Journal of Apicultural Research 51(2): 204-211 (2012)
DOI 10.3896/IBRA.1.51.2.09

ORIGINAL RESEARCH ARTICLE

Humans versus dogs; a comparison of methods for the detection of bumble bee nests

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Received 29 May 2011, accepted subject to revision 15 December 2011, accepted for publication 17 January 2012.

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Summary

This study investigates alternative approaches to locating bumble bee nests for scientific research. We present results from three trials designed to assess: 1. The comparative efficiency of two detection dogs; 2. The ability of a dog to locate nests when carrying out repeat searches of agricultural habitats through the season; 3. The efficiency of a dog compared with human volunteers at finding nests in woodland, with the human volunteers using two methods: 'fixed searches' and 'free searches'. The two dogs varied in their efficiency in finding buried portions of bumble bee nest material (62.5% and 100% correct indications). Searching for real nests in rural habitats, a detection dog located nine nests of four bumble bee species, in a range of habitats, at a rate of one nest for 19 h 24 min of searching time. A comparison of 'free searches' using human volunteers and the dog in woodland found that they located nests at similar rates, one nest for 1 h 20 min of searching time. Fixed searches located nests more slowly (one nest for 3 h 18 min of searching time), but probably provide a reliable estimate of nest density. Experienced volunteers performed no better than novices. Given the investment required to train and maintain a detection dog, we conclude that this is not a cost effective method for locating bumble bee nests. If the aim is to estimate density, then fixed searches are appropriate, whereas if the aim is to find many nests, free searches using volunteers provide the most cost effective method.

Humanos frente a perros; comparación de métodos para la detección de abejorros

Resumen

Este estudio investiga métodos alternativos para localizar nidos de abejorros para la investigación científica. Se presentan los resultados de tres ensayos diseñados para evaluar: 1. La eficacia comparativa de los dos perros de detección; 2. La habilidad de un perro para localizar los nidos tras realizar búsquedas repetidas en hábitats agrícolas a lo largo de la temporada 3. La eficiencia de un perro en comparación con voluntarios humanos en la búsqueda de nidos en el bosque, con los voluntarios humanos utilizando dos métodos, de "registros fijos" y "búsquedas libres ". Los dos perros variaron en su eficacia de encontrar porciones de material de nidos de abejorro enterrados (62,5% y el 100% de las indicaciones correctas). En la búsqueda de nidos reales en los hábitats rurales, un perro de detección localizó nueve nidos de cuatro especies de abejorros, en una amplia gama de hábitats, a un ritmo de un nido cada 19 h 24 min de tiempo de búsqueda. En una comparación de "búsquedas libres" con voluntarios humanos y el perro realizada en el bosque, los humanos encontraron los nidos a un ritmo similar, un nido cada 1 h 20 min de tiempo de búsqueda. Mediante las búsquedas fijas se localizaron los nidos más lentamente (un nido durante 3 h 18 min de tiempo de búsqueda), pero probablemente proporciona una estimación fiable de la densidad de nidos. Los voluntarios con experiencia no realizaron las búsquedas mejor que los novatos. Teniendo en cuenta la inversión necesaria para formar y mantener un perro de detección, llegamos a la conclusión de que este no es un método rentable para la localización de los nidos de abejorros. Si el objetivo es estimar la densidad, entonces las búsquedas fijas son adecuadas, mientras que si el objetivo es encontrar muchos nidos, las búsquedas libres con voluntarios son el método más rentable.

Keywords: *Bombus,* nest density, nest location, public survey, detection dog

Introduction

Bumble bee nests are difficult to find due to their small size (relative to honey bees or social wasps) and their tendency to be located in relatively inconspicuous places such as the burrows and runs of small mammals (Sladen, 1912; Cumber, 1953; Free and Butler, 1959; Fussell and Corbet, 1992; Kells and Goulson, 2003). The difficulty associated with finding bumble bee nests has hampered studies of numerous aspects of bumble bee biology. For example, little is known about rates of colony success and the relative importance of different mortality factors such as parasitism, predation and resource availability for bumble bee colony survival in wild populations (Goulson, 2010; Goulson *et al*., 2010). Artificially reared colonies have been used to investigate many aspects of bumble bee biology, e.g. homing range and flight distances (Goulson and Stout, 2001; Greenleaf *et al*., 2007), nest growth rates in different habitats (Muller and Schmid-Hempel, 1992; Goulson *et al*., 2002; Carvell *et al*., 2008), effects of inbreeding (Whitehorn *et al*., 2009), longevity and reproductive output (Beekman and van Stratum, 1998; Lopez-Vaamonde *et al*., 2009) usurpation and resource availability (Carvell *et al*., 2008), drifting of workers (Lopez-Vaamonde *et al*., 2004), inter colony variation in learning abilities (Raine *et al*., 2006) and interspecific competition (Thomson, 2004). Such experiments, whilst providing a valuable insight, may however, not be representative of natural nests. For example, strains that have been bred in captivity for many generations may display altered susceptibility of parasitic infection; allowing *ad libitum* feeding in the early stages of nest founding may produce a nest which has an advantage over wild nests founded at a similar time; and setting out nests inside artificial boxes may make them easier for usurping queens of *Bombus* species or *Psithyrus*, to locate (Frehn and Schwammberger, 2001; Goulson *et al*., 2002; Carvell *et al*., 2008).

Many bumble bee species have shown dramatic declines in recent decades which are thought to be due primarily to changes in agricultural practices (Williams and Osborne, 2009). Most attempts to quantify the effect of conservation management strategies on bumble bees have focused on counts of workers (Walther-Hellwig *et al*., 2006; Redpath *et al*., 2010). In social Hymenoptera such as bumble bees, the effective population size is the number of colonies rather than individuals, since a colony represents a single breeding pair (Chapman *et al*., 2003). Population estimates, and the effects of environmental change and of conservation management practices ought therefore to be based on nest densities, rather than counts of individual foragers in the field. Recent studies have attempted to estimate nest density by using microsatellite analysis to identify nest mates amongst foraging workers (Knight *et al*., 2005). This technique is, however, expensive and constrained by its dependency on foraging range estimates to infer the actual location and density of the nests. Foraging range probably varies between species, nest size and location and is itself hard to quantify accurately (Osborne *et al*., 1999; Walther-Hellwig and Frankl, 2000; Westphal *et al*., 2006; Greenleaf *et al*., 2007; Wolf and Moritz, 2008; Hagen *et al*., 2011).

The development of a technique for detecting large numbers of bumble bee colonies would be a valuable tool for the conservation of these important pollinator species. Bumble bee colonies can be located by intensive observation of fixed areas, but the rate at which nests are detected is low (Cumber, 1953; Harder, 1986; Osborne *et al*., 2008). Dogs are many times better at detecting scents than people and detection dogs have been trained by law enforcement agencies to recognise and respond to a wide range of odours, such as explosives, narcotics or missing persons (Helton, 2009). There is a long history of the use of detection dogs as a tool for ecological and conservation studies. In the late nineteenth century, a dog was trained to locate endangered kakapo, *Strigops habroptilus,* and kiwi, *Apteryx australis*, which were then relocated to an island free from the introduced predators that threaten them on the mainland (Hill and Hill, 1987). Since this time, detection dogs have been used in many countries to assist in conservation efforts, to find endangered or invasive species of a wide range of taxa including mammals such as black footed ferrets, *Mustela nigripes*, (Reindl-Thompson, 2006), reptiles such as desert tortoises, *Gopherus agassizii*, (Cablk and Sagebiel, 2008) and invertebrates such as termites, *Isoptera*, (Brooks *et al*., 2003).

In 2006 a male springer spaniel was trained to detect bumble bee nests. The dog was subjected to trials to ascertain the efficacy of this technique (Waters *et al*., 2010). As described by Waters *et al.* (2010), this dog was found to be 100% effective at finding hidden bumble bee nest material in trials, and located 33 wild bumble bee nests of four different species when searching plots of various habitat on the island of Tiree, Scotland. This detection dog was retired in 2007 due to unforeseen circumstances and so in the same year, a second, male springer spaniel, was trained in order to investigate this approach further.

Here, we compare the rate at which nests are located by human volunteers using two different methods with the rate at which the dog located nests in the same habitat. We also compare the abilities of the two dogs, and assess the current dog's ability to find nests in various farmland habitats. The aim of this study is therefore to determine which methods for locating bumble bee nests are most cost effective.

Materials and methods

The detection dog was trained to locate fragments of commercially reared *Bombus terrestris* nests at the Melton Mowbray Defence Animal Centre, UK. The dog was trained by the same team of professional dog trainers who trained the previous bumble bee sniffer dog, following the same positive reward procedures as used by Waters *et al.* (2010). Approximately 10 g of frozen bumble bee nest was hidden in a wooden box within a secure room. The dog was fitted with a harness and given the command "Fetch" before being allowed to explore the room. When he happened upon the novel scent of the bumble bee nest a reward (a tennis ball) was given. This process was repeated over several weeks until the dog learned that the harness and command "Fetch" required him to search for bumble bee nest which was hidden in progressively more difficult places e.g. amongst dense vegetation, within rabbit warrens, under turf, etc. Nest samples were handled with gloves and forceps and kept in bags to avoid contamination with human scent. Reinforcement training using pieces of bumble bee nest was carried out by the handler several times each week.

Detection dog efficiency

Between 18 February and 5 March 2010, trials were carried out to test the dog's ability. Five 200 m x 50 m areas within grassland (n = 4) or woodland (n = 1) were chosen and five cylindrical plastic pots buried randomly within each area by an independent party in the absence of both the dog and handler. Pots were 5 cm in height, 3.5 cm in diameter and had six 5 mm diameter holes drilled in their lids. Approximately 7 g of bumble bee nest material was placed inside the test pots. A commercially available 'bulb planter' of diameter 7 cm was used to remove a core of soil to create a hole of a standard depth (10 cm). One of the pots was placed into the hole and the turf section of the core was then replaced. For each of the trials, one pot was buried empty as a control, whilst the other four contained nest material from one of the following species; commercially reared *Bombus terrestris*, wild *B. terrestris*, wild *B. pascuorum* or *B. hypnorum* (Linnaeus). All pots were kept in separate plastic bags and handled using gloves.

The method followed the trial carried out in 2007 testing the abilities of the previous nest detection dog, except that Waters *et al*. (2010) used material belonging to *B. muscorum* and *B. distinguendus*, rather than *B. pascuorum* and *B. hypnorum*. In order to avoid the possibility of the dog locating natural nests during the trials, and such indications being regarded as false positives, trials were carried out at a time when no natural nests were likely to be present, again following Waters *et al.* (2010). Temperature during the trials varied from -3 to +7°C.

The dog searched the plots after a period of at least 24 hours had elapsed. This interval enabled the escape of volatiles from the buried pots and minimised the effect of 'detectable disturbance' as dogs are prone to preferentially investigate disturbed ground (Dutch Mulholland, Defence Animals Centre, pers. comm.). The dog was worked using the standard search technique (see Waters *et al*., 2010). Numbers of positive finds, missed pots and false positives (either finding the control pot or indicating at some other inappropriate item) were recorded. The accuracy of a detection dog can be described as: Proportion of Correct Detections = Hits/(Hits + Misses) according to (Helton, 2009). The term 'Misses' included undetected positive samples and incorrect indications on controls or other objects.

Nest density in the rural environment

In the spring and summer of 2008, the detection dog and his handler were deployed in farmland near Stirling, Scotland, UK. Six habitats were selected in order to represent a range of typical habitat types and features found in the rural environment which bumble bees are known to utilize for nesting (Alford, 1975; Carvell, 2002; Osborne *et al*., 2008). These were hedgerow, fence line (within one metre of the fence), bank (i.e., steeply sloping earth bordering lanes and ditches), long grass (>15 cm), short grass (<10 cm) and woodland edge (within 10 metres of the woodland edge). For each habitat type, 10 replicates of 1000 m^2 were selected at random (Table 1).

All areas were searched for 25 minutes, seven times, once fortnightly from 26 May to 29 August 2008. The standard search technique was used as described above. Searches were carried out between 08.00 h and 20.00 h.

Effectiveness of detection dog searches versus human searches for locating bumble bee nests.

In order to compare the effectiveness of searches conducted with the detection dog against those using human volunteers, trials were carried out in open deciduous woodland (a habitat favoured by the detection dog) at the campus of the University of Stirling (OS *Grid Reference* NS 8096 and 8196) between 15 July and 29 August 2009. Trials were conducted between 08.00 h and 19.00 h in dry conditions. Forty volunteers were asked to complete a brief questionnaire in order to ascertain their knowledge of bumble bees. They were specifically asked whether they were able to distinguish a bumble bee from other flying invertebrates. If they were unable to do so or were unsure of their ability, they were shown ten colour photographs of common species of bumble bee, five dead specimens and live bumble bees as available in the field, before the experiment started. If volunteers had never previously seen a bumble bee nest and could not identify bumble bees to species they were deemed 'unfamiliar' with bumble bees. Had they either seen a nest previously or were able to identify bumble bees to species, they were classed as being 'familiar'. Many of the volunteers were students and staff of the University of Stirling. They were aged between 18 and 70, representing both sexes (18 males and 22 females). Each volunteer carried out two surveys, a 'fixed search' and a 'free search', each lasting for 20 minutes. The order in which these took place was randomised. Volunteers were accompanied by a single guide (S.O.). The guide explained that bumble bees tend to nest in holes in the ground, beneath leaf litter or in clumps of vegetation, and that a bumble bee flying into or out of such an area would be likely to indicate the presence of a nest. As

Table 1. Distribution of the sixty habitat transects at each of 14 rural farm sites around Stirling, Central Scotland. OS Grid reference (NS) is given for the centre of each site.

Site	Grid Reference	Short Grass	Long Grass	Woodland Edge	Fenceline	Hedgerow	Bank	Total
1	766965	0	1	1	1	3	2	8
2	765975	0	1	1	0	0	0	2
3	795986	2	0	0	1	0	0	3
4	825969	2	0	1	0	0	0	3
5	835963	1	0	1	1	1	0	4
6	850962	1	2	0	1	1	1	6
7	870969	0	1	0	0	2	3	6
8	933949	0	0	3	1	0	0	4
9	978947	0	0	0	1	0	0	1
10	012962	1	1	1	2	1	2	8
11	905899	0	2	0	1	2	2	7
12	844972	1	0	0	0	0	0	1
13	851955	1	2	0	1	0	0	4
14	925910	1	0	2	0	0	0	3
	Total	**10**	**10**	**10**	**10**	**10**	**10**	**60**

male bumble bees were commonly seen carrying out patrolling behaviour in similar sites, this behaviour was also described to the volunteers. The guide ensured that the protocol was correctly followed and looked for bumble bee nests simultaneously.

Fixed search

The 'fixed search' methodology was adapted from that used by Osborne *et al.* (2008) in which volunteers were asked to observe a fixed area of ground for a set period of time. In this study, each volunteer conducted a fixed search in one of 40, 6 x 6 m arenas in woodland clearings that were free from large shrubs such as *Rhododendron* spp. or other dense undergrowth, in order to maximise the likelihood of nest detection. Arenas were marked out with flags and volunteers were asked to remain on the perimeter of the marked arena for the duration of the survey, observing the entirety of the plot for 20 minutes. Osborne *et al.* (2008) argued that any nest present within the area is likely to be detected within this period of time. If a volunteer discovered a nest before the end of the 20 minute survey, they were asked to continue watching the plot and advised that there could be more than one nest within the arena. Whilst volunteers were surveying the plot, the guide also looked for bumble bee nests.

Free search

During free searches, volunteers were asked to search for bumble bee nests in any way that they chose. This generally resulted in volunteers moving through an area of woodland at their own pace, searching for activity that might indicate the presence of bumble bee nests. Volunteers were accompanied by the guide who remained behind or to one side. Flagged arenas for the fixed search were not included in the free search.

Dog search

The detection dog was used after each volunteer had carried out their free search, in a nearby area of woodland for the same amount of time. A total of 40 x 20 minute searches were carried out by the detection dog using the standard search technique. This provided an equal search effort to that used by the human volunteers in their 'free searches'. During the free volunteer and dog searches, the guide recorded the approximate route so that the approximate area searched could subsequently be calculated, assuming a 5 m radius detection area (within this distance, volunteers readily noticed bumble bees). Areas were plotted and calculated using ArcGIS software.

A binary logistic regression was used to determine variables influencing the likelihood of a volunteer finding a nest during their free search. Covariates used were date and time of search (all times were rounded to the nearest hour in which the search took place). Factors included in the model were volunteer age (three categories were used, 18-30, 31-45 and 46-70), sex, and prior knowledge (unfamiliar or familiar). Variables that did not contribute significantly to the model were removed in a backwards, stepwise fashion ($\alpha = 0.05$). The analysis was conducted using SPSS version 1.5.

Table 2. Results from trials in 2010 with a bumble bee detection dog (☐= indication, X = no indication). In the first search, the pot containing wild *B. terrestris* was removed by a wild animal prior to the search and so was discounted from the trials. An indication at an empty control pot is a false positive.

Habitat	**Commercial *B. terrestris***	**Wild *B. terrestris***	**Wild *B. hypnorum***	**Wild *B. pascuorum***	**Control**	**False Indications**
Grassland 1	☐	Removed	☐	☐	☐	1
Grassland 2	☐	☐	X	☐	X	0
Grassland 3	☐	☐	X	☐	☐	0
Grassland 4	☐	☐	☐	☐	☐	1
Woodland 5	X	☐	☐	X	X	0

Results

Detection dog efficiency

The dog located 79% of pots containing bumble bee nest, (i.e. 15 out of a total of 19) but also gave five false positive indications (Table 2). Three of these were directed at control pots, one at a patch of bare ground with no evidence of a previous nest, and one where the independent party had attempted to dig a hole but had failed to achieve the required depth due to the ground being frozen. This represents a percentage of correct detections of 62.5% (Helton, 2009; see Methods).

Nest density in the rural environment

Nine bumble bee nests were located by the dog during the searches conducted on agricultural land; three were located in woodland edge habitat and three within hedgerows, and one was found in each of short grass, long grass and bank habitats with none detected along fences. The nests of four species of bumble bee were found; three each of *B. terrestris* and *B. pascuorum,* two of *B. lucorum* and one *B. hortorum*. No nests were located during the first search, carried out 26 May to 6 June (Fig. 1). The largest number of nests (three) found in any one survey period were found during the last search (18 August to 29 August). A total of 175 hours were spent searching for nests. This equates to a rate of one nest located for 19 h 24 min of searching time.

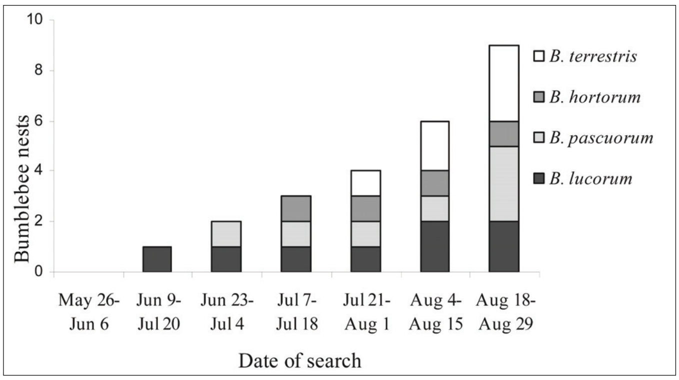

Fig. 1. Cumulative bumble bee nests located by the dog in searches on farmland from May to August, separated by species.

Fixed search by humans

Four bumble bee nests were found by volunteers whilst carrying out fixed searches (three nests of *B. terrestris* and one *B. pratorum*). The total area of all the fixed search plots was of 1440 m^2, giving a minimum nest density of 27.78 ± 13.33 nests ha^{-1} for this woodland habitat. This translates into a nest detection rate of one nest for 3 h 20 min of searching. The guide detected all nests identified by the volunteers but no additional nests.

Free search by humans

Ten bumble bee nests were found during the free searches, translating into a nest detection rate of one nest for 1 h 20 min of searching (seven nests of *B. terrestris*, two *B. lucorum* and one *B. pratorum*). The mean area searched was estimated to be 1735.0 ± 376.6m^2. Hence the estimated nest density was 1.44 nests ha^{-1} (compared to 27.8 for fixed searches). Assuming the nesting density calculated from the fixed searches is a reasonably accurate approximation to the true number of nests, the free search resulted in the discovery of approximately 5.1% of total nests, but found nests at a rate 2.5 times faster than the fixed search.

The likelihood of a volunteer in finding one or more nests during the free search was not affected by age ($\chi^2_{2,}$ = 1.544, p = 0.462), sex ($\chi^2_{1,}$ = 0.876, p = 0.349), familiarity with bumble bees ($\chi^2_{1,}$ = 0.875, p = 0.350), date ($\chi^2_{1,}$ = 1.473, p = 0.225) or time of day ($\chi^2_{1,}$ =0.440, p = 0.507).

Dog search

The dog located ten nests (seven nests of *B. terrestris*, one *B. lucorum*, one *B. hortorum* and one *B. lapidarius*) during his searches of the same area as the human volunteers. The dog searched a mean area of 1777.5 ± 266.5 m^2 resulting in a nest density of 1.41 nests ha^{-1}, which is equal to volunteers carrying out the free search, resulting in an efficiency in terms of nests located per hour equal to that of volunteers.

Discussion

The current detection dog proved to be less effective than his predecessor during the artificial trial (62.5% versus 100% for the current and previous dogs, respectively; (Waters *et al.*, 2010). The previous bumble bee detection dog was used to search for bumble bee nests in the Western Isles, Scotland, and located 33 nests at a rate of one nest for 9 hr 5 min searching (Waters *et al.*, 2010). These searches took place in August and September, the peak period for bumble bee activity in the Western Isles. The current dog found nests at a rate of one per 19 h 24 min in repeated searches of rural farmland sites, but found one per 1 h 20 min during searches of woodland on the University campus. The searches on rural farmland began in May, when nests are small and a few may not yet have been founded (none were found in the first search). They were also repeated seven times in the same area, which might explain the low efficiency in terms of nests located per hour.

The efficiency of detection dogs is known to vary (Helton, 2009). In the conservation literature, Engeman *et al.* (2002) reported success of approximately 63% for trained snake detection dogs, and Reindl-Thompson *et al.* (2006) found that one dog trained to find black footed ferrets detected 100% of the ferrets, whilst another only detected 57-71% of them.

Despite being initially trained using only nest material collected from one bumble bee species (harvested from artificially reared colonies of *B. terrestris*), the detection dog located wild nests belonging to four different species. This supports the findings of the previous bumble bee detection dog, which detected nests of four different bumble bee species during field trials in the Hebrides, Scotland (Waters *et al.*, 2010). Detection dogs used for conservation purposes have been shown to be able to generalise between similar target substances (Long *et al.*, 2007) and this is considered an important attribute to their use. This is particularly important for bumble bee nest detection dogs, as nests of the rarer bee species are unlikely to be commonly available for training purposes.

The nest density across all farmland habitats resulting from the detection dog searches was 1.5 ha^{-1}, based on seven consecutive visits to the same sites. Based on estimates from Osborne *et al.* (2008), nest density would have been 22.52 ha^{-1} for the same area of these habitats (not including bank which was not investigated in their study). The estimated density from free searches of woodland was 1.4 ha^{-1} (using either dog or human volunteers), whilst that from fixed searches in woodland was 27.8 ha^{-1}. Osborne *et al.* (2008) reported a range of nest densities for different habitats, based upon volunteers performing fixed searches, which ranged from 10.8 ha^{-1} for woodland to 37.2 ha^{-1} for fencelines. Our figures from fixed searches are therefore broadly similar, and in marked contrast to free searches. It would seem that fixed searches are necessary if the aim is to estimate nest density, since in free searches both volunteers and the detection dog failed to find an estimated 95% of the nests present. Even with repeated visits to the same sites, the number of nests detected by the detection dog, and hence the estimates of nest density, are far below estimates from fixed searches. In contrast, if the aim is to find lots of nests for study, then free searches appear to be more efficient (approximately 2.5 times more efficient in the habitats used in this study) in terms of the number of nests detected per hour.

During fixed searches, volunteers found all nests observed by the experienced guide, confirming the findings of Osborne *et al.* (2008) that this is probably a reliable way of detecting the majority of bumble bee colonies. The fact that nests were found regardless of the level of familiarity that volunteers have with bees (in both fixed and free searches) suggests that volunteers can provide a valuable tool for locating bumble bee colonies with minimal training. Whilst our detection dog can readily detect nests, in this study he performed no better than naive humans. Given the cost of initial training and subsequent maintenance training (several hours each week, all year round), and the need for a person to handle the dog in the field, simply employing a person to search for nests for the duration of the experiment would appear to be more cost effective, especially where keen members of the public are willing to volunteer their time.

Acknowledgements

We would like to thank the Leverhulme Trust for funding this research. Thanks to the two referees who provided improvements to a previous draft of the manuscript, Gillian Lye and Penelope Whitehorn for providing assistance with field work, and to Jenny Norwood and Dave Hollis for training the detection dog. We would also like to thank the farmers who allowed the dog onto their land and the forty people who volunteered their time to look for bumble bee nests.

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