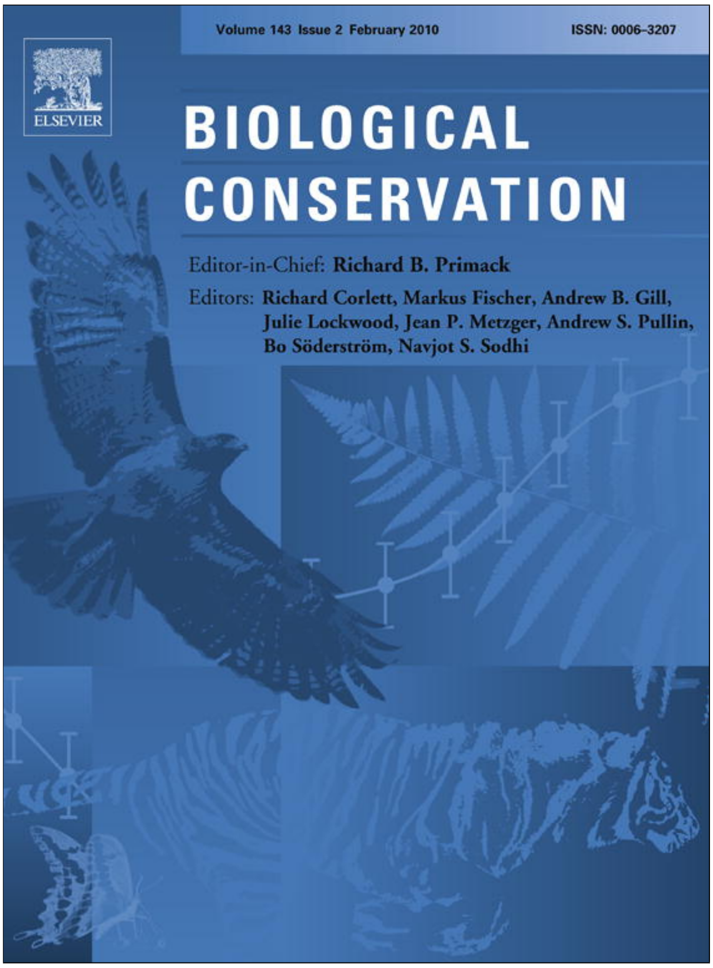
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Crofting and bumblebee conservation: The impact of land management practices on bumblebee populations in northwest Scotland

Nicola Redpath *[,1], Lynne M. Osgathorpe *[,1], Kirsty Park, Dave Goulson

School of Biological and Environmental Sciences, University of Stirling, Stirling, FK9 4LA, UK

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ABSTRACT

The northwest of Scotland is a stronghold for two of the UK's rarest bumblebee species, *Bombus distinguendus* and *Bombus muscorum*. The predominant form of agricultural land management in this region is crofting, a system specific to Scotland in which small agricultural units (crofts) operate rotational cropping and grazing regimes. Crofting is considered to be beneficial to a wide range of flora and fauna. However, currently there is a lack of quantitative evidence to support this view with regard to bumblebee populations. In this study we assessed the effect of land management on the abundance of foraging bumblebees and the availability of bumblebee forage plants across crofts in northwest Scotland. The results of our study show that current crofting practices do not support high densities of foraging bumblebees. Traditional crofting practice was to move livestock to uplands in the summer, but this has been largely abandoned. Summer sheep grazing of lowland pasture had a strong negative impact on bumblebee abundance and forage plant availability throughout the survey period. The use of specific 'bird and bee' conservation seed mixes appears to improve forage availability within the crofted landscape, although the number of bees observed remained low. Of the forage plants available, the three most frequently visited species were from the Fabaceae. We therefore conclude that the creation of agri-environment schemes which promote the use of Fabaceae-rich seed mixes and encourage the removal of sheep grazing on lowland areas throughout the summer are essential in order to conserve bumblebee populations within crofted areas.

1. Introduction

Farming is the predominant land use in much of Western Europe. In the UK, agricultural holdings spanned more than 17.3 million hectares in 2007, equivalent to 77% of the total landmass (DEFRA, 2007). Intensification of agricultural practices in Western Europe reached its peak in the latter half of the 20th century (Robinson and Sutherland, 2002), leading to a widespread reduction in landscape heterogeneity and a loss of many semi-natural habitats from farmed areas (Chamberlain et al., 2000; Green, 1990; Robinson and Sutherland, 2002). This is exemplified by the reduction in the area of unimproved lowland grassland in the UK, which declined by more than 90% between 1932 and 1984 (Fuller, 1987).

Habitat loss through agricultural intensification has led to extensive declines in biodiversity throughout the UK and Western Europe (Chamberlain et al., 2000; Green, 1990). In particular, population declines in a number of bumblebee (*Bombus*) species have primarily been attributed to the reduced availability of suitable foraging resources within the farmed landscape (Goulson, 2003a; Carvell et al., 2006; Goulson et al., 2008a). A reduction in nesting and hibernation sites (Goulson, 2003a; Goulson et al., 2008a), competition from introduced species (Goulson, 2003b) and potential pathogen spillover from commercially reared colonies (Colla et al., 2006) have also been identified as possible contributing factors to the decline of bumblebees.

Three of the 25 British bumblebee species are now extinct (Benton, 2006) and the rarest of the remaining species persist only in small isolated pockets which have largely escaped agricultural intensification (Goulson et al., 2006). The most north westerly fringes of Scotland are now considered to be an important stronghold for two of the UK's rarest bumblebee species, *Bombus distinguendus* and *Bombus muscorum* (Benton, 2006; Goulson et al., 2005). Maintaining appropriate management in these remote areas is vital if these species are to persist in the UK. Typically, agricultural units in these areas are called crofts, a Gaelic term used to describe a small area of enclosed land (Stewart, 2005), although crofters also have rights to communal grazing areas. Crofting practices exist only in certain parts of Scotland known as the 'crofting counties' and these include the former counties of Caithness, Sutherland, Orkney, Shetland, the Outer Hebrides, Skye and the Small Isles,

* Corresponding authors. Tel.: +44 1786 466540; fax: +44 1786 467843.
E-mail addresses: nicola.redpath@stir.ac.uk (N. Redpath), lynne.osgathorpe1@stir.ac.uk (L.M. Osgathorpe), k.j.park@stir.ac.uk (K. Park), dave.goulson@stir.ac.uk (D. Goulson).
[1] Joint first authors.

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Argyll, Ross and Cromarty and Inverness (Stewart, 2005). Within these counties, crofts are clustered together forming villages or crofting townships in which crofters implement small scale rotational cropping regimes alongside livestock production. Traditionally cattle and sheep graze the hills and moorland adjacent to the townships in the summer and lowland grasslands are grazed during the winter (Caird, 1987; Hance, 1952; Love, 2003; Moisley, 1962). These cropping and grazing regimes, combined with a limited use of artificial fertilisers and pesticides, renders crofting a very low intensity form of agriculture.

Crofted areas create a mosaic of habitats. Multiple small units in a township operate a range of land management practices on a small scale, including the implementation of fallow areas, a practice which is now often redundant elsewhere as artificial fertilisers remove the need to 'rest' nutrient poor soil. A mosaic of habitats is understood to promote high biodiversity and abundance within the agricultural landscape. Hence, crofting supports significant populations of a number of species which have declined elsewhere in the UK; for example corn buntings (*Miliaria calandra*) and corncrakes (*Crex crex*) (Stroud, 1998; Love, 2003; Mackenzie, 2007). However, crofting communities are changing. In the Western Isles of Scotland, the declining population size combined with an ageing population as a result of high outward migration of the young (Mackenzie, 2007; Western Isles Council, 2009), increasing house prices (Mackenzie, 2007), changes in agricultural subsidies and the Crofting Reform Act (2007) are all leading to changes in the way crofts are managed.

At present there is a lack of quantitative information with which to assess the influence of different croft management practices on biodiversity. This paper examines how land management practices currently implemented on crofts influence the abundance of foraging bumblebees and the availability of their key forage plant species. In order to conserve rare bumblebee populations within crofted regions it is necessary to identify land management practices which are of benefit to foraging bumblebees. The results of this study are intended to reduce the gaps in our knowledge regarding bumblebee populations within low intensity agricultural systems in the UK, and thereby inform future conservation strategies within these areas.

2. Methods

2.1. Study sites

Fieldwork was carried out on 31 crofts at four locations in northwest Scotland: Lewis, Harris, the Uists (considered as one study area as differences in crofting practices between North and South Uist were negligible in the context of this study), and Durness. A total of 10 crofters were responsible for the management of the 31 croft units surveyed. The land within each croft was subdivided into sections according to the management type implemented. In most cases a section was equivalent to a field. Each croft consisted of between 1 and 7 sections and the area of these sections ranged from less than 1 ha to a maximum of 5 ha. The land management type classifications used and their definitions are listed in Table 1. Most crofters employed a subset (1–7) of these management types.

2.2. Bumblebee sampling methods

Each croft was surveyed for bumblebees three times between 5th June and 22nd August 2008. Each croft was surveyed once in each of the 3 months with the exception of July when restricted access to crofts managed by one of the ten crofters meant that only 27 of the 31 crofts were surveyed. Surveys were conducted along a zigzag transect line established in each section of the croft. The transect looped across sections at 25 m intervals in order to ensure that a representative area of each section was surveyed and that the incidence of multiple recording of individual bumblebees would be minimised. The bumblebee surveying methodology used here was adapted from the standard butterfly recording protocol developed by Pollard (1977). All actively foraging bumblebees observed within 2 m on either side of the transect were recorded and identified to species level. In addition, the plant species on which bumblebees were foraging were also recorded. In sections containing arable crops, which could not be accessed, the zigzag transect was replaced by an 'L' shaped transect along two adjacent perimeter edges and all bumblebees foraging within 2 m of the crop side of the transect recorded as before. Surveys took place in dry weather and when temperatures exceeded 12 °C. The number and species of livestock present within a section was also recorded.

2.3. Forage plant sampling methods

The availability of bumblebee forage plants was recorded by carrying out vegetation surveys on all croft sections. A 0.5×0.5 m quadrat was positioned every 50 m along each of the bumblebee transects and all inflorescences present were counted and identified to species level. In arable sections quadrats were placed every 20 m along the bumblebee transect as zigzag transect walks could not be performed. This allowed more representative sampling of this management type. Quadrats were placed within the crop, but in order to reduce crop damage these were sampled from the edge of the field; therefore, they may not necessarily be representative of the whole crop area. Vegetation surveys were repeated once in June, July and August so that the availability of bumblebee foraging resources on each management type could be quantified throughout the bumblebee flight period.

2.4. Data analysis

The effect of land management on bumblebee abundance was examined using Generalised Linear Models (GLM) with quasipoisson

Table 1
Land management types and their definitions, including the area of each management type surveyed.

Management	Definition	Transect area surveyed (m^2)
Arable	Cultivated land sown with an annual crop, including mixed cereals (barley, oats and rye) and root vegetables	160–600
Bird and bumblebee conservation mix	A brassica-rich mix sown primarily to benefit a number of bird species and also foraging bumblebees. Contains kale, mustard, phacelia, fodder raddish, linseed and red clover	200–2000
Fallow	Cultivated land that has not been seeded for one or more years	600–4200
Mixed grazing	Land grazed throughout the year by a combination of both cattle and sheep	800–4600
Sheep grazed	Land grazed at various times throughout the year by sheep	800–7000
Silage	Grass crop harvested whilst green and then partially fermented for livestock fodder	600–4600
Unmanaged pasture	Formerly grazed pasture where active management has ceased	1200–3600
Winter grazed pasture	Pasture grazed between September and May	1600–6000

errors in the software package R version 2.7.2. Management type and crofter were included in the models as factors and transect area was used as an offset to account for the differences in the total area of each management type. For some sections, management changed over the 3 months of the study, so a separate model was constructed for each month of the survey period a R^2 value, was calculated to assess the fit of each model to the observed data. Where management was significant ($p < 0.05$), pair-wise post hoc comparisons were conducted to assess differences in bumblebee abundance between management types.

In addition to management type, the influence of sheep grazing on bumblebee abundance was specifically examined by categorising each croft section into either 'sheep present' or 'sheep absent' and performing a Mann–Whitney U test.

The availability of forage plants in each month was examined using generalised linear models in the same way as described above. The effect of croft management type was examined in relation to the mean number of bumblebee forage plant inflorescences per quadrat per section. Analyses were restricted to known bumblebee forage plants (Table 2; Charman, 2007), and included any additional species on which we observed bumblebees foraging.

The relationship between bumblebee abundance and bumblebee forage availability was analysed using generalised linear models with quasi-poisson errors and included crofter as a factor and transect area as an offset.

3. Results

3.1. Bumblebee species

A total of 246 foraging bumblebees belonging to six species were recorded on crofts throughout the survey period (Table 3). *B. muscorum* was the most commonly recorded species across the study area. *Bombus lucorum* was recorded less frequently but remained relatively common compared with *Bombus hortorum* and *B. distinguendus* which were both scarce. *Bombus jonellus* was not recorded on any crofts, although it does occur in the study areas.

The bumblebee species recorded varied between study areas. Geographic location governed the species present on some sites, such as the 'mainland ubiquitous' species *Bombus terrestris* and *Bombus pascuorum* (Benton, 2006) which were only observed at Durness. Whilst the ranges of the remaining species extend across the study area (Benton, 2006), *B. distinguendus* was only recorded on North Uist crofts and *B. hortorum* was absent from crofts on Harris.

There were seasonal variations in the abundance of bumblebees (Fig. 1a-c), and these patterns were consistent across species. Abundance was highest in August when 58% of all bees were observed (<0.003 bees m^{-2} in June and July, <0.03 bees m^{-2} in August). Notably, *B. hortorum* increased fivefold in numbers between June and August.

Table 2
The proportion of visits made by foraging bumblebees to each of the key forage plant species throughout the survey period.

Flower species	Family	% Total bumblebees		
		June	July	August
Trifolium repens	Fabaceae	49.2	33.3	8.0
Trifolium pratense	Fabaceae	1.7	13.3	15.9
Lotus corniculatus	Fabaceae	5.1	0	0
Vicia cracca	Fabaceae	1.7	13.3	11.6
Vicia sepium	Fabaceae	1.7	0	0
Lathyris pratensis	Fabaceae	0	4.4	0.7
Cirsium vulgare	Astercaeae	1.7	0	4.3
Cirsium arvense	Astercaeae	0	0	1.4
Centaurea nigra	Astercaeae	0	0	13.0
Leontodon spp.	Astercaeae	0	0	6.5
Hypochaeris glabra	Astercaeae	0	0	1.4
Rhinanthus minor	Scrophulariaceae	30.5	11.1	5.8
Pedicularis sylvatica	Scrophulariaceae	1.7	4.4	1.4
Odontites verna	Scrophulariaceae	0	8.9	3.6
Euphrasia officinalis	Scrophulariaceae	0	0	0.7
Prunella vulgaris	Labiatae	0	11.1	2.2
Lamium purpureum	Lamiaceae	0	0	0.7
Lamium amplexicaule	Lamiaceae	0	0	6.5
Brassica spp.	Brassicaceae	6.8	0	5.1
Succisa pratensis	Dipsacaceae	0	0.1	8.7
Filipendula ulmaria	Rosaceae	0	<0.1	0.7
Phacelia spp.	Boraginaceae	0	<0.1	0.7
Lychnis flos-cuculi	Caryophyllaceae	0	<0.1	0.7

Table 3
The percentage of each bumblebee species (total $n = 246$) observed foraging on crofts across the study area.

Bumblebee species	% Total bumblebees
B. muscorum/pascuorum[a]	77.2
B. lucorum/terrestris[a]	19.5
B. hortorum	2.4
B. distinguendus	0.8
B. jonellus	0.0

[a] *B. pascuorum* and *B. terrestris* were not present in the Outer Hebrides but due to the difficulty in distinguishing them from *B. muscorum* and *B. lucorum* respectively, these species were combined at Durness.

3.2. Croft management and bumblebee abundance

Bumblebee abundance was consistently low on all croft management types across all 3 months. This was demonstrated by a total of 246 bumblebees counted across a 3 month period compared with Carvell (2002) who observed 475 bumblebees on Salisbury Plain over a much shorter period (five weeks). In addition, surveys on the southern Hebridean island of Oronsay, which also took place in the summer 2008, found 283 bumblebees within three weeks (N. Redpath unpublished data).

Despite low overall numbers, land management type did have a significant effect on bumblebee abundance in all months (Tables 4). The effect of crofter on bumblebee abundance was significant in July and August only (Table 4). These models explained 22%, 70% and 47% of the variance in bee numbers in June, July and August respectively.

The utilization of each management type by foraging bumblebees varied between months (Figs. 1a–c). Bumblebee abundance was low in June with little variation observed between management types (Fig. 1a, Table 5). However, significantly more bumblebees were observed on sections sown with 'bird and bee' conservation seed mixes or managed for silage than either sheep grazed sections or winter pasture. Using the median number of bees observed, 'bird and bee' conservation mix and silage sections supported 47 and 27 times as many foraging bumblebees respectively than sheep grazed areas. The differences in abundance remained relatively large between the 'bird and bee' conservation mix and silage sections when compared to winter grazed sections, with 16 and 9 times as many bumblebees supported by these two management types respectively in June.

In July, mixed grazing sections contained significantly fewer bumblebees than fallow, silage and winter pasture (Fig. 1b, Table 6). The greatest difference in abundance was found between fallow and mixed grazed sections, with fallow supporting nine times the number of bumblebees than mixed grazed sections. Silage and winter grazed pasture were three and six times better for foraging bees than mixed grazed sections.

Significant differences between management types occurred more frequently in August than in either June or July (Fig. 1c, Table

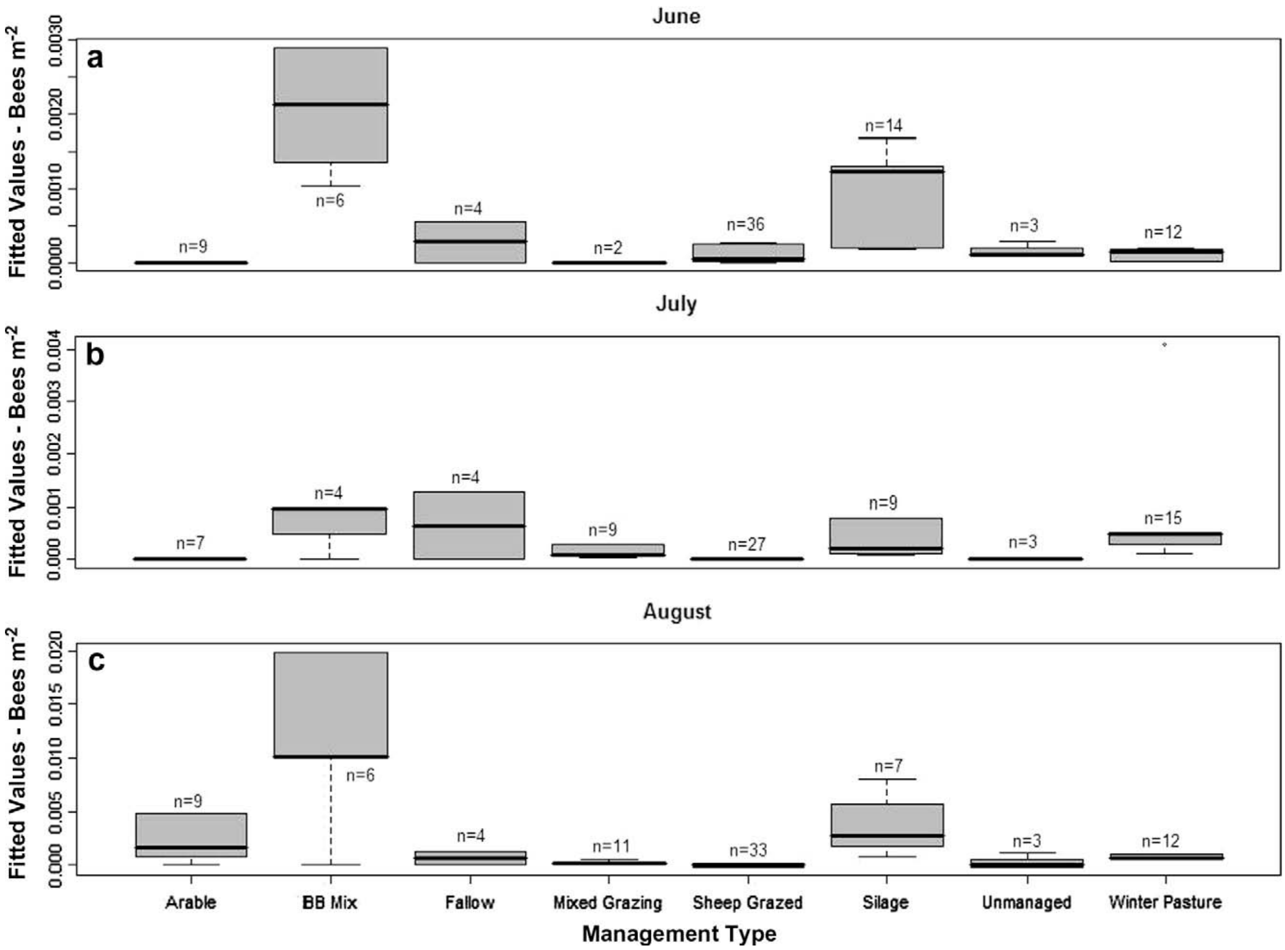

Fig. 1. a–c Box plots showing fitted values from the models for bumblebee abundance across eight different croft management types in June, July and August respectively. Boxes represent the location of the middle 50% of the data and the whiskers indicate the interquartile range of the data.

Table 4
A summary of test statistics derived from the model examining the effect of land management type and crofter on bumblebee abundance and on the abundance of bumblebee forage plant inflorescences across the survey period ($^{*}p = 0.05$, $^{**}p = 0.01$, $^{***}p = <0.001$).

Month	Bumblebee abundance		Floral abundance	
	Management	Crofter	Management	Crofter
June	$\chi^2_7 = 18.24^{***}$	$\chi^2_9 = 13.00$	$\chi^2_7 = 25.14^{***}$	$\chi^2_9 = 13.00^{***}$
July	$\chi^2_7 = 109.74^{***}$	$\chi^2_8 = 69.13^{***}$	$\chi^2_7 = 17.82^{*}$	$\chi^2_8 = 10.24$
August	$\chi^2_7 = 71.76^{***}$	$\chi^2_9 = 41.444$	$\chi^2_7 = 5.56$	$\chi^2_9 = 31.56^{***}$

7). 'Bird and bee' conservation sections supported significantly more bumblebees than all other management types except unmanaged pasture in this month. The difference in the median number of bees was greatest between the 'bird and bee' conservation mix and sheep grazed sections, the 'bird and bee' mix supporting a remarkable 248 times more bumblebees than sections grazed throughout the year by sheep. Mixed grazed sections also supported much lower numbers of foraging bumblebees than the 'bird and bee' mix with 65 times fewer bees found on this management type. Differences in the median bumblebee densities for the remaining management types were much lower and ranged from

Table 5
Pair-comparisons for management type on bumblebee abundance in June following a GLM indicating a significant effect of management. Where the relationship is significant the values have been highlighted in bold. Negative *t* values show that the management types listed along the rows of the table supported fewer bumblebees than the management listed as the column heading, and vice versa ($^{*}p = 0.05$, $^{**}p = 0.01$, $^{***}p = <0.001$).

Management types	Arable		B and B mix[a]		Fallow		Silage		Sheep grazed		Mixed grazing		Unmanaged pasture	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
B and B mix[a]	0.006	1.00												
Fallow	0.005	1.00	−1.500	0.14										
Silage	0.005	1.00	−1.263	0.21	0.773	0.44								
Sheep grazed	0.005	1.00	**−2.559**	*	−0.767	0.45	**−2.187**	*						
Mixed grazing	−<0.001	1.00	−0.002	1.00	−0.002	1.00	−0.002	1.00	−0.002	1.00				
Unmanaged pasture	0.005	1.00	−1.228	0.22	0.195	0.85	−0.162	0.87	0.675	0.50	0.002	1.00		
Winter pasture	0.005	1.00	**−2.403**	*	−0.874	0.39	**−2.057**	*	−0.270	0.79	0.002	1.00	−0.740	0.46

[a] B and B mix refers to the bird and bumblebee conservation mix.

Table 6
Pair-comparisons for management type on bumblebee abundance in July following a GLM indicating a significant effect of management. Where the relationship is significant the values have been highlighted in bold. Where the relationship is significant the values have been highlighted in bold. Negative *t* values show that the management types listed along the rows of the table supported fewer bumblebees than the management listed as the column heading, and vice versa (*p = 0.05, **p = 0.01, ***p = <0.001).

Management types	Arable		B and B mix[a]		Fallow		Silage		Sheep grazed		Mixed grazing		Unmanaged pasture	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
B and B mix[a]	0.003	1.00												
Fallow	0.003	1.00	<0.001	1.00										
Silage	0.003	1.00	<0.001	1.00	−1.124	0.27								
Sheep grazed	<−0.001	1.00	−0.005	1.00	−0.006	1.00	−0.006	1.00						
Mixed grazing	0.003	1.00	<0.001	1.00	**−2.881**	**	**−2.018**	*	0.005	1.00				
Unmanaged pasture	<−0.001	1.00	−0.002	1.00	−0.002	1.00	−0.002	1.00	1.44×10^{-6}	1.00	−0.002	1.00		
Winter pasture	0.003	1.00	<0.001	1.00	−0.466	0.64	0.550	0.58	4.00×10^{-3}	1.00	**2.343**	*	0.002	1.00

[a] B and B mix refers to the bird and bumblebee conservation mix.

Table 7
Pair-comparisons for management type on bumblebee abundance in August following a GLM indicating a significant effect of management. Where the relationship is significant the values have been highlighted in bold. Where the relationship is significant the values have been highlighted in bold. Negative *t* values show that the management types listed along the rows of the table supported fewer bumblebees than the management listed as the column heading, and vice versa (*p = 0.05, **p = 0.01, ***p = <0.001).

Management types	Arable		B and B mix[a]		Fallow		Silage		Sheep grazed		Mixed grazing		Unmanaged pasture	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
B and B mix[a]	**3.298**	**												
Fallow	−1.792	0.08	**−4.463**	***										
Silage	0.892	0.38	**−3.727**	***	**2.677**	**								
Sheep grazed	**−3.281**	**	**−5.596**	***	−1.842	0.07	**−4.104**	***						
Mixed grazing	**−2.824**	**	**−5.380**	***	−1.069	0.29	**−3.845**	***	0.963	0.34				
Unmanaged pasture	0.205	0.84	−1.875	0.07	1.116	0.27	−0.182	0.86	**2.311**	*	1.744	0.09		
Winter pasture	−1.152	0.25	**−4.535**	***	0.825	0.41	**−2.507**	*	**2.897**	**	**2.187**	*	−0.743	0.46

[a] B and B mix refers to the bird and bumblebee conservation mix.

4 to 16 times fewer bumblebees on these sections compared to the 'bird and bee' conservation seed mix.

Sheep grazed sections supported significantly fewer bumblebees than all other management types except mixed grazing and fallow (Table 7). The median number of bumblebees supported by mixed grazing and fallow was 4 and 16 times greater than that of sheep grazed sections (Fig 1c.). In addition to the differences between sheep grazed and 'bird and bee' conservation mix sections, silage and arable sections also maintained a much greater density of bumblebees than sheep grazed areas (68 and 41 times as many bumblebees respectively).

Sheep grazing had a negative effect on bumblebee abundance throughout the summer (Fig. 2). There were significantly fewer foraging bumblebees observed on croft sections used for sheep grazing at any point during the survey period compared with all other sections (June: $w = 2182.0$, $p = 0.02$; July: $w = 1782.5$, $p = 0.006$; August: $w = 2126.0$, $p < 0.0001$).

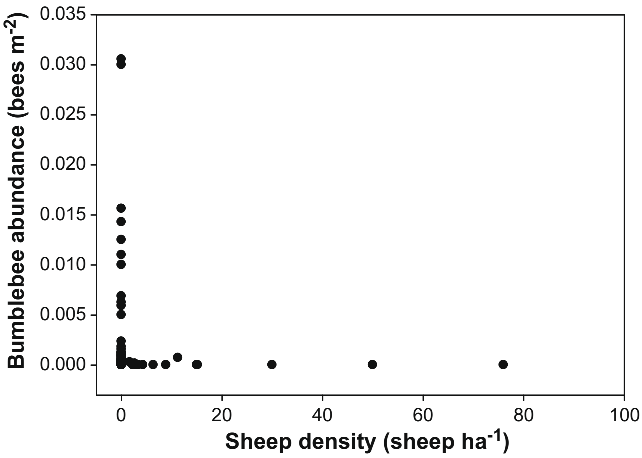

Fig. 2. The relationship between the density of grazing sheep and the relative abundance of foraging bumblebees on crofts in August. The pattern was identical for June and July.

3.3. Croft management and forage plant availability

The relationship between the availability of bumblebee forage plants and management type throughout the survey period broadly paralleled the trend observed in bumblebee abundance, with peak inflorescences recorded in August (Fig. 3c). However, the density of inflorescences recorded per quadrat was relatively low throughout the season (<15 flowers quadrat^{-1} in June and July, <25 flowers quadrat^{-1} in August). There was a significant effect of management type on inflorescence availability in June and in July (Tables 4, 8 and 9). Crofter was only significant in June and August (Table 4). Despite the highest mean number of inflorescences per quadrat within each section occurring in August, variation between management types was greatly reduced when compared to the previous months (Fig. 3a–c, Table 10). Consequently, the effect of management type on the availability of forage plants was not significant in August (Table 4). Again, a relatively large proportion of the variation observed within the dataset was explained by the models (R^2 for June: 61%, July: 55%, August: 60%) and this relationship between forage plants and land management type was broadly similar to that observed in July.

3.4. The relationship between bumblebee abundance and forage plant availability

The relationship between the numbers of bumblebees and flowers varied throughout the survey period in line with the temporal availability of foraging resources. June was a particularly poor

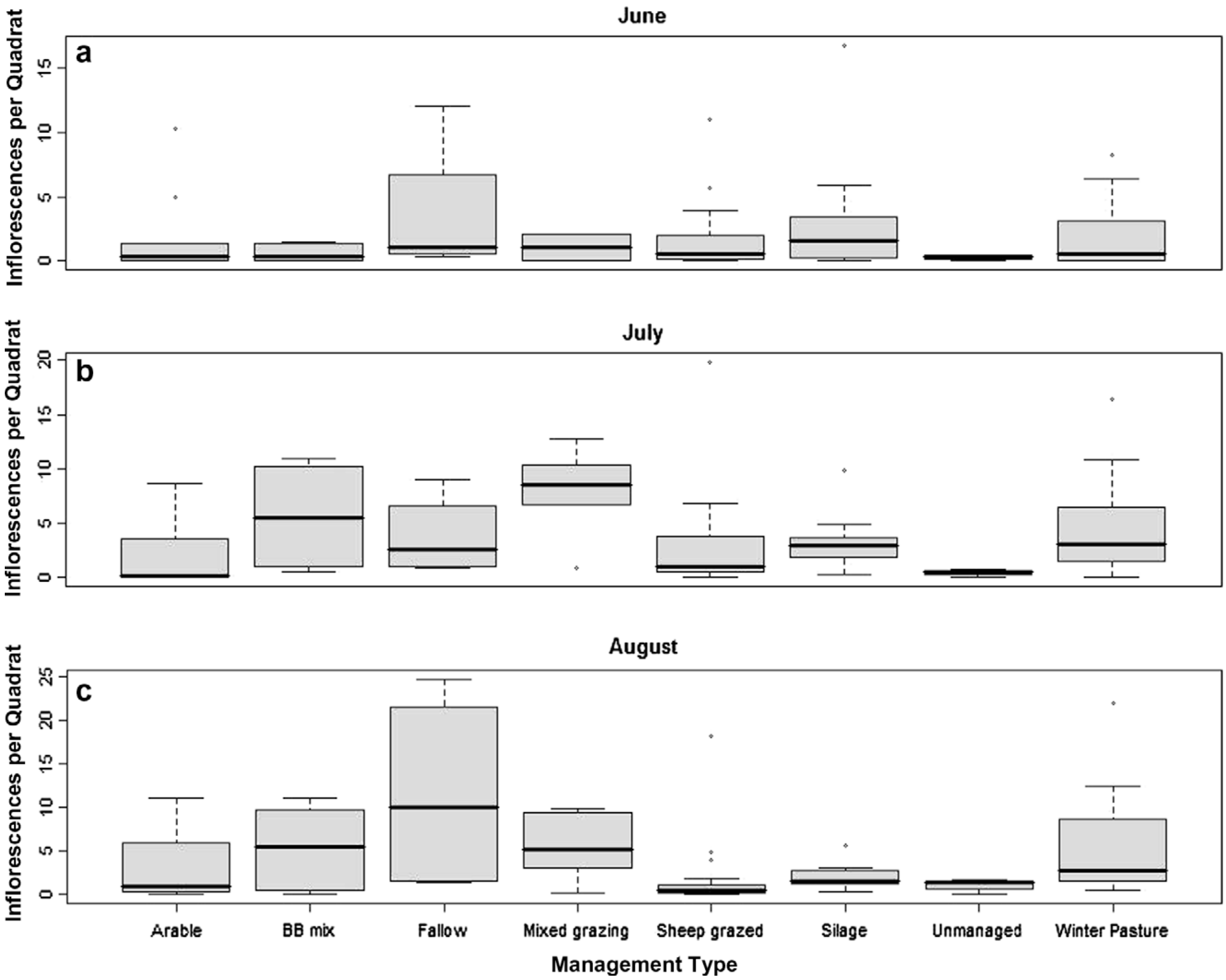

Fig. 3. a–c Box plots showing variation in the abundance of forage plant abundance across eight different croft management types in June, July and August respectively. Abundance was measured as the mean number of inflorescences recorded per quadrat for each management type. Boxes represent the location of the middle 50% of the data and the whiskers indicate the interquartile range of the data.

Table 8
Pair-comparisons for management type on floral abundance in June following a GLM indicating a significant effect of management. Where the relationship is significant the values have been highlighted in bold. Negative *t* values show that the management types listed along the rows of the table had lower floral abundance than the management listed as the column heading, and vice versa (* *p* = 0.05, ** *p* = 0.01, *** *p* = <0.001).

Management types	Arable		B and B mix[a]		Fallow		Silage		Sheep grazed		Mixed grazing		Unmanaged pasture	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*P*	*t*	*p*	*t*	*p*
B and B mix[a]	−0.933	0.35												
Fallow	−0.555	0.58	0.135	0.89										
Silage	**2.124**	*	**2.557**	*	1.699	0.09								
Sheep grazed	0.023	0.98	1.128	0.26	0.593	0.56	**−3.316**	**						
Mixed grazing	−0.252	0.80	0.563	0.58	0.323	0.75	−1.958	0.05	−0.306	0.76				
Unmanaged pasture	−1.031	0.31	−0.453	0.65	−0.492	0.62	−1.929	0.06	−1.112	0.27	−0.816	0.42		
Winter pasture	1.213	0.23	1.92	0.06	1.261	0.21	−0.803	0.42	1.827	0.07	1.207	0.23	1.617	0.11

[a] B and B mix refers to the bird and bumblebee conservation mix.

month for flowering plants across the study area due to a prolonged period of unusually dry weather in the preceding months, and the number of bumblebees per croft section did not vary significantly with flower abundance ($\chi^2 = 0.27$, d.f. 1, $p = 0.602$). Floral abundance increased in July and August across the study area and inflorescence availability became a significant predictor of bumblebee abundance in both months ($\chi^2 = 8.30$, d.f. = 1, $p = 0.004$ in July, $\chi^2 = 10.67$, d.f. = 1, $p = 0.001$ in August). The amount of variation in bumblebee abundance explained by these models was low (all R^2 values were <0.1), indicating that models using management type are a better predictor of bumblebee abundance across the study area.

3.5. Bumblebee forage plants

The floral resources utilised by foraging bumblebees varied throughout the season (Table 2). In line with increasing floral abundance and diversity, the number of species visited by

Table 9
The effect of management type on floral abundance in July. The *t* and *p* values are derived from pair-wise comparisons made between each of the management types, where the relationship is significant the values have been highlighted in bold. Negative *t* values show that the management types listed along the rows of the table had lower floral abundance than the management listed as the column heading, and vice versa ($^{*}p = 0.05$, $^{**}p = 0.01$, $^{***}p = <0.001$).

Management types	Arable		B and B mix[a]		Fallow		Silage		Sheep grazed		Mixed grazing		Unmanaged pasture	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
B and B mix[a]	1.364	0.18												
Fallow	1.373	0.18	−0.074	0.94										
Silage	1.554	0.13	0.474	0.64	0.713	0.48								
Sheep grazed	1.341	0.19	−0.254	0.80	−0.177	0.86	−1.213	0.23						
Mixed grazing	1.641	0.11	0.768	0.45	1.068	0.29	0.514	0.61	1.862	0.07				
Unmanaged pasture	0.601	0.55	−1.116	0.27	−1.057	0.29	−1.368	0.18	−1.065	0.29	−1.518	0.13		
Winter pasture	1.634	0.12	0.758	0.45	1.048	0.30	0.450	0.65	1.977	0.05	−0.056	0.96	1.513	0.14

[a] B and B mix refers to the bird and bumblebee conservation mix.

Table 10
Pair-comparisons for management type on floral abundance in August following a GLM indicating a significant effect of management. Where the relationship is significant the values have been highlighted in bold. Negative *t* values show that the management types listed along the rows of the table had lower floral abundance than the management listed as the column heading, and vice versa ($^{*}p = 0.05$, $^{**}p = 0.01$, $^{***}p = <0.001$).

Management types	Arable		B and B mix[a]		Fallow		Silage		Sheep grazed		Mixed grazing		Unmanaged pasture	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
B and B mix[a]	1.269	0.21												
Fallow	1.787	0.08	0.084	0.93										
Silage	0.401	0.69	−1.017	0.69	−1.009	0.32								
Sheep grazed	0.638	0.53	−1.062	0.53	−1.376	0.17	0.111	0.91						
Mixed grazing	0.464	0.64	−0.970	0.64	−1.233	0.22	0.005	0.10	−0.152	0.88				
Unmanaged pasture	0.443	0.66	−0.442	0.66	−0.471	0.64	0.175	0.86	0.130	0.90	0.179	0.86		
Winter pasture	0.704	0.48	−0.807	0.48	−1.062	0.29	0.224	0.82	0.227	0.82	0.365	0.72	−0.050	0.96

[a] B and B mix refers to the bird and bumblebee conservation mix.

bumblebees more than doubled between the beginning of the survey period and August, when a total of 21 flowering plants were utilised. However, it must be noted that many more bees were observed in August, and with more records we would expect to detect more visits to minor food sources.

Early in the season white clover (*Trifolium repens*) and yellow rattle (*Rhinanthus minor*) were the most frequently visited flower species receiving 49% and 30% of all visits in June, respectively. Sections managed as silage and winter pasture contained a high proportion of these two species (between 12% and 65%), and the greatest proportion of yellow rattle (65%) was found in areas of silage. Sheep grazed sections supported the greatest proportion of white clover in flower during June, with over 56% of all inflorescences recorded on this management type. However, no significant relationship was observed between bumblebee and flower abundance in this month.

Visits to white clover declined in July to 33% although it still remained the most frequently visited species and its abundance remained greatest on sheep grazed sections where 63% of this species was recorded. The use of other species increased during July, particularly those belonging to the Fabaceae. Red clover (*Trifolium pratense*) and tufted vetch (*Vicia cracca*) increased from less than 2% of visits each in June to both receiving 13% of visits in July. In contrast to white clover, records of red clover and tufted vetch on sheep grazed sections were negligible with <1% of flowers observed on this land management type. The greatest proportion of red clover was found on fallow and winter grazed areas (38% and 31% respectively), and 19% were recorded on sections sown with the 'bird and bee' conservation seed mix. Tufted vetch was less well distributed with over 95% of all inflorescences recorded on the 'bird and bumblebee' mix sections. The remaining 5% of flowers were found on silage and winter grazed sections. Overall, 67% of foraging visits observed in July were to species belonging to the Fabaceae.

Fabaceae continued to be the most important forage plant family in August although the proportion of visits declined to 36% in total. The Asteraceae also received a large proportion of total visits (26%) and the Scrophulariaceae were the third most frequently visited family, receiving 11% of foraging visits. All remaining plant families accounted for less than 10% of visits in August.

In August the number of plant species visited by foraging bumblebees was greater than in June and July. However, just three species (red clover, tufted vetch and common knapweed (*Centaurea nigra*)) accounted for over 40% of all bumblebee foraging visits in August (Table 2). Both red clover and common knapweed were predominately found on fallow sections which contained over 75% of all inflorescences recorded belonging to each species during August. The majority (78%) of tufted vetch was recorded on sections of 'bird and bee' conservation seed mix, although this species is not included in the 'bird and bee' seed mix and must therefore have come from the existing seed bank or seed rain.

4. Discussion

The highly intensive nature of farming in Western Europe is considered to be the primary factor driving bumblebee declines (Goulson et al. 2008a). However, this study found that even in the relatively low intensity crofting systems in northwest Scotland, bumblebees and their forage plants were present only at very low densities. The limited number of *B. distinguendus* observed on crofts is of particular concern as the study area encompasses some of the few remaining strongholds for this species in the UK (Benton, 2006; Goulson, 2003a). Although not described as a habitat specialist, *B. distinguendus* is now strongly associated with rare flower-rich machair habitats which are limited in their distribution to Scotland's northwest coast (Angus, 2001; Benton, 2006). Due to the location of crofts in relation to the machair, only a small proportion of the crofts included in this study encompassed actively managed areas of machair and this could go some way in explaining the limited number of observations of B. distinguendus on crofts.

Heterogeneous landscapes are often associated with high species richness (e.g. Weibull et al., 2003). Small scale, low intensity agricultural systems promote a mosaic of habitat types and therefore they are often considered to be of benefit to biodiversity compared with more intensive systems. However, studies of bumblebee diversity in low intensity agricultural systems in Estonia have demonstrated that even in these heterogeneous farming systems, the adjacent non-agricultural habitats supported a greater diversity of bumblebee species (Mänd et al., 2002). Although we did not include habitats adjacent to crofts in this study, these non-agricultural areas could potentially be providing important foraging resources for bumblebees and therefore explain why such low numbers were recorded on crofts. During the period of fieldwork we observed more than 20 *B. distinguendus* on roadside verges but only 2 on the crofts in our study (N. Redpath and L. Osgathorpe, pers. obs.). Research into this area is on-going. Non-croft habitats may also provide hibernation and nesting sites, two key ecological requirements which are important factors for bumblebee conservation, and we recommend that further research in this area is conducted.

4.1. The effect of land management type on the abundance of bumblebees and their forage plants

In general, the 'bird and bee' conservation mix, fallow and silage were the land management types which supported the greatest number of bumblebees. However, the efficacy of each of these management types in attracting foraging bumblebees varied throughout the season which reiterates the importance of a heterogeneous agricultural landscape (Weibull et al., 2003). Significantly more foraging bumblebees were observed on areas of crofts which were not sheep grazed. The absence of livestock in the summer allows plants to flower and set seed, whilst grazing in the winter promotes plant species diversity by creating an open sward which allows wildflowers to compete with grasses (Stewart and Pullin, 2008). In particular, our findings demonstrate that there is a marked negative relationship between the abundance of foraging bumblebees and sheep grazing. Even at low density, sheep grazed pasture supported negligible numbers of bumblebees and therefore management of sheep is a key factor in determining the value of crofts for bumblebees. Previous studies have revealed a benefit of cattle grazing over sheep grazing or unmanaged pasture in maintaining bumblebee diversity and abundance (Carvell, 2002), but we were unable to survey pasture grazed solely by cattle as any cattle present were in a mixed livestock system.

In August, sections of 'bird and bee' conservation mix and silage supported significantly more bumblebees than other management types. Although these sections supported a lower abundance of bumblebee forage material than fallow or winter grazed sections they contained the highest proportions of red clover and tufted vetch which were two of the most frequented species by foraging bumblebees during August. However, it should be noted that tufted vetch was not a component of the sown mix and therefore its presence in these sections must be a result of the existing seed bank or seed rain from the surrounding area. This suggests that it is the availability and abundance of certain key plants and not the overall diversity of forage material which is important for maintaining bumblebee populations throughout the season. This is exemplified by our results which show that although the range of forage plants available was greatest in August, foraging bumblebees predominantly visited only three species.

4.2. Management recommendations for bumblebee conservation

The data presented here demonstrate that crofting practices in northwest Scotland are not currently supporting high numbers of bumblebees or their forage plants. Whilst some land management types have been identified as more beneficial than others in promoting forage plant availability and bumblebee abundance, the low overall number of bumblebees recorded on crofts would suggest that none of the management types surveyed are of great benefit to the conservation of bumblebees.

Sheep grazing on crofts is on the increase partly due to the dramatic increase in sheep numbers in these areas since the 1940s (Hance, 1952; Willis, 1991). Stocking densities, particularly sheep densities, are increasing habitat homogeneity across crofted areas as sheep grazing has a particularly detrimental effect on floral diversity and abundance. In turn, this has a negative impact on the number and diversity of bumblebees which are able to exploit the remaining limited forage resources. If populations of rare bumblebees are to persist in crofted regions, we would strongly recommend a return to the historically traditional grazing regimes which ensure livestock are grazed on lowland areas in the winter and put out to graze on the hill and moor lands in the summer months, allowing the lowland grassland areas to flourish and flower. If this is not always practical, then an alternative possibility may be to increase sheep density in some areas, thereby allowing others to be left ungrazed on a rotational basis.

The species composition and abundance of foraging resources are key for maintaining the diversity of foraging bumblebees (Goulson et al., 2008b). This study supports previous work which suggests that sufficient areas of key forage plants are of importance when conserving bumblebees, even within low intensity agricultural systems (Mänd et al., 2002). The provision of forage material throughout the entire bumblebee season, from the time when queens emerge from hibernation throughout the summer until the reproductives are produced is particularly important (Bäckman and Tiainen, 2002; Westphal et al., 2006). Successional sowings of conservation seed mixes may achieve this lengthy flowering period (Carreck and Williams, 2002), and the inclusion of spring flowering species would also be of additional conservation value to nest founding queen bumblebees (Lye et al., 2009).

Several studies have helped to identify which conservation seed mixes are most useful for foraging bumblebees (e.g. Carvell et al., 2007). However, to date, research has been focussed almost exclusively on intensive lowland farms in England (Pywell et al., 2004, 2006; Carvell et al., 2007). In areas of low intensity agriculture such as the crofted regions of Scotland the implementation of bumblebee conservation measures is perhaps more pressing than previously thought. Conservation measures for bumblebees on crofts should perhaps not aim to maximise floral diversity but instead increase the availability of a narrower range of key plant species. It is possible that a greater diversity in the plant community may support a greater diversity of invertebrates, but for bumblebees, a number of key forage plant species appears to be more important than the creation of hugely diverse swards. In addition, *Parotapion ryei*, another UK BAP invertebrate species which has a stronghold in the Hebrides but is classified as nationally scarce, relies on red clover as a larval food source and therefore promoting clover rich seed mixes for the conservation of bumblebees may be of benefit to populations of this rare weevil. However, we also recognise that a broad range of flowering species may be of greater benefit to a larger suite of invertebrates not considered in this study.

The results of this study show that despite the use of a wide range of flower species by foraging bumblebees throughout the summer, over 44% of all visits were to just three species belonging to the Fabaceae (red clover, white clover and tufted vetch). This supports work by Goulson and Darvill (2004) showing that 65%

of bumblebee foraging visits on Salisbury plain were to just six species.

5. Conclusions

Although current croft management techniques do not support significant numbers of bumblebees, crofting can still play an important role in their conservation. This could be achieved through the adoption of agri-environment schemes tailored specifically for low-intensity systems but these are not currently available. In order to encourage bumblebees, particularly the rare long-tongued species such as *B. distinguendus*, to thrive within the crofted regions of northwest Scotland we recommend the development of targeted schemes which promote the implementation of bumblebee-specific seed mixes in conjunction with the late cutting of grass crops. Mixes containing a high proportion of Fabaceae, specifically red and white clover, have been identified as important for bumblebees within agricultural landscapes elsewhere in Europe (Bäckman and Tiainen, 2002; Goulson and Darvill, 2004; Goulson et al., 2005; Carvell et al., 2006; Diekötter et al., 2006). Our research suggests that these Fabaceae-rich mixes would also be highly appropriate within the context of bumblebee conservation in northwest Scotland. We also recommend that payments for the removal of sheep from lowland areas during the summer months should be included in future agri-environment schemes. This would help to ensure that the floral diversity added to the landscape through the use of conservation seed mixes is not compromised and also potentially enable natural regeneration of sward diversity in otherwise overgrazed areas.

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