Imperial College London

# An Assessment of Pollen Nectar Margins in Cambridge

**by**

**Katherine S. Taylor**

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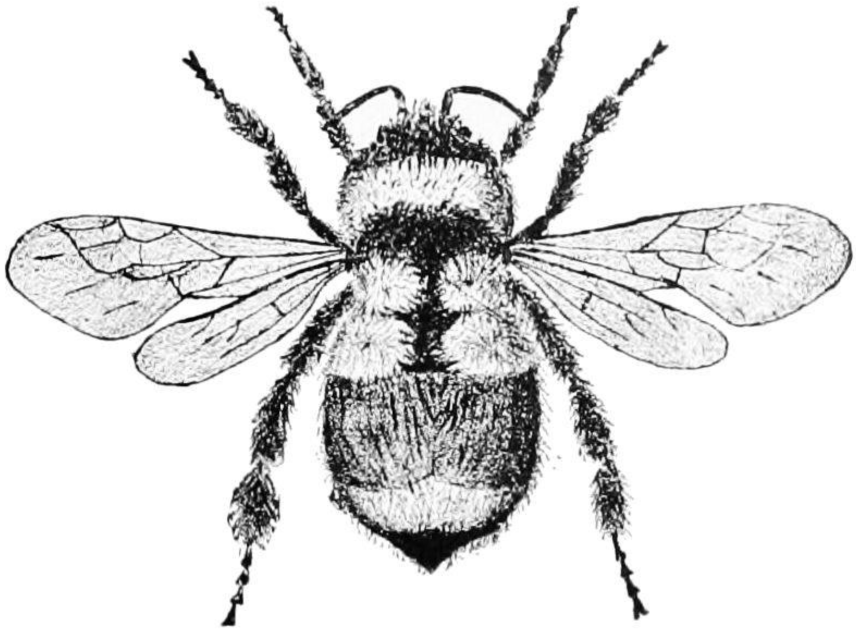

A thesis in partial fulfilment of the requirements for the degree of Master of Science at Imperial College, London

## Declaration

I declare that this thesis:

"An Assessment of Pollen Nectar Margins in Cambridge"

is entirely my own work and that where material could be construed as the work of others, it is fully cited and referenced, and/or with appropriate acknowledgement given.

Signed……………………………………………

Student: Katherine Taylor

Supervisors: John Holland and Richard Gill

## Table of Contents

## List of Figures



## List of Tables

## Appendices

## Abstract

In the UK the decline of some bumblebee species due to changes in farming practices has been widely reported. Pollinators are important for the reproduction of wild plants with various literature reporting they pollinate between 63-94% of the world's wild flowers.

To reverse the declines in plants and pollinators, in particular bumblebees, it is mandatory for European Union member states to operate agri-environment schemes. In Cambridgeshire, a group of farmers have tried to support biodiversity and wildlife conservation by using a range of agri-environment options including sowing pollen nectar mixes at field margins.

This is a field-based study of six farms in Cambridgeshire. Its aim is to assess if pollen nectar mixes are effective in attracting bumblebees in terms of species diversity and abundance. The primary hypothesis is that a greater density of flower coverage and greater floral diversity along the margins will attract more foraging bumblebees. A secondary hypothesis is that margins with more diverse floral assemblage will be better at attracting a greater variety of bumblebee species. An additional objective of the study is to assess, through a questionnaire sent to 30 farms in the area, the farmer's attitudes to agri-environment schemes and evaluate whether the farmers appreciate the value of pollinators.

This study has found good evidence to support the first hypothesis but is more equivocal on the second. Naturally regenerated margins attracted considerably fewer bumblebee numbers. Although this has study reviewed links between flower coverage and diversity it also considered species of flowers. Knapweed, birds foot trefoil, sainfoin and white clover were the species most utilised by bumblebees.

The response to the questionnaire was disappointing and although many interesting points were raised no firm conclusions can be made on attitude to the agri-environment schemes.

## Word Count

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# 1 Introduction

## 1.1 The Bumblebee Crisis

Globally, declines in species richness have been recorded in insect pollinators (Steffan – Dewenter et al., 2005; Williams and Osbourne, 2009; Wratten et al., 2012). In Europe and the UK monitoring of species richness at local scales has been relatively well documented although the monitoring of abundance of species has been very poor (Senapathi et al., 2015). In the UK the decline of some bumblebee species has been widely reported. Declines in species richness has been documented and are relatively well understood however we know a lot less about numbers of bumblbees (Burkle et al., 2013; Kleijn et al., 2015). These declines have been driven by habitat loss and a reduction in floral diversity and abundance as a result of agricultural intensification (Goulson et al., 2008). Between 1932-1984, 90% of unimproved lowland grassland was lost in the UK. Grants were given to remove hedgerows, to plough and reseed pastures and to drain marshy areas. This led to a reduction in foraging areas because of the loss of wildflowers, and nesting sites (Goulson et al, 2007). As a result, of the 97 preferred bumblebee forage species of flowers in the UK, 71% have suffered range restrictions and 76% have seen a decline in abundance (Goulson et al., 2008). Some 97% of suitable bumblebee habitat has been lost in the UK since 1920 (Friends of the Earth, 2015). Three of the 26 species of UK native bumblebees have become extinct (Agriland Leeds, 2015). One in the 19$^{th}$ century (*Bombus pomorum*). Two have become extinct since agricultural practices changed in the latter part of the 20$^{th}$ Century. These are the short haired bumblebee (*Bombus subterraneus*) which became extinct in 2000 but was successfully reintroduced since 2009 (Bumblebee Conservation Trust, 2105) and Cullem's bumblebee (*Bombus cullumanus*), which was last recorded in 1941 (Buglife, 2015).

Changes in farming practices such as the use of competitive crops, herbicides and inorganic fertilizers introduced to switch from hay to silage have reduced floral resources on the margins of fields and within the fields (Marshall et al., 2001 and Wallis de Vries et al., 2012). These changes have also led to the restriction of floral availability seasonally (Carvell et al., 2006 and Goulson et al., 2005). This impacts bumblebees as they require a continuous supply of food throughout the year to support the colony and allow for successful population growth and reproduction (Bowers, 1986). A reduction in flowers over several years can lead to a decline in bumblebee diversity and numbers.

## 1.2 The Importance of Pollinators

Pollinators are important for the reproduction of wild plants. Various literature reports they pollinate between 63-94% of the world's wild plants (Wratten et al., 2012). However, these estimates were not based on data unlike Ollerton et al. (2011) who found that pollinators pollinated 78% of plants in temperate-zone communities and 94% in tropical communities. The Food and Agriculture Organisation (FAO) found that 100 crop species which provide 90% of the world's food require pollinators and, of these, 71% are bee pollinated. The production value of one tonne of pollinator-dependent crop is approximately five times higher than one of the crop categories that do not depend on pollinators (Gallai et al., 2009). Vazquez et al. (2005) found that frequent visits from pollinating insects and subsequent crop yield are higher in areas located closer to natural or semi-natural habitats. Yield of fruit, seed and nut crop could decrease by more than 90% without pollinators (Klein et al., 2007). In Europe, 84% of cultivated crop species depend directly on insect pollinators particularly bees (Williams, 1994 and Gallai et al., 2009). Without bumblebees the world runs the risk of a severe decline in food production.

Many bumblebees are generalist pollinators which have the potential to pollinate an array of plant species (Goulson, 2003). Some species, however, rely on a few plant species. It is argued that, as most insect pollinated plants depend on multiple pollinators, the loss of one or two pollinator species is buffered by alternative pollination networks (Goulson et al, 2007, Astegiano et al., 2015). However, a study by Memmott et al., (2007) tested the removal of individual species from pollination networks and demonstrated that the removal of bumblebees produced the highest rate of decline in plant species diversity.

The decline in wild bees in North West Europe calls for solutions to protect pollinator communities and the ecosystem service they provide (Biesmeijer et al, 2006). Garibaldi et al (2013) found we cannot rely on honeybees to adequately compensate for the decline in wild pollinators to pollinate crops and therefore it is important to encourage bumblebees.

## 1.3 Agricultural Policy

To reverse the declines in plants and pollinators, in particular bumblebees, it is mandatory for European Union member states to operate agri-environment schemes as a part of the Common Agricultural Policy (CAP). These schemes are targeted at habitat improvement and are aimed to enhance habitat availability for a range of species. As part of these schemes species-specific management options are available to target pollinators, beetles and wild birds.

The CAP includes measures whereby farmers are paid to manage their land to benefit particular habitats and species (Ovenden et al., 1998). The CAP was first established in 1958 and the latest CAP reform for 2014-2020 (European Commission, 2015) aims to offer a more ‘integrated’ approach to policy support. Specifically it claims to introduce a new structure for direct payments; better targeted, more equitable and greener, an enhanced safety net and strengthened rural development (European Commission, 2015).

The CAP comprises of two pillars . Pillar 1 focuses on single common market organisation and direct payment schemes. Pillar 2 focuses on Rural Development Programmes which include Environmental land management schemes which agri-schemes fall under.

## 1.4 The Current Project

The Games Wildlife Conservation Trust (GWCT) is reviewing the effectiveness of agri-schemes on UK farmland. In Cambridgeshire, a group of farmers have attempted to improve their farms to support biodiversity and wildlife conservation. They have taken up a range of agri-environment options including sowing down strips of cover at the edges of their fields. This current project is a field-based study of the Cambridgeshire scheme and aims to assess the success of various methods to promote pollinators through identifying whether nectar mixes have been successful and, if so, which nectar mix is most effective in attracting pollinators.

### *1.4.1 Aim and Objectives of the Current Project*

Aim:

The project aims to assess which agri-environment schemes are most effective in attracting bumblebees in terms of species diversity and abundance. To do this, six farms in Cambridgeshire were available for the study (a map showing the location of these farms is included in Section 2.8). Each farm has used a different combination of pollinator options under Entry Level Stewardship (ELS) and Organic Entry Level Stewardship (OELS) schemes (see Section 2.3).

Objectives:

1. To identify which pollen nectar mixes used in the agri-environment schemes attract the greatest number and species diversity of bumblebees and which mix, if any, attracts rare bumblebee species.
    - The primary hypothesis is that a greater density of flower coverage and greater floral diversity along the margins will attract more foraging bumblebees.
    - A secondary hypothesis is that margins with more diverse floral assemblage will be better at attracting a greater variety of bumblebee species
2. To assess the farmers views on agri-schemes and evaluate whether the farmers appreciate the value of pollinators.

# 2 Background Research

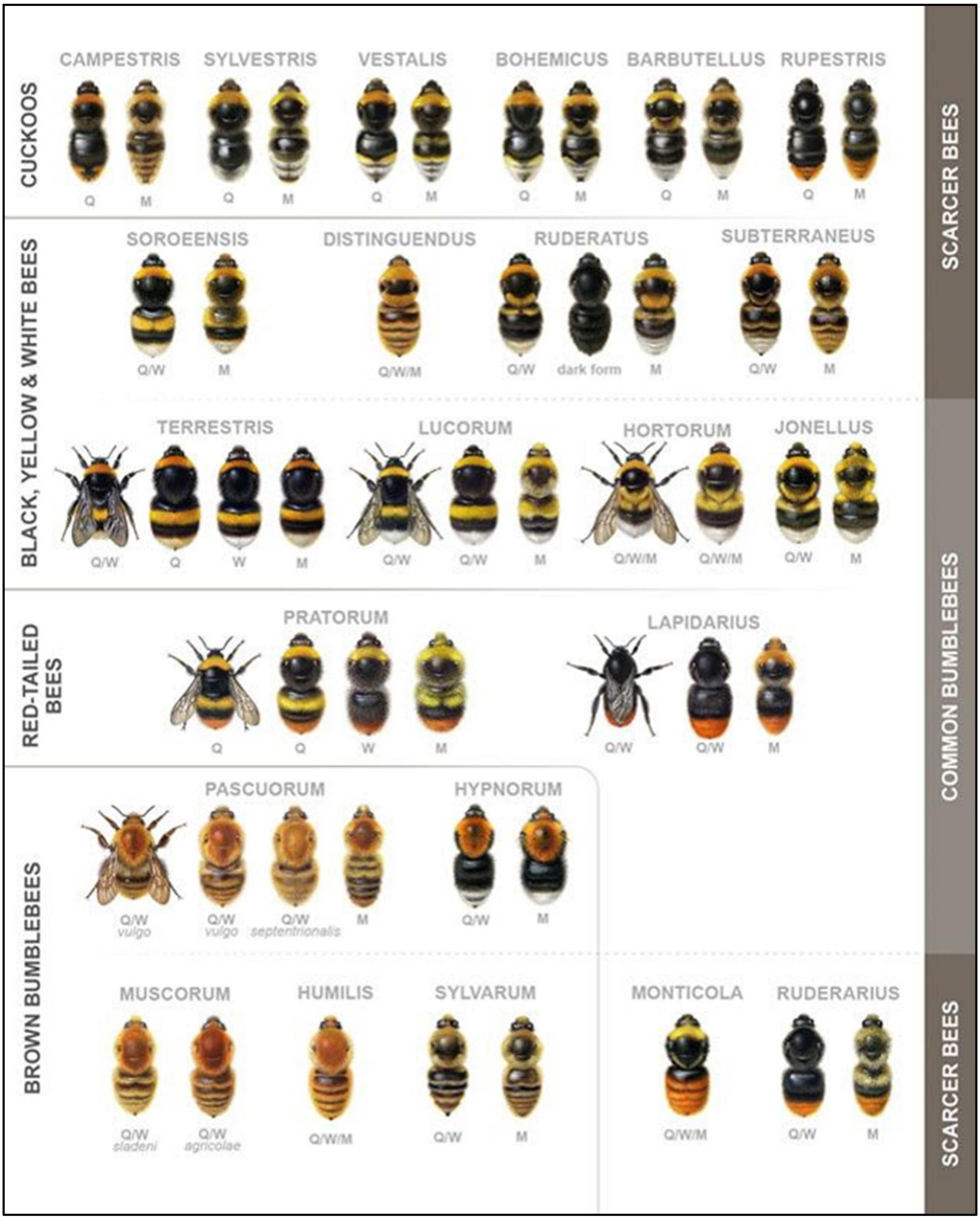
The objectives of the project are to identify which pollen nectar mix attracts the largest number of bumblebees and the greatest variety of species. An additional objective is to assess farmers' views on agri-environment schemes and evaluate whether the farmers appreciate the value of pollinators to their trade. This section summarises background research on: -

- Foraging and impacts on foraging behaviour
- Agricultural policy that affects foraging habitats and environmental schemes designed to preserve or enhance habitats
- Methods of collecting and counting bee populations
- Statistical approaches to understanding diversity indices
- Approaches to collecting data on farmers' attitudes and perceptions on the agri-environment schemes.

## 2.1 Bumblebees Species in the UK

There are around 250 species of bumblebee in the world, and most are found in the northern hemisphere. In the UK there are 23 species of bumblebee but only eight are commonly found (Bumblebee Conservation Trust, 2015). Figure 1.1 shows images of the Queen, worker and male of key UK bumblebee species.

The Queen is observed in late winter or spring searching for a nesting site, provisioning the nest with pollen. She then lays eggs. Workers, once they have emerged, forage for the queen and add to the pollen and nectar store in the nest. Workers can also lay eggs, usually when the queen switches from reproducing males to producing young queens. The workers lay male eggs. Males provide little pollen or nectar for the hive and usually forage for themselves while searching for a mate (Goulson, 2010).




NB: Q = Queen, W = Worker, M = Male

***Figure 2-1: UK Bumblebee Species (Nature Guides Ltd., 2015)***

## 2.2 Bumblebees and Foraging

The hypotheses being tested are which pollen nectar mixes in field margins are most effective in attracting greater numbers and species diversity of foraging bumblebees. It is important, therefore, to understand certain aspects of foraging behaviour. Foraging, when bumblebees search for nectar and pollen, takes place from April to September in the UK. Worker bees undertake most of the foraging while the queen concentrates on producing offspring. Bumblebees will fly up to 400 meters or more from the nest to forage (Edwards and Jenner, 2005). Literature suggests that temperature, flower selection and the type of field margin may impact foraging activity. Each of these factors is discussed in the next sub-sections.

### *2.2.1 Impact of Temperature on Foraging*

In order to fly, bumblebees have to raise the temperature of their flight muscles to above $30^oC$ and Heinrich, 1971). The maximum thoracic temperature they can tolerate is around 42-$44^oC$ (Heinrich and Heinrich, 1983). However, different bumblebee species have different thermal preferences for flight.

Therefore when looking at the number of foraging bees within an area it is important to note the ambient temperature as this could control thermogenesis in bees and thus their foraging behaviour.

### *2.2.2 Impact of Flower Selection on Foraging*

Bumblebees have been known to exhibit fidelity to flowers of a particular plant species from which they have previously found pollen or nectar. They will often ignore many suitable flowers along with unsuitable flowers (Goulson, 2010). Young bees have an innate preference to certain colours but preferences change quickly with experience (Lunau, 1990; Gumbert, 2000). When choosing a flower the bumblebee uses a combination of sensory learning involving scent, colour and shape to help identify rewarding flower species. The learning process can take three to five consecutive rewards (i.e. successfully finding pollen or nectar) and once learnt a preference can last sevaral days (Chittka, 1998).

Bumblebees generally prefer to visit the largest flowers available (Galen and Newport, 1987), possibly because larger flowers are more apparent and produce more pollen and nectar and therefore provide a greater reward for the bees. Bumblebees have also been known to discriminate between ages of plants based on visual clues (Goulson, 2010).

Plants can promote the fidelity and reliability of bumblebees by producing protein rich pollen (Hanley et al., 2008). Hanley et al. found that protein content of pollen and bumblebee visitation rates are positively correlated therefore suggesting that agri-environment schemes should focus on protein rich pollen plants in order to encourage foraging.

### *2.2.3 Impact of Type of Field Margins on Foraging*

In 2008 GWCT research was carried out to assess a Scottish Rural Stewardship Scheme designed to enhance habitat of species in farms. The GWCT work reviewed how the scheme impacted bumblebee queens foraging and searching for nest sites. Five farms were surveyed with grass margins, beetle banks (raised grass mounds, about two metres wide in arable fields to attract beetles), managed hedgerows and species-rich grasslands. They found that field margins improved under the stewardship scheme and, in turn, this led to increased sightings of queens foraging and searching for nest sites. Grass mixes were found to be good for nest sites for bumblebees. Hedgerows were least attractive to queens.

In 2007 Carvell et al. found field margins sown with a split treatment of a mixture of tussocky grass and wildflowers attracted as many bees as margins sown with just wildflowers. The result of this study meant that farmers could provide attractive foraging and nesting habitats for bees within relatively small areas by implementing a mixture of wildflowers and tussocky grass, which may be cheaper than more complex mixes.

## 2.3 Policy

Government policy and funding may influence the implementation of agricultural environmental schemes. In this section, the key aspects of environmental policy relevant to wildlife habitats that impact pollinators are discussed.

### *2.3.1 Common Agricultural Policy*

The CAP includes measures whereby farmers are paid to manage their land to benefit particular habitats and species (Ovenden et al., 1998). The latest CAP reform (2014-2020, European Commission, 2015) aims to offer a more integrated approach to policy support.

However, funding for the CAP for 2014-2020 will be frozen at the level of 2013 which will mean it will potentially become harder for farmers to be accepted onto the scheme.

The CAP comprises of two pillars.  Pillar 1 focuses on single common market organisation and direct payment schemes.  Pillar 2 focuses on Rural Development Programmes which include Environmental land management schemes which agri-environment schemes fall under.  Farmers can apply for Pillar 2 scheme entry in two ways: the first being self-service and the second being by invitation.  Self-service entry is available nationally but is targeted for landscape-scale rural development.  Entry via invitation targets the most important locations and priority sites.  The CAP aims for quality rather than quantity and looks to cut scheme coverage, i.e. the number of farms involved, from 70% to 35-40% by 2020 (Natural England, 2014).  This may be beneficial as the quality of margins should improve but, conversely, it may mean a reduction in the amount of margins set aside for developing habitats.  The relative complexity of entry to these schemes may be a deterrent to farmers becoming involved and is one of the issues addressed in the questionnaire to farmers in the current study.

CAP schemes which involve the implementation of agri-environment schemes relevant to pollinators include:

- Pollen and nectar mixes – a continuous supply of pollen and nectar is made available by establishing a mixture of flowering plants and through management to encourage late flowering.  These need to contain at least three legume species and consist of a mix 80% fine grasses and 20% legumes sown at a rate of 15-20 kg/ha.
- Arable field margins- 6m margins of wild flowers are maintained in sunny areas. Wild flower should comprise of 5% and 20% of the mix by weight and include native species such as yarrow, knapweed and ox-eyed daisy.
- Wild Bird Seed Mixes - Two to five blocks per 100 ha of wild bird seed mixtures. These may be particularly important on livestock farms where other seed sources are not available.  Each block should be up to 0.5 ha in size.  A mix including a cereal and an oil-rich crop (e.g. kale, linseed or quinoa) will benefit the widest range of species.

- Hedges – Trimming only in January/February. Trimming on a 2-3 year rotation rather than annually and avoiding trimming all hedges in the same year.
- Beetle banks - Beetle banks are grass mounds, about two metres wide that run through the middle of large arable fields. They can lie within a field headland not connecting with the field edge so that a field can still be farmed as one unit.

These schemes are all potentially of interest but, clearly, studies are needed to demonstrate which may be worth investing in.

### *2.3.2 Environmental Stewardship Schemes*

Many of the schemes discussed above will have been implemented under Environmental Stewardship (ES). ES is a land management scheme in England which is now closed to new applicants. Existing agreements will still be managed, until they reach their agreed end date.

There are 3 levels to the scheme:

- Entry Level Stewardship (ELS) – includes Uplands ELS (UELS): simple and effective land management agreements with priority options
- Organic Entry Level Stewardship (OELS) – includes Uplands OELS: organic and conventional mixed farming agreements
- Higher Level Stewardship (HLS): more complex types of management and agreements tailored to local circumstances

Under the Entry Level Stewardship scheme the following methods shown in Table 2-1 were offered to promote bees, butterflies and vulnerable grasslands for ELS.

*Table 2-1: ELS Methods*

| Code | Option description |
|---|---|
| EB3 | Hedgerow management for landscape and wildlife |
| EB10 | Combined hedge and ditch management (incorporating EB3) |
| EC4 | Management of woodland edges |
| EE12 | Supplement to add wildflowers to field corners and buffer strips on cultivated land |
| EF1 | Management of field corners |
| EF4 | Nectar flower mixture |
| EK3 | Permanent grassland with very low inputs |
| EK20 | Ryegrass seed-set as winter/spring food for birds |
| EK21 | Legume- and herb-rich swards |

Under this stewardship scheme farmers had to comply with certain protocols when applying nectar flower mixtures (full details are given in Appendix 1)

## 2.4 Agri-environment Schemes

Agri-environment habitat schemes can help support declining pollinators. Holland et al (2015) assessed pollinator habitat management, type, quantity and spatial layout on farms. Habitat management included florally enhanced grass, wild bird seed mix, insect rich cover and natural regeneration. They found that increasing the proportion of new wildlife habitats through agri-environment schemes increased many pollinator taxa. Doubling the existing wildlife habitat doubled the numbers of wild bees. Organic farming and spatial configuration had few effects on pollinators.

Flower-rich habitats are utilised by pollinators (Pywell et al, 2005 and Pywell et al, 2006). Blaauw and Issacs (2014) found the provision of wildflower strips adjacent to pollinator-dependent crops can conserve wild pollinators as they help to stabilise and support populations. Over time they suggested that the wildflower strips can support higher crop yields and bring a return on the initial investment in wildflower seed and planting.

Lye (2009) found that agri field margins contained six times as many flowering plants and 10 times as many flowers than the equivalent cropped areas. Kells and Goulson (2002) looked at the conservation and foraging ecology of bumblebees in agro-ecosystems. It was found that species richness increased on flowering margins, however all the species recorded were common across the UK suggesting that flowering margins don't attract the rarer species. Kells and Goulson (2002) also found that the diversity of flowers was a key factor rather than the density of flowers that led to an increase in bees.

Jonsson et al (2015) assessed local and landscape-wide effects of flower strips on pollinator abundance using selected landscapes across southern Sweden which were distributed along independent gradients of landscape heterogeneity and farming intensity. This research was carried out to investigate whether flower strips increased the growth of pollinator populations in the landscape. Many studies had identified that flower strips were preferred for foraging by pollinators over other habitats (Haenke et al., 2009 and Meek et al., 2002). However, few studies had shown whether flower strips have impacts on pollinator populations across the surrounding landscape (Scheper et al., 2013). In order to demonstrate positive effects of flower strips on pollinator populations Jonsson et al. (2015) needed a) to show increased abundances of pollinators at landscape scales and that b) attraction of pollinators to flower strips did not leave depleted abundances in the vicinity of the strips. They found that flower strips were more attractive to bumblebees compared to field borders, but not for solitary bees. It was also found that farms with larger and/or better quality flower strips had higher abundance in both solitary and bumblebees.

Similarly, Goulson et al. (2007) concluded that the foraging range of bumblebees indicated that bees exploit patches of wildflower habitat at a landscape level suggesting that the scale of management must be appropriate. The integration of many farms across a large area is more likely to succeed than localized efforts. This is because the large scale integrated approach limits the continued fragmentation and isolation of small scale populations.

### 2.5 Collecting and Counting Bees

This project requires collection of data on bumblebee numbers and species diversity to test the various hypotheses related to pollen nectar mixes. The following section discusses the rationale for the choice of survey method.

Collection methods of insects can be divided into two categories: -

- Relative sampling which provides absence/presence data and can indicate how abundant one species is against another but does not allow measurement of population sizes.
- Absolute sampling including pitfall traps and flight intercept traps. Absolute sampling allows for the density of a species to be calculated.

Whether using absolute or relative sampling methods it is important to remember that no single method will collect all the species present in a sample area. By using absolute techniques comparisons can be made between different study sites or studies.

### *2.5.1 Pan Traps*

Pan traps are a simple method which can be made using a shallow tray or container. The pan is partly filled with water and a preservative and detergent. Traps can vary in colours to attract different invertebrates. An example of how traps can be set out is found in research carried out by Popic et al. (2013). Pan traps were deployed across 100 metre transects. Pans were made from polyethylene plastic bowls and painted in three UV fluorescent colours. Six pans, two of each colour were placed along the transect 15 metres apart in alternating colours. Pans were checked, cleared and reset daily. Specimens were then stored in 70% ethanol.

Advantages of using pan traps are traps are cheap and can cover virtually any area that can be reached. However, the main disadvantage is the impact of weather. Heavy rain can wash away catches and traps can dry up in very warm temperatures. Traps also need to be emptied regularly. Pan size may also be a factor. Research by Droege (2005) found that pan trap size did not affect the bee abundance recorded. However, research by Starley and Wilson (2011) showed that the larger traps found greater bee abundance but had no impact on species richness. Traps have the potential to draw bees to an area where they may not have been present thereby giving an inaccurate representation of bee species in the area. In contrast pan traps may miss bees which focus on foraging on flowers as suggested by Minckley and Kervin (2000).

Another disadvantage of using traps is that all trapped bees are killed in the process. As bee numbers are on the decline research should focus on effective sampling methods that will not add to this decline.

### *2.5.2 Walking Transect with Hand Netting*

Another method of recording bee abundance is transect walks and counts. Hand netting during the transect involves sampling bees by catching them in a hand net on patches of flowers. Hand net samples can either be released after capture or collected as specimen samples and placed in zip lock bags and placed in a portable cooler (Munyuli, 2013). The Bumblebee Conservation Trust has initiated 'Bee Walks', a national recording scheme to monitor the abundance of bumblebees across the UK. The walks involve volunteers walking a fixed transect of between 1-2 km. Transects are walked monthly for an hour and bees sightings are recorded. Volunteers record the species of bee, whether it is a Queen, worker or male, the habitat they are surveying and the flowers on which bees are foraging (Bumblebee Conservation Trust, 2015).

The fixed route approach is one method used for surveying bumblebees. In this approach the search is based on a pre-determined route. The same route is followed for each survey visit. The fixed route approach is suitable for large areas, with routes typically 1-2 kilometres long, and areas where there is relatively uniform variation in habitat structure. The route is divided into sections reflecting changes in habitat and land use. Bumblebees are recorded at regular intervals in an area two metres to each side and two metres ahead of the observer. Bumblebees observed either to land within, or take off from, the recording area are recorded but bumblebees observed flying past are not be included.

The availability of different flower species, flowering at different times, affects the distribution of bumblebees. Therefore it is essential to record the flower species present and flowers which bees are foraging on.

Variable walks are where search effort is determined by time. This provides an index of bumblebee activity for a particular site. With this approach, patches of suitable flowers are investigated in turn. It is possible to incorporate this approach to a fixed route "bee walk", to provide additional information. The variable route method may be more effective in detecting rare bumblebee species in areas where they are known to occur at low density. However, it is recommended that this approach is only used in areas where the availability of suitable flowers is very patchy.

To carry out a variable walk, the study site should be divided into segments, e.g. different fields, according to land use or habitat type. The search aims to visit all flower-rich areas in the survey area by walking at a steady pace. This encourages a more even coverage of the site with a greater likelihood that patches of tall and low-growing useful flowers are equally visited. Recording is not restricted to the two metre area on each side and ahead of the observer. Individual flower-rich patches should not be revisited during a visit and there should not be any backtracking on the route. The size and flowering richness of a site will impact the time required. It is recommended to use a fixed search duration, for example 30 or 60 minutes (Bumblebee Conservation, 2010).

### *2.5.3 Pros and Cons of Collecting Methods*

McGavin (2001) suggests that bees are observed and collected with greater ease when at the flower therefore bee surveys along transect routes are more favourable than methods such as pan traps. This survey method is preferred to pan traps because it records what is seen without altering the environment and without enticing bumblebees into the survey area.

Research by Munyuil (2013) looked at line transects, pan trapping and netting as sampling methods and assessed which was more effective when looking at agri-environments and bee abundancy in Uganda. To provide a baseline of the effectiveness of different sampling methods, 26 sites with varying landscape characteristics were sampled in 2006 in agricultural landscapes in Uganda. Sampling methods assessed included line transect counts, coloured pan traps and hand net methods. Munyuil found a total, 80,883 bee individuals were collected of which 59, 314 and 559 bee species were recorded in transect counts, pan traps and hand nets, respectively. Hand nets captured more species overall. Munyuil also found that few species overlapped across the three sampling methods suggesting that a combination of each would be the most effective for a better representation of the population. These findings support those found by Roulston et al. (2007) and Popic et al (2013) who also found net sampling to be a more effective method than pan trapping. However, one important concern raised by all three papers is the collector's experience and bias in bee identification which can impact species abundance and richness analyses if species are incorrectly identified.

## 2.6 Diversity Indices

The hypotheses to be tested rely on the understanding of biological diversity. Biological diversity can be quantified in many ways. The two main factors taken into account when measuring diversity are richness and evenness. The number of species per sample is a measure of richness. The more species present in a sample, the 'richer' the sample. Evenness is a measure of the relative abundance of the different species making up the richness of an area.

### *2.6.1 Simpson Index*

The Simpson index is a dominance index which gives more weight to common or dominant species. A few rare species with only a few representatives will not affect the diversity.

In the Simpson index, p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), Σ is still the sum of the calculations, and s is the number of species (see below).

$$\text{Simpson Index (D)} = \frac{1}{\sum_{i=1}^{s} p_i^2}$$

Disadvantages of Simpsons Index include the fact that not all species are required to be represented and that it is weighted towards more abundant species. Therefore rarer species with low counts will be overlooked. This could impact future conservation efforts if the Index might not represent a rare species which may be believed to be absent from an area with detrimental impacts on conservation efforts in that area. Simpsons Index is sensitive to changes in common species and measures the chance that two individuals are from the same species.

### 2.6.2 Shannon Index

The Shannon index is an information statistic index, which means it assumes all species are represented in a sample and that they are randomly sampled.

In the Shannon index, p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations, and s is the number of species (see below).

$$\text{Shannon Index (H)} = -\sum_{i=1}^{s} p_i \ln p_i$$

All species represented are included in the Shannon Index. This is good as it gives an accurate representation of species without overlooking any. The Shannon Index is relatively easy to calculate and is sensitive to changes in rare species. Sensitivity to the rarer species makes it more appropriate to use in conservation projects.

### 2.6.3 Differences between Simpson and Shannon Indices

The Simpson and Shannon Diversity indices emphasise different aspects of diversity (Nagendra, 2002). The Shannon index stresses the richness component and rare cover types, whilst the Simpson index lays greater emphasis on the evenness component and on the dominant cover types (Riitters, Wickham, Vogelmann and Jones, 2000). As a result, these indices can show considerable variation in their response to changes in landscape or community composition.

As to which diversity index should then be used, and in what situation The Ecological Society of America's Committee on Land Use (Dale et al., 2000) strongly recommends rare landscape cover types and their associated species should be retained within a landscape as these provide habitats for sensitive species and facilitate critical ecological processes. As such Shannon's index of diversity, with greater sensitivity to rarer cover types, should be given greater importance during interpretation. However, in landscapes where a single dominant land cover type is of interest, notably during the design of single-species conservation reserves, Simpson's index of diversity might be preferred.

A successful study of bumblebees based on Shannon diversity was carried out by Verboven et al. (2014). It looked at different responses of bees and hoverflies to land use in an urban–rural gradient. They caught a total of 1,623 pollinators of which 597 (37%; 42 species) were bees and 1,026 (63%; 43 species) were hoverflies. *Bombus pascuorum* made up 298 individuals or almost 50% of all bees that we caught. Abundance and diversity of pollinator communities were both found to be highest in rural-natural sites.

### 2.7 Farmers Attitudes and Perceptions

One of the objectives of this project is to assess farmers' views on agri-environment schemes and evaluate whether farmers appreciate the value of pollinators through a survey of their attitudes and perceptions.

Several attitude studies have been carried out on farmers to inform researchers on management decisions and policy decisions and attitudes (Tranter et al., 2007; Gorton et al., 2008; Alarcon et al., 2014; Zhang et al., 2015). In order to gather this information survey methods including face to face interviews and postal surveys.

Tranter et al. (2007) carried out a postal survey on farmers. They surveyed 4,500 farmers in a number of countries. A questionnaire was used which included a stepwise approach to defining new policy scenarios and examining individual reactions. The response rate was 40.2 in the UK, 38.6% for Germany and 33.4% in Portugal. These rates were particularly high for voluntary postal surveys. To validate the responses behind the postal surveys, interviews with 50 respondents in each country were also conducted.

Challenges with postal surveys include sample bias as responses are voluntary it usually results in responses being supplied by individuals with strong views/opinions on the topic. However, the larger the sample size the more chance the responses will have an even spread of opinion.

An advantage of using a postal survey is its speed. To interview 4,500 farmers face to face would take many man-days. However, questions may be misinterpreted and participants cannot clarify the question with the researcher thereby leading to responses which do not answer the question. It is, therefore, important that questionnaires are written in a clear concise manner which is easy to understand and are simple to fill in.

Alarcon et al. (2014) interviewed twenty English pig farmers to understand their perceptions, attitudes, influence and management of information in the decision making process for disease control. A structured three-part interview was carried out. The first section was about the case background. The second focused on understanding the factors farmers used in the decision making process for use of disease control. The third section looked at attitudes and perceptions towards five key aspects of disease control. Interviews were set out in this manner to ease farmers into the interview process and to give a clear stricture to the interview. A similar interview structure involving higher degrees of code was used by Zhang et al. (2015).

Challenges with interviews include the use of leading questions which can alter the response of the individual resulting in responses which may not be a true representation of the individual's actual opinion. Interviews are also time consuming. However, when the sample size numbers are about twenty as per Alarcon et al. (2014) the interviews are much more manageable. An advantage of an interview is that the interviewer can clarify any queries or misunderstandings an individual may have. The interviewer can also expand on answers provided if unexpected or need verification by the interviewer.

### 2.8 Study Area – Cambridgeshire

The study took place in the south-west of the county between Cambridge and Royston. The area has relatively low lying, gently undulating, topography with good quality agricultural land. The six farms at which suitable margins were available for this study were Hatley, Longstowe, Wimpole, Barton, Highfield and Thrift farms. The locations of these farms are shown in Figure 2-2.


*Note: Image taken from Google Maps*

***Figure 2-2: Location of Farms Surveyed***

# 3 Methodology

## 3.1 Farms

Hatley, Longstowe and Wimple had been pre-selected by the British Wildlife Trust and GWCT. During a reconnaissance of the area it was apparent that these farms provided an insufficient number and variety of mixes to study. Consequently farmers at Barton, Highfield and Thrift farm were asked if they would take part in the project to broaden the range of margins surveyed.

Details of the type of margins and the experimental design the farmers had used to plan the margins were collected. Meetings were held with each farm to discuss and confirm their participation in the project.

The field work associated with the project lasted from the 18$^{th}$ April -17$^{th}$ July 2015.

Maps showing the location of each survey site at each farm can be found in Appendix 2.

## 3.2 Mixes used in the Margins in each Farm

Specific details of the compositions of each mix used at each farm are given in Appendix 3.

Some of the mixes were only found on one farm whereas others mixes had been implemented on several farms. This limited sample size is not ideal for subsequent statistical analysis, however these were the only farms available for this project.

### *3.2.1 Hatley*

The margins at Hatley were planted in spring 2007 and were sown with Emorsgaste Wild Flower Mixture (ESF1) which is a mix of grass and perennials.

The natural balance of meadow perennials in ESF1 provides a succession of attractive flowers over the season, providing a good source of pollen and nectar as well as food plants for a variety of insects. Managed grassland containing a diversity of plants is reported to be one of the best habitat resources that can be created (Emorsgate, 2015).

### *3.2.2 Longstowe*

The margins at Longstowe were sown in April 2011. They were patched-up in spring 2012 as the drought in 2011 meant the margins had not established uniformly. The seed mix used was Emorsgate ESF2.

In ESF2 the pollen and nectar is provided by a wide range of wild flowers. ESF2 contains species that have been shown to be particularly important to bumblebees like red clover and birds foot trefoil. It also contains open-flowered plants like wild carrot and oxeye daisy which are important for other insect groups such as hoverflies. ESF2 sown with a grass mix can develop into flower-rich stable grassland. With the longer lived wild red clover and other plants it offers a long lived sustainable alternative to the short-lived pollen and nectar mixtures based on agricultural forage varieties.

### *3.2.3 Wimpole*

The margins at Wimpole are the only margins in the study area which are under the OELS scheme. The margins studied at Wimpole included one naturally regenerated margin and two margins which have been sown with an organic fertility mix which was also used in the adjacent field.

### *3.2.4 Barton*

At Barton, two naturally regenerated margins and one Syngenta original pollen mix were surveyed. The margins at Barton have been left to naturally regenerate for 5-6 years. The margins have not been sown subsequently.

### *3.2.5 Highfield*

Two mixes were surveyed at Highfield. The first mix was ESF3 which is a cheaper alternative to ESF2 and which contains agricultural legumes. These cultivated varieties are quick to establish but are short persistence (Emorsgate, 2015).

The second mix surveyed was the Cotswold Wild Flora Mix. This mix combines annuals which are dominant in the first year and perennials which get better from the second year of establishment.

### 3.2.6 Thrift

The final farm involved in the project was Thrift farm. Here two mixes were surveyed: EM3 and Kings Grass free pollen and nectar mix. EM3 is a meadow mixture which contains a very wide range of species.

Kings Grass free pollen and nectar mix is a nectar-rich mix that has the potential to last five to ten years if well maintained. It can be agronomically managed to keep unwanted grass species at bay and is an interesting alternative to the more traditional mixtures. Exact percentages of each species are not available for this mix.

### 3.2.7 Margin size

Margins were generally 6 metre wide strips along the edge of a field. However at certain sites Wimpole (Site 2 & 3), Barton (Site 3), Highfield (Site 1) and Thrift (Site 2) the margins were sown as blocks.

## 3.3 Survey Methodology

### 3.3.1 Margins Surveyed

At each farm four different margins were surveyed. Three margins in each farm had pollen nectar mixes and one margin at each farm had a grass margin (N.B. the grass margin at each farm is always Site 4). Each margin is called a 'site' in the field records, on the maps in Appendix 2 and in tables and graphs in the results section.

Transects of 100 meters length were marked out along each of the four sites (or margins) surveyed at each farm. At each site four transects were surveyed in the following positions:

Transect 1: In the centre of the nectar mix buffer strip

Transect 2: At the edge of the buffer strip along the adjacent hedgerow.

Transect 3: 100 meters from the edge of the nectar mix buffer strip

Transect 4: 200 metres from the edge of the nectar mix buffer strip

The eight-week field work period was split into four two-week survey periods. In each survey period, all four transects on every margin at all farms were surveyed. Two weeks were allocated to each survey period to allow spare days in case of bad weather which prevents bees from foraging. For the purposes of this study bad weather was considered to be heavy rain. Surveys went ahead if it had just rained but had stopped and in light rain and drizzle.

### *3.3.2 Survey Procedure*

As each transect was walked, all bumblebee species that were observed within two meters to the side and in front of the observer were recorded. Each transect walk took 30 minutes to cover the 100 meters. In order to reduce identification error bumblebees were caught in a net and transferred to a clear pot, identified and then released. Bees were identified using the Field Guide to the Bumblebees of Great Britain & Ireland (Edwards & Jenner, 2009) as a reference. It is particularly hard to distinguish between *Bomubus terrestris* and Bombus *lucorum* workers so these were grouped together as 'white tailed' bumblebees.

Only bees foraging on the transect were recorded. There was the risk that bumblebees could be counted multiple times if they flew up and down the transect. No bees flying past were recorded.

The species of flower being visited by each individual bumblebee was recorded along with the percentage coverage of flowering plants on every transect and an estimate of the number of flowering species present.

Additional information such as date and time of the survey and prevailing weather conditions were also recorded. Actual temperature during the transect was not recorded.

Appendix 4 shows an example of the data recording sheet in which weather conditions, time, bee count, flower diversity and coverage and any additional notes were recorded.

### 3.4 Statistical Analysis of Bee Survey Data

Data were compiled into one large spreadsheet (see Appendix 6). The Shannon diversity index was calculated out for bumblebee species diversity. A Pearson's correlation was run to test the strength of the relationship between the Shannon diversity index of bumblebees and the flower coverage and diversity and between bumblebee abundance and flower diversity and coverage. However, the limitation of using Pearson's correlation is it can only test the relationship between two variables. Bumblebee abundance and diversity, as suggested in the background research, are impacted by a range of variables therefore to explore this further, multivariable tests using a General Linear Model (GLM) were carried out using R programming code.

The GLM is a procedure in which the calculations are performed using a least squares regression approach to describe the statistical relationship between one or more predictors, in this case flower coverage, flower diversity, the weather conditions and survey, and a continuous response variable such as the total bumblebee count. GLM codes factor levels, for example flower coverage and flower diversity, as indicator variables using a 1, 0, -1 coding scheme, although this can be changed to a binary coding scheme (0, 1). For the weather conditions a binary coding scheme was applied. GLM can perform multiple comparisons between factor level means to find significant differences (Minitab, 2015). The GLM was used to test the strength of the relationship between individual variables and total bumblebee count and the Shannon diversity of bumblebee species and to test the interactions between the variables.

### 3.5 Questionnaire/Focus groups

Approximately 30 questionnaires were e-mailed to farmers within the local Cambridgeshire area by the British Wildlife Trust. This was rather fewer than had been hoped but included all the farms on their database in the area. A sample of the questionnaire can be found in Appendix 5. Only six responses were received. Therefore, the information collected from these responses and from discussions with the farmers involved in the experiment was collated and treated as a focus group response rather than analysed statistically.

# 4 Results

The following section describes the results of the data analyses to test whether the two hypotheses underlying this project are valid namely that a) a greater density of flower coverage and greater floral diversity along the margins will attract more bumblebees and b) that margins with more diverse floral assemblage and greater flower coverage will be better at attracting a greater variety of foraging bumblebee species.

## 4.1 Mixes on Margins Surveyed

The mixes present on the margins at the six farms summarised in Table 4-1.

***Table 4-1: Type of mixes on Margins Surveyed***

| **Farm** | **Site 1** | **Site 2** | **Site 3** | **Site 4** |
|---|---|---|---|---|
| Hatfield | ESF1 | ESF1 | ESF1 | 6 m buffer grass margin |
| Longstowe | ESF2 | ESF2 | ESF12 | 6 m buffer grass margin |
| Wimpole | Natural Regeneration | Organic Fertility Mix | Organic Fertility Mix | 6 m buffer grass margin |
| Barton | Syngenta | Natural Regeneration | Natural Regeneration | 6 m buffer grass margin |
| Highfield | Natural Regeneration | ESF3 | ESF3 | 6 m buffer grass margin |
| Thrift | EM3 | Kings | EM3 | 6 m buffer grass margin |

All margins at Hatley, Barton and Highfield, and margins at Site 2 at Thrift and Sites 1 and 2 at Longstowe had crops in the adjacent field of non-flowering species such as barely and oat. However, all margins at Wimpole, two margins at Longstowe and one margin at Thrift had margins with flowering crops in the adjacent fields. At Wimpole Farm the crop in the adjacent field was the same organic fertility mix as the margin, at Longstowe Farm it was peas and at Thrift Farm a wild bird habitat mix.

## 4.2 Bumblebee Count Observations

A total of 2,661 bumblebees were observed during the survey period. No queens were observed. All bumblebees were either male or workers but no attempt was made to differentiate between males and workers. During the project, 11 species of bumblebee were recorded and identified. A summary of bumblebee species observed is shown in Table 4-2

***Table 4-2: Species of Bumblebees Observed.***

| Species | Survey Period 1 | Survey Period 2 | Survey Period 3 | Survey Period 4 | Total number observed | Percentage of total recorded species* |
|---|---|---|---|---|---|---|
| *Bombus lapidarius* | 125 | 358 | 448 | 475 | 1,406 | 52.8 |
| *Bombus lucorum/terrestris* | 50 | 142 | 159 | 191 | 542 | 20.4 |
| *Bombus pratorum* | 25 | 26 | 5 | 59 | 115 | 4.3 |
| *Bombus pascorum* | 30 | 148 | 113 | 75 | 366 | 13.8 |
| *Bombus hypnorum* | 5 | 41 | 9 | 0 | 55 | 2.1 |
| *Bombus campestris* | 0 | 0 | 19 | 67 | 86 | 3.3 |
| *Bombus sylvarum* | 53 | 14 | 10 | 7 | 84 | 3.1 |
| *Bombus muscorum* | 5 | 0 | 0 | 0 | 5 | 0.2. |
| *Bombus hortorum* | 0 | 0 | 1 | 0 | 1 | 0.0 |
| *Bombus distinguendus* | 1 | 0 | 0 | 0 | 1 | 0.0 |
| *Percentages rounded to one decimal place | | | | | | |

*Bombus lapidarius* was the most frequently observed species accounting for 52.8% of all recorded bumblebees followed by the white tail bees *Bombus lucorum* and *Bombus terrestris* which, as discussed in Section 3 were grouped together as they are very hard to differentiate. Of the species observed, *Bombus sylvarum, Bombus muscorum, Bombus campestris* and *Bombus distingundus* are known to be scarcer bumblebees in the UK (Bumblebee Conservation Trust, 2015).

Figure 4-1 depicts the breakdown of the total bumblebee count at each site during the four survey periods at the various farms. Transects with increasing distance from the margin are shown along the x-axis with Transect 1 being in the margin and Transect 4 furthest from the margin (See Section 3 for details). Site 4 at each farm was a grass buffer margin. N.B. Appendix 7 contains similar graphs showing the results for each survey period at each farm.

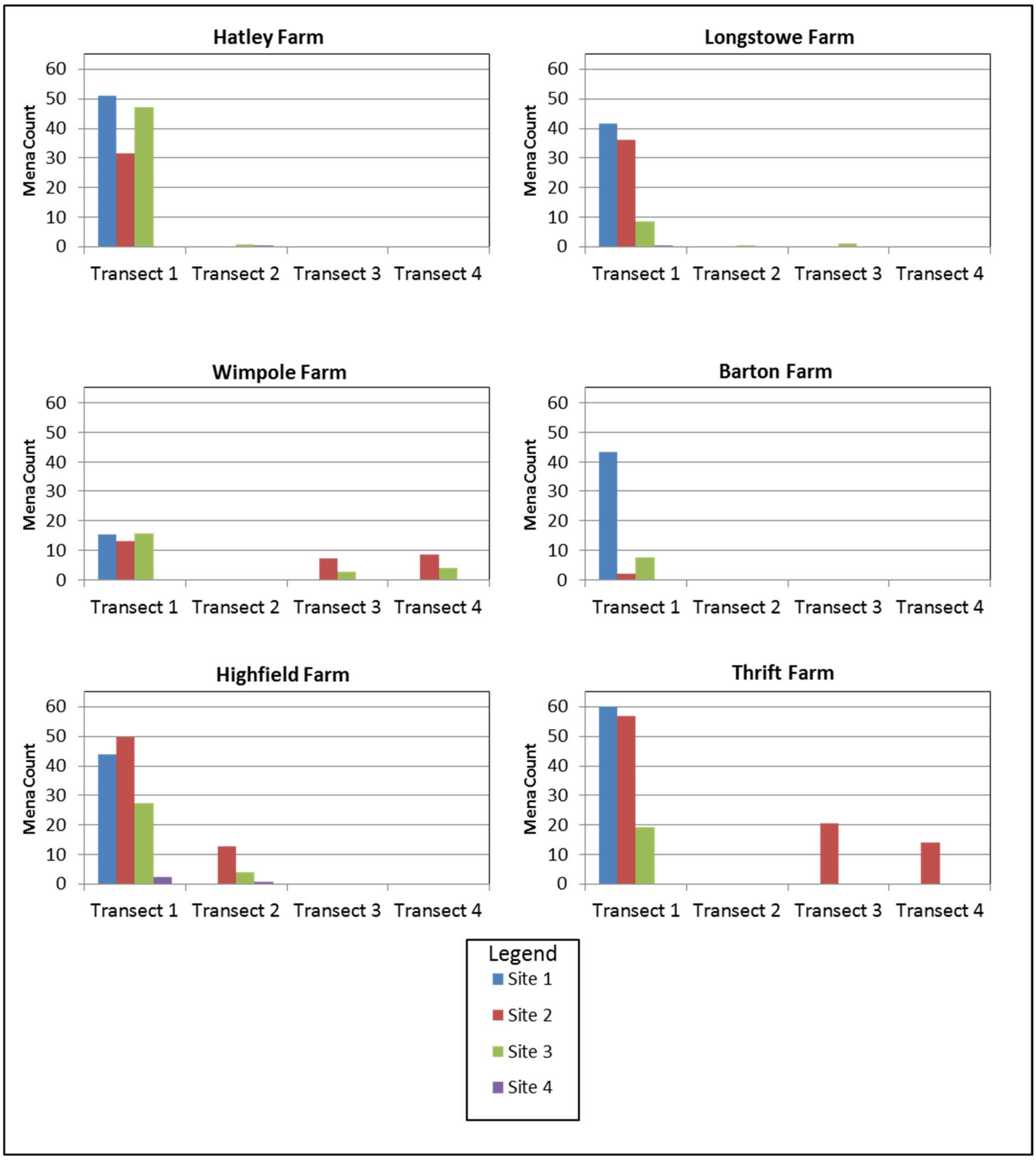



*Figure 4-1: Total Bee Count by Farm (all survey periods)*

Thrift Farm had the highest total bumblebee count of 683, followed by Highfield Farm (603), Hatley Farm (527), Longstowe Farm (362), Wimpole Farm (272) and finally Barton Farm (214).

Figure 4-1 shows that the margins (Transect 1 in each case) generally had far greater numbers of individual bumblebees than transects 100 metres (Transect 3) and 200 metres (Transect 4) away from the margins. This is summarised in Table 4-3 where the mean bumblebee counts across all sites and survey periods are tabulated against transect.

***Table 4-3: Mean Bumblebee Count per Transect (All Surveys)***

| Transect | Mean Count | Standard Deviation | Standard Error |
|---|---|---|---|
| 1 (In margin) | 24.23 | 30.35 | 3.10 |
| 2 (Hedgerow adjacent to margin) | 0.93 | 5.59 | 0.57 |
| 3 (100 m inside field) | 1.47 | 5.95 | 0.62 |
| 4 (200 m inside field) | 1.21 | 5.25 | 0.54 |

Where fields contained crops of non-flowering species, Transects 3 and 4 which were 100 and 200 metres, respectively into the field away from the margin had very low, or no, bumblebee counts (one-two individuals, if any). Conversely, many bumblebees were observed in similar transects 100 to 200 metres away from the margin into fields with flowering crops (when the crops were flowering) albeit in much lower abundancies compared to the pollinator mix margins.

At Wimpole Farm, at Sites 2 and 3 the fields were sown with the same mix as the margins and in Transects 3 and 4 (100 and 200 metres into the field), the adjacent crop had similar numbers of bumblebees present as in the pollinator margins (see Figure 4-1).

Table 4-4 shows the mean bumblebee count in all pollen nectar margins at all farms during all survey periods and the mean count for grass buffer zones for all farms during all survey periods

*Table 4-4: Mean Bumblebee Count on Grass Buffer and Pollen Nectar Margins*

| Type of Margin | | Mean Count | Standard Deviation | Standard Error |
|---|---|---|---|---|
| Sites 1 to 3 | (Pollen nectar mixes) | 9.32 | 21.34 | 1.28 |
| Sites 4 | (Grass buffer zones) | 0.54 | 3.93 | 0.40 |

Site 4 at each farm was a margin with a grass buffer and, as would be expected, there is a marked difference between the number of bumblebees observed at these sites as compared to other sites where margins were sown with a pollen nectar mix.

## 4.3 Hypothesis 1

The primary hypothesis underlying this project is that a greater density of flower coverage and greater floral diversity along the margins will attract more bumblebees. The number of bees counted in all transects is plotted as a function of flower coverage in Figure 4-2 and as a function of flower diversity in Figure 4-3.

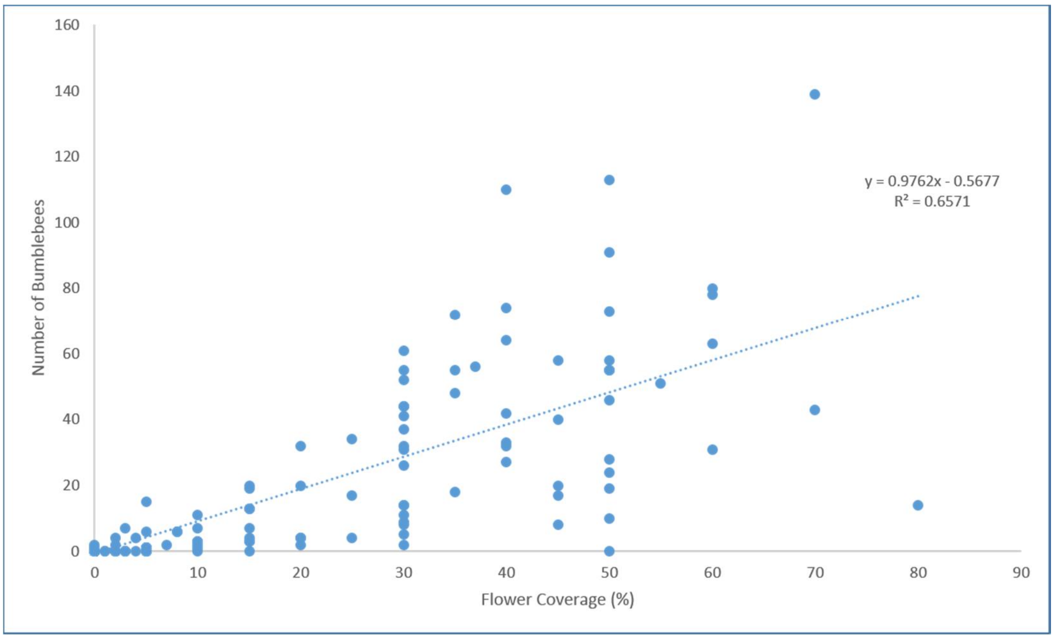



***Figure 4-2: Bumblebee Count vs. Flower Coverage***

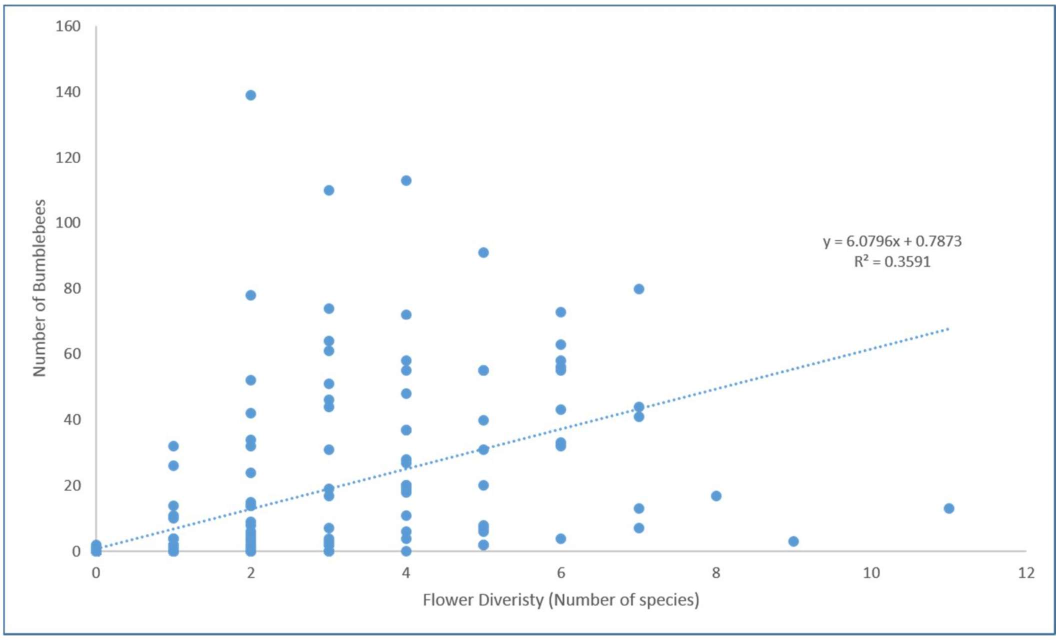



***Figure 4-3: Bumblebee Count vs. Flower Diversity***

Figure 4-2 shows there is a strong positive linear correlation between flower coverage and bumblebee count ($R^2$ = 0.657) which tends to support the hypothesis. Figure 4-3 shows the correlation between flower diversity i.e. number of species and bee count is much weaker ($R^2$ = 0.359). Similar analyses were undertaken for the Transects 1 only (i.e. along the margin itself). The correlation was slightly stronger in the case of flower coverage ($R^2$ = 0.687) but much weaker in the case of flower diversity ($R^2$ = 0.144).

Table 4-5 shows the mean number of bees attracted to each mix in each survey period and the total mean.

*Table 4-5: Mean Bumblebees on Different Mixes*

| Mixture | Mean Total Bumblebees | | | | Mean Total over whole project period |
|---|---|---|---|---|---|
| | Survey Period 1 | Survey Period 2 | Survey Period 3 | Survey Period 4 | |
| ESF1 [3] | 3.3 | 42.3 | 42.0 | 85.3 | 42.23 |
| ESF2 [3] | 37.6 | 28.6 | 28.6 | 20.3 | 28.78 |
| ESF3 [2] | 10.0 | 108.5 | 35.5 | 10.5 | 41.13 |
| EM3 [2] | 48.0 | 80.0 | 51.0 | 61.0 | 60.00 |
| Meadow Mix [1] | 13.0 | 44.0 | 28.0 | 91.0 | 44.00 |
| Kings [1] | 33.0 | 64.0 | 58.0 | 73.0 | 57.00 |
| Organic Fertility Mix [3] | 3.5 | 10.0 | 39.5 | 5.0 | 14.50 |
| Syngenta [1] | 13.0 | 7.0 | 40.0 | 113.0 | 43.25 |
| Natural Regeneration [3] | 0.0 | 11.6 | 21.7 | 4.3 | 9.40 |

[1] One margin of the mix was surveyed
[2] Two margins of the mix were surveyed
[3] Three margins of the mix were surveyed

The EM3 mix (used at Sites 1 and 3 at Thrift Farm) attracted the highest mean across the entire project period 60 bumblebees (standard deviation = 1.45, standard error = 7.22) while the Kings mix (used only in Site 2 at Thrift) attracted a mean count of 57 (standard deviation = 17.14, standard error = 8.57). These mixes had the highest flower coverage (39.5% and 50%, respectively) and diversity (5.9% and 5.3%, respectively). Therefore, in accordance with the hypothesis these mixes would be expected to attract more bumblebees. However, as this is the only farm at which these mixes were used it is difficult to draw any conclusions.

### *4.3.1 Abundance of Bumblebees vs Flower Diversity*

A Pearson's correlation was run to test the strength of the relationship between the abundance of bumblebees and the flower diversity. It found a correlation of 0.73, t=20.57, df = 374, p= <2.2e-16, with a 95% confidence interval of 0.68, which suggests there is a relatively strong positive relationship.

### *4.3.2 Abundance of Bumblebees vs Flower coverage*

A Pearson's correlation was run to test the strength of the relationship between the abundance of bumblebees and the flower coverage. It found a correlation of 0.73, t=20.90, df = 373, p value = <2.2e-16, with a 95% confidence interval of 0.68, which suggests there is a relatively strong positive relationship between the two and is a significant relationship.

The correlation between Shannon diversity of bumblebee species and flower coverage was 0.02 higher than the Shannon diversity and flower diversity.

## 4.4 Hypothesis 2

The secondary hypothesis is that margins with more diverse floral assemblage and greater flower coverage will be better at attracting a greater variety of foraging bumblebee species. The Shannon Diversity index for bumblebee species counted in all transects is plotted as a function of flower coverage in Figure 4-4 and as a function of flower diversity in Figure 4-5.

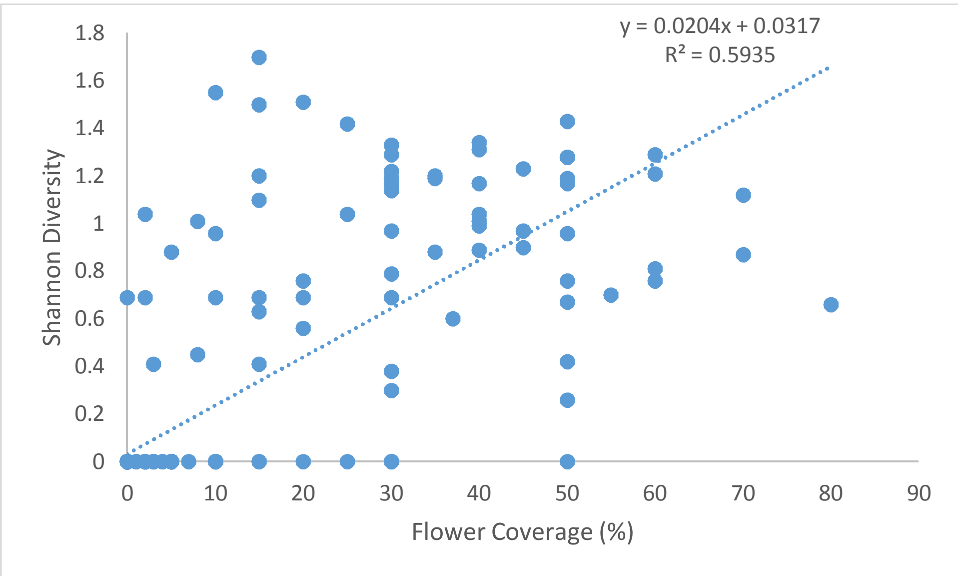



***Figure 4-4: Shannon Diversity Index of Bumblebee Species vs. Flower Coverage***

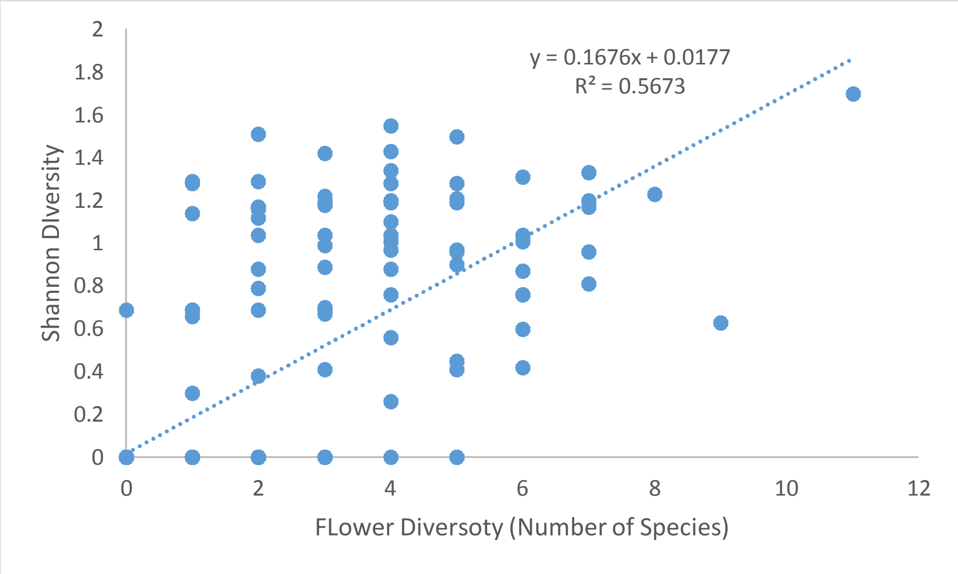



***Figure 4-5: Shannon Diversity Index of Bumblebee Species vs. Flower Diversity***

Figure 4-6 compares the Shannon Diversity Index of bumblebee species observed in each mixture.

***Table 4-6: Shannon Diversity Index Observed on Different Mixes***

| Mixture | Mean Shannon Diversity Index | | | | Mean Shannon Diversity Index |
|---|---|---|---|---|---|
| | Survey 1 | Survey 1 | Survey 1 | Survey 1 | |
| ESF1 [3] | 0.56 | 1.31 | 0.72 | 1.10 | 0.92 |
| ESF2 [3] | 0.49 | 0.83 | 1.24 | 0.94 | 0.88 |
| ESF3 [2] | 1.09 | 1.21 | 0.52 | 0.67 | 0.87 |
| EM3 [2] | 0.60 | 0.79 | 0.79 | 0.97 | 0.79 |
| Meadow Mix [1] | 1.70 | 1.17 | 0.26 | 0.96 | 1.02 |
| Kings[1] | 1.01 | 0.81 | 0.97 | 1.31 | 1.03 |
| Organic Fertility Mix [3] | 0.51 | 0.60 | 1.18 | 0.28 | 0.64 |
| Syngenta [3] | 1.20 | 0.96 | 0.9 | 1.28 | 1.09 |
| Natural Regeneration 3 | 0.00 | 0.79 | 0.59 | 0.23 | 0.40 |

[1] One margin of the mix was surveyed
[2] Two margins of the mix were surveyed
[3] Three margins of the mix were surveyed

These indices suggest that in terms of species diversity the Syngenta mix (used at Barton Farm) had the highest overall mean diversity of 1.09. This was followed by the Kings mix (used at Thrift Farm) with a diversity index of 1.03 and then the Meadow mix (used at Highfield Farm) with a diversity index of 1.02. The EM3 mix which had a high bumblebee total count had one of the lower Shannon Diversity scores of 0.79. This suggests that if the farm wants to focus on the number of bumblebees on their margins then EM3 would be a wise choice but, if the farm wants to focus on bumblebee diversity and/or attracting rarer species then the Syngenta, Meadow or Kings mixes are more appropriate. The naturally regenerated margins had the lowest Shannon index diversity with a score of 0.40 and the lowest meal total implying this is not the best choice for attracting bumblebees.

### *4.4.1 Shannon Diversity of Bumblebees vs Flower Diversity*

The flower diversity was considered to be the number of different flowering species present on the pollinator margins.

A Pearson's correlation was run to test the strength of the relationship between the Shannon diversity index of bumblebees and the flower diversity. It found a correlation of 0.75, t=22.06, df = 371, p= <2.2e-16, with a 95% confidence interval of 0.71, which suggests there is a relatively strong positive relationship between the two. This means the more diverse the margins the higher the Shannon diversity.

### *4.4.2 Shannon Diversity of Bumblebees vs Flower coverage*

A Pearson's correlation was run to test the strength of the relationship between the Shannon diversity index of bumblebees and the flower coverage. It found a correlation of 0.77, t=23.24, df = 370, p value = <2.2e-16, with a 95% confidence interval of 0.73, which suggests there is a relatively strong positive relationship between the two and is a significant relationship.

The correlation between Shannon diversity of bumblebee species and flower coverage was 0.02 higher than the Shannon diversity and flower diversity.

### 4.5 Utilization of species of flowers by bumblebees

During the survey, when each bumblebee sighting was recorded, the species of flower it was visiting was also recorded. Figure 4-6 shows the species of plant visited by bumblebees during each survey period.

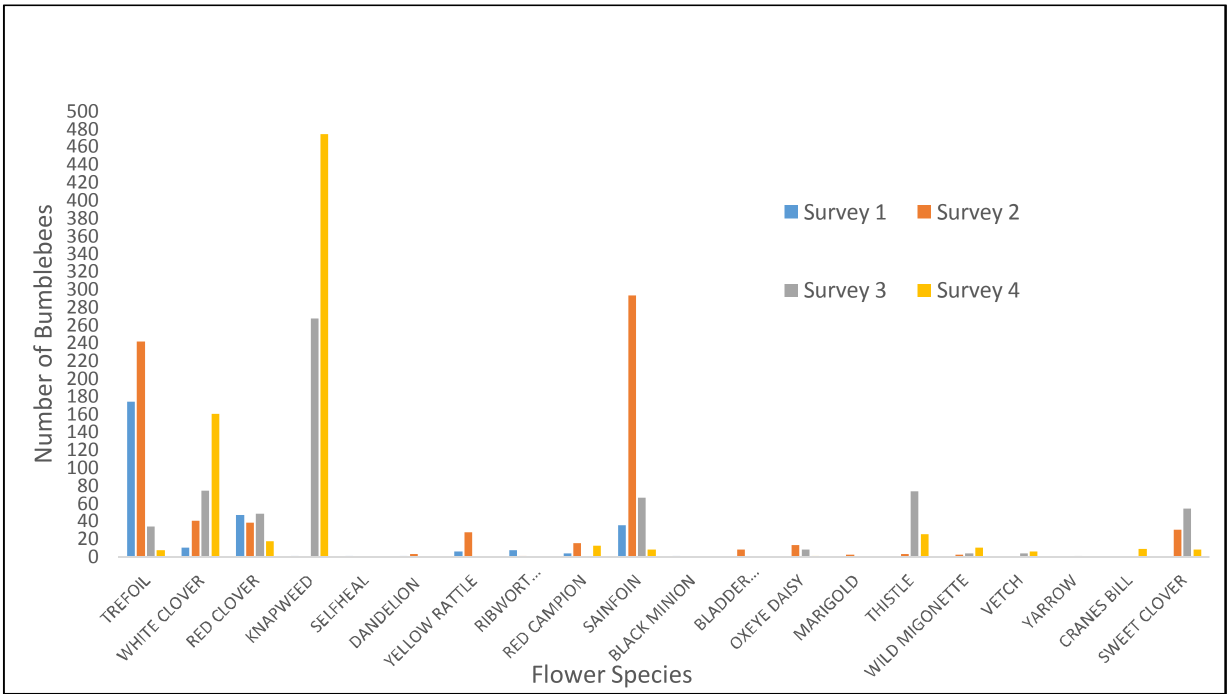



***Figure 4-6: Utilisation of Flowers by Bumblebees***

Four flower species were visited most frequently by bumblebees. These are knapweed (31.3% of total visits), trefoil (19.2%), sainfoin (17.0%) and white clover (12.0%).

Trefoil and sainfoin were relied upon by bumblebees during the first two survey periods. In the latter two surveys knapweed and white clover then became more heavily relied upon. Trefoil and sainfoin were present in these early surveys but died off towards the latter part of the survey period. During the latter part of the survey period, knapweed became more prevalent in the margins. However, white clover was present throughout the whole survey period.

## 4.6 R Models

The next phase of the study was to explore how other variables influenced bee abundance and diversity. A general linear model (GLM) was run in R in order to determine the most important variables affecting bumblebee numbers and diversity. Variables were tested individually against both Shannon diversity indices of bumblebee species and also against bumblebee abundance.

As the Shannon Index of bumblebee species and the bumblebee count are not normalised values, the GLM assumptions would not be appropriate. Also, as bumblebee numbers are Count Data and bounded below (i.e. they can have no values below zero) the values have to be corrected. Therefore the GLM was modified to fit the model with a log link (which ensures that the fitted values are bound below) and Poisson errors (to account for the non-normality).

The variables tested were flower coverage, flower diversity (number of individual species), and four weather conditions (raining, sunshine, overcast but dry and wind) and the survey period. Two tests were attempted; one tested interactions between all the above variables and the Shannon diversity of species and the other tested interactions between all the above variables and the total bumblebee count. However, this could not be done as there were not enough degrees of freedom and the model was saturated. As a result, a more limited number of interactions were tested. These were between: -

Test 1

- flower coverage: flower diversity and Shannon diversity of species
- flower coverage: rain and Shannon diversity of species
- flower diversity: rain and Shannon diversity of species
- flower coverage: flower diversity: rain and Shannon diversity of species

Test 2

- flower coverage: flower diversity and bumblebee count
- flower coverage: rain and bumblebee count
- flower diversity: rain and bumblebee count

- flower coverage: flower diversity: rain and bumblebee count

Results of the GLM are shown in Table 4-7and Table 4-8.

***Table 4-7: GLM Model Output Test 1***

| | Estimate | Std. Error | z value | Pr (>\|z\|) |
|---|---|---|---|---|
| (Intercept) | -4.531676 | 0.695354 | -6.517 | 7.17e-11*** |
| Flower Coverage (FC( | 0.082614 | 0.011099 | 7.443 | 9.82e-14*** |
| Flower Diversity (FD) | 0.590524 | 0.080651 | 7.322 | 2.44e-13*** |
| Rain1 | -0.456263 | 2.427090 | -0.188 | 0.851 |
| Sun1 | 0.200762 | 0.426113 | 0.471 | 0.638 |
| Cloud1 | -0.169793 | 0.377785 | -0.449 | 0.653 |
| Wind1 | 0.395279 | 0.314592 | 1.256 | 0.209 |
| Survey | 0.150991 | 0.140497 | 1.075 | 0.283 |
| FC:FD | -0.013366 | 0.002761 | -4.840 | 1.30e-06*** |
| FC:rain1 | -0.033744 | 0.079472 | -0.425 | 0.671 |
| FD:rain1 | 0.399222 | 1.496751 | 0.267 | 0.790 |
| FC:FD:rain1 | 0.005981 | 0.070506 | 0.085 | 0.932 |
| Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05’.’ 0.1’’ 1 | | | | |
| Null deviance: 236.757 on 371 degrees of freedom<br>Residual deviance: 66.486 on 360 degrees of freedom | | | | |
| AIC : Inf | | | | |

This GLM produced an Akaike information criterion (AIC), an indicator of how good the model is, of infinity. The more negative the value of the AIC the stronger the model. Therefore, this is a very weak model and won’t be discussed in detail any further.

*Table 4-8: GLM Model Output Test 2*

| | Estimate | Std. Error | z value | Pr (>\|z\|) |
|---|---|---|---|---|
| (Intercept) | 0.1107030 | 0.1047413 | 1.057 | 0.29055 |
| Flower Coverage (FC( | 0.0578642 | 0.0017665 | 32.757 | <2e-16*** |
| Flower Diversity (FD) | 0.4030697 | 0.0128777 | 31.300 | <2e-16*** |
| Rain1 | 0.3571359 | 0.2164633 | 1.650 | 0.09897. |
| Sun1 | 0.1392952 | 0.0698528 | 1.994 | 0.04614* |
| Cloud1 | -0.1025537 | 0.0638459 | -1.606 | 0.10822 |
| Wind1 | 0.4033241 | 0.0489808 | 8.234 | <2e-16*** |
| Survey | 0.0465414 | 0.0225932 | 2.060 | 0.03940* |
| FC:FD | -0.0080954 | 0.0004524 | -17.895 | <2e-16*** |
| FC:rain1 | -0.0472447 | 0.0087621 | -5.392 | 6.97e-08*** |
| FD:rain1 | 0.1094736 | 0.1452449 | 0.754 | 0.45102 |
| FC:FD:rain1 | 0.0206210 | 0.0076125 | 2.709 | 0.00675** |
| Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05'.' 0.1'' 1 | | | | |
| Null deviance:5492.8 on 374 degrees of freedom<br>Residual deviance: 1578.7 on 363 degrees of freedom | | | | |
| AIC 2609.3 | | | | |

This GLM produced an AIC of 2,609 which is a very weak model. N.B. an earlier run of the GLM without corrections to account for non-normalised data produce a stronger model.

The GLM model found that of the individual variables on bumblebee count that were tested, flower coverage and flower diversity were the two most significant variables affecting bumblebee numbers (Table 4-4). This is based on the strength of the probability at which the variables are estimated to intercept the y-axis and the difference between this and the intercept output. If the estimate is a negative value it suggests a decrease in bumblebee numbers as flower diversity or coverage increases and vice versa for a positive number. Flower diversity had an estimate of 0.4030697, t value: 31.3 and a Pr(>t|t|): <2e-16 and flower coverage had an estimate of 0.082614, t value: 7.443 and a Pr(>t|t|): 9.82e-14. This demonstrates that increases in both lead to an increase in bumblebee numbers. The results suggest weather conditions did not have a significant impact on bumblebee numbers.

A Cohen's d-test was performed between flower coverage and bumblebee numbers and between Flower Diversity and bumblebee numbers to test their effect on bumblebee count. The Cohen's d-test produces a d-estimate which represents the relationship of the effect of size on the response. The tests found that flower diversity appears to have a very slightly stronger effect on bumblebee count than flower coverage (d-estimates of 0.039 and 0.449, respectively). Both variables are very closely linked and both important. However, it is important to note Cohen's d test is not based on the GLM but merely the means of the variables tested. Despite this Cohen's d test supports the GLM.

A linear model was run between flower diversity and flower coverage. As flower diversity increases flower coverage increases with an estimate of 5.9877 for flower diversity suggesting a strong positive relationship between flower coverage. This was significant with a t value of 19.51, Pr(>t|t|) of <2e-16. We would expect this relationship to occur based on biological theory, as flower diversity increases flower coverage will increase (Tilman, 2001). However, the GLM suggested that the interaction between flower coverage and flower diversity in fact has a negative relationship on bumblebee count suggested by the estimate of -0.0080954. This was also found to be significant as shown by the t value of -17.895 and Pr (>t|t|) of <2e-16. This suggests that in fact an increase in flower coverage and an increase in flower diversity would have a negative effect on the Shannon diversity resulting in lower diversity indices.

Of the other interactions between variables and the bumblebee numbers and flower coverage: rain had a significant affect in decreasing bumblebee count with an, estimate:-0.0472441, t value: -5.392, Pr(>t|t|): 6.97e-08.

### 4.7 Focus groups

Of the thirty plus questionnaires sent to farmers in the Cambridgeshire area, disappointingly, only six responded. As this is an extremely low number no statistical tests were run on the data due to the sample size. A qualitative summary of the results is given below.

### *4.7.1 Agri-environment Schemes*

From the responses four out of six respondents were in the ELS scheme. The four in the scheme all had six meter buffer margins, wild bird mixes, and nectar mixes. The two that were not had also implemented six metre buffer margins. Two of the farms also had implemented beetle banks. Five of the respondents had chosen their preferred method due to its ease of implementation. Two respondents also said price was a factor in their choice. Only one farmer said that they chose their agri-environment schemes as it targeted the species they wanted to protect and help.

Five of the respondents said they would not be partaking in new schemes. Only one of the current ELS participants said they would be applying for the new Country Stewardship schemes. Reasons behind respondents unwillingness to partake included regulations which respondents believed to be 'ridiculous' and counterproductive and the effort and time required to implement and manage the schemes under the regulations were too great.

Five of the six respondents strongly agreed and one respondent agreed that the CAP in relation to pollinator margins was hard to understand and follow. All disagreed that more money should be provided for agri-environment schemes.

### *4.7.2 Other Issues Raised*

All the respondents strongly agreed that bumblebees were important for pollination of crops and that it was important to conserve bumblebees.

Two of the six disagreed that more guidance needed to be provided on the selection of seed mixes, the other four agreed with the statement. Similarly, two of the six respondents disagreed that more information needed to be provided on the success of different mixes. The other four agreed with this statement.

Finally, all the respondents strongly agreed that more needed to be done on public awareness of the habitat enhancement taking place on farms.

#### *4.7.3 Countryside Etiquette*

Three of the respondents also expressed concern over members of the public trespassing by walking on the margins making the farmers vulnerable to fines as the margins made access to their farms easier.

# 5 Discussion

## 5.1 Project findings

The two hypotheses being tested by this project are a) that greater density of flower coverage and greater floral diversity along the margins will attract more bumblebees and b) that margins with more diverse floral assemblage and greater flower coverage will attract a greater variety of foraging bumblebee species.  This study has found good evidence to support the first hypothesis but is more equivocal on the second.

### *5.1.1 Impact of Flower Diversity and Coverage on Bumblebee Abundance*

This study clearly found that flower coverage and to a lesser extent flower diversity increase bumblebee abundance in the margins.  Flower margins attracted higher bumblebee numbers compared to grass margins or the non-flowering crops in the field adjacent to the flower margins.  This supports previous findings by Backman and Tiainen (2002), Potts et al. (2011), and Peterson and Nault (2014).

While the individual impact of both flower diversity and flower coverage on bumblebee abundance was positive, the interaction between flower diversity and flower coverage on bumblebee abundance in the GLM showed a small negative affect.

### *5.1.2 Impact of Flower Diversity and Coverage on Bumblebee Diversity*

The evidence to support this hypothesis was less strong.  Floral diversity was found to be important by Potts et al. (2011) who found bee species were richer and more diverse in the sown treatments and virtually absent from the grass-based treatments.  The current study found that there was some impact on bumblebee diversity as represented by the Shannon index.

Again, while the individual impact of both flower diversity and flower coverage on Shannon Index of bumblebee diversity was positive, the interaction between flower diversity and flower coverage on bumblebee abundance in the GLM showed a small negative affect.  This contradicts biological theory in which as flower richness/diversity increases plant productivity increases which in turn leads to an increased flower coverage (Tilman, 2001).  Conversely, it is possible that should only one flower species monopolise an area it can become very dense and thus increasing flower coverage. The results obtained from the GLM in this study may reflect the fact total flower coverage was analysed rather than the percentage coverage of individual species. It is possible that the relative percentages of particular species could be as important as overall flower coverage.

#### *5.1.3 Organic Margin*

The only organic margin surveyed in this project, at Wimpole, had one of the lower total bumblebee counts and Shannon diversity indeces. This may be due to the mix chosen at Wimpole which was an organic fertility mix. Although it had a few legumes which attract bumblebees, it was not very diverse in pollen-rich species, particularly compared to other mixes surveyed.

#### *5.1.4 Naturally Regenerated Margins*

Table 4-5 and Table 4-6 show the naturally regenerated margins attracted considerably fewer bumblebee numbers. This would be expected as the longer margins are left to regenerate naturally there is less artificial stimulation of flower species. These margins were observed to have very low flower coverage (7.5%) and flower diversity (3.5%)

#### *5.1.5 Flower Type*

Although this study focused od links between flower coverage and diversity it also considered species of flower. Backman and Tiainen (2002) found that diacotlydendous flowers (dicots) were preferred over grasses by bumblebees in research evaluating Southern Finnish field margins. In this study it was observed that knapweed, birds foot trefoil, sainfoin and white clover, which are all dicots, were the species most utilised by bumblebees. As bumblebees were preferentially utilising these four dominant flower types, a greater number of flower species may not necessarily increase numbers or bee diversity. Further research would be beneficial into whether mixes should have a greater proportion of these flower types germinating, emerging and flowering.

### 5.1.6 *Impact of Weather*

Weather conditions had less of an affect than expected. Research by Vicens and Bosch (2000) found that temperature, solar radiation and wind speed, albeit they may be partially correlated with each other, all affect bee activity. However, this research took place in America and the tolerance to weather of American bumblebees may be very different to those in UK. The results from the present study, which took place in various weather conditions except heavy rain, suggest that of all weather conditions the sun had the greatest positive increase on bumblebee count and Shannon diversity. This was also observed in studies by Heinrich and Heinrich (1983) discussed in Section 2.2.1. Clearly farmers cannot control when the sun shines, so the mixes are designed such that flowers bloom at times which coincide with periods when sunshine is most likely whilst attempting to ensure flowers are available throughout the foraging season.

Peat and Goulson (2005) found that temperature, wind speed and cloud cover did not significantly influence the foraging rate negatively. This in part supports the findings of this study which also found cloud cover and wind speed did not significantly influence abundance or diversity. Peat and Goulson (2005) suggested in their findings that pollen was preferably collected when it was warm, windy, and particularly when humidity was low; and preferably during the middle of the day. This study did not record whether bees were foraging for pollen or nectar.

## 5.2 Limitations of the Project

There are several limitations of this project.

The main limitation is the sample size in terms of: -

- number of farms involved
- number of mixes surveyed
- sample size of the responses from the survey.

Only six farms were available for this project. Some mixes were present at three sites, some at two sites and some only at one site. This is not particularly satisfactory as the more times each mix is surveyed in different settings the better the finding.

The mixes were subject to different environmental and farming practices from farm to farm. This means that a mix that performed particularly well on one farm maybe have a very different response on a different farm. However, due to the limited time available and the fact there was a single person surveying all the sites it was not possible to surveys more farms.

Sample size was also an issue with regards to the response to the questionnaire. Although some interesting points were raised by the respondents we cannot say whether the responses are representative of the farming community due to such a small sample size. Additionally, those respondents obviously had a particular interest in the survey and therefore the responses could be biased towards their particular issues with agri-environment schemes. The responses therefore may not be presentative of the majority of farmers in this part of Cambridgeshire.

Due to the lack of response to the survey, the responses received could not be considered to have any statistical significance and were, therefore, treated as a focus group. However, focus groups are usually structured discussions composed of six to nine participants brought together to discuss a particular topic. Focus groups often result in extremely detailed responses due to the time allowed for the meeting and the facilitator being able to explore answers. Thus, if a full focus group was actually held we may have got more detailed responses.

This study didn't take into account the age of the margins nor the width of the margins. These are both variables which have been established in other research to be variables that can affect bumblebee diversity and richness (Holland et al., 2015).

## 5.3 Future Study

### *5.3.1 Data Collection and Analysis*

Further studies incorporating more mixes and more farms would be beneficial. However, any survey should be based on a larger sample size per mix. The mixes tested in this study are just a small proportion of those available to farmers. Testing more mixes would allow a more comprehensive assessment of which mix is the best in terms of bumblebee count and Shannon diversity.

In this study where a specific mix was found on only one farm, a landscape scale variable such as soil quality and type could be impacting the quality of the margin and consequently bumblebee abundance or diversity. Stefan-Dewenter et al., (2002) suggested from their findings a similar conclusion that the analysis of multiple spatial scales may detect the importance of the landscape context for local pollinator communities. Research by Tscharntke et al. (2006) found that many studies have looked largely at local scales but don't fully explain the effect of partitioning on species diversity. Tscharntke et al. (2006) investigated the effects of the landscape-wide availability of different resources (mass flowering crops and semi-natural habitats) on the local densities of four bumblebee species at 12 spatial scales and concluded that coexistence in bumblebee communities could potentially be mediated by species-specific differences in the spatial resource utilisation patterns, which should be considered in conservation schemes. It would therefore be interesting to map mixes across the landscape of Cambridge and assess the resource utilisation and determine which margins work best in providing resources over a much broader scale.

It would be interesting to repeat this study on an annual basis to assess the ongoing performance of the margins. If annual studies were carried out it would be advisable to survey until early September to allow for the entire duration of bumblebee activity to be assessed. Unfortunately due to the constraints of the academic year, the field portion of this study had to be completed by mid-July.

If this study were to be repeated it would be worth testing against the size of the margins and the age of the margins to assess their significance. It would also be interesting to record, if possible, whether the bees were gynes, males or workers.

### *5.3.2 Farmers Attitudes and Perceptions*

In order to analyse farmer perceptions and attitudes towards agri-environment schemes and policy a survey with a larger sample size would be required. However, as the survey questionnaire, which was sent to about 30 farms, received only six responses it would be valuable to seek to interview range of farmers as to what method would be the most suitable way to obtain an understanding of their attitudes and perception towards policy and its implementation. It would be valuable to repeat the attitude perception survey based on the new CAP Countryside Stewardship Scheme once it has been fully established and after farmers have enrolled on the scheme. In order to try an increase the response rate a range of survey techniques could be tried such as phone call interviews, emailed questionnaires, postal questionnaires and focus groups.

## 5.4 Implementation of Results

### *5.4.1 Recommendations for Farmers*

Based on the results shown in Section 4, this study found that EM3, Meadow mix and King's mix are the top three performing mixes in the study area. However, the King's mix in particular is one of the most expensive mixes on the market making it potentially an uneconomic mix for farmers to sow.

It was found that knapweed, birds foot trefoil, white clover and sainfoin were popular foraging plants for bumblebees. If cost of a particular mix is a concern for a farmer, the selection of a cheaper mix with a high content of trefoil, knapweed, white clover and sainfoin would be recommended.

Naturally regenerated margins although beneficial for other species, such as ground nesting birds and other insects (RSPB, 2015), would not be recommended if the farmer is looking to specifically attract bumblebees to the farm. Naturally regenerated margins were the lowest performing margins apart from grass margins which were not expected to attract bumblebees as the grasses do not flower.

A mid-season mow of the margin took place during the survey period at many of the farms. This is done to stimulate late flowering to meet the peak demand from bees. Half of the margin is cut to 20 cm height in late June or early July. During this project observation of the margins in the days after they were mown suggested that margins planted with ESF1 and ESF2 mixes appeared to respond most rapidly to the mow. From this limited empirical observation a mid-season mow appears to be beneficial.

Although not related to the results, when carrying out the project a few issues were encountered which could be avoided with better management. For some farms the exact location of mixes in each margin was uncertain due to changes in farm managers and poor record keeping. Also some of the farms were unsure of the dates mixes were sown. Ensuring up to date maps with location, type and date of sowing the mixes are available would be useful.

If farmer attitudes and perceptions are to be taken into account when making policy changes it is important that they respond to surveys on these matters although maybe they have done so in the past and have become disenchanted by lack of action. Changes of policy and government attitudes cannot be expected to be supported if only a small proportion of farmers are providing information. As time available for farmers to answer such surveys is limited due to their busy schedules, it is important that any future surveys are simple, short and sent out during the quieter months for farmers.

### *5.4.2 Recommendations for Government*

Although the significance of the findings from the focus group are limited by the size of the sample, a few issues were raised which, in author's perception, appear to be essential to encourage farmers to enter the Countryside Stewardship Schemes.

Understanding the scheme and its implementation and following the rules seemed to be a pressing issue for the focus group. This suggests that the new Countryside Stewardship scheme needs to be clearer. The regulation of the scheme and the risk of fines was also raised. It suggests that both policy and regulations would benefit from more consultation with the farmers. Clearer, achievable rules and regulations which can be implemented by farmers alongside the other pressures of farm management are required. More guidance needed to needed to be given about mixture selection.

At present the confusion, risk of fines based on what are perceived to be 'ridiculous' regulations and the time and effort required by the farmers to follow these rules and regulations are discouraging the farmers that responded to the questionnaire from joining the scheme.

Kleijn et al (2015) carried out research on pollinator services in the ecosystem and protection of pollinators. They found that while most bee species decline in abundance with expansion of agriculture, the species currently providing most of the pollination services to crops persist. Conserving the biological diversity of bees therefore requires more than just ecosystem-service-based arguments. This suggests that conservation targets and policy should be more focused towards the impact on biodiversity rather than pollination of crops. It is important that this is considered by government in terms of new policy and when creating targeted campaigns for members of the public. As suggested from the responses from the questionnaire, farmers were very aware of the benefits of crop pollination and implemented agri-environment schemes to enhance this rather than to benefit species diversity.

It was also noted from the farmers that responded to the questionnaire that more public awareness of their efforts to protect bumblebees, and thus encourage habitat enhancement, would be appreciated. The government could help with public awareness via advertisements or possibly by introducing a bumblebee-friendly product logo that could be placed on produce sourced from farms that have developed pollen and nectar margins.

As well as a campaign focused on produce, a campaign to encourage public etiquette on farms may also prove helpful as several of the farmers raised issues about trespassing on the land by members of the public using the margins as pathways across fields of crop.

In summary it would be suggested that more discussion between farmers would be beneficial for any future agricultural policy.

## 5.5 Conclusions

In conclusion, if bumblebee declines are to be prevented further investment in pollen and nectar margins by farmers may be a key contributor to support foraging bumblebees and help potentially stabilise populations while enhancing pollination services on farms.

The study demonstrated that bumblebees are attracted to the pollen nectar margins at the survey sites which have encouraged flower coverage and diversity but, clearly, it cannot show whether this impact is sufficient to support bumblebee populations. Naturally regenerated margins appear to have very little benefit in enhancing bumblebee habitat and clearly, as grasses do not flower, nor do grass margins.

In order for farmers to continue or increase investment in margins, policy and regulation needs to be addressed. Farmers sowing such margins would be advised, based on this study, to invest in mixtures with high content of knapweed, sainfoin, birds foot trefoil and white clover. It is also important that when choosing mixes farmers look for a mix which encourages high coverage. In order to support the coverage, spraying margins to reduce weeds, re sowing margins and possibly mowing mid-season may be required.

However, as only a limited number of mixes were assessed and individual mixes were often not replicated across farms the results obtained may not be representative. Therefore, it is recommended that further research is carried out to test a broader range of mixes and test larger samples of mixes so that the impact of specific mixes on bumblebee numbers and Shannon diversity indices can be differentiated from the impact of landscape or farm management.

## 6 References


Agriland Leeds (2015) Available at www.agriland.leeds.ac.uk/about/Evidence.php

Alarcon. P., Wieland. B., Mateus.A. and Dewberry. C. 2014. Pig farmers' perceptions, attitudes, influences and management of information in the decision-making process for disease control. Preventive Veterinary Medicine, 116, 223-242.

Astegiano.J., Massol. F., Morais Vidal. M., Cheptou. P., Guiamaraes. Jr. P. 2015. The robustness of plant pollinator assemblages: linking plant interaction patterns and sensitivity to pollinator loss. PLoS One, 10(2):e0117243

Backman.C. and Tiainen. J. 2002. Habitat quality of field margins in a Finnish farmland area for bumblebees (Hymenoptera: Bombus and Psithyrus). Agriculture, Ecosystems and Environment, 89, 53–68.

Biesmeijer. J.C., Roberts. S.P.M., Reemer. M., Ohelmueller. R., Edwards. M., Peeter. T., Schaffers. A.P., Potts. S.G., Leukers. R., Thomas. C.D., Settele. J. and Kunin. W.E. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science, 313, 351-354.

Blaauw. B.and Issacs. R. 2014. Flower plantings increase wild be abundance and the pollination services provided to a pollination-dependent crop. Journal of Applied Ecology.

Bowers, M. A. (1985). Bumble bee colonization, extinction, and reproduction in subalpine meadows in northeastern Utah Ecol 66(3): 914-927.

Buglife. 2015. Bumblbees pdf. Available at:
https://www.buglife.org.uk/sites/default/files/Bumblebees.pdf

Bumblebee Conservation Trust. 2015. Bumblebee conservation. Avaiblable at:
http://bumblebeeconservation.org/

Burkle. L.A., Marlin. J.C. and Knight. T.M. 2013. Plant-pollinator interactions over 120 years: loss of species, co-occurrence, and function. Science, 339, 1611-1615.

Carvell. C., Westrich. P., Meek. W., Pywell. R. and Nowakowski. M. 2006. Assessing the value of annual and perennial forage mixtures for bumblebees by direct observation and pollen analysis. Apidologie, 37, 326-340.

Carvel. C., Meek. R., Pywell. F., Goulson. D., Nowakowski. 2007. Comparing the efficacy of agri-environment schemes to enhance bumblebee abundance and diversity on arable field margins. Journal of Applied Ecology, 4, 29-40.

Chittka. L. 1998. Sensorimotor learning in bumblebees: long-term retention and reversal training. Journal pf Experimental Biology, 201, 515-524.

Droege, S. 2005. The Bee Inventory Plot. h p://online.sfsu.edu/˜beeplot

Edwards. M. and Jenner. M. 2005. Field Guide to the bumblebees of Great Britain and Ireland. Ocelli Limited.

European Commission. 2015. The CAP after 2013. Available at: http://ec.europa.eu/agriculture/cap-post-2013/index_en.htm

Friends Of the Earth. 2015. The Bee Cause. Available at: http://www.foe.co.uk/what_we_do/the_bee_cause_home_map_39371

Galen. C. and Newport. M. 1987. Bumble bee behaviour and selection on flower size in the sky pilot. Oecologia, 74, 20-23

Gallai. N., Salles J., Settele. J. and Vassiere. B. 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecology Economics, 68, 810-821.

Games Wildlife Trust (GWCT). 2008. https://www.gwct.org.uk/research/species/invertebrates/pollinators/bumblebee-use-of-farmland-habitats/

Garibaldi. L.A., Steffan-Dewenter. I. and Winfree. R. 2013. Wild pollinators enhance fruit set regardless of honeybee abundance. Science, 339, 1608-1611.

Goulson. D. 2003. Conserving eild bees for crop pollination. International Journal Food Agriculture and the Environment

Goulson.D., Hanley. ME., Darvill. B. and Ellis. JS. 2005. Causes of rarity in bumblebee. Biological Conservation, 122:1-8

Goulson. D., Carvell. C., Meek. W.R., Pywell. R.F and Nowakowski. 2007. Comparing the efficacy of agri-environment schemes to enhance bumble bee abundance and diversity on arable field margins. Journal of Applied Ecology, 44, 29-40.

Goulson. D., Lye. G. and Darvill. B. 2008. Decline and conservation of bumble bees. Annual Review of Entomolgy, 53, 191-208.

Goulson. D. 2010. Bumblebees: behaviour, ecology, and conservation. Oxford University Press

Gorton. M., Douarin. E., Davidova. S and Latruffe. L. 2008. Attitudes to agricultural policy and farming futures in the context of the 2003 CAP reform: A comparison of farmers in selected established and new Member States. Journal of Rural Studies, 24, 322-336.

Government Scotland. 2015. http://www.gov.scot/Topics/farmingrural/Agriculture/CAP/CAPEurope10112012/budget-facts31102012

Guide to Cambridge. 2015. http://www.visitcambridge.org/

Gumbert. A. 2000. Colour choices by bumblebees (Bombus terrestris): innate preferences and generalization after learning. Behavioural Ecology and Sociobiology, 48, 36-43.

Haenke, S., Scheid, B., Schaefer, M., Tscharntke, T., Thies, C., 2009. Increasing syrphid fly diversity and density in sown flower strips within simple vs. complex landscapes. J. Appl. Ecol. 46, 1106–1114

Heinrich. B. 1971. Temperature regulation of the sphinx moth, Manduca sexta II. Journal of Experimental Biology, 54, 141-166.

Heinrich. B. and Heinrich. M.J.E. 1983. Size and caste in temperature regulation by bumblebees. Physiological Zoology, 56, 552-562.

Holland. J., Smith. B., Storkey. J., Lutman. P. and Aebischer. N. 2015. Managing habitats on English farmland for insect pollinator. Biological Conservation, 182, 215-222.

Jonsson. A., Ekroos. J., Danhardt. J., Andersson, G., et al. 2015. Sown flower strips in southern Sweden increase abundances of wild bees and hoverflies in the wider landscape. Biological Conservation, 184, 51-58.

Kells. A. and Goulson. D. 2002. Preferred nesting sites of bumblebee queens (Hymenoptera: Apidae) in agroecosystems in the UK. Biological Conservation, 109, 165-174

Klein. A., Vassiere. B., Cane. J., Steffan-Dewenter. I., Cunningham. S., Kremen. C. and Tscharntke. T. 2007. Importance of pollinators in changing landscapes for world crops. Proc. R. Soc. Lond. B: Biol, 274, 303-313.

Kleijn. D., Winfree. R., Bartomeus. I., Carvalheiro. L., Isaacs. R., Klein. AM., Kremen. C., M'Gonigle. L., Rader. R., Ricketts. T., Williams. T., et al. 2015. Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications, 6: 7414.

Lunau. K. 1990. Colour saturation triggers innate reactions to flower signals: flower dummy experiments with bumblebees. Journal of Comparative Physiology A, 166, 827-834.

Lye. G. 2009. Assessing the value of Rural Stewardship schemes for providing foraging resources and nesting habitat for bumblebee queens (Hymenoptera: Apidae), Biological Conservation, 142 (10), pp. 2023-2032

Marshall, E.J.R. & Moonen, A.C. (2001) Field margins in northern Europe: their functions and interactions with agriculture. Agriculture Ecosystems and Environment, 89, 5–21.

McGavin. G. 2001. Essential Entomology. Oxford University Press.

Minckley. C.and Kervin L. (2000). Sampling Bees (Hymenoptera: Apiformes) for Pollinator Community Studies: Pitfalls of Pan-Trapping. Journal of the Kansas Entomological Society 73: 225–231

Meek, B., Loxton, D., Sparks, T., Pywell, R., Pickett, H., Nowakowski, M., 2002. The effect of arable field margin composition on invertebrate biodiversity. Biol. Conserv. 106, 259–271.

Memmott.J. et al. 2007. Global warming and the distribution of plant pollinator interactions. Ecological Letters, 10, 710-717.

Munyuli. M. 2013. Is pan-trapping the most reliable sampling method for measuring and monitoring bee biodiversity in agroforestry systems in sub-Saharan Africa? International Journal of Tropical Insect Science, 33, 14-37

Natural England. 2014. New Environmental Land Management Schemes & CAP Reform Update. Available at: http://www.cfeonline.org.uk/cfe-kent-pollinators-event-4614-nelms-cap-update/

Nagendra. H. 2002. Opposite trends in response for the Shannon and Simpson indices of landscape diversity. Applied Geography, 22, 175-186

Nature Guides Ltd. 2015. Bumblebee Identification Guide.

Petersen. J. and Nault. B. 2014. Landscape diversity moderates the effects of bee visitation frequency to flowers on crop production.  Journal of Applied Ecology, 51, 1374-1356.

Ollerton. J., Winfree. R and Tarrant. S. 2011. How many flowering plants are pollinated by animals? Oikos, 120, 321-326

Ovenden, G.N., Swash, A.R.H. & Smallshire, D. 1998. Agri-environment schemes and their contribution to the conservation of biodiversity in England. Journal of Applied Ecology, 35, 955–960

Peat. J. and Goulson. D. 2005. Effects of experience and weather on foraging rate and pollen verus nectar collection in the bumblebee, Bombus terrestris. Behavioural Ecology and Socio-biology, 58, 152-156.

Popic. T., Davila. Y. and Wardle. G. 2013. Evaluation of common methods for sampling invertebrate pollinator assemblages: net sampling out-perform pan traps.

Potts. S., Woodcock. B., S. Roberts., Tscheulin. T., Pilgrim. E., Brown. K. and Tallowin. J. 2009. Enhancing pollinator biodiversity in intensive grasslands. Journal of Applied Ecology, 46, 369-379.

Pywell . R., Warman. E., Carvell. C., Sparks. T., Dicks. L., Bennett. D., Wright. A., Critchley. C and Sherwood. A. 2005. Providing foraging resources for bumblebee in intensively farmed landscapes. Biological Conservation, 121, 479-494.

Pywell. R., Warman. E., Carvell. C., Sparks. T., Dicks. L., Bennett. D., Wright. A., Critchley. C and Sherwood. A. 2006. Effectiveness of new agri-environment schemes in providing foraging resources for bumblebee in intensively farmed landscapes. Biological Conservation, 129, 192-206.

Riitters, K.H., Wickham, J.D., Vogelmann, J.E., and K.B. Jones. 2000. National land-cover pattern data. Ecology 81:604-604.

Roulston. T., Smith. S. and Brewster. A. 2007. A comparison of pan trap and intensive net sampling techniques for documenting a bee (Hymenoptera: Apiformes) fauna. Journal of Kansas Entomology Society, 80, 170-181.

RSPB. 2015. Flower rich margins. Available at: https://www.rspb.org.uk/forprofessionals/farming/advice/economics/margins.aspx

Scheper, J., Holzschuh, A., Kuussaari, M., Potts, S.G., Rundlöf, M., Smith, H.G., Kleijn, D., 2013. Environmental factors driving the effectiveness of European agrienvironmental measures in mitigating pollinator loss – a meta-analysis. Ecol. Lett. 16, 912–920.Popic et al (2013).

Senapathi. D., Carvalherio. L., Biesmeijer. J., Dodson. C., Evans. R., McKerchar. M., Morton.D., Moss. E., Roberts. S., Kunin. W. and Potts.S, 2015. The impact of over 80 years of land cover changes on bee and wasp pollinator communities in England. Proc. R. Soc. B 282: 20150294.

Starley. L. and Wilson. J. 2011. Using pan traps to measure bee richness. Department of Biology, Utah state.

Stefan-Dewenter. I., Munzenberg. U., Burger. C., Thies. C. and Tscharntke. T. 2002. Scale dependent effects of landscape context on three pollinator guilds. Ecology, 83, 1421-1432.

Steffan –Dewenter. I., Potts. S. and Packer. L. 2005. Pollinator Diversity and crop pollination services are at risk. Trend in Ecological Evolution, 20, 1-2.

TIlman. 2001. Diversity and Productivity in a Long-Term Grassland Experiment. Science, 294, 834.

Tscharntke. T., Steffen-Dewenter. I., Westohal. C. 2006. Bumblebees experience landscapes at different spatial scales: possible implications for coexistence. Oecologia, 149, 289-300.

Tranter. R., Swinbank. A., Wooldridge. M., Costa. L., Knapp. T., Little. G. and Sottomayer. M. 2007. Implications for food production, land use and rural development of the European Union's single farm payment: Indications from a survey of farmers' intentions in Germany, Portugal and the UK. Food Policy, 32, 656-671.

Vazquez. D., Morris. W. and Jordano. P. 2005. Interaction frequency as a surrogate for the total effect of animal mutualists on plants. Ecological Letters, 8, 1088-1094.

Verboven. H., Uyttenbroeck. R., Brys. R. and Hermy. M. 2014. Different responses of bees and hoverflies to land use in an urban-rural gradient show the importance of the nature of the rural land use. Landscape and Urban Planning, 126, 31-41.

Vicens. N. and Bosch. J. 2000. Weather-dependent pollinator activity in an apple orchard, with special reference to Osmia cirnuta and Apis mellifera. Environmental Entomology, 413, 413-420.

Wallis De Vries. M.F., Van Swaay. C.A.M. and Plate. C.L. (2012) Changes in nectar supply: a possible cause of widespread butterfly decline. Current Zoology, 58, 384–391.

Williams. I.H. 1994. The dependence of crop production within the European Union on pollination by honey bees. Agric. Zool. Rev, 6, 229-257.

Williams. P. and Osbourne. J. 2009. Bumblebee vulnerability and conservation worldwide. Apidologie, 40, 367-387.

Wratten. S., Gillespie. M., Decourtye. A., Mader. E., and Desneux. N. 2012. Pollinator habitat enhancement: Benefits to other ecosystem services. Agriculture, Ecosystem and Environment, 159, 112-122.

Zhang. G., Xiao. H., Duan. M., Zhang. X. and Zhenrong. Y. 2015. Farmers' attitudes towards the introduction of agri-environmental measures in agricultural infrastructure projects in China: Evidence from Beijing and Changsha. Land use policy, 49, 92-103.

# APPENDIX 1

**APPENDIX 1: Details of Stewardship Schemes Relevant to Pollen Nectar Margins**

Under the stewardship scheme farmers had to comply with certain protocols when applying nectar flower mixtures

- Remove any compaction in the topsoil if you need to prepare a seedbed, except on archaeological features.
- Sow a mixture of at least four nectar-rich plants (eg red clover, alsike clover, bird's-foot-trefoil, sainfoin, musk mallow, common knapweed), with no single species making up more than 50% of the mix by weight.
- Sow in blocks and/or strips at least 6 m wide in early spring or late summer. Re-establish the mix as necessary, to maintain a sustained nectar supply (this is typically after three years).
- Regular cutting and removal of cuttings in the first 12 months after sowing may be needed to ensure successful establishment of sown species.
- Only apply herbicides to spot-treat or weed-wipe for the control of injurious weeds (i.e. creeping and spear thistles, curled and broad-leaved docks or common ragwort) or invasive non-native species (Himalayan balsam, rhododendron or Japanese knotweed). Non-residual, non-selective herbicides may be applied prior to sowing, to help re-establishment.
- Do not apply any other pesticides, fertilisers, manures or lime.
- To stimulate valuable late flowering to meet the peak demand from bees, cut half the area to 20 cm between mid-June and the end of the first week of July. Do not cut if ground-nesting birds are present.
- Cut the whole area to 10 cm between 15 September and 31 October, removing or shredding cuttings to avoid patches of dead material developing.
- Do not graze in the spring or summer. Late autumn/early winter grazing of areas is allowed and will benefit legumes, but take care to avoid poaching damage and compaction, particularly when conditions are wet.
- Do not use the area for access, turning or storage.

The same methods provided under the ELS scheme were available for OELS. However the OELS had a few differences in protocol for the maintenance of Nectar Flower mixtures as listed below with the rest of the protocol being the same as ELS margins:

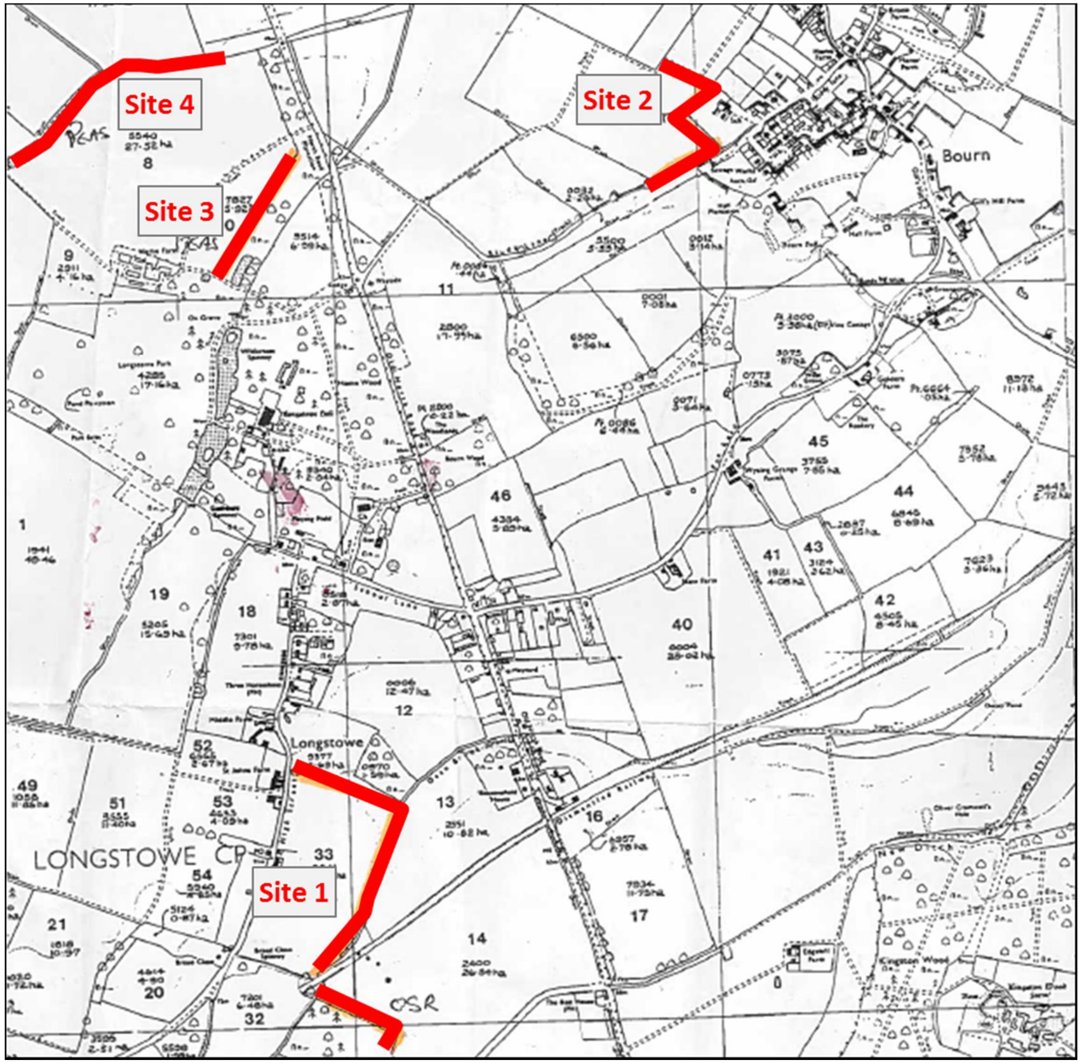
- Use only organic seed mixes on OELS-eligible land. Where this is not possible, you must contact your Organic Inspection Body for a derogation.
- Re-establish the mix as necessary, to maintain a sustained nectar supply (this is typically after three years).
- Control injurious weeds (ie creeping and spear thistles, curled and broad-leaved docks and common ragwort) or invasive non-native species (eg Himalayan balsam, rhododendron or Japanese knotweed) by cultivation before establishment, by cutting in the first year and by selective trimming or manual removal thereafter.

The Countryside Stewardship has now replaced Environmental Stewardship under the changes in the CAP. Under the Countryside Stewardship the following schemes are available under the Pollen and Nectar package:

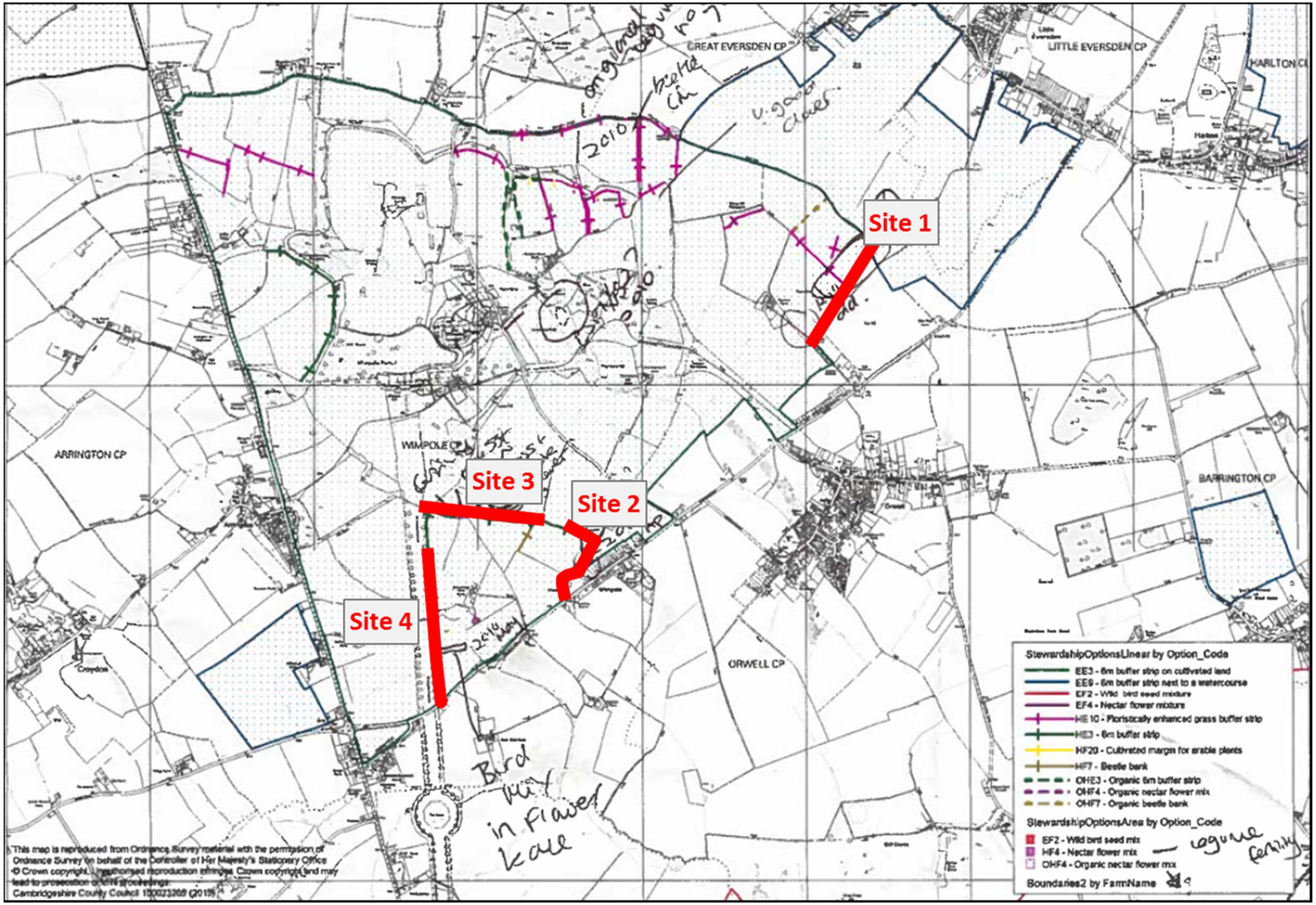
- AB1 - Nectar flower mix
- AB8 - Flower-rich margins and plots
- AB11 - Cultivated areas for arable plants
- AB15 - Two year sown legume fallow
- AB16 - Autumn sown bumblebird mix
- BE3 - Management of hedgerows
- GS4 - Legume and herb-rich swards
- OP4 - Multi species ley

# APPENDIX 2

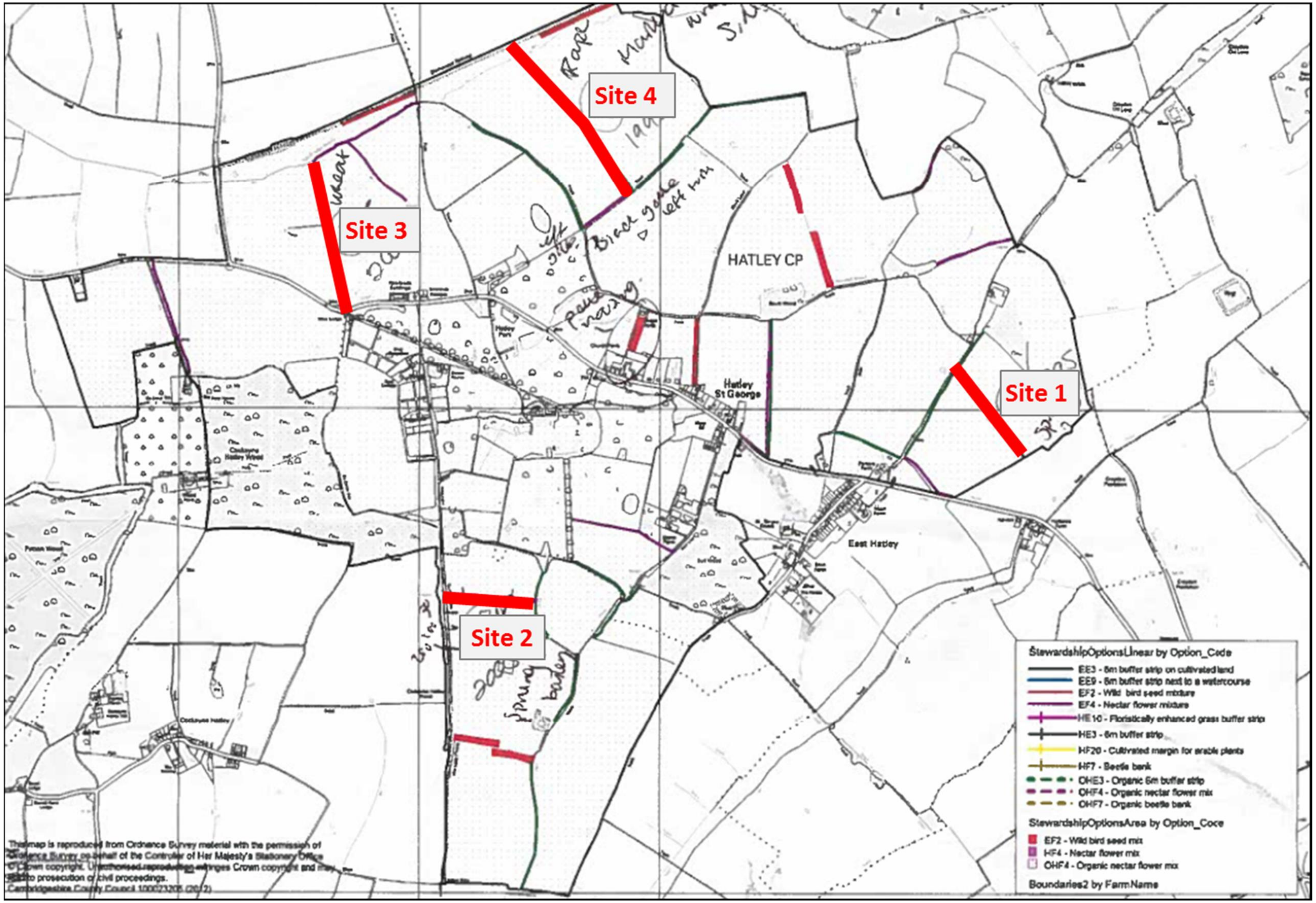
**APPENDIX 2: Maps Showing Location of Margins Surveyed at Each Farm**



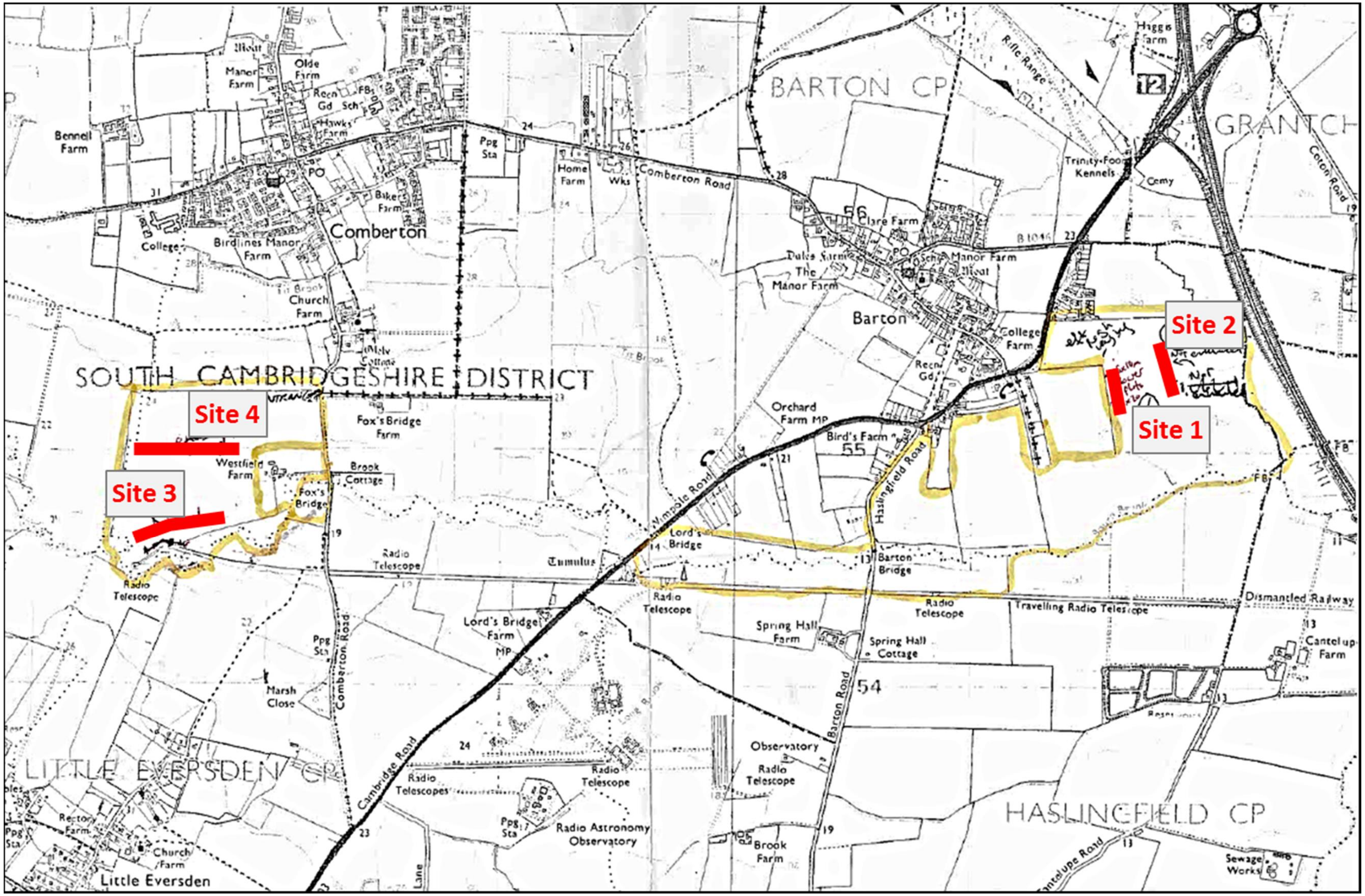

***Appendix Figure 1: Transect Sites at Longstowe Farm***



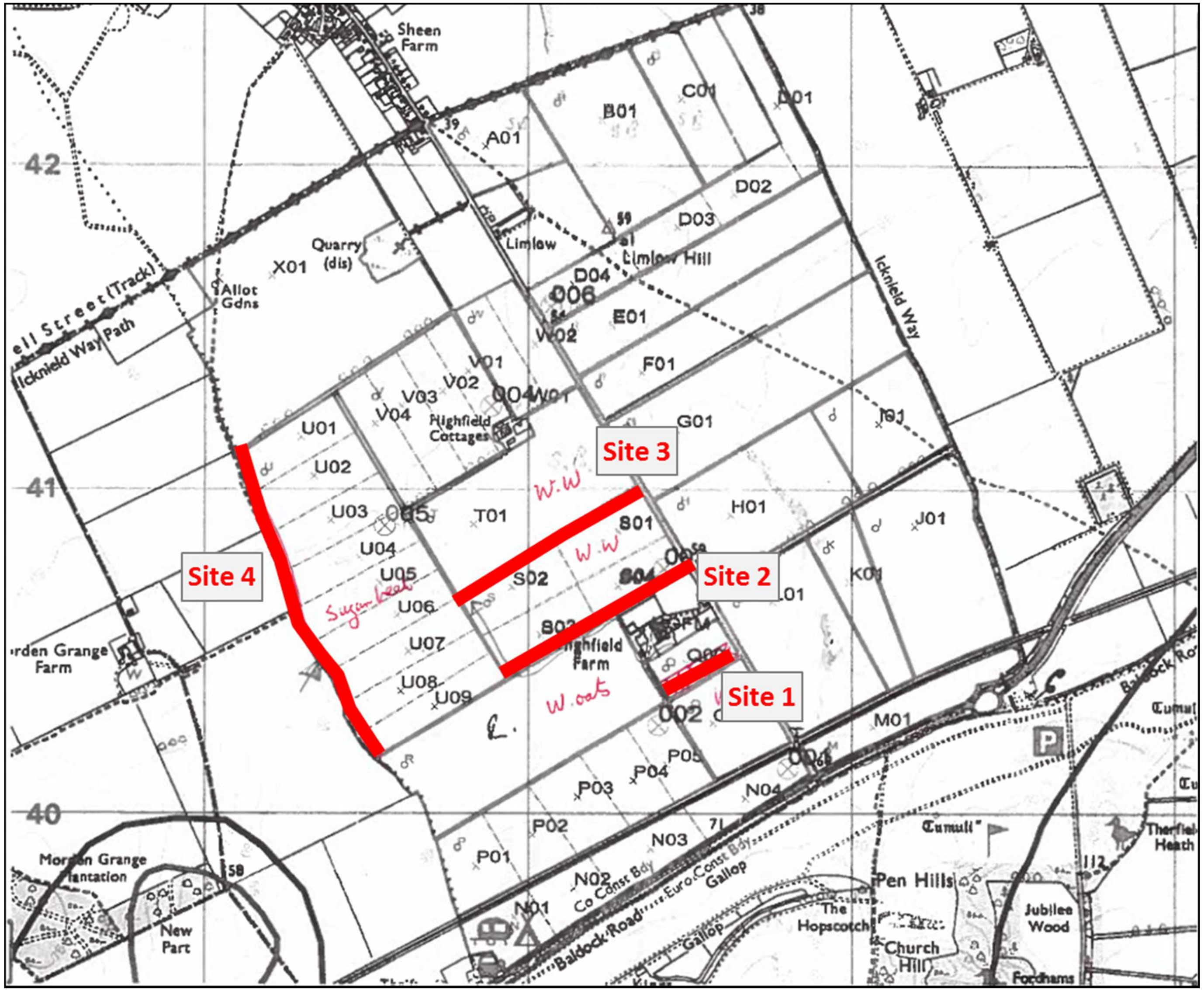

***Appendix Figure 2: Transect Sites at Wimpole Farm***



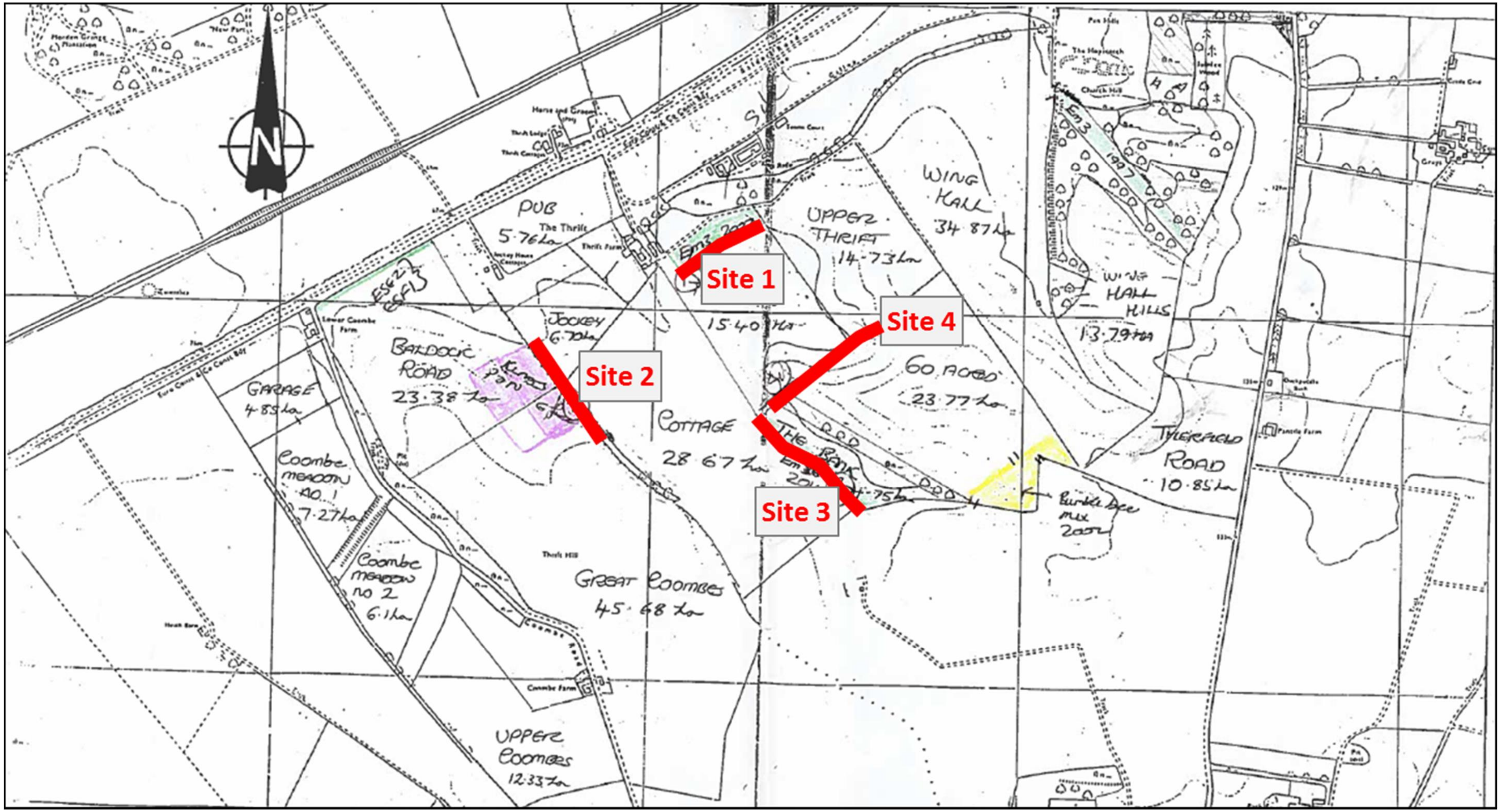

***Appendix Figure 3: Transect Sites at Hatley Farm***




*Appendix Figure 4: Transect Sites at Barton Farm*




***Appendix Figure 5: Transect Sites at Highfield Farm***




*Appendix Figure 6: Transect Sites at Thrift Farm*

# APPENDIX 3

## APPENDIX 3: Details of Composition of Mixes in Survey Area

***Table A2-1: Composition of ESF1 Flower Mix***

| Proportion of mix (%) | Latin name | Common name |
|---|---|---|
| 2.5 | Achillea millefolium | Yarrow |
| 15 | Centaurea nigra | Common Knapweed |
| 5 | Galium verum | Lady's Bedstraw |
| 5 | Leucanthemum vulgare | Oxeye Daisy |
| 5 | Lotus corniculatus | Birdsfoot Trefoil |
| 15 | Plantago lanceolata | Ribwort Plantain |
| 15 | Poterium sanguisorba - (Sanguisorba minor) | Salad Burnet |
| 15 | Ranunculus acris | Meadow Buttercup |
| 2 | Rumex acetosa | Common Sorrel |
| 10 | Silene dioica | Red Campion |
| 10 | Silene vulgaris | Bladder Campion |
| 0.5 | Trifolium pratense | Wild Red Clover |

***Table A2-2: Composition of ESF2 flower mix***

| Proportion of mix (%) | Latin name | Common name |
|---|---|---|
| 6 | Achillea millefolium | Yarrow |
| 12 | Centaurea nigra | Common Knapweed |
| 5 | Daucus carota | Wild Carrot |
| 10 | Knautia arvensis | Field Scabious |
| 10 | Leucanthemum vulgare | Oxeye Daisy |
| 8 | Lotus corniculatus | Birdsfoot Trefoil |
| 8 | Malva moschata | Musk Mallow |
| 10 | Plantago lanceolata | Ribwort Plantain |
| 2 | Primula veris | Cowslip |
| 3 | Prunella vulgaris | Selfheal |
| 10 | Ranunculus acris | Meadow Buttercup |
| 5 | Silene dioica | Red Campion |
| 6 | Trifolium pratense | Wild Red Clover |

*TableA2-3: Composition of Organic Fertility Mix*

| Proportion of Mix (%) | Latin name | Common name |
|---|---|---|
| 35 | | Ryegrass |
| 5 | | Timothy |
| 10 | | Cocksfoot |
| 10 | | Medium leafed white clover |
| 10 | Trifolium pratense | Red Clover |
| 20 | Medicago sativa | Lucerne |
| 8 | Trifolium incarntum | |
| 1.5 | Medicago lupulina | |
| 0.5 | Cichorium Intybus | |

*TableA2-4: ESF3 Legume and Pollen and Nectar Flowers*

| Proportion of mix (%) | Latin name | Common name |
|---|---|---|
| 20 | Lotus corniculatus | Birdsfoot Trefoi |
| 40 | Onobrychis viviifolia | Sainfoin |
| 15 | Trifolium hybridum | Alsike Clover |
| 25 | Trifolium pratense | Red Clover |

*Table A2-5: Costwold Wild Flora Mix*

| Oroportion of mix (%) | Latin name | Common name |
|---|---|---|
| 5 | Agrostis capillaris | Common Bentgrass |
| 5 | Cynosurus cristatus | Crested Dogstail |
| 5 | Anthoxanthum odaratum | Sweet Vernal Grass |
| 10 | Phleum bertolonii | Smaller Catstail |
| 20 | Fesuca ovina | Sheeps fescue |
| 15 | Festuca rubra | Red fescue |
| 15 | Poa pratensis | Smooth Meadowgrass |
| 1 | Primula veris | Cowslip |
| 1 | Knautia arvensis | Field Scabious |
| 2 | Galium verum | Ladys Bedstraw |
| 2 | Centairea nigra | Lesser Knapweed |
| 1 | Ranunculus acris | Meadow Buttercup |
| 1 | Filipendula ulmaria | Meadowsweet |
| 1 | Leucanthemum vulgare | Ox-eye Daisy |
| 1 | Silene dioica | Red Campion |
| 1 | Plantago lanceolata | Ribwort Plantain |
| 2 | Prunella vulgaris | Self-heal |
| 2 | Poterium sanguisorba - (Sanguisorba minor) | Salad Burnet |
| 1 | Rumex acetosa | Sorrel |
| 1 | Silene latifolia | White Campion |
| 1 | Daucus carota | Wild Carrot |
| 1 | Achillea millefolium | Yarrow |
| 1 | Rhinanthus minor | Yellow Rattle |
| 2 | Agrostemma githago | Corn Cockle |
| 1 | Glebionis segetum | Corn Marigold |
| 1 | Centaurea cyanus | Cornflower |
| 1 | Papaver rhoes | Field Poppy |

*TableA2-6: EM3 Mix*

| Proportion of mix (%) | Latin name | Common name |
|---|---|---|
| **0.5** | Achillea millefolium | Yarrow |
| **2.4** | Centaurea nigra | Common Knapweed |
| **1** | Centaurea scabiosa | Greater Knapweed |
| **0.6** | Daucus carota | Wild Carrot |
| **0.6** | Filipendula ulmaria | Meadowsweet |
| **0.8** | Galium verum | Lady's Bedstraw |
| **1.5** | Knautia arvensis | Field Scabious |
| **0.3** | Leontodon hispidus | Rough Hawkbit |
| **1** | Leucanthemum vulgare | Oxeye Daisy |
| **1** | Lotus corniculatus | Birdsfoot Trefoil |
| **0.1** | Origanum vulgare | Wild Marjoram |
| **1** | Plantago lanceolata | Ribwort Plantain |
| **0.5** | Plantago media | Hoary Plantain |
| **1.8** | Poterium sanguisorba - (Sanguisorba minor) | Salad Burnet |
| **0.5** | Primula veris | Cowslip |
| **2** | Ranunculus acris | Meadow Buttercup |
| **1** | Rhinanthus minor | Yellow Rattle |
| **0.6** | Rumex acetosa | Common Sorrel |
| **1** | Silene dioica | Red Campion |
| **0.2** | Silene flos-cuculi - (Lychnis flos-cuculi) | Ragged Robin |
| **1** | Silene vulgaris | Bladder Campion |
| **0.1** | Trifolium pratense | Wild Red Clover |
| **0.5** | Vicia cracca | Tufted Vetch |
| **8** | Agrostis capillaris | Common Bent |
| **40** | Cynosurus cristatus | Crested Dogstail |
| **28** | Festuca rubra | Slender-creeping Red-fescue |
| **4** | Phleum bertolonii | Smaller Cat's-tail |

*TableA2-7: Kings Grass free pollen and nectar mix*

| Latin name | Common name |
|---|---|
| **Trifolium hybridum** | Alsike Clover |
| **Lotus corniculatus** | Birdsfoot Trefoil |
| **Vicia sativa** | Common vetch |
| **Trigonella foenum-graecum** | Fenugreek |
| **Medicago sativa** | Lucerne |
| **Phacelia** | Phacelia |
| **Latin name** | Common name |
| **Silene dioica** | Red Campion |
| **Trifolium pratense** | Red Clover |
| **Onobrychis viviifolia** | Sainfoin |
| **Melilotus officunalis** | Sweet Clover |
| **Silene latifolia** | White Campion |
| **Medicago lupulina** | Yellow Trefoil |

# APPENDIX 4

**APPENDIX 4: Example of Data Collection Sheet**

| Farm: | Location: | Treatment: | Date: | Transect Number: |
|---|---|---|---|---|

| Time | Weather Conditions | Number of Bumblebee | Species of Bumblebee | Flower Diversity score | Flower Cover score | Other Flower Notes | Other Bumblebee notes |
|---|---|---|---|---|---|---|---|
| | | Red tailed bumblebees<br><br>White tailed bumblebees<br><br>2 band bumblebee<br><br>3 band bumblebee<br><br>Yellow/brown | | | | | |

# APPENDIX 5

## APPENDIX 5: Example Questionnaire/Survey

### Agri-environment schemes and Pollinators

You are about to answer questions on agri-environment schemes and pollinators as part of an MSc project for Imperial College in collaboration with the Games Wildlife Conservation Trust. Your answers will be anonymous. Answers will be analysed and help assess agri-environment schemes and pollinators and your experience as farmers with these schemes. Please answer all the questions below. If you have any further questions about the project or how this data will be used please feel free to email the following address with your questions: Katherine.taylor14@imperial.ac.uk

### Section 1

Do you take part in any agri-schemes under the CAP?

Yes NO

If you answered yes please continue through Section 1A.

If you answered no please turn to section 1B.

### Section 1A

### What schemes do you do and why?

| **Agri-Scheme** | **Please tick the applicable schemes** |
|---|---|
| 6m buffer strips | |
| Organic 6m buffer strips | |
| Wild bird seed mixture | |
| Nectar Flower Mix | |
| Organic Nectar Flower Mix | |
| Beetle bank | |
| Organic beetle bank | |
| Cultivated margins for arable plants | |

**Why did you choose these schemes?**

| **Reason** | **Please tick the appropriate answer** |
|---|---|
| Money | |
| Easiest to implement in terms of practicality | |
| Targeted species you wanted to target | |
| Chosen based on advice from others | |
| Other | |

**Please use space below to expand on your answer**

………………………………………………………………………………………………………………………………………………
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………………………………………………………………………………………………………………………………………………

Of the schemes you do how did you decide where to implement them on your land?

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………………………………………………………………………………………………………………………………………………
………………………………………………………………………………………………………………………………………………
………………………………………………………………………………………………………………………………………………

Would you chose an alternative scheme/schemes if you could?

Yes No

**Why?**

| Reason | Please tick applicable answers |
|---|---|
| Too expensive | |
| Hard to implement | |
| Don’t appear to be attracting targeted species | |
| Too time consuming | |
| Other | |

## Section 1B

If you answered no, please tick the appropriate reason as to why not.

| **Reason** | **Please tick the appropriate answers** |
|---|---|
| Would rather use the land for a different purpose | |
| The incentives given by the CAP are not enough for it to be cost effective | |
| Do not think you qualify for the CAP subsidies/incentives | |
| Do not believe the schemes are effective in benefiting targeted species | |
| The schemes are too time consuming/hard to implement | |
| Other | |

Please use the space below to expand on your answer

……………………………………………………………………………………………………………………………………………
……………………………………………………………………………………………………………………………………………
……………………………………………………………………………………………………………………………………………
……………………………………………………………………………………………………………………………………………
…………………………………………………………

**Section 2**

Circle one of the following based on how strongly do you agree or disagree with the below statements:

1. 'Bumblebees are important for the pollination of many crops across the world'

   Strongly Agree Agree Disagree Strongly Disagree

2. 'It is important we protect and conserve bumblebees and their habitat'

   Strongly Agree Agree Disagree Strongly Disagree

3. 'The CAP is hard to follow and understand'

   Strongly Agree Agree Disagree Strongly Disagree

4. 'More money needs to be provided for agri-schems'

   Strongly Agree Agree Disagree Strongly Disagree

Thank you for taking part in this questionnaire. Your answers will be anonymous. The MSc project is looking to assess which nectar mix is the most effective in terms of attracting species of bumblebees. Bee transects have been carried out on several farms in the Cambridgeshire area. The project would also like to assess the practicality of these agri-schemes and your views as farmers on such schemes. Your answers will help to assess this. Once again thank you for taking part. For any further details please email **Katherine.taylor14@imperial.ac.uk**.

# APPENDIX 6

## APPENDIX 6: Summary of Data Collected

Legend
FC = Flower coverage percentage, FD = Flower diversity percentage, BC = Bumblebee count, SpN = Number of bumblebee species, Shannon = Shannon diversity index for bees

| Farm | Site | Trans | Survey | FC % | FD | BC | SpN | Shannon | rain | sun | cloud | wind | time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hatley | 1 | 1 | 1 | 25 | 6 | 4 | 3 | 1.04 | 0 | 0 | 1 | 1 | 11.50 |
| Hatley | 1 | 2 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11.00 |
| Hatley | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 10.50 |
| Hatley | 1 | 4 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 10.00 |
| Hatley | 2 | 1 | 1 | 15 | 3 | 3 | 1 | 0 | 0 | 0 | 1 | 1 | 12.00 |
| Hatley | 2 | 2 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 12.50 |
| Hatley | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 13.00 |
| Hatley | 2 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 13.30 |
| Hatley | 3 | 1 | 1 | 15 | 9 | 3 | 2 | 0.63 | 0 | 0 | 1 | 1 | 14.00 |
| Hatley | 3 | 2 | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.30 |
| Hatley | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 15.00 |
| Hatley | 3 | 4 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 15.30 |
| Hatley | 4 | 1 | 1 | 5 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 9.30 |
| Hatley | 4 | 2 | 1 | 2 | 1 | 2 | 2 | 0.69 | 0 | 1 | 1 | 0 | 10.00 |
| Hatley | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 10.30 |
| Hatley | 4 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 11.00 |
| Longstowe | 1 | 1 | 1 | 35 | 4 | 55 | 4 | 0.88 | 0 | 1 | 0 | 0 | 12.00 |
| Longstowe | 1 | 2 | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 12.30 |
| Longstowe | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 13.00 |
| Longstowe | 1 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 13.30 |
| Longstowe | 2 | 1 | 1 | 37 | 6 | 56 | 2 | 0.6 | 0 | 1 | 0 | 0 | 14.00 |
| Longstowe | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 14.30 |
| Longstowe | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 15.00 |
| Longstowe | 2 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 15.30 |
| Longstowe | 3 | 1 | 1 | 7 | 5 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 10.00 |
| Longstowe | 3 | 2 | 1 | 10 | 5 | 2 | 1 | 0 | 0 | 1 | 0 | 0 | 10.30 |
| Longstowe | 3 | 3 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 11.00 |
| Longstowe | 3 | 4 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 11.30 |
| Longstowe | 4 | 1 | 1 | 0 | 0 | 2 | 2 | 0.69 | 0 | 1 | 0 | 0 | 12.00 |
| Longstowe | 4 | 2 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 12.30 |
| Longstowe | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 13.00 |
| Longstowe | 4 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 13.30 |
| Wimpole | 1 | 1 | 1 | 5 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 14.30 |
| Wimpole | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 15.00 |
| Wimpole | 1 | 3 | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 15.30 |
| Wimpole | 1 | 4 | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 16.00 |
| Wimpole | 2 | 1 | 1 | 8 | 4 | 6 | 3 | 1.01 | 0 | 1 | 0 | 0 | 10.00 |
| Wimpole | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10.30 |
| Wimpole | 2 | 3 | 1 | 5 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 11.00 |
| Wimpole | 2 | 4 | 1 | 5 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 11.30 |
| Wimpole | 3 | 1 | 1 | 5 | 2 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 12.00 |
| Wimpole | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.30 |
| Wimpole | 3 | 3 | 1 | 10 | 2 | 3 | 1 | 0 | 0 | 1 | 0 | 1 | 13.00 |
| Wimpole | 3 | 4 | 1 | 10 | 2 | 2 | 1 | 0 | 0 | 1 | 0 | 1 | 13.30 |
| Wimpole | 4 | 1 | 1 | 5 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.00 |
| Wimpole | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.30 |

| Farm | Site | Trans | Survey | FC % | FD | BC | SpN | Shannon | rain | sun | cloud | wind | time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wimpole | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.00 |
| Wimpole | 4 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Barton | 1 | 1 | 1 | 15 | 7 | 13 | 4 | 1.2 | 0 | 1 | 1 | 1 | 9.00 |
| Barton | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 9.30 |
| Barton | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 10.00 |
| Barton | 1 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 10.30 |
| Barton | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 11.30 |
| Barton | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.00 |
| Barton | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.30 |
| Barton | 2 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 13.00 |
| Barton | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.00 |
| Barton | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.30 |
| Barton | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.00 |
| Barton | 3 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Barton | 4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.00 |
| Barton | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.30 |
| Barton | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 17.00 |
| Barton | 4 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 17.30 |
| Highfield | 1 | 1 | 1 | 15 | 11 | 13 | 7 | 1.7 | 0 | 1 | 1 | 0 | 10.00 |
| Highfield | 1 | 2 | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 10.30 |
| Highfield | 1 | 3 | 1 | NA | NA | N/A | NA | NA | NA | NA | NA | NA | NA |
| Highfield | 1 | 4 | 1 | NA | NA | N/A | NA | NA | NA | NA | NA | NA | NA |
| Highfield | 2 | 1 | 1 | 20 | 4 | 20 | 3 | 0.76 | 0 | 1 | 1 | 0 | 12.00 |
| Highfield | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 12.30 |
| Highfield | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 13.00 |
| Highfield | 2 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 13.30 |
| Highfield | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 14.00 |
| Highfield | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 14.30 |
| Highfield | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 15.00 |
| Highfield | 3 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 15.30 |
| Highfield | 4 | 1 | 1 | 25 | 3 | 17 | 5 | 1.42 | 0 | 1 | 1 | 0 | 16.00 |
| Highfield | 4 | 2 | 1 | 5 | 2 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 16.30 |
| Highfield | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 17.00 |
| Highfield | 4 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 17.30 |
| Thrift | 1 | 1 | 1 | 35 | 4 | 48 | 4 | 1.19 | 0 | 1 | 0 | 0 | 10.00 |
| Thrift | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10.30 |
| Thrift | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 11.00 |
| Thrift | 1 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 11.30 |
| Thrift | 2 | 1 | 1 | 40 | 6 | 33 | 3 | 1.01 | 0 | 1 | 0 | 0 | 12.00 |
| Thrift | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 12.30 |
| Thrift | 2 | 3 | 1 | 20 | 1 | 4 | 2 | 0.69 | 0 | 1 | 0 | 0 | 13.00 |
| Thrift | 2 | 4 | 1 | 20 | 1 | 2 | 1 | 0 | 0 | 1 | 0 | 0 | 13.30 |
| Thrift | 3 | 1 | 1 | 15 | 4 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.00 |
| Thrift | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.30 |
| Thrift | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.00 |
| Thrift | 3 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Thrift | 4 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 16.00 |
| Thrift | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 16.30 |
| Thrift | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 17.00 |
| Thrift | 4 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 17.30 |
| Hatley | 1 | 1 | 2 | 40 | 4 | 27 | 5 | 1.34 | 0 | 1 | 0 | 1 | 11.00 |
| Hatley | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 11.30 |
| Hatley | 1 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.00 |

| Farm | Site | Trans | Survey | FC % | FD | BC | SpN | Shannon | rain | sun | cloud | wind | time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hatley | 1 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.30 |
| Hatley | 2 | 1 | 2 | 40 | 2 | 42 | 4 | 1.17 | 0 | 1 | 0 | 1 | 14.00 |
| Hatley | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.30 |
| Hatley | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.00 |
| Hatley | 2 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Hatley | 3 | 1 | 2 | 50 | 4 | 58 | 5 | 1.43 | 0 | 1 | 0 | 1 | 11.00 |
| Hatley | 3 | 2 | 2 | 2 | 2 | 4 | 3 | 1.04 | 0 | 1 | 0 | 1 | 11.30 |
| Hatley | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.00 |
| Hatley | 3 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.30 |
| Hatley | 4 | 1 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 16.00 |
| Hatley | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 16.30 |
| Hatley | 4 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 17.00 |
| Hatley | 4 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 17.30 |
| Longstowe | 1 | 1 | 2 | 50 | 5 | 55 | 5 | 1.28 | 0 | 0 | 1 | 1 | 15.00 |
| Longstowe | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 15.30 |
| Longstowe | 1 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 16.00 |
| Longstowe | 1 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 16.30 |
| Longstowe | 2 | 1 | 2 | 60 | 5 | 31 | 5 | 1.21 | 0 | 0 | 1 | 1 | 9.00 |
| Longstowe | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 9.30 |
| Longstowe | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 10.00 |
| Longstowe | 2 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 10.30 |
| Longstowe | 3 | 1 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11.00 |
| Longstowe | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11.30 |
| Longstowe | 3 | 3 | 2 | 5 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 12.00 |
| Longstowe | 3 | 4 | 2 | 10 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 12.30 |
| Longstowe | 4 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 13.00 |
| Longstowe | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 13.30 |
| Longstowe | 4 | 3 | 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.00 |
| Longstowe | 4 | 4 | 2 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.30 |
| Wimpole | 1 | 1 | 2 | 15 | 5 | 7 | 2 | 0.41 | 0 | 0 | 1 | 1 | 13.00 |
| Wimpole | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 13.30 |
| Wimpole | 1 | 3 | 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.00 |
| Wimpole | 1 | 4 | 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.30 |
| Wimpole | 2 | 1 | 2 | 50 | 3 | 19 | 4 | 1.19 | 0 | 0 | 1 | 1 | 11.00 |
| Wimpole | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11.30 |
| Wimpole | 2 | 3 | 2 | 15 | 3 | 4 | 2 | 0.69 | 0 | 0 | 1 | 1 | 12.00 |
| Wimpole | 2 | 4 | 2 | 10 | 3 | 3 | 1 | 0 | 0 | 0 | 1 | 1 | 12.30 |
| Wimpole | 3 | 1 | 2 | 10 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 9.00 |
| Wimpole | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 9.30 |
| Wimpole | 3 | 3 | 2 | 30 | 2 | 8 | 2 | 0.38 | 0 | 1 | 0 | 1 | 10.00 |
| Wimpole | 3 | 4 | 2 | 30 | 2 | 14 | 3 | 0.79 | 0 | 1 | 0 | 1 | 10.30 |
| Wimpole | 4 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 15.00 |
| Wimpole | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 15.30 |
| Wimpole | 4 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 16.00 |
| Wimpole | 4 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 16.30 |
| Barton | 1 | 1 | 2 | 10 | 7 | 7 | 3 | 0.96 | 0 | 1 | 0 | 1 | 13.00 |
| Barton | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 13.30 |
| Barton | 1 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.00 |
| Barton | 1 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.30 |
| Barton | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.00 |
| Barton | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Barton | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.00 |
| Barton | 2 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.30 |

| Farm | Site | Trans | Survey | FC % | FD | BC | SpN | Shannon | rain | sun | cloud | wind | time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Barton | 3 | 1 | 2 | 3 | 3 | 7 | 2 | 0.41 | 0 | 1 | 0 | 1 | 9.00 |
| Barton | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 9.30 |
| Barton | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 10.00 |
| Barton | 3 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 10.30 |
| Barton | 4 | 1 | 2 | 10 | 4 | 11 | 5 | 1.55 | 0 | 1 | 0 | 1 | 11.00 |
| Barton | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 11.30 |
| Barton | 4 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.00 |
| Barton | 4 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.30 |
| Highfield | 1 | 1 | 2 | 30 | 7 | 44 | 4 | 1.17 | 0 | 1 | 0 | 1 | 15.00 |
| Highfield | 1 | 2 | 2 | 10 | 2 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Highfield | 1 | 3 | 2 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Highfield | 1 | 4 | 2 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Highfield | 2 | 1 | 2 | 70 | 2 | 139 | 6 | 1.12 | 0 | 1 | 0 | 0 | 9.00 |
| Highfield | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 9.30 |
| Highfield | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10.00 |
| Highfield | 2 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10.30 |
| Highfield | 3 | 1 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 13.00 |
| Highfield | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 13.30 |
| Highfield | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 14.00 |
| Highfield | 3 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 14.30 |
| Highfield | 4 | 1 | 2 | 60 | 2 | 78 | 4 | 1.29 | 0 | 1 | 1 | 0 | 11.00 |
| Highfield | 4 | 2 | 2 | 30 | 3 | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 11.30 |
| Highfield | 4 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 12.00 |
| Highfield | 4 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 12.30 |
| Thrift | 1 | 1 | 2 | 60 | 7 | 80 | 3 | 0.81 | 0 | 1 | 0 | 1 | 15.00 |
| Thrift | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Thrift | 1 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.00 |
| Thrift | 1 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.30 |
| Thrift | 2 | 1 | 2 | 40 | 3 | 64 | 3 | 0.89 | 0 | 1 | 0 | 1 | 9.00 |
| Thrift | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 9.30 |
| Thrift | 2 | 3 | 2 | 30 | 2 | 14 | 1 | 0 | 0 | 1 | 0 | 1 | 10.00 |
| Thrift | 2 | 4 | 2 | 30 | 2 | 5 | 1 | 0 | 0 | 1 | 0 | 1 | 10.30 |
| Thrift | 3 | 1 | 2 | 10 | 3 | 2 | 2 | 0.69 | 0 | 1 | 0 | 1 | 11.00 |
| Thrift | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 11.30 |
| Thrift | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.00 |
| Thrift | 3 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.30 |
| Thrift | 4 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 13.00 |
| Thrift | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 13.30 |
| Thrift | 4 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.00 |
| Thrift | 4 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.30 |
| Hatley | 1 | 1 | 3 | 60 | 6 | 63 | 4 | 0.76 | 0 | 1 | 1 | 1 | 13.00 |
| Hatley | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 13.30 |
| Hatley | 1 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 14.00 |
| Hatley | 1 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 14.30 |
| Hatley | 2 | 1 | 3 | 45 | 5 | 8 | 3 | 0.97 | 0 | 0 | 1 | 1 | 9.00 |
| Hatley | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 9.30 |
| Hatley | 2 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 10.00 |
| Hatley | 2 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 10.30 |
| Hatley | 3 | 1 | 3 | 50 | 6 | 55 | 3 | 0.42 | 0 | 0 | 1 | 1 | 11.00 |
| Hatley | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11.30 |
| Hatley | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 12.00 |
| Hatley | 3 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 12.30 |
| Hatley | 4 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3.00 |

| Farm | Site | Trans | Survey | FC % | FD | BC | SpN | Shannon | rain | sun | cloud | wind | time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hatley | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3.30 |
| Hatley | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4.00 |
| Hatley | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4.30 |
| Longstowe | 1 | 1 | 3 | 30 | 4 | 37 | 3 | 0.97 | 0 | 1 | 0 | 1 | 11.00 |
| Longstowe | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 11.30 |
| Longstowe | 1 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.00 |
| Longstowe | 1 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.30 |
| Longstowe | 2 | 1 | 3 | 45 | 8 | 17 | 4 | 1.23 | 0 | 1 | 0 | 1 | 13.00 |
| Longstowe | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 13.30 |
| Longstowe | 2 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.00 |
| Longstowe | 2 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.30 |
| Longstowe | 3 | 1 | 3 | 20 | 2 | 32 | 8 | 1.51 | 0 | 1 | 0 | 0 | 9.00 |
| Longstowe | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 9.30 |
| Longstowe | 3 | 3 | 3 | 50 | 1 | 10 | 4 | 1.28 | 0 | 1 | 0 | 0 | 10.00 |
| Longstowe | 3 | 4 | 3 | 50 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10.30 |
| Longstowe | 4 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.00 |
| Longstowe | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Longstowe | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.00 |
| Longstowe | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.30 |
| Wimpole | 1 | 1 | 3 | 50 | 3 | 46 | 3 | 0.67 | 0 | 1 | 0 | 1 | 11.00 |
| Wimpole | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 11.30 |
| Wimpole | 1 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.00 |
| Wimpole | 1 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.30 |
| Wimpole | 2 | 1 | 3 | 50 | 2 | 24 | 4 | 1.17 | 0 | 1 | 0 | 1 | 15.00 |
| Wimpole | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Wimpole | 2 | 3 | 3 | 30 | 1 | 26 | 4 | 1.29 | 0 | 1 | 0 | 1 | 16.00 |
| Wimpole | 2 | 4 | 3 | 30 | 1 | 32 | 4 | 1.14 | 0 | 1 | 0 | 1 | 16.30 |
| Wimpole | 3 | 1 | 3 | 30 | 5 | 55 | 7 | 1.19 | 0 | 1 | 0 | 1 | 9.00 |
| Wimpole | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 9.30 |
| Wimpole | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 10.00 |
| Wimpole | 3 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 10.30 |
| Wimpole | 4 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 13.00 |
| Wimpole | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 13.30 |
| Wimpole | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.00 |
| Wimpole | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 14.30 |
| Barton | 1 | 1 | 3 | 45 | 5 | 40 | 4 | 0.9 | 0 | 1 | 0 | 0 | 11.00 |
| Barton | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 11.30 |
| Barton | 1 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 12.00 |
| Barton | 1 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 12.30 |
| Barton | 2 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 9.00 |
| Barton | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 9.30 |
| Barton | 2 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10.00 |
| Barton | 2 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10.30 |
| Barton | 3 | 1 | 3 | 15 | 4 | 19 | 3 | 1.1 | 0 | 1 | 0 | 0 | 15.00 |
| Barton | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 15.30 |
| Barton | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 16.00 |
| Barton | 3 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 16.30 |
| Barton | 4 | 1 | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 13.00 |
| Barton | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 13.30 |
| Barton | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 14.00 |
| Barton | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 14.30 |
| Highfield | 1 | 1 | 3 | 50 | 4 | 28 | 2 | 0.26 | 0 | 1 | 0 | 0 | 11.00 |
| Highfield | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 11.30 |

| Farm | Site | Trans | Survey | FC % | FD | BC | SpN | Shannon | rain | sun | cloud | wind | time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Highfield | 1 | 3 | 3 | NA | NA | NA | NA | NA | NA | NA | NA | NA | 12.00 |
| Highfield | 1 | 4 | 3 | NA | NA | NA | NA | NA | NA | NA | NA | NA | 12.30 |
| Highfield | 2 | 1 | 3 | 25 | 2 | 34 | 1 | 0 | 0 | 1 | 0 | 1 | 15.00 |
| Highfield | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Highfield | 2 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.00 |
| Highfield | 2 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.30 |
| Highfield | 3 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 9.00 |
| Highfield | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 9.30 |
| Highfield | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10..00 |
| Highfield | 3 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10.30 |
| Highfield | 4 | 1 | 3 |  | 4 | 37 | 5 | 1.04 | 0 | 1 | 1 | 0 | 13.00 |
| Highfield | 4 | 2 | 3 | 30 | 1 | 11 | 2 | 0.3 | 0 | 1 | 1 | 0 | 13.30 |
| Highfield | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 14.00 |
| Highfield | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 14.30 |
| Thrift | 1 | 1 | 3 | 55 | 3 | 51 | 3 | 0.7 | 0 | 0 | 1 | 0 | 13.00 |
| Thrift | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 13.30 |
| Thrift | 1 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 14.00 |
| Thrift | 1 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 14.30 |
| Thrift | 2 | 1 | 3 | 45 | 6 | 58 | 3 |  | 0 | 0 | 1 | 0 | 15.00 |
| Thrift | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 15.30 |
| Thrift | 2 | 3 | 3 | 45 | 4 | 20 | 3 |  | 0 | 0 | 1 | 0 | 16.00 |
| Thrift | 2 | 4 | 3 | 35 | 4 | 18 | 3 |  | 0 | 0 | 1 | 0 | 16.30 |
| Thrift | 3 | 1 | 3 | 70 | 6 | 43 | 5 | 0.87 | 0 | 0 | 1 | 0 | 9.00 |
| Thrift | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 9.30 |
| Thrift | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 10.00 |
| Thrift | 3 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 10.30 |
| Thrift | 4 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 11.30 |
| Thrift | 4 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 11.00 |
| Thrift | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 12.00 |
| Thrift | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 12.30 |
| Hatley | 1 | 1 | 4 | 40 | 3 | 110 | 3 | 0.99 | 0 | 0 | 1 | 1 | 13.00 |
| Hatley | 1 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 13.30 |
| Hatley | 1 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.00 |
| Hatley | 1 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.30 |
| Hatley | 2 | 1 | 4 | 40 | 3 | 74 | 4 | 1.04 | 0 | 1 | 0 | 1 | 9.00 |
| Hatley | 2 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 9.30 |
| Hatley | 2 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 10.00 |
| Hatley | 2 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 10.30 |
| Hatley | 3 | 1 | 4 | 35 | 4 | 72 | 5 | 1.2 | 0 | 0 | 1 | 1 | 15.00 |
| Hatley | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 15.30 |
| Hatley | 3 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 16.00 |
| Hatley | 3 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 16.30 |
| Hatley | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11.00 |
| Hatley | 4 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11.30 |
| Hatley | 4 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 12.00 |
| Hatley | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 12.30 |
| Longstowe | 1 | 1 | 4 | 15 | 5 | 20 | 5 | 1.5 | 0 | 0 | 1 | 1 | 13.00 |
| Longstowe | 1 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 13.30 |
| Longstowe | 1 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.00 |
| Longstowe | 1 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.30 |
| Longstowe | 2 | 1 | 4 | 30 | 7 | 41 | 5 | 1.33 | 0 | 0 | 1 | 1 | 9.00 |
| Longstowe | 2 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 9.30 |
| Longstowe | 2 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 10.00 |

| Farm | Site | Trans | Survey | FC % | FD | BC | SpN | Shannon | rain | sun | cloud | wind | time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Longstowe | 2 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 10.30 |
| Longstowe | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 15.00 |
| Longstowe | 3 | 2 | 4 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 15.30 |
| Longstowe | 3 | 3 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 16.00 |
| Longstowe | 3 | 4 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 16.30 |
| Longstowe | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 11.00 |
| Longstowe | 4 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 11.30 |
| Longstowe | 4 | 3 | 4 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 12.00 |
| Longstowe | 4 | 4 | 4 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 12.30 |
| Wimpole | 1 | 1 | 4 | 30 | 2 | 9 | 2 | 0.69 | 1 | 0 | 1 | 0 | 9.00 |
| Wimpole | 1 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 9.30 |
| Wimpole | 1 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 10.00 |
| Wimpole | 1 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 10.30 |
| Wimpole | 2 | 1 | 4 | 20 | 4 | 4 | 2 | 0.56 | 1 | 0 | 1 | 0 | 13.00 |
| Wimpole | 2 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 13.30 |
| Wimpole | 2 | 3 | 4 | 5 | 2 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 14.00 |
| Wimpole | 2 | 4 | 4 | 5 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 14.30 |
| Wimpole | 3 | 1 | 4 | 5 | 2 | 6 | 1 | 0 | 1 | 0 | 1 | 0 | 15.00 |
| Wimpole | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 15.30 |
| Wimpole | 3 | 3 | 4 | 5 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 16.00 |
| Wimpole | 3 | 4 | 4 | 5 | 2 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 16.30 |
| Wimpole | 4 | 1 | 4 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 11.00 |
| Wimpole | 4 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 11.30 |
| Wimpole | 4 | 3 | 4 | 5 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 12.00 |
| Wimpole | 4 | 4 | 4 | 5 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 12.30 |
| Barton | 1 | 1 | 4 | 50 | 4 | 113 | 6 | 1.28 | 0 | 0 | 1 | 1 | 15.00 |
| Barton | 1 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 15.30 |
| Barton | 1 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 16.00 |
| Barton | 1 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 16.30 |
| Barton | 2 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 13.00 |
| Barton | 2 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 13.30 |
| Barton | 2 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.00 |
| Barton | 2 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 14.30 |
| Barton | 3 | 1 | 4 | 4 | 1 | 4 | 1 | 0 | 0 | 0 | 1 | 1 | 11.00 |
| Barton | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11.30 |
| Barton | 3 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 12.00 |
| Barton | 3 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 12.30 |
| Barton | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 9.00 |
| Barton | 4 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 9.30 |
| Barton | 4 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 10.00 |
| Barton | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 10.30 |
| Highfield | 1 | 1 | 4 | 50 | 5 | 91 | 6 | 0.96 | 0 | 1 | 1 | 1 | 15.00 |
| Highfield | 1 | 2 | 4 | 5 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 15.30 |
| Highfield | 1 | 3 | 4 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Highfield | 1 | 4 | 4 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Highfield | 2 | 1 | 4 | 8 | 5 | 6 | 2 | 0.45 | 0 | 1 | 1 | 1 | 13.00 |
| Highfield | 2 | 2 | 4 | 30 | 2 | 52 | 6 | 1.16 | 0 | 1 | 1 | 1 | 13.30 |
| Highfield | 2 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 14.00 |
| Highfield | 2 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 14.30 |
| Highfield | 3 | 1 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 9.00 |
| Highfield | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 9.30 |
| Highfield | 3 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 10.00 |
| Highfield | 3 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 10.30 |

| Farm | Site | Trans | Survey | FC % | FD | BC | SpN | Shannon | rain | sun | cloud | wind | time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Highfield | 4 | 1 | 4 | 5 | 2 | 15 | 3 | 0.88 | 1 | 0 | 1 | 0 | 11.00 |
| Highfield | 4 | 2 | 4 | 80 | 1 | 14 | 3 | 0.66 | 1 | 0 | 1 | 0 | 11.30 |
| Highfield | 4 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 12.00 |
| Highfield | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 12.30 |
| Thrift | 1 | 1 | 4 | 30 | 3 | 61 | 5 | 1.18 | 0 | 1 | 0 | 1 | 11.00 |
| Thrift | 1 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 11.30 |
| Thrift | 1 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.00 |
| Thrift | 1 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 12.30 |
| Thrift | 2 | 1 | 4 | 50 | 6 | 73 | 4 | 0.76 | 0 | 1 | 0 | 1 | 13.00 |
| Thrift | 2 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 13.30 |
| Thrift | 2 | 3 | 4 | 30 | 3 | 44 | 5 | 1.22 | 0 | 1 | 0 | 1 | 14.00 |
| Thrift | 2 | 4 | 4 | 30 | 3 | 31 | 5 | 1.19 | 0 | 1 | 0 | 1 | 14.30 |
| Thrift | 3 | 1 | 4 | 40 | 6 | 32 | 6 | 1.31 | 0 | 1 | 0 | 1 | 15.00 |
| Thrift | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 15.30 |
| Thrift | 3 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.00 |
| Thrift | 3 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 16.30 |
| Thrift | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 9.00 |
| Thrift | 4 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 9.30 |
| Thrift | 4 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 10.00 |
| Thrift | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 10.30 |

# APPENDIX 7

## APPENDIX 7: Results of Total Bee Count at Each Farm Broken Down by Survey Period

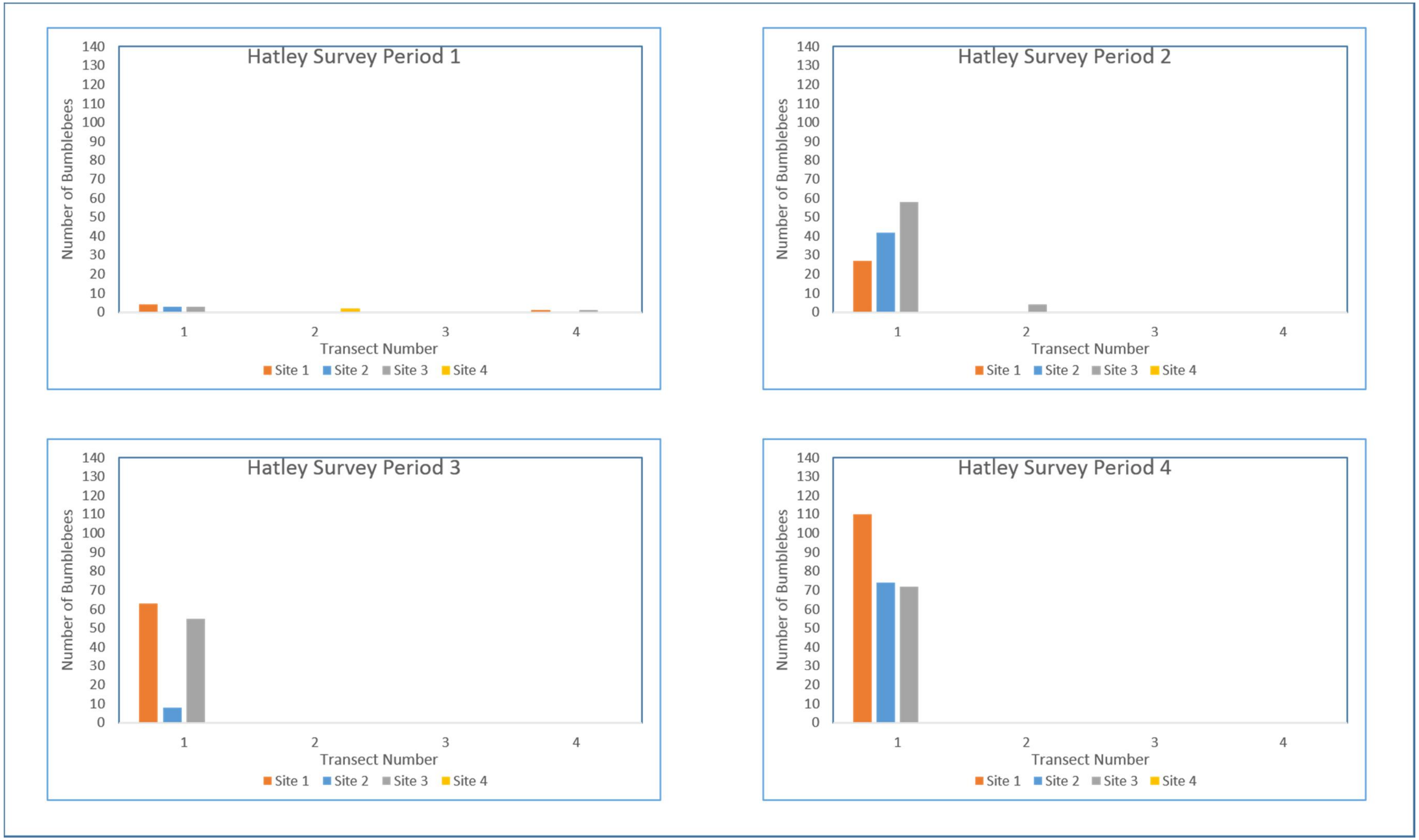


***Figure A7-1: Results of Hatley Farm Surveys***

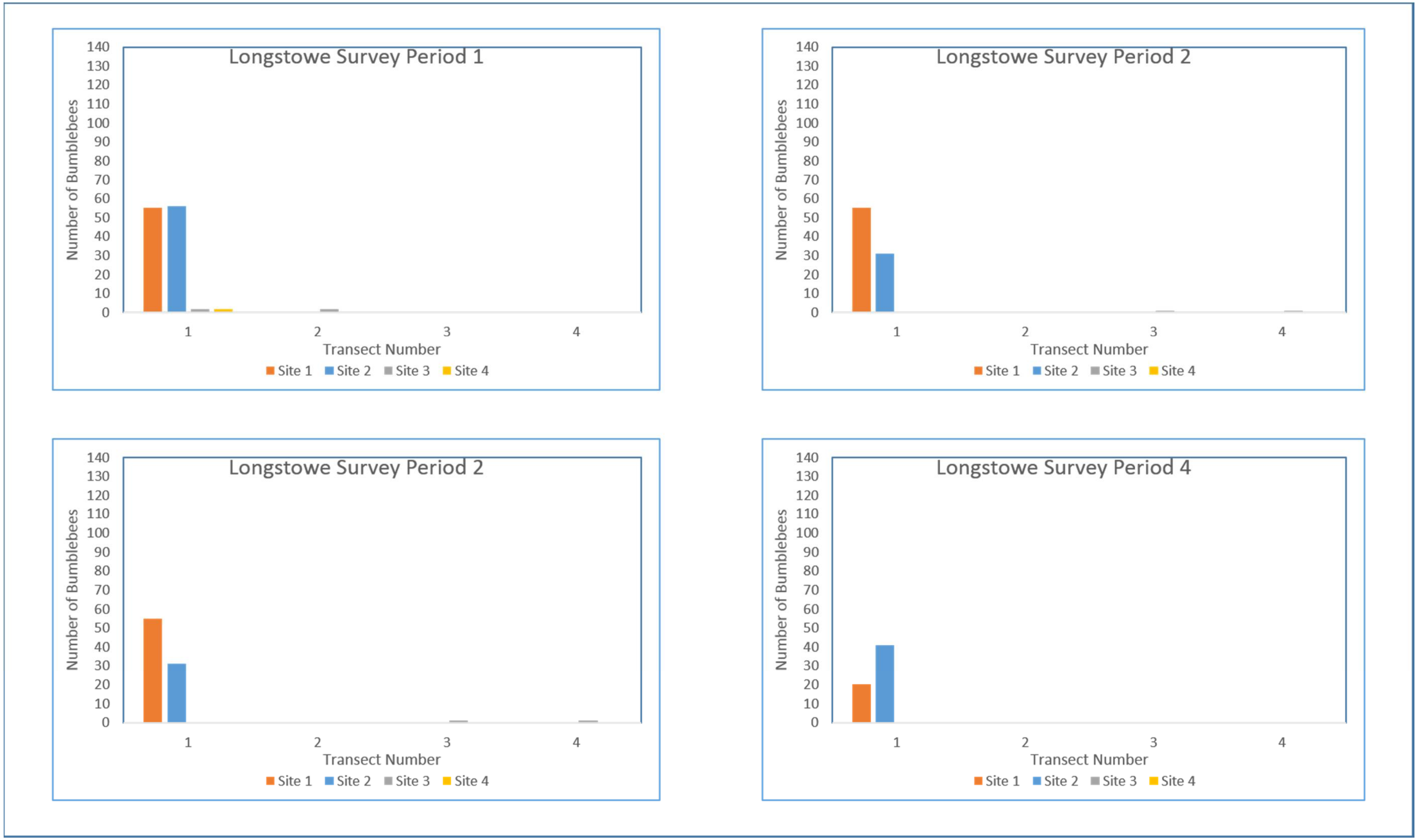


***Figure A7-2: Results of Longstowe Farm Surveys***

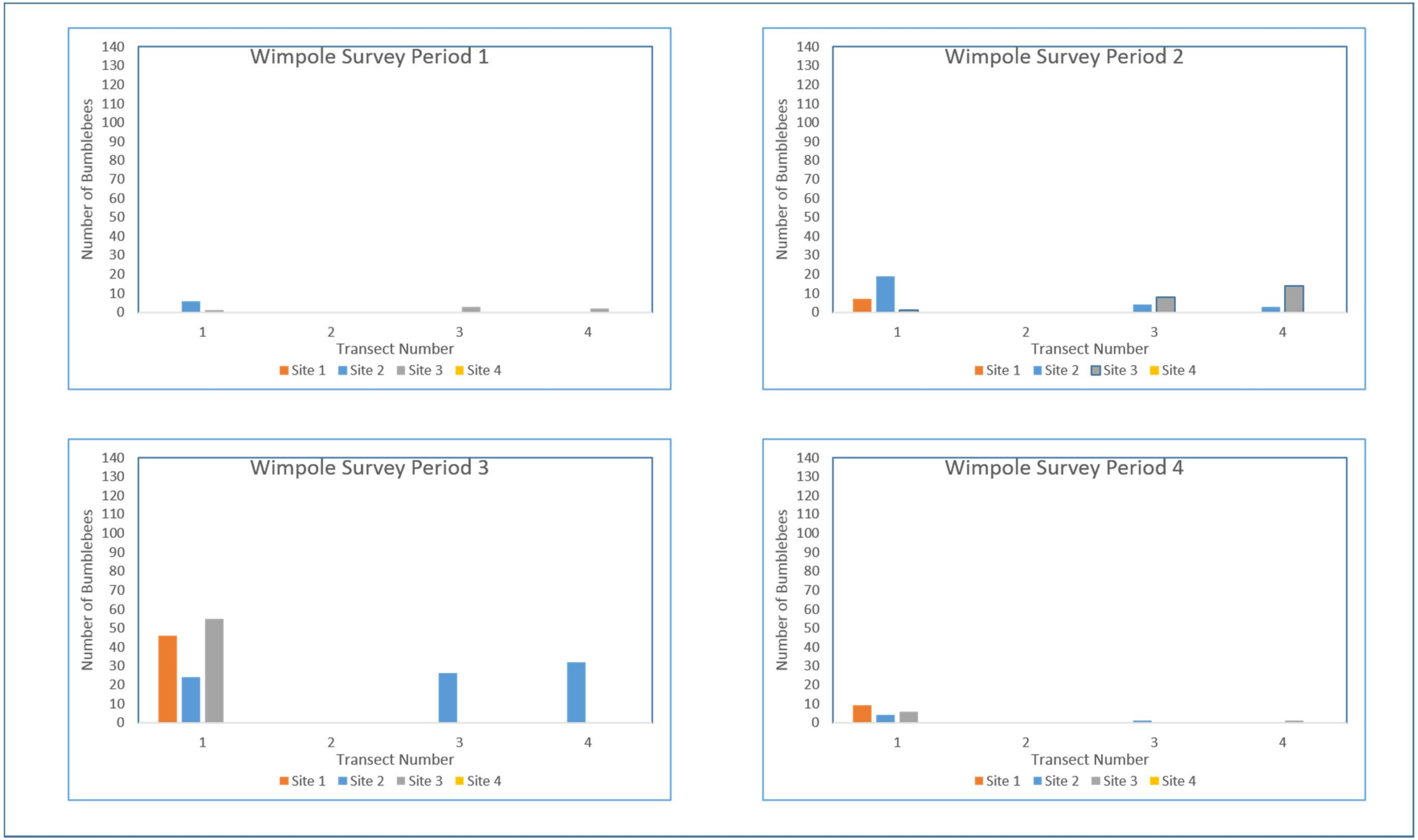


***Figure A7-3: Results of Wimpole Farm Surveys***

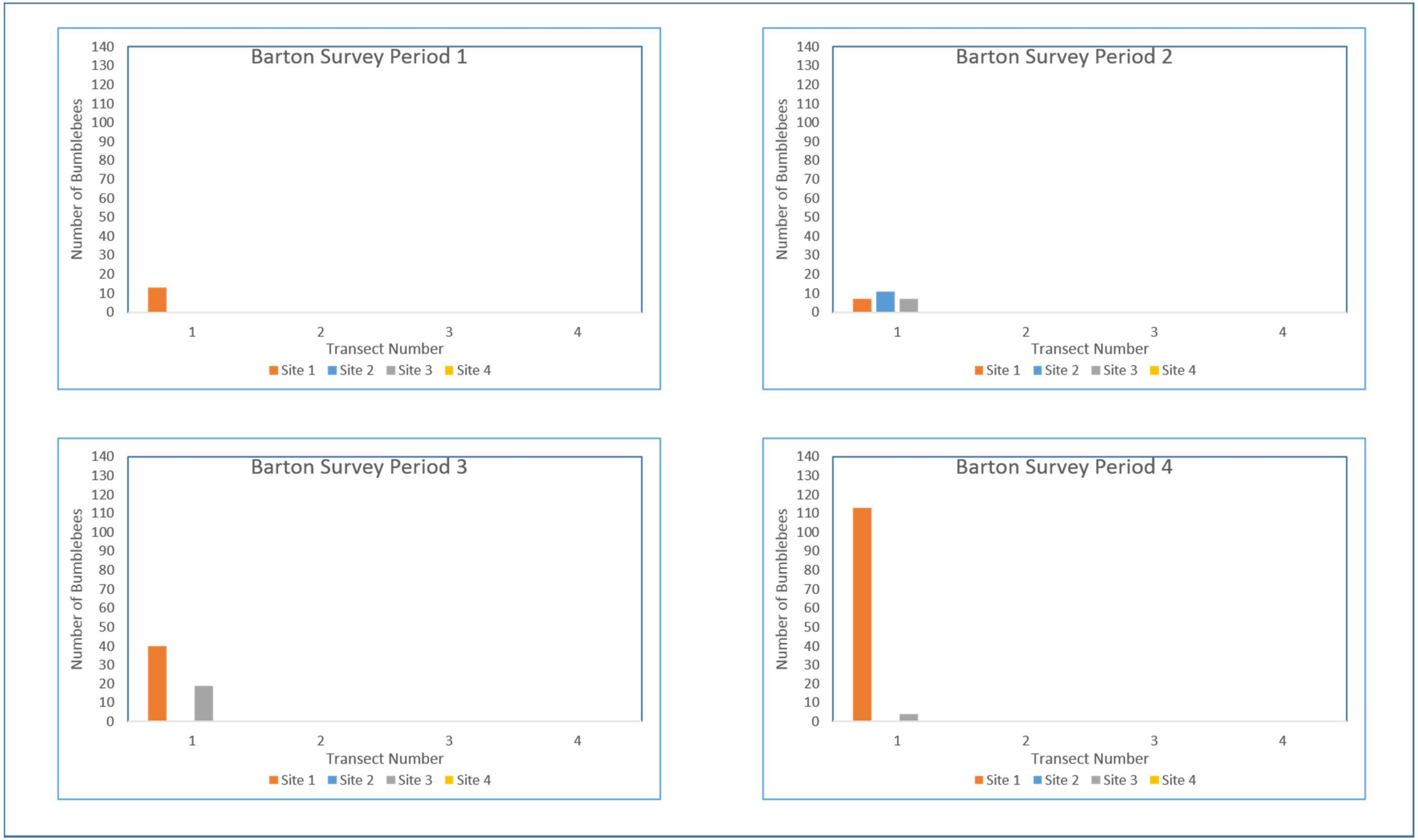


***Figure A7-4: Results of Barton Farm Surveys***

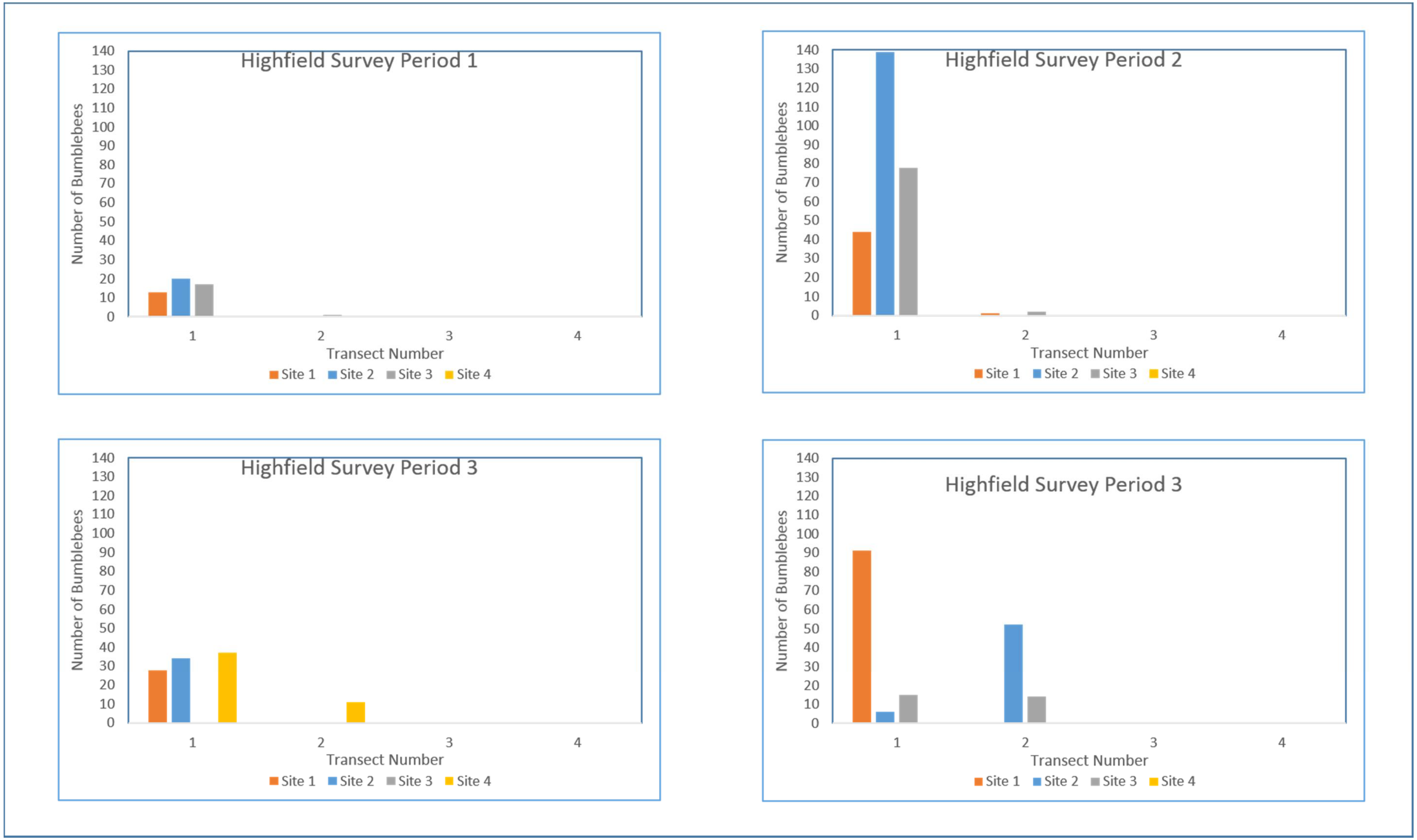


***Figure A7-5: Results of Highfield Farm Surveys***

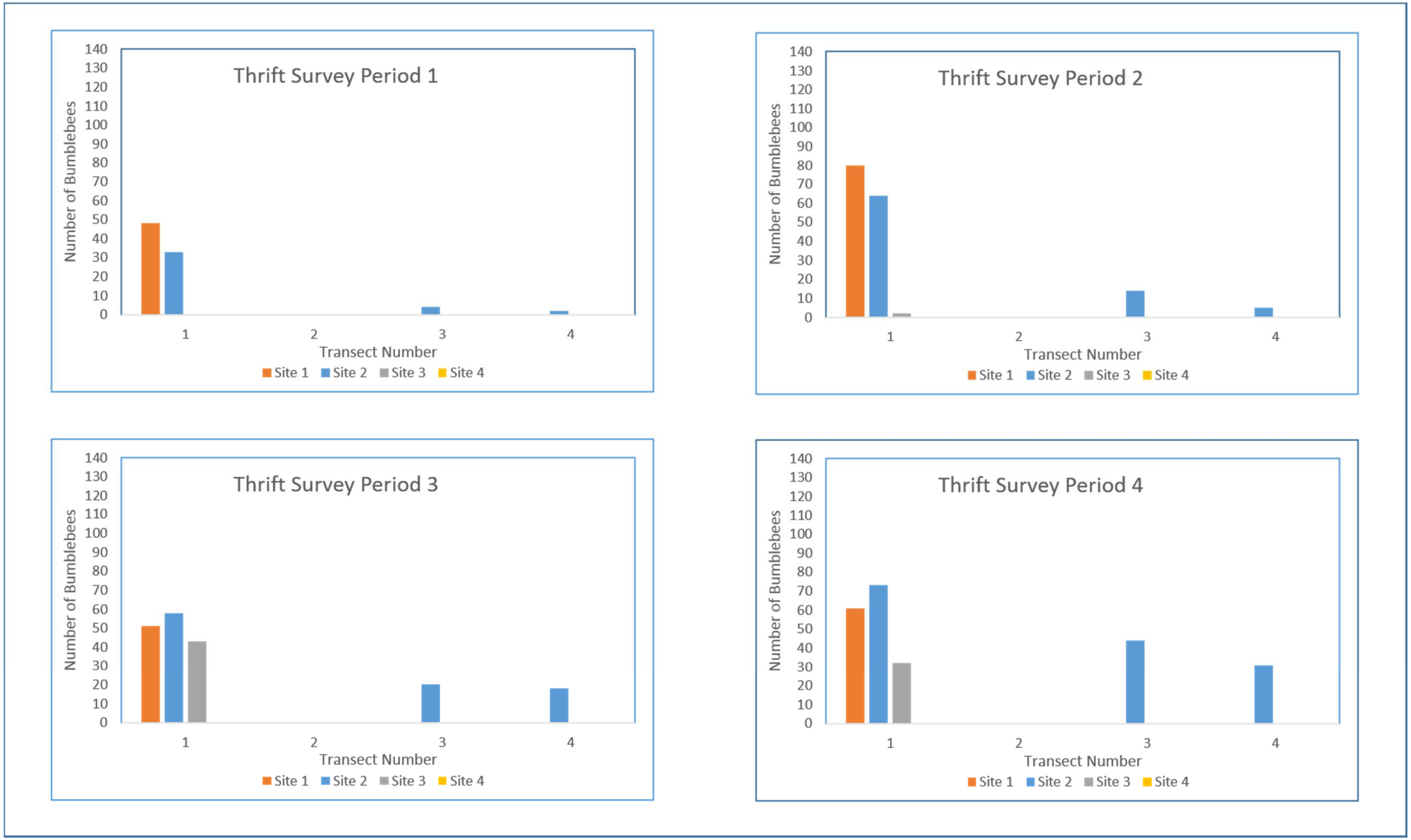


***Figure A7-6: Results of Thrift Farm Surveys***