collected from lawns cut to 4cm (Table 2). As a method to maintain plant
337 survival in lawns (Jacques and Edmond, 1952; Crider, 1955), the responsive mowing regimes

338 specifically removed only the top third of the lawn, both the post-cut lawns retained an
339 equivalent resource of two thirds from which to regrow before being cut again. This
340 equivalent level of resource from which to regrow may go some way in accounting for the
341 same annual requirement for mowing that was found in both years; however the biomass
342 equivalency of the amount removed seems more likely to have been influenced by the
343 specific height at which the cut is applied and its influence on the patterns of growth in the
344 component species.

345 In mixed plant species populations it is difficult to directly determine the effect of a mowing
346 regime, however mowing is generally recognised to reduce leaf area, reduce competition for
347 light, influence apical dominance and plant architecture, and post-cut resource allocation in
348 cut plants (Jameson, 1964). The height at which the cut is applied can influence subsequent
349 regrowth (Schmid and Harper, 1985) and lower growing plants not as severely affected will
350 continue their low growth (Graber, 1931), while mowing affected species may regrow with
351 shorter internodes, greater stem density and other potentially dwarfing responses (De Kroons
352 and Hutchings, 1995).

353 This is highly complex behaviour and although not specifically tested for, our observations of
354 post cut aesthetics indicated that with the least amount of space in which to grow and expand,
355 the 2cm cut lawns may have produced lawn components with both shorter internodes and a
356 greater stem density than that observed in 4cm cut lawns. These characteristics were only
357 clearly observed in the *T. repens* form that came to be the dominant species in mixed and
358 native lawns, and the 2cm vertical growth space of the 4cm cut regime was observed to be
359 being largely taken up by extended *T. repens* leaf petioles rather than by mixed species
360 vegetation. The equivalent amounts of biomass produced by both treatments appear to reflect
361 these variations in growth pattern and lawn density. In light of this complex behaviour and
362 the number of significant factors and interactions found to influence flowers per unit biomass

363 in grass-free lawns (Table 4), it seems unlikely that lawn biomass can be practicably
364 managed to favour floral performance.

365 In 2012 despite a shorter growing season than 2011, the lawns required more frequent and
366 additional mowing. The increase in the frequency and amount of mowing influenced biomass
367 production in a negative manner with smaller amounts of biomass collected with each cut
368 (Table 2). It seems likely that in manner similar to that observed in pasture, the more
369 frequently a grass-free lawn is mown and growth interrupted, the less overall biomass is
370 produced (Kennedy, 1950;Wagner, 1952). That there was sufficient continuous growth to
371 triggering more cuts during 2012 than in 2011 is an indication that the qualities of the
372 biomass produced can also be variable within any one year. The summer of 2012 was
373 exceptionally wet, and the increased requirement for cutting suggests that growth was
374 particularly lush in response to the unusually high level of moisture availability.

375 The cut applied to grass-free lawns significantly influenced floral outcomes (Table 4). In
376 2011 monthly cut lawns produced the greatest amount of flowers in all grass-free groups and
377 with the exception of the 4cm cut native group, within group responsively cut lawns had
378 flower numbers that were not significantly different from each other. This suggests that the
379 different frequency between fixed monthly and responsive application of mowing was
380 influencing flower number. This also suggests that the timing of mowing and the length of
381 the time period between cuts can influence flower number. Certainly cutting immediately
382 prior to a species' flowering will negatively influence its floral outcomes, and conversely
383 extended periods of plant growth between cuts potentially allows for greater floral
384 development to be expressed. That the monthly and responsively cut 2cm and 4cm treatments
385 differed by only one cut and showed such clear differences in floral productivity is indicative
386 that just one cut can significantly influence floral outcomes.

387 In 2012 the frequency of mowing increased in responsively cut treatments, however a
388 significant drop in flower numbers was not observed. In mixed and native groups flower
389 numbers were not significantly different compared to 2011 and in the non-native group
390 flower numbers had increased. This appears to be due to the changes in the composition and
391 structure within groups produced by the treatments applied. The treatments influenced flower
392 number by changing the proportional composition of species within lawns over time (Smith
393 & Fellowes 2014). The richness of individual species contributing to flower number fell
394 between years in all grass-free groups, mixed and native lawns becoming dominated by *T.*
395 *repens* and non-native lawns by *M. reptans* (Fig 2). This two species domination in lawns
396 largely restricted the period of floral visibility to their individual floral periods, a negative
397 trait for a perennial feature, however their floral productivity was high and seen to
398 compensate for the loss of floral performance by other species.

399 The best floral outcome in both years was observed to be the 4cm cut native lawns where
400 although floral variety was low in 2012 both mean flower number, flower number per cut and
401 floral visibility were seen to be greatest within the responsively cut lawns (Table 2). That the
402 lawns moved toward low floral diversity within two years also suggests that if greater floral
403 diversity is the aim, that the initial construct of would benefit from taking into consideration
404 the vigour of the species and forms used and that equal proportions at inception may not be
405 the most suitable method.

406 Of the twenty species used as plug plants in equal measure at inception only six species were
407 seen to make significant floral contributions over both years, only one of these *M. reptans*
408 was non-native. This was initially due to poor winter survival rates among non-natives and
409 subsequently to the competitive influence of *T. repens* within mixed and native lawns (Smith
410 and Fellowes, 2014a). However the behaviour of the surviving species has shown that those

411 native to the British Isles are likely to be a good choice as main constituents in a UK based
412 grass-free lawn, since they have proved to be both better suited climatically and to produce
413 flowers in sufficient number to give a higher level of floral visibility than the non-natives
414 used (Fig 3). Non-natives are not necessarily excluded from use in a grass-free lawn, since
415 they contribute to the community structure and amount of ground coverage achieved (Smith
416 and Fellowes, 2014b). Non-native species survived in both the mixed and non-native lawns;
417 however from these results it seems that used alone they are unlikely to be a good choice for
418 maximum floral performance since floral visibility was lower compared to lawns that
419 contained natives (Fig 3). This does not exclude the value that non-natives may have in a
420 mixed origin lawn where they may extend the floral season and bring novelty and floral
421 colour variations.

422 Within the grass lawns no significant influences were identified on total biomass, floral
423 production or visibility, with only biomass per cut seen to be affected by the year and the
424 mowing regime. That grass lawns do not behave in the same manner as grass-free lawns is
425 indicative that the two formats are very different. Visually the internal structuring of species
426 and the dynamics of grass based lawns is for the most part not clearly visible due to the visual
427 similarity of grasses, in grass-free lawns the continuous internal flux of mixed forbs is much
428 more visually evident and is indeed a feature of the grass-free format.

429 Conclusions

- 430 • Grass-free lawns behave in a significantly different manner to grass lawns and aesthetic
431 outcomes are very different.
- 432 • Mowing based on height averages is impracticable. Unlike grass lawns where a surface of
433 roughly equal height is achievable, grass-free lawns produce an uneven surface. The use

- 434 of a drop meter was required to determine an averaged measure of height. This
435 methodology seems unlikely to be practical in everyday usage.
- 436 • Mowing should be applied when individual or groups of plants are observed to be
437 detrimentally affecting neighbours.
 - 438 • Highly vigorous and tall varieties of *T. repens* should be avoided. Although producing
439 lawns with a high floral visibility, this tends to be single species visibility and post cut
440 aesthetics are poor due to extensive cut petioles post-mowing.
 - 441 • British native species known to inhabit short grass were found to be the most suitable but
442 not only choice. They had greater overall survival rates and better overall visual
443 performance, with flowers being of sufficient size and produced in sufficient quantity to
444 be more visually effective than the non-natives used.
 - 445 • The height of the responsive cut applied did not directly influence flower production,
446 rather it influenced the structure of the lawn community and subsequently the species
447 source of flowers.
 - 448 • Responsive mowing was seen to be the best method of management when a cut height of
449 4cm was applied as this produced the best floral visibility and lawn species diversity.
 - 450 • Specifically mowing on a fixed monthly basis was not a useful method as it was seen to
451 favour vigorous and taller growing species, reduce floral diversity and produce a poor
452 overall lawn aesthetic, particularly post cut.
 - 453 • Visual performance may be influenced by manipulating the proportions of species used.
454 Larger proportions of smaller flowered species are required if they are to contribute
455 similar amounts of floral visibility to larger flowered species.

456 Grass-free lawns retain the familiar lawn management technique of mowing and the
457 traditional low cut aesthetic, they show human intention and ongoing care and additionally
458 bring diverse foliage and floral performance to an area traditionally managed to be a planed

459 monotone green. We used ten native and ten non-native species in our trials, but we see no
460 reason why species number should remain so restricted, and believe that by reducing the need
461 for mowing and enhancing the plant species diversity and floral resource of an otherwise
462 traditionally flower poor area that grass-free lawns show a clear ecological motivation.

463 The use of plant species relevant to conditions found within the British Isles was suitable to
464 our location and aims, although all of the species we trialled are not exclusive to the UK and
465 can be found in lawns around the globe. The plug sized non-native plants we used at
466 inception did not respond well to the unseasonably early start to the winter of 2011. Better
467 developed plants are likely to have fared better since the selection was of a group of species
468 marketed as hardy in horticulture in the UK. It is possible to speculate that by using the
469 species we trialled and similar format relevant and climatically suitable species that grass-free
470 lawns and appropriate mowing frequencies might be formulated to suit other regions,
471 although it seems probable that outcomes will vary dependent on the local environment and
472 the characteristics of the plants that might be used. Both the application of grass-free lawns
473 beyond the UK and how pollinators and other lawn dwelling insects interact with them are
474 areas that would benefit from further research.

475 Having obtained some insight on the type and characteristics of plant species to use, and
476 found a potentially useful management methodology, we hope that this novel and
477 unconventional approach to lawn space will prove to be ecologically useful, aesthetically
478 pleasing and a socially acceptable lawn alternative.

479 Acknowledgements

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

483

484

485

Native Group		
Latin	Common Name	Stellaria equivalent
<i>Achillea millefolium</i> L.	Yarrow	80
<i>Bellis perennis</i> L.	Daisy	23
<i>Pilosella officinarum</i> Vaill.	Mouse-Ear Hawkweed	19
<i>Potentilla reptans</i> L.	Cinquefoil	16
<i>Prunella vulgaris</i> L.	Selfheal	23
<i>Ranunculus repens</i> L.	Creeping Buttercup	19
<i>Stellaria graminea</i> L.	Lesser Stitchwort	1
<i>Trifolium repens</i> L.	White Clover	21
<i>Veronica chamaedrys</i> L.	Germander Speedwell	6
<i>Viola odorata</i> L.	Sweet Violet	23
Non-native Group		
<i>Diascia integerrima</i> E.Mey. ex Benth.	Twinspur	10
<i>Lindernia grandiflora</i> Nutt.	Blue Moneywort	9
<i>Lobelia angulata</i> G.Forst	Pratia 'Tredwellii'	7
<i>Lobelia oligophylla</i> (Wedd.) Lammers	Hypsela	5
<i>Lobelia pedunculata</i> R.Br.	Pratia 'County Park'	3
<i>Mazus reptans</i> N.E. Br.	Creeping Mazus	5
<i>Mentha pulegium</i> L.	Penny Royal	7
<i>Parochetus communis</i> D.Don	Blue Oxalis	8
<i>Phuopsis stylosa</i> (Trin.) Hook.f. ex B.D.Jacks.	Crosswort	10
<i>Pilosella aurantiaca</i> (L.) F.W.Schultz & Sch.Bip.	Fox & Cubs	48

486

487 Table 1. Species groups and Stellaria values.

GROUP	CUT	Mean Annual Biomass (g) (±SE)		Mean Biomass per Cut (g) (±SE)		Mean Flower Number (±SE)		Mean Flower Number per Cut (±SE)		Mean Flowers per Unit Biomass (g) (±SE)		Mean Visibility (Stellarias) (±SE)		Mean Visibility per Cut (Stellarias) (±SE)	
		2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Mixed	Monthly	1027.9 (62.8)	723.7 (46.7)	128.4 (7.8)	103.3 (6.6)	520 (44.7)	394.2 (71.9)	65 (5.5)	56.3 (10.2)	0.51 (0.06)	0.56 (0.12)	7435 (310)	8068 (1510)	929 (38)	1152 (215)
	2cm	689.3 (24.4)	625.1 (31.9)	76.5 (2.7)	56.8 (2.9)	309.5 (29.0)	321.5 (14.8)	34.3 (3.2)	29.2 (1.3)	0.70 (0.06)	0.52 (0.03)	5324 (535)	6180 (343)	592 (60)	561 (31)
	4cm	644.0 (15.3)	545.0 (21.7)	71.5 (1.7)	49.5 (1.9)	336.5 (12.0)	339.0 (45.9)	37.3 (1.3)	30.8 (4.1)	0.41 (0.03)	0.62 (0.09)	5500 (172)	6777 (848)	611 (19)	616 (77)
Native	Monthly	1048.4 (21.3)	696.3 (28.8)	131.0 (2.6)	99.4 (4.1)	479.2 (25.5)	434.5 (62.1)	59.9 (3.1)	62.7 (8.8)	0.30 (0.03)	0.63 (0.10)	8730 (639)	9055 (1284)	1091 (80)	1293 (183)
	2cm	718.1 (36.1)	602.1 (29.5)	79.8 (4.0)	54.7 (2.6)	303.5 (33.5)	338.2 (57.4)	33.7 (3.7)	30.7 (5.2)	0.43 (0.07)	0.55 (0.07)	6134 (616)	7410 (1327)	681 (68)	673 (120)
	4cm	733.0 (43.7)	588.2 (29.6)	81.4 (4.8)	53.4 (2.6)	400.7 (18.6)	432.5 (27.7)	44.5 (2.0)	39.3 (2.5)	0.26 (0.05)	0.75 (0.09)	7900 (226)	9111 (474)	878 (25)	828 (43)
Non-Native	Monthly	786.7 (172.3)	391.9 (16.6)	98.3 (21.5)	55.9 (2.3)	264 (20.1)	201.2 (24.8)	33.0 (2.5)	28.7 (3.5)	0.49 (0.09)	0.52 (0.08)	1624 (287)	2426 (167)	203 (36)	347 (24)
	2cm	457.8 (24.3)	287.9 (13.4)	50.8 (2.7)	26.1 (1.2)	184 (21.5)	368.2 (22.5)	20.4 (2.3)	33.4 (2.0)	0.88 (0.01)	1.28 (0.08)	1165 (217)	3176 (321)	129 (24)	289 (29)
	4cm	450.1 (25.0)	333.3 (25.8)	50.0 (2.7)	30.3 (2.3)	158.5 (12.7)	271.7 (48.9)	17.6 (1.4)	24.7 (4.4)	0.36 (0.05)	0.86 (0.20)	714 (24)	2884 (319)	79 (3)	262 (29)
Grass	Monthly	507.2 (50.0)	451.3 (65.3)	63.4 (6.2)	64.4 (9.3)	23.2 (10.6)	51.2 (9.8)	2.9 (1.3)	7.3 (1.4)	0.06 (0.03)	0.13 (0.04)	429 (152)	1463 (577)	54 (19)	209 (82)
	2cm	417.6 (40.7)	461.7 (72.8)	46.4 (4.5)	41.9 (6.6)	20.5 (7.9)	53.0 (17.9)	2.2 (0.8)	4.8 (1.6)	0.05 (0.02)	0.14 (0.06)	453 (183)	1090 (639)	50 (20)	99 (58)
	4cm	411.7 (21.9)	317.5 (16.9)	45.7 (2.4)	28.8 (1.5)	19 (4.1)	17.2 (5.9)	2.1 (0.4)	1.5 (0.5)	0.04 (0.01)	0.06 (0.02)	396 (103)	450 (197)	44 (12)	41 (18)

488

489 Table 2 Biomass and floral performance by group and cut for 2011 & 2012.

490

GROUP	FACTOR	Mean Annual Biomass (g)	Mean Biomass per Cut (g)	Mean Flower Number	Mean Flower Number per Cut	Mean Flowers per Unit Biomass (g)	Mean Visibility (Stellarias)	Mean Visibility per Cut (Stellarias)
Mixed	Year	$P = 0.002$ $F_{1, 23} = 118.05$	$P < 0.001$ $F_{1, 23} = 242.07$	ns	ns	ns	ns	ns
	Cut	$P < 0.001$ $F_{2, 23} = 17.01$	$P < 0.001$ $F_{2, 23} = 57.67$	$P = 0.007$ $F_{2, 23} = 0.72$	$P < 0.001$ $F_{2, 23} = 33.60$	ns	ns	$P = 0.001$ $F_{2, 23} = 18.21$
	Year*Cut	$P = 0.001$ $F_{2, 23} = 15.62$	ns	ns	ns	ns	ns	ns
Native	Year	$P < 0.001$ $F_{1, 23} = 93.36$	$P < 0.001$ $F_{1, 23} = 93.36$	ns	ns	$P < 0.001$ $F_{1, 23} = 81.89$	ns	ns
	Cut	$P = 0.001$ $F_{2, 23} = 17.91$	$P < 0.001$ $F_{2, 23} = 77.04$	ns	$P = 0.003$ $F_{2, 23} = 12.30$	ns	ns	$P = 0.005$ $F_{2, 23} = 7.93$
	Year*Cut	ns	ns	ns	ns	$P = 0.005$ $F_{2, 23} = 9.90$	ns	ns
Non-Native	Year	$P < 0.001$ $F_{1, 23} = 34.71$	$P < 0.001$ $F_{1, 23} = 49.20$	ns	ns	ns	$P < 0.001$ $F_{1, 23} = 106.46$	$P < 0.001$ $F_{1, 23} = 74.16$
	Cut	$P = 0.004$ $F_{2, 23} = 10.86$	$P < 0.001$ $F_{2, 23} = 33.87$	ns	ns	$P = 0.001$ $F_{2, 23} = 15.76$	ns	ns
	Year*Cut	ns	ns	$P = 0.009$ $F_{2, 23} = 8.37$	ns	ns	$P = 0.014$ $F_{2, 23} = 7.20$	ns
Grass	Year	ns	$P = 0.003$ $F_{1, 23} = 16.08$	ns	ns	ns	ns	ns
	Cut	ns	$P = 0.012$ $F_{2, 23} = 7.61$	ns	ns	ns	ns	ns
	Year*Cut	ns	$P = 0.010$ $F_{2, 23} = 7.94$	ns	ns	ns	ns	ns

491

492 Table 3. Results of ANOVA showing within group significant influences on biomass and
 493 floral performance between 2011 & 2012.

494

495

GRASS-FREE LAWNS	Year	Group	Cut	Year *Group	Year *Cut	Group *Cut	Year *Group*Cut
Total Biomass	$P < 0.001$ $F_{1,71} = 110.5$	$P < 0.001$ $F_{2,71} = 103.1$	$P < 0.001$ $F_{2,71} = 39.4$	ns	ns	ns	ns
Total Biomass per Cut	$P < 0.001$ $F_{1,71} = 182.1$	$P < 0.001$ $F_{2,71} = 103.1$	$P < 0.001$ $F_{2,71} = 141.9$	ns	ns	ns	ns
Total Flowers	ns	$P < 0.001$ $F_{2,71} = 36.6$	$P = 0.001$ $F_{2,71} = 8.6$	ns	ns	$P = 0.002$ $F_{2,71} = 5.8$	ns
Total Flowers per Cut	ns	$P < 0.001$ $F_{2,71} = 39.3$	$P < 0.001$ $F_{2,71} = 33.6$	ns	ns	ns	ns
Total Flowers per unit Biomass	$P < 0.001$ $F_{1,71} = 32.8$	$P = 0.001$ $F_{2,71} = 8.8$	$P = 0.001$ $F_{2,71} = 9.8$	$P = 0.002$ $F_{2,71} = 7.8$	$P = 0.001$ $F_{2,71} = 8.3$	ns	ns
Total Visibility	$P = 0.001$ $F_{1,71} = 13.4$	$P < 0.001$ $F_{2,71} = 127.1$	$P < 0.009$ $F_{2,71} = 5.6$	ns	ns	ns	ns
Total Visibility per Cut	ns	$P < 0.001$ $F_{2,71} = 195.4$	$P < 0.001$ $F_{2,71} = 29.4$	$P = 0.001$ $F_{2,71} = 8.6$	ns	ns	ns

496

497 Table 4. Results of ANOVA showing significance influences on biomass and floral
 498 performance in grass-free lawns between 2011 & 2012.



Native Lawn



Non-native Lawn



Mixed Lawn

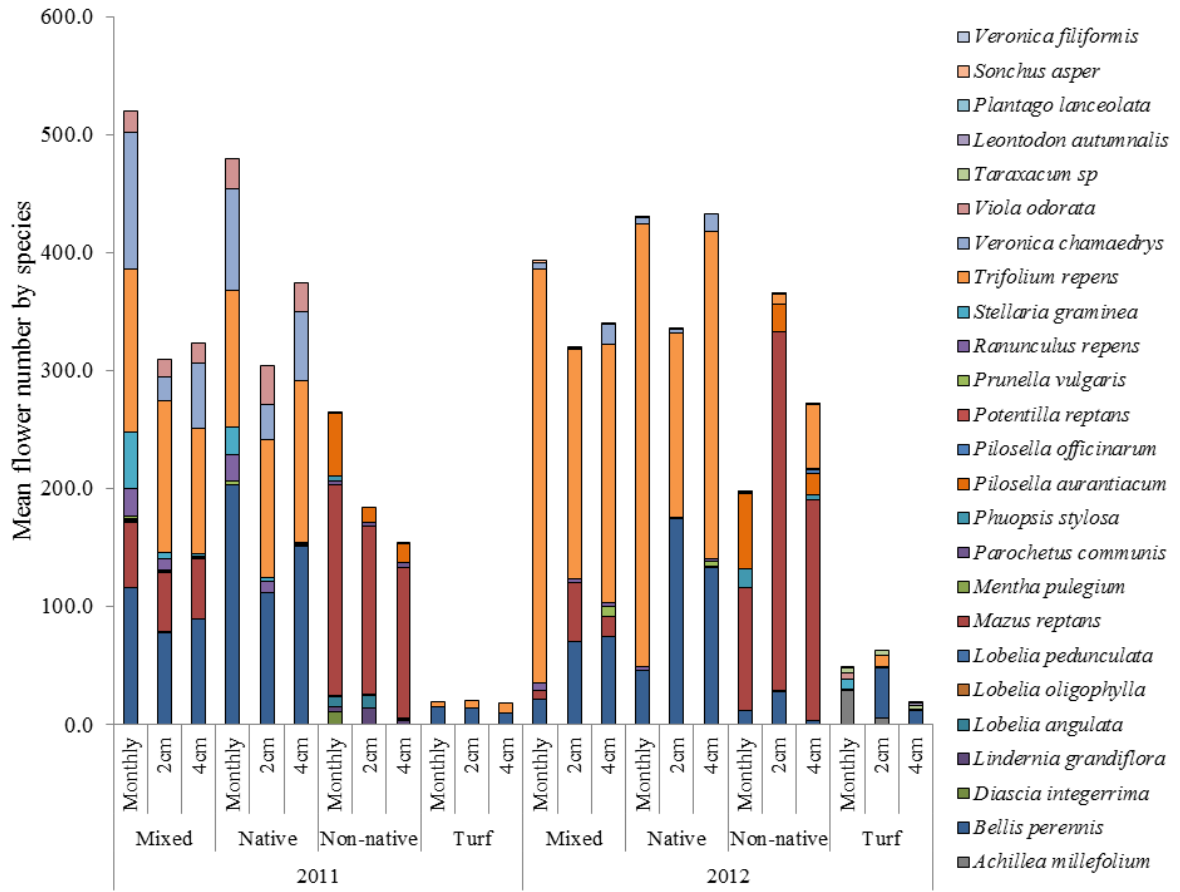


Grass Lawn

499

500 Fig 1. Examples of the four experimental lawn groups. Images created 26th May 2011.

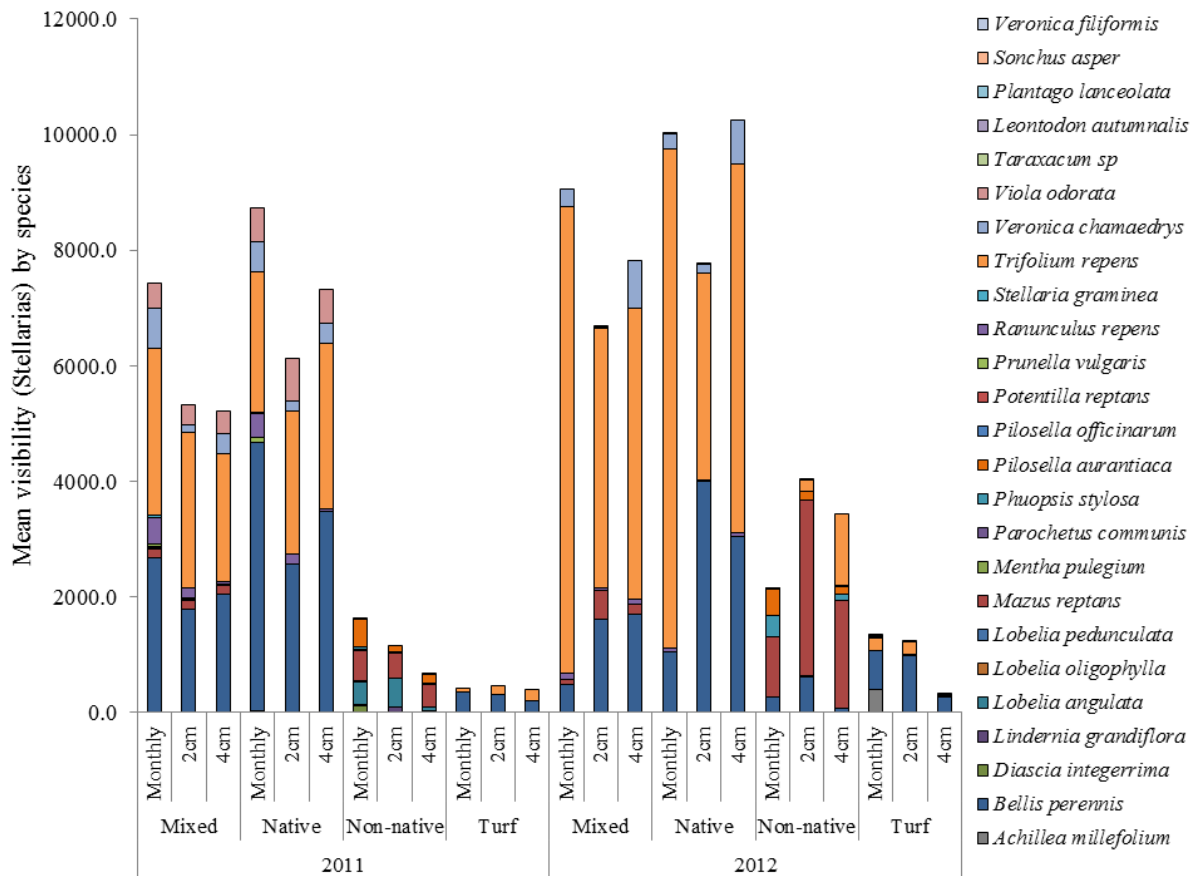
501



502

503 Fig 2. Mean flower number within groups by species 2011 & 2012.

504



505

506 Fig 3. Mean visibility within groups by species (Stellarias) 2011 & 2012.

507

508

509

510

511

512

513

514

515

516

517

518

519

520

521 Appendix A

522 Stellaria Equivalents.

Flower Diameter (mm)	Stellaria Equivalent
5	1
7	2
9	3
10	4
11	5
12	6
13	7
14	8
15	9
16	10
17	11
18	13
19	14
20	16
21	17
22	19
23	21
24	23
25	25
26	27
27	29
28	32
29	33
30	35
31	38
32	40
33	43
34	45
35	48
36	51
37	54
38	57
39	60
40	63
41	66
42	69
43	73
44	76
45	80
46	83
47	87
48	91
49	95
50	99
60	144
70	196
80	256
90	324
100	400

523

524 Rational and methodology for creating whole number values for *Stellaria* equivalents.

525 It quickly becomes apparent that when looking at a grouping of different plant species in flower at the
526 same time that flowers with a larger size are immediately more visible, they take up more visual area.

527 This feature is commonly used in garden design where larger flowers can be placed further from the
528 viewer than smaller ones to maintain the illusion of a constant flower size over a distance. This
529 technique is usually a judgement made by eye and experience.

530 To ensure ease of use and a level of repeatability in representing the visibility of the flowers it was
531 necessary to construct a method that was relevant and could be extrapolated from data collected easily
532 in the field.

533 From experience *Stellaria graminea* flowers of approximately 5mm diameter were the smallest
534 visible flowers from head height and therefore chosen as a reference flower size.

535 The question then is how many *Stellaria* flowers (5mm diameter circles) can fit into the visible area of
536 the flower being measured to make a comparison. This initially presents a series of challenges as there
537 is great variety in flower size, shape, form and distribution on variously structured flowering
538 inflorescences. However, since only an approximate value is required, by using a template of circle
539 diameters it is possible to measure the diameter of a single or clustered group of flowers in the field
540 by seeing which diameter circle the flower can easily fit through at its widest point.

541 Not all measured sizes allow for a fit as a whole number. For example a sample flower or grouped
542 tiny flowers that can fit through a circle at its widest point with a diameter of 8mm is equivalent to 1.6
543 *Stellaria* flowers. However, values that are not in units of 5mm are not required since measurements
544 below 5mm as mentioned previously are not clearly visible, i.e. the 0.6 of a *Stellaria* is difficult to
545 distinguish, the measurements needs to be clearly for either 1 or 2 *Stellaria* flower equivalents.

546 Whole unit *Stellaria* equivalents are required and make the basis for any determination of size.

547 Using $A = \pi r^2$ the area of 1 *Stellaria* with a radius of 2.5mm = 19.63495mm²

548 Worked example:

549 1 Stellaria = 19.63495mm²

550 For 11 Stellarias: 11 x 19.63495 = 215.9845mm²

551 Using $r^2 = \frac{A}{\pi}$ (to determine the radius²)

552 $68.75 = \frac{215.9845}{\pi}$

553 $\sqrt{68.75} = 8.291562$ (radius)

554 Radius x 2 = Diameter = 16.58312395mm

555 This is allocated as follows:

Flower Diameter (mm)	Flower Radius (mm)	Flower Area (mm)	Stellarias	Amended
16.58312395	8.291561976	215.984495	11	NA

556

557 Although this provides for whole Stellaria values having a flower measuring template with such

558 precise diameters is not practicable. Whole diameters are more useful, so they need to be rounded to

559 the nearest whole number e.g.

Diameter (mm)	Radius (mm)	Area (mm)	Stellarias	Amended
17	8.291561976	215.984495	11	NA

560

561 This changes the Diameter to 17mm. Although in this case this is for 11 Stellarias this value is also

562 shared by 12 Stellarias since they produce a 17.32mm diameter. See below.

563 To account for this the lowest Stellaria value is used so the amended value for 12 Stellarias becomes

564 11. The lower value is preferentially used since with increasing flower size the visual difference – the

565 perceived change in visibility, becomes less distinguishable i.e. the visual difference between a 10mm

566 diameter flower and an 20mm diameter flower (an increase of 100%) is perceived to be greater than
 567 that between a 110mm flower and a 120mm flower (an increase of 8.4%).

568 Example:

Diameter (mm)	Radius (mm)	Area (mm)	Stellarias	Amended
14.14213562	7.071067812	157.079633	8	na
15.00	7.5	176.714587	9	na
15.8113883	7.90569415	196.349541	10	na
16.58312395	8.291561976	215.984495	11	na
17.32050808	8.660254038	235.619449	12	na

569

AMENDED Diameter (mm) rounded to nearest whole number	Radius (mm)	Area (mm)	Stellarias	AMENDED Stellarias rounded down to match amended diameter
14	7.071067812	157.079633	8	8
15	7.5	176.714587	9	9
16	7.90569415	196.349541	10	10
17	8.291561976	215.984495	11	11
17	8.660254038	235.619449	12	11

570

571 Where the inflorescence being measured is longer than it is wide the length of the inflorescence
 572 should be used to determine the diameter and a visual assessment made of how many inflorescences
 573 might approximately fill the remaining space within the circle the diameter proscribes. The visibility
 574 score can be adjusted by division to account for this.

575

576

577 References

- 578 Allen, W., Balmori, D. & Haeg, F. 2010. *Edible Estates: Attack on the Front Lawn.*,
579 Metropolis Books.
- 580 Anon. 2011a. Lawn Alternatives. Climate Appropriate Grasses and Ground Covers. Santa
581 Barbara Water Conservation Information Document. Available:
582 <http://www.sbwater.org/documents/Climate%20Appropriate%20Grasses.pdf>
583 [Accessed 01/07/2011].
- 584 Anon. 2011b. Winter 2010/11 Online Report. Available:
585 <http://www.metoffice.gov.uk/climate/uk/2011/winter.html> [Accessed 12/05/2011].
- 586 Anon. 2012. UK Climate: Summer 2012 Online Report. Available:
587 <http://www.metoffice.gov.uk/climate/uk/2012/summer.html> [Accessed 01/12/2012].
- 588 Barnhart, S. K. 1998. Estimating available pasture forage. Online report. Available:
589 <http://www.extension.iastate.edu/Publications/PM1758.pdf> [Accessed 21/11/2010].
- 590 Borman, F. H., Balmori, D. & Geballe, T. G. 2001. *Redesigning the American Lawn. A*
591 *Search for Environmental Harmony.*, New Haven & London, Yale University Press.
- 592 Brown, C. S. 2011. *Native Plants & Wildlife Gardens.* Professional contribution web
593 resource. [Online]. Available: <http://nativeplantwildlifegarden.com/> [Accessed
594 23/09/2011].
- 595 Byrne, L. B. Of looks, laws and lawns: How human aesthetic preferences influence landscape
596 management, public policies and urban ecosystems. *In: LABAND, D., ed. Emerging*
597 *Issues Along Urban-Rural Interfaces: Linking Science and Society.*, 2005 Auburn
598 University, Auburn, AL., 42-46.
- 599 Clayton, S. 2007. Domesticated nature: Motivations for gardening and perceptions of
600 environmental impact. *Journal of Environmental Psychology.*, 27, 215-224.
- 601 Cook, T. W. 1993. Low Maintenance Turf. *Hardy Plant Society of Oregon*, 9(1), 9-15.

602 Crider, F. J. 1955. Root growth stoppage resulting from defoliation of grass. Technical
603 Bulletin 1102.: US Department of Agriculture.

604 Daniels, S. 1995. *The Wild Lawn Handbook. Alternatives to the traditional front lawn.* ,
605 Macmillan.

606 De Kroons, H. & Hutchings, M. J. 1995. Morphological plasticity in clonal plants: the
607 foraging concept reconsidered. *Journal of Ecology.*, 83, 143-152

608 Feagan, R. B. 2001. Reading private garden space: competing geographic identities at the
609 level of the lawn. *Philosophy & Geography*, 4, 79-95.

610 Feagan, R. B. & Ripmeester, M. 1999. Contesting Natural(ised) Lawns: A Geography of
611 Private Green Space in the Niagra Region. *Urban Geography*, 20, 617-634.

612 Fogelfors, H. 1983. *Grass in cultivated areas - agriculture, parks and gardens*, Uppsala,
613 Sveriges lantbruksuniv.

614 Fort, T. 2000. *The Grass is Greener*. London: Harper Collins.

615 Gaston, K. J., Fuller, R. A., Loram, A., Macdonald, C., Power, S. & Dempsey, N. 2007.
616 Urban domestic gardens (XI): variation in urban wildlife gardening in the United
617 Kingdom. *Biodiversity Conservation*, 16, 3227–3238.

618 Godefroid, S. 2001. Temporal analysis of the Brussels flora as indicator for changing
619 environmental quality. *Landscape and Urban Planning.*, 52, 203-224.

620 Graber, L. F. 1931. Food reserves in relation to other factors limiting the growth of grasses.
621 *Plant Physiology.*, 6, 43-71.

622 Hadden, E. J. 2012. *Beautiful No-Mow Yards. 50 Amazing Lawn Alternatives*, Portland,
623 Timber Press.

624 Helfand, G. E., Park, J. S., Nassauer, J. I. & Kosek, S. 2006. The economics of native plants
625 in residential landscape designs. *Landscape and Urban Planning.*, 78, 229-240.

626 Henderson, S. P. B., Perkins, Nathan. H., Nelischer, Maurice. 1998. Residential lawn
627 alternatives: a study of their distribution, form and structure. *Landscape and Urban*
628 *Planning*, 42, 135 -145.

629 Hta. 2014. *Autumn Planting. Nature's natural time to plant*. [Online]. Horticultural Trades
630 Association. Available: <http://www.the-hta.org.uk/page.php?pageid=959> [Accessed
631 03/01/2014].

632 Ignatieva, M. E. & Stewart, G. H. 2009. Homogeneity of urban biotopes and similarity of
633 landscape design language in former colonial cities. . In: MCDONNELL, M. J.,
634 HAHS, A. K. & BREUSTE, J. H. (eds.) *Ecology of cities and towns : a comparative*
635 *approach. p399-421*. Cambridge. UK.: Cambridge University Press.

636 Jacques, W. A. & Edmond, D. B. 1952. Root development in some common New Zealand
637 pasture plants V. The effect of defoliation and root pruning on cocksfoot (*Dactylis*
638 *glomerata*) and perennial rye-grass (*Lolium perenne*). *New Zealand Journal of*
639 *Science.*, 34, 231-248.

640 Jameson, D. A. 1964. Responses of individual plants to harvesting. *The Botanical Review.*,
641 29.4, 532-594.

642 Jefferson, R. 2007. Wildflower meadows:how to create one in your garden. Natural England.

643 Kennedy, W. K. 1950. Simulated grazing treatments, effect on yield, botanical composition,
644 and chemical composition of a permanent pasture. Cornell University. Agricultural
645 Experiment Station.

646 Kiesling, F. M., Manning, C.M. 2010. How green is your thumb? Environmental gardening
647 identity and ecological gardening practices. *Journal of Environmental Psychology*, 30,
648 315-327.

649 Macinnis, P. 2009. *The Lawn. A Social History.*, Millers Point. NSW., Murdock Books.

650 Marinelli, J. 1993. *The Natural Lawn & Alternatives (Plants & Gardens)*, Brooklyn, New
651 York., Brooklyn Botanic Garden Inc.

652 McMahan, L. R. 2006. Understanding cultural reasons for the increase in both restoration
653 efforts and gardening with native plants. *Native Plants Journal*, 7, 31-34.

654 Minitab. 2012. Minitab16 Statistical Software. Minitab Inc.

655 Müller, N. 1990. Lawns in German cities. A phytosociological comparison. *In: SUKOPP, H.*
656 *(ed.) Urban Ecology*. The Hague. The Netherlands.: SPB Academic Publishing.

657 Nassauer, J. I. 1995. Messy Ecosystems, Orderly Frames. *Landscape Journal*, 14, 161-170.

658 Nassauer, J. I., Wang, Z. & Dayrell, E. 2009. What will the neighbours think? Cultural norms
659 and ecological design. *Landscape and Urban Planning*, 92, 282-292.

660 Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C.
661 & Costanza, R. 2001. Urban Ecological Systems: linking terrestrial ecological,
662 physical and socioeconomic components of metropolitan areas. *Annual Review of*
663 *Ecology and Systematics*, 32, 127-157.

664 Piekielek, B. N. 2003. *Suburban Dynamics of Lawn Care*. Masters Thesis, University of
665 Georgia, Athens GA.

666 Purchase, M. 1997. *Factors that influence the adoption of lawn alternative residential*
667 *landscapes*. Masters Thesis, University of Guelph. Ontario.

668 Rayburn, E., Lozier, J. 2003. A falling plate meter for estimating pasture forage mass.
669 Available: <http://www.wvu.edu/~agexten/forglvst/fallplate.pdf> [Accessed
670 21/12/2010].

671 Robbins, P. 2007. *Lawn People. How Grasses, Weeds and Chemicals Make Us Who We Are.*,
672 Philadelphia, Temple University Press.

673 Robbins, P., Sharp, Julie. 2003. The Lawn-Chemical Economy and Its Discontents. *Antipode*,
674 35, 955-979.

675 Ryall, C. & Hatherell, P. 2003. A Survey of Strategies Adopted by UK Wildlife Trusts in the
676 Promotion of Gardening for Wildlife. *Environmentalist*, 23, 81-87.

677 Sargent, R. D., Goodwillie, C., Kalisz, S. & H., R. R. 2007. Phylogenetic Evidence for a
678 Flower Size and Number Trade-Off. *American Journal of Botany*, 94, 2059-2062.

679 Schmid, B. & Harper, J. L. 1985. Clonal Growth in Grassland Perennials: I. Density and
680 Pattern-Dependent Competition Between Plants with Different Growth Forms.
681 *Journal of Ecology*, 73, 793-808.

682 Simmons, M., Bertelson, M., Windhager, S. & Zafian, H. 2011. The performance of native
683 and non-native turfgrass monocultures and native grass polycultures: An ecological
684 approach to sustainable lawns. *Ecological Engineering*, 37, 1095-1103.

685 Slater, E. 2007. The Front Lawn as a work of art and nature in the age of chemical
686 reproduction. *Annual Meeting of the American Sociological Association 2007*. New
687 York.

688 Smith, L. S. & Fellowes, M. D. E. 2013. Towards a lawn without grass: the journey of the
689 imperfect lawn and its analogues. *Studies in the History of Gardens and Designed
690 Landscapes*, 33, 1-13.

691 Smith, L. S. & Fellowes, M. D. E. 2014a. The grass-free lawn: management and species
692 choice for optimum ground cover and plant diversity. *Urban Forestry & Urban
693 Greening.*, 13, 433-442

694 Smith, L. S. & Fellowes, M. D. E. 2014b. The influence of species number on productivity,
695 ground coverage and floral performance in grass-free lawns. *Landscape and
696 Ecological Engineering.* , DOI: 10.1007/s11355-014-0264-9.

697 Steinberg, T. 2007. *American green: The Obsessive Quest for the Perfect Lawn*, New York,
698 NY, W.W. Norton & Co.

- 699 Stewart, G. H., Ignatieva, M. E., Meurk, C. D., Buckley, H., Horne, B. & Braddick, T. 2009.
700 URban Biotopes of Aotearoa New Zealand (URBANZ) (I):Composition and diversity
701 of temperate urban lawns in Christchurch. *Urban Ecosystems.*, 12, 233-248.
- 702 Thomas, A. 2010. *Royal Society for the Protection of Birds. Gardening for Wildlife. A*
703 *complete guide to nature-friendly gardening.*, London, A&C Black.
- 704 Thompson, K., Hodgeson, J. G., Smith, R. N., Warren, P. H. & Gaston, K. J. 2004. Urban
705 domestic gardens (III):Composition and diversity of lawn floras. *Journal of*
706 *Vegetation Science*, 15, 371-376.
- 707 Wade, A. 2012. Greenacres: Landscaping with Native Plants. Prarie Maintenance. *Wild Ones*
708 *Handbook.*: US Environmental Protection Agency.
- 709 Wagner, R. E. 1952 Effects of differential clipping on growth and development of seedling
710 grasses and legumes. *Journal of Agronomy and Crop Science.*, 44, 578-584.

711

712