Effectiveness of Artificial Nests for Bees

A summary paper of existing evidence on effectiveness and which species benefit

1. Introduction

This report is a summary on the success of artificial nest boxes, focusing heavily on the document 'Bee Conservation: Evidence for the effects of intervention' (Dicks *et al.,* 2010). It highlights the design and materials of individual boxes, size of materials and location of these boxes, particularly in relation to agricultural land.

One of the main objectives of this summary is to establish which and how well species benefit from having artificial nest boxes located on agricultural land, with the purpose to continue improving agri-environment schemes in the UK.

The document states the findings of numerous experiments on artificial nest boxes that have taken place throughout Europe and globally on species of solitary bee and a few bumblebee species. Some of these experiments have been conducted over tropical rainforest, agricultural land and other forms of land management.

Points of discussion include preferred material type and size, nest location in relation to above ground/underground nesting, material and nest success, and habitat type.

This report focuses on the evidence found for both solitary bees (section 3) and bumblebees (section 4).

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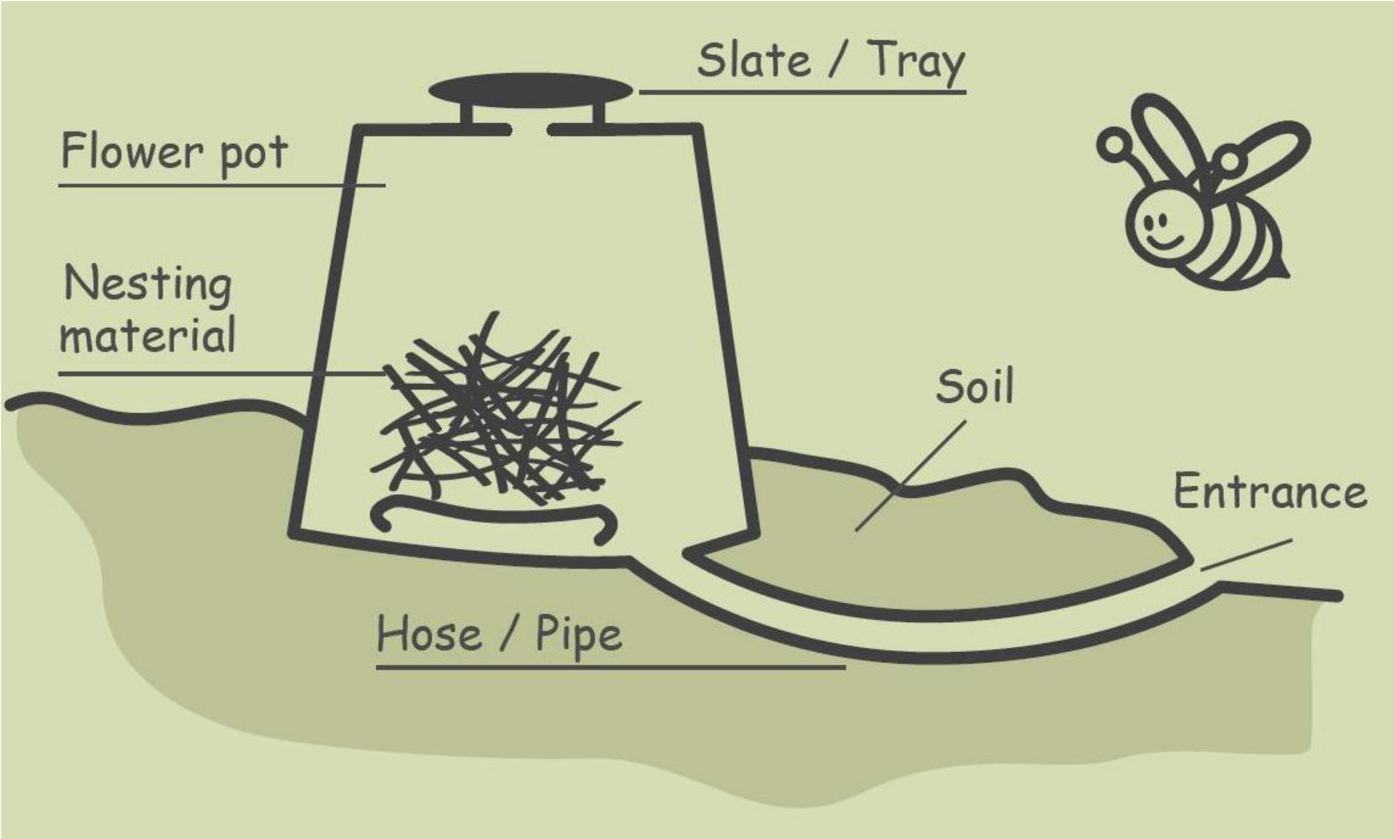
This review does highlight the benefits of artificial nest boxes from a conservation point of view, in light of the importance of bees as pollinators and the decline in numbers over recent years; however its main focus is on the design and practicalities of in-field application, and the evident gaps in knowledge.

2. Methods

The main document utilised was 'Bee Conservation: Evidence for the effects of intervention' (Dicks *et al.,* 2010). Additional papers 'Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances' (Zurbuchen *et al.,* 2010) and 'Foraging ranges of solitary bees' (Gathmann and Tscharntke, 2002) were reviewed for points around distance and location of artificial nests in habitats. These points are looked at in the discussion.

The 'Bee Conservation: Evidence for the effects of intervention' document included a chapter on 'Providing artificial nest sites for bees' with literature on 'Providing artificial nest sites for solitary bees' and 'Providing artificial nest sites for bumblebees', the only groups being researched in this report.



Relevant trials and experiments were reviewed from this chapter and information on design of nest boxes, material size, habitat location, country, date, species benefiting and reference extracted and put into a table (table 1). Trials were grouped together via their design rather than being tabulated individually.

3. Solitary Bees

From the evidence gathered it became clear that artificial nests which had the most success and recordings were that which were made fully or partially with reed stems. This was followed by wooden blocks with manually drilled holes and bamboo stems. The size of the cavities in these materials showed some variation with the smallest hollows ranging from 4-6mm in a study in Sheffield (Gaston *et al.,* 2005) to 11-13mm in diameter in a Costa Rican survey (Thiele, 2002, Thiele, 2005). Reed stem nest boxes proved most favourable with results showing that up to 33 species of solitary bee were recorded from one experiment in Germany conducted over agricultural and semi-natural habitat (Tscharntke *et al.,* 1998). Additionally, a separate study utilising reed stems as its nest box design identified 5 species classed as endangered to Germany (Gathmann *et al.,* 1994).

Table 1. Important aspects of the recorded trials discussed in this review on solitary bee species as detailed in the Bee Conservation paper. The hyperlinked references are the only papers which could be fully accessed and read, the information from the other papers was solely what was given in the 'Bee Conservation' report. If individual species benefiting are not stated in table 1, they were not given in the report.

Design	Material Size	Habitat Location	Countries	Date	Species Benefiting	Reference
Reed stems/bundles		40 fields of 10 management types	Germany	April 1990	14 species inc. 5 species classed as endangered in Germany *Anthidium lituratum* *Heriades crenulatus* *Megachile alipcola* *Osmia gallarum* *Osmia leaiana*	(Gathmann *et al.,* 1994)
	15x20cm	15 different sites (not identified)	Germany	1994-1996	13 species	(Gathmann and Tscharntke., 1997)
		Agricultural and semi natural sites	Germany	1990-1996	33 species- no individual species identified	(Tscharntke *et al.,* 1998)
120 (reed stem) boxes		15 different agricultural sites	Lower Saxon, Germany	1997	*Osmia rufa*,*Hylaeus communis* (two most widespread),*Osmia leaiana*,*Hylaeus difformis*,*Hylaeus confusus*,*Megachile versicolor*,*Megachile lapponica*,*Megachile alpicola*,*Heriades truncorum*,*Chelostoma florisomne*,*Chelostoma fuliginosum*	(Steffan-Dewenter., 2002) 7 species listed in the UK (highlighted)
		Agricultural experimental station	Poland	2000-2001	*Osmia rufa* 3.5 bees/nest	(Wilkaniec and Giejdasz., 2003)
		48 plots in agricultural areas	South West Ecuador	June 2003-May 2004	31 bee and wasp species	(Tylianakis *et al.,* 2005)

Tin cans filled with paper drinking straws	4-6mm diameter	20 Urban gardens	Sheffield, UK	2000-2002	*Osmia rufa*	(Gaston *et al.*, 2005)
Plastic Tubes		Agricultural experimental station	Poland	2000-2001	*Osmia rufa* 80-100% occupation	(Wilkaniec and Giejdasz., 2003)
Drilled wooden blocks inserted with cardboard straws			Pernambuco, Brazil	2009	17 nests in 5 wooden blocks -8.5% occupancy	(Oliveira and Schlindwein, 2009)
	4mm diameter holes 6mm diameter holes 8-10mm diameter holes	20 Urban gardens	Sheffield, UK	2000-2002		(Gaston *et al.*, 2005)
(24) Hardwood nesting blocks each with 80 drilled holes	11 and 13mm diameter drilled holes	Lowland Tropical Forest	Costa Rica	2002 2005	*Duckeanthidium thielei* 16 species	(Thiele 2002) (Thiele 2005)
Grooved Wooden Boards			Pernambuco, Brazil	2009	48 nests in 12 wooden boards -40% occupancy	(Oliveira and Schlindwein, 2009)
Wood		Agricultural experimental station	Poland	2000-2001	*Osmia rufa* 7.2 bees/nest	Wilkaniec and Giejdasz., 2003
Bamboo stems in plastic pipes	20cm	20 Urban gardens	Sheffield, UK	2000-2002	*Hylaeus communis*	Gaston *et al.*, 2005
Bamboo stem sections and cardboard tubes inserted into drilled wooden blocks		Two fragments of semi-deciduous tropical forest	Sao Paulo, Brazil	2000-2002	*Centris analis,Centris tarsata* (2 most abundant)*Centris sp,Centris labrosa,Tetrapedia rugulosa,Tetrapedia curvitarsis,Eufriesea surinamensis,Eufriesea auriceps,Euglossa townsendi,Megachile xanthoptera,Megachile sp,Megachile (Pseudocentris) sp,Saranthidium marginatum,Anthodioctes megachiloides,Colletes rufipes* 528 nests recovered altogether	(Gazola and Garofalo 2009) None of these species are from/listed in the UK

4. Key Research on Solitary Bees

From the results it is clear that most of the studies recorded in 'Bee Conservation: Evidence for the effects of intervention' (Dicks *et al.,* 2010) were conducted out of the UK, namely Europe and South America. However for artificial nest application in the UK to continue, firstly more research needs to be conducted in the UK- only 1 study from table one is based in Britain and secondly, research needs to be more detailed to gather more comprehensive evidence. As there is only one study based in Britain, all areas need to be focused on: Design, material size, habitat location and species benefiting. There is some evidence of which particular UK species benefited which is discussed below, however, many of the studies did not specify individual species benefiting, meaning there is lack of evidence to assess the success of artificial nests in general in the UK. Species benefiting is a key area for research as knowing which UK species benefit and which don't will help in expanding designs and application within the UK.

From the studies in table 1, the following species have been recognised as found in all or parts of the UK:

Osmia Rufa- England, Wales and lowland Scotland and continental Europe.

Hylaeus communis- UK

Osmia leaiana- England and Wales

Heriades truncorum- South East England

Hylaeus confuses- Europe, UK

Chelostoma florisomne- England and Eastern Wales

Megachile versicolor- Southern Britain and records extending to South Scotland

Megachile lapponica was also recorded but is now extinct in Britain.

All of these species were found in the same study, Steffan- Dewenter (2002) and only this study apart from *Osmia rufa*, *Osmia leaiana* and *Hylaeus communis* which were found occupying artificial nests from other studies (refer to table 1).

It is important to recognise this study as it recorded 7 solitary bee species which are found within the UK. In-field application of artificial nest boxes in the UK is much more likely to be successful when there is firm evidence of UK solitary bee species benefiting from artificial nest boxes.

The Steffan-Dewenter (2002) study was conducted over different agricultural sites in Lower Saxon, Germany using 120 reed stem nest boxes. The results gathered are fairly encouraging and it is likely that such results are directly related to location (agricultural land type), and the design of the nest boxes. These two factors are discussed in more detail further down in the discussion.

Although this study does show fairly encouraging results, this is the only study from table 1 with such results and in-field application will not be successful on this study alone, particularly as this study was conducted in Germany and not Britain. This emphasises the point made earlier that for artificial nest application in the UK to continue, more research needs to be conducted within the UK.

As stated previously, not all of the studies recorded which specific species of solitary bee had been identified from the trials. This makes it difficult to interpret the benefits for individual species, particularly for rare and threatened species. However, in those that did record individual species *O. rufa* were the predominant species found. Due to their widespread distribution through mainland Europe it is likely that *O. rufa* were among the species recorded from the trials which did not identify within the literature the specific species which had been found. If so, the results from these trials will be relevant for the continuation of suitable artificial nesting habitats of *O. rufa.*

O. rufa are a common and widespread species so it would therefore be easy to suggest they would benefit more from artificial nests, and to use the results from these species as a basis for the application of artificial nests for other UK solitary bee species, due to the success artificial nests have on *O. rufa* occupancy and abundance rates. However, there is no 'one size fits all' approach and different UK solitary bee species have different nesting requirements and so assumptions cannot be made nesting habitats created on the basis of the needs of *O. rufa* will be suitable for other solitary species, and research and/or results on other UK species must be conducted/published to provide more specific information.

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5. **Materials used for Solitary Bees**

Artificial nests constructed fully or partially from reed stems/bundles were by far the most popular and successful nests with rather encouraging results. The results from the Steffan-Dewenter (2002) study in particular supports this. Additionally, table 1 trial one shows that within the 14 species found, 5 are classed as endangered to Germany and all 5 occupied reed stem nests (Gathmann *et al.,* 1994).

In a separate experiment also conducted in Germany, the use of artificial reed nests over agricultural and semi-natural sites saw a total of 33 species recorded (Tscharntke *et al.,* 1998). In addition, a reed nest trial in South West Ecuador recorded 31 bee and wasp species in one year over 48 plots of agricultural land (Tylianakis *et al*., 2005).

Apart from 2 studies from table 1 (where location is not specified but from the description some form of agricultural land use can be assumed), all the studies involving reed stems as their primary nesting material were conducted over some form of agricultural land type. The success of these nests and the location highlight a positive relationship between the two, and should be taken into serious consideration for future application.

Wooden blocks with drilled holes also proved popular nesting habitats for solitary bee species with holes ranging from 4mm-13mm and results showing high numbers of nests being built in these holes, see the Pernambuco Brazil study in the results table.

High occupancy nest rates of 80-100% were evident in plastic lined tubes in a study for *O. rufa* (Wilkaniec and Giejdasz, 2003); however, due to problems such as mould and parasitism they did not prove favourable in terms of nest success and sustainability.

In regards to bamboo stems, the study by Gaston *et al* (2005) recorded only *Hylaeus communis* occupying the nests, however the study by Gazola and Garofalo (2009) recorded 16 species and 528 nests. The latter study involved bamboo stem sections and cardboard tubes being inserted into drilled wooden blocks whereas the Gaston *et al* (2005) study involved bamboo stems inserted into plastic pipes. The use of other materials could have influenced the species and occupancy rates, especially in the Gazola and Garofalo (2009) study as wood has proved to be a successful nesting material from other studies. As stated earlier, plastic is an unreliable material for this purpose and again, could have influenced the results. As only two of the studies in table 1 designed their nests with bamboo stems and they both incorporated other materials into their designs, it is hard to assess just how successful these are as a suitable material for artificial nests, and in particular for artificial nests in the UK, especially as the most successful study using bamboo was conducted in Brazil.

Paper straws were only used in one study by Gaston et al (2005), and it was recorded that *O. rufa* were the only species to occupy any of the tin cans filled with paper drinking straws. Abundance or occupancy rate was not specified.

Overall, when comparing the results, the evidence clearly demonstrates the success of reed stems/bundles. Using materials with thicker, sturdier and more weather proof structures such as reed stems are a good foundation for artificial bee nests. They also offer cavities of various sizes which individual bees can safely nest in. All of this is also true of drilled wooden blocks if a range of hole sizes are used. Plastic lined tubes are not concealed enough allowing for wind and rain to pass through, creating changes in temperature and conditions for mould to manifest (pers comms, Falk, 2014). Added to this, paper is a poor material which once wet, is useless. Bamboo stems seem to require further study as they could have the potential to be successful as they are fairly sturdy, however, the studies from the Bee Conservation document are minimal and incorporate various other materials and therefore do not form a good basis for justification.

6. **Location of artificial bee nests**

Many of the studies highlighted in table 1 were conducted over agricultural land and all of them have shown promising results. Again, this is heavily supported by the results from the Steffan-Dewenter (2002) study as 7 species found in the UK were recorded.

Overall, the number of solitary bee species recorded ranged from 11-33 including common species such as *O. rufa* and *Hylaeus communis* and other species that were not specified. The third study from table one included orchard meadows, old hay meadows, set-aside fields, field margins and chalk grasslands (Tscharntke *et al.,* 1998). It is unclear what species were found where but the overall number of species recorded (33), implies these agricultural and semi-natural habitats provided welcoming nesting and even potentially welcoming foraging resources.

Again, in study one table one; experiments were conducted over various types of set-aside field, crop fields and old meadows (Gathmann *et al.,* 1994). The two endangered *Osmia* species were found exclusively occupying reed stem nests in old meadows, the remaining three occupied nests in two year old mown set-aside and the species *A. lituratum* and *M. alpicola*, were found to be nesting in a variety of field types including cereal crops.

This highlights a second positive relationship with agriculture: Location and agriculture. Artificial nests created here show high occupancy rates by a number of solitary bee species (although not all are specified). The evidence suggests that many solitary bee species are in favour of nesting on agricultural land type, and conservation efforts should be acted upon to increase the availability of artificial nesting boxes for solitary bees at these locations.

Preference for these locations could be due to the benefits agricultural land provides such as proximity of forage resources (as briefly mentioned below), and variability of foraging resources.

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7. Distance of foraging

Very little information was given on distance including maximum foraging range. From the chapters reviewed, only one study made a reference to distance. Gathmann and Tschcarntke (2002) estimated that medium to large female solitary bees of the European species *Andrena barbilabris*, *Andrena vaga, Andrena flavipes* and *Osmia rufa*, have a maximum foraging range of 150m-600m, concluding that nest boxes must be placed within this distance of foraging resources. From the same study, they reported that next boxes had a 50% chance of being occupied by two oligolectic solitary bee species *Chelostoma rapunculi* and *Megachile lapponicaI,* if their required forage plants were at a distance of 256-260m from their nesting sites (Gathmann and Tscharntke, 2002).

As this is the only study on distance the summary document as a whole provides little insight into the relationship of maximum foraging range.

From the additional paper 'Foraging ranges of solitary bees' (Gathmann and Tscharntke, 2002), it was concluded that the maximum foraging range of solitary bees is best predicted by their body size and not the food plant specialisation (Gathmann and Tscharntke, 2002). Insects with larger bodies have longer foraging ranges and insects with smaller bodies have shorter foraging ranges.

Another theory in regards to maximum foraging ranges of solitary bees is that although larger insects do have more energy and therefore expend this energy at a slower rate when travelling enabling them to cover longer distances, in general food sources closer to nesting sites are favoured by insects of all sizes (pers comms, Falk, 2014).

These theories are slightly contradictive of each other but should be considered. The latter certainly makes sense in regards to energy expenditure, however, species have particular foraging requirements (particularly oligolectic species), and it would therefore be assumed they would travel as far as possible to locate their preferred specialist plant, regardless of nest proximity. Again, this can be applied to the Gathmann and Tscharntke (2002) study as the specialist foraging resources for smaller insects may require them to travel further than predicted in regards to body size.

'Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances' by Zurbuchen *et al* (2010) support this statement as they concluded that maximum foraging distances of bees at species level (in relation to body size) have potentially been underestimated. Experiments showed that a small species of bee *Hylaeus punctulatissimus* collected pollen at a maximum distance of 1,100m from its nest, whereas its actual expected maximum foraging distance is much smaller at 100-250m. This was evident in other species also such as *Hoplitis adunca* which was found to travel a maximum distance of 1400m from its nest, although it's predicted maximum foraging range is 400-600m (Zurbuchen *et al.,* 2010). These studies have various conclusions, and some that are contradictive of each other. Again, it is evident there is a gap in knowledge and research on maximum foraging ranges to allow a concise conclusion to be reached.

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8 Conclusion/Suggestions on Solitary Bees

There are a few conclusions that can be drawn from this paper:

- There is a big gap for research on artificial bee homes in the UK for UK bee species. This has been recognised from the main document and the additional papers. Further research in the UK is needed on native UK solitary bee species and genera to allow for practical application. Data and literature from UK species provides a stronger argument for application in the UK than data from European studies and species- even if the species recorded in the European studies are also found within the UK.
- Agricultural land showed a positive relationship with artificial nests for solitary bee species. Although this is good, all of the studies utilising agricultural land types were European. The success of these results should encourage UK research utilising agricultural land types and artificial nests for UK solitary bee species, as their success creates an opportunity for artificial nests to be used and have benefit in the agricultural landscape.
- The need for UK research on agricultural landscapes is supported in that many of the species found in the studies based on agricultural land were not identified, and it is likely that some of these unidentified species are found in the UK as well as mainland Europe.
- The success of agricultural land type as a home for solitary bee species in Europe demonstrates an obvious gap for research on agricultural land type and artificial nests for UK solitary bee species, as this is clearly a favoured nesting habitat.
- Knowledge gaps on the relationship between UK solitary bee species and artificial nests also extends to distance and maximum foraging range. The literature reviewed on this topic was somewhat conflicting and again, not based in the UK. It is therefore suggested this relationship is investigated further, as maximum foraging range is a key factor in identifying how far nests should be from specialist food resources.
- From the evidence that was gathered, one of the main concluding points is artificial nests made from reed stems and drilled wooden blocks are popular and viable resources, particularly reed stems which proved to be the most popular design. Their weather proof and sturdy structure and variable cavity sizes make them good nesting sites for many species and for reproduction. Again however, the studies using reed stems were conducted out of the UK highlighting yet another gap in knowledge in UK research.
- As mentioned, drilled wooden blocks are also a viable resource again due to their sturdy structure, warmth and different cavity sizes they provide, and gathered the second most successful results after reed stems/bundles. Drilled wooden blocks inserted with cardboard straws were used in the UK study however, no information on species benefiting and success could be obtained.
- Bamboo canes require further research in the UK and out, as only 2 studies used this material and obtained opposite results. Paper and plastic are not viable resources as they are thin allowing for mould to grow, with unsuccessful occupancy and reproductive rates.
- In regards to materials, it is suggested that reed stems should be incorporated into future studies on artificial nests for UK solitary bee species, in order to monitor and analyse their use and success for UK solitary bee species. Should they prove as beneficial as in European studies, they should be fully integrated into artificial nests for UK solitary bee species, and agri-environment practices in the UK. Continued research should be conducted on wooden nest box designs on UK species, as they also show promising results. Bamboo canes have the potential to be a useful and successful material for artificial nests as they are fairly sturdy and can vary in diameter. Studies on bamboo are minimal in and out of the UK but it is suggested they should be highly considered due to the properties they provide.
- It is clear there are many gaps in knowledge on the relationship between artificial nests and UK solitary bee species. These gaps have been highlighted in the conclusion and suggestions have been made to attempt to improve research and fill these knowledge gaps.

9.Bumblebees

9.1 Results

The research on bumblebees showed a clear preference for underground nesting boxes with spouts at ground level. One study showed that false underground nesting boxes were preferable with higher occupancy rates than above ground level nesting boxes and surface nesting boxes (Hobbs, 1967). Results showed that nesting boxes made from terracotta plant pots were the most favourable.

Table 2. Important aspects of the recorded trials discussed in this review on bumblebee species as detailed in the Bee Conservation paper. Lye (2009) is the only paper which could be fully accessed and read, the information from the other papers was solely what was given in the 'Bee Conservation' report. If individual species benefiting are not stated in table 1, they were not given in the report.

Design	Material Size	Habitat Location	Countries	Date	Species Benefiting	Reference
Underground nest boxes made from tin or cypress wood, entrance spout at ground level		Woodland Meadows	Urbana, Illinois, USA	1915-1919	48% of the boxes occupied by 5 species	(Frison, 1926)
-Surface boxes -Underground (Underground boxes were at the surface but with a partially buried entrance pipe giving the appearance of a subterranean nest) -False underground -Above ground		Mixed woodland Grassland	Southern Alberta, Canada	1961-1966	Underground boxes had an occupancy rate of 58%; false underground boxes had an occupancy rate of 48%, surface boxes had an occupancy rate of 26% and above ground boxes attached to tree trunks had an occupancy rate of 35%. All approximate percentages.	(Hobbs, 1967)
Wooden -Underground -False underground -Surface -Above ground	Underground-30cm plastic pipe to the entrance		South Western Alberta, Canada	1970 and 1971	14 species	(Richards, 1978)
Wooden -Underground -Above ground -Half buried		Grassland Woodland	Southern Alberta, Canada	1962	49% 32% 36%	(Hobbs *et al.*, 1962)
-Aerial wicker -Dug holes covered with concrete slabs or upturned flower pots		Gardens Farmland	England and Scotland	2009		(Lye, 2009)

-Semi-underground wooden nest boxes -Wooden surface boxes -Underground flower pot incorporating ventilation and drainage	30cm entrance pipe				40% occupancy rate of nests put out in English botanic garden	
-Above ground terracotta plant pots -Buried terracotta plant pots with entrance holes at the top -Wooden boxes			Sheffield, UK	2005	Between 52 and 72 nest boxes were put out each year over a 3 year period in 20 domestic gardens- not a single nest box was found to be occupied.	(Gaston *et al.*, 2005)

9.2 Discussion

Key research

'Bee Conservation: Evidence for the effects of intervention' (Dicks *et al.*, 2010), focused mainly on solitary bee species and so little literature was given on the success of artificial nesting homes for bumblebees. From the studies that were documented only one was conducted in the UK with the rest mainly from North America. Although different species may have similar nesting habitats, the difference in North American fauna makes in-field application of these results in the UK a lot harder to justify. The studies are also all very outdated, (disregarding Lye, 2009 and Gaston *et al* 2005) suggesting that more modern research would be reliable.

As the studies by Lye and Gaston were conducted in England, the results are of particular interest as this report is aimed at applying conservation measures in the UK; therefore results from English studies are of higher importance for application.

Lye, 2009

Lye (2009) tested 6 different bumblebee nest box designs in gardens and farmland in England and Scotland, including aerial wicker nest boxes (120), dug holes covered with concrete slabs or upturned flower pots (100), semi-underground wooden nest boxes (100), wooden surface boxes (26) and a buried nest box design (which incorporated drainage, ventilation and a 30cm entrance pipe) made with 2 pairs of flower pots placed mouth to mouth (170). Apart from the underground flowerpot design all the designs had uptake rates of just 0-2%.

The flower pot design showed more promising results with a maximum uptake rate of 40%. 150 of this type of design were placed on Scottish farmland with 2% being occupied, and 20 were placed in English botanic gardens with an uptake rate of 40%- 8 out of 20.

The higher uptake in English botanic gardens could be due to the array of pollinating flowers they may contain which appeal to bumblebee species, and the proximity of these flowers to the nests. It is possible that the farmland in

Scotland did not place nest boxes in close location to suitable forage. Nearby foraging plants to nesting locations may be a key factor in nest occupancy rates.

Gaston *et al*., 2005

Gaston *et al* (2005) conducted their study over 3 years in Sheffield, placing between 52-72 nest boxes per year in 20 domestic gardens. They used above ground terracotta plant pots, buried terracotta plant pots with entrance holes at the top and wooden boxes. Throughout the whole study no artificial nest boxes of any design were occupied by any bumblebee species.

Compared to Lye and the other studies from table 1, these results are a bit of an anomaly. As with Lye, Gaston *et al* used gardens as their nesting sites which again would provide flowering plants in close proximity to nests. Additionally, the other studies looked at have shown encouraging results for underground nesting boxes, particularly those made from terracotta plant pots. However, not a single one was occupied in this study.

It is hard to interpret these results, but a possible explanation could be location. The location of the study in the UK may be unpopular for bumblebee species due to factors such as weather or lack of required forage.

Materials

Underground nesting is typical of many bumblebee species; therefore it is no surprise that underground artificial nests and false underground artificial nests generated the highest species numbers and occupancy rates. Underground nests made from terracotta plant pots were the most favoured, particularly ones which provided an entrance spout or pipe, assumedly because an entrance pipe would make the nest easier to access and potentially because it would cause less energy expenditure.

Results from wooden nest boxes have also demonstrated encouraging results. Frison (1926) included wooden nest boxes within his design and overall found a 48% occupancy rate- although the percentage using just wooden boxes is not clarified. Richards (1978) and Hobbs et al (1962) used just wooden nest box designs, and it was found that Richards (1978) recorded 14 different species of bumblebee and Hobbs et al (1962) recorded occupancy rates between 36% and 49%.

The results have not singled out a particular material that has shown to be constantly the least successful or that doesn't work. In the studies, the designs have been mainly focused on terracotta and wooden nest boxes. The only exceptions to this are Frison (1926) which also included tin it its designs and Lye (2009) which incorporated aerial wicker nest boxes and dug holes covered with concrete slabs. As stated before the aerial wicker boxes and dug holes covered with concrete slabs had low uptake rates of 0-2% and the tin design uptake percentage rate cannot be clarified as the occupancy percentage covered all the designs from this study.

However, what can be taken from the results is that underground nesting boxes are favoured over any other design, i.e. surface level boxes and above surface level such as attached to trees, and terracotta is favoured over any other materials. As stated earlier in this section, as many bumblebees naturally nest underground, this is unsurprising.

Location

Most of the studies were conducted in the same habitat type: woodland, meadow, grassland, gardens or farmland. As the results are fairly successful, this is evidence that bumblebee colonies show preference for these habitats. It is likely that they provide nearby foraging resources.

Distance

No literature was provided on distance and maximum foraging range of bumblebees in any of the papers reviewed.

9.3 Conclusion/Suggestions

- Underground nesting boxes are favoured over any other location for nesting boxes i.e. surface level, and above surface level (attached to trees)
- In general, terracotta pots are very successful nesting box designs
- Designs which incorporate entrance spouts or pipes are popular;
- Although the report illustrates research has been conducted in the UK, it is minimal with one study gathering no results. This study used purely terracotta plant pots which although popular in other studies, were clearly not in Gaston *et al* (2005)'s study. With this in mind, it should not provide a basis for negative opinion on the use of plant pots in the UK, particularly as Lye (2009) found success with this design. If anything, it supports the need to conduct more constant and thorough research in the UK using this design, to further assess the benefits of these designs to UK bumblebee species.
- Additionally, the need for testing in different areas of England is important as this could be a key factor in why results from English studies vary.
- More research needs to be undertaken on the relationship between the success of artificial nesting boxes for bumble bees and location in the UK, with emphasis on agricultural land as they have the potential to provide resourceful nesting sites.
- Four of the six studies in table 1 are outdated; clearly identifying current, up to date research is desperately required not just in the UK, but globally. This is especially true in reflection of the status of bumblebee numbers in the UK today.

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