Faculty of Science and Technology

# A Study of Pollinator Resources and the Competition Between Honeybees and Bumblebees at Arne Nature Reserve

A dissertation submitted as part of the requirement for the BSc (Hons) Ecology and Wildlife Conservation

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# Abstract

Anthropogenic habitat loss is becoming an increasingly worrisome biodiversity and ecosystem threat which has already shown to have drastic effects on the ever increasing important bumblebee and honeybee population numbers. With heathland being hit by this habitat loss and its scarcity growing better understanding of the relationship between bumblebees, honeybees, and heathland in terms of its resources is increasingly important.

This study investigates the relationship between floral resources found within Arne nature reserve and Studland heath, and if heathland growth stages affect the floral resource availability for bumblebees and honeybees. It also investigates whether there is a difference in floral resource use by bumblebees and honeybees within these two sites, comparing the difference between domesticated honeybees and feral honeybees. The study also investigates whether there is evidence of competitive exclusion between bumblebees and honeybees within both sites, comparing again the difference between domesticated honeybees and feral honeybees. Results show that floral resources differ between sites and between the different heathland growth stages stated by Watt 1947, showing how mature heath is the most important for floral resources for pollinators. Bumblebees and honeybees were shown to have a niche overlap in terms of floral resource use, with some differences being stated including a difference in floral resource use between domesticated and feral honeybees. Competitive exclusion was also found with significant decreases of bumblebee numbers in the presence of honeybees, with feral honeybees at Studland being found to have a stronger competitive exclusion compared to domesticated commercial honeybees found at Arne.

The results from this study can help inform management decision and the conservation of these crucial pollinators. Whilst highlighting the need for further research looking into why domesticated honeybees have been found to have less of a competitive exclusion compared to feral honeybees.

# Acknowledgments

I would like to thank RSPB at Arne and National Trust at Studland for allowing me to undertake this research project within their nature reserves. I would like to say a huge thankyou to my dissertation supervisor, Anita Diaz. Anita offered crucial guidance and help throughout this whole dissertation whilst also being the person who created the opportunities which flourished and encouraged my passions for bees and has been inspiration to me throughout my entire time at Bournemouth University

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# 1.0 Introduction

## 1.1 Heathland as a pollinator resource for bumblebees and competition from honeybees

Heathland has a significant importance for rare and threatened species of vertebrates and invertebrates, and is an important home for both *Bombus* species and *A. mellifera* (Peters et al. 2008). Huge conservation efforts are focused on heathlands and their management due to their international scarcity and the habitats ecological importance in protecting species (Forup and Memmott 2005). It is crucially important to better understand the limitation of pollinator resources for bumblebees due to the steady decrease in native Bombus species within the UK and globally (Carvell 2002). One of the main factors causing this significant decrease in bee species numbers is habitat loss (Fuller 2017). Another important factor causing a decrease in native bumblebee numbers is competitive suppression from the European honeybee (*Apis mellifera),* with much evidence citing that their colonies do competitively suppress native bee species (Thomson 2004, Paini 2004, Forup and Memmott 2005, Torné-Noguera et al. 2015 and Linström et al. 2017). Pollinator declines have important negative ecological and economic impacts which can significantly affect wider ecosystem stability, crop production, food security and human welfare (Potts et al 2010). The deeper the understanding of the relationship between *Bombus spp*., *A. mellifera* and heathland management and restoration in affecting resource availability for bumblebees, the better the conservation of their population numbers and the prevention of further population extinctions.

## 1.2 Heathland history and its current management

Lowland heathland is a scarce European biotype composed of evergreen dwarf shrubs growing on impoverished soils, usually in temperate and relatively oceanic climates (Pickess et al. 1989). It is an ecologically important habitat for pollinator species such as *B. terrestris, B. lucorum, B. humilis, B. pascorum* and *A. mellifera*. The floral resources heathland provide these pollinators include pollen and nectar from *Calluna vulgaris, Erica cinerea, Erica tetralix* and *Ulex minor*. The lowland heaths of Southern Britain are of international conservation importance, particularly so for Dorset heaths as their climatic location support a diverse and important flora and fauna (Pickess et al. 1989). However, heathland is now a scarce and declining habitat throughout Europe, with the remaining British heathland forming a crucial part of the European resource (Britton et al. 2001, Farrell 1989). In the last century a significant proportion of heathland has been destroyed through agricultural intensification, afforestation with conifers and the encroachment of human populations on heathland (Moore 1962, Pickess et al. 1989). Large habitat fragmentation and successional change following abandonment of 'traditional' practices has also led to this decline in heathland, population declines and widespread loss of ecological richness and distinctiveness (Fuller 2017, Spitzer et al 2008). Areas of heaths are also being lost due to invasions of *Betula spp., Pinus sylvestris, Pteridium aquilinum, Rhododendron ponticum* and *Ulex europaeus (*Mitchell et al. 1998). An additional threat has also become apparent for heathlands since the 1980s, eutrophication as a result of atmospheric nitrogen deposition is leading to grasses such as *Deschampsia* and *Molinia caerulea* becoming dominant (Britton et al. 2001, Heil & Diemont 1983). Since the 1800 around 90% of Western European lowland heathland has been destroyed, with this figure being stated in 1989 this number can arguably only be assumed to have risen (Pickess 1989). When looking at heathland within Dorset and Hampshire west of the River Avon, during the period 1811-1960, there was a loss of around 50,000 acres of heath (Moore 1962).

Heathland used to be a crucial resource for human use and an integral part of peoples livelihoods; the heathland would have also been used for livestock grazing and regular cutting of bracken *Pteridium aquilinum*, heather *Calluna vulgaris* and *Erica spp*., and gorse *Ulex spp*., for thatch, fodder, animal bedding and fuel (Webb 1998, Fuller 2017). This cutting would have allowed for the crucial mosaic of different successional stages of heath, maintained nutrient impoverishment by the removal of above-ground biomass and nutrients and thus maintained heath vegetation (Fuller et al. 2017, Pickess et al. 1989, Britton et al. 2001). The aims of current management of heathland is to create a patchwork of age-structures in the heather and to preserve a high biodiversity (Blindow 2017), allowing for the mosaic that the previous traditional uses of the land would have. This includes the periodic removal of standing crops, removal of trees and bracken which invade the heath (Pickess et al. 1989), this can be done by the pulling of saplings or burning and cutting. Burning and cutting regimes allow the maintenance of succession, with burning being an effective way to deplete nutrients (Webb 1998). The placement of livestock, such as sheep or cattle for grazing is also a management option, but this can be difficult to organise on smaller patches of heathland (Webb 1998, Blindow 2017). Inland heaths and the impact of different current management measures has been intensively studied, whereas coastal heathland management has not been investigated thoroughly (Blindow 2017). There is a need for a better holistic understanding of the impacts of current management of coastal heathland so the positive and negative effects on pollinators is understood.

## 1.3 Bumblebees and the introduction of the honeybee

Insect pollination is an essential component of global food security and human welfare as three quarters of agricultural crop yields depends on its support (Linström et al. 2017, Potts et al. 2010). The decline in pollinators will also have significant negative ecological impacts such as affecting the maintenance of wild plant diversity and broad ecosystem stability (Potts et al 2010). Currently, due to anthropogenic activities the biosphere is entering a period of significantly increased extinctions of local populations and entire species (Memmott et al. 2004), these extinctions include bee species (Goulson et al. 2007). The decline in bee numbers is of great global concern among scientists, governments, businesses and the public (Dicks et al. 2015, Geib et al. 2015). The reduction in the species richness and abundance of bumblebees may lead to widespread changes in plant communities, this will have knock-on effects for associated plant dependent herbivores (Goulson 2010). In the UK 6 out of the 16 non-parasitic bumblebees have declined considerably, with the species *B. subterraneaus* already becoming extinct (Potts et al 2010). This is of particular concern as it has been shown that the removal of bumblebees, a highly linked pollinator, produces the greatest rate of decline in plant species diversity, compared to the removal of less polylectic pollinators (Memmott et al. 2004, Goulson 2010).

Bumblebees are social bees often described as primitively eusocial, as their social organisation is said to be simpler than that of the honeybee (Goulson 2010). Bumblebee colonies are annual, founded in spring by a single queen and built up by brood rearing, which in the mid-to-late summer produce males and daughter queens (Plowright and Laverty 1984). *Bombus* colonies generally consist of 50-500 workers at peak size (Thomson 2004) and individual workers live two to four weeks (Heinrich 1979). Bumblebees only store several days' worth of reserves, so therefore require an almost continuous supply of food resources within foraging distance from the nest (Carvell 2006, Prŷs-Jones and Corbet 1991). A few of the causes of declining bumblebee numbers are loss of habitat (as seen with the decline in heathland), pesticides, pathogens, impacts of invasive non-native species, climate change, commercial beekeeping and the interaction between them all (Goulson 2010, Potts et al. 2010).

The honeybee (*Apis mellifera*), native to Eurasia (Thomson 2004) was introduced in the nineteenth century for economic gain through honey production (Paini 2004), since then they have become a highly successful global invader, with a near worldwide distribution (Thomson 2004). Darwin in 1872 was evidently the first to speculate that *Apis* may competitively suppress native species (Thomson 2004), but it was not until the late 1970s that honeybees were first viewed as an invasive species that might be out-competing native fauna for nectar and pollen (Paini 2004). *Apis* colonies are perennial with their colonies usually consisting of 10,000 to 50,000 workers, this larger size and need for winter provisions means their resource use is significantly higher than that of *Bombus* colonies (Thomson 2004). A study by Heinrich 1979, calculated that a one strong apiary in the U.S. would in one year collect the equivalent amount of nectar and pollen to support 38,400 bumblebees, or 102 colonies. It has recently been found that adding honeybees decreases the overall densities of wild insects with these displacement effects being more pronounced on bumblebees and solitary bees, with the effects being more significant within larger fields than smaller fields (Linström et al. 2017). Bearing this in mind, it can be seen why the overlap of ecological niches between the species has been the focus of many studies and why *A. mellifera* can be accredited to be detrimental to native bees (Paini 2004, Torné-Noguera et al 2015, Elbgami et al. 2014).

## 1.4 Aims and Objectives

This study aims to identify if heathland stages and domesticated *A. mellifera* hives on heathland at Arne Nature Reserve affect resource availability for bumblebees. The specific questions asked are

1) What is the floral resource availability across both sites?
2) Do heathland growth stages affect floral resource availability for bumblebees and honeybees?
3) Is there is a difference in floral resources used by bumblebees and honeybees at Arne and Studland? Comparing domesticated honeybees and feral honeybees.
4) Is there evidence of competitive exclusion between bumblebees and honeybees? Again comparing if there is a difference between domesticated honeybees and feral honeybees

# 2.0 Method

## 2.1 Experimental Design

This study was conducted in the summer of 2016, between the months of August and July with the data collection only taking place on sunny days with minimum cloud cover, taking into account that pollen production is prevented by rain and is halted in the height of midday sun (Percival 1949). The study took place within two sites, one being Arne Nature Reserve situated within Wareham, Dorset located on the west coast of Poole Harbour (Uzal et al. 2003). Arne has been managed as a nature reserve since 1966 (Manning et al 2004), it is currently maintained by Royal Society for the Protection of Birds (RSPB) and is a 608-hectare protected nature reserve being designated as a Site of Special Scientific Interest (SSSI) in 1986 (Uzal et al. 2003). It encompasses one of the largest (340ha) remaining tracts of Dorset lowland heath (Pickess et al 1989), the vegetation is relatively dry and is dominated by *Erica tetralix, Molinia caerulea* and *Calluna vulgaris* (Manning et al 2004). This site was selected as it was known that in the Western area of the reserve there were numerous domesticated *A. mellifera* hives of the Buckfast breed, genetically bred to be more docile. The Second comparison site is Studland and Godlingston heath, with all data being collected from within Studland heath. The area consists of a mosaic of dry, humid and wet heath, mires, scattered scrub and bracken which support scarce or threatened invertebrate fauna species (Peters et al. 2008). This site is a National Nature Reserve, a SSSI and Special Area of Conservation (Edwards 2006). It is known that Studland is dominated by feral honeybees, with no domesticated honeybee hives found on the site.

## 2.2 What is the floral resource availability across both sites?

The floral resource availability for bumblebees and honeybees across Arne and Studland was investigated by conducting quadrat sampling within both sites. The site of each quadrat was determined by the sighting of either a bumblebee or honeybee, with 100 quadrats being recorded at Arne and 100 quadrats at Studland. Each quadrat measurement consisted of recording the percentage coverage of flowering flora species found within a 1 m radius and then within a 3 m radius of the sighted bee species. Using the mean value of the percentage cover for each species found, IBM SPSS version 23 software was used to create histograms showing the floral resource availability found within the sites.

## 2.3 Do heathland growth stages affect floral resource availability for bumblebees and honeybees?

The difference in floral resources within the different stages of heath including pioneer, building, mature and degenerate, as described by Watt 1947, was investigated by random quadrat sampling within each stage. The same quadrat sampling method was used as above, including recording the percentage cover of flowering flora species within a 1 m radius and a 3 m radius, completing 20 quadrats within each different stage. The mean of each percentage coverage of flowering floral species was worked out to allow for the data to be put into histograms. Using IBM SPSS version 23 software, a Kruskal-Wallis analysis was used to compare the means and test for a significant difference in the means of each flowering floral species within each heathland stage.

A western area of Arne nature reserve was surveyed, annotating aerial photographs from google maps of sectioned areas of the reserve. Using ArcMap version 10.3.1 (Esri, Redlands) software, a GIS map of this area was created. Overlaying the heath type and stage, again following the described stages of Watt 1947, and any other land cover habitat types found on top of a base map of Arne Nature reserve. This allows for a visual representation of the different stages of heath and the floral resource available, with annotations showing the approximate study site areas of the quadrat sampling. The annotations depicted what the land cover and habitat type of the reserve was, including whether it was dry or wet heath and what stage the heath was in. Also, annotating where woodland areas are found and where the areas of the reserve which have been deforested under RSPB management are located. Areas within the study site which were dominated by Gorse, Bracken and Scots Pine were also annotated on the map, being recorded as ‘Dominant Gorse and Bracken’ due to spatial issues within the GIS map itself.

## 2.4 Is there a difference in the floral resource use by bumblebees and honeybees?

When a bumblebee or honeybee feeding on a floral resource was sighted a 1 m radius was placed around the bee species with the flowering flora species, the bee species found and what they are feeding on all being recorded. Any other bumblebee or honeybee species found within the 1 m radius was also recorded and what they were feeding on. This was then repeated for the 3 m radius. This data was put into IBM SPSS, version 23 to create histograms to show the difference in floral resource use by bumblebees and honeybees across both sites. The histograms show the actual number of bumblebees and honeybees found feeding on each flowering flora species. Investigating the difference in floral resource use between the domesticated honeybees at Arne and the feral honeybees found at Studland using the histograms.

## 2.5 Is there evidence of competitive exclusion between bumblebees and honeybees?

Competitive exclusion was studied by looking at the avoidance of close foraging, using indirect evidence of competition looking for a negative correlation of abundance of honeybees and bumblebees at closer proximity compared to more distant proximity. This was done by testing for a significance in relationship between the abundance of bumblebees and honeybees at 1 m and 3 m. Pearson's correlation significance was tested separately for 1 m and 3 m abundance of bumblebees and honeybee at Arne and again repeated for 1 m and 3 m abundance at Studland. Testing for the hypothesis that there will be a significant decrease in bumblebee numbers when there are more honeybees. Using Pearson's correlation to also test to see if there is a significant difference of competitive exclusion between domesticated honeybees at Arne and feral honeybees at Studland. The domesticated *A. mellifera* stock found within Arne are of the Buckfast strain, bred in Denmark, and are a breed which has continually been developed since the nineteenth century combining the best traits from different races, such as increased fecundity, good temper and calm behaviour and expelling the bad traits (Adam 1987).

# 3.0 Results

In total, 800 bees were observed split amongst the two study sites, with over 300 quadrats sites recording the resource availability within the nature reserves. The only bumble species recorded during the study include *B. pascuorum*, *B. humilis, B. terrestris and B. lucorum,* with the most abundant and frequent being *B. terrestris* and *B. lucorum*. Observations of *B. humilis* were rare but significant since this species is on the UK Biodiversity Action Plan as priority for conservation (UK Biodiversity Group, 1998). No other flowering species were observed within the heath, during the study apart from *Calluna vulgaris, Erica cinerea, Erica tetralix* and *Ulex minor.*

## 3.1 What is the floral resource availability across both sites?

Within both sites the most frequent and abundant species found were *Calluna vulgaris* and *Erica cinerea,* with Erica cinerea being significantly more abundant within Studland compared to Arne (Figure 1). *U. minor* was also more abundant within Studland compared to Arne, whilst *E. tetralix* average percentage coverage is very similar showing how both areas where the bee observations took place were for the majority dry heath. *C. vulgaris* was also found to have an average percentage coverage increase of 5% within Arne compared to Studland (Figure 1).

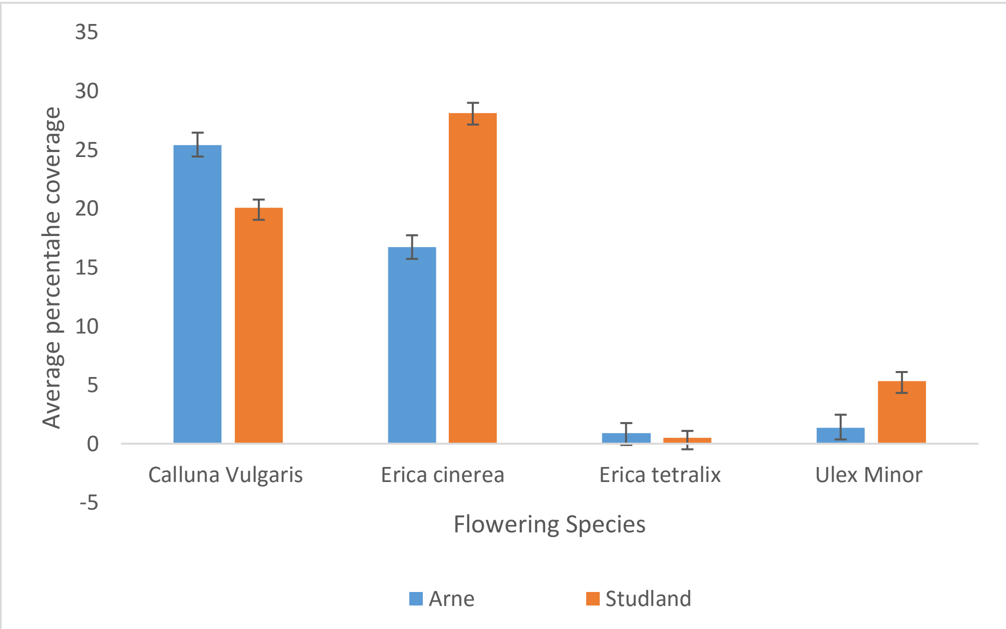


Figure 1: Floral resource availability for honeybees and bumblebees at Arne and Studland, with standard error bars.

## 3.2 Do heathland growth stages affect floral resource availability for bumblebees and honeybees?

It was found that the floral resource availability changes drastically within different stages of heathland within Arne. With the highest floral resource availability being found within mature heath for all species, *C. vulgaris, E. cinerea* and *E. tetralix* (Figure 2). Building heath follows mature heath in being the next stage to provide the most floral resources, with pioneering following and the lowest floral resource availability being found within degenerate heath (Figure 2). The most abundant species within the different stages of heathland is *C. vulgaris*, apart from degenerate heath where *E. cinerea* was found in a slightly higher number (Figure 2). There were no recordings of *U. minor* within any stages of the heath within these quadrat sampling, identifying how the species is less frequent than the other ericaceous species within Arne (Figure 2). Whilst *E. tetralix* was found within mature heath, it was found to be significantly less frequent than *C. vulgaris* and *E. cinerea* (Figure 2).

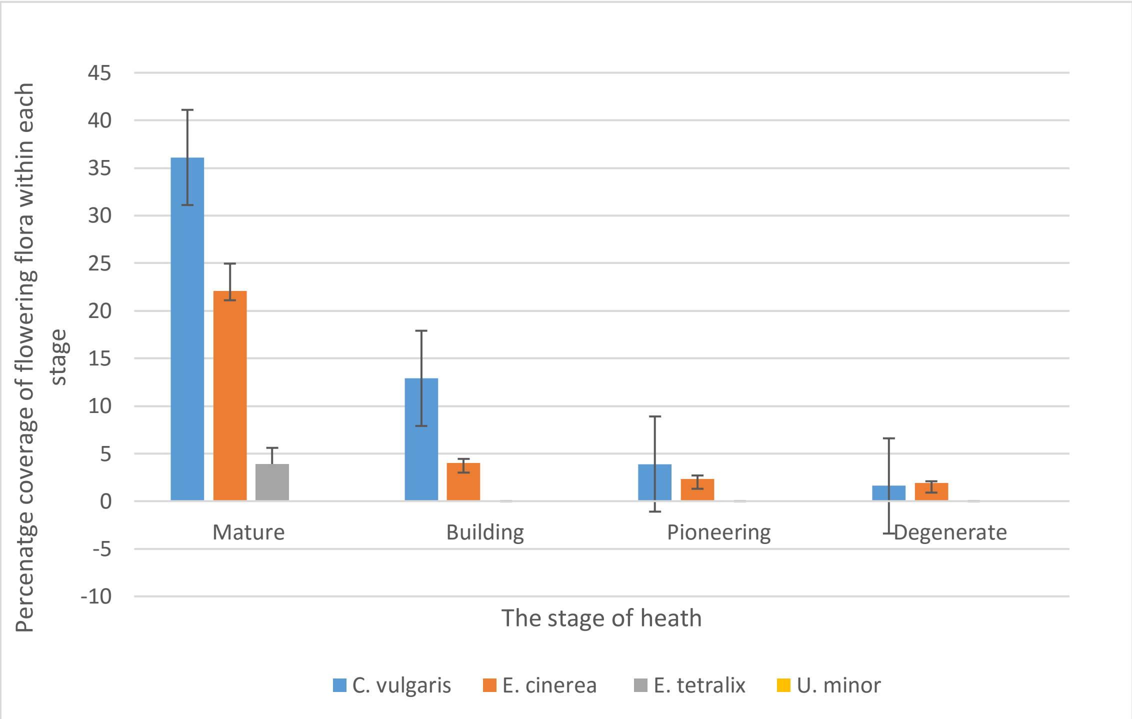


Figure 2: The floral resource available within different stages of heath found within Arne nature reserve

Using Kruskal-Wallis statistical analysis it can be see that there is a significant difference in the abundance of flowering *Calluna vulgaris, Erica cinerea* and *Erica tetralix* within the different stages of heath. Using Kruskal-Wallis statistical test it was found that there was a significant difference in the abundance of *C. vulgaris* within the different heath stages (Chi-Squared =63.609, df =3, P=<0.05). It was also found that there was a significant difference in the abundance of *E. cinerea* within the different stages of heath (Chi-Squared =45.376, df =3, P = <0.05). For *E. tetralix* it was found that there was a significant difference in the abundance of the floral resource within the different stages of heath (Chi-Square =64.914, df =3, p =<0.05). The Kruskal-Wallis statistical analysis was not conducted for *U. minor* as there was no percentage coverage of this flowering floral species within any of the quadrats samples.

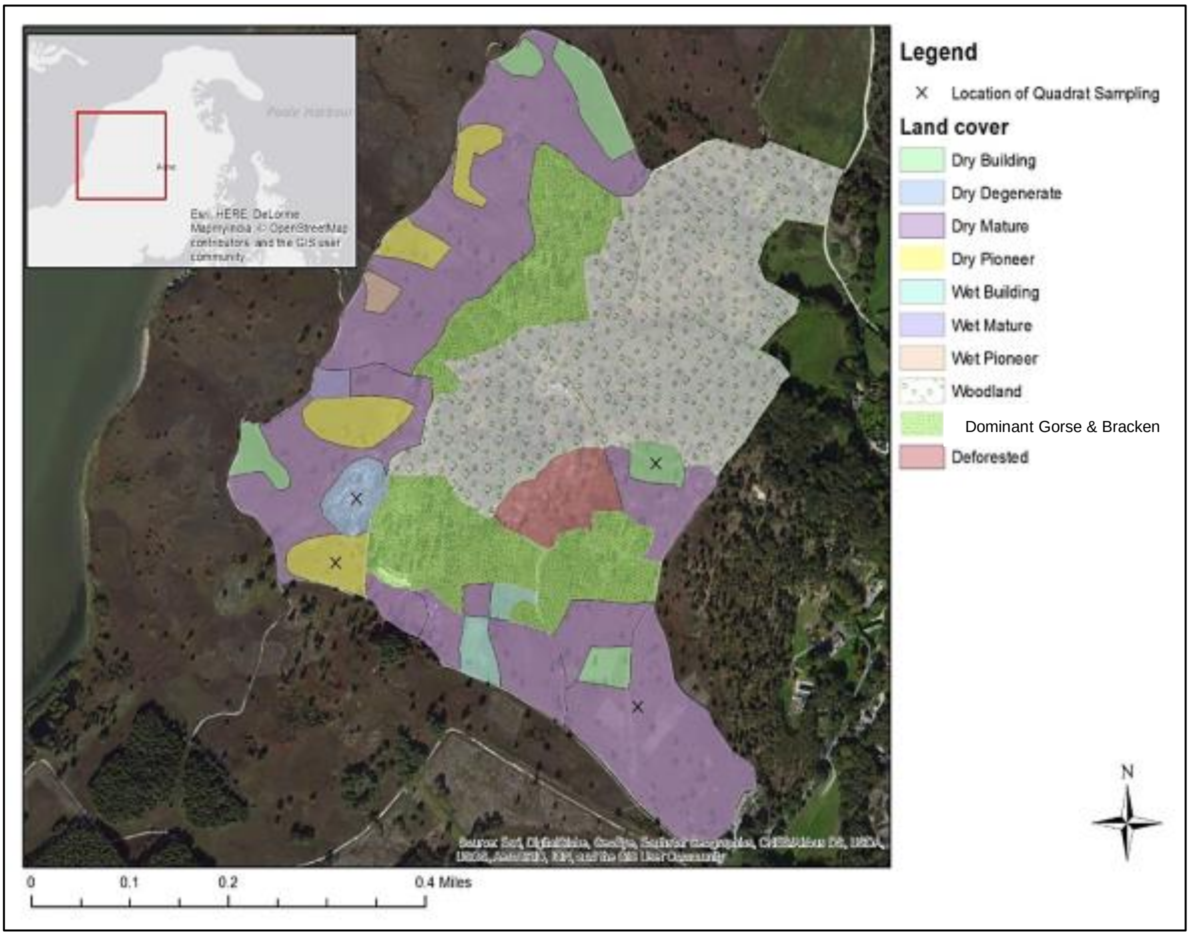


Figure 3: Visual representation of the study site, showing the abundance of different heath stages, habitat types and the location of the quadrat sampling for Figure 2

The mapping of the western area of Arne nature reserve, which includes the locations of the study sites for the quadrat sampling of percentage coverage of different heath stages, shows the abundance of each heath stage (Figure 3). It can be seen that this area of Arne is the most abundant in dry mature heath (Figure 3) and with the highest percentage coverage of all flowering floral species being found within mature heath (Figure 2), it can be assumed that these mature heath areas are the most abundant in flowering floral resources. With dry building heath and dry pioneering heath being the next most abundant heath type found, and with dry degenerate heath taking up the smallest area within the study site. It can be seen that there are small areas of wet mature heath and wet building heath found but with the study site being mostly dominated with dry heath (Figure 3). A substantial majority of this western area of Arne is made up of woodland, with areas dominated by Gorse (*Ulex europaeus),* Bracken (*Pteridium*) and Scots Pine (*Pinus Sylvestris*) also making up a substantial amount of the study site (Figure 3). A large section of the study site has also been deforested under RSPB management (Figure 3), with the use of the Mangalista (*Sus scrofa domesticus*) pigs which disturb the land to rip up any *P. sylvetris* roots with the aim of preventing regrowth of *P. Sylvestris* and regenerating this area into heathland once more (Figure 3).

## 3.2 Is there a difference in floral resource use by bumblebees and honeybees?

The floral resource use was found to vary greatly between Studland and Arne, with a particularly strong difference found between the domesticated honeybees at Arne and the feral honeybees at Studland (Figure 2 and Figure 3). Within Arne it was found that *A. mellifera* has a higher preference for *C. vulgaris* compared to *E. cinerea*, this relationship could be explained by the fact Arne was found with a higher percentage cover of *C. vulgaris* compared to that of Studland (Figure 1). Within Studland it was found that the feral honeybee resource use was much more evenly spread between *C. vulgaris* and *E. cinerea (Figure 3). Bombus* feeding was more evenly spread at Studland, including *E. tetralix* (Figure 3), whereas at Arne feeding was more favoured towards *C. vulgaris* (Figure 2). There were only 5 recordings of *B. humilis* overall and four out of the five were found feeding on *U. minor*, showing a preference for this floral resource.

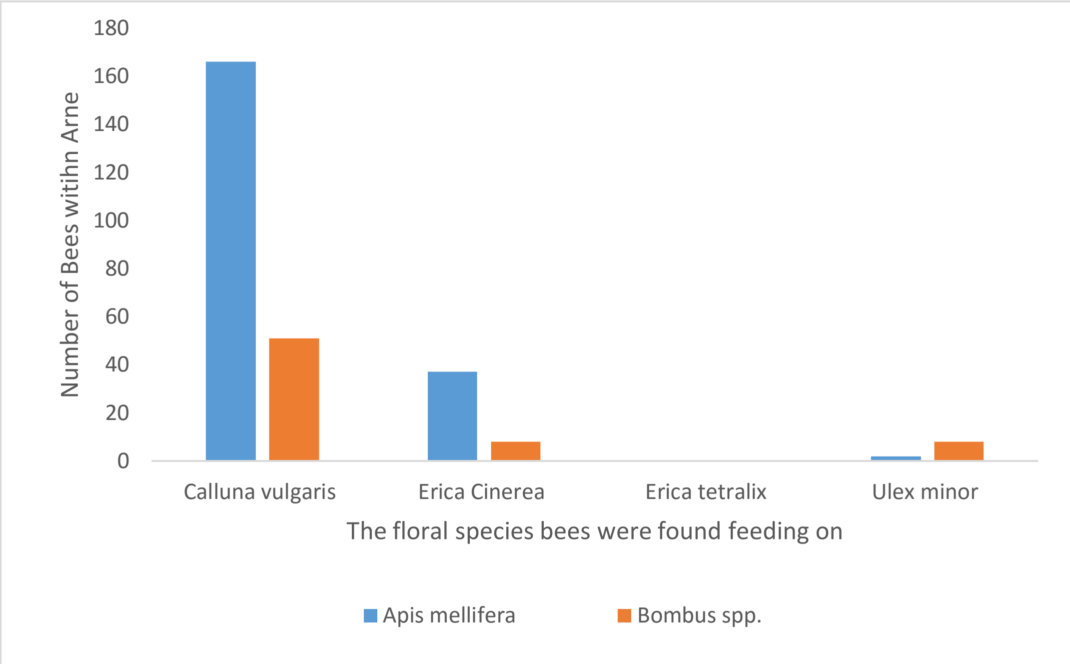


Figure 3: The floral resource use by domesticated honeybees and bumblebees at the Arne study site

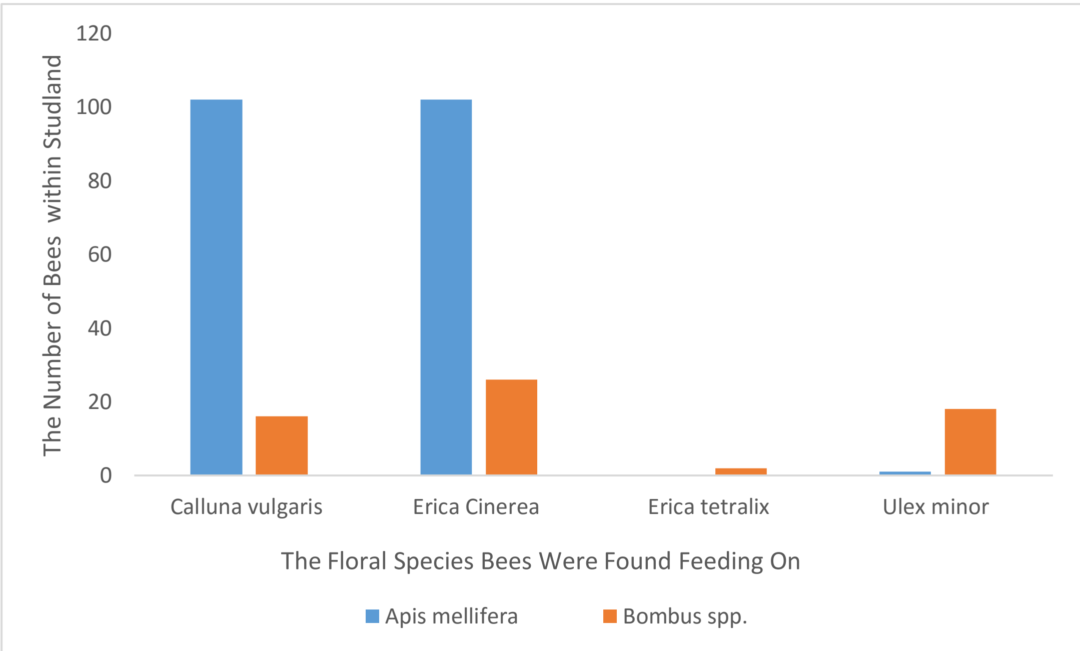


Figure 4: The Floral resource use by feral honeybees and bumblebees at the Studland study site

## 3.3 Is there evidence of competitive exclusion between bumblebees and honeybees?

The number of *Bombus* species was found to be lower than the number of *A. mellifera* across all sites, with *A. mellifera* likely to be found in higher numbers within the sites compared to *Bombus* spp (Figure 2 and Figure 3). It was found that within 1 m it was much more likely to have a *Bombus* spp., and no *A. mellifera* (Table 1 and Table 3) compared to 3 m where it was rare to find a *Bombus* without *A. mellifera* present (Table 2 and Table 4).

The number of *Bombus* species was found to be decreased by the presence of *A. mellifera*, with a significant decrease being found for both Arne and Studland within the 1 m radius. Within Arne there was not a significant decrease in the number of *Bombus* species where there were more *A. mellifera* within the 3 m radius, however at Studland there were significantly fewer *Bombus* species where there were more *A. mellifera*.  These results show a stronger competitive exclusion for feral *A. mellifera* than the domesticated *A. mellifera* found at Arne.

### 3.3.1 Correlation between number of bumblebees and honeybees within 1 m radius at Arne

The Pearson's correlation showed there are significantly fewer bumblebees where there are more honeybees (Pearson's r=-0.513, P<0.001).

Table 1: The number of A. mellifera and Bombus spp., found within a 1 m radius at Arne

| | **Number of *A. mellifera*** | | | | | |
|---|---|---|---|---|---|---|
| **Number of *Bombus*** | | **0** | **1** | **2** | **3** | **4** |
| | **0** | 0 | 34 | 12 | 1 | 0 |
| | **1** | 27 | 16 | 3 | 0 | 0 |
| | **2** | 4 | 2 | 1 | 0 | 0 |
| | **3** | 0 | 0 | 0 | 0 | 0 |
| | **4** | 0 | 0 | 0 | 0 | 0 |

### 3.3.2 Correlation between number of bumblebees and honeybees within 3 m radius at Arne

The Pearson's correlation showed there is no significant difference in the number of bumblebees where there are more honeybees (Pearson's r = -0.003, P=0.976).

Table 2: The number of *A. mellifera* and *Bombus spp*., found within a 3 m radius at Arne

| | Number of *A. mellifera* | | | | | |
|---|---|---|---|---|---|---|
| **Number of *Bombus*** | | **0** | **1** | **2** | **3** | **4** |
| | **0** | 19 | 38 | 20 | 4 | 1 |
| | **1** | 1 | 11 | 1 | 1 | 0 |
| | **2** | 0 | 1 | 0 | 0 | 0 |
| | **3** | 0 | 0 | 0 | 0 | 0 |
| | **4** | 0 | 0 | 0 | 0 | 0 |

### 3.3.3 Correlation between number of bumblebees and honeybees within 1 m radius at Studland

The Pearson's correlation showed there are significantly fewer bumblebees where there are more honeybees (Pearson's r=0.672, P<0.001).

Table 3: The number of *A. mellifera* and *Bombus spp*., found within a 1 m radius at Studland

| | Number of *A. mellifera* | | | | | |
|---|---|---|---|---|---|---|
| **Number of *Bombus*** | | **0** | **1** | **2** | **3** | **4** |
| | **0** | 0 | 32 | 20 | 5 | 0 |
| | **1** | 30 | 11 | 1 | 1 | 0 |
| | **2** | 2 | 1 | 0 | 0 | 0 |
| | **3** | 0 | 0 | 0 | 0 | 0 |
| | **4** | 0 | 0 | 0 | 0 | 0 |

### 3.3.4 Correlation between number of bumblebees and honeybees within 3 m radius at Studland

The Pearson's correlation showed there are significantly fewer bumblebees where there are more honeybees (Pearson's r=0.218, P<0.005).

Table 4: The number of *A. mellifera* and *Bombus spp*., found within a 3 m radius at Studland

| | **Number of *A. mellifera*** | | | | | |
|---|---|---|---|---|---|---|
| **Number of *Bombus*** | | **0** | **1** | **2** | **3** | **4** |
| | **0** | 12 | 45 | 23 | 1 | 0 |
| | **1** | 6 | 11 | 0 | 13 | 0 |
| | **2** | 0 | 1 | 0 | 0 | 0 |
| | **3** | 0 | 0 | 0 | 0 | 0 |
| | **4** | 0 | 0 | 0 | 0 | 0 |

# 4.0 Discussion

## 4.1 What is the floral resource availability across both sites?

It can be seen from the results that both of the sites investigated for this study fit within the *Calluna vulgaris-Ulex minor* heath (H2) community of the British National Vegetation Classification (Rodwell 1992); it is dominated by *Calluna vulgaris*, with *Erica cinerea* and *Ulex minor* playing a frequent and sometimes dominant role (Rodwell 1992). The presence of *Erica tetralix* is of great significance for defining floristic variation within this community (H2). *E. tetralix* was uncommonly found within both sites, again matching the *Calluna-vulgaris-Ulex minor* heath (H2) community. *E. tetralix* is more frequent within sub-communities such as heath in this community which extends on seasonally-waterlogged soils or experiences more rainfall (Rodwell 1992). U. minor shows a variety of different abundance within this H2 community (Stokes et al. 2003, Rodwell 1992), and within Studland it was found at a higher abundance than compared to Arne. In areas where grazing still occurs *U. minor* can be widely reduced (Rodwell 1991), and this could explain the difference in abundance of this species between the two sites as Arne has a high densities of Sika deer which could graze on these floral resources (Uzal 2003). It has been found that the total vegetation volume and cover of ericaceous species has been reduced on the dry heaths due to the grazing of Sika Deer at Arne (Underhill-Day and Liley 2006) and thus, this could also explain why *E. cinerea* is also found in lower abundance at Arne compared to Studland. Whereas, there is currently no grazing on Studland heath which could be affecting the floral resource availability. However, there are current proposals to introduce grazing onto Studland heath in order to maintain varied vegetation structures and control scrub development (Peters et al. 2008).

The results for the floral resource availability throughout both the sites have to be questioned however, as some flowers may have been emptied of their rewards and not all flowers offer pollen and nectar rewards as soon as they open (Zimmerman and Pleasants 1982). Nonetheless, it has been argued that the true measure of resource availability is almost impossible to obtain (Tepedino and Stanton 1982). The growth of bee population is likely to correspond to resource availability, when it is not limited. Since this study took place during the height of summer months, floral resources would not have been as limited as they would have been earlier or later in the season, therefore bees should have been out in their highest numbers (Forup and Memmott 2005).

## 4.2 Do heathland growth stages affect floral resource availability for bumblebees and honeybees?

Within heathland ericaceous species are the main plants that provide valuable pollen and nectar resources for the species (Moquet et al. 2016), the results show that ericaceous species are found within all heathland growth stages providing these valued resources. Whilst all stages provide these ericaceous floral resources for pollinators the most important for floral resource availability was found to be mature heath, followed by building heath then pioneering and finally degenerate proving the least floral resources. Disruptions in the continuity of flowering resources can threaten bumblebee life cycles, such as the fragmentation found within heathland (Moquet et al 2016), this disruption can be seen within the GIS mapping of the study site, which shows large quantities of the area are dominated by gorse (*Ulex europaeus*), bracken (*Pteridium*) and scots pine (*Pinus sylvestris*), as well as large areas of woodland. However, it was also shown how a large majority of the study site consists of mature dry heath and this heathland stage provides the highest frequency of floral resource, which allows for *Bombus* species high fidelity for ericaceous species to take place (Moquet et al. 2016). The fragmentation of the heath stages involving large areas dominated by *U. europaeus*, *Pteridium* and *P. sylvestris* can be seen as a disruption of flowering resources for *Bombus* spp. and *A. mellifera*. Whilst vast areas within Arne are dominated by these three species, it needs to be remembered that *Ulex europaeus* is a pollinator resource for *Bombus* species and *A. mellifera,* with *Bombus* species having a stronger preference for the pollen and nectar of the floral resource than *A. mellifera* (Forup and Memmott 2005).

It has been found that *Bombus* species and *A. mellifera* are the most efficient pollinators of *Calluna vulgaris*, out of a wide range of insects including Hymenoptera, Diptera and Lepidoptera (Mahy et al. 1998), therefore the mature heath stage would be the most valuable heathland stage for pollinator resources (Figure 2). With this knowledge, it can be put forward that the mature heath stage is the most important for *Bombus* species and *A. mellifera* in terms of pollinator resource availability, and therefore lowland heath should be managed to ensure a vast majority of the site is made up of mature heath to increase pollen and nectar availability for these important pollinators. The different area shown within the Arne study site which are dominated by *U. europaeus, Pteridium* and *P. sylvestris* should receive particular management, with the aim of restoring these areas to heathland; allowing for the cyclic succession to occur (Watt 1947). Eventually allow for a higher frequency of the most floral resource rich heath stage according to these results - mature heath. Also, allowing for mitigation of the loss of some of the current dry and wet mature heath succession into degenerate heath, which offers a very scarce amount of floral resources.

This study looked at only Arne and only sampled dry heathland stages when investigating how different stages of heath affect floral resource availability for pollinators. Whilst the majority of the Arne study site was dry lowland heath, there were still patches of wet heath which could have been have been included in the quadrat sampling. More data from within the Arne study site and another site, such as Studland, on the floral resources of different stages of heath, including both wet and dry, could have improved the validity of these results.

## 4.3 Is there a difference in floral resource use by bumblebees and honeybees?

It can be seen that *A. mellifera* are much higher intensive resource users compared to the *Bombus* species within both sites, this is due to their larger colony size and their need to store nectar and pollen provisions for the winter which gives them a foraging advantage (Thomson 2004). Through this higher abundance of *A. mellifera*, it can be understood how *A. mellifera* can reduce *Bombus* species food base. These results supporting past studies which have shown that a high *A. mellifera* density can have an impact on local pollen and nectar availability (Torné-Noguera et al. 2015, Thomson 2004).

A difference in floral resource use can be seen as *Bombus* species were the only species found feeding on *E. tetralix* and were also found feeding on *U. minor* in a much higher number compared to *A. mellifera;* these results support Forup and Memmott's study (2005) which show the same feeding preference relationship. *A. mellifera* mostly fed on *Calluna vulgaris* and *Erica cinerea*, with a very small amount feeding on *Ulex minor*; whilst *A. mellifera* are more generalist foragers (Thomson 2004), they have been found to have more of a preference for *C. vulgaris* and *E. cinerea* (Forup and Memmott 2005). *B. terrestris* and *B. lucorum,* the most abundant bumblebee species recorded, are also more generalist species feeding on a range of flora (Goulson 2010); within the two sites studied they were most frequently found foraging on *C. vulgaris* and *E. cinerea.* This result shows very similar floral resource use between *A. mellifera*, *B. terrestris* and *B. lucorum* within these lowland heath communities. Late emerging, long-tongued species with a more specialised diet, such as the rare and threatened *B. humilis* (Goulson

& Darvill 2004) were found to have a feeding preference for *U. minor* within the sites. This species has been found to respond to *A. mellifera* with a shift between plant species (Walther-Hellwig et al. 2006) and this may be the reason as to why *B. humilis* were rarely observed feeding from *C. vulgaris* or *E. cinerea*, which were the most abundant floral resource recorded within both sites. Therefore, conservation actions for the rare *B. humilis* should include managing heath to ensure a higher frequency of *U. minor*. This could be additionally advantageous since *A. mellifera* were found to not have a particular feeding preference for *U. minor*, which thus allows more availability of pollen and nectar from *U. minor* for more specialist *Bombus* species, such as *B. humilis*, which are at higher risk of population crashes and are also in greater need of conservation actions (Goulson et al. 2005). However, it does need to be stated that recordings of *B. humilis* were very low. With only five recordings across both sites, with the rarity of the species contributing to this (Goulson & Darvill 2004). The need for more data and research on this topic has been highlighted through these results.

The difference in floral resource use between domesticated *A. mellifera* and feral *A. mellifera* is an area which has not been studied greatly, with a noteworthy lack of literature which has explored this difference. *A. mellifera* hives are usually set up in late summer within heathland, during the flowering period of *C. vulgaris* thus allowing for this to be their main floral resource (Moquet et al. 2015), and this may be a factor contributing to the floral resource preference found for the domesticate A. mellifera within Arne for *C. vulgaris*. However, this study finding that there is a difference in the feeding behaviour of feral *A. mellifera* and domesticated *A. mellifera* highlights the importance to explore this relationship furthermore. The need for more data, increased replication and comparisons across different sites is also required to accurately test this difference to allow for results which have a higher validity and increased reliability.

## 4.4 Is there evidence of competitive exclusion between bumblebees and honeybees?

According to Paini (2004), for competition to occur between honeybees and bumblebees there must first be an overlap of floral resource use, with the honeybees collecting nectar and pollen from the same flower species as bumblebees - this overlap can be seen within the results, and is also mentioned above. Although both *A. mellifera* and *Bombus* species can be seen to be visiting the same floral resource, competition can still be absent if the presence of *A. mellifera* fails to interfere with native bee visitation rates or if the floral resources are not limited (Paini 2004). The results from this study however indicate that the presence of *A. mellifera* significantly decrease the presence of *Bombus* species and therefore, are affecting native bee visitation rates. These results support many studies which show the same relationship (Thomson 2004, Forup and Memmott 2005, Elbgami et al. 2014 and Linström et al. 2017). In terms of the floral resources being limited, it can be argued that the increasing scarcity of lowland heath and the significant decrease in heathland habitats within Dorset over the last 150 years (Fuller et al. 2017, Natural England 2014), means that the floral resources are becoming progressively limited. Competitive exclusion between short-tongued *Bombus* species, such as *B. terrestris* and *B. lucorum* has been observed in terms of minor spatial changes in the *Bombus* species abundance in the presence of *A. mellifera* (Walther-Hellwig et al. 2006). Evidence of this can be seen within the significant decrease in *Bombus* species in the presence of *A. mellifera* within the results. This is predominantly evident within Arne where a very literal minor spatial change was observed with *Bombus* species showing a significant decrease in their numbers where the proximity to *A. mellifera* was too close, but no decrease where the proximity was lessened.

The results from this study indicate a difference in competitive exclusion between feral *A. mellifera* and domesticated *A. mellifera*. This difference in impact of the commercial and feral *A. mellifera* is something that has not been investigated much, and therefore there is a lack of literature to explain this exclusion difference (Paini 2004). The results show that feral *A. mellifera* at Studland had a significantly stronger sign of exclusion on the number of *Bombus* species with there being a decrease in the number of *Bombus* within both proximities measured. One possibility is that feral *A. mellifera* are present in the same site throughout the year whilst domesticated *A. mellifera* are rotated, and this difference in presence may interact in the relationship between *Bombus* species and *A. mellifera* (Paini 2004). An alternative explanation is that the feral *A. mellifera* found within Studland are more aggressive in their behaviours than the domesticated *A. mellifera* at Arne (Kastbergeer et al. 2009), and this is further explained below. The domesticated *A. mellifera* at Arne where the results showed a strong sign of exclusion at 1 m but no sign at all at 3 m show that the domesticated commercial *A. mellifera* still have an impact on *Bombus* species, however with the comparison study it can be seen that this impact is of a lesser degree to that of the feral *A. mellifera.* The exclusion at 1 m found for the domesticated *A. mellifera* can be explained by the fact that commercial honeybee hives are rotated, often in an opportunistic way with the rotation being decided by good flowering seasons, with large numbers of hives being put into the area (Paini 2004). During the study there were 17 hives within the studied area of Arne. This large number of *A. mellifera* hives - with each one having a large colony size - can be seen to be the cause of the competitive exclusion found, as their significantly higher number, when compared to *Bombus* species, gives them a competitive edge (Potts el al. 2015). However, even with commercial domesticated *A. mellifera* having this competitive edge due to higher numbers, feral *A. mellifera* were still found to have a stronger competitive exclusion. It can be argued that this difference is down to the fact that the commercial domesticated *A. mellifera* are genetically bred to be more docile and good tempered (Kastberger et al. 2009). The *A. mellifera* stock found within Arne are of the Buckfast strain, bred in Denmark, and are a breed which has been continually being developed since the nineteenth century, combining the best traits from different races, whilst simultaneously expelling the bad traits (Adam 1987). The extreme docility of the Buckfast breed allows them to be worked with little smoke and protective clothing (USDA 2017). With the results showing a decreased competitive exclusion in the domesticated *A. mellifera* found at Arne, with *Bombus* species found to more readily collect pollen and nectar within a 3 m radius of *A. mellifera* at Arne, it can be said to be down to the difference in character traits between the two different *A. mellifera* found within each site. The bred docility and decreased aggressive territorial traits which have been bred into the Buckfast strain found at Arne and many other commercial *A. mellifera* strains (Kastbergeer et al. 2009), can be argued to cause a more harmonious cohabitation between them and *Bombus* species. The difference in results found for competitive exclusion between the domesticated Buckfast *A. mellifera* and feral *A. mellifera* across both sites are certainly interesting. This is deemed especially important in light of the recent and significant declines of pollinating species both within Europe and globally and in relevance to the need to manage against these declines (Geib et al. 2015). It is also important in regards to the growing controversy on whether beekeeping within nature reserves is a sustainable practice (Torné-Noguera et al. 2015). With little literature on this topic, these results further highlight the importance of investigating this matter more thoroughly, and the need to repeat this research and to test it within different sites.

With the main foraging distance of *A. mellifera* in the UK found to be 5.5km (Beekman and Ratnieks 2000), the results run the risk of false recordings of *A. mellifera* from other sites which do not correspond with the comparison at hand (Forup and Memmott 2005). This study lacks proper replication and as mentioned it can be seen how the study is not independent from confounding factors. The results to study the difference in competitive exclusion between feral *A. mellifera* at Studland and domesticated *A. mellifera* within Arne need to be considered in light of possible confounding variables which could damage the internal validity of the comparison.

## 4.4 Conclusion

This study has identified that whilst both the study sites at Arne and Studland are for the majority within the H2 *Calluna vulgaris-Ulex minor* community the floral resources available differs. With the potential reason for these differences involving management of the sites, with particular reference to the management of grazing that takes place within the sites. The study also found that heathland growth stages do affect floral resource availability for Bombus spp. and A. mellifera, with the most important heathland stage for floral resource availability being mature heath. It was also found that there is a similarity in floral resource use between *Bombus* spp. and *A. mellifera* with a niche overlap being found most predominantly for *Calluna vulgaris* and *Erica Cinerea* within both sites. A difference in floral resource use by Bombus spp. and A. mellifera was found as *Bombus* spp. were the most dominant user of *Ulex minor* within both sites, with *B. humilis* showing a strong feeding preference for this floral species. *A. mellifera* were very rarely found feeding on *U. minor*, highlighting the importance of this floral resource in terms of its pollen and nectar resource for *Bombus* spp. A difference in floral resource use between domesticated *A. mellifera* and feral *A. mellifera* was also found, with a lack of literature found on this matter the results highlighted how this difference in feeding preference between the two should be investigated more thoroughly. This study also found evidence of competitive exclusion between *Bombus* spp. and *A. mellifera*, showing how *A. mellifera* presence decreased the number of *Bombus* spp. present within a close proximity. There was a difference found within the comparison of domesticated *A. mellifera* and feral *A. mellifera*, with the results showing how feral *A. mellifera* at Studland had a stronger sign of competitive exclusion towards *Bombus* spp. compared to the domesticated commercial *A. mellifera* found at Arne. With the genetic breeding of domesticated *A. mellifera* to create a more docile and gentle breed being stated as the reason behind this.

Further studies which are suggested by this work include a more comprehensive investigation looking into the differences of feeding preferences between domesticated *A. mellifera* and feral *A. mellifera*. Competition from *A. mellifera* towards declining *Bombus* species is an increasingly important matter and therefore the importance of better understanding on the floral resource use differences between feral *A. mellifera* and domesticated *A. mellifera* should be acknowledged. Enhancing floral resources is a widely accepted method to aiding the conservation of bee species, and therefore better understanding of the difference in floral resource use of these pollinators will allow for better informed and targeted restoration and management of the appropriate floral resource.

This study showing evidence of increased competition towards *Bombus* spp. from feral A. mellifera compared to domesticated A. *mellifera* should again suggest the need to further investigate these findings. More comprehensive and systematic studies looking into this difference in competition with the same results could shape the academic understanding of commercial *A. mellifera* and beekeeping. With beekeeping in decline and the questioning of the sustainability of beekeeping within nature reserves growing due to known suppression of native wild bee populations due to A. mellifera, better understanding of this matter is very important to the management of pollinators.

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# 7.0 Appendices

## APPENDIX A

## Evaluative Supplement

The main strength of this project is the significance of the data, with the significance of data showing honeybees having competitive exclusion towards bumblebees. Additionally, a significant difference between domesticated commercial honeybees and feral honeybees. The difference found between domesticated honeybees and feral honeybees is something there is minimal literature review on, with literature having a tendency to focus on competition between *A. mellifera* in general and native pollinators. With beekeeping becoming an increasingly important practice, in times of significant declines in native pollinators and commercial honeybees, a better understanding in the differences between these feral and domesticated honeybees is fundamental. Within this main strength of the project, lies the potential for future work.

Another strength of this study was the ability to be able to study the domesticated Buckfast bred honeybees at Arne and the feral honeybees within Studland, with it being confirmed that there are no domesticated honeybees within Studland heath. This was a very fortunate situation and allowed for the appropriate comparison between the two honeybees to take place. Both these sites were very fortunately local, allowing for increased ease in the data collection. However, a lack of control of the honeybee species being recorded within each site is a weakness due to the risk of false recordings from honeybees from other sites which didn’t match the comparison at hand. For future studies of this comparison between feral honeybees and domesticated honeybee tighter control of this may enable for more reliable and valid results.

In terms of data collection of the different honeybees a weakness lies in the fact that is could never been truly known whether the honeybee species being recorded were 100% domesticated or feral as honeybee varying flight distance could allow for these anomalies and the possibility of this false recording should be taken into account. These anomalies could only be prevented in a controlled study.

A limitation of this study is time constraints, as the strength of the results could have been greatly improved with repeats of all objectives within each study site, or across two different study sites, using the same comparison of domesticated commercial honeybees and feral honeybees. For this to happen effectively it would have been great to carry out the research across two summer periods, to enable data collection within the same months of summer. This would enable repeats, thus allowing for increased reliability of the results.

By undertaking this independent research project, I have gained the skills and knowledge needed to allow myself to undertake future independent projects. I have gained understanding of what is needed to structure feasible objective and aims and how to break these objectives down into the data collection that is essential to achieve them. I have gained better understanding of the need to work out which statistical analysis is going to be used for each objective before the data collection itself, whilst also being open-minded to mid-project changes which are sometimes required to achieve the best outcomes. My overall understanding of the different statistical test and analysis has also muchly improved. Overall, I have improved my ability to use SPSS software, with a wider knowledge of many more tests which can be undertaken using the software. My ArcGIS skills have greatly improved and I now feel more confident and capable of using more ArcGIS tools to allow for better interpretation of data to allow for the optimum visual representation of what is trying to be shown to the reader.

In terms of the report write up I have learnt the importance of ensuring a comprehendible and understandable flow with the reader always being kept in mind. Ensuring the introduction clearly explains why the aims and objectives are being studied and keeping a consistent flow without, with answering the aims and objectives always in mind. Whilst it is a scientific report in some way you need to treat the data and results as a story that needs to be told in a way that is not confusing to the reader and is cohesively easy to follow.

Although this study had to undergo a few changes from the original design and has its weaknesses, the outcome is very interesting and offers valuable insight into this area of research. With results showing domesticated honeybees are less competitive than feral honeybees, it offers benefits to ongoing real-world debates about the sustainability of beekeeping within nature reserves, with the insight showing the need for more research.

The project has been an extremely rewarding experience, with my knowledge on bumblebees, honeybees and heaths greatly increasing. I have improved and gained skills as well, and these skills are ones in which I know I will be able to use in my future career path.