



LEC.505

**Exploring the influence of environmental factors on pollinator
diversity in farmland.**

Eleanor Gillard (36579498)

Lancaster University

Lancaster

LA1 4YQ

UK

Submitted September 2024

Supervisor: Dr Rosa Menendez Martinez

This Dissertation is submitted in partial fulfilment of the degree of

MSc Environmental Management

The work contained within this report is the result of my own investigations. All sections of the text and results which have been obtained from other work are fully referenced. I understand that plagiarism constitutes a breach of University regulations and will be dealt with accordingly.

I do consent for this submission to be stored in electronic format for use in the LEC.505 archive and for sharing with future students, relevant funding bodies and external partners.

Word count: 9440

Exploring the influence of environmental factors on pollinator diversity in farmland.

Abstract

The intensification of agriculture, along with the resulting habitat homogenisation and fragmentation, is a major driver of global pollinator population declines. A number of schemes have been implemented aiming to counter these declines. However, their effectiveness is variable, likely due to the lack of targeted measures. This study explores how pollinators respond to environmental factors, and identifies which habitats are associated with drivers of abundance.

Pollinator transect surveys were conducted across three different farms in Brampton, all of which participate in Countryside Stewardship Schemes. A total of 16 transect routes, encompassing three habitat types (raised bog, hedgerow and pasture), were surveyed for pollinators on three separate occasions. For each transect route, vegetation characteristics were measured, including floral cover, bare ground cover, vegetation height and floral resource. Generalised linear models were used to analyse the significance of these variables on pollinator abundance, and to what extent they are driven by habitat type.

The results show that vegetation factors were important determinants of pollinator abundance, but the magnitude of effects differed between groups. Vegetation height significantly influenced the abundance of all pollinator groups, while other variables showed mixed effects. Butterfly abundance was strongly driven by floral resource availability and forb cover, which also showed a strong correlation with overall pollinator diversity. Bumblebees and hoverflies, however, were more strongly influenced by the availability of bare ground, which was significantly higher in hedgerow habitats.

These findings have implications for habitat management and environmental land management schemes. Conservation efforts should be tailored to target specific pollinator communities based on their varied habitat preferences. Priority actions should include maintenance of hedgerows, varied sward height and bare ground plot creation. Understanding local drivers is important, but further research would determine key resources over a broader scale.

Contents

1. Introduction	5
1.1. Pollination Services	5
1.2. Pollinator Diversity	5
1.3. Availability of Nectar and Floral Resources.....	6
1.4. Agri-Environment Schemes	6
1.5. Aims of this study	7
2. Methods	9
2.1. Study Sites	9
2.2. Pollinator Surveys.....	10
2.3. Survey Conditions	10
2.4. Floral Resource Estimation.....	10
2.5. Vegetation Sampling.....	11
2.6. Data Analysis	11
3. Results	13
3.1. How does pollinator species richness and abundance vary in different farmland habitats?.....	13
3.2. What is the relationship between floral cover and pollinator diversity?	16
3.3. Which aspects of vegetation composition drive higher pollinator species richness, and with which habitats and management practices are these associated?	17
4. Discussion	23
4.1. Comparison of Pollinator Biodiversity	23
4.2. Effect of Vegetation Height	23
4.3. Influence of Grazing and Land Management	24
4.4. Effect of Floral Resource and Forb Cover.....	24
4.5. Effects of Bare Ground	26
4.6. Effect of Habitat Type	27
4.6.1. Hedgerow Habitat.....	27
4.6.2. Pasture Habitat.....	28
4.6.3. Bog Habitat.....	30
5. Study Limitations and Recommendations for Future Research	31
5.1. Species Specific Impacts.....	31
5.2. Habitat Comparisons	31
5.3. Sampling Limitations.....	31
5.4. Management Practices	32
5.5. Seasonal Variation	32
5.6. Floral Species Diversity	32
6. Research Implications	33

7. Conclusions	34
8. Acknowledgements	35
9. References	35
10. Appendices	45
Appendix 1: Coordinates of each sampling point.	45
Appendix 2: List of pollinator groups and species recorded, with total abundance.	46

List of Tables

Table 1: Linear Mixed Model assessing the effect of habitat on vegetation height	17
Table 2: Linear Mixed Model assessing the effect of habitat on floral resource	17
Table 3: Linear Mixed Model assessing the effect of habitat on forb cover	17
Table 4: Linear Mixed Model assessing the effect of habitat on bare ground cover	18
Table 5: Generalised Linear Mixed Model assessing the influence of significant vegetation variables on total pollinator abundance.....	19
Table 6: Generalised Linear Mixed Model assessing the influence of vegetation height, forb cover, bare ground coverage and floral resource on butterfly abundance	21
Table 7: Generalised Linear Mixed Model assessing the influence of vegetation height, forb cover, bare ground coverage and floral resource on bumblebee abundance	21
Table 8: Generalised Linear Mixed Model assessing the influence of vegetation height, forb cover, bare ground coverage and floral resource on hoverfly abundance	22

List of Figures

Figure 1: Map of the location of study sites, within wider national context	9
Figure 2: Rarefaction curve of pollinator groups represented depending on number of individuals sampled per transect route	14
Figure 3: Non-metric multi-dimensional scaling (NMDS) plot to visualise the level of similarity in community composition of all three habitats	15
Figure 4: Linear regression for the relationship between forb cover and pollinator diversity across farmland habitats	16
Figure 5: Box plots depicting the difference in vegetation variables between bog, hedgerow and pasture habitats.....	18
Figure 6: Scatter plots showing model variables that were significant in explaining total pollinator abundance	20

1. Introduction

Insect biodiversity has declined globally over recent decades (Raven *et al.*, 2021). The evidence of insect population declines and range shifts is clear (Wagner, 2020; Sánchez-Bayo and Wyckhuys, 2021; Wilson and Fox, 2021). Preventing further biodiversity loss is important to maintain ecosystem services such as pollination, soil fertility, climate change resilience and biological pest control (Dangles and Casas, 2019; Kovács-Hostyánszki *et al.*, 2017).

1.1. Pollination Services

Insect pollinators are crucial in supporting ecosystem functions essential for agriculture (Garibaldi *et al.*, 2013; Levenson *et al.*, 2022; Nath *et al.*, 2023). This paper focuses on butterflies, bumblebees, bees and hoverflies which support ecosystem functioning and crop pollination. Insect pollinators support up to 35% of global crop production (Klein *et al.*, 2007) and are valued at approximately £690 million annually in the UK (Natural Resources Wales, 2024). Pollinators also support wild plant production, soil stabilisation, genetic diversity and culturally significant habitats (Tanda, 2022; Senapathi *et al.*, 2015). Understanding threats to pollinator populations is imperative given these valuable services.

1.2. Pollinator Diversity

Pollinator diversity depends on habitat heterogeneity and environmental factors. Semi-natural habitats are critical for their persistence, yet habitat loss and fragmentation are key drivers of pollinator decline (Jaureguiberry *et al.*, 2022). For example, the UK Butterfly Monitoring Scheme reported a 62% decrease in butterfly species abundance over the last 50 years (Fox *et al.*, 2023). This is partly attributed to fragmentation of habitats limiting pollinator dispersal, leading to population isolation (Ekroos *et al.*, 2010). Sedentary species are more at risk from fragmentation of semi-natural habitats due to a limited dispersal ability (Habel *et al.*, 2019). This can be detrimental to populations if they are unable to move between areas to sustain metapopulations, leading to isolation and reduced diversity (Ekroos *et al.*, 2010).

Numerous UK bumblebee species declined from 1960 to 1980, with subsequent range shifts driven by climatic changes (Casey *et al.*, 2015). Habitat specialist species are particularly vulnerable (Lami *et al.*, 2021). Warzecha *et al.* (2016) provide evidence for selection towards increased body size in wild bee communities driven by habitat fragmentation. This is likely due to smaller species being more susceptible to land use change due to their limited dispersal ability and therefore lower chances of recolonisation (López-Urbe *et al.*, 2019). Declines in less mobile hoverfly species have also been documented (Sánchez-Bayo and Wyckhuys, 2019). The decline of these species could simplify ecosystems, making them less productive (Clavel *et al.*, 2011).

1.3. Availability of Nectar and Floral Resources

Different habitats components within agricultural landscapes provide key floral resources for insect pollinators (Cole *et al.*, 2017). Many plants considered to be agricultural weeds are important for flower-visiting insects due to their generalist flowers, which are accessible to a variety of pollinators and provide valuable sources of nectar (Balfour and Ratnieks, 2022). Herbicide applications result in loss of these nectar resources which correlates with decreased pollinator diversity (Baude *et al.*, 2016). Bumblebees, solitary bees and butterflies have therefore all been demonstrated to exhibit a negative relationship with farming intensity (Gabriel *et al.*, 2013).

Intensive grazing and the establishment of monocultures further decreases floral resources, with diverse plant communities supporting greater pollinator diversity (Isbell *et al.*, 2017). Moreover, Geiger *et al.* (2010) show that increased reliance on pesticides consistently results in marked declines in species diversity on farmland. Neonicotinoids, in particular, impair bee foraging and nectar collection (Goulson *et al.*, 2015; Siviter *et al.*, 2021). Specialist pollinators, like solitary bees, are especially vulnerable to these effects due to their constrained active period and shorter foraging range (Grüter and Hayes, 2022). Pollinators therefore require abundant foraging resources within well connected habitats.

1.4. Agri-Environment Schemes

Agri-environment schemes (AES) aim to counter biodiversity loss by incentivizing farmers to adopt wildlife-friendly practices. However, the outcomes vary depending on the specific measures implemented (Bullock *et al.*, 2021; Scheper *et al.*, 2013). Landowners may be hesitant to implement unfamiliar measures without adequate financial incentives (Tyllianakis and Martin-Ortega, 2021; Lastra-Bravo *et al.*, 2015). Additionally, low-maintenance, economically viable options may not be most beneficial for biodiversity (Austin *et al.*, 2015).

There is a debate surrounding whether land sparing (preserving natural habitats separately from farmland) or land sharing (making agricultural land more biodiverse) is most effective for policies (Grass *et al.*, 2019). The UK's Environmental Land Management (ELM) scheme, replacing the EU's Common Agricultural Policy post-Brexit, promotes sustainable farming practices that deliver wider environmental benefits, such as flood prevention and carbon storage (DEFRA, 2020). This approach aligns more closely with land sharing principles, supported by research indicating that incorporating biodiversity-friendly practices into agricultural systems not only increases yields, but also strengthens resilience to climate change (Beillouin *et al.*, 2021).

Incorporating pollinator ecological needs into agriculture is a key component of the revised UK ELM policy, with actions such as nectar flower mixes, hedgerow maintenance, no

insecticide use and varied grazing intensity. However, the scheme has faced criticism for its complex application process and lack of clarity, hindering farmer participation (House of Commons, 2022). In response, incentives like the Farmer Cluster Scheme are being developed to promote landscape-scale benefits and enhance habitat connectivity (Game and Wildlife Conservation Trust, 2018).

1.5. Aims of this study

Given the increasing pressures on land use, it is crucial to enhance pollinator diversity on farmland without compromising crop yields. Despite extensive knowledge of pollinators' habitat requirements, the success of AES has been inconsistent and often lacks longevity. More targeted, site-specific approaches are needed for long-term success (Ekroos *et al.*, 2014). By assessing the importance of various habitats and landscape features in maintaining biodiversity, clear priority actions for farmland management can be identified.

Citizen science initiatives have increased greatly over the past few decades (Gardiner and Roy, 2022). Community engagement in biodiversity enhancement practices and monitoring can help collect vast volumes of data while reducing costs. The local community of the study sites in this research is involved in conservation and broader environmental goals as part of the community group 'Brampton 2 Zero'. Projects aim to increase resilience to climate change through carbon sequestration and biodiversity enhancement. Ruck *et al.* (2024) suggest that greater community involvement in biodiversity monitoring may increase willingness to incorporate biodiversity-friendly practices into land management. This research will help identify the most beneficial factors and highlight areas to target efforts.

This paper aims to investigate the environmental components of pollinator community variance in farmland, representing different habitat types and management practices. It will also examine the extent to which changes in pollinator abundance and diversity are affected by the availability of floral resources. As the functional importance of pollinators within ecosystems is high, identifying priority habitat features is essential. This was achieved by focussing on the following key questions:

1. How does pollinator species richness and abundance vary in different farmland habitats?
2. What is the relationship between floral cover and pollinator diversity?
3. Which aspects of vegetation composition drive higher pollinator species richness, and with which habitats management practices are these associated?

These questions will help inform future management by identifying which farming practices and habitat types are most beneficial for biodiversity and should therefore be prioritised in

conservation. Understanding how pollinator diversity varies at a local scale is essential for detecting responses to environmental changes and reflecting farm scale management practices. Insights into how pollinators respond to management can guide actions to enhance pollinator diversity in agricultural landscapes. The potential benefits of AES are highly dependent on the success of wildlife-friendly farming. Therefore, prioritising the most biodiversity-friendly management practices and maintaining habitats associated with higher pollinator abundance is important to ensure the success of these efforts.

2. Methods

2.1. Study Sites

The study was conducted across three farms across Brampton, Cumbria (Figure 1). The sites are dominated by agricultural land, primarily used for rotational cattle and sheep grazing or silage cutting. All three farms are under Mid-Tier to Higher Level Countryside Stewardship Schemes and manage hedgerows as part of the Sustainable Farming Incentive. Three dominant habitats were investigated: pastureland, hedgerow and lowland raised bog. Each site was visited three times for pollinator counts, with surveys taking place between late June and mid-July 2024. Permission was sought from landowners prior to field surveys taking place.



Figure 1: Map of the study sites location, within wider national context (indicated by red outline). A represents Cumcatch Farm, B represents Brampton Fell Farm, C represents Unity Farm. Source: OpenStreetMap.

2.2. Pollinator Surveys

At each farm, pollinator biodiversity was assessed using the standardised UK butterfly transect survey method (Pollard and Yates, 1993). This involved establishing 100 m transect routes, with 16 transects walked on three occasions, distributed across three different habitats and three farms. Of the 16 transects, 6 were designated for pastures and 6 were in hedgerows (two in each farm) and 4 in the raised bog (all at the same farm). The limited number of transects in the raised bog was due to its localised and restricted size. Transects were strategically placed near the centre of fields and the raised bog to minimise edge effects. The precise coordinates of each transect were recorded to ensure consistency in sampling areas (Appendix 1).

Each transect was walked at a slow, steady pace for 10 minutes to standardise sampling effort. All butterflies within a fixed distance of 5 m ahead of the observer and 2.5 m either side of the transect were recorded. Other pollinators, including bumblebees, bees and hoverflies, were also noted. The taxa surveyed were selected for their dependence on floral resources. In terms of taxonomic resolution, butterflies and bumblebees were identified to species level in the field using identification keys (Lewington, 2015; Falk, 2016), with a net used for confirming identification when necessary. All other bees and hoverflies were recorded by total abundance rather than identification to species level. Transects are recommended for sampling pollinators, provided sufficient time is allowed (Popic *et al.*, 2013). Alternative methods of surveying invertebrates, such as pan traps, are associated with greater taxonomic bias linked with pan trap colour and involve killing individuals (Cane *et al.*, 2000).

2.3. Survey Conditions

Site visits for pollinator and floral surveys took place between 10:30 a.m. and 4:30 p.m. over three days, adhering to the UK Butterfly Monitoring Scheme recommended conditions (UKMBS, 2021). These conditions consisted of warm temperatures (at least 13°C), sunny skies (at least 60% clear) no rain, and wind speeds no greater than moderate (~2 m/s). Alternatively, on days with higher cloud cover, the temperature required was at least 17°C. These conditions were important as they represent the peak activity period for pollinators.

2.4. Floral Resource Estimation

Immediately following each pollinator survey, floral resource availability was estimated. Each transect was divided into 10 m sections, and the number of floral units along each section within a 1 m band was estimated. This design is consistent with the scale of Carvell *et al.* (2011), using the following ranges for each section: 1-5; 6-25; 26-200; 201-1000 and 1001-5000 flower units. Floral abundance was expressed as the midpoint value of each range. For

consistency, floral units were defined as either a single flower or flowers on an umbel, spike, or a capitulum, as defined by Heard *et al.* (2007). Floral units across all sections of the transect were then summed to estimate the floral resource.

2.5. Vegetation Sampling

Vegetation composition was measured over two days, without specific weather requirements. Vegetation sampling was conducted using 2m x 2m quadrats equally spaced along the same transects using for pollinator and floral surveys. Within each quadrat, the percentage cover of flowering plants, grasses, and bare ground was recorded. The vegetation sward height was measured at four points within each quadrat using a ruler, measuring the height of leaf blades.

2.6. Data Analysis

All statistical analyses were performed in R Studio (version 4.3.1) and graphs were created using 'ggplot2'. To assess the biodiversity of pollinators across different habitats, species richness was calculated for butterflies and bumblebees, the groups identified to the highest taxonomic resolution. Data from the bog transects were excluded from the inter-farm variation analysis since this habitat was exclusively found at Site C, making it non-comparable across other farms. Pollinator abundance per sampling period was calculated for all groups, including other bees and hoverflies. Mean values were calculated per habitat type from individual transect data.

For each habitat, butterfly and bumblebee species data were collated per site and rarefied using 100 randomisations to estimate rarefied species richness and produce rarefaction curves (package: 'vegan'). Rarefied species richness was calculated for each transect route, excluding samples with zero counts. This allows for comparison between samples, corrected for the number of individuals per sample. Mean vegetation height, bare ground coverage and percentage forb cover were calculated for each transect.

Simpson's Diversity Index was calculated as a measure of species diversity of butterflies and bumblebees (package: 'vegan'). Simpson's Reciprocal Index was calculated, with higher values representing greater diversity. The Sorenson Similarity index was used to assess compositional similarity among habitats. Non-metric multi-dimensional scaling (NMDS) plots were used to visualise similarity in species community composition among habitat types (package: 'vegan'). Similarity in habitat type was plotted using 95% confidence intervals. To explore the effect of other environmental variables on species composition, the function 'envfit' was used to plot environmental vectors of vegetation height, forb cover, bare ground cover and floral resource as well as the factor of habitat. As the relationship between

percentage forb cover and the diversity of pollinators was a key aim in this study, it was examined using linear regressions (package: 'car', 'lm').

Linear mixed models (package: 'lme4') were used to test for significant differences between the effect of habitat type on environmental variables. Considering the nature of the data, a Gaussian distribution was used for the analysis of response factors (all continuous variables). The fixed effect was habitat type (categorical with three levels), and farm was included in all models as the random effect. The model specification is as follows: $\text{Vegetation variable} \sim \text{Habitat} + (1 | \text{Farm})$. By default, R does not calculate p values associated with each variable in linear mixed models. Therefore best estimates were used to test for significance via the Satterthwaite approximation method (package: 'lmerTest'). The model fit was assessed by calculating the marginal R^2 , which represents the variance explained by fixed effects only, and the conditional R^2 , which takes into account both the fixed and random effects (package: 'MumIn').

To investigate the effects of environmental variables on the abundance of pollinators groups, individual generalised linear mixed models (GLMMs) with a log link were used for pollinator abundance. Poisson regression (package: 'lme4') was used to predict butterfly, bumblebee and hoverfly abundance as the data was not normally distributed. The log link function ensures positive values, and the Poisson distribution is appropriate for species richness and abundance as they are count data. GLMMs were used rather than multiple linear regression as pollinator abundance is count data (discrete variable) rather than prediction of a continuous variable.

The response variable was pollinator abundance. Vegetation height, floral cover, floral resource and bare ground were used as independent variables and the survey site (farm) as a random effect. Stepwise regression was used to select the most influential environmental variables on pollinator abundance. Any non-significant predictor variables were experimentally removed to assess whether this improved the fit of the model by comparing Akaike Information Criterion (AIC) scores. The final model fit was assessed by checking the distribution of residuals and performing a Goodness of Fit test (package: 'DHARMA') to ensure no significant deviations from expected residuals.

3. Results

3.1. How does pollinator species richness and abundance vary in different farmland habitats?

A total of 317 individuals were recorded from 48 transects across the three sites. This comprised six butterfly species and five species of bumblebee, along with other bees and hoverflies not identified to species level (Appendix 2). Hoverflies were the most frequently observed group, representing 34% of the individuals collected (n=109). *Aphantopus hyperantus* (ringlet) was the most abundant butterfly species (n=40), while *Bombus terrestris* (buff-tailed bumblebee) was the most frequently recorded bee species (n=29). The greatest number of individuals was recorded in hedgerow habitats (n=187), compared to the bog habitat (n=84) and pasture habitats (n=46).

Pollinator biodiversity varied across and within the sites. On average per transect, a total butterfly abundance of 2.3 ± 0.39 and bee abundance of 1.9 ± 0.34 was recorded across all habitats, excluding the bog. At the site level, the average total number of pollinator individuals observed per transect was 4.8 ± 1.6 in site A (Cumcatch), 6.7 ± 1.1 in site B (Brampton Fell), and 7.9 ± 2.2 in site C (Unity Farm). Similarity across the three sites (beta diversity) was higher for bees and hoverflies than for butterfly assemblages, with 100% similarity and 60% similarity in species present, respectively. Pollinator biodiversity also varied between habitat types. On average, 2.6 ± 0.7 individuals were recorded per transect in pasture habitats, compared to 10.4 ± 1.2 individuals in hedgerow habitats and 7.0 ± 1.4 individuals in the bog habitat. To assess community similarity across sites, beta diversity was measured using the Sorenson index. According to the calculated Sorenson coefficient of 0.67, the three habitat types have 67% community similarity, indicating that although there is some similarity, certain habitat types have distinct communities with unique species.

Overall, hedgerow habitats had the greatest average abundance of pollinators per transect (n = 11.7), while pasture habitats had the fewest (n = 2.9). Simpson's index was used to calculate alpha diversity, as it is less sensitive to sample size variations, with few or no individuals recorded on some transects. The average Simpson's index of diversity for pollinators was 0.55 in pasture habitats, 0.72 in hedgerow habitats, and 0.66 in bog habitats. This indicates a greater probability of two random individuals in a community belonging to different species in the hedgerow habitat compared to the less diverse pasture habitats. The lower diversity in pasture habitats was influenced by the absence of pollinators on two transects.

A rarefaction curve was used to standardise sampling effort, representing the number of species expected per sample drawn at random (Figure 2). The curve is relatively steep initially, as the most common species are likely to be found early. The curve begins to plateau as only the less common species are observed, suggesting at least 30 individuals are needed to represent a substantial number of the groups present at the sites and it is unlikely that many new groups would be recorded beyond this point. There is a higher level of uncertainty in transects with very few individuals. Fewer than 15 individuals were recorded at many of the transect routes, which is unlikely to represent the true number of orders present. Increasing sampling effort, by collecting further samples, would therefore likely discover more species.

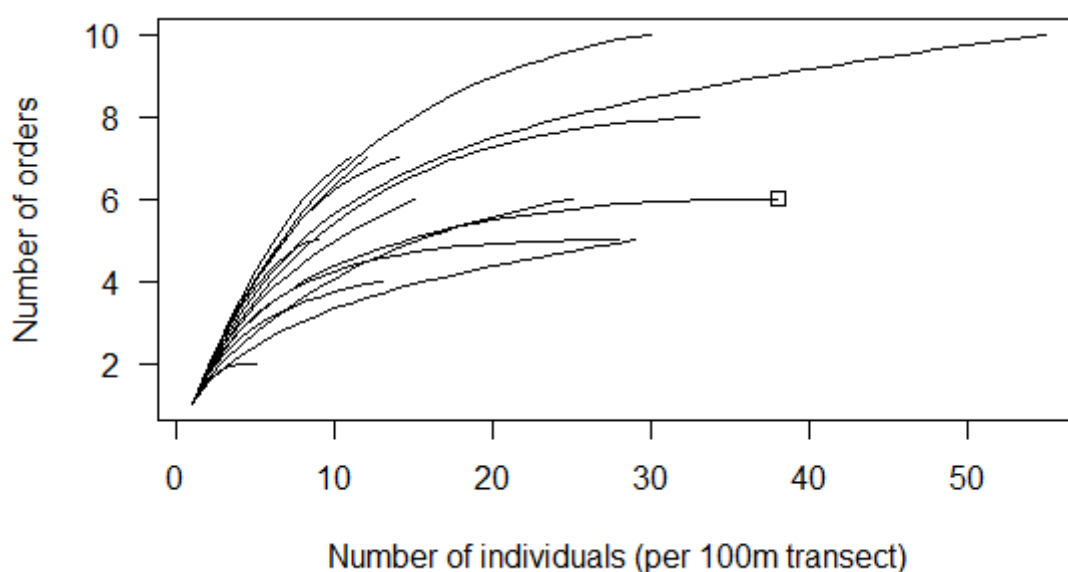


Figure 2: Rarefaction curve of pollinator groups represented depending on number of individuals sampled per transect route.

The NMDS plots illustrate the similarity in the community composition of the sampling points (Figure 3). The closer points are within the plot represents greater similarity between the pollinator communities of the points. The axes indicate a relatively high level of variation between samples across the habitat types. Grey shaded ellipses represent how communities cluster based on habitat type, with pasture and hedgerow habitats present at all three sites. It is evident from the plots that three of the four bog transect routes share a similar pollinator community composition. Hedgerow habitats also have a similar community composition to each other, with variation between pasture habitats slightly greater. *Thymelicus sylvestris* (small skipper) is frequently found in pasture habitats, whereas *Maniola jurtina* (meadow brown) and *Pieris napi* (green-veined white) are most associated with hedgerows. Notably,

Aphantopus hyperantus (ringlet) is closely linked with the bog habitat, which shows less variation in species composition.

Environmental variables are also represented in the NMDS plot. The longer arrows indicate that vegetation height and forb cover have a greater effect on driving species composition compared to bare ground coverage. The direction of arrows for vegetation variables indicates the direction of change in the variable, suggesting hedgerow habitats are associated with increased vegetation height and a higher proportion of bare ground, while forb cover rapidly decreased at two of the pasture transects.

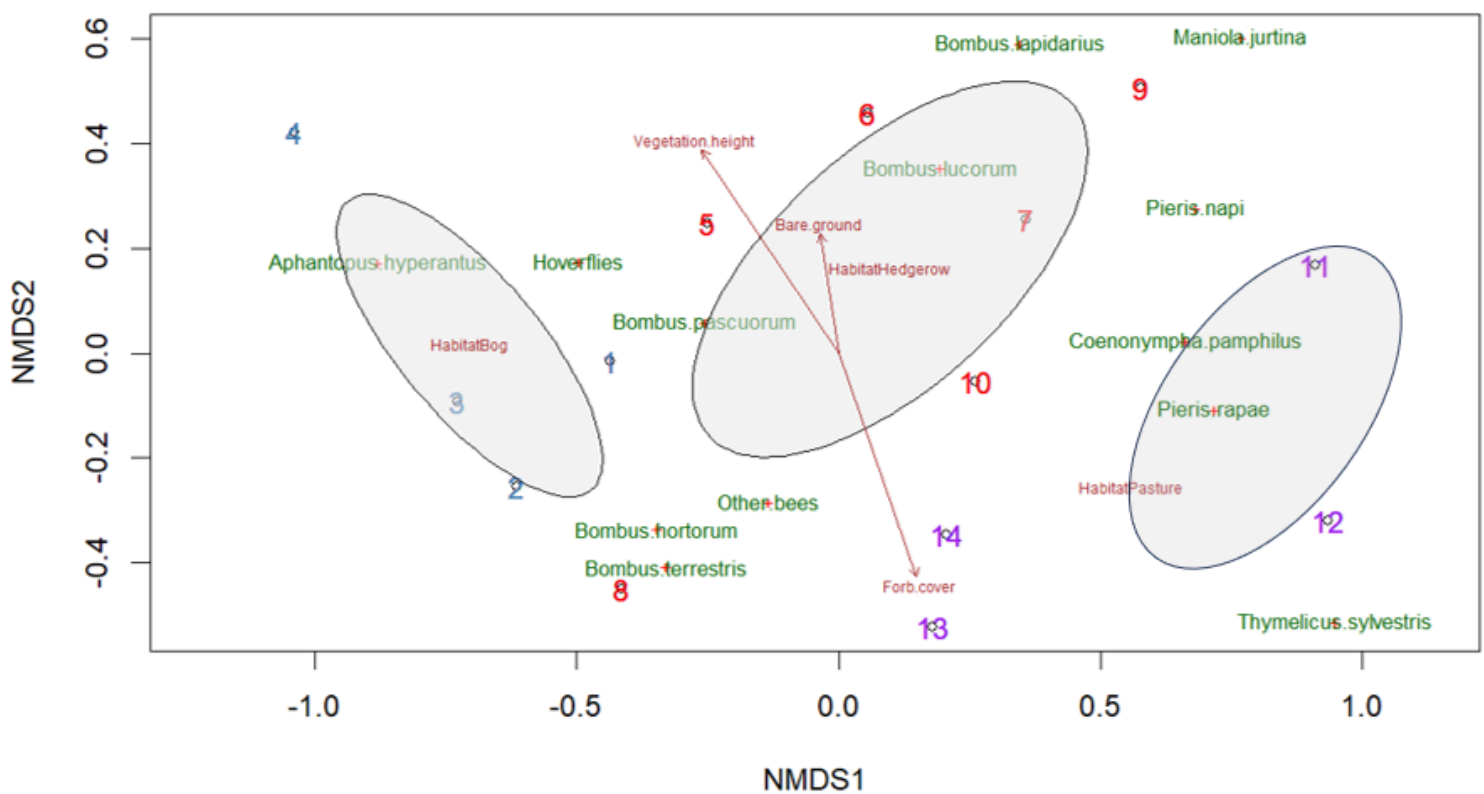


Figure 3: Non-metric multi-dimensional scaling (NMDS) plot to visualise the level of similarity in community composition of all three habitats. Species are represented as red crosses and sites are represented as hollow circles. Sites are colour coded, with samples from bog habitats shown in blue, hedgerow habitats shown in red, and pasture habitats in purple. The effect of habitat types are shown to 95% confidence intervals (indicated by grey shaded ellipses).

3.2. What is the relationship between floral cover and pollinator diversity?

Analysis showed a significant, strong positive correlation between the percentage of forb cover and the diversity of butterfly, bumblebee and hoverfly groups as measured by Simpson's index (Spearman's $r = 0.82$, $N=16$, $p < 0.001$). A simple linear regression was then calculated to predict the pollinator diversity (measured by inverse Simpson's index) based on the percentage of forb cover (Figure 4). The analysis provided strong evidence that pollinator diversity increases significantly with higher forb cover ($p < 0.001$). The regression line predicts that forb cover accounts for approximately 51% of the variation in pollinator diversity ($R^2 = 0.56$). Forb cover had a significant positive effect on diversity, with the relationship described by the equation: predicted pollinator diversity = $1.88 + 0.24 * \text{forb cover (\%)}$.

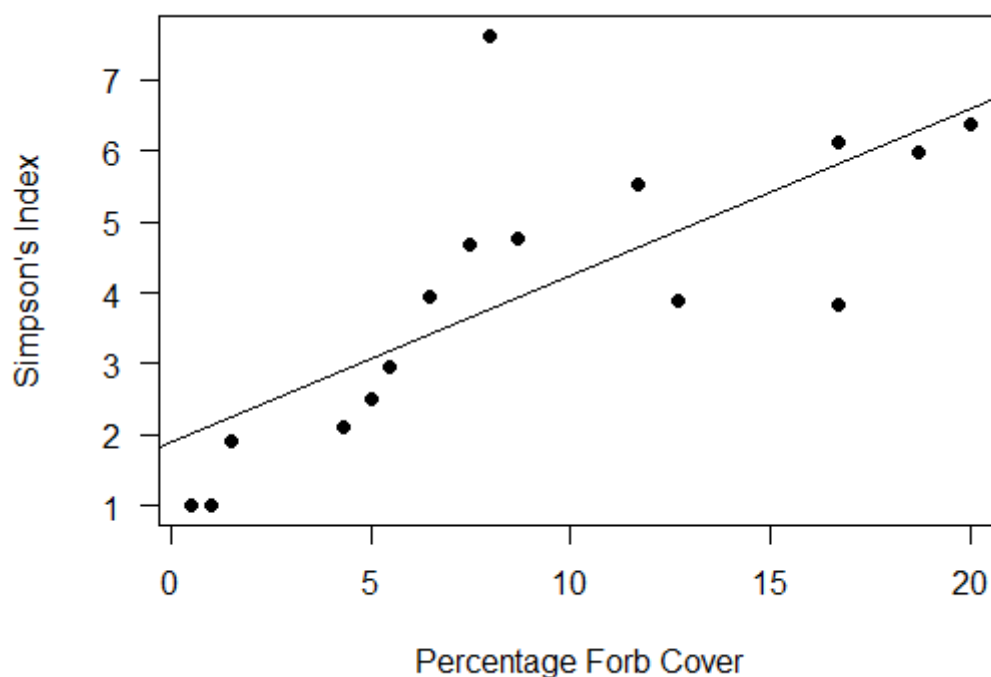


Figure 4: Relationship between forb cover (%) and pollinator diversity (measured by inverse Simpson's index) across farmland habitats ($n=16$). The equation is for the regression line shown.

3.3. Which aspects of vegetation composition drive higher pollinator species richness, and with which habitats and management practices are these associated?

Bog and hedgerow habitats had a significant effect on increasing vegetation height, whereas pasture habitats were not a significant predictor of vegetation height (Figure 5; Table 1). The model results showed that the average vegetation height was 24.2 cm lower in pasture habitats compared to bog habitats (Table 1). The R^2 values confirm that random effects (farm) did not account for any variance in vegetation height, whereas the effect of habitat was substantial. Hedgerow and pasture habitats did not have a significant effect on floral resource (Table 2). There was also no significant interaction between habitat type in explaining forb cover (Table 3). Random effects accounted for moderate variance in floral cover and resource. Hedgerows were a significant predictor of increased bare ground coverage (Table 4), with habitat type accounting for a substantial amount of the variance.

Table 1: Results of linear mixed effect model showing the effect of habitat type for vegetation height. All models included farm as a random effect. Bold values indicate a significant effect at the $P < 0.05$ level.

	Vegetation height			
	Estimate	Std.error	t value	p value
(Intercept)	32.5	3.2	10.0	<0.001
Hedgerow	-4.5	4.2	-1.1	<0.001
Pasture	-24.2	4.2	-5.8	0.282

Conditional $R^2 = 0.74$, Marginal $R^2 = 0.74$

Table 2: Results of linear mixed effect model showing the effect of habitat type for floral resource. All models included farm as a random effect. Bold values indicate a significant effect at the $P < 0.05$ level.

	Floral resource			
	Estimate	Std.error	t value	p value
(Intercept)	2.8	0.4	6.4	<0.001
Hedgerow	0.03	0.4	0.1	0.954
Pasture	-0.04	0.4	-0.1	0.937

Conditional $R^2 = 0.30$, Marginal $R^2 = 0.14$

Table 3: Results of linear mixed effect model showing the effect of habitat type for percentage forb cover. All models included farm as a random effect.

	Percentage forb cover			
	Estimate	Std.error	t value	p value
(Intercept)	3.9	4.5	0.9	0.388
Hedgerow	5.4	3.9	1.1	0.262
Pasture	4.9	3.9	1.5	0.137

Conditional $R^2 = 0.55$, Marginal $R^2 = 0.09$

Table 4: Results of linear mixed effect model showing the effect of habitat type for percentage bare ground cover. All models included farm as a random effect. Bold values indicate a significant effect at the $P < 0.05$ level.

	Percentage bare ground cover			
	Estimate	Std.error	t value	p value
(Intercept)	2.8	3.6	0.8	0.438
Hedgerow	7.1	3.6	1.9	0.043
Pasture	-1.2	3.6	-0.3	0.757

Conditional $R^2 = 0.51$, Marginal $R^2 = 0.29$

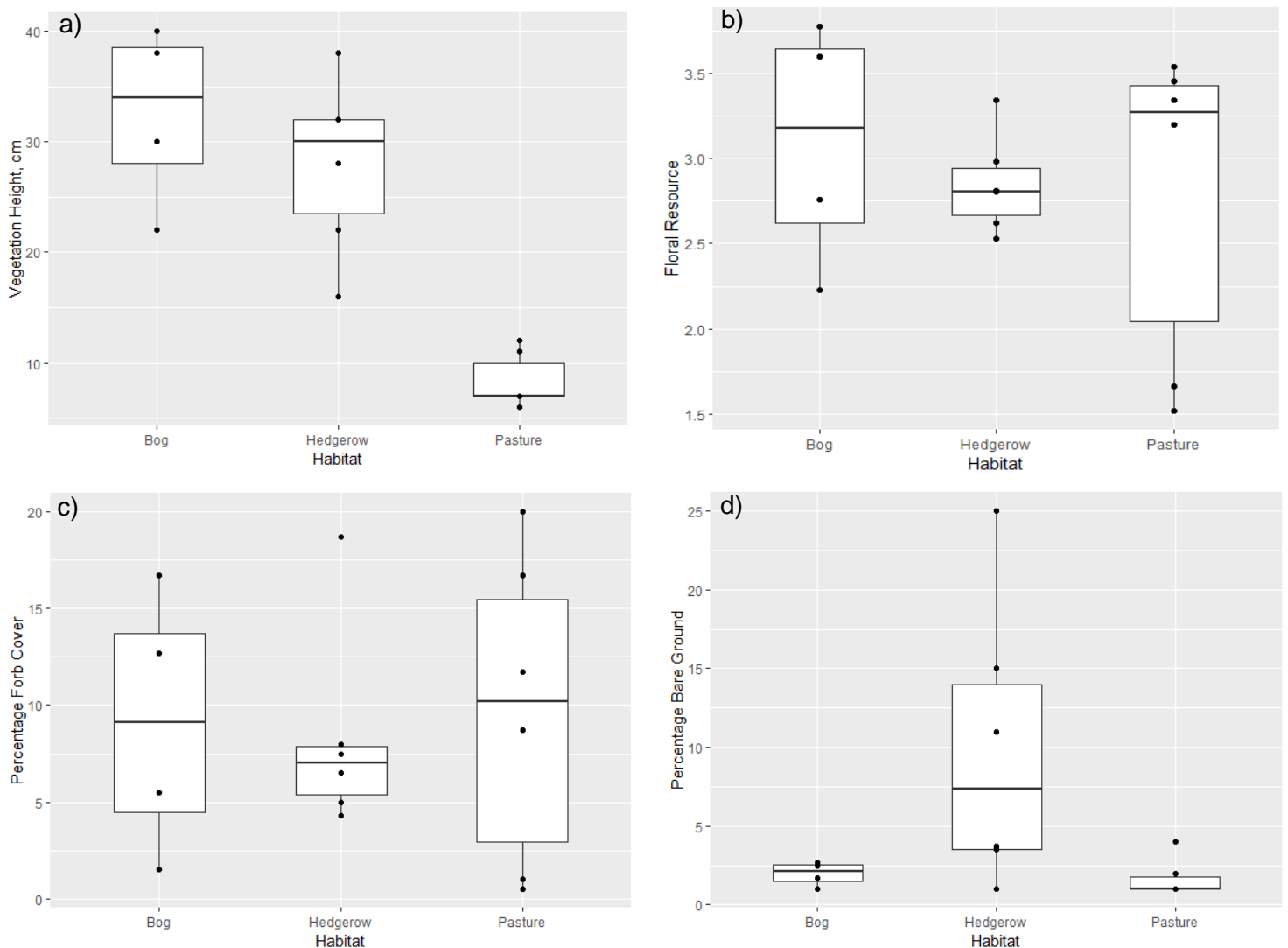


Figure 5: Difference in a) average vegetation height (cm) b) floral resource c) percentage forb cover and d) percentage bare ground between bog, hedgerow and pasture habitats. The boxes depict the median (solid black line) and interquartile range, and the whiskers extend to the maximum and minimum values.

Differences in pollinator abundance across habitats were assessed using Poisson regression. Generalised linear mixed models (GLMMs), with a Poisson distribution and a log link, were used to predict the abundance of butterfly and bee species based on vegetation variables (Table 5). Pollinator abundance was not significantly affected by the percentage of bare ground in habitats. This variable was therefore removed from the model, decreasing its AIC score and improving model fit. The model was evaluated with a Goodness of Fit test, showing that residuals were not significantly different from expectations ($p = 0.78$, $df = 12$), and the R^2 value is equal to 0.94, indicating a reasonable model fit.

Table 5: Generalised linear mixed effect model output testing the impacts of environmental variables on butterfly and bumblebee pollinator abundance. Model: Pollinator count ~ vegetation height + percentage forb cover + floral resource. The model was evaluated using Goodness of Fit and was found to have a small difference between observed data and fitted values ($R^2 = 0.94$). Bold values indicate a significant effect at the $P < 0.05$ level.

Pollinator Abundance				
Fixed effect	Estimate (β)	Std. error	z value	p value
Intercept	1.115	0.673	1.657	0.09
Vegetation height	0.040	0.007	5.950	<0.001
Forb cover	3.320	0.620	5.359	<0.001
Floral resource	0.913	0.363	2.513	<0.01

Pollinator abundance was significantly affected by vegetation height, percentage forb cover and floral resource (Figure 6). The percentage forb cover ($\beta = 3.32$, $p < 0.001$) and floral resource ($\beta = 0.91$, $p < 0.01$) had a significant, positive effect on butterfly, bee and hoverfly abundance. Vegetation height ($\beta = 0.04$, $p < 0.001$) had a smaller but still significant effect on butterfly and bee abundance.

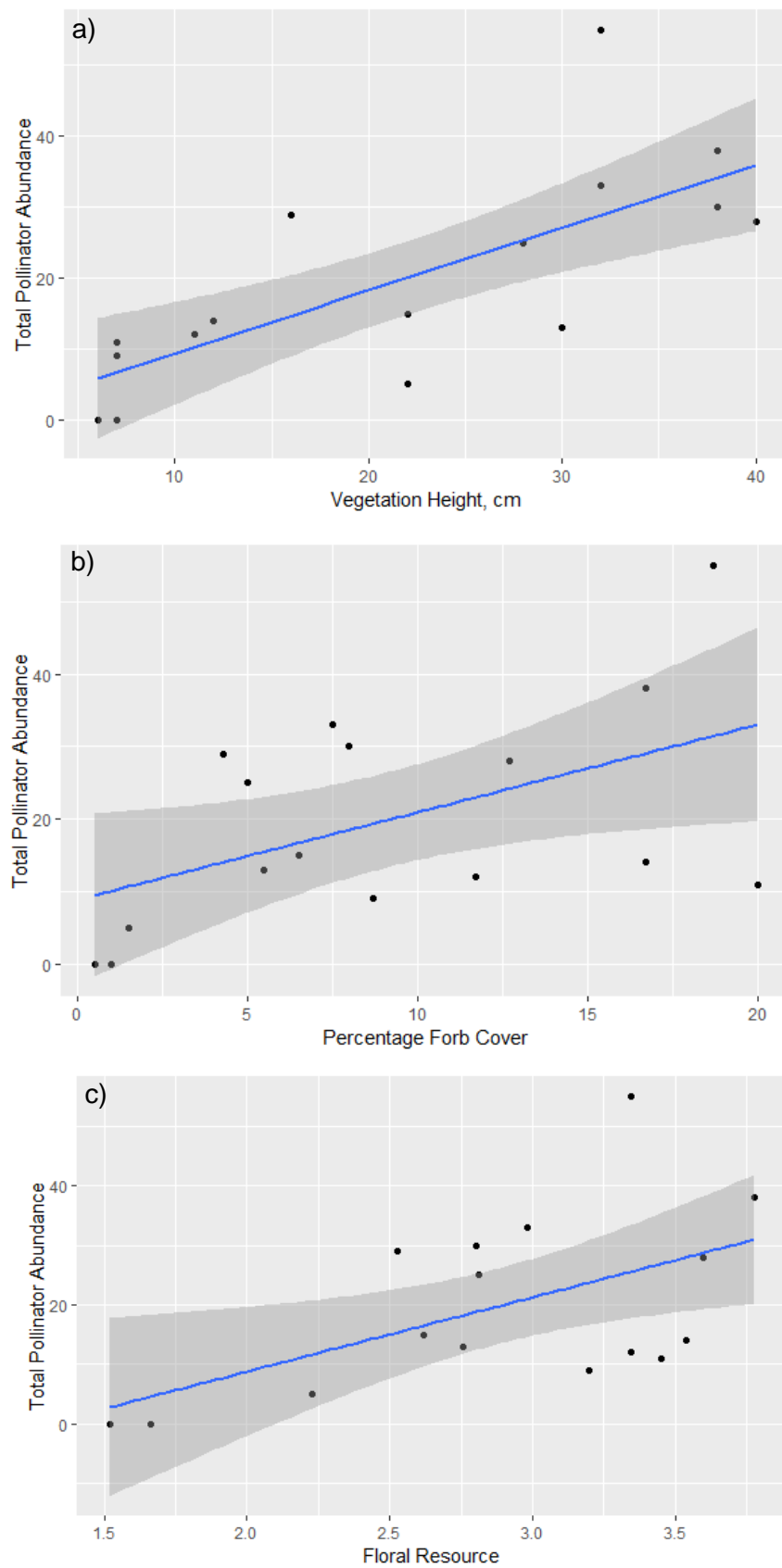


Figure 6: Visualisation of model variables that were significant in explaining total pollinator abundance, showing a) vegetation height b) percentage forb cover and c) floral resource using grey shading around the lines to represent 95% confidence intervals. Data from transect surveys ($n=16$).

A combination of environmental variables affected the abundance of groups to varying extents (Tables 6-8). The percentage of forb cover was the most influential variable for butterfly abundance (Table 6) but was not a significant factor for bumblebee or hoverfly abundance (Tables 7 and 8). Floral resource significantly affected butterfly abundance only. The percentage of bare ground in the habitat had a significant positive effect on both bumblebee and hoverfly abundance but was not significantly influential in butterfly abundance. Vegetation height significantly influenced all groups, with positive effects on the abundance of butterflies, bumblebees and hoverflies.

Table 6: Results of generalised linear mixed model testing variation in butterfly abundance explained by environmental variables. Model: Butterfly abundance ~ vegetation height + percentage forb cover + floral resource + percentage bare ground. Bold values indicate significance at $P < 0.05$ level.

Fixed effect	Estimate (β)	Std. error	z value	p value
Intercept	1.738	0.891	1.950	0.05
Vegetation height	0.042	0.009	4.561	<0.001
Forb cover	4.554	0.872	5.330	<0.001
Floral resource	1.640	0.496	3.304	<0.001
Bare ground	0.297	0.242	1.228	0.219

$R^2 = 0.75$

Table 7: Results of generalised linear mixed model testing variation in bumblebee abundance explained by environmental variables. Model: Bumblebee abundance ~ vegetation height + percentage forb cover + floral resource + percentage bare ground. Bold values indicate significance at $P < 0.05$ level.

Fixed effect	Estimate (β)	Std. error	z value	p value
Intercept	2.088	1.270	1.643	0.10
Vegetation height	0.035	0.013	2.725	<0.001
Forb cover	1.350	1.023	1.318	0.19
Floral resource	0.382	0.667	0.573	0.57
Bare ground	0.585	0.278	2.104	<0.05

$R^2 = 0.78$

Table 8: Results of generalised linear mixed model testing variation in hoverfly abundance explained by environmental variables. Model: Hoverfly abundance ~ vegetation height + percentage forb cover + floral resource + percentage bare ground. Bold values indicate significance at $P < 0.05$ level.

Fixed effect	Estimate (β)	Std. error	z value	p value
Intercept	0.754	1.046	0.721	0.47
Vegetation height	0.030	0.012	2.582	<0.001
Forb cover	0.973	0.804	1.210	0.23
Floral resource	0.303	0.565	0.536	0.59
Bare ground	0.921	0.199	4.616	<0.001

$R^2 = 0.84$

4. Discussion

The results of this study indicate that a combination of environmental factors influence pollinator biodiversity on farmland. Although no significant difference in pollinator abundance or richness were found between farms, distinct variations were observed between habitats, and the drivers of diversity varied between pollinator groups. These findings suggest that the ecological factors affecting pollinator populations are complex and habitat-specific.

4.1. Comparison of Pollinator Biodiversity

The abundance of pollinator groups in this study aligns with the results of similar research. For example, an average butterfly count of 2.3 ± 0.39 and an average bee count of 1.9 ± 0.34 per 100m transect were recorded. This is consistent with Holland *et al.* (2015), who reported averages of 2-4 butterflies and 2-3 bees per 100m transect on English farmland. However, the data revealed that pollinator biodiversity was not consistent across different habitats. Hedgerows supported the highest average abundance of pollinators, with 3.2 ± 0.77 butterflies and 3 ± 0.48 bees per transect. In comparison, pasture habitats had significantly lower averages, with 1.4 ± 0.35 butterflies and 0.78 ± 0.32 bees per transect. These differences highlight the importance of habitat type, suggesting that factors such as land management practices and environmental variables play pivotal roles in shaping pollinator communities.

4.2. Effect of Vegetation Height

Vegetation height emerged as a key environmental variable influencing pollinator abundance across the pollinator groups studied. The modelled response shows that higher vegetation is a significant positive predictor of pollinator abundance. Specifically, hedgerow and bog habitats, which had significantly greater average vegetation heights, supported more pollinators. In contrast, pasture habitats, characterised by shorter vegetation, exhibited lower pollinator abundance. This suggests that shorter swards may be limiting pollinator populations in pastures, possibly due to fewer available resources or less suitable microhabitats.

The positive relationship between vegetation height and pollinator abundance has been demonstrated in previous studies. Bumblebees, for example, show a preference for taller vegetation, with management practices that reduce vegetation height having a negative impact on bee populations (McHugh *et al.*, 2022). However, butterfly species may benefit from more structurally heterogeneous vegetation. Shorter swards provide warmer microclimates ideal for oviposition sites, while taller vegetation offers diverse feeding resources, microclimates and shelter (Morris, 2000). The variation among species highlights

the need for varied management intensity across agricultural landscapes to promote a heterogeneous sward (Jerrentrup *et al.*, 2014).

4.3. Influence of Grazing and Land Management

Habitat type was not a significant predictor of floral resource and cover, suggesting that other factors are causing the variation amongst habitats. Land management practices, particularly grazing intensity, play a role in determining vegetation cover and, consequently, pollinator abundance. As expected, sites with higher grazing pressure, particularly those grazed by sheep and cattle, had shorter swards and lower pollinator abundance. Grazing is beneficial in promoting nutrient cycling, preventing scrub encroachment, and disturbing the ground to disperse seeds (Morris, 2000). However, it can also reduce the sward height to levels that limit pollinator populations. Pöyry *et al.* (2006) found that butterfly species responded positively to increased vegetation height up to 30 cm. This suggests that moderate grazing can be beneficial, but excessive grazing can be detrimental.

In the absence of grazing or regular mowing, pasture habitats would undergo ecological succession, gradually transitioning into woody areas dominated by shrubs and trees. This process would reduce floral diversity and pollinator habitat availability, as many flowering plants would be outcompeted and shaded out. Grazing helps to maintain an intermediate successional stage, which is often optimal for pollinators, as it promotes variation in sward height to accommodate varying needs of butterfly species (Bussan, 2022). However, excessive grazing pressure can lead to homogenisation and a loss of niche habitats, which may reduce pollinator diversity.

To optimize pollinator biodiversity, land management practices should aim to create a more heterogeneous landscape. Rotational grazing and limiting livestock numbers can help maintain varied vegetation heights, which are beneficial to different pollinator species. Notably, Öckinger *et al.* (2006) found sheep grazing to be less favourable for pollinators compared to cattle grazing, as sheep consume more flowers and disturb the ground less, leading to fewer areas of bare ground, which are valuable for some pollinator species.

4.4. Effect of Floral Resource and Forb Cover

In this study, floral resource cover and availability had a greater effect on pollinator abundance than vegetation height. While vegetation height is an important factor, studies have shown that nectar availability has a stronger influence on pollinator diversity than sward height. Carvell (2002) demonstrated that bumblebees prefer sites with higher floral abundance, even when vegetation height is lower. This suggests that managing sward height alone is insufficient for pollinator conservation. Instead, management practices must

also prioritise the provision of floral resources and other habitat requirements essential for pollinator persistence.

All pollinator groups in this study showed positive responses to increased floral resource and forb cover. The analysis revealed a strong positive correlation between floral cover and the diversity of invertebrates on farmland. Floral cover had a particularly strong positive effect on butterfly abundance. This is consistent with previous research demonstrating a strong relationship between nectar availability and butterfly population abundance (Curtis *et al.*, 2015). Adequate food supply is crucial for butterflies, as it ensures suitable oviposition sites and improves habitat quality. Similarly, floral resource availability had a significant positive effect on butterfly abundance in this study. This is further indication that habitat quality, as determined by the availability of nectar resources, is key for butterfly conservation.

In contrast, bumblebees and hoverflies appeared to be less sensitive to floral resource availability compared to butterflies. Byrne (2019) found that floral diversity did not significantly impact bumblebee abundance, but higher floral cover was more beneficial. These findings align with the results of this study, where floral cover explained more of the variation in bumblebee abundance than floral resource availability. Similarly, Meyer *et al.* (2009) concluded that hoverfly abundance benefited from greater cover of flowering plants, but this effect was largely attributed to hoverflies' reliance on specific plant species. Hoverfly larvae, being phytophagous, have more specialised dietary needs compared to the polylectic feeding habits of adult hoverflies, which can utilise a wide range of plants for nectar (Speight, 2017). Therefore, the presence of key plant species is highly important for hoverfly early life stages.

The lack of significance of floral cover and resource for bumblebees and hoverflies suggests that other variables, such as floral species composition, may play a more crucial role in shaping their populations. Investigating the floral species composition within habitats may explain some of the variation, particularly if key plant species beneficial to certain pollinators were present. Given that different pollinator taxa have varied food preferences, it is crucial that habitat management strategies consider both floral cover and species composition to enhance overall pollinator diversity. For example, some plant species favoured by bees may be inaccessible to hoverflies, underscoring the need for taxon-specific management approaches.

For many butterfly and bee species, increasing landscape heterogeneity is widely recognised as beneficial for species diversity (Botham *et al.*, 2015). In contrast, hoverflies respond differently. Studies such as Power *et al.* (2016) have demonstrated that hoverflies benefit from homogenous landscapes, potentially due to the availability of larval

macrohabitats. Similarly, Bergholz *et al.* (2022) found that large-scale landscape heterogeneity had a negative effect on hoverflies, likely due to the fragmentation of suitable habitats. In large-scale agricultural matrices, field boundaries can act as barriers to hoverfly dispersal, restricting their movement and access to resources. Therefore provision of resources will only have a limited effect if habitats are not well connected. Further investigation would be required to determine the large scale habitat connectivity in the study area.

4.5. Effects of Bare Ground

The percentage of bare ground across habitats was found to have a significant positive impact on the abundance of bees and hoverflies. Many solitary bees species are ground nesters, relying on patches of bare ground with minimal vegetation cover as breeding habitat. *Bombus pascuorum* (common carder bee), unlike most *Bombus* species, frequently nests on or just below the soil surface (Bumblebee Conservation Trust, 2024). This nesting behaviour may explain its strong association with hedgerow habitats, which had a higher percentage of bare ground and experience less disturbance from farm machinery seen in pasture habitats.

Although most research is dedicated towards identifying the floral communities required to support pollinating insects (Ouvrard *et al.*, 2018), this study found bare ground to be more significant in determining bee abundance. Nichols *et al.* (2020) recommend the construction of scraped plots within farmland to provide adequate nesting areas for bees. However, agri-environment schemes do not currently incorporate creating areas of bare ground nesting areas within farmland, which could be a consideration for future conservation efforts.

Conventional farming practices, such as tillage, often disrupt the nesting habitats of many bee species. Consequently, field margins and hedgerows may be utilised as suitable habitat. Habitat type accounted for a substantial amount of the variation in bare ground availability in this research, suggesting that semi-natural areas play a crucial role in providing suitable nesting sites for bees. Morandin *et al.* (2007) found that 94% of the variation in bumblebee abundance in fields was explained by the amount of semi-natural habitat within close proximity to field edges. The results from this study agree with this, where hedgerow habitats, which contained higher amounts of bare ground, supported the highest bee abundance.

Conversely, butterfly abundance was not significantly affected by the amount of bare ground in the habitat. This can likely be attributed to the diverse habitat preferences among butterfly species. For example, *Aphantopus hyperantus* (ringlet) and *Ochlodes sylvanus* (large skipper), two species abundant species in this study, have been shown to prefer areas of

dense vegetation with low bare ground coverage (Toivonen *et al.*, 2016). The habitat preferences of these species likely reduced the overall influence of bare ground on butterfly abundance, suggesting that while bare ground is important for some pollinator groups, its role varies depending on species-specific requirements.

4.6. Effect of Habitat Type

4.6.1. Hedgerow Habitat

Hedgerow habitats exhibited the highest pollinator diversity and abundance in this study, highlighting their ecological importance in agricultural landscapes. To persist in agricultural landscapes, pollinators rely on suitable nesting sites. Hedgerow habitats in this study were significant in increasing bare ground availability. These habitats also provide vital shelter between fragmented habitat patches (Alison *et al.*, 2022). Research by M'Gonigle *et al.* (2015) demonstrated that even small-scale hedgerow restoration can enhance colonisation and promote the persistence of bees and syrphid fly populations. Semi-natural elements may therefore allow pollinators to persist in otherwise resource poor areas. This underlines the value of hedgerow habitats in sustaining species-rich pollinator communities, as outlined in this research.

Two primary hypotheses explain how hedgerows influence pollinator diversity within agricultural fields. The first, the spillover effect, suggests that pollinators located at field margins may migrate into adjacent semi-natural areas, thereby enhancing pollination services (Hanley *et al.*, 2011). The alternative hypothesis is that hedgerows serve as local concentration zones for pollinators, where the availability of resources is greatest, leading to limited spillover into field interiors (Zamorano *et al.*, 2020). While this study's findings align more with the latter hypothesis, hedgerows likely act as attractors of pollinators, contributing to broader ecosystem services over larger spatial scales. Dainese *et al.* (2017) suggest that, although they also found no significant spillover benefits into neighbouring fields, hedgerows function as ecological corridors to facilitate the movement of pollinators through fragmented agricultural landscapes.

A key factor influencing pollinator diversity, particularly for butterfly species, is the height of hedgerows. According to Luppi *et al.* (2018), hedgerows under three meters in height are most beneficial for butterflies, particularly for less mobile species, as taller hedgerows can present barriers to movement. Therefore, increasing hedgerow cover, while maintaining appropriate heights, can create a more heterogeneous landscape to promote pollinator diversity and ecosystem service delivery at larger spatial scales. The three farms included in this study participate in Countryside Stewardship Schemes to manage their hedgerows, reflected in the high pollinator abundance and diversity at this habitat type.

Hoverflies and bees often forage on the flowering plants in the understorey of hedgerows, making these plants an essential resource in more intensively farmed landscapes (Garratt *et al.*, 2017). The type of habitat did not account for much of the variance in floral cover and resource in this study, indicating that other factors such as management are more significant drivers. Reducing mowing and herbicide application in these areas would enhance the value of hedgerows as pollinator habitats, ensuring that vital foraging resources are preserved.

Butterflies, however, display a variety of responses to hedgerows depending on species. For some species, hedgerows create high quality habitats by offering shelter from wind, nectar sources, and host plants. As barriers against wind, hedgerows provide relief from adverse weather, enabling butterflies to travel more easily between habitat patches within the agricultural matrix (Dennis, 2010). Additionally, hedgerows create sheltered microclimates that are important for the larval stages of some butterfly species (Thomas *et al.*, 2011). This is especially true for nemoral species which are better adapted to sheltered environments.

Conversely, highly mobile butterfly species, such as those from the Pieridae family, tend to benefit less from hedgerows and may even experience them as movement barriers. This was not observed in this study, as *Pieris napi* (green-veined white) and *Pieris rapae* (small white) were frequently found around hedgerows, likely due to regular hedgerow maintenance preventing barrier effects. Species like *Coenonympha pamphilus* (small heath) have been observed to cross tall, dense boundaries, indicating their dispersal ability across fragmented landscapes without significant habitat isolation concerns (Kallioniemi *et al.*, 2014). This may explain the abundance of *Coenonympha pamphilus* across all study sites, as their movement across the landscape is relatively unrestricted.

4.6.2. Pasture Habitat

Typically, fields provide an abundance of nectar sources, making them strong drivers of pollinator abundance. However, at Farm A, recent mowing and the presence of cattle resulted in a shorter sward height and reduced floral resources, limiting their attractiveness to pollinators. For example, *Thymelicus sylvestris* (small skipper), which tend to inhabit taller vegetation (Lewington, 2015), were absent from Farm A. Halbritter *et al.* (2015) recommend reducing mowing frequency during peak butterfly activity to increase vegetation height and the availability of both butterfly larval host plants and nectar sources, thus supporting greater pollinator diversity.

The lower species diversity in pasture habitats contrasts with findings from other studies that reported a positive relationship between the proportion of grassland area and butterfly abundance and species richness (Botham *et al.*, 2015; Tamburini *et al.*, 2022). In this case, the lower abundance of pollinators observed in pasture habitats may be attributed to the

limited floral resources within some fields. Farm A pastures, in particular, showed markedly lower butterfly abundance compared to the other farms, with the two transects recording no pollinators at all. However, the surrounding hedgerows provided sufficient floral resources, with a high pollinator diversity across the farm as a whole. This indicates that pollinators remained concentrated in hedgerow areas rather than spilling over into the fields. This supports the view that floral availability is a highly localised driver of biodiversity, as demonstrated by Zamorano *et al.* (2020), who found no consistent evidence for spillover effects of pollinators from hedgerows into field interiors. While flower-rich field margins can still play a valuable role in conservation by attracting pollinators, they cannot fully compensate for a lack of resources within the field itself.

A positive relationship between floral cover and bumblebee abundance was observed, suggesting that fields with higher floral cover are more attractive to bumblebees. Although it was not a significant driver, as detecting significant effects may have been challenging due to the low floral cover in many quadrats, a positive effect was observed. Different bumblebee species exhibit preferences for specific pollen and nectar sources, largely due to variations in tongue length. For example, short-tongued species like *Bombus terrestris* and *Bombus lucorum* favour flowers with short corolla lengths, whereas long-tongued species such as *Bombus hortorum* and *Bombus pascuorum* prefer flowers with longer corolla lengths (Lye *et al.*, 2009). Although this study did not specifically measure floral species richness, it is likely that fields with higher forb cover contain a more diverse range of floral resources, supporting a broader range of bee species.

Floral abundance in itself is a critical factor in supporting bumblebee communities, as more flowers provide sufficient pollen to meet their dietary needs. Although hoverflies also rely on pollen and nectar as adults, their larval feeding habits are more varied. Consequently, high floral abundance ensures adequate foraging resources for adult hoverflies. Like short-tongued bees, hoverflies tend to visit flowers with easily accessible pollen, using their unspecialized mouthparts or short proboscises (Branquart and Hemptinne, 2000). However, less variation in hoverfly abundance was explained by floral cover, suggesting that other environmental factors, such as habitat structure, may play a more significant role in determining hoverfly distribution.

Few hoverflies were observed in pasture habitats, indicating they likely did not meet their habitat requirements. Unlike hedgerows, pasture areas often lack the bare ground that hoverfly larvae require for development. This scarcity of bare ground may have driven the low species richness of hoverflies in these habitats, indicating that floral abundance alone is not sufficient to support diverse hoverfly populations. Instead, well connected habitats,

providing other key resources such as sufficient bare ground availability, are essential for maintaining hoverfly communities.

4.6.3. Bog Habitat

The bog habitat exhibited a relatively high pollinator abundance, and had significantly taller vegetation than pasture habitats, which emerged as a significant predictor of bumblebee abundance in this study. The varied vegetation height within the bog habitat is likely to have contributed to the diversity of species present, as habitat heterogeneity has been identified as particularly beneficial for invertebrates (Jerrentrup et al., 2014).

Historically, large-scale drainage and destruction of peatlands, primarily for peat extraction and agricultural development, have degraded these habitats. The raised bog at Site C is undergoing restoration, but recovery from past disturbances and colonisation by new species may take several years. As Räsänen *et al.* (2023) emphasise, retaining the peat layer and raising the water table are key to successful peatland restoration. Additionally, establishing dominant plant species associated with key butterfly species should be prioritised. Removing birch trees from the site is expected to aid water retention and promote early successional stages, benefiting butterfly populations (Natural England, 2021).

The presence of *Coenonympha tullia* (Large Heath) depends heavily on habitat quality. This species is a habitat specialist, typically restricted to bogs and swampy moorlands. It has a close association with its preferred nectar source as an adult, *Erica tetralix* (Cross-leaved Heath), and its larval food plant, *Eriophorum vaginatum* (Hare's-tail Cottongrass). Osborne *et al.* (2024) identified both plant species as significant predictors of *Coenonympha tullia* presence. Although the model had a relatively low R^2 value of 0.12, suggesting other factors also play important roles, the availability of these plants is a crucial factor. This may explain why *Coenonympha tullia* has yet to establish a population at Unity Bog, despite restoration efforts.

Farm C, with its restored lowland raised bog, offers suitable habitat for future *Coenonympha tullia* colonisation, yet the species remains absent from the site. As a relatively sedentary butterfly, it struggles to migrate and establish new populations. Allee effects, combined with increasing habitat fragmentation, can result in genetic erosion and reduced inter-population connectivity (Dapporto and Dennis, 2013). The vulnerability of *Coenonympha tullia* is further compounded by its narrow dietary preferences and restricted dispersal range. Unlike bumblebees, where all species were found across all three sites in this study, butterfly species appear to have more specific habitat requirements. Provision of high quality, well-connected habitats is therefore crucial for immigration and population persistence, helping to mitigate further declines.

5. Study Limitations and Recommendations for Future Research

While this study provides valuable insights into pollinator communities, the limitations highlight several areas where adjustments in methodology and further research would enhance the understanding of drivers of pollinator diversity in agricultural landscapes. Primarily, a combination of greater sampling effort, including farms with different management and species specific research is required.

5.1. Species Specific Impacts

While this study demonstrates that pollinators are affected by a combination of factors, further research is needed to focus on how individual species respond to environmental drivers. Only butterflies and bumblebees were identified to species level as there is a trade-off between taxonomic resolution and time constraints. Further research should focus on species specific responses. Additionally, expanding the study to include other pollinator groups, such as moths, would allow for a broader understanding of how different taxa respond to environmental drivers.

5.2. Habitat Comparisons

This study focussed on agricultural landscapes, but it would be valuable to compare the pollinator abundance recorded with those in non-agricultural habitats. Such comparisons could reveal how different landscapes support pollinator diversity and abundance. Surveying the quality of the surrounding habitats, not just the study sites, would provide greater insight into how the broader landscape matrix influences the distribution of pollinator populations.

5.3. Sampling Limitations

Pollinators were not recorded at two of the pastures, which may be due to either genuinely low pollinator abundance or limitations in the sampling technique. Transect surveys risk underestimating the presence of cryptic or sedentary species, so the data obtained is potentially biased towards more conspicuous, active species. Contrary to this, Barkmann *et al.* (2023) compared transect walks with area-time counts and found this not to be the case, finding few surveys with relatively low sampling effort to be highly correlated with comprehensive counts.

While a standardised sampling method was used to ensure comparability across sites, alternative methods may have yielded different results. For instance, pan traps, in addition to the sweep nets used, could have provided a more comprehensive assessment of biodiversity. Employing a combination of sampling methods would offer a more accurate and complete representation of pollinator diversity across different management and habitat

types. Additionally, as shown by species richness curves, greater sampling effort would likely uncover a greater number of species, sufficiently capturing the richness present. As biodiversity estimations in this study were based on a relatively small sample size, rarefied species richness was used for more meaningful comparisons.

5.4. Management Practices

The three farms included in this study were managed similarly, limiting the conclusions that can be drawn about the impact of different management practices. Replicating the study across farms with diverse management approaches, such as organic farming, would allow for a better understanding of how management actions influence pollinator communities. Furthermore, sites with cattle present throughout the surveys had the lowest pollinator diversity, but investigating diversity over a longer term could determine whether this low abundance of pollinators was just temporary. More controlled research specifically comparing heavily grazed to rotationally grazed fields, would be necessary to quantify these impacts more accurately and determine the extent to which they account for the unexplained variation in pollinator communities.

5.5. Seasonal Variation

The vegetation surveys conducted in this study only captured a snapshot of resource availability at the time. Including seasonal variation in future studies would help identify how resource availability changes throughout the year and which factors are most beneficial for supporting pollinator biodiversity over time. In particular, floral cover, which was not found to be a significant driver of bumblebee abundance in this study, may have been influenced by limited floral resources at some sites. Enhancing floral resources and reassessing pollinator activity could offer insights into the relationship between floral availability and pollinator abundance.

5.6. Floral Species Diversity

Floral resources were not measured to species level in this study, which limits the ability to assess pollinators' specific feeding preferences. Future research that includes floral species composition could provide more targeted management recommendations. For instance, such research would help identify whether the presence of specific host plants is a critical driver of butterfly abundance. This would be particularly useful for the bog habitat to understand why *Coenonympha tullia* are yet to establish populations.

6. Research Implications

The findings of this study have important implications for the design and implementation of AES aimed at enhancing pollinator conservation in agricultural landscapes. Although this study examined a variety of pollinator groups and was relatively broad in scope, the key trends observed offer valuable insights for improving AES. By identifying key drivers of pollinator diversity, such as habitat quality, vegetation composition, and local management practices, the study highlights the importance of maintaining high-quality habitats to meet the diverse needs of pollinators.

Several measures emerged as particularly valuable for pollinator conservation. Vegetation height, for instance, is a key factor in pollinator abundance, suggesting that grazing intensity should be managed to create a varied sward structure. Cattle grazing, which promotes greater habitat variability, is preferable to sheep grazing. Additionally, reducing mowing to retain floral cover during summer can support pollinator biodiversity, particularly in areas where floral resources may be limiting.

One of the major insights of this study is the significance of bare ground as a driver of bumblebee and hoverfly abundance, a feature currently underrepresented in AES. This study suggests that the presence of bare ground is crucial for bees and hoverflies, and future conservation efforts should incorporate bare ground patches into conservation strategies to provide nesting resources for these species.

Hedgerows also proved to be highly valuable for pollinators in this study, provided they are managed appropriately. The farms surveyed demonstrated that well-maintained hedgerows can play a critical role in promoting biodiversity. Hedgerows should be managed to avoid excessive height, allowing taller vegetation and nectar-rich plants to persist. This is particularly beneficial in times when other areas, such as pastures, have been heavily grazed or mown. Ensuring the presence of semi-natural areas within well-connected farmland is vital for providing continuous resources to pollinators.

The predominance of generalist pollinators in the study sites indicates that current AES may favour common species while providing less support for specialist or threatened species. This emphasises the need for more targeted schemes that cater to the specific habitat requirements of specialist pollinators. Tailoring AES to the needs of different taxa, such as butterflies, which benefit from abundant floral resources, and bumblebees and hoverflies, which depend on bare ground, is essential for improving pollinator conservation.

7. Conclusions

This study demonstrates the complexity of environmental factors influencing pollinator diversity and abundance across agricultural landscapes. Although no significant difference in pollinator abundance and richness was observed between farms, the findings reveal variation between habitats, with key drivers of pollinator diversity differing across taxa. The farms in this study, all of which make efforts under various schemes to deliver environmental benefits, proved to support a diverse range of pollinator taxa.

The significance of bare ground availability in determining bumblebee and hoverfly abundance is particularly noteworthy, as it is overlooked in stewardship schemes. Hedgerows emerged as key habitats for pollinators, offering floral resources for foraging, bare ground for nesting and shelter for pollinators. They also act as ecological corridors to counter fragmentation impacts, sustaining pollinator populations. Although spillover effects into adjacent fields were minimal, hedgerows can help sustain pollinator populations without taking land out of production, so their management should be a priority.

Vegetation height and floral cover significantly influenced pollinator abundance, with taller swards and greater floral cover supporting higher pollinator numbers. Grazing intensity likely affected these variables, with low vegetation height and sparse floral resources associated with reduced pollinator numbers. Higher vegetation height strongly driven by hedgerow and bog habitats appeared to support greater biodiversity. These habitats increase heterogeneity in the landscape, benefitting pollinator communities.

Butterflies were most responsive to habitats rich in floral resources, while bumblebees and hoverflies were significantly influenced by bare ground availability. These findings suggest that targeted management strategies are necessary to meet the needs of different pollinator species. Further research incorporating species diversity of floral resources would clarify the specific requirements of various pollinator taxa.

Overall, this study emphasises the importance of habitat heterogeneity in maintaining pollinator diversity. While hedgerows, fields, and bog habitats each provide essential resources, habitat connectivity is crucial to counter fragmentation. Future agri-environment schemes should prioritise floral resource availability, structural vegetation diversity, and the provision of suitable nesting sites to sustain pollinator communities. Well-managed, interconnected habitats will not only enhance biodiversity but also improve ecosystem resilience in the face of ongoing environmental change. Further studies on species-specific needs and broader scale drivers are needed to refine conservation efforts.

8. Acknowledgements

I would like to thank my supervisor Dr Rosa Menendez Martinez for her continued guidance throughout this project. I would also like to thank Philip Furneaux from the community group Brampton 2 Zero, for his support with the project, as well as the landowners who kindly allowed me to conduct surveys at their farms.

9. References

- Alison, J., Botham, M., Maskell, L.C., Garbutt, A., Seaton, F.M., Skates, J., Smart, S.M., Thomas, A.R., Tordoff, G., Williams, B.L. and Wood, C.M. (2022) Woodland, cropland and hedgerows promote pollinator abundance in intensive grassland landscapes, with saturating benefits of flower cover. *Journal of Applied Ecology*, 59, 342-354.
- Austin, Z., McVittie, A., McCracken, D., Moxey, A., Moran, D. and White, P.C. (2015) Integrating quantitative and qualitative data in assessing the cost-effectiveness of biodiversity conservation programmes. *Biodiversity and Conservation*, 24, 1359-1375.
- Balfour, N.J. and Ratnieks, F.L. (2022) The disproportionate value of 'weeds' to pollinators and biodiversity. *Journal of Applied Ecology*, 59, 1209-1218.
- Barkmann, F., Huemer, P., Tappeiner, U., Tasser, E. and Rüdiger, J. (2023) Standardized butterfly surveys: comparing transect counts and area-time counts in insect monitoring. *Biodiversity and Conservation*, 32, 987-1004.
- Baude, M., Kunin, W.E., Boatman, N.D., Conyers, S., Davies, N., Gillespie, M.A., Morton, R.D., Smart, S.M. and Memmott, J. (2016) Historical nectar assessment reveals the fall and rise of floral resources in Britain. *Nature*, 530, 85-88.
- Beillouin, D., Ben-Ari, T., Malézieux, E., Seufert, V. and Makowski, D. (2021) Positive but variable effects of crop diversification on biodiversity and ecosystem services. *Global Change Biology*, 27, 4697-4710.
- Bergholz, K., Sittel, L.P., Ristow, M., Jeltsch, F. and Weiss, L. (2022) Pollinator guilds respond contrastingly at different scales to landscape parameters of land-use intensity. *Ecology and Evolution*, 12, p.e8708.
- Botham, M.S., Fernandez-Ploquin, E.C., Brereton, T., Harrower, C.A., Roy, D.B. and Heard, M.S. (2015) Lepidoptera communities across an agricultural gradient: how important

- are habitat area and habitat diversity in supporting high diversity? *Journal of Insect Conservation*, 19, 403-420.
- Branquart, E. and Hemptinne, J.L. (2000) Selectivity in the exploitation of floral resources by hoverflies (Diptera: Syrphinae). *Ecography*, 23, 732-742.
- Bullock, J.M., McCracken, M.E., Bowes, M.J., Chapman, R.E., Graves, A.R., Hinsley, S.A., Hutchins, M.G., Nowakowski, M., Nicholls, D.J., Oakley, S. and Old, G.H. (2021) Does agri-environmental management enhance biodiversity and multiple ecosystem services?: A farm-scale experiment. *Agriculture, Ecosystems & Environment*, 320, 107582.
- Bumblebee Conservation Trust (2024) *Common Carder Bumblebee (Bombus pascuorum)*. <https://www.bumblebeeconservation.org/learn-about-bumblebees/species-guide/common-carder-bee/> [18.08.24]
- Bussan, S.K. (2022) Can cattle grazing benefit grassland butterflies? *Journal of Insect Conservation*, 26, 359-374.
- Byrne, F. (2019) The effect of management practices on bumblebee densities in hedgerow and grassland habitats. *Basic and Applied Ecology*, 35, 28-33.
- Cane, J.H., Minckley, R.L. and Kervin, L.J. (2000) Sampling bees (Hymenoptera: Apiformes) for pollinator community studies: pitfalls of pan-trapping. *Journal of the Kansas entomological society*, 73, 225-231.
- Carvell, C. (2002) Habitat use and conservation of bumblebees (*Bombus* spp.) under different grassland management regimes. *Biological Conservation*, 103, 33-49.
- Carvell, C., Osborne, J.L., Bourke, A.F.G., Freeman, S.N., Pywell, R.F. and Heard, M.S., (2011) Bumble bee species' responses to a targeted conservation measure depend on landscape context and habitat quality. *Ecological Applications*, 21, 1760-1771.
- Casey, L.M., Rebelo, H., Rotheray, E. and Goulson, D. (2015) Evidence for habitat and climatic specializations driving the long-term distribution trends of UK and Irish bumblebees. *Diversity and Distributions*, 21, 864-875.
- Clavel, J., Julliard, R. and Devictor, V. (2011) Worldwide decline of specialist species: toward a global functional homogenization?. *Frontiers in Ecology and the Environment*, 9, 222-228.
- Cole, L.J., Brocklehurst, S., Robertson, D., Harrison, W. and McCracken, D.I. (2017) Exploring the interactions between resource availability and the utilisation of semi-

natural habitats by insect pollinators in an intensive agricultural landscape. *Agriculture, Ecosystems & Environment*, 246, 157-167.

Curtis, R.J., Brereton, T.M., Dennis, R.L., Carbone, C. and Isaac, N.J. (2015) Butterfly abundance is determined by food availability and is mediated by species traits. *Journal of Applied Ecology*, 52, 1676-1684.

Dainese, M., Montecchiari, S., Sitzia, T., Sigura, M. and Marini, L. (2017) High cover of hedgerows in the landscape supports multiple ecosystem services in Mediterranean cereal fields. *Journal of Applied Ecology*, 54, 380-388.

Dangles, O. and Casas, J. (2019) Ecosystem services provided by insects for achieving sustainable development goals. *Ecosystem services*, 35, 109-115.

Dapporto, L. and Dennis, R.L. (2013) The generalist–specialist continuum: testing predictions for distribution and trends in British butterflies. *Biological Conservation*, 157, 229-236.

DEFRA (2020) *The Path to Sustainable Farming: An Agricultural Transition Plan 2021 to 2024*. Available at:
<https://assets.publishing.service.gov.uk/media/60085334e90e073ec94cc80b/agricultural-transition-plan.pdf>

DEFRA (2020) *New details of the flagship Environmental Land Management scheme unveiled by Environment Secretary*. Available at:
<https://deframedia.blog.gov.uk/2020/02/25/new-details-of-the-flagship-environmental-land-management-scheme-unveiled-by-environment-secretary/> [12.07.24]

Dennis, R.L. (2010) *A Resource-Based Habitat View for Conservation: Butterflies in the British Landscape*. England: John Wiley & Sons.

Ekroos, J., Olsson, O., Rundlöf, M., Wätzold, F. and Smith, H.G. (2014) Optimizing agri-environment schemes for biodiversity, ecosystem services or both? *Biological conservation*, 172, 65-71.

Falk, S. (2016) *Field Guide to the Bees of Great Britain and Ireland*. London: Bloomsbury Wildlife.

Fox, R., Dennis, E.B., Purdy, K.M., Middlebrook, I., Roy, D.B., Noble, D.G., Botham, M.S. and Bourn, N.A.D. (2023) *The State of the UK's Butterflies 2022*. Butterfly Conservation. Wareham: UK.

- Gabriel, D., Sait, S.M., Kunin, W.E. and Benton, T.G. (2013) Food production vs. biodiversity: comparing organic and conventional agriculture. *Journal of applied ecology*, 50, 355-364.
- Game and Wildlife Conservation Trust (2018) *Farming through Brexit: a vision for the future*. Available at: <https://www.gwct.org.uk/media/878712/farming-through-brexit-lr.pdf>
- Garratt, M.P., Senapathi, D., Coston, D.J., Mortimer, S.R. and Potts, S.G. (2017) The benefits of hedgerows for pollinators and natural enemies depends on hedge quality and landscape context. *Agriculture, Ecosystems & Environment*, 247, 363-370.
- Gardiner, M.M. and Roy, H.E. (2022) The role of community science in entomology. *Annual review of entomology*, 67, 437-456.
- Garibaldi, L.A., Steffan-Dewenter, I., Winfree, R., Aizen, M.A., Bommarco, R., Cunningham, S.A., Kremen, C., Carvalheiro, L.G., Harder, L.D., Afik, O. and Bartomeus, I. (2013) Wild pollinators enhance fruit set of crops regardless of honey bee abundance. *Science*, 339, 1608-1611.
- Geiger, F., Bengtsson, J., Berendse, F., Weisser, W.W., Emmerson, M., Morales, M.B., Ceryngier, P., Liira, J., Tschardtke, T., Winqvist, C. and Eggers, S. (2010) Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and Applied Ecology*, 11, 97-105.
- Goulson, D., Nicholls, E., Botías, C. and Rotheray, E.L. (2015) Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, 347, 1255-1257.
- Grass, I., Loos, J., Baensch, S., Batáry, P., Librán-Embid, F., Ficiciyan, A., Klaus, F., Riechers, M., Rosa, J., Tiede, J. and Udy, K. (2019) Land-sharing/-sparing connectivity landscapes for ecosystem services and biodiversity conservation. *People and Nature*, 1, 262-272.
- Grüter, C. and Hayes, L. (2022) Sociality is a key driver of foraging ranges in bees. *Current Biology*, 32, 5390-5397.
- Habel, J.C. and Schmitt, T. (2018) Vanishing of the common species: empty habitats and the role of genetic diversity. *Biological Conservation*, 218, 211-216.
- Habel, J.C., Samways, M.J. and Schmitt, T. (2019) Mitigating the precipitous decline of terrestrial European insects: Requirements for a new strategy. *Biodiversity and Conservation*, 28, 1343-1360.

- Halbritter, D.A., Daniels, J.C., Whitaker, D.C. and Huang, L. (2015) Reducing mowing frequency increases floral resource and butterfly (Lepidoptera: Hesperioidea and Papilionoidea) abundance in managed roadside margins. *Florida Entomologist*, 98, 1081-1092.
- Hanley, M.E., Franco, M., Dean, C.E., Franklin, E.L., Harris, H.R., Haynes, A.G., Rapson, S.R., Rowse, G., Thomas, K.C., Waterhouse, B.R. and Knight, M.E. (2011) Increased bumblebee abundance along the margins of a mass flowering crop: evidence for pollinator spill-over. *Oikos*, 120, 1618-1624.
- Heard, M.S., Carvell, C., Carreck, N.L., Rothery, P., Osborne, J.L. and Bourke, A. (2007) Landscape context not patch size determines bumble-bee density on flower mixtures sown for agri-environment schemes. *Biology Letters*, 3, 638-641.
- Hevia, V., Carmona, C.P., Azcárate, F.M., Heredia, R. and González, J.A. (2021) Role of floral strips and semi-natural habitats as enhancers of wild bee functional diversity in intensive agricultural landscapes. *Agriculture, Ecosystems & Environment*, 319, 107544.
- Holland, J.M., Smith, B.M., Storkey, J., Lutman, P.J. and Aebischer, N.J. (2015) Managing habitats on English farmland for insect pollinator conservation. *Biological Conservation*, 182, 215-222.
- House of Commons (2022) *Environmental Land Management Scheme Thirty-First Report of Session 2021-22*. Available at:
<https://committees.parliament.uk/publications/8357/documents/85142/default/>
- Isbell, F., Adler, P.R., Eisenhauer, N., Fornara, D., Kimmel, K., Kremen, C., Letourneau, D.K., Liebman, M., Polley, H.W., Quijas, S. and Scherer-Lorenzen, M. (2017) Benefits of increasing plant diversity in sustainable agroecosystems. *Journal of Ecology*, 105, 871-879.
- Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D.E., Coscieme, L., Golden, A.S., Guerra, C.A., Jacob, U., Takahashi, Y., Settele, J. and Díaz, S. (2022) The direct drivers of recent global anthropogenic biodiversity loss. *Science Advances*, 8, p.eabm9982.
- Jerrentrup, J.S., Wrage-Mönnig, N., Röver, K.U. and Isselstein, J. (2014) Grazing intensity affects insect diversity via sward structure and heterogeneity in a long-term experiment. *Journal of Applied Ecology*, 51, 968-977.

- Kallioniemi, E., Zannese, A., Tinker, J.E. and Franco, A.M. (2014) Inter-and intra-specific differences in butterfly behaviour at boundaries. *Insect Conservation and Diversity*, 7, 232-240.
- Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C. and Tscharntke, T. (2007) Importance of pollinators in changing landscapes for world crops. *Proceedings of the royal society B: biological sciences*, 274, 303-313.
- Kovács-Hostyánszki, A., Espíndola, A., Vanbergen, A.J., Settele, J., Kremen, C. and Dicks, L.V. (2017) Ecological intensification to mitigate impacts of conventional intensive land use on pollinators and pollination. *Ecology letters*, 20, 673-689.
- Lami, F., Bartomeus, I., Nardi, D., Beduschi, T., Boscutti, F., Pantini, P., Santoiemma, G., Scherber, C., Tscharntke, T. and Marini, L. (2021) Species–habitat networks elucidate landscape effects on habitat specialisation of natural enemies and pollinators. *Ecology Letters*, 24, 288-297.
- Lastra-Bravo, X.B., Hubbard, C., Garrod, G. and Tolón-Becerra, A. (2015) What drives farmers' participation in EU agri-environmental schemes?: Results from a qualitative meta-analysis. *Environmental Science & Policy*, 54, 1-9.
- Levenson, H.K., Sharp, A.E. and Tarpay, D.R. (2022) Evaluating the impact of increased pollinator habitat on bee visitation and yield metrics in soybean crops. *Agriculture, Ecosystems & Environment*, 331, 107901.
- Lewington, R. (2015) *Pocket Guide for Butterflies of Great Britain and Ireland*. London: Bloomsbury Wildlife.
- López-Urbe, M.M., Jha, S. and Soro, A. (2019) A trait-based approach to predict population genetic structure in bees. *Molecular Ecology*, 28, 1919-1929.
- Luppi, M., Dondina, O., Orioli, V. and Bani, L. (2018) Local and landscape drivers of butterfly richness and abundance in a human-dominated area. *Agriculture, Ecosystems & Environment*, 254, 138-148.
- Lye, G., Park, K., Osborne, J., Holland, J. and Goulson, D. (2009) Assessing the value of Rural Stewardship schemes for providing foraging resources and nesting habitat for bumblebee queens (Hymenoptera: Apidae). *Biological Conservation*, 142, 2023-2032.
- McHugh, N.M., Bown, B., McVeigh, A., Powell, R., Swan, E., Szczur, J., Wilson, P. and Holland, J. (2022) The value of two agri-environment scheme habitats for pollinators:

- Annually cultivated margins for arable plants and floristically enhanced grass margins. *Agriculture, Ecosystems & Environment*, 326, p.107773.
- Meyer, B., Jauker, F. and Steffan-Dewenter, I. (2009) Contrasting resource-dependent responses of hoverfly richness and density to landscape structure. *Basic and Applied Ecology*, 10, 178-186.
- M'Gonigle, L.K., Ponisio, L.C., Cutler, K. and Kremen, C. (2015) Habitat restoration promotes pollinator persistence and colonization in intensively managed agriculture. *Ecological Applications*, 25, 1557-1565.
- Morandin, L.A., Winston, M.L., Abbott, V.A. and Franklin, M.T. (2007) Can pastureland increase wild bee abundance in agriculturally intense areas? *Basic and Applied Ecology*, 8, 117-124.
- Morris, M.G. (2000) The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands. *Biological Conservation*, 95, 129-142.
- Nath, R., Singh, H. and Mukherjee, S. (2023) Insect pollinators decline: an emerging concern of Anthropocene epoch. *Journal of Apicultural Research*, 62, 23-38.
- Natural England (2021) *Cumbria BogLife - Bringing Cumbria's Raised bogs to Life*. <https://assets.publishing.service.gov.uk/media/5a74b370ed915d502d6ca44d/cumbria-boglife-project-leaflet.pdf> [12.07.24]
- Natural Resources Wales (2024) *Love Pollinators*. <https://naturalresources.wales/guidance-and-advice/environmental-topics/wildlife-and-biodiversity/pollinators/love-pollinators/?lang=en#:~:text=The%20value%20of%20pollination%20to,Pollinators%20are%20good%20for%20tourism.> [12.07.24]
- Nichols, R.N., Holland, J. and Goulson, D. (2020) Methods for creating bare ground on farmland in Hampshire, UK, and their effectiveness at recruiting ground-nesting solitary bees. *Conservation Evidence*, 17, 15-18.
- Öckinger, E., Eriksson, A.K. and Smith, H.G. (2006) Effects of grassland abandonment, restoration and management on butterflies and vascular plants. *Biological conservation*, 133, 291-300.
- Ouvrard, P., Transon, J. and Jacquemart, A.L. (2018) Flower-strip agri-environment schemes provide diverse and valuable summer flower resources for pollinating insects. *Biodiversity and Conservation*, 27, 2193-2216.

- Osborne, A., Griffiths, S., Caporn, S. and Coulthard, E. (2024) Optimising the reintroduction of a specialist peatland butterfly *Coenonympha tullia* onto peatland restoration sites. *Journal of Insect Conservation*, 1-18.
- Pollard, E. and Yates, T.J. (1993) *Monitoring butterflies for ecology and conservation: the British butterfly monitoring scheme*. London: Chapman and Hall.
- Popic, T.J., Davila, Y.C. and Wardle, G.M. (2013) Evaluation of common methods for sampling invertebrate pollinator assemblages: net sampling out-perform pan traps. *PloS one*, 8, p.e66665.
- Power, E.F., Jackson, Z. and Stout, J.C. (2016) Organic farming and landscape factors affect abundance and richness of hoverflies (Diptera, Syrphidae) in grasslands. *Insect Conservation and Diversity*, 9, 244-253.
- Räsänen, A., Albrecht, E., Annala, M., Aro, L., Laine, A.M., Maanavilja, L., Mustajoki, J., Ronkanen, A.K., Silvan, N., Tarvainen, O. and Tolvanen, A. (2023) After-use of peat extraction sites—A systematic review of biodiversity, climate, hydrological and social impacts. *Science of the Total Environment*, 882, p.163583.
- Raven, P.H. and Wagner, D.L. (2021) Agricultural intensification and climate change are rapidly decreasing insect biodiversity. *Proceedings of the National Academy of Sciences*, 118, e2002548117.
- Ruck, A., van der Wal, R., SC Hood, A., L. Mauchline, A., G. Potts, S., F. WallisDeVries, M. and Öckinger, E. (2024) Farmland biodiversity monitoring through citizen science: A review of existing approaches and future opportunities. *Ambio*, 53, 257-275.
- Sánchez-Bayo, F. and Wyckhuys, K.A. (2019) Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*, 232, 8-27.
- Sánchez-Bayo, F. and Wyckhuys, K.A. (2021) Further evidence for a global decline of the entomofauna. *Austral Entomology*, 60, 9-26.
- Scheper, J., Holzschuh, A., Kuussaari, M., Potts, S.G., Rundlöf, M., Smith, H.G. and Kleijn, D. (2013) Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss—a meta-analysis. *Ecology Letters*, 16, 912-920.
- Senapathi, D., Biesmeijer, J.C., Breeze, T.D., Kleijn, D., Potts, S.G. and Carvalheiro, L.G. (2015) Pollinator conservation—the difference between managing for pollination

- services and preserving pollinator diversity. *Current Opinion in Insect Science*, 12, 93-101.
- Siviter, H., Johnson, A.K. and Muth, F. (2021) Bumblebees exposed to a neonicotinoid pesticide make suboptimal foraging decisions. *Environmental Entomology*, 50, 1299-1303.
- Speight, M.C.D. (2017) Species accounts of European Syrphidae, 2017. *Syrph the net, the database of European Syrphidae (Diptera)*, 97, 294.
- Tamburini, G., Aguilera, G. and Öckinger, E. (2022) Grasslands enhance ecosystem service multifunctionality above and below-ground in agricultural landscapes. *Journal of Applied Ecology*, 59, 3061-3071.
- Tanda, A.S. (2022) Why insect pollinators important in crop improvement? *Indian Journal of Entomology*, 84, 223-236.
- Thomas, J.A., Simcox, D.J. and Hovestadt, T. (2011) Evidence based conservation of butterflies. *Journal of Insect Conservation*, 15, 241-258.
- Toivonen, M., Herzon, I. and Kuussaari, M. (2016) Community composition of butterflies and bumblebees in fallows: niche breadth and dispersal capacity modify responses to fallow type and landscape. *Journal of Insect Conservation*, 20, 23-34.
- Tyllianakis, E. and Martin-Ortega, J. (2021) Agri-environmental schemes for biodiversity and environmental protection: How we are not yet “hitting the right keys”. *Land Use Policy*, 109, 105620.
- UKMBS (2021) *Field Guidance Notes for Butterfly Transects*.
<https://ukbms.org/sites/default/files/downloads/UKBMS%20G2%20Transect%20field%20guidance%20%20notes.pdf>
- Wagner, D.L. (2020) Insect declines in the Anthropocene. *Annual review of entomology*, 65, 457-480.
- Warzecha, D., Diekötter, T., Wolters, V. and Jauker, F. (2016) Intraspecific body size increases with habitat fragmentation in wild bee pollinators. *Landscape Ecology*, 31, 1449-1455.
- Warzecha, D., Diekötter, T., Wolters, V. and Jauker, F. (2018) Attractiveness of wildflower mixtures for wild bees and hoverflies depends on some key plant species. *Insect Conservation and Diversity*, 11, 32-41.

Wilson, R.J. and Fox, R. (2021) Insect responses to global change offer signposts for biodiversity and conservation. *Ecological Entomology*, 46, 699-717.

Zamorano, J., Bartomeus, I., Grez, A.A. and Garibaldi, L.A. (2020) Field margin floral enhancements increase pollinator diversity at the field edge but show no consistent spillover into the crop field: a meta-analysis. *Insect Conservation and Diversity*, 13, 519-531.

10. Appendices

Appendix 1: Coordinates of each sampling point.

Farm A transects:

Hedgerow habitat: NY 549610, NY 547609

Pasture habitat: NY 549609, NY 546610

Farm B transects:

Hedgerow habitat: NY 551598, NY 539594

Pasture habitat: NY 540593, NY 540594

Farm C transects:

Hedgerow habitat: NY 530596, NY 531595

Pasture habitat: NY 530597, NY 531597

Bog habitat: NY 528588, NY 528589, NY 528589, NY 527589

Appendix 2: List of pollinator groups and species recorded, with total abundance.

Order Hymenoptera:

Species/group	Total Abundance
<i>Bombus lapidarius</i>	8
<i>Bombus hortorum</i>	19
<i>Bombus terrestris</i>	29
<i>Bombus pascuorum</i>	11
<i>Bombus lucorum</i>	8
Other bees	18

Order Lepidoptera:

Species	Total Abundance
<i>Aphantopus hyperantus</i>	40
<i>Coenonympha pamphilus</i>	24
<i>Pieris napi</i>	24
<i>Pieris rapae</i>	16
<i>Maniola jurtina</i>	5
<i>Thymelicus sylvestris</i>	6

Family Syrphidae

Group	Abundance
Hoverflies	109