Investigating the impact of beehive proximity and food availability on insect pollinator diversity

BSc Research Project - 24 EC

Biology, Leiden University

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1. Abstract

This research project investigated the effect of beehive proximity and food availability on insect pollinator diversity in a biologically diverse polder landscape. Research was conducted in the Polderlab near Leiden, where the study focused on how the introduction of managed honeybees impacts wild pollinators such as hoverflies, wild bees, and bumblebees. Using pan traps and visual identification techniques, data was collected over several months to analyze the diversity of pollinators along a transect that varies in distance from a beehive. The results indicate that distance from the beehive has a small but significant positive effect on pollinator diversity, with wild pollinators showing increased diversity farther from the hive. Food availability, particularly in June, also influenced diversity, as flower-rich areas near cranberry fields attracted more pollinators. While competition between honeybees and wild pollinators was minimal under the specific conditions of this study, the findings suggest that honeybees may displace wild species in floral-dense areas. The study highlights the need for more controlled and extended research, particularly in varying weather conditions and using larger sample sizes, to better understand the interactions between managed honeybees and native pollinators in agricultural ecosystems.

2. Acknowledgements

I would like to show my gratitude to a few people for this project.

I would first like to thank my supervisors, Dr. Maarten Schrama, Dr. Krijn Trimbos and Fleur van Duin. Thank you for allowing me the opportunity to work on a project that has truly become very near and dear to me. I have learned so incredibly much from this project and will take this new knowledge with me as I go on in my life. Thank you for your support and guidance through this project.

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3. Introduction

The importance of insect pollinators
Food is considered one of the basic necessities of life. As the main source of energy and nutrients for living organisms, life without food is not sustainable. Besides the importance of food for survival, its production also plays a major role in global economics, with roughly twenty five percent of jobs worldwide being connected to agriculture (TRADING ECONOMICS, n.d.).
Research has shown that roughly 90% of flowering plants require pollination for their sexual reproduction and the formation of fruits and seeds (Ollerton et al., 2011). Nearly 75 percent of crops used for food rely at least partially on insect pollination (Lindström et al., 2016). Insect pollinators are a broad group of species that contain bees (*Apiformes*) and bumblebees (*Bombus*), butterflies (*Lepidoptera*), but also hoverflies (*Syrphidae*) and beetles (*Coleoptera*) and even some wasps (*Apocrita*). All these species aid in the pollination and reproduction of crops and flowering plants.
Studies have shown that allowing all types of pollinators onto a field increases the quality and/or yield of flowering crops compared to exclusion of certain pollinator species (Bartomeus et al., 2014; Garratt et al., 2014).

The decline in pollinator diversity and number (Hallmann et al., 2017) has been proven to have a potentially devastating impact. A decrease in the number of pollinators will lead to a decreased yield of crops, which could lead to food shortages (Bishop et al., 2022; Potts, 2016; Smith et al., 2015). Research by Janousek et al. (2023) predicts that pollinator numbers could keep declining at least 44% in the next 25 years. According to Kopec et al., (2017), nearly one in four native bee species in North America and Hawaii is currently endangered. Other research has shown expected declines of roughly 75% of bumblebee species in Europe of up to 30% in the next 35-50 years (Ghisbain et al., 2023).

Honeybee *Apis mellifera* and other pollinators
With approximately half of the surface area being used for agriculture (CBS, 2021) and the export of agricultural goods bringing in over 50 billion euros in the past year (CBS, 2024), the Netherlands is especially vulnerable for loss of pollinators. Not only is the production of some on the Netherlands' most common crops (such as maize, cereals and onion (*Crop Type for All Agricultural Parcels in the Netherlands*, n.d.)) highly benefited by insect pollination (Thapa & Institute of Agriculture and Animal Sciences (IAAS), Rampur, Chitwan, Nepal, 2006), we are also one of the biggest re-exporters of exotic fruits and vegetables that are entirely dependent on insect pollination for crop yield (Wageningen University, 2022). The increase in agricultural land and pesticide use destroy both habitats and food sources and have a detrimental effect on the health of insects, leading to loss of diversity (Potts, 2016; Raven & Wagner, 2021; Sánchez-Bayo & Wyckhuys, 2019), which could then in turn threaten insect pollinated crops.

To replace the lost diversity in insect pollinators, the honeybee *Apis mellifera* is often managed by humans and considered to be one of the most important crop pollinators worldwide (Aizen & Harder, 2009). Due to their large colonies and cooperative and hierarchical nature, they tend to exhibit a broad foraging range (Beekman & Ratnieks, 2000). They are also considered extremely generalist (Giannini et al., 2015), showing interactions with a broad range of plant species (Aslan et al., 2016), which is useful in agriculture due to

the increased chance of pollination of all crops by this species. Research by Phiri et al. (2022) shows that managed honey bee colonies have doubled in the last sixty years.
The major increase in honeybee usage for crop pollination has led to many questions regarding the safety of insect diversity. Multiple studies have indicated that the addition of honeybees to a natural or agricultural system can have a negative impact on wild bees or other pollinating insects in that area (Elbgami et al., 2014; Hung et al., 2019; MacInnis et al., 2023; Mallinger et al., 2017; Weekers et al., 2022).

Although the introduction of honeybees in agriculture is usually based on the pollinating capabilities of the species, merely using *A. mellifera* is not optimal for crop yield. Research indicates that honeybees can have foraging distances up to multiple kilometers (Zurbuchen, Landert, et al., 2010). Although honeybees have a high maximum foraging distance and are considered highly generalist, they will often only use this skill when necessary. If a sustainable food source, preferably high in amino acids, is present, honeybees will show a clear preference for this resource (Ghosh et al., 2020). Research by Leponiemi et al. (2023) indicates that honeybees actively select specific plants for pollen or nectar, and only use a fraction of the plants offered.

To ensure the pollination of all plants in a field, it is therefore highly beneficial to have a diverse group of pollinators. Research by Katumo et al. (2022) mentions the benefits of using a diverse group of pollinators for agriculture, such as enhanced plant productivity and better crop yield. Fründ et al. (2013) showed that by introducing multiple bee species in the same area, flowers that did not get visited in the presence of only one species were visited and pollinated when multiple bee species were present, as avoidance of competition created a niche shift.
Most wild pollinators such as hoverflies, wild bees and bumblebees can live together within a system, as they are either non-colony forming, or the colony sizes are small, containing 50-1500 individuals on average (Cueva Del Castillo et al., 2015). Wild pollinators tend to have a maximum foraging distance of about 1 km, but often fly closer to their nest (200-500 meters), as further flight can lead to a trade-off between foraging distance and offspring production (Zurbuchen, Landert, et al., 2010; Zurbuchen, Cheesman, et al., 2010). Research shows that honeybees and wild bees or other pollinators tend to utilize different species of plants or differ in visitation rates of floral abundance, which is how they avoid competition for resources (Urbanowicz et al., 2020; Rollin et al., 2013). Research by Steffan-Dewenter and Tscharntke (2000) indicates that resource overlap between honeybees, solitary wild bee species and social wild bee species was 45%, even with honeybees flying less far than their foraging distance allows.

Insect pollinators in Dutch peatland meadows

Peatlands, being a distinctive type of wetland, span an estimated 4 million m² worldwide (Bonn et al., 2016). In many places, the peatlands have been reclassified as mineral soils, as the peat has completely disappeared, or the layer has degraded significantly (Kempen et al., 2009; Koster et al., 2020). This degradation of the peat layer is credited with being responsible for 5% of global greenhouse gas emissions (Gewin, 2020).
With an estimated 80% of peatlands in the Netherlands drained for dairy farming (Verhagen et al., 2009), carbon emissions from these peatlands have been calculated at approximately 3 percent of the total emissions of the Netherlands (Van Den Akker et al., 2008). One of the

suggested methods of reducing these emissions is by raising the water level. However, this would make the dairy farming that currently takes place in these areas nearly impossible, as the soil would become too wet for cattle.
A potential alternative for dairy farming has been found in paludiculture. Paludiculture is a form of agriculture adapted to high water levels, and as such highly appropriate for wet peatlands. Research by De Jong et al. (2021) has shown promising results in decreasing greenhouse gas emissions from Dutch peatlands by using paludiculture instead of dairy farming. Current paludiculture practices have mainly focused on growing plants such as peat moss (*Sphagnum* spp.) and cattail (*Typha latifolia*/*angustifolia*) (Milner, 2022; Ozola et al., 2023). However, small scale farming of crops on flooded peat could potentially lead to interesting discoveries.
A paper by Milner (2022) mentions the possible options for agricultural crops on wet peat soils. One of these crops is cranberry. Cranberries have the additional benefit of growing well on acidic soil with lower temperatures and are therefore a good contender for Dutch paludiculture. However, cranberries are a pollination dependent plant (Gaines-Day & Gratton, 2013), and it is therefore essential that pollinators be present in a field to ensure the pollination of these plants. The most efficient form of pollination for cranberries is buzz pollination, which is mainly practiced by wild bumblebees, mining bees and sweat bees. (Campanelli & Kuzovkina, n.d.). Research by Albrecht et al. (2020), Maclaren (2019) and Morandin and Kremen (2013) showed that increasing flower abundance by adding flower strips or hedgerows to agricultural field count increase pollinator diversity and abundance, which could benefit the farming of paludiculture crops like cranberries. However, if insect numbers will remain in decline, the introduction of honeybees may prove necessary to compensate for pollinating services to make paludiculture profitable.
Whilst plenty of research has been done on the diversity of species in peatlands (Beyer et al., 2023; Desrochers et al., 2006; Spitzer & Danks, 2006), with many papers even focusing on the diversity of wild bee species in wetlands (Bartholomew & Prowell, 2006; Moroń et al., 2008; Purvis et al., 2020), little is still known about the diversity of insects, and specifically pollinators, in Dutch peat landscapes. The introduction of honeybees could potentially cause negative impacts such as shifts in diversity for these native species.

Even though studies have shown a potentially negative effect of introducing honeybees in areas with other wild pollinators, research still shows diverging results to the true impact on the wild pollinators (Mallinger et al., 2017), depending on the environment and conditions under which research took place. Furthermore, research by Fijen et al. (2022) even indicates that the limited introduction of beehives in a natural area can decrease the trade-off between the conservation of biodiversity and the cultivation of crops, because the additional pollinators are beneficial for crops, and in small amounts will not cause significant impact on other present pollinators. Introducing honeybees in a small enough ratio in areas with both agricultural land use and natural native plant species may therefore improve both crop yield, native plant growth and pollinator diversity.

Objectives and aims

Based on the so far still rather inconclusive research found on the impact of honeybees on other pollinators, especially in agricultural fields or in wetlands, this experiment will attempt to discover if such an impact truly exists in a Dutch peatland where land use is turning from peat meadows to agriculture. Therefore, the research question for this experiment is:

What is the impact of distance to a beehive and food availability on the diversity of insect pollinators in a biologically diverse hedge within a polder landscape?

By studying both the impact of distance and food availability, knowledge of a potential impact should be gained.

Expectations

The expected impact of distance to the beehive in the pollinator diversity is that the beehive will cause a displacement of wild pollinators. The increasing distance from the beehive serves as a proxy for honeybee abundance, where I expect a decrease in honeybees as distance from the hive increases. This decrease in honeybees will reduce the chance at competition for resources with wild pollinators, which leads to the assumption that wild pollinators will move away from honeybee dense areas (near the hive) and towards areas with less abundance of honeybees (away from the hive).
Research by Urbanowicz et al. (2020) indicates that with increasing flower abundance, wild pollinator visitation numbers decrease, and managed honeybees increase. By studying along a transect, we expect to see honeybees stick close to the beehive in case a large enough number of flowers are found to be considered a reliable food source, whilst wild pollinators such as hoverflies will appear throughout the field and near smaller patches of flowers, as they do not require pollen and nectar as vigorously as bee pollinators (Jones & Rader, 2022).

The expected impact of food availability is as follows: food availability will most likely impact the distribution and foraging behavior of the different pollinator species, with competition avoidance leading to niche shifts when food availability is abundant. Species should show a gradient in diversity along the hedge that shifts depending on food availability, with species diversity increasing in the grassland plots when the meadow has an abundance of flowers. However, when food availability is low, pollinators will either flock around the same available food source within the polder landscape or will leave the field altogether to look for food elsewhere.

4. Methods

Research area

The Polderlab is an experimental crop cultivation area near Leiden and Oud Ade. Originally used as a grassland system for dairy farming, the peat meadow is currently being slowly transformed to cultivate imported crops like cranberries and rice. The surrounding area of the meadow is still dominated by grassland and contains grazers during the spring and summer months. A hedge was planted in 2021 which mainly contains hawthorn plants and runs almost the entire length of the polder.

Figure 1. Research site in Polderlab with research transect and plots.

Honeybees in the field

At the end of March 2024, two beehives were introduced on the Eastside of the meadow (see Fig. 1). According to prior knowledge, no other beehives were present in a one-kilometer radius. During the first days, close watch was kept by the beekeeper as the colony sizes were small and fragile. On the 10th of April, one colony was moved into a bigger beehive where they could spend the summer. Due to fragility caused by their small number, the other colony had not survived. After this, the beekeeper visited every few days to check the health of the colony.

On the 30th of April, only a handful of honeybees survived. Due to poor weather conditions (i.e. rain and wind), many individuals did not survive. As the queen did survive, a new colony was introduced to replace the lost one for the research. The colony was given a lump of sugar to ensure they had enough food until the colony could gather food itself.

On the 9th of May, an extra colony was introduced as support to the other colony and scales were placed to measure the growth of the hives.

The bees were once again given extra feed in the form of sugar water to compensate for a lack of resources in the field to ensure their health.

Figure 2. The weight of the beehive during the period of 15-05 to 22-05. The graph indicates a decline in weight, pointing to a loss of bees. The labels above indicate the weight change in the last 24 hours, 7 days, 30 days, current weight and active bees.

This trend continued into the start of June. The colonies proved to be aggressive, presumably due to too little food availability. Als resources immediately went into colony growth, leading to a decrease in weight even after additional feeding (see Fig. 2).

Figure 3. The weight of the beehive during the period of 27-05 to 02-06. Even with additional feeding, the weight decreases, pointing to a malnutritioned hive. The labels above indicate the weight change in the last 24 hours, 7 days, 30 days, current weight and active bees.

Due to the worsening condition of the colonies (see Fig. 3), the choice was made to remove one hive to protect the bees. On June fourth, one colony was removed, and the other was once again given additional food.

Figure 4. The weight of the beehive during the period of 15-06 to 22-05. The graph indicates a 5 kilogram increase in weight, pointing to a healthily growing colony. The labels above indicate the weight change in the last 24 hours, 7 days, 30 days, current weight and active bees.

2.5 weeks after the removal of one of the colonies, the condition of the honeybees improved drastically, most likely caused by the good weather and the decrease in colony size (see Fig. 4).

Research setup and data collection

To ensure consistent data locations for the duration of the research, data was collected in set out plots. Between the months of April and June, eleven plots marked in a two meter long transect were set up along the hedge. These plots were placed roughly 100 meters apart, starting near the very furthest end of the hedge from the beehives. On the grass-dominated field in between the cranberry fields, five plots of one square meter were set out, with roughly 50 meters between them. Plot 1, 3 and 5 of the grassland were placed parallel to a hedge plot (see Fig. 1).

Pan traps were placed within the plot. Every pan trap consisted of a wooden block with 3 metal rings, each with a painted plastic container in fluorescent blue, yellow and white (see Fig. 5). Pan traps near the hedge or in high grass were placed on wooden poles to allow them to match the height of the surrounding plant coverage and not become covered.

Figure 5. A pan trap placed along a hedge plot. The order of the colored containers was randomized per plot and date.

Pan traps were set out in the morning on days with technical weather, i.e. no rain and a wind speed of less than 19 km/h, as higher wind speeds and low temperatures (i.e. <14° C) prevent certain insects from flying (Ghosh et al., 2020; Simioni et al., 2015). The traps were filled with circa 2 cm of water, with a 1.5 liter bottle containing a small amount (3-6 droplets) of dish soap.
After roughly 24 hours, the plots were emptied and the insects were collected in test tubes with ethanol for later identification. Identification was done in the lab with the use of binoculars and identification aids such as ObsIdentify and Naturalis species register (*Zweefvliegen Tot Op Groep*, n.d.). Visual identification was carried out on days with technical weather. Plots for visual identification were chosen based on the floral coverage within one square meter (100+ floral units/m²). Plots were either placed within the grassland or in the floral ridges. Plot locations were not repeated. Measurements were taken for a duration of ten minutes. Data was collected through video footage, live identification or pictures. Species that proved hard to identify in the field were filmed or photographed and later identified with the use of identification aids.

Identification was done through video recording and visual identification, with assistance of pictures when possible for unknown species.

The order of placing and emptying the plots was based on the fastest walking route due to the total distance between plots. This led to the following placing order:

21 - 22 - 11 - 12 - 23 - 13 - 14 - 24 - 25 - 26 - 27 - 28 - 29 - 30 - 31
The full list of materials used for the pan trap data collection can be found in Appendix A.

Food availability was analyzed by researching the flowering period of four native grassland plant species and four planted floral species in the floral ridge. The plant species were chosen based on their presence and abundance in the field when blooming appeared for at least 2 consecutive sampling dates and their total coverage contained multiple one square meter plots. Data on the size of the pollen per plant was also gathered to compare.

Data analysis

All analyses were run in RStudio (2024.04.2+764). For the analysis of the gathered data on Shannon Diversity Indices, two linear mixed models were run to investigate the effect of distance and food availability on pollinator diversity separately. This approach effectively handles the hierarchical and nested structure of the data, where measurements are taken at various distances and across multiple days, and distances are nested within different land types. By incorporating both fixed effects and random effects (such as distance, land type and month), the LMM accounts for within-group correlations and variability.
Prior to running the models, the normality of the data distribution was assessed using a histogram. Furthermore, the assumptions of linearity, independence, normality and homoscedasticity of the residuals were assessed after the mixed linear model to ensure the model properly fit the data. Results were considered statistically significant if the probability was $\alpha \leq 0.05$.
For the visual identification data, no statistical analysis was run, due to the small sample size and variation in time stamps in the data. A visual plot was created to examine the data.

5. Results

The final dataset contained observations of 377 individuals from 41 distinct species collected over 48 distinct sampling dates. These observations have been gathered in Appendix B. This data shows an abundance of species, most of which are part of the family *Syrphidae* (hoverflies) (light blue). Wild bees (dark blue) and bumblebees (green) were present in lower numbers but were similar to one another. Honeybees (red) were only found on very few sample dates and often as a single individual.

Impact of distance on pollinator diversity

To study the impact of distance on the diversity of pollinators in the field, a mixed linear model was set up to analyze the relationship between the SDI and Distance. This model also accounted for the relationship between the SDI and land type and variability of the SDI across different months. This resulted in the model depicted in Figure 6 & Figure 7.

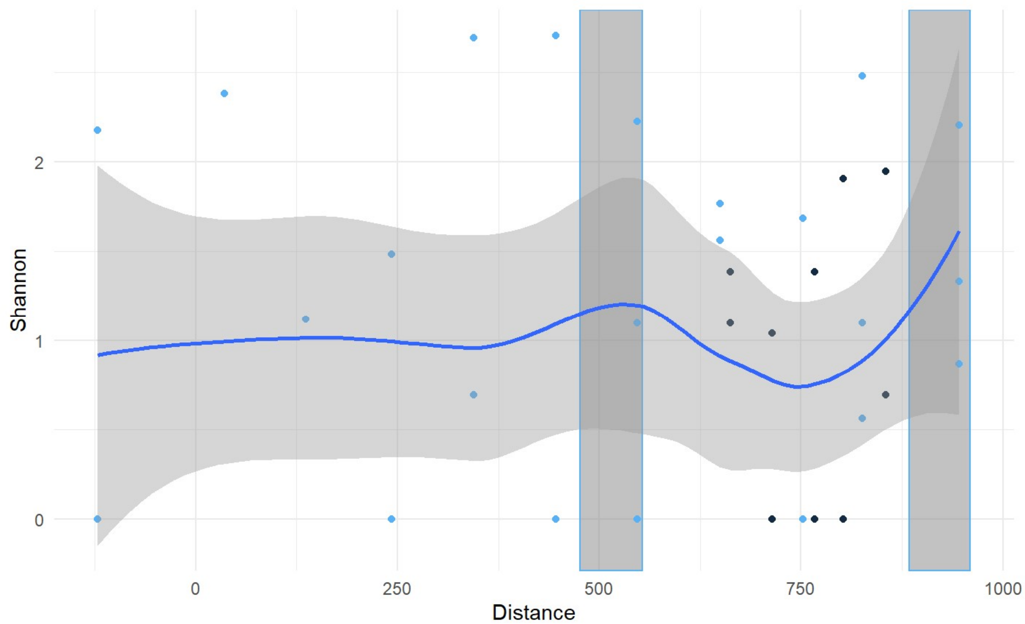

Figure 6. Plot showing the SDI with increasing distance from the beehive. The black dots indicate the grassland type plots, and blue dots indicate the Hedge type plots. The location of cranberry fields with floral ridges are indicated by the grey shaded areas.

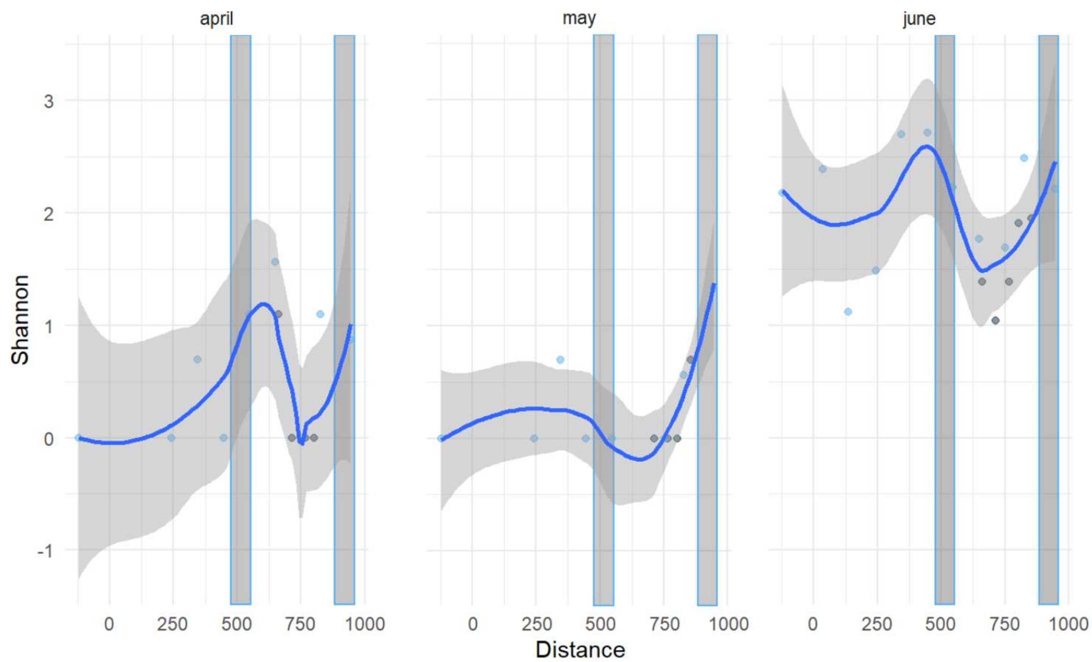

Figure 7. Plot showing the SDI with increasing distance from the beehive, split per month. The black dots indicate the grassland type plots, and blue dots indicate the Hedge type plots. The location of cranberry fields with floral ridges are indicated by the grey shaded areas.

These figures show that the SDI differs throughout the sampling plots and sampling months. Both figures show a rise in SDI near the cranberry fields with floral ridges. These higher SDI values indicate that the floral ridges appear to be a attractive food source for the pollinators we discovered in the field.

Distance was found to have a small but significant positive effect on Shannon diversity (Estimate = 0.0007, SE = 0.0003, $t = 2.16$). Additionally, land use had a significant effect on Shannon diversity (Estimate = 0.53, SE = 0.18, $t = 2.95$), indicating that different land types are associated with varying levels of diversity and that the hedge supports a higher diversity than grassland.
The random effects associated with Month had a variance of 0.81 (SD = 0.90), while the residual variance was 0.23 (SD = 0.48).

Impact of food availability on pollinator diversity
To study the impact of food availability in the pollinator diversity, extra data was gathered on eight flowering plant species present in the Polderlab. Four of these species are meadow species that naturally occur in grassland, and the other four were planted in the floral ridges to attract pollinators. The flowering periods of these plants were checked on the website of Verspreidingsatlas and compared to create Figure 8.

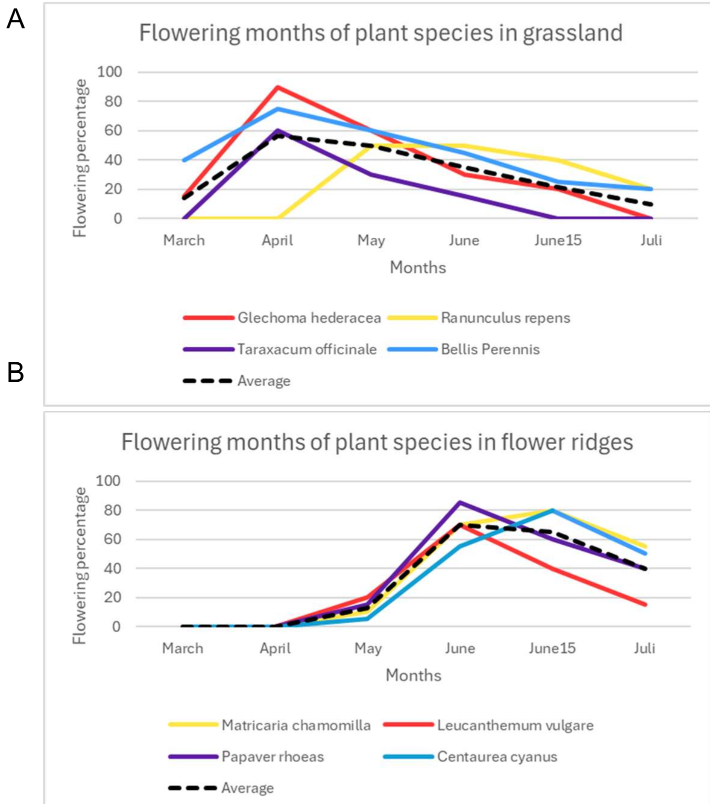

Figure 8. Graphs depicting four flowering species found in grassland (A) and on the ridge (B) and their flowering months. The average line shows the combined value.

Based on this figure, flower availability should theoretically be higher during the months of April and June, with flower numbers decreasing throughout the field but increasing in the ridges in May. To check whether this food availability was truly found in the research field, a linear mixed-effects model was conducted to investigate the effects of month on the Shannon Diversity Index. The resulting model is shown in Figure 9

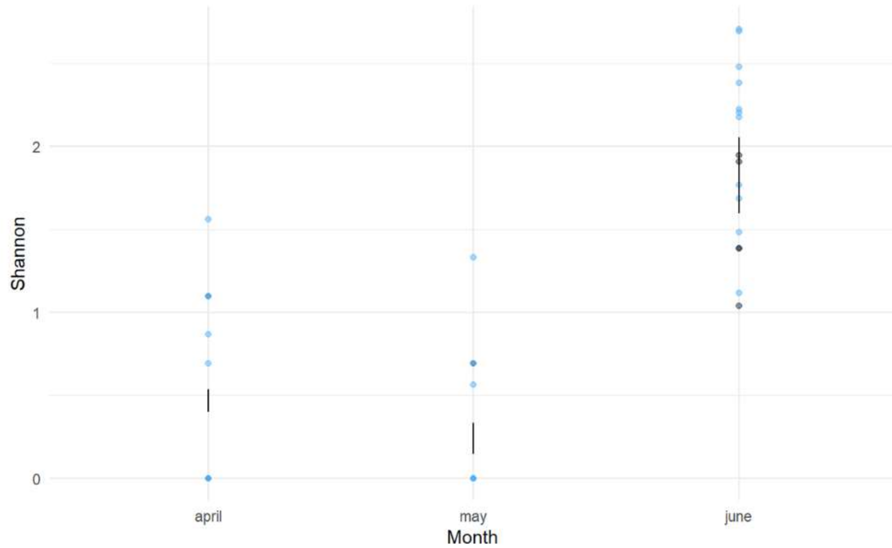

Figure 9. Plot visualizing the Mixed Linear Model for food availability. Hedge plots are indicated in blue and grassland plots are indicated in black. The MLM estimate is indicated in a black line.

The variable of month has a significant impact on the pollinator diversity. The SDI was significantly higher in June than April or May (Estimate = 1.42, SE = 0.19, $t = 7.55$), and the SDI of May was lower than both April and June (Estimate = -0.21, SE = 0.20, $t = -1.06$).

When analyzing the visual identification data, due to the variation in time of the visual measurements and the small sample size, no statistical analysis was run. In Fig. 10, the data is visualized to examine any potential patterns. This Figure indicates a noticeable difference in insect abundance and therefore SDI in the flower ridges compared to the grassland. The flower ridges show a sizable number of bumblebees, with a variety of hoverflies and honeybees. The grassland however only shows hoverflies and no bumblebees or honeybees.

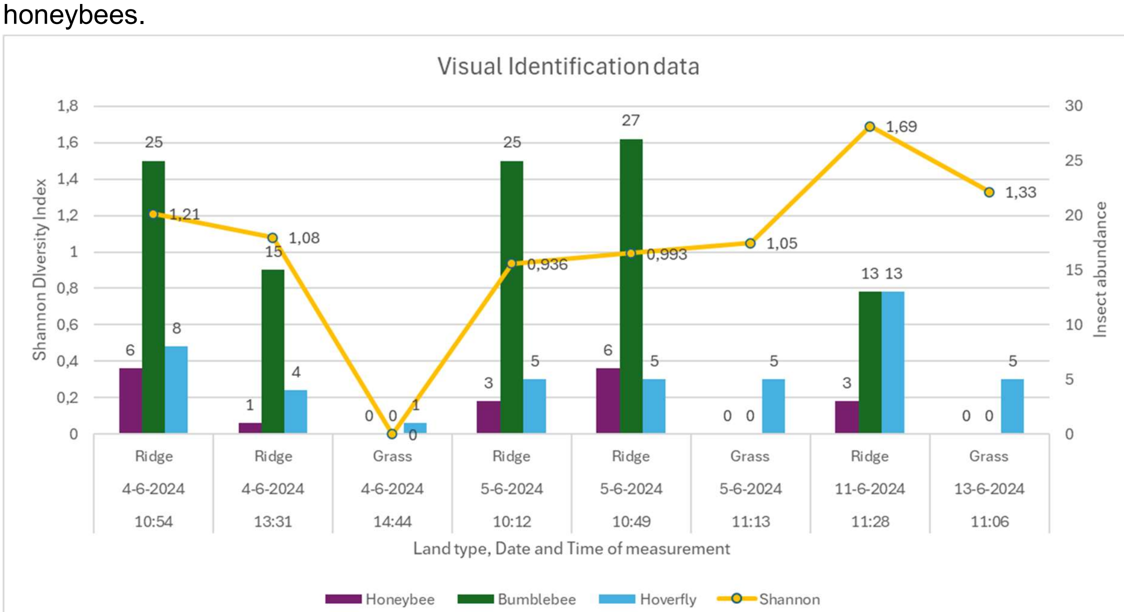

Figure 10. Plot showing the visual identification data. Data was sorted into three groups: 1) Honeybees, 2) Bumblebees, or 3) Hoverflies. An SDI was calculated for every observation and is depicted as a line.

6. Discussion

This study investigated two research questions regarding the potential impact on the diversity of pollinators in a polder landscape. The first research question focused on the potential impact of proximity to a managed beehive in the field on pollinator diversity, while the second research question focused on the potential impact of food availability in the field on the diversity of pollinators.

The results of this research demonstrated that increasing distance from the beehive showed a small positive impact on pollinator diversity (*t=2.16)* and the type of land use (hedge > grassland) significantly impacted pollinator diversity *(1=2.95)*. This is in line with the expectations. As mentioned before, research has already investigated the positive effect of distance from a beehive and the presence of hedgerows on pollinator diversity and thus the SDI.
A small deviation from the hypothesis is apparent in the lack of floral abundance near the beehive. With the nearest abundance of flowers being the ridge near the cranberry fields, this part of the hypothesis seemed to be incorrect. However, this could be a result of the honeybees using flowering plants outside of the research field as a food source. The beekeeper who managed the honeybees personally remarked that the honeybees showed a flight direction often aimed towards the town instead of into the field. Research by Jacquemart et al. (2018) indicates that *Tilia* trees are a type of plant often visited by honeybees, bumblebees and hoverflies for its large flower abundance, sugary nectar and protein-rich pollen. *Tilia* trees are often used in urban landscaping and are present in the town near the research field. This could indicate that the honeybees used the *Tilia* trees as a food source instead of any of the flowers in the field, potentially causing skewed results. Regardless of the potential deviation of honeybees, the results from this study regarding displacement of the wild pollinators is in line with earlier research by Elbgami et al. (2014), Hung et al. (2019), MacInnis et al. (2023) and others, whose research indicate the introduction of honeybees could negatively impact other pollinators.

When considering the available food resources based on the flowering period of eight plant species present in the research field, the month in which data was collected was partially significant for pollinator diversity, with June showing a significant increase in pollinator diversity (*t=7.55)* compared to April*,* whilst May was not significant (*t=-1.06)* in comparison to April. This is partially in line with my hypothesis, where I expected shifts in diversity to prevent competition when resources are abundant. However, as mentioned above, the honeybees likely chose a resource outside of the research field, leading to a considerable decrease in the chance of competition avoidance. As a result, no pollinator gradient was created in the hedge. This lack of competitive pressure would have also led the wild pollinators in the field to flock to bigger food sources, which led to a low pollinator diversity in the grassland plots. However, not all pollinators flocked towards the same food source, as the visual identification data shows that hoverflies still visited flowers in grassland, and not just the flower ridges. This could be a result of small-scale competition avoidance, as hoverflies are non-colony forming and need less resources than bumblebees or honeybees who require nectar and pollen to feed their offspring (Jauker et al., 2009).

Certain aspects need to be considered when looking at this study.

Data collection could be influenced by the non-technical weather conditions and the poor state of the honeybee colonies (see Appendix C for weather conditions). Due to the lack of honeybees found in the pan traps, it was not possible to consider the presence of honeybees in the statistical analysis. Due to the young age of the plants in the hedgerow, it did not bloom consistently, which went against the assumptions for this research.
Future research could highly benefit from using a baseline measurement without the introduced honeybees to truly compare the impact of the presence of honeybees. Shifting the research period or extending it to August could give valuable insights into flowering plants and their food availability throughout the summer months and how this impacts insect diversity and abundance. Repeating this research with better weather conditions and a healthier honeybee colony could potentially drastically impact the results, leading to other conclusions. Furthermore, in future research, it would be beneficial to take measurements of flower coverage in a set out plot to properly determine the actual available food resources. A regular collection of these measurements could more accurately determine the resources available for the insects.

7. Conclusion

This study aimed to discover the potential impact of distance from a managed beehive and food availability on the pollinator diversity in a polder landscape, focusing on the diversity in a biologically diverse hedge. The findings show that within this research, increasing distance appeared to have a small positive impact on the pollinator diversity. Food availability in June appeared to have a significant positive impact on pollinator diversity when comparing to April, whilst May had no significant impact.
Visualizations of the collected data show differing SDI dependent on the location and time of the measurement. However, to truly gain an insight on whether the impact of distance and food availability on pollinators exists, future research should focus on controlled measurements of pollinators over a longer time span. Moreover, future research should focus on comparing a baseline measurement without honeybees present and compare this data to both visual and pan trap data, where more focus is put into gathering data on plant species that attract the pollinators.
This study implicates that even though competition between wild pollinators and managed honeybees in a Dutch polder landscape appears to be minimal under the current circumstances, the permanent placement of a managed beehive could have a negative impact on pollinator diversity and abundance. With altered circumstances (i.e. more floral abundance, better weather conditions, a mature diverse hedgerow), this research could show the benefit of using both wild and managed pollinators, but for now, this placement is not sustainable.

In conclusion, whilst this research indicates a positive effect of distance from a beehive and mixed effects of food availability on pollinator diversity, more research is needed to truly analyze the risk of introducing honeybees to a wild pollinator landscape. This study makes a valuable contribution to understanding the complex interactions between managed honeybee colonies and native pollinator diversity in peatland ecosystems. While aspects such as limited time, weather conditions and challenges with data collection may have influenced the findings, this research still provides an insight on the dynamics of pollinator species. The observations and gathered data may form a baseline for future studies, emphasizing key areas for further investigation and offering an introductory understanding to potentially inform conservation of insect pollinators in peatlands.

This study underscores the importance of continued research in this field, as even with its limitations, it adds to the knowledge necessary to protect and enhance pollinator diversity in fragile ecosystems.

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9. Appendices

Appendix A: Materials used for the data collection

Pan trap material:

- Wooden poles, 1 meter, 16x
- Wooden blocks for rings, 16x
- Wire rings, 48x
- Pan trap container, blue, 16x
- Pan trap container, white, 16x
- Pan trap container, yellow, 16x
- Tap water, 4.5 liters for every measuring day
- Biodegradable dish soap, 3-6 drops per 1.5 liters

Collection material:

- Plastic test tubes with screw cap, 12 mL, 48x
- Black marker
- Ethanol wash bottle
- Small kitchen sieve
- Sharp forceps
- Funnel

Identification material:

- Phone with camera and Obsidentify
- Binocular microscope with lamp
- Petri dishes
- Ethanol wash bottle

- Tissues

Appendix B: Graph depicting observed species and abundance

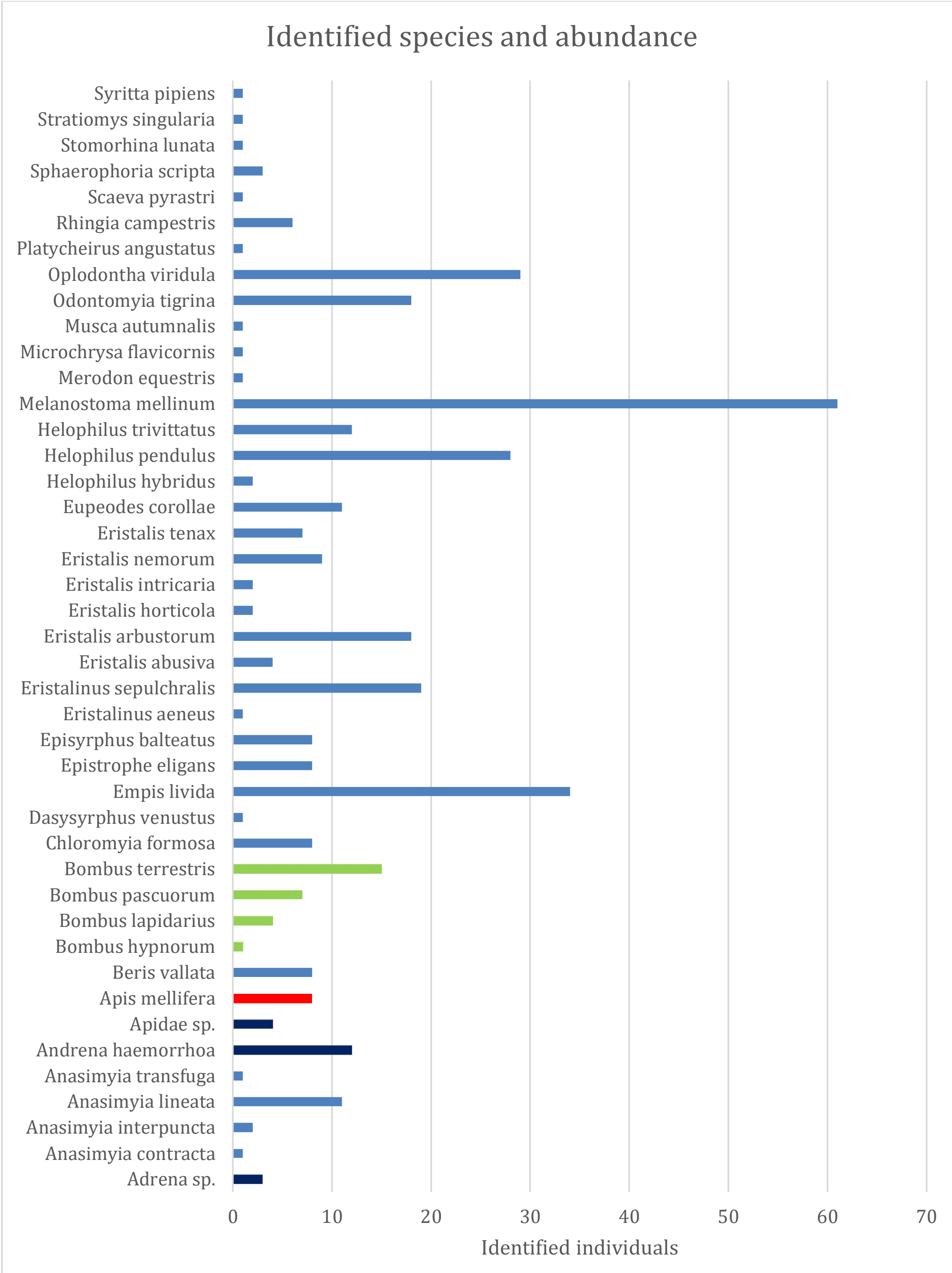

Figure 11. Graph depicting total species diversity and abundance discovered during research period. Species were split into groups of hoverflies (light blue), bumblebees (green), honeybees (red) and wild bees (dark blue).

Appendix C: Graph depicting average weather conditions during fieldwork

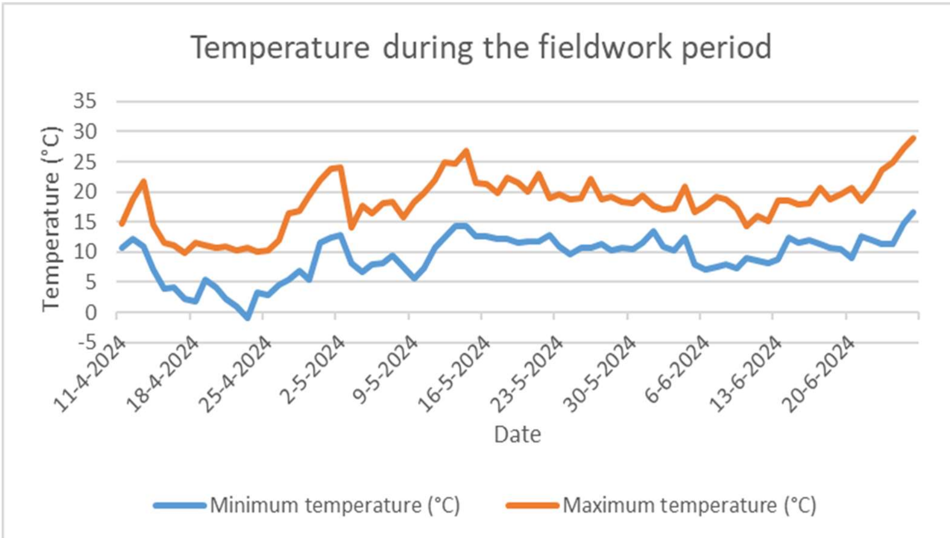

Figure 12. Average temperature during field work period.

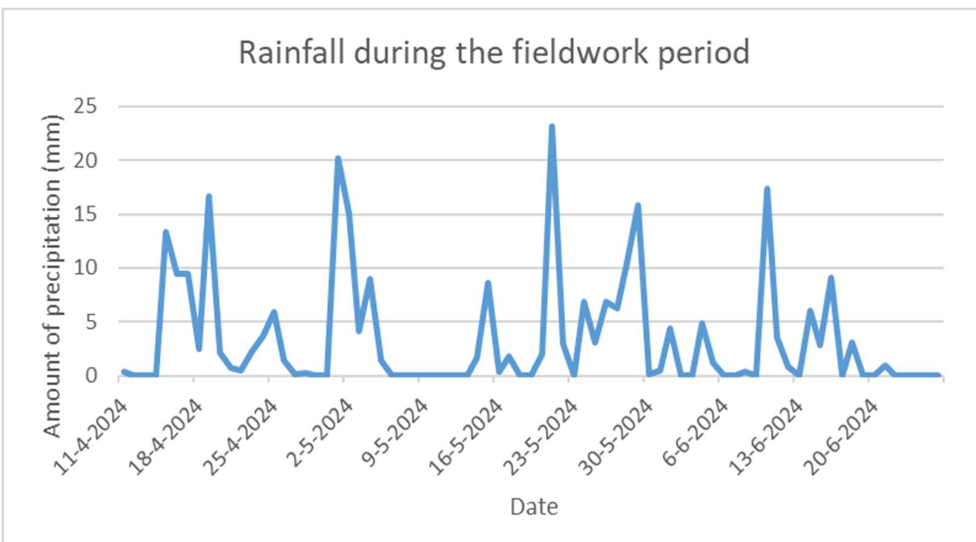

Figure 13. Average rainfall during research period.

Appendix D: Graphs depicting statistical analysis results

Null values were systematically removed from the data. Data was then grouped per month, to calculate a Shannon Diversity Index (SDI) per plot per month. The resulting dataset was visualized in Figure .

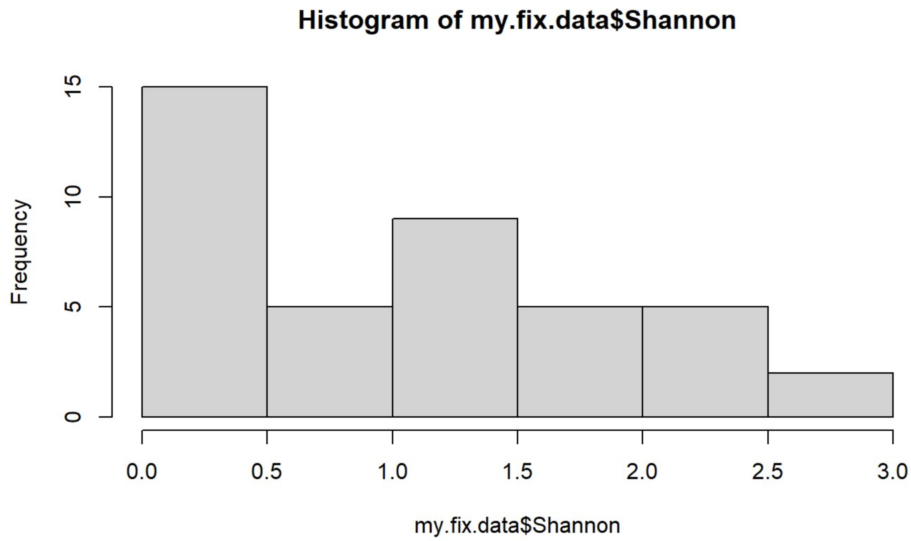

Figure 14. Histogram showing the distribution of the data after removal of the null values.

Skewness was checked using the moments package and assumed normally distributed (skewness = 0.342). Additionally, the data was checked for outliers by plotting the data with a boxplot. No outliers were found, as seen in Figure 7.

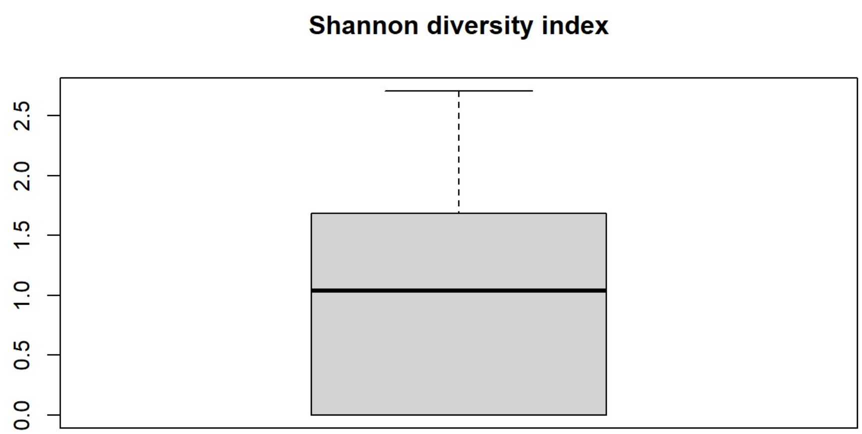

Figure 15. Boxplot of SDI.

The model converged with a Restricted Maximum Likelihood (REML) criterion of 80.3. The residuals indicate that the model's predictions were reasonably close to the observed values, though some variation was present, as shown in figure 10.

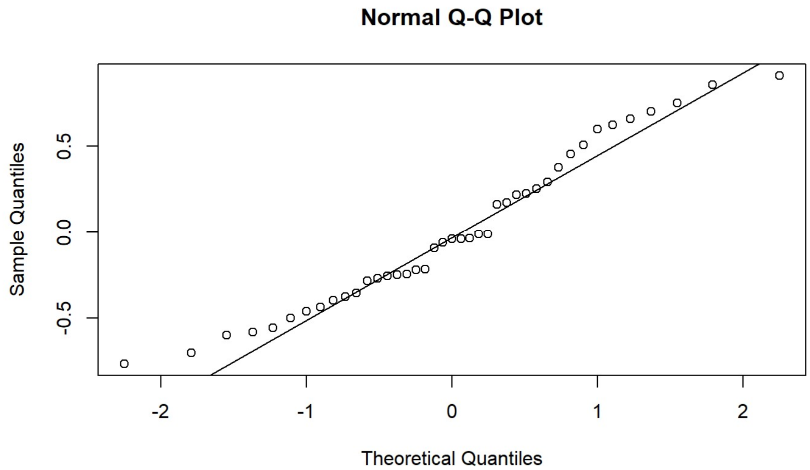

Figure 16. Plot of the residuals of the Mixed Linear Model for beehive proximity.

The model has 37 DF, leading to critical t value of *2.026*. The fixed effects showed that the intercept was not significantly different from zero (Estimate = -0.41, SE = 0.68, *t* = -0.61).

Residuals suggest some variability in the prediction of the observed values, with a few extreme residuals, as seen in Figure 13.

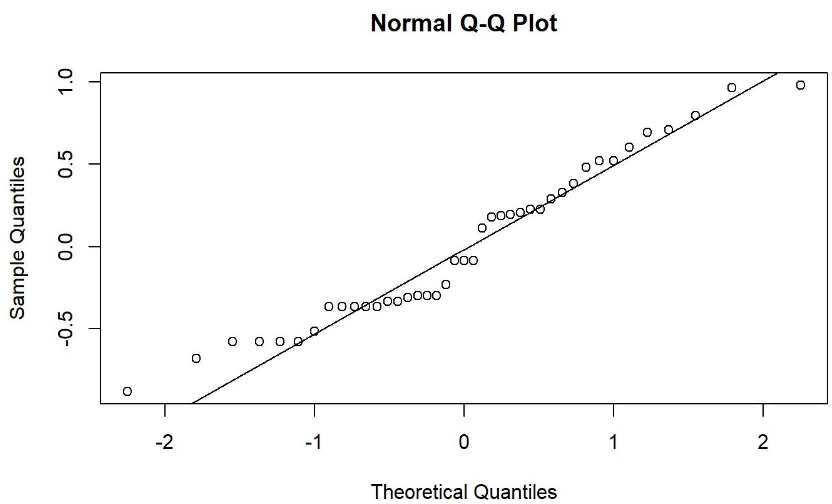

Figure 17. Plot visualizing the residuals of the Mixed Linear Model for food availability.

The model converged with a Restricted Maximum Likelihood (REML) criterion of 65. The model has 38 degrees of freedom, leading to a critical t-value of *2.024*. The random effects associated with land type had a variance of 0.05 (SD = 0.22), while the residual variance was 0.25 (SD = 0.50).

Appendix E: Table depicting flower species information

Latin name	Dutch name	Location	Pollen size (µm)
Glechoma hederacea	Hondsdraf	Grassland	26-50
Taraxacum officinale	Paardenbloem	Grassland	10-25
Ranunculus repens	Kruipende boterbloem	Grassland	26-50
Bellis perennis	Madeliefje	Grassland	10-25
Matricaria chamomilla	Echte kamille	Floral ridge	10-25
Papaver rhoeas	Klaproos	Floral ridge	26-50
Leucantemum vulgare	Margriet	Floral ridge	26-50
Centaurea cyanus	Korenbloem	Floral ridge	26-50

Figure 18. Table depicting data gathered on flowering plant species during field work period and their pollen size.

Appendix F: Locations data plots

Plot name	Coordinates	Distance from beehive along hedge	Plot name	Coordinates	Distance from beehive along hedge
Grass 11	52°11'35.62332" 4°32'59.09244"	854,78	Hedge 21	52°11'35.50" N 4°32'53.72"E	945,56
Grass 12	52°11'35.86776" 4°33'1.40904"	802,42	Hedge 22	52°11'36.2"N 4°32'59.9"E	826,27
Grass 13	52°11'36.14964" 4°33'3.7476"	766,64	Hedge 23	52°11'36.55" N 4°33'03.76"E	752,37
Grass 14	52°11'36.3894" 4°33'6.53112"	713,99	Hedge 24	52°11'37.18" N 4°33'09.13"E	649,52
Grass 15	52°11'36.69864" 4°33'9.08028"	662,31	Hedge 25	52°11'37.61" N 4°33'14.48"E	547,06
			Hedge 26	52°11'38.21" N 4°33'19.70"E	446,61
			Hedge 27	52°11'38.67" N 4°33'25.02"E	344,73
			Hedge 28	52°11'38.6"N 4°33'30.2"E	243,22
			Hedge 29	52°11'35.2"N 4°33'29.9"E	136,9
			Hedge 30	52°11'32.2"N 4°33'29.4"E	35,96
			Hedge 31	52°11'29.2"N 4°33'28.7"E	121,27