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Honey Bees and Wild Bees in Apple Orchards in Telemark and Hardanger

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This thesis is worth 60 study points

Summary

The decline in bee species richness and abundance has been a global concern in the past few decades because of our dependence on bees as agricultural pollinators. The loss of habitat is one of the main factors in this development. The expansion of agriculture with unsuitable nesting and foraging areas is a detriment especially to wild bee species. European honey bees (*Apis mellifera*) live in apiaries and are generalists who can feed off many kinds of flowers, so they are not as vulnerable as wild bees, but they face other challenges in line with parasites and pesticides. There are several reasons why honey bees are popular pollinators in agriculture: population densities are easily manipulated, they can be placed anywhere, and they pollinate many different flowers. The competition between honey bees and wild bees is especially apparent when flower levels are low, and there is larger niche overlap between the bee species.

Because of all these factors, honey bees are expected to be the most abundant bee species in apple orchards. A survey of bees in apple orchards in Hardanger and Telemark showed that the European honey bee is the most abundant of all bee species present – with more individuals than all other bee species combined – and this was true for all five orchards sampled. The second largest group included several species of bumble bees (*Bombus* spp.), and the rest of the identified bees consisted of mining bees (*Andrena* spp.) (two species), mason bees (*Osmia* sp.) and long-horned bees (*Eucera* sp.). Apart from the latter, all are known pollinators commonly found in apple orchards.

Honey bees dominated the apple orchards in terms of abundance, but research shows that there might be advantages to having more diverse and abundant wild bees present as well. Many of them are effective pollinators of apple trees, and are also actively foraging in lower temperatures than honey bees, which can be an advantage in early spring apple blossoms.

Contents

Foreword

There are many people who have helped me in this work. First of all, I want to thank my supervisors, Live and Stefanie, for their invaluable help and advice in the writing of this thesis. I also thank Nicolas of the CliPS project, for giving me the opportunity to contribute to their data gathering. Thank you to all the farmers who allowed me to run around your orchards with a net, to Frode and Mathias for helping me with the field work, to Martin for providing much of the equipment, to Liv for being my travel companion, and to the librarians at the university for getting me all the articles I needed. Last but not least, to Inger Lise and Maria, who have been a moral support and always listened to all my frustrations, thesis-related or not.

Bø i Telemark, 14.05.20

Åsne Skjøtskift Øygarden

1 Introduction

Pollinators and Ecosystem Changes

Biodiversity is decreasing because of human activities (Butchart et al., 2010). Some of the changes, such as increased agriculture, have been necessary to meet growing needs for food and water for an increasing human population, at the expense of inadvertent degradation or changes of many ecosystem services (World Health Organization et al., 2005). For example, increased use of land area in agriculture leads to changes in natural habitats. Habitat destruction is considered the most severe driver for species extinction (Tilman et al., 1994).

Pollinating insects are also affected by habitat destruction. Estimates say that over 90 % of the approximately 250 000 species of modern angiosperms are pollinated by animals (Kearns et al., 1998). Although many major food crops are wind-pollinated, insect-pollinated crops are an important part of human food consumption. Around 35 % of the global food crop production depend on animal pollinators (Klein et al., 2007). Most vegetables, fruits, berries and nuts are pollinated by bees, and some crops such as coffee, soya beans and cotton need pollination by bees to increase yield (Hein, 2009). In the absence of animal pollination, total agricultural production is expected to be reduced by 3-8 % (Aizen et al., 2009). To compensate for these deficits in food production, the amount of cultivated area would need to increase, resulting in an even larger impact on biodiversity and natural ecosystems (Batra, 1995).

Honey Bees and Wild Bees

The bee (Anthophila) clade belongs to the bees and digger wasps (Apoidea) superfamily and are closely related to stinging wasps (Vespidae family) and ants (Formicidae family). Bees are believed to have emerged along with angiosperms, and the oldest fossil is dated to be nearly 80 million years old (Michener, 2007). Estimates suggest that there are at least 20 000 bee species in the world (Michener, 2007). The distribution of bee species depends on climatic and vegetational factors, and the bee's dispersal abilities. Warm-temperate areas house the greatest abundance of bees, both number of individuals and species. Mesic temperate, tropical areas and arctic areas have markedly fewer species and individuals due to temperature, humidity, predators and interspecific competition (Michener, 2007).

In this thesis, wild bees (or native bees) are referred to as all bees species excluding honey bees (*Apis* spp.). The presence of various wild bee species depends on nature type and landscape use, as well as nesting opportunities and forage distance. Wild bee abundance and richness are greater in organic and diversified fields, and the impacts of intensive monoculture agriculture can be offset by maintaining high-quality habitats around farms (Kennedy et al., 2013). Historically, wild bees have always played a role in agricultural pollination, and were found to be adequate pollinators of apple orchards before the introduction of insecticides (Batra, 1995). As wild pollinating bee populations declined and crop yields were diminished, due to adverse agronomic and environmental impacts, beekeepers began using their managed honey bees to pollinate crops (Batra, 1995).

The European honey bee (*A. mellifera*) is the most widely distributed honey bee species, and it is domesticated and used commercially for honey production and pollination services all over the world (*Global Survey of Honeybees and Other Pollinators*, 2018). The European honey bees are polylectic generalists (Michener, 2007), which makes them popular as easily manageable pollinators that can adapt to many flowers and crops. Admittedly, Batra (1995) argues that they are not very efficient, and can stray from the intended crop to weeds or flowers outside their farm area.

For this reason, interest has increased in keeping alternative bee species, that are efficient pollinators who prefer the crop host, and do not stray from the orchard. Bumble bees have been widely used in greenhouses on tomatoes and other crops that require the use of buzz-pollination. Specialized species that are more suitable to the given crops have been imported from other parts of the world for nearly 150 years. In New Zealand, the clover-fertilizer large earth bumble bee (*B. terrestris*) was successfully imported from Europe in early 1885, and by late 1886 they proliferated, with farmers reporting considerable increase in red clover seed yield from the previous year (Royal Entomological Society of London, 1886). Various subspecies of the large earth bumble bee have been used extensively in areas outside their natural range, but the risk they pose to habitats and co-evolved plant-pollinator relationships have prompted governments in Norway, Japan, the Canary Islands, China, South Africa and Australia to ban or restrict importation of all or some of the subspecies (Winter et al., 2006). Today, the large earth bumble bee is categorized to have a severe impact (SE) on native biodiversity in Norway (Artsdatabanken, 2018).

Decline in Bee Populations

Wild bee populations have declined in many places. A study from the USA showed a decline of up to 96 % in four of eight monitored bumble bee species during the last few decades, with a reduction in geographic range by 23-87 % (Cameron et al., 2011). The reduced population had a significantly higher level of pathogens and lower genetic diversity than the other four species who were not in decline (Cameron et al., 2011). In the UK, two of 28 bumble bee species are extinct, with another six found in smaller areas than 80 years ago (Department for Environment, Food and Rural Affairs, 2014), although the rate of decline seems to be slower in recent decades. Bumble bee diversity is also declining in the Netherlands, Ireland, Sweden, and in many temperate regions in the northern hemisphere (ibid.).

For wild bees, the loss or fragmentation of habitat is reported as the biggest threat in most regions (*Global Survey of Honeybees and Other Pollinators*, 2018). There are detailed records on the impact of human activities on bee populations in Europe, which include forestry, agriculture, industry, recreation, urban development, pesticides, pollution, drainage, irrigation and weed invasions (Batra, 1995). All of these impacts contribute to the destruction of most natural habitats for bees in Europe (Westrich, 1996). Land-use changes which lead to reductions in food plants and pathogens are widely blamed for the decline of some bumble bee species in Europe, North America and Asia (Williams & Osborne, 2009). Case studies have found that agricultural intensification of managed natural pollination services jeopardized wild bee communities and their stabilizing effect on pollination services at the landscape scale (Klein et al., 2007).

Pesticides have also been speculated to have a contributing factor to decline in bee health, possibly increasing susceptibility to the parasitic Varroa mite (*Varroa destructor*) and the parasitic Nosema fungus (*Nosema apis*), leading to suggested restrictions on the use of so-called neonicotinoids as a precaution (Cressey, 2013).

In a global survey of honey bee population trends, 58 % of the countries reported steady to increasing honey bee populations, which corresponds to an increase in beekeepers (*Global Survey of Honeybees and Other Pollinators*, 2018). 63 % of respondent countries are actively working for the conservation of honey bees and their genetic diversity, with the government carrying the main responsibility in most of these countries. Research organisations and NGOs such as beekeeping associations and conservation groups were also active in this work. The greatest threat to honey bees vary in different regions, with pesticides and pathogens as two of the most important factors for bee loss (*Global Survey of Honeybees and Other Pollinators*, 2018). Many countries have strict regulations in place to control pests or pathogens related to transport of honey bees both between and within country borders, requiring a health inspector or veterinarian to declare hives to be disease free before transport. Some countries restrict where bees can be imported from, and many require beekeepers who rear honey bee queens to have a licence (*Global Survey of Honeybees and Other Pollinators*, 2018).

Extensive loss of managed honey bee colonies has gotten a lot of attention in recent years. Colony collapse disorder (CCD), is the name given to a widespread phenomenon of healthy worker bees leaving the hive and never returning. The phenomenon was named in 2006, after this happened in high numbers in the United States, and in the winter of 2009/2010, it was estimated to account for 4 % of losses in the US (Dainat et al., 2012). CCDs have also happened in Europe (Dainat et al., 2012). No one has been able to point to a culprit single-handedly responsible for CCDs; it is likely that several risk factors interact and lead to stress with increased susceptibility to parasites. The current theory is that several risk factors interact and contribute to lowered resilience, such as pathogens and other stress factors (vanEngelsdorp et al., 2009).

In order to provide more high-quality habitats for wild bees, yields on already existing crop fields must increase, for example by using the most efficient pollinators for the given crops (Batra, 1995). As this may involve import of bee species, meticulous care needs to be given to quarantine and monitor populations to reduce risk of also importing parasites and diseases. The increase in imported managed bumble bees may have also detrimental effects on wild bumble bee populations, through parasite transmission (Graystock et al., 2016). Imported species that carry parasites transfer these to flowers, which are in turn foraged by wild bumble bee species, who then receive the parasite.

Bees in Norway

There are 208 species of bees recorded in Norway. There is the European honey bee, 35 different bumble bees, and the remaining 172 are divided by 6 families of wild bees (Ødegaard, 2014). The subspecies Nordic brown bee (*A. mellifera mellifera*) is native to Norway, but - allegedly due to a reputation of being difficult to manage - they are not in widespread use, and they are currently endangered (Ruottinen et al., n.d.). During the 20th century, other subspecies were imported from Southern Europe, such as the Carniolan honey bee (*A. mellifera carnica*) from Slovenia and the Italian honey bee (*A. mellifera ligustica*) from Italy.

Of the wild bee species in Norway, especially bumble bees have been studied and mapped extensively. Astrid Løken's mapping of bumble bees from the 1940s-70s (Løken, 1973) provides a detailed and valuable source of comparison for today's situation. A group of scientists replicated part of the inventory in 2012 and found changes in bumble bee abundance related to increased temperatures and precipitation rates (Fourcade et al., 2019).

Mapping of bees is conducted by several institutions, such as the Norwegian Biodiversity Information Centre or the Norwegian Institute for Nature Research. Norway has several ongoing campaigns dedicated to mapping, researching and conservation of bees. Mapping is typically done by either on-site identification and subsequent release, or by vouchering (lethal sampling) where the bees are identified later. According to Gezon et al. (2015), vouchering does not have a significant impact on the bee populations.

In the Norwegian Red List for Species of 2010, bees were included for the first time, and a quarter of Norwegian bee species were classified as threatened. Bees became part of the research areas in Nature Index for Norway in 2010 and 2015. In Norway, managed honey bee losses have not been as dramatic as in the US and several European countries, but are also here found to be related to the presence of pathogens (Dahle, 2010). Norway has banned importation of some industrially raised bees, such as the large earth bumble bee, and only allow the commercial use of this species if they have been bred in Norway (Winter, 2006).

In Norway, the state of ecosystems was assessed in 2000, and the biodiversity in the ocean and cultural landscapes were found to be the most threatened (Nybø et al., 2008). Changes in agricultural management, and the decline of old agricultural practices like grazing, haying and pollarding lead to species and nature types associated with these practices to disappear. It is unlikely that these will be brought back in a large scale since it is costly and work demanding.

Common Bee Pollinators in Apple Orchards

Apple flowers are dependent on insects for cross-pollination to set fruit (Woodcock, 2012). Many wild bee species find suitable habitats in apple orchards and play an important role in pollination, especially species in the *Andrena*, *Bombus*, and *Osmia* families (Park et al., 2010). Some species of the *Osmia* family are effective apple pollinators, but live in hollow cavities of old wood, and so might be naturally scarce in regularly pruned orchards (Gardner & Ascher, 2006). However, honeybees are still the most commonly used managed pollinator by far (*Global Survey of Honeybees and Other Pollinators*, 2018).

2 Aim of the Study

Bees are important pollinators, both honey bees which are managed, and wild bees who are declining in population because of loss of habitat. It is therefore important to monitor and research the species that we have, in order to learn more about their biology and response to climate change and changing habitats. Increased knowledge in this field can aid in conservation of vulnerable populations.

This study is part of a greater project called CliPS (Climate change and its effect on Pollination Services). Originating in Belgium, the project aims to examine pollinator communities in apple orchards in several countries in both the northern and southern hemisphere. The data collected in this survey is just

In this thesis, I will compare number of individual bees and number of bee species in apple orchards between the two target zones Telemark and Hardanger with two and three orchards, respectively. Is there a difference in bee abundance and bee diversity between regions? Is there a difference between honey bees and wild bees in distribution? I will also look at the effects of temperature on the various bee species.

3 Methods

The CliPS protocol (see appendix) describes the method for this project. Researchers in several countries have shown interest in participating, and the protocol was written in great detail, aiming for high replicability and accuracy across all participants. Sampling took place in 2019, and the project leaders expected to have data from 200-250 sites in 38 countries in the end. The sampling and identification were done by the participants in each country, and in cases where identification was difficult, the samples were sent to experts.

3.1 Location, Target Zones and Orchard Selections

Each location in the CliPS project is divided into larger target zones, or regions (defined as a zone of 100 km radius). The target zones should be ecologically contrasting zones, in order to see what effect this can have on the distribution/abundance of bee species. In our location, two orchards were sampled from inland parts of Telemark (Ytre Årnes, Valen), and three from coastal parts of Hardanger (Jaastad, Måkestad, Åkre). This area in Telemark has a continental climate, with moderate precipitation rates, low air humidity and wind, and large daily and annual temperature differences. The chosen part of Hardanger is next to a fjord and has a partially coastal climate with a lot of wind and precipitation. Temperature differences are not that large, with relatively cool summers and mild winters. Both target zones are well known apple producing districts in Norway.

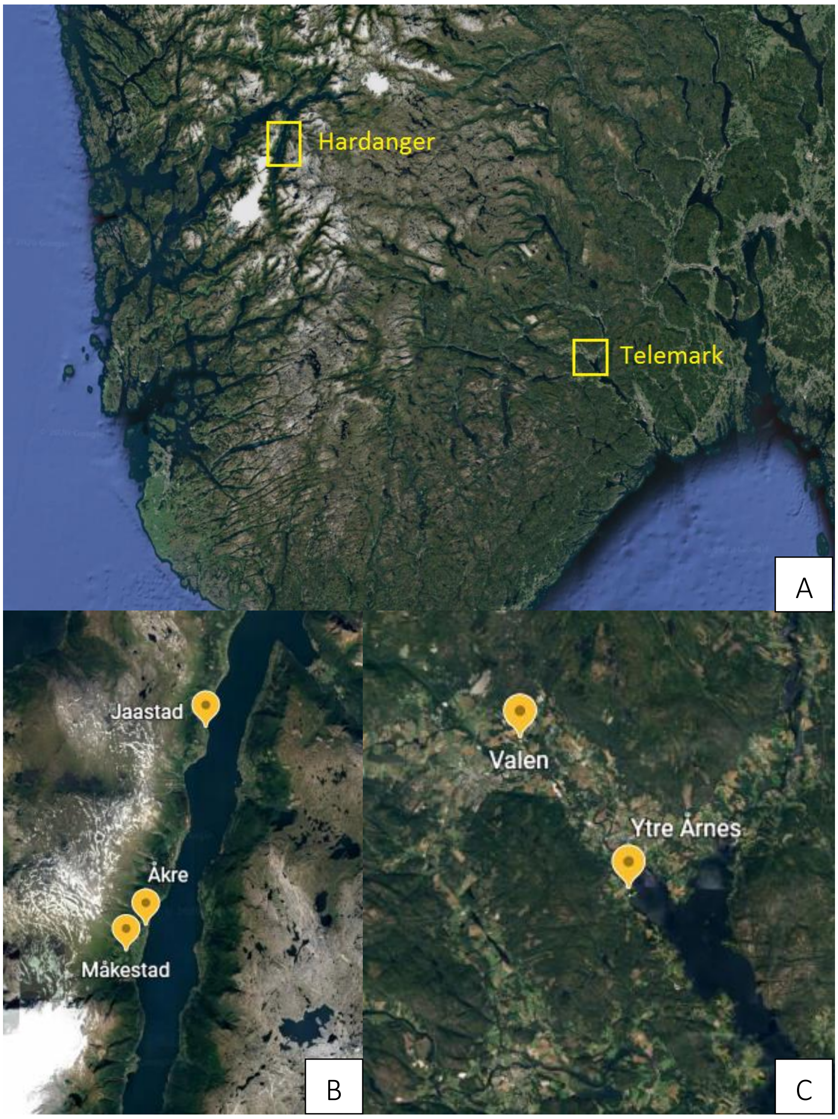


Figure 3-1. A – The target zones in Southern Norway. B – The orchards in Hardanger. C – The orchards in Telemark.

3.2 Orchard Descriptions and Sampling Period

In each orchard, the sampler recorded some properties of the orchard prior to sampling. These include estimation of flower abundance and diversity on the ground inside the orchards, as well as grass height. In the following table, properties and sampling times and conditions for each orchard are described. Landscape type for the given coordinates is taken from NiN (Natur i Norge).

Table 3-1 Information on the five apple orchards, including location, time of flowering and sampling, site recorders, properties of the orchards and landscape and vegetation.

Target zone	Telemark		Hardanger		
Site	Ytre Årnes	Valen	Jaastad	Åkre	Måkestad
Coordinates	59.366666°, 9.185277°	59.425000°, 9.106111°	60.347222°, 6.625833°	60.261111°, 6.573333°	60.250000°, 6.556388°
Elevation (m.a.s.l)	35	100	20	27	220
Start of flowering period	02.05.19	02.05.19	02.05.19	02.05.19	07.05.19
Sampling time	14.05.19 15.05.19 16.05.19	25.05.19 26.05.19 28.05.19	20.05.19 21.05.19	20.05.19 21.05.19	20.05.19 21.05.19
Site recorder	Åsne	Åsne	Åsne	Mathias	Frode
Age of orchard (years)	> 15	> 15	> 15	> 15	> 15
Landscape type/land use	*Open valley landscape below the forest line with a larger lake with human settlement and agricultural dominance.*	*Sloping to undulating hill and mountain landscape below the forest line with human settlement.*	*Steep fjord landscape with human settlement.*	*Open fjord landscape with human settlement.*	*Steep fjord landscape with human settlement.*
Wildflower abundance	Medium	Very low	Medium	Low	Medium
Wildflower diversity	Very low	Very low	Low	Low	Low
Orchard grass height (cm)	< 30	< 30	Ca. 40	< 30	< 30

The sampling period started when the apple trees were blossoming, and the sampling was done between 09.00 to 16.00 on days when the weather was warm and sunny. We noted some daily conditions in each orchard. These included weather conditions (sunny/mixed/cloudy/rainy), average temperature between 09:00-16:00 (< 15° C, 15°-20° C, > 20° C), and average wind speed based on visual cues (e.g. drifting smoke, rustling leaves). Temperature data was checked on Yr.no.

Figure 3-2. Pictures of three of the orchards, showing the apple blossom as well as ground flowers. The pictures are shown in chronological order of when they were sampled. A – Ytre Årnes (Telemark), b – Jaastad (Hardanger), c – Valen (Telemark).

3.3 Sampling of Bees

There were two methods of sampling bees: pan traps and netting. Each sampling day, at around 09.00, the sampler placed out three groups of three differently coloured pan traps (white, yellow and blue). These were provided by the CliPS-project, to ensure that all participants in the project have the same colour, size and material quality of pan traps. The groups were spread across the orchard. In each trio, there were about 2 metres between the individual traps. They were filled with ca. 1/3 litre of soap water, where the mixing ratio was 10 ml liquid, odourless and colourless soap per litre of water. These were checked for insects at around 16.00.

There were two sessions of netting each sampling day, one in the morning and one in the afternoon. Each session lasted 1 hour and 30 minutes. Three different samplers have contributed to this field work. The samplers were instructed according to the CliPS protocol to only catch bees that were around the apple flowers, i.e. not flowers on the ground or other bushes at the edges of the orchard. In addition, all the apple trees in the orchard should be visited, with no extra time being given to any particular area. The sampled area was sometimes a smaller segment of the orchard, in cases where only some of the trees still had flowers left (such as in Valen). The pace should be even, and if a bee escaped capture, the sampler should move on rather than linger around and try to net it.

The netted bees were killed with ethyl acetate, and all bees and unidentified insects were placed into containers filled with an alcohol solution. There was one container for the netted bees, and one for each of the colours of pan traps. The containers were labelled with the date, orchard, and method of collection (net/white/yellow/blue).

3.4 Washing and Preparing Bees

Each specimen container was handled separately, and the contents were poured into a sieve to discard the alcohol solution. The bees were placed into a glass jar with a little liquid soap, and a metal ring and a piece of mesh/mosquito netting was fitted over the opening. Water was added into the jar. To avoid soap water escaping from the jar, the mesh was closed by pressing one hand towards it when shaking for one minute. This was done to remove sticky remnants of pollen from the bees. After this, with the mesh still on, the jar was emptied and refilled with warm water until all the soap suds were washed out. The bees were then left on a sheet of paper to soak up the extra water.

The bees were carefully pinned, by holding the sides of the bee gently while pushing a needle slightly askew through the hard thorax. The pinned bees were then placed on a piece of rubber foam, after a note stating which location, date, and method of catching was used for the respective jars.

Figure 3-3. The rinsed and pinned bees, prior to identification. All bees are sorted by the orchard they came from, the day of sampling, and the catching method that was used (netting, yellow pan traps, white pan traps, or blue pan traps).

3.5 Identifying Bees

Identification of the bee species was done by me. I used the book The Bees of the World (Michener, 2007) to start learning about the various characteristics that can be used to determine bee species. I started by finding all the European honey bees, which have a worldwide distribution, and a similar morphology across the world. For the wild bee species, such as bumble bees, the book *Humler i Norge* (Staverløkk et al., 2012) was used, along with the Norwegian website Artsdatabanken.no (Norwegian Biodiversity Information Centre). These give a description of the registered bee species in Norway. These species have a more limited distribution than the honey bees, and using Norwegian books and sources is faster and more direct.

The first part of the process was to determine whether all the specimen were bees. A large part of the insects in the pan traps were clearly not bees and were discarded. Of the remaining, some were identified, and some I was unsure of. These were sent to an expert for identification, but unfortunately lost in the shipping. Of the netted insects, three were removed, two of which were wasps, and the last was unidentified, but lacked the characteristics of bees.

All bees were sexed, either based on morphological appearance (honey bees) or by counting the segments in the antennae using a magnifying lens. In most bee species, males have 13 segments, while females have 12 (Michener, 2007, p. 43). All sampled bees were female, with a possible exception of a group of unidentified bees, as these might belong to a species that deviates from this standard.

I started the identification process by singling out all the social bees, i.e. the honey bees and bumble bees. The females of these species have corbiculae, or pollen baskets, smooth grooves or indentations in the tibiae, which they fill with pollen. These grooves are surrounded by lines of hairs that keep the pollen in place. Other species have a scopa, a dense mass of elongated and branched hairs on the hind legs that also carry pollen. Some species carry pollen internally instead of having corbiculae or scopas.

The bumble bees have a rounder and thicker form than the honey bees. The honey bees are straighter and have thinner limbs. Bumble bees are identifiable by their tail colour, banding pattern and colours, and presence or absence of corbiculae.

Of the bumble bees, there were a number of *Bombus s. str.*, a subgenus that have a lot of morphologically similar species. The band colours are black and yellow, with a white tail. There are variations on these colours, and the thickness of the stripes, but these can vary between members of the same species even, so I did not decide these down to species level.

After identifying all the social bees, not many were left. I did not have a straightforward method for determining the family or genus of the rest, so I went through the characteristics of several species previously found in Norway (recorded in Artsdatabanken). Specimens were compared to written descriptions and pictures, and through a process of elimination, I came up with suggestions for a few more species.

The descriptions shown in the results only relate to female bees, i.e. queens and workers. Male bees may differ to varying degrees from the female counterparts. All distribution maps are screenshots taken from Artsdatabanken.no, which is the website of the Norwegian Biodiversity Information Centre, and it is the source of pictures and descriptions of the bee species, and also description of nature types in the selected locations.

3.6 Collecting Climate Data

Temperature data have been downloaded from the Norwegian Meteorological Institute, from the stations in Bø (for Valen), Gvarv (for Ytre Årnes) and Ullensvang (for Jaastad, Åkre and Måkestad). A set of temperature data from Åkre and Måkestad (both in Hardanger) was collected from climate loggers belonging to the University of South-East Norway, but only up to May 19th of 2019. To get a picture of the temperatures in the sampling period (May 20th and 21st), these data were compared with the temperatures of Ullensvang, which is located on the other side of the fjord from the three orchards in Hardanger. A test of correlation for the maximum, mean and minimum temperatures from January 1st to May 19th 2019, between Åkre, Måkestad and Ullensvang showed a very strong (> 0.95) positive correlation, and the temperatures for Ullensvang have therefore been used to illustrate the temperature during the days of sampling in Hardanger.

3.7 Data Analysis

The Shannon Index was used to estimate the species diversity.

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

H is the Shannon index value, p_i is the proportion of individuals for each species, **ln** is the natural logarithm, and **s** is the number of species in the community.

The Shannon index uses the species richness (number of species) and their relative abundances (number of individuals in each species) data to measure the diversity in a community. H is generally somewhere between 0-5, with the higher number indicating higher diversity. H can be calculated in several communities in order to compare the diversities to each other.

Because of the uneven number of orchards per target zone (three in Hardanger and two in Telemark), and the uneven number of days each orchard was sampled (two days per orchard in Hardanger, three per all in Telemark), a **balanced ANOVA** was used to test for difference in composition of honey bees and wild bees between the two target zones (Telemark and Hardanger), and among the five orchards. Due to the unbalanced data set on catching methods shown in table 4-1 and figure 4-14, only the netted category of bees was used in the statistical calculation.

4 Results

4.1 Bees in Apple Orchards in Telemark and Hardanger

More bees were captured in Telemark than in Hardanger (table 4-1), with an equal number of sampling days (three orchards with two sampling days in Hardanger, and two orchards with three sampling days in Telemark). Both target zones overall had the same species richness, but there was some variation among the orchards within the target zones. In Måkestad, only one species (the European honey bee) was present. Overall, Telemark showed a greater species diversity, as represented by the Shannon index, but the individual orchard with the highest index value was in Åkre in Hardanger.

Table 4-1 Descriptive statistics of bee abundance, bee species richness and bee species diversity for orchards sampled in 2019. N = number of sampling days. For the purposes of this table, the B.s.str. group is counted as one species. The unidentified bees are excluded.

	Descriptive statistics					Bee species diversity and richness		
Target zones and orchards	N	Min	Max	Mean	SD	Shannon Index	Bee abundance	Species richness
Hardanger	6	33	46	39.5	5.89	0.66	198	9
Jaastad	2	33	41	37	5.657	0.78	79	6
Åkre	2	33	46	39.5	9.192	0.93	74	6
Måkestad	2	38	46	42	5.657	0	84	1
Telemark	6	21	58	33	5.391	0.87	237	9
Ytre Årnes	3	26	35	31	4.583	0.7	105	5
Valen	3	21	58	35	20.075	0.84	93	7

A total of 435 bees were caught during the sampling period. Of these, 91.5 % were identified down to species level, and 5.1 % were identified down to genus level. The remaining 3.4 % were not identified due to loss of the samples during shipping. The unidentified bees were all a type of one or more species minute wild bee, and are added to the pooled category “all wild bees”.

From the 420 identified bees, the *Apidae* family with 98.1 % of all sampled bees was the most abundant and was present in all orchards. From the *Andrenidae* family, a total of four individuals were found, and they were present in three of five orchards. From the *Megachilidae* family, four individuals were sampled, present in two of five orchards (in Telemark only).

Table 4-2 Number of species sampled per family and the percentage of the total bee abundance made up by each family.

Family	Number of species	% of total abundance
Apidae	7 spp + 1 species group	98.1
Andrenidae	2 spp	1
Megachilidae	1 sp	1

Honey bees constituted 81.84 % of all sampled bees (table 4-3). It was the most abundant species in all orchards, and the only species to be present in every orchard. The *B. s. str.* and unknown groups, which are not identified to species level, make up 8.51 %. The remaining identified species range from 1-13 individuals, which corresponds to 0.23 – 2.99 % of the total bee abundance.

Table 4-3 Count and percentage of bees sampled in all the orchards in descending order of magnitude.

Bee species	Count	Percent
A. mellifera (Linnaeus, 1758)	356	81.84
B. s. str.	22	5.06
Unknown	15	3.45
B. hypnorum (Linnaeus, 1758)	13	2.99
B. pratorum (Linnaeus, 1761)	13	2.99
Osmia bicornis (Linnaeus, 1758)	4	0.92
Andrena scotica (Perkins, 1916)	3	0.69
B. lapidarius (Linnaeus, 1758)	3	0.69
B. muscorum (Linnaeus, 1758)	2	0.46
B. pascuorum (Scopoli, 1763)	2	0.46

Andrena nigroaenea (Kirby, 1802)	1	0.23
Eucera longicornis (Linnaeus, 1758)	1	0.23
Sum	435	100

As for the sex distribution of the sampled bees, 100 % of identified bees were female. A total of 8 queens were identified, all of which were bumble bees (table 4-4), and all caught with a net. All sampled *B. lapidarius* and *B. pascuorum* were queens. Of *B. hypnorum* and *B. s. str.*, 1 of 13 and 2 of 22 were identified as queens, respectively.

Table 4-4 List of bee queens with species name, and the target zone and orchard where they were captured.

Queens	Target zone	Site
B. hypnorum	Hardanger	Åkre
B. lapidarius	Telemark	Ytre Årnes
B. lapidarius	Telemark	Valen
B. lapidarius	Telemark	Valen
B. pascuorum	Hardanger	Åkre
B. pascuorum	Hardanger	Åkre
B. s. str.	Telemark	Ytre Årnes
B. s. str.	Telemark	Valen

Species richness and species abundance were plotted against each other, and shows a negative trend (figure 4-1), meaning where there were more bee species, there were fewer bees. However, there was no significant relationship between the number of individual bees and the number of species. The trend is heavily influenced by the outlier Måkestad, where only honey bees were sampled.

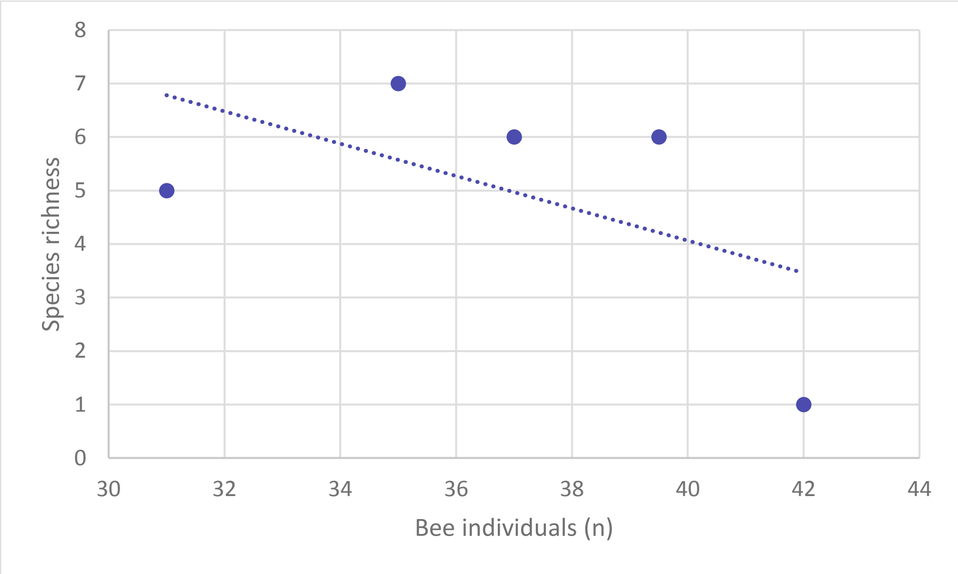
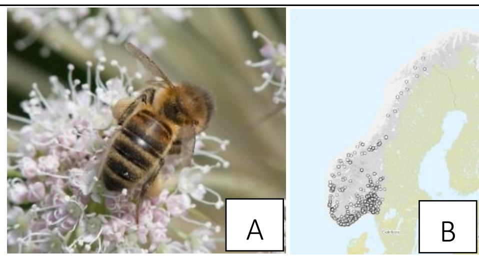
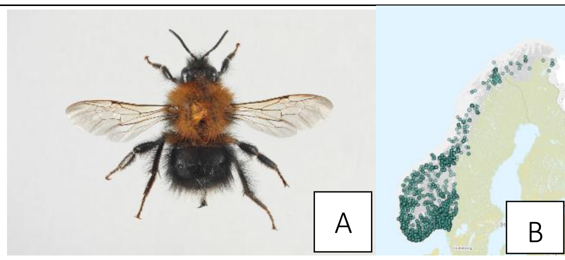


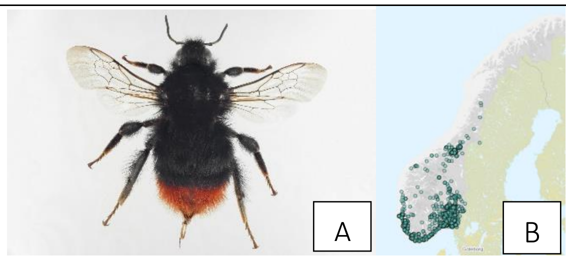
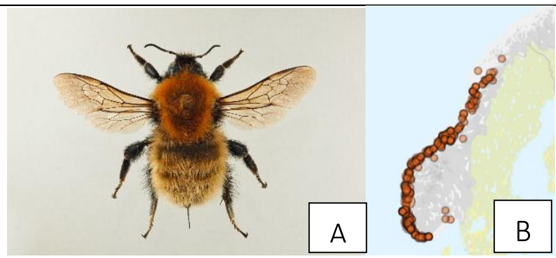
Figure 4-1. Dotplot showing species abundance and species richness in all orchards. The dots represent the daily average number of all bees sampled in the five separate orchards, and their respective species richness.

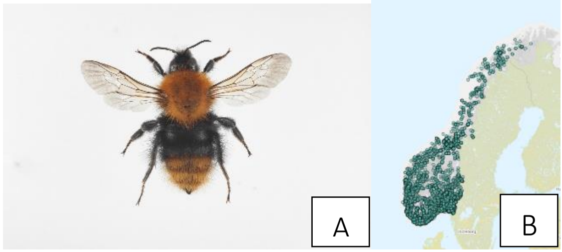
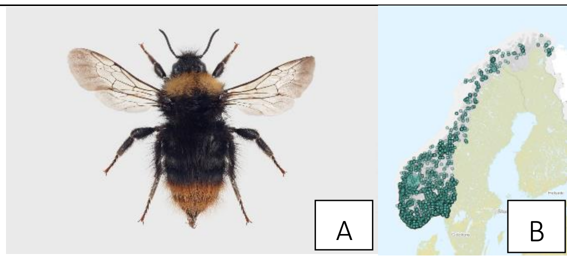
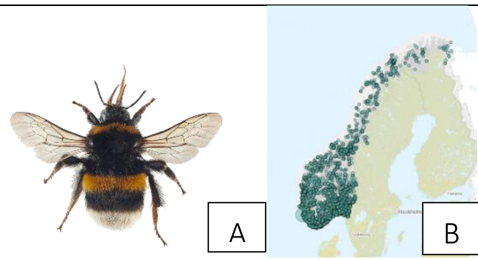
4.2 Sampled Species Description

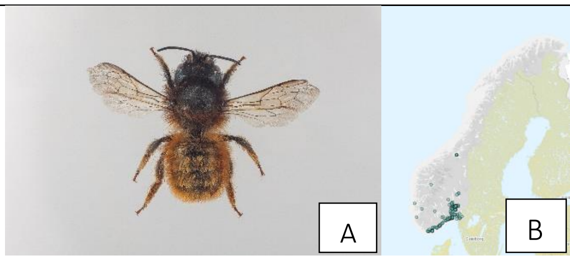
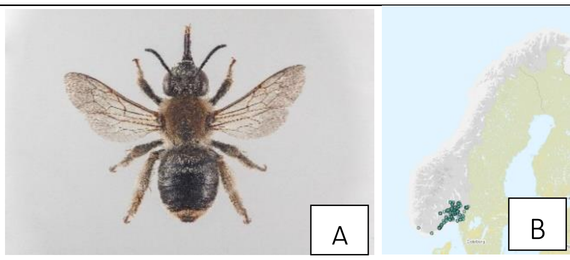
Characteristics of the sampled bee species are presented in table 4-5.

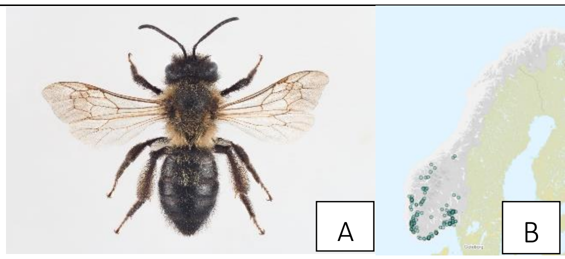
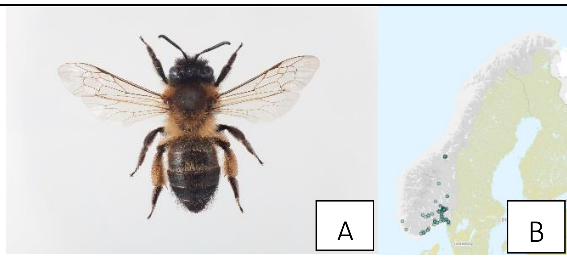
Table 4-5 Description of the sampled bee species, what they look like, how they can be identified, and the distribution in Norway based on observations in Artsdatabanken.

Name	Description	Picture
European honey bee *(A. mellifera)*	Wasp-like in shape, but without the pinched waist. Hairy body and legs, and a corbicula in the tibia of the hind leg. Colours can vary a little, but they are usually light brown, with yellow and brown bands on the abdomen.	 *Figure 4-2. A – A. mellifera. Photo by Hallvard Elven, Naturhistorisk museum, Universitetet i Oslo. CC BY 3.0. (https://www.artsdatabanken.no/Files/1072). B - Map of A. mellifera observations.*
Tree bumble bee *(B. hypnorum)*	Brown to orange hairs on the thorax. Black hairs on the abdomen, with a white tail. Can be mistaken for *B. cingulatus*, but that one has black hairs on part of the thorax between the wings. (*B. hypnorum* may lose the hairs on this part, so that the black body can resemble black hairs.)	 *Figure 4-3. A - B. hypnorum worker. Photo Arnstein Staverløkk, Norsk institutt for naturforskning. CC BY 3.0. (https://artsdatabanken.no/Files/6944). B - Map of B. hypnorum observations.*

Red-tailed bumble bee (*B. lapidarius)*	The Queen is large, with a black body and a red/orange tail. It has black hairs on the corbiculae on the hind legs, which distinguishes it from *B. ruderarius* and *B. sylvarum*, who both have orange hairs. Small workers are reminiscent of other black bumble bees with red tails.	 *Figure 4-4. A - B. lapidarius. Photo Arnstein Staverløkk, Norsk institutt for naturforskning. CC BY 3.0. (https://www.artsdatabanken.no/Files/7015). B - Map of B. lapidarius observations.*
Large carder bee (*B. muscorum)*	Brown to orange thorax hairs and yellow abdomen hairs. May be confused with light-coloured *B. pascuorum* in parts of Northern Norway, but it is distinguishable by the contrast in colour on the thorax and the abdomen. May also be confused with *B. humilis*, but *B. humilis* does not share geographical extent with *B. muscorum*.	 *Figure 4-5. A - B. muscorum. Photo Arnstein Staverløkk, Norsk institutt for naturforskning. CC BY 3.0. (https://www.artsdatabanken.no/Files/7024). B - Map of B. muscorum observations.*

Common carder bee *(B. pascuorum)*	Varying in colours, but often brown/orange colour on thorax and tail. They often have black hairs on the first tergite of the abdomen, but these may also be missing, or greyish in colour. The ones without the black hairs may be confused with *B. humilis* and *B. muscorum*.	 *Figure 4-6. A - B. pascuorum. Photo Arnstein Staverløkk, Norsk institutt for naturforskning. CC BY 3.0. (https://www.artsdatabanken.no/Files/6901). B - Observations of B. pascuorum.*
Early bumble bee *(B. pratorum)*	Yellow hairs on the part of the thorax between the head and the wings. Red to orange tail.	 *Figure 4-7. A - B. pratorum. Photo Arnstein Staverløkk, Norsk institutt for naturforskning. CC BY 3.0. (https://www.artsdatabanken.no/Files/6967). B - Observations of B. pratorum.*
B. s. str.	This group of species share many features, and individuals from each species may have several morphological variations. Among the shared common characteristics are	 *Figure 4-8. A – B. terrestris. Photo Arnstein Staverløkk, Norsk insititutt for naturforskning. CC BY 3.0.*

	patterns of black and yellow bands on the abdomen, and a white tail. The group consists of the following species: *B. lucorum* *B. magnus* *B. terrestris* *B. cryptarum* *B. soroensis* *B. jonellus* *B. sporadicus* *B. hortorum*	*(https://artsdatabanken.no/Pages/F6164).* *B - Observations of species in the B. s. str. group.*
Red mason bee *(Osmia bicornis)*	Characterized by two horn-like formations on the forehead.	 *Figure 4-9. A – O. bicornis. Photo Arnstein Staverløkk, Norsk institutt for naturforskning. CC BY 3.0. (https://www.artsdatabanken.no/Files/625).* *B - Observations of O. bicornis.*
Long-horned bee *(Eucera longicornis)*	The male has characteristically long antennae, but the females' antennae are shorter. The female resembles a large Andrena bee but has a more compact shape.	 *Figure 4-10. A - Female E. longicornis. Photo Arnstein Staverløkk, Norsk institutt for naturforskning. CC BY 3.0.*

		(https://www.artsdatabanken.no/Files/687). B - Observations of E. longicornis.
Chocolate mining bee *(Andrena scotica)*	The male has very long antennae. The female has shorter antennae, and can be confused with other Andrena species, but they have dark hairs on the hindlegs, unlike the very similar Andrena nigroaenea.	 *Figure 4-11. A - Female A. scotica. Photo Arnstein Staverløkk, Norsk institutt for naturforskning. CC BY 3.0. (https://www.artsdatabanken.no/Files/631). B - Observations of A. scotica.*
Buffish mining bee *(Andrena nigroaenea)*	Large and commonly found in Southern Norway. Red hairs on the hind leg tibiae. May be confused with Andrena scotica, but the antennae are shorter than Andrena scotica.	 *Figure 4-12. A - Female A. nigroaenea. Photo Arnstein Staverløkk, Norsk institutt for naturforskning. CC BY 3.0. (https://www.artsdatabanken.no/Files/651). B - Observations of A. nigroaenea.*
Unknown	These specimens were smaller than the others. They had hairy legs. Their shapes were similar, but the sizes varied a little, and it is not confirmed if these all belong to the same species.	 *Figure 4-13. Two of the unidentified bees.*

4.3 Catching Method

The capture methods showed different results (figure 4-14 and annex 4). From all the sampled bees, 94 % were caught with a net, and 6 % were caught in pan traps. Of the pan trapped bees, 68 % were in the yellow pan trap, 20 % in the white, and 12 % in the blue. The pan traps attracted ten honey bees and 15 wild bees; there were no bumble bees among the wild bees, only minute species.

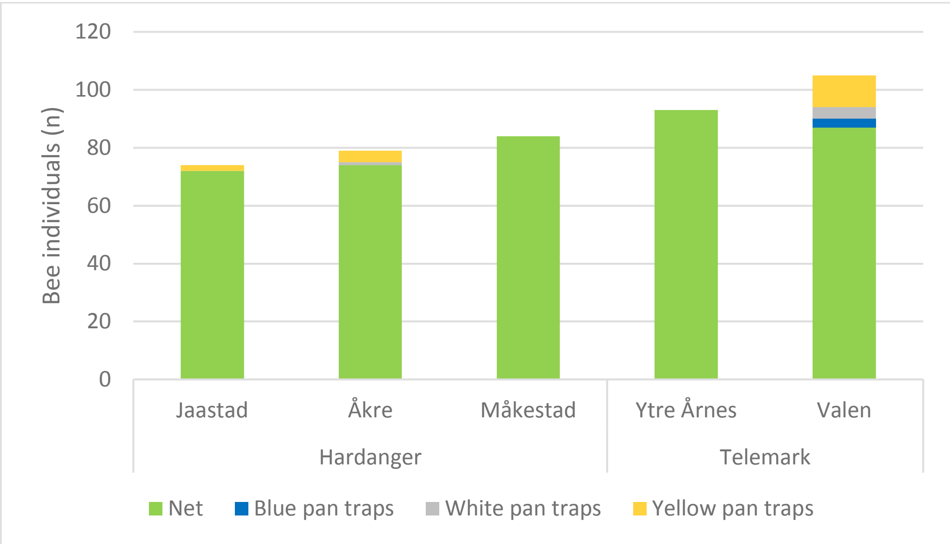


Figure 4-14. Number of sampled bees divided by catching method for each orchard.

As seen in figure 4-14 and annex 4, the pan traps did not catch any bee individuals in either Måkestad or Ytre Årnes. They were most successful in Valen, with 18 bees in total caught in the three different pan traps. The blue pan traps were only successful in Valen, the white pan traps in Åkre and Valen, while the yellow were able to catch bees in Jaastad, Åkre and Valen.

4.4 Wild Bees vs. Honey Bees

The balanced ANOVA analysis of netted bees (see annex 3) showed that there was no significant difference between the target zones or orchards with regard to the number of honey bees or wild bees. The daily variation on each orchard was greatest in

Valen (Figure 4-15), where the largest discrepancy between the mean and corresponding minimum and maximum values is found, with 51 honey bees sampled on day one, and only 15 and 17 sampled the other days.

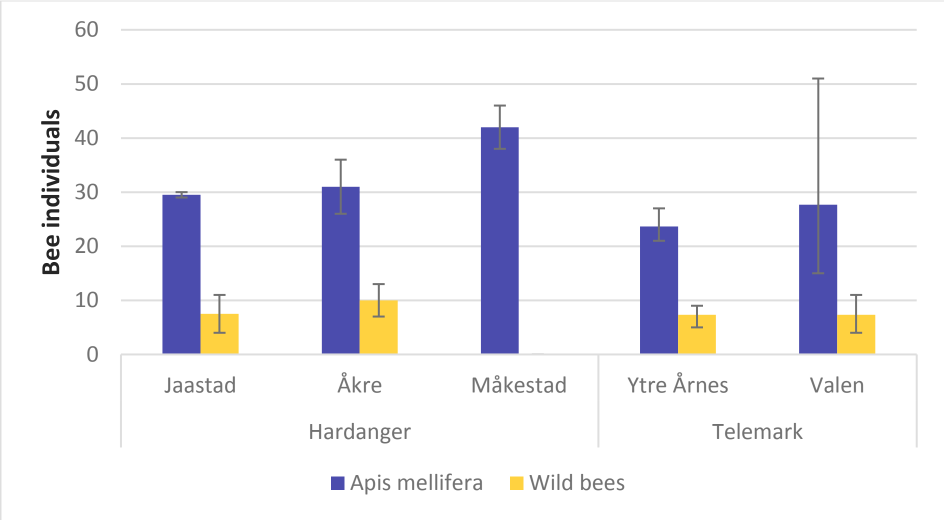


Figure 4-15. Daily average of honey bees and wild bees sampled in each orchard. Includes all catching methods. All bees that are not identified to species level are included in the pooled wild bees category. There are two sampling days for all the orchards in Hardanger, and three for all in Telemark. The error bars show the maximum and minimum daily values.

The following dotplot (Figure 4-16) shows the relationship between the number of netted honey bees and wild bees. There is a negative trend in Hardanger, strongly influenced by the two outliers (both from Måkestad, with no wild bees sampled), but it is not significant. The slightly positive trend in Telemark is significant, with a p-value of 0.006.

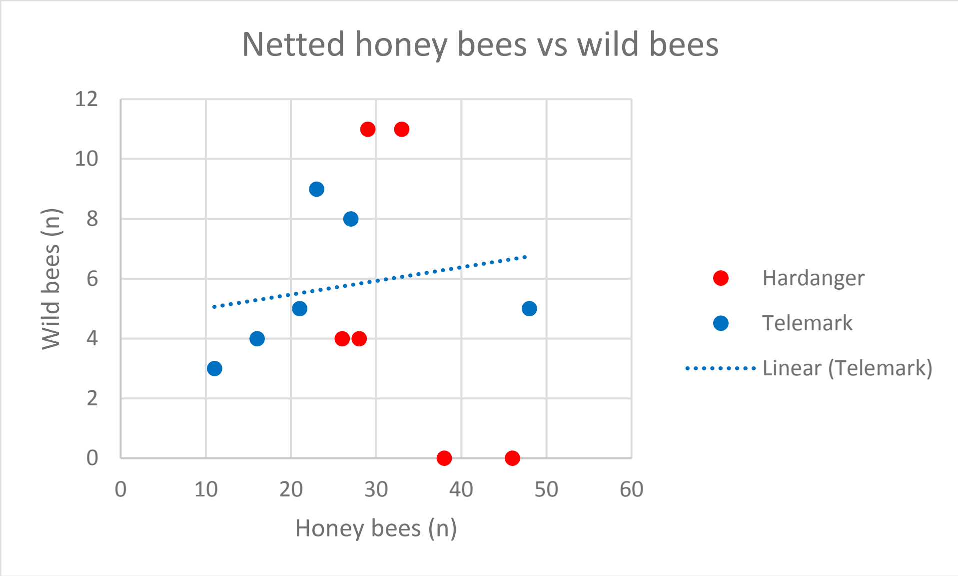


Figure 4-16. Number of netted honey bees vs netted wild bees. Each dot represents a day's worth of sampling in the orchards. The regression equation for Telemark is: Wild bees = 0.4913 + 0.1149 honey bees.

4.5 Temperature Data and Bees

The two meteorological stations in Telemark (figure 4-17 A and B) generally show lower temperatures from January to May than the one in Hardanger (figure 4-17 C). The range of temperatures is not as high in Ullensvang. A warm April accelerated the development of the apple tree flower buds in both target zones. However, they both had a period of cold temperatures in early to mid-May, and in Telemark, there were frost nights in some areas after the flowering period began (around the 2nd of May).

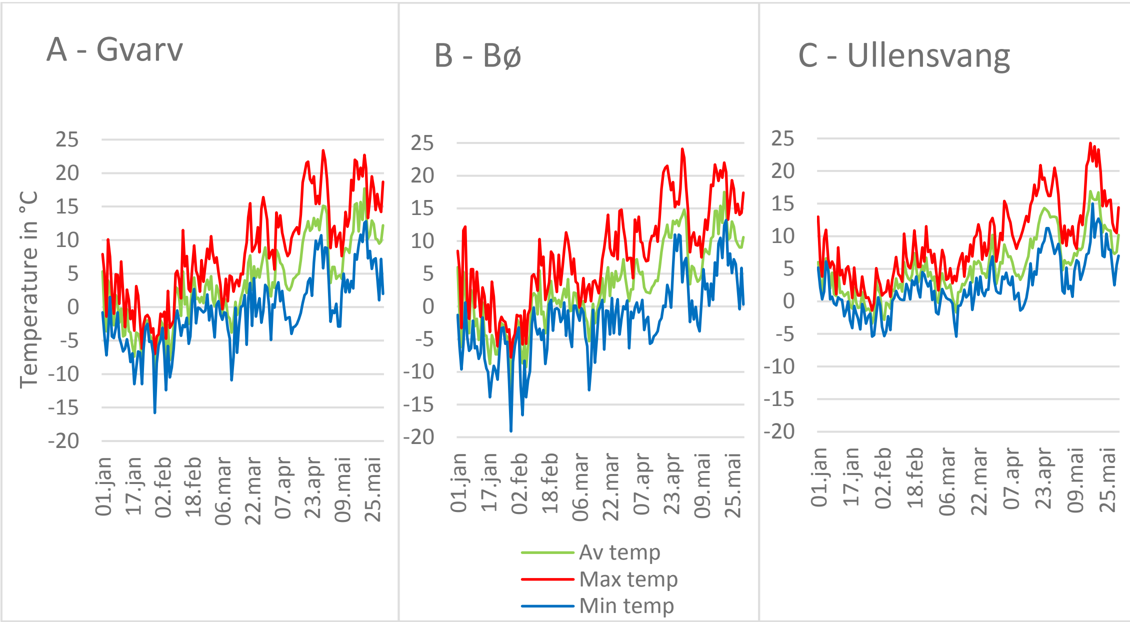


Figure 4-17. Temperatures in °C, January-May 2019, from the weather stations closest to each orchard (Gvarv - Ytre Årnes, Bø - Valen, Ullensvang – Jaastad/Åkre/Måkestad).

During the days of sampling, in general, more bees were captured on days with warmer mean temperatures (Figure 4-18).

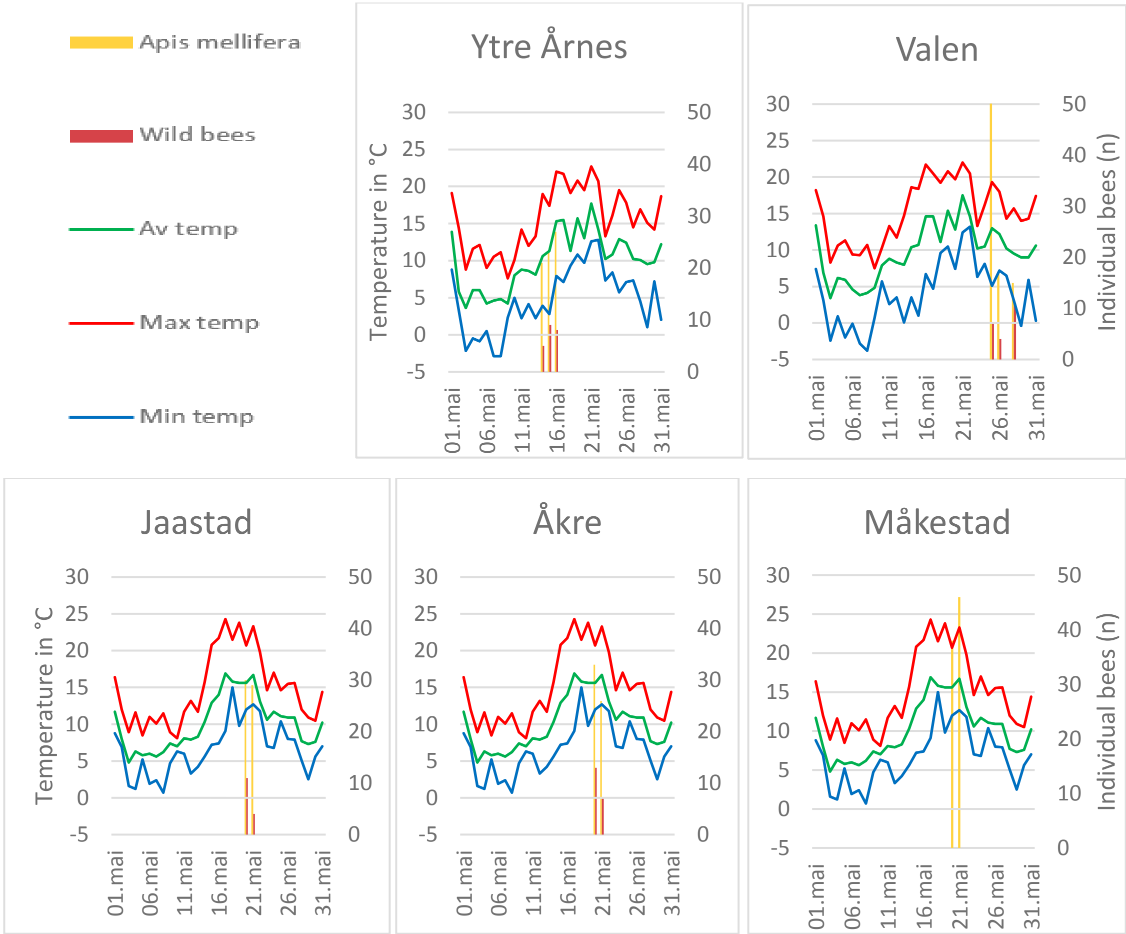


Figure 4-18. Temperature graphs of May 2019 from each orchard with columns showing the number of honey bees and wild bees caught on the sampling days.

5 Discussion

5.1 Bee Species Composition in Apple Orchards

The 10 different bee species identified in apple orchards in Hardanger and Telemark in the present study, belong to genera that are generally common to find in apple orchards (Park et al., 2010). The European honey bee was the most abundant in all orchards, and even exclusively present in Måkestad in Hardanger. This is not unexpected, since the apple orchards frequently utilize honey bees to optimize pollination of the fields, and they are the most abundant bee species in orchards (Klein et al., 2007). Using honey bees in the pollination process increases both the yield and the quality of the fruit sets in crosspollinating apple trees (Park et al., 2010).

The honey bee is commonly the most abundant pollinator in apple orchards worldwide (Gardner & Ascher, 2006; *Global Survey of Honeybees and Other Pollinators*, 2018; Ramírez & Davenport, 2013). In my surveys, honey bees constituted 81.84 % of all sampled bees. The largest group of wild bee species captured in my survey was the bumble bees. During the sampling period in May 2019, several species were still at an early stage, as suggested by the number of queens captured in some species (especially *B. lapidarius* and *B. pascuorum*). As the queens were still in the process of establishing their nests during the apple blossom, the lack of workers in these species may also explain some of the low total abundance of bumble bees. All identified bees were female. This is not unusual, as the study sites are foraging areas, and it is the females of the social species that are responsible for foraging, and that are more prevalent at that stage of the apple blossom (Michener, 2007). Bumble bees are spread almost all over Norway, although less in Northern Norway (figures 4-3 B, 4-4 B, 4-6 B, 4-7 B, 4-8). *B. muscorum* is almost exclusively found along the coastline, mostly on the southern and western part of Norway (figure 4-5 B). Thus, my results showing *B. muscorum* in Hardanger only, agree with this observation.

The remaining identified wild bees were all solitary species. This explains some of their low abundance, as compared to social species like bumble bees and especially honey bees, their nests do not house many individuals. Some solitary species lay eight or fewer eggs in a lifetime (Michener, 2007).

Wild bee contribution to apple tree pollination is not as well documented as honey bees', as it is difficult to separate experimentally. However, studies indicate that wild bees provide a high level of pollination, and that they are equally (or sometimes more) effective than honey bees (Blitzer et al., 2016; Rader et al., 2012). *Andrena spp*. and *Bombus spp*. deposit more pollen than honey bees since they directly contact the stigma more often, but per-visit they were found to be equally effective as honey bees after accounting for resulting fruit and seed set (Park, 2014). Bumble bees tend to visit more flowers than honey bees, and so may carry a lot of pollen that is incompatible with the apple flowers, reducing their efficiency as cross-pollinators of apple trees (Kendall, 1973).

Wild bee abundance and richness are shown to be negatively impacted by agricultural practices (Le Féon et al., 2010). This is especially true of intense farming areas, with low diversity (Kennedy et al., 2013), but the presence of surrounding high-quality habitats can offset this effect to some degree (Kennedy et al., 2013). Therefore, to get the whole picture of agricultural impact on wild bee communities, it is necessary to consider a wider area (Kennedy et al., 2013).

There are higher levels of wild bee richness and abundance in organic and diverse agricultural fields than in conventional fields with low diversity (Kennedy et al., 2013). I have not taken into consideration the management type or pesticide use in the present study, as there were too few sites to give reliable analyses of effects of different practices. The much larger dataset in the overall CliPS-project also includes management practice, and the project aims to examine the effect of different practices on bee richness and abundance.

5.2 Bee Species Richness and Abundance – Do Honey Bees Outcompete Wild Bees?

About a third of all bee species in Norway appear in the Norwegian red list for species from 2015. Of the bee species sampled in this survey, the tree bumble bee, early bumble bee, red-tailed bumble bee, common carder bee, red mason bee, and buffish mining bee were listed as Least Concern in both 2010 and 2015. The chocolate mining bee was not listed at all. The large carder bee was listed as Near Threatened in both 2010 and 2015. The long-horned bee was listed as Near Threatened in 2010, but in 2015 its status was changed to Least Concern. It is uncertain if this is reflective of a real improvement in conditions, as its distribution is connected to dry open fields, which are receding (Henriksen & Hilmo, 2015).

In this study, across all the orchards, the majority of sampled bees were honey bees, far outnumbering all the wild bee species combined. The relationship and possible competition between honey bees and wild bees have been a subject of research in recent years. Although honey bees are native to Europe, they require human intervention to persist in Northern Europe, at least at high densities (Goulson & Sparrow, 2009), and there is a possibility of human-mediated negative impacts on other pollinating insects. Bumble bees are naturally abundant in temperate zones in the northern hemisphere but have suffered range declines in the last decades. This is primarily due to agricultural intensification, but also due to a higher density of honey bees (Goulson & Sparrow, 2009).

There are many studies implying negative impacts of increased densities of honey bees near wild bees. Experimentally introduced honey bee hives significantly reduced foraging rates and reproductive success of bumble bee colonies in close proximity to the hives in Western USA (Thomson, 2004). Bumble bee foragers were more abundant further away from experimentally introduced honey bees in Scotland (Thomson, 2006). Increased densities in honey bee populations have also led to smaller body size in bumble bee workers, which is believed to be a detriment to the colony (Goulson & Sparrow, 2009).

These negative impacts might be due to competition for foraging grounds between the species (Mallinger et al., 2017). This competition does not only impact wild bees, but can also be detrimental to honey bees, reducing nectar and pollen harvesting (Henry & Rodet, 2018). In a study by Thomson (2006), it was shown that there was a positive relationship between the number of honey bees and the number of bumble bees relatively early in the season, at a time when floral resources were abundant, but they became progressively more negative in the late season as resources decreased and there was a higher niche overlap between honey bees and bumble bees. Transmission of pathogens from honey bees to wild bees is another risk factor when densities of honey bees increase (Mallinger et al., 2017).

The regression analysis for the relationship between honey bees and wild bees was positive in Telemark ($p = 0.006$). This suggests that – for Telemark – where there are more honey bees, there are also more wild bees. This seems to go against a lot of research on the detrimental effects of competition between honey bees and wild bees. The positive relationship could be due to it being early in the season and many foraging opportunities being available, as was shown by Thomson (2006), but when looking at the two orchards, there were large differences in flower abundance. Ytre Årnes (figure 3-2 A), was at the peak apple blossoming period, and also had a medium abundance of other wildflowers on the ground. Valen was at the very end of the blossoming (figure 3-2 C), with barely any apple flowers remaining, and basically no wildflowers on the ground. The result could be due to other unknown confounding factors. Although statistically significant, the regression for Telemark had a low adjusted R squared value of 26.44 %, meaning just over a quarter of the variation in the data is explained by this model.

There are also differences in how strong the impact of competition is on different species. Long-tongued bumble bee species have (generally) a shorter foraging range than honey bees or short-tongued bumble bees (Walther-Hellwig & Frankl, 2000). Honey bee hives being experimentally placed near patches of wild flowers in an agricultural landscape showed that the abundance of some short-tongued species (*B. terrestris*) had minor spatial changes, while long-tongued species (such as *B. pascuorum* and *B. muscorum*), were more negatively affected by competition as resources close by were depleted (Walther-Hellwig et al., 2006). Limited range foraging bumble bees cannot shift to alternative food plants as easily, and even short periods of food shortage can expose the colonies to decreased defence against parasites and affect brood development. Mass flowering crops increases densities of flexible generalists, possibly displacing long-tongued bumble bees in nearby foraging habitats (Walther-Hellwig et al., 2006).

There are several unknown factors influencing the rarity of a bee species. For example, the foraging behaviour of bumble bees can be affected by the presence of other bumble bee species – the bumble bee can decide which flower to forage on based on what other species have been on it (Lázaro et al., 2011). This may affect how different species respond when the abundance of another species increases, but it is not yet known in what way. Bees that start late in the season may struggle to find available nest sites and enough available flowers, based on their relationship with other bee species.

5.3 Effect of Temperature on the Foraging Activity of Bees

Bees exist in an extraordinary range of thermal environments, from hot deserts to the high arctic (Michener, 2007). Bees' activities are limited by temperature and the available food sources, and the colder the body temperature (below peak activity temperature), the slower the rate of foraging (Heinrich, 1977). The ability to thermoregulate during flight varies in different species, and ecological and phylogenetic effects are more significant than the body mass of the bees (Roberts & Harrison, 1998). Bees thermoregulate during flight by balancing heat gain and heat loss via convection, evaporation, and metabolic heat production (Roberts & Harrison, 1998).

The bee survey in Valen showed a large discrepancy in number of honey bees sampled between the first day and the two next. Due to low temperatures and sporadic rain, the third day of sampling was delayed for one day. Being late in the season, and having lower temperatures, the abundance of honey bees seemed to drop more drastically than wild bees. The few remaining flowers on the trees, along with the absence of ground flowers might give rise to competition between honey bees and especially bumble bees, who may have had an advantage in the lower temperatures.

Looking at the temperatures, there was a peak in honey bee abundance on May 25th in Valen, following a colder day (May 24th) (figure 4-18). This might be due to an increased foraging activity following a day of little activity. The next sampling days are slightly colder, and yielded fewer honey bees, indicating that their activity is decreased.

Honey bees can remain in activity at higher temperatures than bumble bees, who in turn are more active in lower temperatures than honey bees are. Bumble bees can fly in temperatures from 9-10°C, while honey bees will not forage in temperatures of 16°C or lower (Woodcock, 2012). In flight, honey bees greatly increase evaporative heat loss with ambient temperature above 33°C (Woodcock, 2012). They also thermoregulate by varying metabolic heat production, primarily through wingbeat frequency (Roberts & Harrison, 1998). They have been reported to fly in air temperatures up to at least 46°C (Heinrich, 1980), and are able to avoid overheating by keeping thoracic temperature close to ambient temperature.

Due to their insulating fur and high metabolism, bumble bees' body temperature is higher than the surrounding air temperature, and this allows them to forage in many types of weather (Heinrich, 1977). Bumble bees are able to redistribute heat to the abdomen during flight, and cool down through convective heat loss (Roberts & Harrison, 1998). Bumble bees are at peak foraging activity at 25°C, but cease at 32°C and over (Kwon & Saeed, 2003). Flight muscles are contracted about 130 times per second, which results in heat production (Heinrich, 1977), and the body temperature increases from equal to air temperature while at rest, to well over 30°C before take-off. This ensures that the muscles twitches are fast enough to lift the bumble bees. Bumble bees must collect more calories than they use, and so most of their time is spent foraging (Heinrich, 1977).

Honey bees and bumble bees can start foraging early in the morning thanks to their thermoregulation, and they can possibly deplete nectar before many other wild species begin their foraging (Goulson, 2003). However, *Osmia* visits flowers at lower temperatures than honey bees do (McGregor, 1976). *Osmia cornuta* was active in lower temperatures and lower solar radiation, and were also active in strong winds and light rain, unlike the honey bees (Vicens & Bosch, 2000). They have a longer seasonal and daily pollination period than honey bees due to their difference in weather and temperature tolerance.

6 Conclusion

The surveys of bee species in apple orchards in Telemark and Hardanger revealed ten different species: European honey bee, tree bumble bee, red-tailed bumble bee, large carder bee, common carder bee, early bumble bee, red mason bee, long-horned bee, chocolate mining bee, and buffish mining bee. In addition, a group of bumble bees were identified down to the *B. s. str.* family level.

There were no significant differences in the composition of honey bees and wild bees between the two target zones. The European honey bee was by far the most abundant bee species in the surveyed orchards in both Hardanger and Telemark. This confirms that honeybees are important pollinators in apple orchards. The second most abundant bee species group were the bumble bees. Honey bees are used as pollinators in agriculture because they can be supplied in large enough numbers to pollinate a large amount of flowers. Honey bee declines makes it interesting to look at wild bees as replacement pollinators. Several species of wild bees are also more active in colder temperatures than honey bees. Without honey bees, there would probably not be enough bees to pollinate all the apple trees in the surveyed orchards.

The abundance and diversity in wild bee species could possibly be improved by enhancing nesting habitats close to the orchards and providing attractive foraging grounds through wildflower meadows when the crop blossoms are low. This could reduce competition between wild bees and honey bees, through abundant available food resources. It can also provide wild bees with nutrition after honey bee hives are eventually removed at the end of the season.

This type of sampling in only a few days out of one year is not enough to give a complete picture of the pollinator bee species in the apple orchards in Hardanger and Telemark. Repeated surveys over a longer period can give a better picture of the pollination community in these orchards, and also a better understanding of the effect of temperature on the abundance and diversity of bees.

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Figure 4-4. A - B. lapidarius. Photo Arnstein Staverløkk, Norsk institutt for naturforskning. CC BY 3.0. (https://www.artsdatabanken.no/Files/7015). B - Map of B. lapidarius observations.

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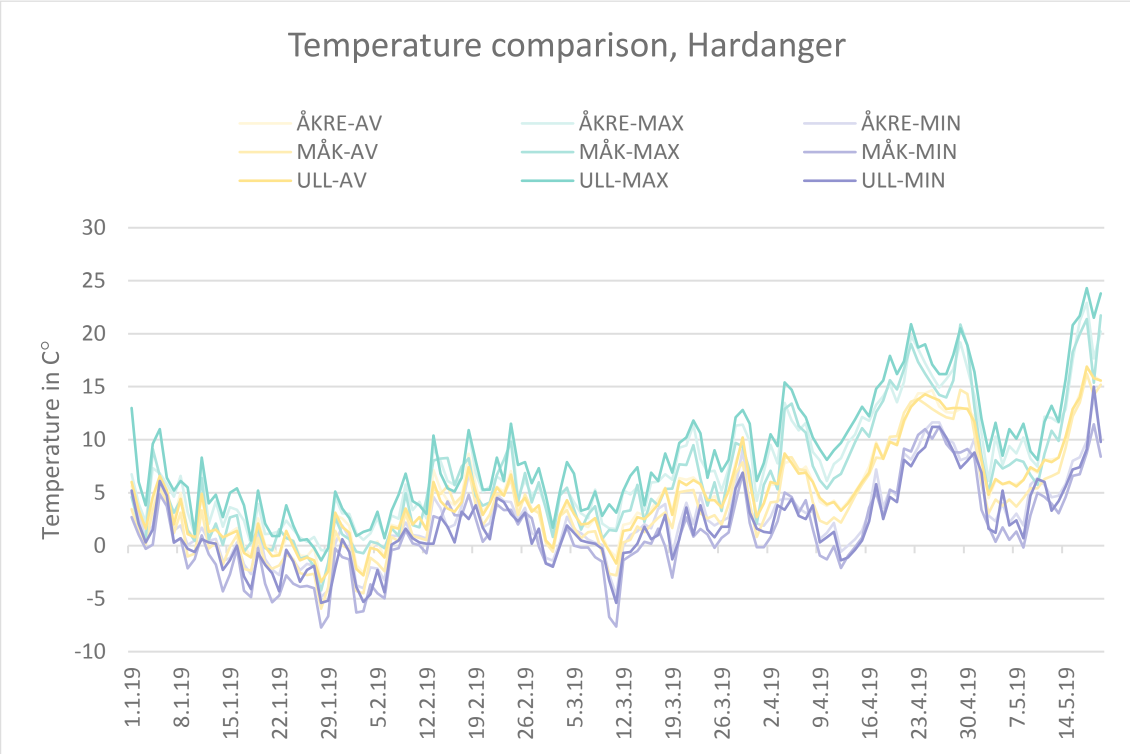
Annexes

Annex 1: Temperature comparison graph, Hardanger.



Annex 2: Test of correlation between temperatures in Åkre, Måkestad and Ullensvang.

	ÅKRE-AV	*MÅK-AV*	*ULL-AV*
ÅKRE-AV	1		
MÅK-AV	0.98526216	1	
ULL-AV	0.99627346	0.98450634	1

	ÅKRE-MAX	*MÅK-MAX*	*ULL-MAX*
ÅKRE-MAX	1		
MÅK-MAX	0.97806545	1	
ULL-MAX	0.98228195	0.96854073	1

	ÅKRE-MIN	*MÅK-MIN*	*ULL-MIN*
ÅKRE-MIN	1		
MÅK-MIN	0.97020265	1	
ULL-MIN	0.98005057	0.95270963	1

Annex 3: Balanced ANOVAs of *Apis mellifera* and wild bees versus zone and site

ANOVA: All_wild versus zone

Factor Information

Factor	Type	Levels	Values
zone	Fixed	2	Hardanger; Telemark

Analysis of Variance for All_wild

Source	DF	SS	MS	F	P
zone	1	1.333	1.333	0.09	0.773
Error	10	151.333	15.133		
Total	11	152.667			

Model Summary

S	R-sq	R-sq(adj)
3.89016	0.87%	0.00%

ANOVA: All_wild versus site

Factor Information

Factor	Type	Levels	Values
site	Fixed	5	Aakre; Valen; Jaastad; Maakestad; Ytre Aarnes

Analysis of Variance for All_wild

Source	DF	SS	MS	F	P
site	4	93.00	23.250	2.73	0.117
Error	7	59.67	8.524		
Total	11	152.67			

Model Summary

S	R-sq	R-sq(adj)
2.91956	60.92%	38.58%

ANOVA: Apis_mellifera versus zone

Factor Information

Factor	Type	Levels	Values
zone	Fixed	2	Hardanger; Telemark

Analysis of Variance for Apis_mellifera

Source	DF	SS	MS	F	P
zone	1	243.0	243.0	2.19	0.170

Error	10	1110.7	111.1
Total	11	1353.7	

Model Summary

S	R-sq	R-sq(adj)
10.5388	17.95%	9.75%

ANOVA: Apis_mellifera versus site

Factor Information

Factor	Type	Levels	Values
site	Fixed	5	Aakre; Valen; Jaastad; Maakestad; Ytre Aarnes

Analysis of Variance for Apis_mellifera

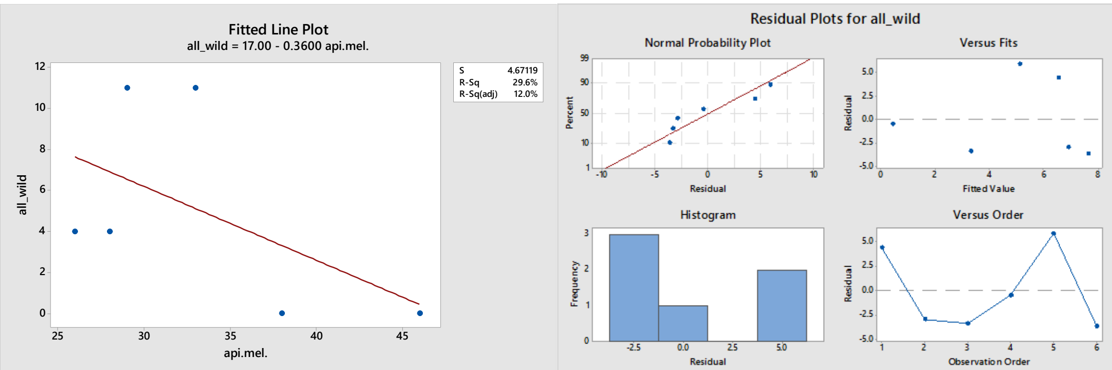
Source	DF	SS	MS	F	P
site	4	472.0	118.0	0.94	0.495
Error	7	881.7	126.0		
Total	11	1353.7			

Model Summary

S	R-sq	R-sq(adj)
11.2229	34.87%	0.00%

Annex 4: Regression analysis of wild bees and honey bees.

<u>Netted honey bees vs netted wild bees, Hardanger:</u>



Regression Analysis: all_wild versus api.mel.

The regression equation is
all_wild = 17.00 - 0.3600 api.mel.

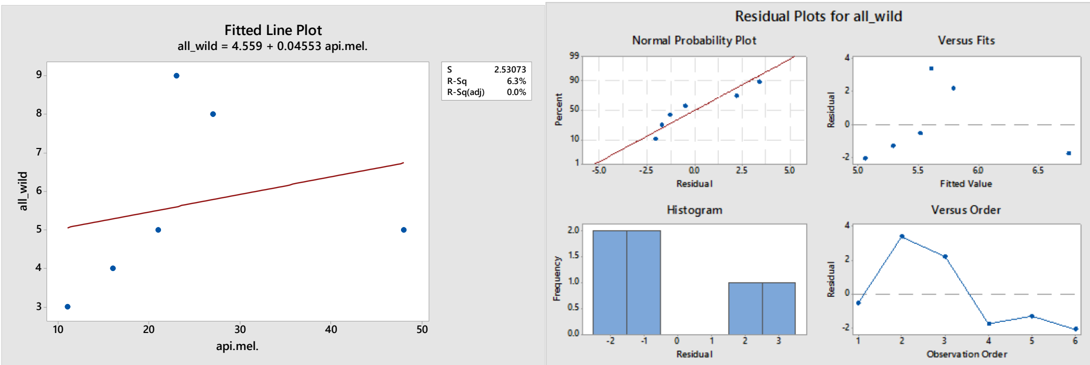
Model Summary

S	R-sq	R-sq(adj)
4.67119	29.61%	12.02%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	36.72	36.72	1.68	0.264
Error	4	87.28	21.82		
Total	5	124.00			

Netted honey bees vs netted wild bees, Telemark:



Regression Analysis: all_wild versus api.mel.

The regression equation is
all_wild = 0.4913 + 0.1149 api.mel.

Model Summary

S	R-sq	R-sq(adj)
2.73552	29.63%	26.44%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	69.330	69.3304	9.26	0.006
Error	22	164.628	7.4831		
Total	23	233.958			

Annex 4: Number of honey bees and wild bees per target zone and orchard, and the sum of both, that were captured with the different methods: net, blue pan traps (B), white pan traps (W) and yellow pan traps (Y).

Target zones and orchards	N	Honey bees				Wild bees				Sum, all bees			
		Net	B	W	Y	Net	B	W	Y	Net	B	W	Y
Hardanger	6	200	0	0	2	30	0	1	4	230	0	1	6
Jaastad	2	57	0	0	2	15	0	0	0	72	0	0	2
Åkre	2	59	0	0	0	15	0	1	4	74	0	1	4
Måkestad	2	84	0	0	0	0	0	0	0	84	0	0	0
Telemark	6	146	1	2	5	34	2	2	6	180	3	4	11
Ytre Årnes	3	71	0	0	0	22	0	0	0	93	0	0	0
Valen	3	75	1	2	5	12	2	2	6	87	3	4	11
Sum orchards	12	346	1	2	7	64	2	3	10	410	3	5	17
Sum, in %	12	97	0	1	2	81	3	4	13	94	1	1	4