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The Diversity and Behavior of Pollinating Insects in Apple Orchards

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Abstract

Diverse assemblages of insects improve the overall productivity and stability of natural and agricultural ecosystems. Cultivated fruit crops, such as apples, that require pollination services by insects are particularly sensitive to changes in insect species richness and abundance. I explored the differences in insect diversity within apple orchards and surrounding wild habitat. Three times as many insects were trapped in wild areas adjacent to the orchards as inside of them, suggesting that even small areas of wild habitat within human dominated landscapes can support a relatively high level of insect diversity. This was also the case for pollinating insects, with 22 bee species were trapped outside the orchards and 17 inside. Honeybees were the only bees more commonly found inside the orchards, as bumblebees were more abundant in more natural habitats and solitary bees showed no difference. Further, I quantified the differences in pollinator behavior within apple orchards to estimate pollinator effectiveness. Bumblebees visited significantly more flowers than honeybees over the observation period of three minutes. The foraging behavior of honeybees and bumblebees differed, with honeybees spending significantly more time on the side of the flower not touching the pollen, but also more time actively gathering pollen. Bumblebees spent more time flying, as they generally flew longer distances. Nearly all bumblebees (96%) visited more than one tree during the observation period, while only about half of honeybees did (56%). Bumblebees were more than three times more likely to visit more than one row within the orchard during the observation than honeybees; a behavior that increases the likelihood of successful crosspollination between cultavrs. Crosspollination between cultivars is essential for apple fruit set, which suggests that bumblebee behavior is more likely to increase overall apple yield. An increase in the amount of wild habitat around the orchards is encouraged to support wild bee populations.

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Background

Species diversity is an important driver of ecosystem function that increases both ecosystem productivity and stability in natural (Tilman et al., 2014) and agricultural landscapes (Fischer et al. 2006). However, the need for high pollinator diversity in order to increase yield of crops has declined as humans have intensified agricultural practices. In particular, the increased the use of pesticides within monocultural crop landscapes has negative effects on insect populations (Raven & Wagner, 2021). This contributes to both the ongoing "insect apocalypse" (Jarvis, 2018) and the sixth global mass extinction (Cowie et al., 2022, Diamond 1989, Dirzo et al., 2014).

The decline in insects, both in diversity and richness, has been well studied in Europe (Hallmann et al., 2017) over the last few decades. Wild pollinators are no exception –rare specialized species are declining in abundance, while generalist species are less affected or even increasing in abundance depending on the type of human land use change (Powney et al., 2019). For example, it has been shown that populations of domesticated honeybee, a generalist pollinator, are higher within fruit orchards than wild habitats, while wild bee diversity and abundance is lower in fruit orchards than in wild habitats (Scott-Dupree & Winston, 1987).

Agricultural and horticultural intensification also results in habitat degradation and fragmentation, which negatively affects all insects, including pollinators such as flies, beetles, butterflies and domesticated and wild bees (Raven & Wagner, 2021). For managed fruit orchards like apple, increased richness and abundance of wild bee species reduces pollen limitation and increases seed set (Blitzer et al., 2016), which improves overall apple quality and yield. Thus, the loss of wild bees can have negative effects on agricultural productivity (Khalifa et al., 2021).

The Western honeybee (*Apis Mellifera)* is the most widely used domesticated, generalist pollinator in agricultural and horticultural production. Honeybees have been introduced to most of the world (Crane, 1992) and can utilize most flowers as a food source. Honeybees have been actively used to pollinate seasonal crops via moveable domestic hives since the middle of the 19^{th} century (Traynor, 2017). However, the effectiveness of honeybees as pollinators is debated, with some even concluding they are relatively poor pollinators due to their behavior (Westerkamp, 1991, Page et al. 2021).

Although managed honeybee populations are generally stable within agricultural and horticultural systems, some colonies have experienced the rapid loss of worker honeybees from the hive, resulting in the collapse of the colony. Colony Collapse Disorder (CCD) can cause economic losses for the farmers and beekeepers. CCD has happened irregularly, which has precluded the ability to understand how to predict or stop outbreaks (VanEngelsdorp et al., 2009). CCD has historically been an issue exclusively for beekeepers in the US, but the most recent outbreak in the 2000's also occured in Europe (Dainat et al. 2011). Therefore, CCD has the potential to threaten local food production in Norway as well.

Apples are a commonly grown fruit in Norway. They are self-incompatible and require pollen from another apple variety to set fruit. Pollination of apples is most commonly done by honeybees, but wild species of Hymenoptera, Coleoptera and Diptera have also been observed (Ramirez & Davenport 2013). Cultivars (apple variety) are genetic copies of each other and are typically planted in rows. Different cultivars are planted as "pollinator trees" within the orchard to cross pollinate and maximize fruit set. As such, it is important that pollinators not only visit as many apple flowers as possible, but also visit several trees across rows to boost the likelihood of visiting different cultivars, and therefore compatible, pollen sources.

Different types of bees behave differently and pollinate at different efficiencies (Mallinger & Gratton 2015). In sweet cherries, wild solitary bees and queen bumblebees show a more effective pollination behavior that promotes cross-pollination, due to more flower visits per minute and a higher proportion of touching the flower stigmas (Eeraerts et al., 2019). Bumblebees have been shown to be better pollinators and increase fruit set in peaches compared to honeybees (Zhang et al 2015). These crops are in the Rosaceae family and therefore have similar flower morphology to apples (Petruzzello, 2022).

Pollinators can be species specific in flower visitation, even if other species of flowers are closer (Grant, 1950). Grüter & Ratnieks (2011) suggested that this flower constancy may be because of an individual's experience; they know how to forage a given flower type rather than learning a different handling method.

The continuous loss of pollinators may make crop production and security a challenge in the future. It is therefore relevant to look for alternative solutions. In this thesis I present two studies related to pollinators: The first focuses on the relationship between insects and apple orchards - the total number of insect orders, pollinator groups and bee species. The second part is about the potential difference in bee behavior and a discussion of to which degree these foraging methods are conducive to pollination. More specifically, these are my hypotheses:

Diversity

- There is a difference between the insect species richness and abundance on the inside and outside of the apple orchards. I predict there are more honeybees and fewer wild bees inside orchards.
- There is a difference in species richness and abundance between farms.
- There is a difference in species richness and abundance between cultivars, as the temporal difference of apple flower varieties matches with how early different wild species start foraging.

Behavior

- Honeybees and wild bees behave differently.
    - I predict that wild bees, particularly bumblebees, visit more flowers per minute.
    - There is a difference in foraging strategy (time spent collecting pollen, collecting nectar from the middle or collecting nectar from the side).
    - Wild bees switch more often between trees and rows within orchards.

Methods

Study sites

Nine study sites were established at three different locations in Svelvik in Eastern Norway (Figure 1), at the farms Sando (Figure 2), Fruktgården (Figure 3) and Berle (Figure 4). All three farms grow the apple cultivars Summerred, Discovery and Aroma. The nine sites varied in size and surroundings. Some cultivars were as few as only two rows, with other cultivars next to them, while others were large sections of only one cultivar. They had varying surrounding habitats, such as forest edges, pastures and other apple cultivars.

Figure 1: Study sites in Svelvik and Sande in Eastern Norway, at the border between the Counties Viken and Vestfold & Telemark

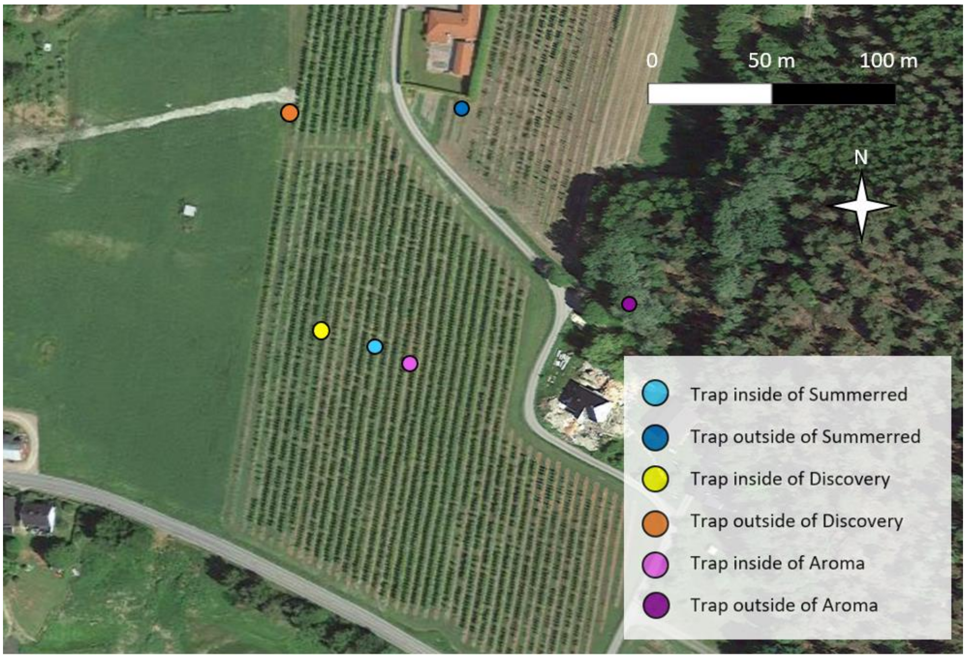

Figure 2: Position of traps at site 1 in Sando

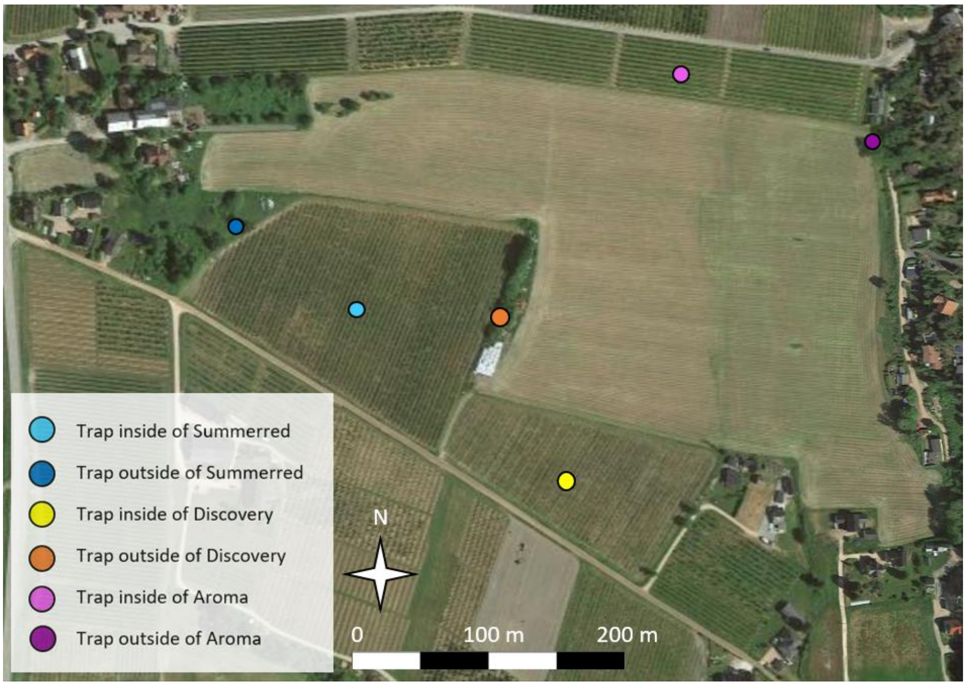

Figure 3: Positions of traps at site 2 in Fruktgården

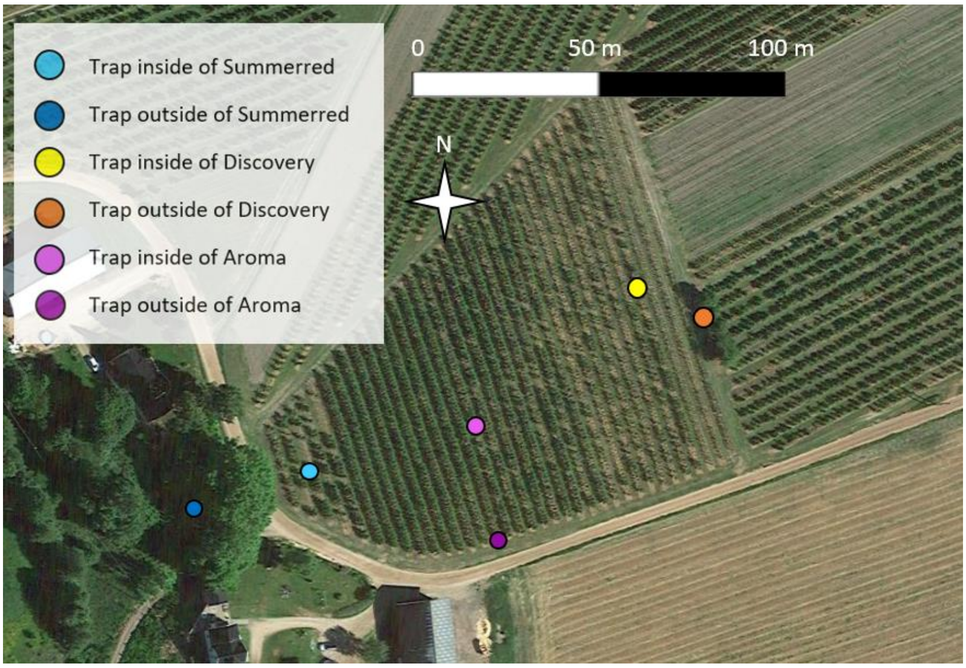

Figure 4: Positions of traps at site 3 in Berle

Passive traps

The trap set up consisted of a pole in the ground and two planks crossing on top in 40-50 cm height (Figure 5). Pan traps were painted fluorescent yellow, blue and white to effectively attract pollinating insects with minimum bias (Nielsen et al., 2011). They were then attached with Velcro to the far end of each plank and filled about 1/3-1/2 full with soapy water (0.2 L of soap without scent or color per 1.3 L of water) to break the surface tension and drown the insects.

Figure 5: Trap set up with a vane trap and pan traps painted white, blue and yellow. Photo: Jane Bergan

Blue vane traps were hung near the pan trap sets in varying heights, with the blue top part generally hung 0.4-1.6 meters above the ground. The collector bottle beneath the trap was filled 1/3 with soap water, sufficient to cover the bottom even if the bottle was tilted. The vane traps in combination with several colored pan traps give a cohesive picture of the diversity of pollinating insects around the orchards and minimizes the sampling bias that comes with each color/type. The blue vane traps were initially hung up with clear collection bottles but were exchanged with spray painted yellow bottles on the 21st of May. Yellow bottles are most commonly used as they generally capture more insects, although in the same proportions with roughly 3/4 of the captured individuals being pollinators (Fajemisin et al., 2023).

Traps were put in the middle of the cultivars in each of the three locations, as well as in a “wild” location in close proximity to the cultivar. There were varying degrees of natural vegetation in the different orchards, these were used as control groups to see the natural insect diversity. Altogether, there were two trap types per set of traps (blue, white and yellow pans + blue vane traps), two per cultivar, three cultivars per location and three locations. This resulted in 72 traps in total, in 18 sets.

The traps were emptied every 48 hours (+-6 hours) for as long as the apple flowers in the given cultivars were blooming – Summerred and Discovery traps were up from May 15th, 2022, and Aroma from May 20th. They were all taken down by May 30th. Some of the pan traps fell over, as the bottom of the pans were not smooth and the Velcro did not stick properly, particularly on rainy days. Wooden utensils were eventually glued onto the horizontal boards, to give the pans a wider base and prevent falling. The fallen pan traps should not influence the results too much, as they mainly fell down after it had been raining. It is therefore less likely to have been large amounts of bees flying around (Lawson & Rads, 2019), that could have gotten trapped.

The insects were rinsed thoroughly to get rid of soap water using a small sieve and put in tubes. One tube was used for each individual trap, and marked with trap type, location, and date. The tubes were then put in the freezer (- 20ºC) for storage until identification or filled with 70% ethanol if freezer space was unavailable.

Lab work

At the lab the rinsed bees were patted dry before shaking them in paper towels for 10-30 seconds to make sure they were fluffy enough to see fur patterns properly. They were then pinned to identify down to species with a microscope and identification keys. The *Field Guide to the Bees of Great Britain and Ireland* by Steven Falk was used to identify the solitary bees, and *Norske insekttabeller – Humler* by Astrid Løken was used for the bumblebees. Several of the smaller solitary bees fell apart in the process and were unable to be identified. The other insects were identified primarily down to family or order, as far down as needed to have relatively similar traits, like pollination.

Small (>5 mm) flies and big (<5 mm) flies are all relevant pollinators due to their sheer abundance, and were often observed on flowers in the field, in addition to pollinating hoverflies (Ssymank et al., 2008). From the Hymenopteran order, the bees from the Antophila clade were considered to be pollinators. Among the Coleopteran order, the soldier beetles in the Cantharidae family were the only pollinating group found (Askham & Hendry, s. a.). Most of the Lepidopteran individuals found were leaf eating caterpillars that had fallen into the traps, rather than grown imagoes who would be attracted to them. Only the imagoes were therefore counted as pollinating insects.

Behavior observation

To look at foraging behavior and visitation rates for bees, individuals were followed for up to three minutes, or until they finished the current activity. Recordings were stopped if they were lost out of sight, scrapping recordings shorter than 30 seconds. The voice recorder function on a smartphone was used to first comment on what kind of bee was being followed (honeybee, solitary bee or bumblebee), then whenever they flew and landed on new flowers. Comments were also made about where these flowers were, whether that was the same tree, different tree or a different row. In addition, comments were made on what precisely they did on the apple flower – collecting nectar from the side, nectar from the middle or gathering pollen, to assess the degree of pollen interaction. A typical observation could sound like "honeybee in the middle of an apple flower – flying – side – crawling– middle - flying – middle on new tree –pollen - flying – new row, lost". The time stamps of the start of each comment were noted down when listening to the recordings and used to estimate the time spent doing each activity.

The method of walking random transects was not particularly effective for spotting solitary bees, as only six were observed – not enough for conclusive results, especially because several flew away within the 30 second minimum requirement. Solitary mason bees have previously been shown to visit more flowers per minute than honeybees (Eeraerts et al., 2019), but this result could not be replicated due to lack of data. They were therefore excluded from the behavior analyzes. Some observations were also discarded if the recordings had too much background noise or wind, making several of the comments hard to make out, or when the recording did not clearly state the type of bee being followed.

Observations were done walking around the orchards on different days and randomly selecting an individual to follow, although preferentially selecting wild bees over honeybees. Sessions were held between 9-12, 12-14 and 14-17. If the sessions were interrupted by rain or spraying from the farmers, they were continued another day somewhere else to maximize randomness.

Statistical methods

All statistical analyzes were done using R (RStudio 2022). Due to the number of traps without bees, Poisson distributed zero inflated models were run on the bee types using the pscl package, using farm, cultivar and placement as explanatory, independent variables. The packages tidyverse and biodiversityR were used to run a species accumulation curve, plotted using ggplot2.

Only six solitary bees were observed, which resulted in too little data to analyze. They are therefore not included in behavior analyses. A general linear mixed effect model (ggplot 2 package) was fitted to estimate the relationship between flower visited by the bee types in relationship to the time they were followed. Chi-square tests were used to compare the probability of tree change and row change.

Results

Diversity

In total 481 traps were emptied during the flowering periods, across the 18 trap sets. 412 contained insects, a total of 8089 individuals. 8 orders were found – 5331 individuals of Diptera (flies and mosquitoes), 1431 Hymenopteran (wasps and bees), 662 Coleopteran (beetles), 449 Hemipteran (bugs, aphids and cicadas), 60 Lepidopteran (butterflies), 33

Thysanopteran (thrips) and 14 Neuropteran insects (lacewings). There were also 109 individuals from the order Araneae (spiders), which had fallen into the traps from nearby vegetation. This was also the case for most of the Lepidopteran individuals, with 43 being caterpillars.

The number of individuals caught outside of the orchard was three times higher than inside the orchard (Table 1), but they were evenly distributed among the farms (Table 2). The first two cultivars had an even number of invertebrates, but it was an increase in numbers in Aroma (Table 3).

Table 1: Distribution of invertebrate orders inside and outside of the orchards

	Diptera	Hymenoptera	Coleoptera	Hemiptera	Lepidoptera	Thysanoptera	Neuroptera	Araneae	Total
Orchard	1267	569	99	191	26	15	8	31	2206
Wild	4064	862	563	258	34	18	6	78	5883
Total	5331	1431	662	449	60	33	14	109	8089

Table 2: Distribution of invertebrate orders between the different farms

	Diptera	Hymenoptera	Coleoptera	Hemiptera	Lepidoptera	Thysanoptera	Neuroptera	Araneae	Total
Sando	1713	628	285	175	18	19	3	52	2893
Fruktgården	1707	298	268	151	17	7	6	37	2491
Berle	1911	505	109	123	25	7	5	20	2705
Total	5331	1431	662	449	60	33	14	109	8089

Table 3: Distribution of invertebrate orders between the apple cultivars

	Diptera	Hymenoptera	Coleoptera	Hemiptera	Lepidoptera	Thysanoptera	Neuroptera	Araneae	Total
Summerred	1801	375	94	147	26	11	5	33	2492
Discovery	1638	548	129	158	14	10	6	46	2549
Aroma	1892	508	439	144	20	12	3	30	3048
Total	5331	1431	662	449	60	33	14	109	8089

For pollinating groups, 5881 insects were found - From the Diptera, 2237 small flies (<5 mm), 2748 big flies (>5 mm), and 21 hoverflies. Mosquitoes, craneflies and assassin flies were excluded. From the Hymenoptera, 460 honeybees, 146 bumblebees and 95 solitary bees, excluding parasitic and plant wasps. 157 soldier beetles from the Coleoptera, and 13 adult moths and 4 butterflies from the Lepidopteran order. In total, 72.7% of the insects caught in the traps were groups that have been observed to pollinate.

There were almost three times more pollinating insects caught outside of the orchards (Table 4), but the total number between the farms is similar (Table 5). There was an increase in insects towards the latest cultivar (Table 6).

Table 4: Distribution of pollinating insects inside and outside of the orchards

	Diptera	Hymenoptera	Coleoptera	Lepidoptera	Total
Orchard	1173	379	3	8	1563
Wild	3833	322	154	9	4318
Total	5006	701	157	17	5881

Table 5: Distribution of pollinating insects between the sites

	Diptera	Hymenoptera	Coleoptera	Lepidoptera	Total
Sando	1560	284	44	6	1894
Fruktgården	1586	115	105	3	1809
Berle	1860	302	8	8	2178
Total	5006	701	157	17	5881

Table 6: Distribution of pollinating insects between the apple cultivars

	Diptera	Hymenoptera	Coleoptera	Lepidoptera	Total
Summerred	1544	186	3	4	1737
Discovery	1647	213	4	6	1870
Aroma	1815	302	150	7	2274
Total	5006	701	157	17	5881

Bees were found in 240 traps, 701 individuals – 460 honeybees, 146 bumblebees and 95 solitary bees. Twenty-four species of wild bees were identified and confirmed, six bumblebees and 18 solitary bees, resulting in 25 in total including the honeybee (table A1). The most common wild bee was *Bombus pratorum* with 117 individuals, with the second being *Andrena Haemorrhoa* with 17. Over half of the solitary bees were *Andrena spp*, and along with *Lasioglossum spp* they accounted for 70% of the solitary bee individuals found in the traps.

The total number of trapped bees were distributed evenly between the inside and outside of the orchard (Figure 6). There were significantly more honeybees and bumblebees trapped inside the orchards than outside, but there was no significant difference for solitary bees (Table 7).

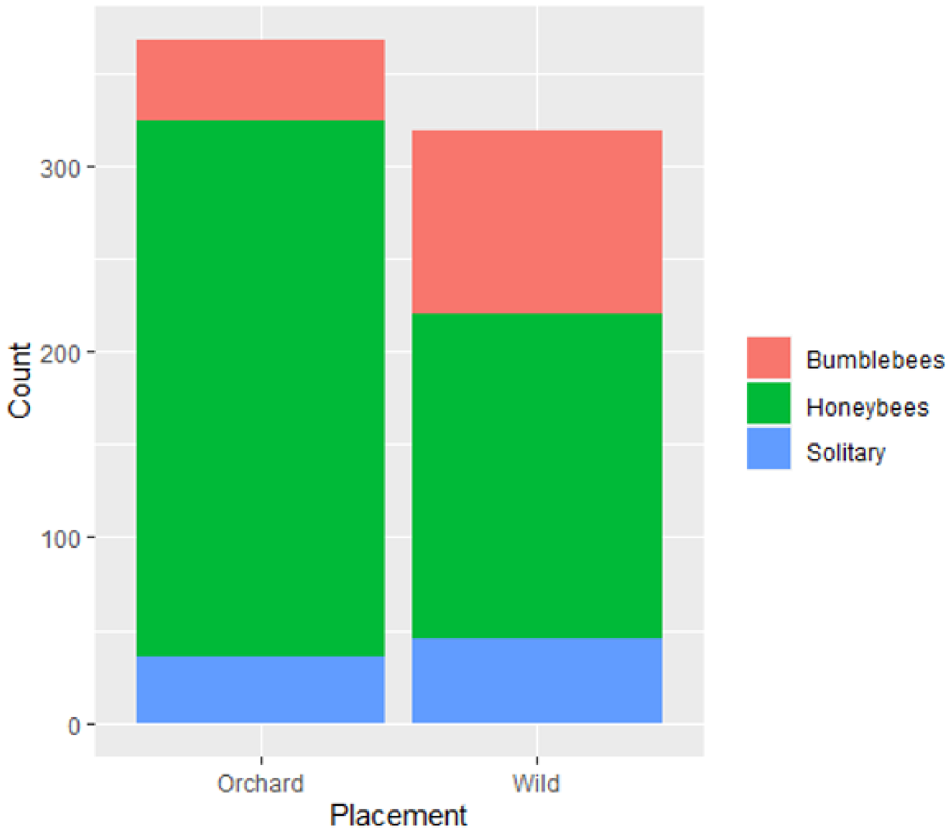

Figure 6: Distribution of bees inside and outside the orchards

Table 7: Statistical significance of bee distribution between inside and outside orchards

Fixed effects	Estimate	Standard error	Z value	Pr(>|z|)	
Orchard Honeybees	-0.06737	0.14655	-0.460	0.646	
Wild Honeybees	1.02034	0.21215	4.809	1.51e-06	*
Orchard Bumblebees	0.3822	0.4981	0.767	0.4429	
Wild bumblebees	1.0938	0.5300	2.064	0.0391	*
Orchard Solitary bees	0.7028	0.4412	1.593	0.111	
Wild Solitary bees	0.7182	0.5036	1.426	0.154	

Fewer bees were caught in Fruktgården (Figure 7). The number of honeybees, bumblebees and solitary bees trapped in Fruktgården were all significantly less than the two other farms (Table 8).

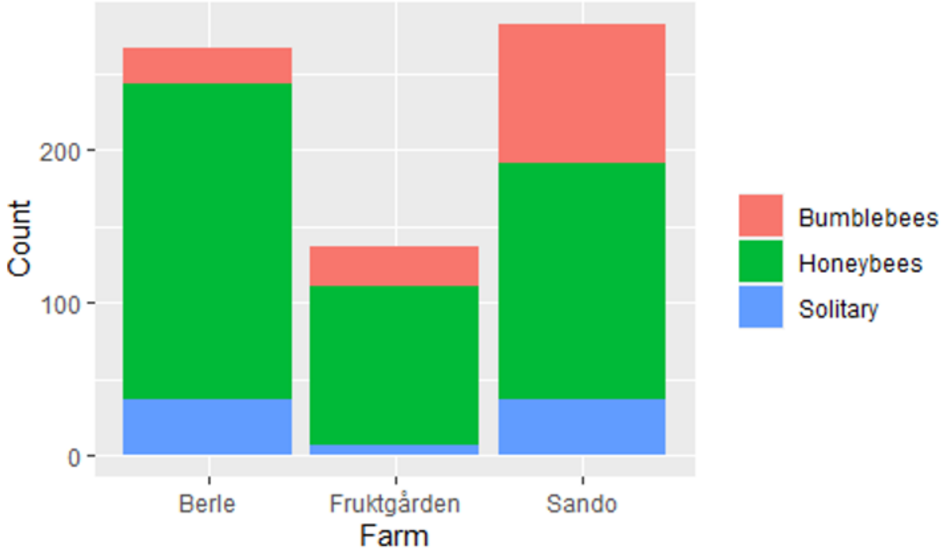

Figure 7: Bee distribution between the farms

Table 8: Statistical significance of bee distribution between farms

Fixed effects	Estimate	Standard error	Z value	Pr(>|z|)	
Berle Honeybees	0.0760	0.1707	0.445	0.6561	
Fruktgården Honeybees	0.6438	0.2596	2.480	0.0131	*
Sando Honeybees	0.3754	0.2461	1.526	0.1271	
Berle Bumblebees	1.8856	0.3544	5.320	1.04e-07	*
Fruktgården Bumblebees	-0.4629	0.5111	-0.906	0.36503	
Sando Bumblebees	-1.1655	0.4079	-2.858	0.00427	*
Berle Solitary bees	0.8011	1.1896	0.673	0.5007	
Fruktgården Solitary bees	0.6876	0.3481	1.975	0.0483	*
Sando Solitary bees	0.3350	0.4603	0.728	0.4667	

There were more bees trapped in the Aroma orchard (Figure 8). The number of honeybees and bumblebees were significantly higher than the other cultivars (Table 9)

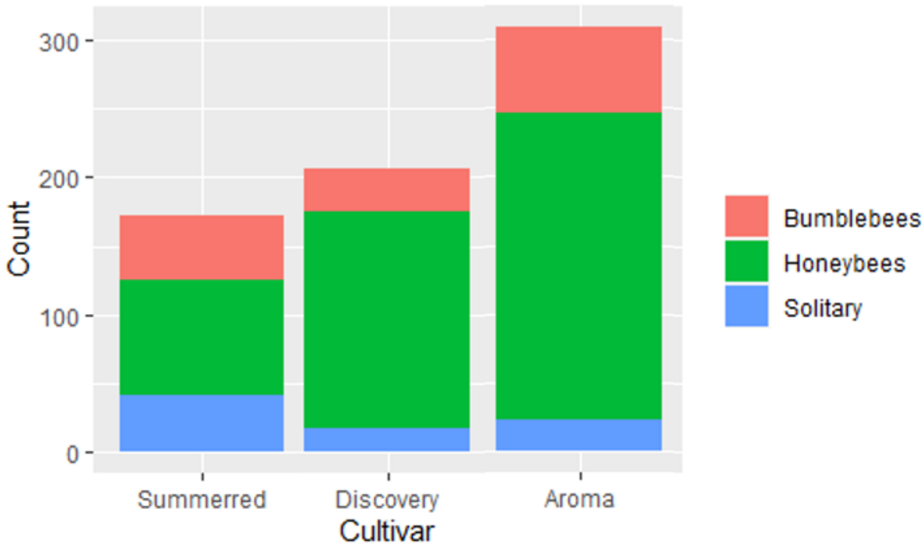

Figure 8: Bee distribution between cultivars

Table 9: Statistical significance of bee distribution between cultivars

Fixed effects	Estimate	Standard error	Z value	Pr(>|z|)	
Summerred Honeybees	0.8897	0.2788	3.192	0.00141	*
Discovery Honeybees	0.7229	0.2504	2.887	0.00388	*
Aroma Honeybees	-0.1786	0.1812	-0.985	0.32442	
Summerred Bumblebees	-0.37527	0.35666	-1.052	0.293	
Discovery bumblebees	-0.01862	0.39749	-0.047	0.963	
Aroma Bumblebees	1.40730	0.23108	6.090	1.13e-09	*
Summerred Solitary bees	0.37267	0.58008	0.642	0.521	
Discovery Solitary bees	0.09813	0.81391	0.121	0.904	
Aroma Solitary bees	0.82175	0.51797	1.586	0.113	

22 different bee species were present outside of the orchard, and 17 were trapped inside. The species accumulation curves for both habitats (Figure 9) failed to become asymptotic, suggesting that the total species richness of each habitat was not found through my trapping methods. However, the species richness was highest in the wild areas outside of the orchards (Figure 9).

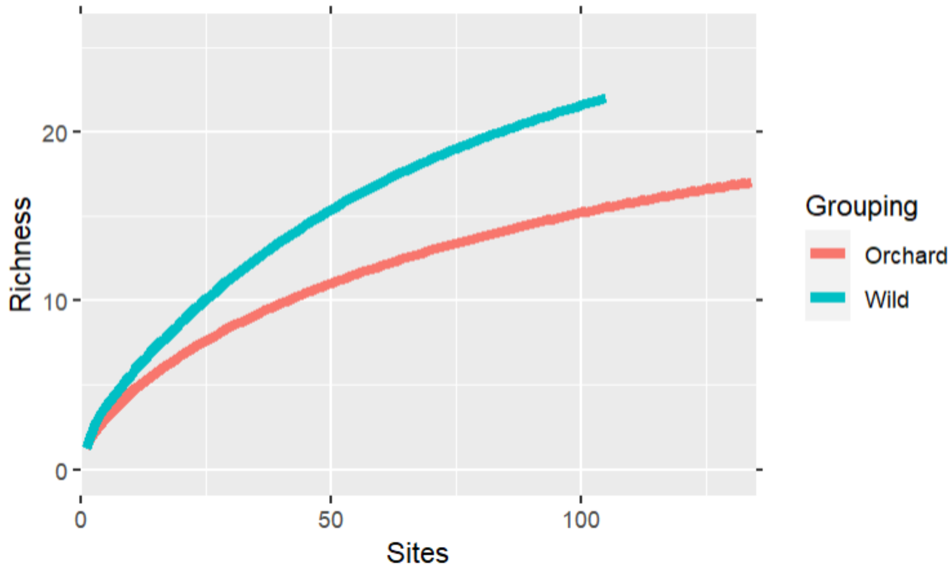

Figure 9: Species accumulation curve for inside (Orchard) and outside (Wild) the apple orchards

Behavior

Observations of 194 bees were successfully recorded – 124 honeybees and 70 bumblebees. The activities of bees during 2020 visits to apple flowers were registered, including how the bees moved between flowers. Activities were split into categories, on and off flowers. "Crawl" is the time the bees spent crawling on the branch between flowers on the same cluster, while "fly" is the time they spent in the air. "Middle" is the time the bees spent gathering nectar while sitting on top of/touching pollen anthers, "side" is time spent gathering nectar but not touching pollen, rather sneaking in between the filaments from the side of the flower. "Pollen" is time spent actively collecting only pollen, either by buzzing or moving their legs to put pollen grains in the pollen baskets on their hind legs.

Bumblebees spent a significantly longer time flying than honeybees, and honeybees spent more time foraging, specifically collecting pollen and gathering nectar from the side (Figure 10)

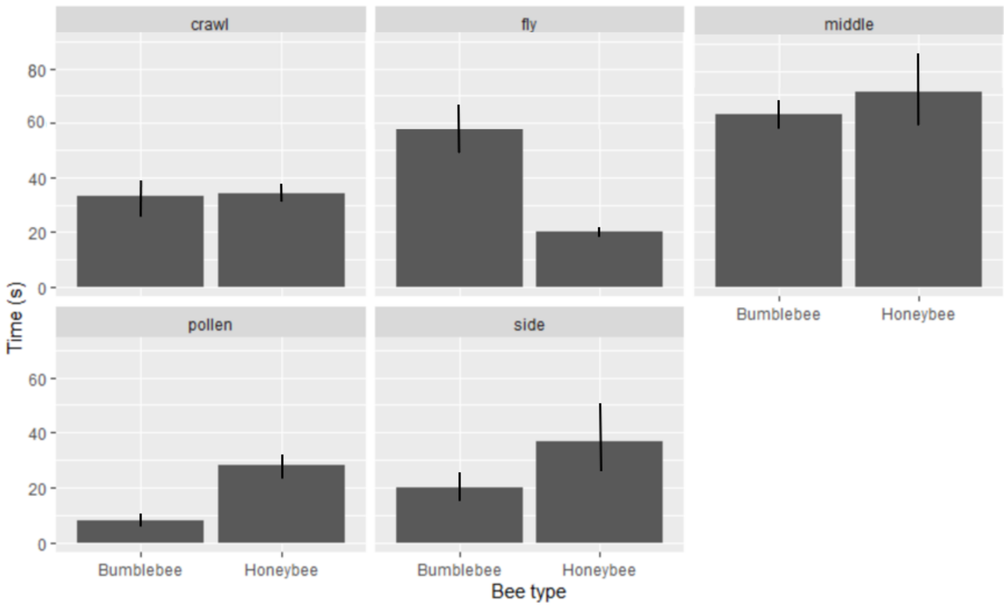

Figure 10: Average time each individual spent doing each activity

Bumblebees visited significantly more flowers per minute than honeybees (Figure 11). After 3 minutes, the average bumblebee had visited 22.6, while the average honeybee had visited 13.9 flowers.

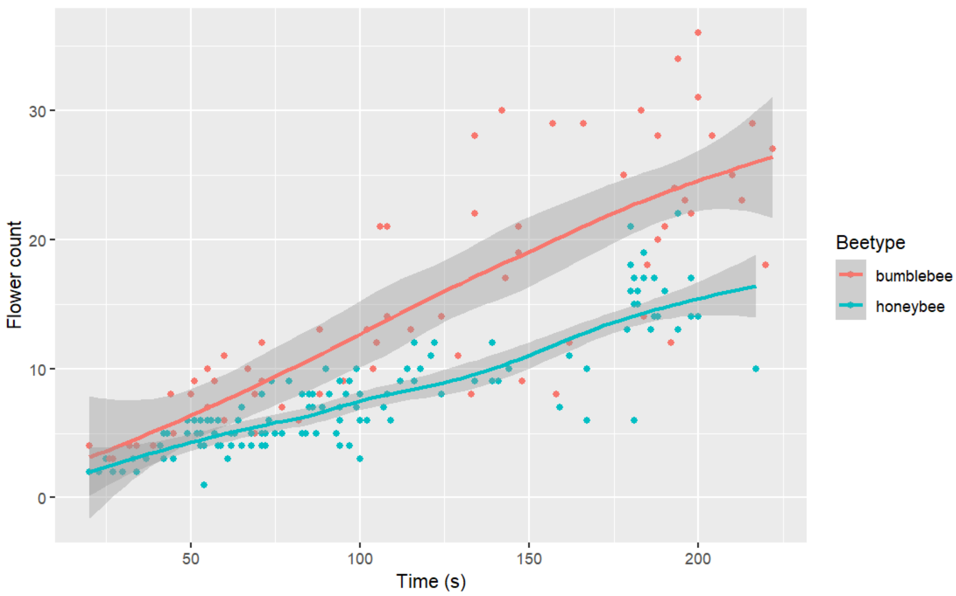

Figure 11: 95% CI of how many flowers each bee group visit per given time

Bumblebees had a higher tree visitation rate than honeybees within the observed time range (Table 10), as well as a higher rate of switching between rows (table 11).

Table 10: Bumblebees flew between trees significantly more than honeybees (p < 0.001)

Bee type	Did fly between trees	Did not fly between trees	Proportion tree change
Honeybee	69	55	55,7%
Bumblebee	67	3	95,7%

Table 11: Bumblebees flew between rows significantly more than honeybees (p < 0.001)

Bee type	Did fly between rows	Did not fly between rows	Proportion row change
Honeybee	17	107	13,7%
Bumblebee	36	34	51,4%

Discussion

Diversity

I found differences in both the insect richness and abundance between the inside and outside of the orchards. The monocultured apple habitat, despite the presence of additional floral resources, such as dandelions (*Taraxicum officinale*), likely did not have sufficient niches to support insect diversity. Consistent with my first hypothesis, I found more than three times as many insects in traps placed in vegetation outside of orchards as inside the orchards. There was greater variation between the traps placed outside the orchards – while the traps placed inside the orchards had similar insect groups. The placement of the traps outside the orchards appears to have been heavily influenced by local plant species. For example, a flowering bush near a trap in Fruktgården was the source of many soldier beetles, while a group of small trees by a trap in Berle was surrounded by flies. However, quantification of such local scale effects were outside the scope of this study.

Insect populations were evenly distributed among the three farms, although the composition of orders seemed to vary. Particularly the Hymenopteran and Coleopteran orders differ from one farm to another. These are, however, the orders that increased the most percentagewise through the flowering season, so it may be that some traps were near source populations and could cause disproportionate numbers.

The number and distribution of all pollinating insects follows the same pattern as the total number of invertebrates – significantly more pollinators were found outside the orchards, pollinators appeared to be evenly spread between the farms, and a higher numbers of pollinators were found in the last flowering cultivar at the end of the season. While bees are often considered to be the most important pollinators, flies, beetles and butterflies can also contribute (Ramirez & Davenport 2013). However, they don’t always carry pollen from another apple flower, and if they do, they do not transfer as much pollen as bees on average (Bernauer et al., 2022). They are also not as easy to domesticate and are therefore provide a more unpredictable pollinating service. Still, previous studies have shown that increases in honeybee abundance within an orchard does not result in increased pollination, but an increase in diversity does (Blitzer et al., 2016). This underscores the importance of increasing the diversity of all pollinating insects within orchards, not just bees.

In my study, more honeybees were trapped inside the orchards, and more bumblebees outside, while there was no difference between the solitary bees. In the case of honeybees, there could be several reasons. According to the optimal foraging theory, it is beneficial to visit the closest and most productive food source – as little effort, but as high reward as possible (Goulson, 1999). If honeybee hives are placed inside the apple orchards, apple flowers will be close and abundant and encourage honeybee foraging within orchards.

A substantial number of honeybees were also caught outside the orchards. Some traps were right next to the rows of apple trees, but honeybees have also been shown to forage from several food sources other than crops. A study on pollen collection in almond orchards found that 79% of analyzed beehives contained pollen other than almonds (da Silva Santos et al., 2022), suggesting that honeybees might prefer a more varied diet.

There was also a difference in the bee communities between the farms, in all groups – there were significantly fewer bees at the Fruktgården farm, which was by far the biggest orchard. In the case of the honeybees, there may have been fewer or smaller colonies compared to the orchard size, or a greater distance to the trap sets resulting in fewer individuals, although hive locations and number were not taken note of. An explanation could be that the large sizes of the orchards in Fruktgården compared to the other farms discouraged the wild bees from traveling from the adjacent forest to a trap in the middle of the orchards, such as is found in blueberry orchards (Nooten et al., 2020). The distance is likely a bigger factor for the wild bees than the honeybees, as they are shown to fly far shorter distances. Honeybees can forage flowers several kilometers from the hive (Beekman & Ratnieks, 2000), but neither bumblebees nor solitary bees typically fly more than a few hundred meters (Osborne et al., 1999, Gathmann & Tscharntke, 2002). Berle was rich in solitary bees, both inside and outside of the orchards. This could be the result of small size of the cultivar patches, especially for the Summerred cultivar, as most species caught outside of the orchard were also caught inside.

The number of honeybees and bumblebees both increased throughout the season. There were significantly more honeybees and bumblebees in the Aroma cultivar, and as these bee groups are both eusocial, this increase in number is most likely due to colonies becoming better established throughout the flowering season. There were noticeably more worker bees in the field towards the end of the season, particularly *B. pratorum*. Honeybees were found in every single trap location, and *Bombus pratorum* in 16/18 of them. *B. pratorum* is also known as the early nesting bumblebee and is observed to be a generalist in terms of where the queen establishes the nest (Lye et al., 2012). The number of solitary bees did not increase significantly, despite the emergence of new species.

Page et al. (2020) suggests that diverse semi-natural habitats surrounding an apple orchard plays a big role in sustaining healthy pollinator communities, while direct management of pollinators is less consistent. Mallinger et al. (2016) found the same, with bee communities being significantly different in various habitats such as woodlands, cropland and orchards.

These landscapes provide diverse flowers and niches that are available the whole foraging period in spring. Planting more heterogenous crops is not a solution for increasing pollinator diversity - regardless of different timing of the mass flowering because it does not appear to positively affect wild pollinator abundance (Pisman et al., 2021). This is also the case for non-pollinating insects, such as natural enemies of insect herbivores, which can increase up to 40% with plant diversification (Wan et al., 2019).

Behavior

While visitation rates among bees have been relatively well studied (Bernauer et al., 2022), exactly what type of foraging behavior is being done at any given time is less well known. As predicted, I found a difference in handling behavior and strategies between honeybees and bumblebees. Honeybees in general had longer handling time than bumblebees, spending especially more time sucking nectar on the side of the flower and gathering pollen from the middle. This behavior is supported by similar findings, such as Bosch & Blas (1994). They observed contact between the flower stigma and honeybee body in ~40-75% of the visits, depending on the foraging strategy of the individual bees (nectar gatherer or pollen gatherer). Eeraerts et al. (2019a) further highlighted the importance of contact with the flower stigma, since time spent on the side of flowers lowers the frequency of pollination.

Honeybees spent longer time on each flower, while bumblebees spent more time flying. This is because bumblebees generally flew further - between not only flowers, but also trees and rows, and visited more flowers during the observation period than honeybees. Bumblebees also tended to acquire nectar in the middle, only occasionally buzzing to gather pollen. Both groups would often crawl between the flowers rather than fly, but honeybees would walk around the flowers and come in from the side, while bumblebees typically crawled across the flowers and their pollen. Bumblebees might therefore have “visited” even more flowers than noted.

Bumblebees visited more flowers per minute than honeybees. This result is inconsistent with a similar study done in Norway (Johansen, 2022), as well as Martins et al. (2015). However, studies suggest visitation rates might be different between years, depending on the proportion of individuals who forage pollen (Park et al., 2016). In addition, visitation rates may be influenced by locale and crop type. Several studies show that bumblebees and solitary bees are less sedentary than honeybees. Eeraerts et al. (2019a) found that mason bees switched between trees more than honeybees in sweet cherry crops. Bumblebees have also been shown to visit more trees and rows in raspberry crops (Willmer et al., 1994). Some studies have found little to no difference, such as mason bees switching rows at the same rate as the honeybees among apples (Vicens & Bosch, 2000). Future studies conducted across greater spatial extents and over multiple years may improve our understand of visitation rates among different pollinator groups.

Wild bees were more likely to fly between multiple trees and multiple rows, while honeybees stayed on one tree/row, as predicted. However, there are some caveats to these results. Honeybees were more likely to get lost out of sight because they flew too high up on an apple tree, or because they flew to the other side of the tree where they could not be seen between the branches. Some individuals that were lost may have flown somewhere else without being noted as a tree/row change. In contrast, bumblebees are louder and bigger and therefore easier to see if they flew to another tree. In addition, there were fewer bumblebees, which reduced the chance of accidentally switching the focus to another individual.

Conclusion

Taken as a whole, wild bees were more likely to fly between trees and rows, visit more flowers, and engage in foraging behaviors that result in successful pollination than were honeybees. Wild bee populations were also higher outside orchards than inside orchards. This suggests that management actions that support the movement of wild bee populations from outside orchards to inside orchards should be encouraged. Most farmers are positive to implementing insect friendly measures, especially if compensated financially (Busse et al., 2021). As fruit farmers’ profit depends on the fruit yield, which directly depends on pollinating insects, it is extra beneficial to facilitate diverse and abundant communities of wild pollinators. This can be done by providing resources for the entire growing season, such as hedges or perennial flower strips (von Königslöw et al., 2022), in addition to having a diverse landscape around the orchard. Flowering plants in the herb layer of the orchards can also support higher diversity of pollinating insects (Eeraerts et al., 2019b).

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Appendix

Table A1: Overview of where each bee species was found. The first letter is farm (Sando, Fruktgården, Berle, the second is cultivar (summerred, discovery or aroma), the last is placement (wild, orchard)

Bee species	S.SR.O	S.SR.W	S.D.O	S.D.W	S.A.O	S.A.W	F.SR.O	F.SR.W	F.D.O	F.D.W	F.A.O	F.A.W	B.SR.O	B.SR.W	B.D.O	B.D.W	B.A.O	B.A.W	Total
Andrena bicolor		1		2															3
Andrena cineraria				1									1					2	4
Andrena clarkella											1								1
Andrena fucata		3																	3
Andrena haemorrhoa	1	4			3				1		1		2	2	1		2		17
Andrena helvola			1										1						2
Andrena lapponica										1									1
Andrena lathyri														1					1
Andrena ruficrus					1	1							1						3
Andrena scotica	1	1			3						1		1	1			1		9
Andrena semilaevis													1	1					2
Andrena spp.		1	1		1									1			1		5
Andrena tibalis		3											1	1					5
Andrena vaga														1					1
Apis mellifera	31	11	31	24	58	3	13	1	27	2	16	55	28	3	65	14	26	52	460
Bombus hortorum					1	1		1					1						4
Bombus hypnorum			2			2							1						5
Bombus lucorum				1	1	4			3										9
Bombus pascuorum										1	1			2					4
Bombus pratorum	4	9	4	12	11	36	2	8	3	4	1	3	3	12		3		2	117
Bombus terrestris	1	1	4									1							7
Eucera longicornis																1			1
Halictus rubicundus						2													2
Hylaeus spp.		1											1	1					3
Lasioglossum albipes																	1		1
Lasioglossum morio		1													1				2
Lasioglossum spp.	1	2	1				1						1	1					7
Nomada spp.					2											1			1
Osmia bicornis												1							3
Unknown bumblebee		1	1	1												1			4
Unknown solitary bee	1	3	1		2				1				3	1				2	14
Total	40	42	46	41	83	49	16	10	35	8	21	60	46	28	67	20	31	58	701

Table A2: Pearson's chi-square tests with Yates' continuity correction for tree change and row change.

	X-squared	df	p-value
Tree change	32.39	1	1.262e-08
Row change	29.006	1	7.217e-08

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