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1   **The effect of management practices on bumblebee densities in hedgerow and grassland**

2   **habitats**

3

4   Fiach Byrne[a], Javier delBarco-Trillo[a,b,*]

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6   [a] *School of Biological, Earth and Environmental Sciences, University College Cork, Cork,*

7   *Ireland*

8   [b] *Environmental Research Institute, Lee Road, Cork, Ireland*

9   * Corresponding author. Tel.: +353 21 4904663.

10   E-mail address: delbarcotrillo@gmail.com.

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12   **Running head**: Management type and bumblebee density

13

14

15   **Abstract**

16   Large-scale declines in pollinator species are a concern at present. Such declines have been

17   attributed to a range of factors that act in tandem, rather than in isolation. Some of the most

18   pervasive factors affecting pollinator populations are habitat loss and degradation, which

19   results in the loss of floral resources, nesting sites and landscape connectivity. Intensification

20   of agriculture and urbanisation are two major causes of such habitat alterations. Hedgerows

21   and grasslands are two vital habitats for pollinators in European landscapes. When managed

22   appropriately, these habitats may provide abundant floral resources and nesting opportunities,

23   as well as connectivity between habitats in a fragmented landscape. This study examined the

24   effects that management practices of hedgerows and grasslands may have on bumblebee

25   species, an important group of wild pollinators. Bumblebee abundance was recorded using

26   transect walks in managed and unmanaged sites, including both hedgerows and grasslands.

27   Greater densities of bumblebees were found in unmanaged grasslands in comparison to

28   managed grasslands. Unmanaged hedgerows were also found to have a greater density of

29   bumblebees than managed hedgerows. These results indicate that sites which are less

30   intensively managed provide a more suitable habitat for bumblebees. Therefore, our study

31   underlines the importance of a) enforcing restrictions on hedge-cutting, and b) reducing the

32   management intensity of grasslands to provide adequate habitat for pollinators.

33   **Keywords**: bumblebees; pollinators; management; anthropogenic disturbance; hedgerow;

34   grassland; floral diversity.

35

36

Introduction

Animal (especially insect) pollination is necessary for the pollination of important crop species and wild plants, and thus is an important ecosystem service (Klein et al., 2007; Gallai et al., 2009; Ollerton et al., 2011). Indeed, the majority of the world's flowering plants are dependent on insects for their pollination (Ollerton et al., 2011) and further large-scale declines in pollinators could lead to a nutritional impoverishment of the human diet (Eilers et al., 2011). Large-scale declines in pollinating insects have occurred across the globe (Williams & Osborne, 2009; Winfree et al., 2009; however, see Ghazoul, 2005). Regionally, such declines are particularly apparent in North America (Colla & Packer, 2008; Grixti et al., 2009; Cameron et al., 2011; Burkle et al., 2013) and Europe (Steffan-Dewenter et al., 2005; Biesmeijer et al., 2006; Kosior et al., 2007; Goulson et al., 2008; Potts et al., 2010a). Several causes have been proposed for such pollinator declines (Potts et al., 2010b), including land use change (Brown & Paxton, 2009; Winfree et al., 2009), agrochemicals (Alston et al., 2007; Holzschuh et al., 2008; Brittain et al., 2010), pathogens (Colla et al., 2006; Rosenkranz et al., 2010), alien species (Stout & Morales, 2009), and climate change (Williams et al., 2007).

Land use is probably the most important driver of bee declines (Brown & Paxton, 2009; Winfree et al., 2009). Although some alterations to habitat (e.g. urbanisation) may have positive effects on bee diversity and local abundance (Cane et al., 2006; Carré et al., 2009), changes in land use normally lead to the loss or degradation of suitable pollinator habitat, thus limiting their floral resources and potential nesting sites. Similar to global declines, natural and semi-natural habitat loss plays a huge role in the decline of pollinators in Ireland (Fitzpatrick et al., 2007; Fitzpatrick & Stout, 2015). The loss and changing nature of grasslands in Ireland is likely a major driver in pollinator losses, as well as shifts or contractions in their range (Fitzpatrick et al., 2007).

61   Twenty-one species of bumblebees have been recorded in Ireland. Six of these species are

62   considered 'threatened', with a further 3 species being 'near threatened' (Fitzpatrick & Stout,

63   2015). The four bumblebee species that have declined the most in Ireland (*Bombus*

64   *distinguendus, B. ruderarius, B. sylvarum* and *B. muscorum*), are all later emerging species

65   associated with open grassland habitats (Fitzpatrick et al., 2007). Declines in these ecologically

66   similar species are likely a result of the shift in the past 30 years from hay production to silage

67   production. This shift in production decreases the amount of wild flowers occurring in

68   meadows throughout the summer, when bees are more active (Vickery et al., 2001).

69   Many bumblebee species in Ireland have become rare in the eastern regions of their original

70   ranges; this is likely a result of urbanisation and increasingly intensive agricultural practices in

71   the east of the country (Santorum & Breen, 2005). Conversely, the midlands and western

72   regions of Ireland have retained much of their grassland habitats and thus bumblebee diversity

73   (Fitzpatrick et al., 2007).

74   Hedgerows are an important habitat for pollinators (Klein et al., 2007; Garibaldi et al., 2014;

75   Goulson et al., 2015). Hedgerows provide food resources and safe nesting sites for pollinators,

76   as well as acting as wildlife corridors, linking other suitable habitats (Stanley & Stout, 2013;

77   Fitzpatrick & Stout, 2015). Hedgerows and uncropped field margins in close association are of

78   particular benefit to pollinator populations in Irish agricultural landscapes (Ghazoul, 2005;

79   Stanley & Stout, 2013).

80   As hedgerows and grasslands are important habitats for pollinator species, finding an

81   appropriate management regime for these two habitat types is imperative to the persistence of

82   sustainable populations of bumblebee species in Ireland. Both grasslands and hedgerows can

83   be found in the Irish landscape in two distinct forms: managed and unmanaged. Our study seeks

84   to establish which of these two management types in hedgerow and grassland habitats hosts a

85   greater abundance of bumblebees. We predicted that unmanaged habitats, possibly having a

4

86   greater floral diversity and abundance than managed habitats, will sustain higher bumblebee

87   densities.

88

89   **Materials and methods**

90   *Study System*

91   Sixty study sites were selected in a rural area of County Carlow, in South East Ireland. All sites

92   were contained within a triangular area of 19.76 km^2 of agricultural landscape. The greatest

93   distance between two sites was 6.8 km. These 60 sites were selected based on their habitat type

94   (hedgerow or grassland), and their management type (managed or unmanaged), resulting in 15

95   sites for each of the following four categories: managed hedgerow, unmanaged hedgerow,

96   managed grassland, and unmanaged grassland. Managed hedgerows were characterised by a

97   very uniform shape along their 100 m stretch. Very little, if any, vegetation in these managed

98   hedgerows protruded out from the hedgerow. The grassy verge beneath managed hedgerow

99   was generally mowed. Unmanaged hedgerows were less uniform in their shape in comparison

100   to managed hedgerows; vegetation height and width often varied, protruding out from the

101   hedge in areas, and no visible signs of recent physical management could be seen. Managed

102   grasslands were within parks, gardens, and road verges, and were frequently mowed, in many

103   cases once or twice every week. Unmanaged grasslands included undisturbed patches in

104   farmlands, and abandoned areas in sports complexes and former construction sites. Areas that

105   are purposely left idle and cultivated on occasion throughout the summer for hay or silage

106   production were not included in our study. Use of herbicides was not observed in any of the

107   sites. Each of the 60 sites was sampled four times (for a total of 240 transect walks, as explained

108   below), on random occasions throughout the sampling period between 11th June and 2nd

109   September 2017. Each of the four visits to a particular site took place at least one week apart.

110   Three of these transects were discounted due to an alteration of management type taking place

111   during the study. All transects were performed between the hours of 10 a.m. and 5 p.m., when

112   bumblebees are most active. No transects were performed during or directly following periods

113   of rain.

114   Prior to the study, we identified all sites, recorded their GPS locations, and measured the length

115   (of hedgerows) or area (of grasslands). Floral diversity (as the number of different flowering

116   plant species) at each site was recorded at the beginning of the study, prior to the first sampling

117   taking place. If a new plant variety came into flower on subsequent visits to a site, this was

118   added to the list of flowering plants for that site. The temperature (°C) and wind speed (km*h^{-1})

119   was logged prior to performing a transect walk at each site using a smartphone weather

120   application (AccuWeather GPS Weather Widget).

121   The method of sampling differed between hedgerows and grasslands. In the case of hedgerows,

122   a fixed 100-metre stretch of hedgerow was walked at a constant speed while scanning for

123   bumblebees. In the case of grasslands, three repeated transect walks or 'laps' were carried out

124   one after the other, due to the small size of some of the selected grasslands (range: 28 to 555

125   m^2; mean ± s.d. for unmanaged grasslands: 150.5 ± 96.74 m^2; mean ± s.d. for managed

126   grasslands: 207.7 ± 135.16 m^2; t-test between areas of managed and unmanaged grasslands: t_{28}

127   = -1.15, p = 0.26). These three repeated laps were performed within the grassland at a constant

128   distance approximately 2 m from the site's outer perimeter. For each visit, the number of

129   bumblebees present in a site was the maximum recorded over the three laps.

130   For both habitat types, we recorded bumblebees that were both landed on flowers and flying.

131   We recorded many more landed than flying bumblebees (total number of bumblebees recorded

132   in hedgerows: landed = 479 bumblebees, flying = 36 bumblebees; total number of bumblebees

133   recorded in grasslands: landed = 273 bumblebees, flying = 44 bumblebees). Consequently,

134   analyses considering only landed bumblebees or all bumblebees (i.e. landed plus flying

135 bumblebees) offered qualitatively similar results. We only present results for the analyses

136 considering all bumblebees recorded. Bumblebee species were not identified in this study.

137

138 ***Statistical Analyses***

139 We conducted our statistical analyses using R, version 3.4.2 (R Core Team, 2017). We set

140 significance at $p < 0.05$. As the sampling method of hedgerows and grasslands was dissimilar,

141 data for both types of habitat were analysed separately.

142 We determined if the number of bumblebees differed between managed and unmanaged

143 hedgerows implementing a generalised linear mixed model (GLMM), with the total number of

144 bumblebees as the response; type of management, wind, and temperature as fixed factors; and

145 site as a random factor (to account for the fact that we sampled each site on four different

146 occasions). We fitted a GLMM with a negative binomial distribution and log link function

147 using the glmer.nb function in the package lme4.

148 To determine if the number of bumblebees differed between managed and unmanaged

149 grasslands, we fitted a GLMM with a Poisson distribution and log link using the function glmer

150 in the package lme4. We used the maximum number of bumblebees observed over three

151 consecutive laps as the response; type of management, wind, and temperature as fixed factors;

152 site as a random factor; and area as an offset (to account for the fact that different grasslands

153 had different areas).

154 To determine the effect of floral diversity on bumblebee abundance in managed and

155 unmanaged habitats we implemented general linear models (GLM) using the function lm in

156 the package stats, with the average of bumblebees recorded during the four visits to each site

157 as the response (log transformed); and type of management and floral diversity as the fixed

158 factors, including their interaction.

159

160 **Results**

161 We found more bumblebees in unmanaged hedgerows (mean ± standard deviation: 5.42 ± 5.97

162 bumblebees per 100 m hedgerow) than in managed hedgerows (3.25 ± 3.64 bumblebees per

163 100 m hedgerow; GLMM: z = 2.06, *p* = 0.039; Fig. 1A). Wind and temperature did not have

164 an effect on the number of bumblebees recorded in hedgerows (*p* > 0.2 for both factors). Floral

165 diversity did not have a significant effect on the number of bumblebees found in hedgerows

166 overall (t = -0.63, *p* = 0.53) or depending on the type of management (interaction: t = 1.26, *p* =

167 0.22). This is not surprising, as floral diversity did not differ between managed hedgerows

168 (mean ± standard deviation: 5.67 ± 1.8 species) and unmanaged hedgerows (5.87 ± 1.69

169 species; *t*-test: t_{28} = 0.31, *p* = 0.76). Unfortunately, we did not measure or estimate floral

170 abundance.

171 We also found more bumblebees in unmanaged grasslands (mean ± standard deviation: 129.28

172 ± 129.54 bumblebees per hectare) than in managed grasslands (30.62 ± 32.08 bumblebees per

173 hectare; GLMM: z = 3.81, *p* = 0.0001; Fig. 1B). Wind and temperature did not have an effect

174 on the number of bumblebees recorded at grasslands (*p* > 0.05 for both factors). Floral diversity

175 did not have a significant effect on the number of bumblebees found in grasslands overall (t =

176 0.63, *p* = 0.54) or depending on the type of management (interaction: t = 0.66, *p* = 0.51). Floral

177 diversity did not differ between managed grasslands (mean ± standard deviation: 5.13 ± 2.13

178 species) and unmanaged grasslands (5.93 ± 1.91 species; *t*-test: t_{28} = 1.08, *p* = 0.29).

179

180 **Discussion**

181 Our results indicate that management of both hedgerows and grasslands can have a detrimental

182 effect on bumblebee abundances. The influence of management on bumblebee densities was

183 less apparent in hedgerows than in grasslands. One factor that can explain this finding is that

184 hedgerows had not been managed as recently, or as frequently as grasslands over the sampling

185   period (June 11th to September 2nd). This is due to the fact that the cutting of hedgerows is

186   nationally prohibited between March 1st and August 31st; although some hedgerows may still

187   be cut back under certain circumstances. Consequently, the first hedgerow transect of the study

188   was walked, potentially, three months or more after the previous cut had taken place in

189   February. This would have allowed plants in managed hedgerows an extended period to set

190   seed and flower undisturbed, from early spring. This contrasts greatly to managed grassland

191   habitats, which were often cut weekly and throughout the period of sampling. Although our

192   aim was not to compare directly bumblebee densities between hedgerows and grasslands, we

193   found that bumblebee densities were clearly higher in the linear habitat (hedgerow) than in the

194   non-linear habitat (grassland), as previously shown (Osborne et al., 2008).

195   We found no difference in floral diversity between managed and unmanaged habitats.

196   However, a greater abundance of floral resources is likely to make a site more valuable to

197   bumblebees, as opposed to a site with fewer plants but with a higher variety of plant species.

198   In fact, bumblebees have been documented to forage on a narrow range of flowering plant

199   species (Santorum & Breen, 2005), so floral diversity may not be a particularly limiting factor

200   to bumblebees. Although we did not measure floral abundance, this is likely to be greater in

201   unmanaged habitats than in those that are routinely or intensively managed.

202   Managed grassland sites in this study were largely confined to roadsides, gardens or public

203   spaces. In such locations, the nature of management is both frequent and intense, especially in

204   the summer months when mowing is more common. Regular mowing will result in flowering

205   plants being cut back; often at times when they are most useful to wild pollinators. Conversely,

206   not managing grasslands will allow the available flora in the seed bank to set seed and flower

207   undisturbed. As a result, flowering plants in unmanaged grasslands will likely be more

208   abundant, and of greater value to bumblebees for a longer period of time than those in managed

209 grasslands. Thus, unmanaged grasslands may be more reliable forage sites than managed

210 grasslands.

211 A greater proportion of edge habitat will provide more benefits to wild pollinators in the form

212 of floral resources and potential nesting sites. Edge habitat of grasslands and croplands is often

213 much richer in floral resources than central areas (Gabriel & Tscharntke, 2007; Stanley &

214 Stout, 2013). However, a few plant species abundant in central areas of grasslands (e.g.

215 dandelions and clover) may also be highly important to pollinators during spring.

216 Neither of the assessed environmental conditions (temperature and wind speed) seemed to

217 influence bumblebee densities to a great extent in this study. The summer months in Ireland

218 are defined by a narrow range of temperatures. Transect walks from this study were carried out

219 at temperatures between 14 °C – 25 °C. The low variability in temperature in Ireland likely

220 means bumblebees can be active throughout the summer, independent of temperature on a

221 given day. Hence, it is not surprising that we found no effect of temperature on bumblebee

222 densities.

223 Wind speed was more variable than temperature (9 km*h^{-1} – 30 km*h^{-1}). Although bumblebees

224 may be less willing to fly greater distances, or with greater frequency, during periods of high

225 winds, the range of wind speeds that we observed may not have been sufficient to significantly

226 affect bumblebee behaviour. In any case, wind speed can be highly changeable during a day,

227 and the number of bumblebees observed at any time may be determined by the current wind

228 conditions.

229 In conclusion, here we show that greater densities of bumblebees are found in unmanaged

230 grasslands and hedgerows than in managed habitats. Floral abundance may be a better measure

231 of a habitat's suitability to bumblebees than floral diversity, and this should be a priority

232 measurement in future studies of a similar nature. A recommendation derived from our findings

233 is for management intensity and frequency to be reduced in order to make grasslands more

234 hospitable for wild bumblebees. During times of peak bumblebee activity, management

235 practices of grasslands should be limited as far as possible, to increase the availability of forage

236 sources. Similarly, well-timed management of hedgerows, when necessary, should be

237 implemented. Although management of hedgerows in February may not have had a great effect

238 on bumblebees in mid-late summer (this study's sampling period), it may affect the floral

239 resources and nesting sites available to them in spring, earlier in their life cycle (Fitzpatrick &

240 Stout, 2015; Goulson et al., 2015). It is proposed that the period in which hedge-cutting is

241 permitted (September – March) should not be extended; and further study should take place in

242 spring to examine the effect of hedgerow management on these important pollinators earlier in

243 the year.

244

247

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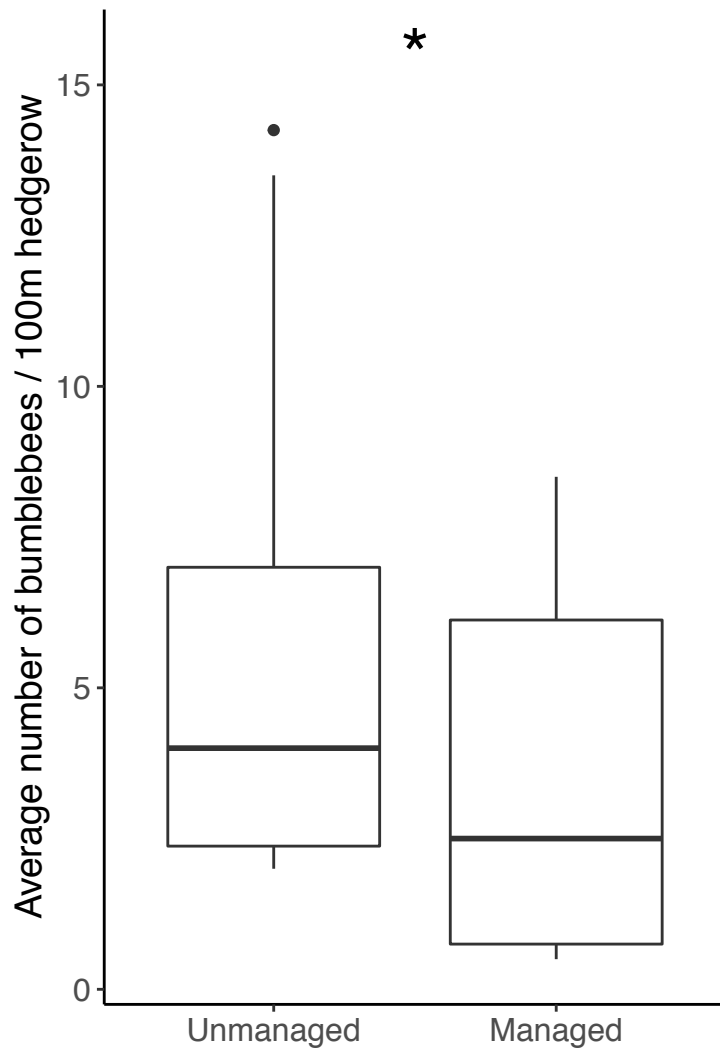345 bees' responses to anthropogenic disturbance. *Ecology*, **90***, (8), pp.2068-2076.

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Figure legends

349 **Fig. 1.** Bumblebee abundance recorded in hedgerows (A) and grasslands (B) that were

350 managed or unmanaged. Values represent the average of bees recorded during four different

351 visits to each site. For each boxplot, the bar within each box represents the median, each box

352 represents the first and third quartiles (or 25th and 75th percentiles), the two whiskers represent

353 the maximum values that are within 1.5 * IQR of the box (where IQR or inter-quartile range is

354 the distance between the first and third quartiles), and points beyond the whiskers represent

355 outliers. Significant differences between managed and unmanaged habitats were obtained

356 using generalised linear mixed models (* denotes $p < 0.05$; *** denotes $p < 0.0005$).

357

(A) Hedgerows — Average number of bumblebees / 100m hedgerow. Unmanaged vs Managed. *

(B) Grasslands — Average number of bumblebees per hectare. Unmanaged vs Managed. ***