The rapid response of foraging bumblebees *Bombus* spp. to hay meadow restoration in the Yorkshire Dales and Forest of Bowland, UK

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SUMMARY

Widespread pollinator and bumblebee decline has been documented across Europe and North America and much of this can be attributed to pressures from agricultural intensification. A greater area of pollinator and bumblebee habitat is needed to reverse this decline. We utilised the Bumblebee Conservation Trust 'Beewalk' to assess the effect of hay meadow restoration on bumblebee numbers in the Yorkshire Dales National Park and Forest of Bowland Area of Outstanding Natural Beauty. The abundance and diversity of bumblebee species significantly increased with restoration, even within the first year post-restoration, and restored meadows were not significantly different from ancient meadows. Data on flowers visited by bumblebees demonstrated that the most important forage plants for bumblebees had been transferred to the restored meadows.

BACKGROUND

There are well-documented declines in some wild insect pollinators, including bumblebees *Bombus* spp., in Europe and North America (Goulson *et al*. 2015, Potts *et al*. 2016). Concerns have been raised about the possible impacts on the valuable ecosystem service they provide (Potts *et al*. 2016). Multiple factors are known to be driving this decline: agricultural intensification causing loss of flower resources and fragmentation of habitat, pesticide use, introduction of pathogens and parasites from imported commercial bees; and possibly climate change (Goulson *et al*. 2005, 2015).

The loss of 97% of the UK's traditionally managed floral rich hay meadows in the last 70 years has greatly depleted an important pollinator resource. Restoration of this type of habitat is a recognised measure to increase bumblebee and pollinator populations in an agricultural setting (Goulson *et al*. 2015). Such restoration has been achieved through agri-environment schemes, with Higher Level Stewardship (HLS) providing financial recompense in return for provision of wildflower field margins and meadow restoration (HLS is a UK government initiative which aims to deliver environmental benefits in priority areas through land management practices). The restoration of the floral diversity of field margins has been shown to increase the number of foraging bumblebees (Kells *et al*. 2001, Carvell *et al.* 2004, 2007). Wood *et al.* (2015) found both higher numbers of foraging bees and higher nest densities under targeted HLS agri-environment schemes. However, most of the pollinator-focussed options in such schemes cover only small areas and contribute relatively little to national nectar resources (Baude *et al*. 2016). Consequently, increasing the floral resource of improved grasslands, which cover a much larger area, should result in a much greater increase in nectar provision (Baude *et al*. 2016).

Grassland restoration tends to be monitored in terms of the response of the flora but, given the key role that meadows could play in pollinator conservation, we need to understand the response of bees to meadow restoration work. Citizen science initiatives such as 'Beewalk', launched by the Bumblebee Conservation Trust (BBCT) in 2013, are designed to collect diversity and abundance data, addressing the recognised lack of data for measuring long-term trends (Goulson *et al*. 2015). We aimed to combine the Beewalk protocol and upland hay meadow restoration projects to investigate how numbers of foraging bumblebees have responded to hay meadow restoration. Three types of hay meadow were surveyed to compare bumblebee numbers in meadows that have been agriculturally intensified (usually re-seeded with commercial grasses; called 'Modern' below) with those that have undergone restoration work to restore floral diversity (Restored) and those historically managed in the traditional manner (which have retained floral diversity – Ancient).

The sites studied are within the Yorkshire Dales National Park and Forest of Bowland Area of Outstanding Natural Beauty (AONB) in the north of England (Figure 1). All meadows were a minimum of 150 m above sea level, in areas of high rainfall, and cooler than national average temperatures.

ACTION

The remnant traditional hay meadows of the Yorkshire Dales and Forest of Bowland have had support from the 'Hay Time' and 'Meadow Links' projects of Yorkshire Dales Millennium Trust (YDMT) and Forest of Bowland AONB, using HLS and project-specific funding for restoration projects to improve their floral diversity. Since 2006 these projects have undertaken restoration works on more than 600 hectares, aiming to increase the area of traditional hay meadow by 60% to add to the surviving 1,000 hectares in the region. The most common restoration method has been transferring green hay from nearby donor sites, enhanced by locally sourced seed in some meadows (St. Pierre 2016, Robinson 2015).

A total of 49 meadows at 16 sites were categorised as 'Ancient', 'Modern' or 'Restored' as follows: -

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Ancient (*n* = 27): Traditional hay meadows that have been maintained by a management regime of one hay cut per annum from mid-July onwards, low stock grazing in autumn and spring, and no inorganic fertiliser treatment.
Modern (*n* = 13): Agriculturally improved hay meadows, usually cut once per annum, with organic and/or inorganic fertiliser treatment, and more intensive grazing in autumn through to spring; some may have remnant hay meadow species, often in refuges on the field margins which escape management.
Restored (*n* = 9): Previous agriculturally improved hay meadows that have been restored and now managed as per Ancient meadows.

Restoration methods varied across the meadows according to what was locally practicable, most commonly using green hay. Following the pre-treatment of restoration sites with crop removal and harrowing, green hay was collected from nearby donor meadows during late July to August (some of which are included in the 'Ancient' meadows for this study), then transported and spread within an hour to avoid heating the crop. The transfer rate ranged from 1 ha donor hay spread onto 3 ha restored meadow, to 1 ha donor:5 ha restored. In most sites the flora successfully re-established but occasionally seed, again harvested from nearby meadows, was added to enhance species richness and abundance in the following year (Robinson 2015, St. Pierre 2016). The year of restoration ranged from 2000 to 2015 but the majority (n = 6) were surveyed only one to three years post-treatment.

Figure 1. Bumblebee survey sites across the Yorkshire Dales and Forest of Bowland AONB shown at markers. Inset: overall survey location within the UK (Digimap, 2016).

Sites were surveyed between mid-June and the end of July 2016 to encompass the flowering times for meadow flora, emergence times of bees and the cutting of the hay crop at the end of July.

Training on the methods used for transects and bumblebee identification was given to 'Beewalk' volunteers prior to the start of the data collection period, including a sample transect to monitor the ability of the volunteers at the end of the training. Transects for this study were walked by 28 volunteers.

Hay meadow transects were walked once weekly for 6 weeks from mid-June to mid-late July (when the hay is cut). All bumblebee species observed within 2 m either side and up to 4 m ahead of the surveyor were recorded, whilst walking at a slow pace, between 09:45 h and 18:00 h, on days with no rainfall, wind speed less than 10 ms^{-1} and minimum temperature of 13°C; (i.e. favourable conditions for bumblebee foraging). Weather conditions were recorded to ensure data collection fell within the required parameters. Transects passed through different meadow types so each was subdivided into sections relating to meadow type.

The workers of the white-tailed bumblebee *Bombus lucorum* and buff-tailed bumblebee *Bombus terrestris* are notably difficult to separate in the field and therefore, in common with other field-based bumblebee studies, they were recorded as a single taxon. Unidentified bumblebees (often those seen in flight) were not included in the data analysis. A small number of cuckoo bumblebees were recorded but were also excluded from the data analysis.

When bumblebees were recorded while visiting flowers the plant species was recorded to provide information on bumblebee foraging habits across the hay meadows.

As the sections of transects differed in length, the count on each section was converted to the number of each species per 1,000 m of transect. This enabled the count data to be comparable across transect sections and habitats. Differences in bumblebee abundance among sites were determined by a Kruskal-Wallis test with post-hoc Tukey and Kramer (Nemenyi) tests to show the location of differences.

CONSEQUENCES

Bumblebee abundance and species richness: Ten bumblebee species were recorded across all the sites. Both white-tailed bumblebee *B. lucorum* and buff-tailed bumblebee *B. terrestris* queens were recorded. The other species recorded were garden bumblebee *B. hortorum*, red-tailed bumblebee *B. lapidarius*, tree bumblebee *B. hypnorum*, early bumblebee *B. pratorum* and the common carder bee *B. pascuorum*; all widespread and common species (Goulson *et al*. 2005). The heath bumblebee *B. jonellus* (a localised heathland specialist), and the bilberry bumblebee *B. monticola* (rare and declining) were recorded in small numbers in the Ancient and Restored meadows. Two field cuckoo bumblebees *B. campestris* were recorded, both on restored sites. Apart from the cuckoos, the other nine species are early to mid-season emerging species (Goulson 2003) and by mid–June the workers of these species would be expected to be actively foraging.

The median abundance of bumblebees 1000 m^{-1} differed among the three types of hay meadow, Ancient = 50, Modern = 9 and Restored = 60 ($H = 13.03$, d.f. = 2, $p < 0.001$, see Figure 2a), with significantly more bumblebees recorded in Ancient and Restored meadows than in Modern meadows. There was a significant difference in the abundance of bumblebees between the Ancient and Modern meadows ($p < 0.01$), and between the Restored and Modern meadows ($p < 0.01$), but no significant difference between the Restored and Ancient meadows ($p = 0.74$). The greatest abundance of bumblebees 1,000m^{-1} of transect was recorded in an Ancient meadow at Bell Sykes Farm, Slaidburn, Lancashire, which can be seen as an outlier in Figure 2a. Two meadows were restored in 2015. The average bumblebee abundance in these one-year post-restoration

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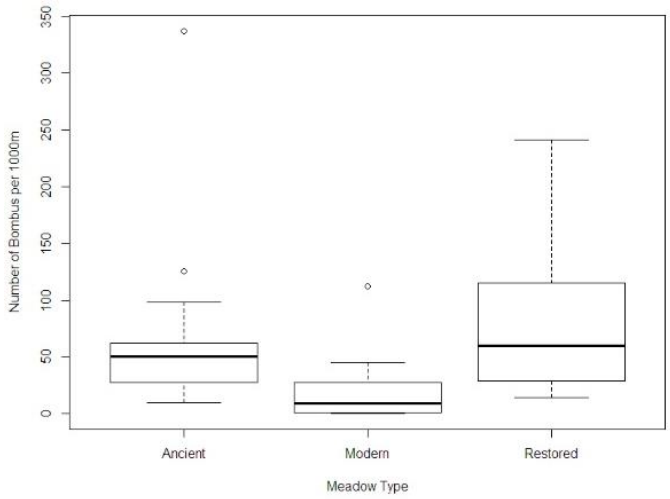

Figure 2a. Abundance of bumblebees 1,000 m^{-1} of transect recorded across three types of hay meadow (n = 49) surveyed June to July 2016: Ancient, Modern and Restored (H = 13.03, d.f. = 2, $p < 0.001$). Boxplot show medians (horizontal line), interquartile range (boxes), 1.5 times interquartile range (whiskers) and outliers (circles). Note - outlier in Ancient meadows.

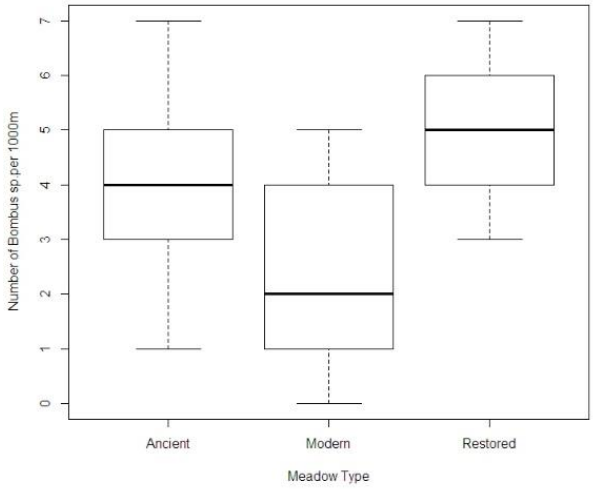

Figure 2b. Number of bumblebee species 1,000 m^{-1} of transect recorded across three types of hay meadow (n = 49) surveyed June to July 2016: (Ancient = 5, Modern = 2, Restored = 5: H = 11.54, d.f. = 2, $p < 0.01$); Boxplot show medians (horizontal line), interquartile range (boxes), and 1.5 times interquartile range (whiskers).

meadows was 63/1,000 m of transect. This is comparable to the numbers recorded in Ancient and all Restored meadows and much greater than the 23/1,000 m of transect recorded in Modern meadows.

The median number of different species recorded across the three types of hay meadow also differed significantly (Ancient = 4, Modern = 2, Restored = 5: H = 11.54, d.f. = 2, $p < 0.01$); with significant differences between the Restored and Modern meadows ($p < 0.01$) and between Ancient and Modern meadows ($p < 0.05$), but there was no significant difference ($p = 0.33$) in species richness between Restored and Ancient meadows. The highest number of species recorded at one site was equal in both Ancient and Restored meadows (see Figure 2b).

Overall the abundance of the combined *B. lucorum* and *B. terrestris* ("*B. lucter*") taxon was the highest recorded across all meadow types, and was more than three times greater than that of the next most abundant species (Figure 3). *B. hortorum* was the only species more common in the Ancient meadows than the Restored meadows, and *B. hypnorum* were most abundant in the Modern meadows, although both were recorded in low numbers. *B. jonellus* and *B. monticola* were recorded in slightly greater numbers in the Restored meadows than in the Ancient meadows and both species were absent from Modern meadows.

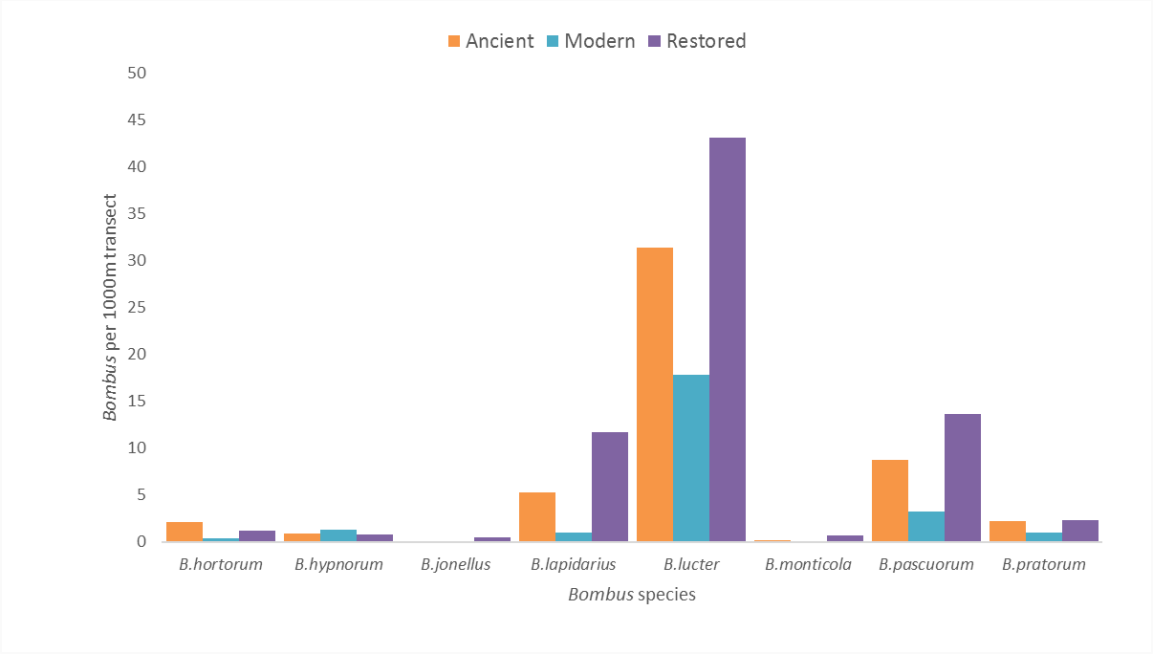

Figure 3. The distribution of bumblebees across three types of hay meadow in the north of England, surveyed June to July 2016. *B."lucter"* = *B. lucorum* and *B. terrestris* combined.

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Table 1. The 15 most common flower types visited by bumblebees, shown as the percentage of all recorded visits across three types of hay meadow in the north of England, June and July 2016. Plant types are presented in order with the most commonly visited first. The Berger-Parker Dominance score represents the proportion of bee visits in a particular meadow type attributable to the most commonly visited flower; lower values show a greater diversity of flowers visited.

			% of all recorded flower visits			
Plant Species	**Common name**	**Family**	**Ancient**	**Restored**	**Modern**	**Total across all meadows**
Trifolium sp.	Clovers	Fabaceae	15.85	12.00	7.12	34.96
Rhinanthus minor	Yellow rattle	Orobanchaceae	11.71	11.84	0.81	24.35
Centaurea nigra	Common knapweed	Asteraceae	8.34	0.71	0.00	9.06
Hypochaeris radicata	Common cat's-ear	Asteraceae	0.61	7.05	0.00	7.66
Leontodon hispidus	Rough hawkbit	Asteraceae	4.75	0.19	1.10	6.05
Lathyrus pratensis	Meadow vetchling	Fabaceae	3.14	0.49	0.39	4.01
Geranium pratense	Meadow crane's-bill	Geraniaceae	1.97	0.00	0.00	1.97
Ranunculus spp.	Buttercups	Rosaceae	0.84	0.94	0.16	1.94
Prunella vulgaris	Selfheal	Lamiaceae	1.42	0.36	0.00	1.78
Euphrasia officinalis agg.	Eyebright	Orobanchaceae	0.87	0.61	0.16	1.65
Cirsium spp.	Thistles	Asteraceae	0.81	0.00	0.74	1.55
Vicia spp.	Vetch	Fabaceae	0.97	0.06	0.06	1.10
Filipendula ulmaria	Meadowsweet	Rosaceae	0.84	0.03	0.10	0.97
Succisa pratensis	Devil's-bit scabious	Dipsaceae	0.84	0.00	0.00	0.84
Rubus spp.	Brambles and wild raspberry	Rosaceae	0.00	0.16	0.00	0.16
TOTAL % visits			**52.96**	**34.44**	**10.64**	**98.06**
Berger Parker Dominance score			**0.299**	**0.348**	**0.669**	

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Floral visitation: The data on bumblebee visits to flowers have some limitations as there is no reference to the abundance or phenology of flowers across the habitats and, due to the varying levels of plant identification skills of the volunteers, some species were aggregated as, for example, 'thistle' or 'clover'. However, they do show which species are of greatest importance to the foraging bumblebees.

The fifteen most visited flowers accounted for 98% of all recorded bumblebee visits across all meadows (Table 1). These favoured flowers are likely to be the species providing the best nectar and pollen, in terms of quantity and quality (Baude *et al*. 2016), but they might also be visited often because they are abundant in the meadows. Clovers *Trifolium* spp. accounted for over one third (35%) of the visits (Table 1) and they were the most commonly visited flowers in all habitats, but they dominated the visits to a much greater extent in the modern meadows. Clovers are recognized as a significant source of nectar in grasslands (Baude *et al*. 2016) and were found to be a dominant source of pollen collected by bees in the study by Wood *et al*. (2015). Yellow rattle *Rhinanthus minor* made up a further quarter of the visits which suggests it has value in the meadow as a pollinator resource as well as reducing the vigour of grasses (Pywell *et al*. 2004). The Ancient meadows contained 14 of the top 15 floral species visited, Restored meadows 12 species and the Modern nine species, which demonstrates that the restoration has effectively transferred favoured species and provided suitable foraging habitat.

DISCUSSION

The restoration of the meadows surveyed in this study was undertaken by YDMT through their 'Hay Time' and 'Meadow Links' projects, to address the loss of traditionally managed hay meadows and provide a linked expansion of invertebrate habitat in the area surrounding the remnant ancient hay meadows that were used as 'donors'. The study has shown that this action has been effective at attracting and providing food for foraging bumblebees.

Bumblebees had significantly higher abundance and species richness in both the Restored and the Ancient meadows compared with the meadows under Modern management. This likely reflects a greater diversity and abundance of flowers in the traditionally managed hay meadows, but we do not have the data to demonstrate this. However, restoration of meadows under modern management can quickly benefit bumblebees, as their abundance, richness and diversity in the Restored meadows was not significantly different from Ancient meadows, despite the fact that the majority of the restored sites were only one to three years post-treatment. Bumblebee expansion into the one year post-restoration meadows shows that this can be a rapid response to the increase in this newly available foraging habitat. This is consistent with studies such as Carvel *et al*. (2004) in which bumblebee foraging activity increased in the first year after treatment with wildflower seed. Furthermore, the occurrence of *B. jonellus* and *B. monticola* in some restored meadow sites demonstrates that the restoration work is expanding the foraging habitat for these more specialised species.

Despite the challenge of ensuring all the sites were surveyed to the correct protocol, the study has been able to demonstrate the positive impact of meadow restoration work on bumblebee numbers in these hay meadows. Hay meadow restoration can be seen as a valuable contribution to invertebrate conservation in the region. Further research into the foraging habitat preferences of the rarer bumblebee species would better inform future restoration projects to increase the numbers of vulnerable species.

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