Pollination as an ecosystem service in Lofthus, Norway: A study on the distribution of wild and managed pollinators on apple crops and how they are affected by the surrounding landscape

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Abstract

Pollination is an important ecosystem service that benefits human welfare by increasing the quantity and quality of fruit and seed set of many crops. The decline in bee abundance and diversity in recent years may result in a decrease in pollination services, which could have a major impact on world food supplies. In Norway, there is a lack of studies on pollination in a farming context.

Here I present a field study on the pollination service in apple orchards in Lofthus, Western Norway. I studied the distribution of managed and wild bees, factors that affect their presence, and how this affects the apple yield. The field methods used were transect walks at the farms, observations at branches, pan traps and transect in various habitat types. Transect walks at farms and observations at branches and pan traps were used for statitstical analyses, while transect walks in various habitat types were combined and used to create a species distribution model (SDM).

There was a high abundance of honeybees in the apple orchards; among the wild pollinators bumblebees were more common. Honeybees were more abundant in sunny weather, while bumblebees were not as strongly affected by weather. Bumblebee abundance increased towards higher elevations on the farms in the transect walk data, while SDM showed increasing elevations (up to 240 meter) to have a positive effect on predicted presence of both honeybee and bumblebees. Distance to forest did not affect the bumblebees, but SDM showed that all of the pollinators preferred the upper, less disturbed parts of the farm areas which were closer to natural habitats. I also showed that pollinator diversity had a positive impact on the fruit set and yield.

These results indicate that both honeybee and bumblebee abundance have a positive impact on the fruit set and yield of apples in Lofthus. They also indicate that to enhance the wild pollinator abundance, undisturbed, flower rich habitat is important.

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Introduction

Ecosystem services are benefits to the human welfare provided by natural ecosystems and their constituent organisms (MA 2005, Palmer et al. 2004). Ecosystem services are traditionally divided into four types: provisioning, regulating, supporting and/or cultural (de Groot et al. 2010). Provisioning services such as food, water, fiber and genetic resources are directly provided by the ecosystem (MA 2005, de Groot et al. 2010). Regulating services are benefits obtained by the regulation of certain ecosystem processes such as pollination, climate regulation, waste treatment and water regulation (MA 2005). Supporting services support other ecosystem services and some examples include soil formation, photosynthesis and primary production (MA 2005). Cultural services are non-material services obtained from the ecosystem through spiritual enrichment, aesthetic experience, reflection and recreation including ecotourism, educational values and inspiration (MA 2005). It is important to understand how natural systems provide ecosystem services to be able to determine which services are declining and why (MA 2005). This knowledge may help us predict what will happen to the services in plausible future scenarios (MA 2005, Palmer et al. 2004).

Pollination is a key ecosystem service that is almost irreplaceable to wild plants and crops (Klein et al. 2007). It is known that pollinators have a great positive effect on the quantity and quality of fruit set in many of the world's major fruit crops (Klein et al. 2007). For instance, pollination can increase the quality and quantity of fruit set in 39 of the world's major 57 crops (Klein et al. 2007). In addition 70 % of the main 124 crops used directly for human consumption are dependent on pollinators (Klein et al. 2007).
Insect pollinators have been shown to decline worldwide and therefore pollination as an ecosystem service is at risk (MA 2005, Vanbergen 2012). The contribution of insect pollination to the world agricultural output economic value was measured using a bio economic approach. This was done by integrating the production dependence ratio on pollinators for the 100 crops that are used directly for human food worldwide as listed by "The Food and Agriculture Organization of the UN 2005" (Gallai et al. 2009). The total economic value of pollination worldwide was calculated to be €153 billion in 2008 representing 9.5% of the value of the world agricultural production that was used for food in 2005 (Gallai et al. 2009). Currently we do not understand the relationship between the pollinator diversity and their services for most pollinators, ecosystems and geographical locations (Vanbergen 2012). Therefore, to obtain a better understanding of pollination as an ecosystem service, we need to quantify the contribution of different pollinator species across different regions and ecosystems to crop species and wildflowers (Vanbergen 2012).

Pollinators differ in geographical distribution, ecology, behavior and thus in pollination service delivery (Archer et al. 2014). Honeybees (*Apis mellifera*) and wild bees are important pollinators for crops worldwide (Klein et al. 2007). Honeybees are globally regarded as the most economically valuable pollinator for crop monocultures ((Watanabe 1994) cited in (Klein et al. 2007). However, for a wide arrange of fruit and crops they are not as efficient as wild pollinators on a per flower basis e.g. almond (Klein et al. 2012), watermelon (Kremen et al. 2002, Kremen et al. 2004), coffee (Klein et al. 2003) and raspberries (Cane 2005). Honeybees are not very tolerant to cold weather compared to e.g. bumblebees (Vicens and Bosch 2000, Heinrich 1979), but have a large foraging range compared to many wild bees (Steffan-Dewenter and Kuhn 2003, Gathmann and Tscharntke 2002). It has been suggested that the advantage of using honeybees as opposed to native bees is that honeybees can be moved long distances to ensure pollination of crops (Morse and Calderone 2000). On the other hand bumblebees (*Bombus sp.*) are known to be important pollinators for wild plants and crops, in orchards and greenhouses (Velthuis and van Doorn 2006, Ockinger and Smith 2007). Bumblebees are important pollinators in European agricultural landscapes and like other wild bees they rely on semi-natural habitats for nesting sites and with flowers available through the growing season as important food resources (Vaughan and Black 2008, Westphal et al. 2006). Bumblebees forage at lower minimum temperatures than honeybees and have been shown to be active down to 10 ^{o}C ((Heinrich 1979) cited in (Velthuis and van Doorn 2006)). It has been shown that honeybees and bumblebees remove similar amounts of pollen from apple flowers, but bumblebees deposit more pollen (Thomson and Goodell 2001). It was long assumed that bumblebees forage close to their nest if food is abundant ((Heinrich 1976) cited in (Osborne et al. 1999)). However more recent studies suggest that some species of bumblebees forage over longer distances, even if resources are available close to their nests (Osborne et al. 1999, Dramstad 1996). Hoverflies (*Syrphidae sp*.) are a taxon recently shown to provide significant pollination services to wild commercial crops (Jauker and Wolters 2008) . It has been shown that some hoverflies such as the genus *Eristalis* can be an potential efficient pollinator on various fruit crops like apple trees ((Kendall and Solomon 1973) cited in (Jauker and Wolters 2008)). Their role as pollinators of commercial crops and their response to increased distance from their natural habitat is less known than bumblebees, honeybees and other wild bees.

Concern has been expressed over the declining number of bees and other pollinators for the last decades, but data on the long term status of bee species are limited (Winfree 2010, Potts et al. 2010a). For instance populations of managed honeybees have decreased periodically since 1947 in USA and since 1985 in Europe (Committee on the Status of Pollinators in North America 2007, Potts et al. 2010b). On the other hand it has been shown that native pollinators have been declining since 1980 in both Britain and the Netherlands (Biesmeijer et al. 2006). A long term study on the relative rates of change has been conducted on regional bee fauna in the northeastern United States, based on more than 30 000 museum records that represented 438 species (Bartomeus et al. 2013). It was shown to be a weak decrease in native species richness, but the decline was only significant for three species in the genus *Bombus* (Bartomeus et al. 2013*)*. The study also showed low latitudinal range to be associated with an increase in abundance (Bartomeus et al. 2013). This study suggests that some ecological traits can be associated with decline in relative abundance of species. The authors highlighted the importance of carrying out term studies and monitoring species because a slow decline represent an early and good warning signal (Bartomeus et al. 2013).

The decline of managed and wild pollinators in many regions during the last decades raises concern that there is a global pollination crisis threatening our food supply and hence the human welfare (Kremen and Ricketts 2000, Kearns et al. 1998). The threats to pollinators and the services they provide seem to be mainly caused by human activities (Kearns *et al.* 1998). Honeybees and other pollinators are declining due to destruction and fragmentation of natural and semi-natural habitat and modern agricultural practices such as land use intensification (Kearns et al. 1998, Kremen et al. 2007, Steffan-Dewenter and Westphal 2008, Abrol 2012). In addition insecticides, fungicides, parasitic mites, viruses and scavengers have a negative effect on honeybees (Potts et al. 2010a, Kearns et al. 1998, Abrol 2012). In the United States of America the Colony Collapse Disorder (CCD) has been described as a major cause of decline of honeybee colonies (Potts et al. 2010a, Abrol 2012). Wild insect pollinators are threatened by habitat loss, a lack of knowledge on potential parasites, diseases, pesticides and insecticides (Potts et al. 2010a, Abrol 2012). However one of the most severe threats to pollinator diversity and pollination as an ecosystem service may be climate change (Winfree 2010, Kearns et al. 1998, Abrol 2012). Climate change can reduce the amount of suitable habitat for pollinators, or change its distribution (Abrol 2012). When a habitat disappears and the pollinator is unable to relocate (to a new habitat) a local extinction can occur (Travis 2003). Climate change may also cause a disruption in the synchrony between the activity season of pollinators and the flowering period (Abrol 2012, Hegland et al. 2009). To ensure crop pollination, it is important that the bee flight period is synchronized with the major blooming period of the crop (Abrol 2012).

Species distribution models (SDMs) can be used to determine the range of species (Polce et al. 2013, Anderson and Gonzalez Jr 2011) and to identify biodiversity hotspots (Cao et al. 2013). SDM predictions have many applications and are used to estimate loss of historic range, and to predict vulnerability to climatic change (Giannini et al. 2012, Franklin et al. 2009). Giannini et al (2012) tested the potential impact of climate change on the geographical distribution of 10 Brazilian bee species. Recently Polce et al (2013) used SDMs to predict the geographical pattern of pollination services to crops in the United Kingdom.

The management of pollinators and farms are important especially in intensive agricultural landscapes where the pollination services are needed the most (Klein et al. 2007). Agricultural habitats often consist of few and homogenous distributed food plants with a short blooming period which may be problematic for the remainder of the wild bee season (Westphal et al. 2008). It has been shown that wild bees often depend on and benefit from floral resources in addition to mass-flowering crops (Kennedy et al. 2013, Holzschuh et al. 2012, Holzschuh et al. 2008) The surrounding habitat can therefore impact the pollination service by providing other food resources such as in semi-natural and natural areas surrounding agricultural fields, making it an optimal habitat for wild bees (Kennedy et al. 2013, Westrich 1996). Farms with diverse fields and surrounding high quality habitats are likely to have a high abundance and species richness of bees (Kennedy et al. 2013). Improved farm management and maintained high quality landscape habitats around a farm can therefore contribute to attracting and keeping bees (Kennedy *et al.* 2013). Pollinator richness has been shown to decrease with increasing distance from their natural habitat (Ricketts et al. 2008). The foraging distance of wild bees can determine at which spatial scale they can provide pollination service to crops because they pollinate crops that are within their foraging range (Ricketts et al. 2008, Ricketts 2004). It has been shown that fragmentation and degradation of semi-natural landscapes can be detrimental to bee communities because this may lead to a loss of important resources, such as wild flowers (Klein et al. 2007, Steffan-Dewenter et al. 2002, Potts et al. 2005).

There is a gap in literature on pollination as an ecosystem service in Norway, and currently pollinator-plant interactions in the country has yet to be systematically mapped (Totland 2013). Introduced honeybees are important for the fruit production in Norway, but they have been declining since 1985 (Potts et al. 2010b, Totland 2013). There is a scarcity of knowledge on how pollinators other than honeybees affect crop species in agricultural habitats in Norway (Totland 2013). Pollination as an ecosystem service in Nordic countries has different conditions to deal with compared to more southern countries; the climate is colder, there are other pollinator groups and different crops and plants (Totland 2013). The unstable weather and cold climate in the north lead to a short growing season which often results in large differences in population size between years (Totland 2013). Insects are the only pollinators in Nordic countries and the diversity of pollinating insects are lower than in many other countries, but still there is a higher diversity of bumblebees and lower diversity of solitary bees in the Nordic countries compared to southern Europe (Totland 2013). The pollinator fauna in Norway consists largely of bumblebees and flies (Totland 2013). Because of the large differences in populations between years it is important to note that with a high diversity of pollinator species to increase the probability that some groups can tolerate the changing weather conditions (Totland 2013). Many pollinators needs sun and warm weather to be active, therefore non-ideal weather in summer and increased precipitation due to changing climate may have a large effect on pollinators and the plants that depend on them (Totland 2013). There is a need to map the pollinators and the plant pollinator interactions in Norway and a need for contribution from Nordic countries to further our international knowledge on pollination as an ecosystem service (Totland 2013).

The blooming periods of fruit in Norway are short and intensive so managed honeybee hives are very common during these periods (Totland 2013). There is no data on the importance of domesticated versus wild bees for fruit crops in Norway (Totland 2013). My research goal will therefore be to determine how managed honeybees and wild bees are distributed, which factors affect the presence of the different pollinators, and how they affect apple crops.

My aims are structured around three main gaps in knowledge that I wish to contribute in filling:
1) What factors regulate pollinator communities and densities in a Norwegian agricultural landscape?
2) How does the pollinator communities and surrounding landscape factors affect the apple crop yield?
3) What field-methods are best suited to test this?

To assess how pollinator abundance varies in agricultural landscapes I ask: i) How does the abundance of all pollinators and species group vary between farms within the landscape? ii) How does surrounding landscape affect the pollinator communities? iii) How does the weather affect the pollinator communities?
To obtain data on yield and how it is affected by the presence of pollinators I ask: iv) How does the density and composition of pollinators at the transects affect the yield? v) How does the number of hives, the surroundings as well as elevation affect the yield? vi) How does abundance of bees at branches and the surroundings affect the fruit set percentage?
To test which methods are best I ask: vii) As the research on pollination in Norway is limited (Totland 2013) which methods work best to obtain this data? I use three methods to collect data: transect walks, observations and pan traps. I then analyze the data statistically. I will also construct a species distribution model to predict the occurrence of pollinators. I will also ask: viii) How does a species distribution model predicting the species occurrence of pollinators used with collected data from the same area compare to the statistically analyzed abundance data from the farms?

Based on the literature reviewed above, I predict that surrounding factors such as the presence of natural habitats, notably forest, and bee hives will have a positive impact on pollinator abundance. I further predict that there will be a higher abundance of honeybees in an area with many hives and that there will be a higher abundance of bumblebees and other wild pollinators in areas closer to forest. I predict that less pollinating insects will be observed in cloudy and rainy weather. I also expect a positive correlation between diversity and abundance of pollinating insects and yield because I expect that pollinating insects enhance the yield of apples in orchards in Norway. I predict that the species distribution model will support the findings on pollinator abundance and diversity on the farms.

Materials and methods

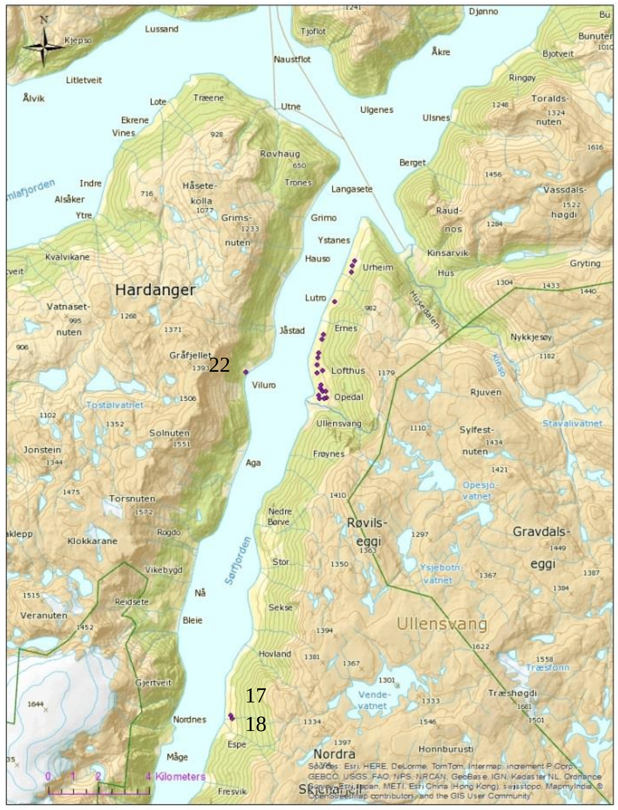
Study sites

Information on the geographical locations of apple farms in Hardanger was obtained from the county governor of Hordaland (Table 1). I selected Lofthus, a small village in the Ullensvang municipality in Hordaland as my study area. Ullensvang is one of the largest fruit growing municipalities in Norway, and is located on the eastern side of the Sørfjorden arm of the Hardangerfjord. The area was chosen because there are more than 80 farms producing apples within a small area and because no other study on apple tree pollination has been conducted here. The fjord is surrounded by high mountains and the elevational differences are dramatic, with mountains reaching 1000 meters above sea level at both sides of the fjord (Thorsnæs 2014). The natural forest type that dominates the landscape is deciduous forest, but there are also some areas dominated by mixed forest of deciduous, pine and spruce, and planted Norwegian spruce (Puschmann 2005, Fylkesmannen 2011). The landscape between 0 and 160 meters above sea level is dominated by orchards (Thorsnæs 2014, pers. obs.) (Figure 1).

Production of fruit, including apples, is an important source of income for farmers in the Ullensvang municipality (Thorsnæs 2014, Fylkesmannen 2013). Other farming sources of income are berry production and animal husbandry (Thorsnæs 2014, Fylkesmannen 2013). Norwegian agriculture advice (Nlr) and Bioforsk have offices in Lofthus that give advice to farmers and conduct research related to fruit farming (Thorsnæs 2014, Fylkesmannen 2013). Hardanger and Ullensvang have climate and soil conditions that are ideal for fruit growing (Thorsnæs 2014). Ullensvang has a transitional climate between the western Norwegian oceanic climate with plentiful precipitation, mild winters and cold summers and inland climate with cold winters and warm summers (Fylkesmannen 2011)(Figure 2). This gives a wet, relatively mild climate that contributes to a long growing season (Fylkesmannen 2011). The average temperatures and precipitation of spring 2013 were measured at Ullensvang research farm of 2013 (see results).

Table 1: UTM locations of the farms and the elevation and distance to hives and forest from the transects at each farm. Each farm is divided into two subareas and the elevation, distance to hive and forest from these two subareas is separated by a slash.

Farm	Number of hives	North	East	Closest hive (m)	Closest forest (m)	Hives within 1 km	Hives within 3 km	Elevation of farm	Elevation of transect (masl)
Farm 1	8	6689675	371081	136/55	54/210	21/27	64/54	41-105 m	90.5/44
Farm 2	-	6689767	370779	206/158	344/274	27/27	54/54	10-70m	11.5/45
Farm 3	4	6689665	370789	211/363	118/33	17/15	54/54	44-84 m	57/82.5
Farm 4	-	6691997	370902	702/713	30/96	19/21	76/76	30-69 m	60.5/47
Farm 5	-	6690183	370862	24/57	416/480	47/42	50/54	31-52 m	41/40.5
Farm 6	6	6690656	370702	34/55	400/220	38/51	66/66	10-58 m	39/28.5
Farm 7	8	6690990	370695	339/179	120/60	46/42	64/76	10-70 m	55/41
Farm 8	-	6689928	370940	326/ 191	400/415	33/33	54/54	14-28 m	26.5/18
Farm 9	-	6690055	370834	380/196	38/200	41/41	59/54	20-161m	153/106.5
Farm 10	-	6690769	370293	378/256	62/124	42/44	71/71	20-150 m	144.5/111
Farm 11	-	6689950	371064	53/134	310/386	27/23	54/54	23-80m	36/31
Farm 12	-	6689950	371064	145/114	296/280	27/27	54/54	40-80 m	49/50.5
Farm 13	7	6693483	371400	189/188	33/25	17/17	59/65	30-150 m	115/116
Farm 14		6694638	372072	422/409	165/145	17/17	30/30	30-82 m	86/86.5
Farm 15	4	6695092	372193	139/175	225/230	12/12	30/30	11-50m	25/23
Farm 16	4	6694885	372094	82/ 63	235/220	12/12	30/30	20-50 m	32.5/34
Farm 17	25	6677134	367304	82/55	34/20	33/33	40/40	60-120 m	68.5/69
Farm 18	-	6677030	367348	84/128	73/30	33/33	40/40	100-120 m	108.5/114
Farm 19	-	6692216	370950	896/901	30/81	16/16	78/78	22-52 m	42/31
Farm 20	-	6691459	370760	150/80	24/30	39/39	75/75	60-100 m	85/76.5
Farm 21	3	6691252	370730	22/71	58/70	39/42	75/75	60-80 m	76.5/72.5
Farm 22	10	6690684	367894	63/102	80/43	10/10	20/20	30-80m	31/65.5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Sørfjorden
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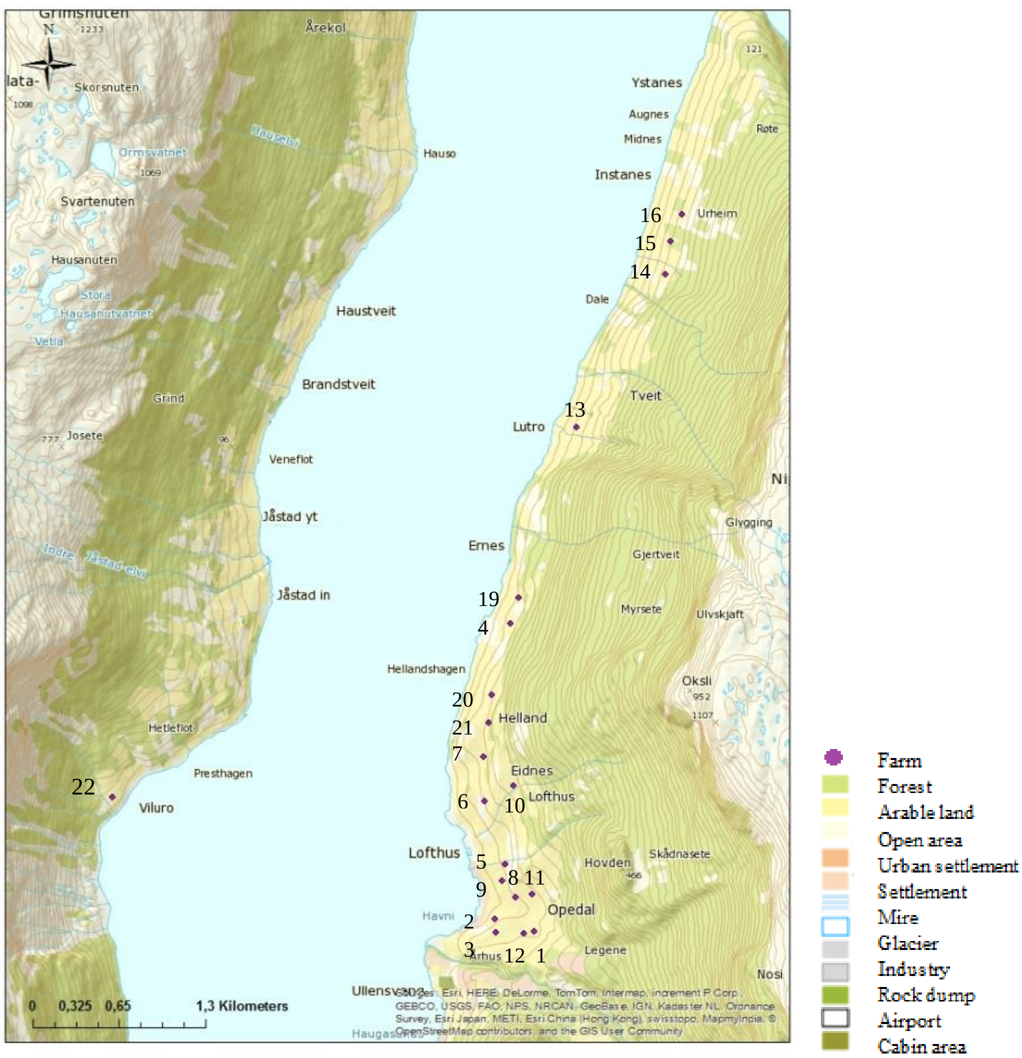
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Ernes
Gjertveit
Myrsete
Hellandshagen
Helland
Eidnes
Lofthus
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Legene
Hovden
Viluro
Presthagen
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11
9
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3
12
1
22
0 0,325 0,65 1,3 Kilometers
Farm
Forest
Arable land
Open area
Urban settlement
Settlement
Mire
Glacier
Industry
Rock dump
Airport
Cabin area

Figure 1: Maps of the location of farms (purple dots) along Sørfjorden arm of Hardangerfjord. Farms that are used in this study are represented by the purple dots on the maps. The farms are numbered in the order that I visited them.

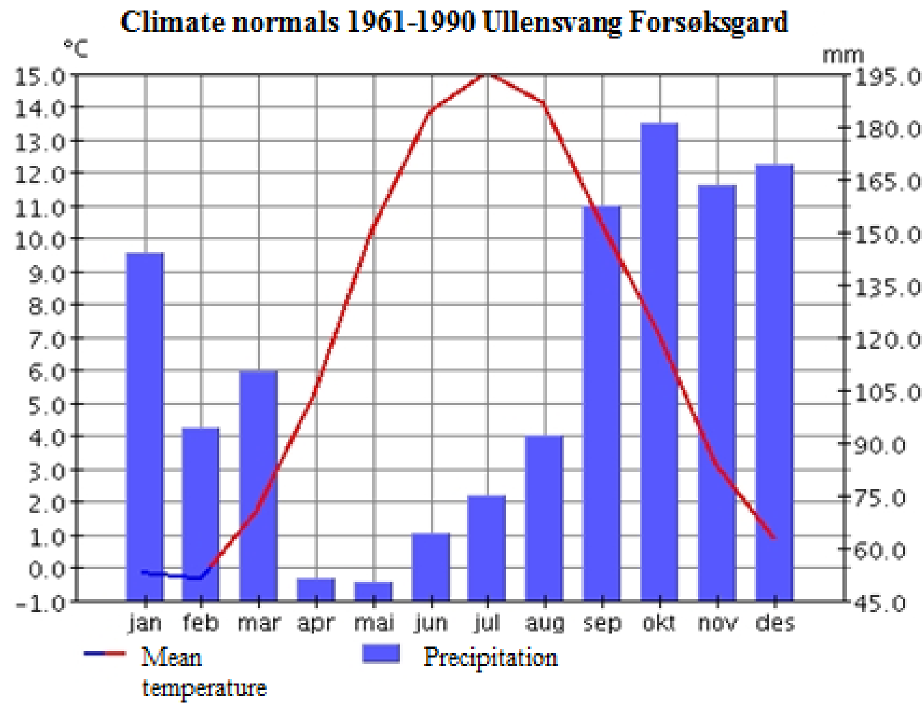


Figure 2: Average temperatures and precipitation for Ullensvang Research farm 1961-1990 (eklima.met.no).

I chose 22 farms for study, 19 of them within 6 km of each other (Table 1, Figure 1). The elevation of the apple orchards used ranged from 12 to 160 meters above sea level (Table 1).

The fieldwork was carried out during the apple blooming period in Hardanger in 2013 and 2014. The transects and observations were carried out from the 2nd of June until the 13th of June 2013 and when the apples had started to grow from the 6th of August until august 13th. The transect walks for Species distribution modeling was carried out from the 23th of May until 29th of May. Honeybees were the only managed bee species in the area. There were around 70 hives in the vicinity of most of the investigated fields, but I estimate the number of honeybee hives in the whole municipality to be around 200.

The layout of my sampling method was stratified sampling, which was selected because it takes into account systematic variation in the population density across the study area (Sutherland 1996). I selected the farms and subareas to represent the variability in 1) presence of honeybee hives; 2) distances to forest; and 3) varying elevations of the farms to evaluate the impact of these factors on the pollinators and yield.

I selected farms that differed in their use of honeybees; 10 farms with and 12 farms without honeybee hives. When I visited each farm I selected 2 subareas as transects, branches and trap locations. At farms with honeybee hives I selected subareas that had varying distances to the honeybee hives, including: areas very close to the honeybee hives (<100 m) and areas (100 m-901 m away). On each farm I chose areas close to forest (<100 m) and areas that were farther away (100 m-480 m) from forest. If available I also selected subareas of each of the categories at varying elevations: areas at low elevations (<100m) and areas at high elevations (>100 m). The total dataset includes 22 farms and 44 subareas.

The crops were homogenously distributed in long rows (Figure 3). I used "distance to forest" as a factor in my analysis. The forest and the area around it was less disturbed than orchards which made it likely that the wild bees would nest there (Svensson *et al.* 2000). Semi natural habitats were often found in the proximity of forests, providing natural habitats with wild flowers facilitating for pollinator presence.

Figure 3: Apple crop rows in Lofthus.

I placed Gemini tiny tag temperature loggers during the summer at some of the farms, from the 11th and 12th of June and collected them between the 7th and 14th of August.

Field methods for of sampling pollinators

I used four methods in the field: standardized transect walks, observations, pan traps and transect walks in different landscape types.

Method 1: Pollinator abundance along transects

Active sampling by walking transects is one of the most common methods for sampling bee diversity (Westphal et al. 2008). Transect walks were conducted once at each of the subareas (2 per farm). Walks were conducted between 10 AM and 6 PM. The location and elevation in meters above sea level (masl) of the start and end point of each transect were obtained from a Garmin GPS. Transects were walked along the rows of apple trees (Figure 3, Figure 4), and bee observations were done on apple trees on both sides of the line for 15 minutes. The distance between the crop rows is around 4 meters and the height of the trees was mostly between 1.5 and 2.5 meters ((Jaastad 2009); personal obs). The apple flower visiting insects were recorded and assigned into taxonomic categories that could be identified by eye and these were: honeybee (*Apis mellifera*), bumble bee (*Bombus sp.*), wild solitary bee and hoverfly (fam: Syrphidae). The weather for the day was recorded and the categories are described below. Transect methods have been shown to be an efficient method in recording bee diversity, but is also subject to a significant collection bias (Westphal et al. 2008). Thus I also used other methods to support my data.

I recorded the weather when I walked along each transect and assigned the conditions into one of five categories; sunny, sun and wind, overcast, sun wind and rain, and overcast with raindrops
at the time each transects was walked and this was assigned into categories: sunny, sun and wind, cloudy, sun wind and overcast with raindrops. Sunny was defined as when there were no or few clouds and the sun was visible. Overcast was when the clouds were obscuring most of the sky. Sun and wind was when there was noticeable wind and I observed that the pollinators were struggling to fly. Sun, wind and drops was when there were also a few drops of rain. Overcast with drops included raindrops in addition to cloud cover. I also collected data from the meteorological institute (eklima) containing data on the temperatures and precipitation of the three months before the season started and these are reported in the results.

To assess the how the landscape affects pollination success, the distance to the forest surrounding the orchards was measured. This was done by plotting the GPS points of the transects in the landcover maps of "gardskart.skogoglandskap.no" where I measured the distance to the closest forest. Distances was also measured from all transects to the closest honeybee hives (Table 1). The number of honeybee hives within 1 km and 3 km of each transect were measured using the GPS data from the transect walks and the marked honeybee hives (Table 1).

Figure 4: The two transect walks and branches at Farm 1. Transects (black lines) with start and end points (purple dots) at farm number 1. Branches (grey points) are located in the middle of one of the transects and at the start of the other transect.

Method 2: Observations at apple tree branches

Observations of all visiting pollinators were carried out on all of the flowers on one branch at one random tree at each of the 44 transects for a 5 minute period. The insects visiting the flowers at the branches were recorded in the same way as in the transect walks (see method above). I also counted the flower clusters on each branch to determine how the number of flowers impacted the fruit set. A flower cluster represents a cluster of about 5 flowers and one cluster usually results in one apple after thinning (*personal communication:* Mekjell Meland). The branches were marked and their GPS location was recorded (Figure 5). To measure fruit set on the marked branches, all apples on the branches were counted between the 6th and the 13th of August. When the apples were picked the farmers sent me information on their yield from the area in which the observational and transect data were collected (Appendix 1).

Figure 5: A marked branch.

Method 3: Traps along transects

The pan trap is a passive sampling method and has been shown to be the most efficient method of sampling bee diversity and abundance in different geographical regions of Europe (Westphal et al. 2008). This method has been shown to be efficient in both agricultural and semi-natural habitats and to have high sample coverage, collect a high number of species, have low collector bias and be the best indicator of the overall bee species richness (Westphal et al. 2008). I used this method because it is an unbiased, efficient and cost-effective method of sampling bee diversity (Westphal *et al.* 2008).

Following the FAO protocol (Survey Protocols FAO), I set up UV-bright pan traps with different colors (white, fluorescent yellow and fluorescent blue) to represent floral colors (Westphal et al. 2008, Survey Protocols FAO). The traps were represented by 500 ml plastic soup bowls. 6 pan traps were placed by rows of apple trees at each site. The traps were placed along a transect, and the colors were alternated through it. In order to ensure that the bees could spot the traps, I placed the pan traps by the trees on the ground, but away from shaded vegetation (Survey Protocols FAO).

I tested different methods with the traps. The most successful traps were those which hung with wire from the trees (Figure 6). I tested if the trap caught pollinators by leaving traps in 4 farms at 8 subareas for 2 days (Appendix 2). I then selected 7 further farms and placed 6 traps at two different locations per farm. The trap locations were near or in the same subareas that I used for the transect walks and observational studies. I also carried out a gradient study where I placed 46 traps at elevations ranging from 10 m to 95 m (Appendix 2). I collected the traps at the 7 locations in August.

Figure 6: One of the more successful traps.

I filled the traps with 500 mL of water and a drop of detergent; the traps left over summer were also filled with salt to preserve any caught specimens. A bee landing on water would normally float due to the surface tension, but, the addition of detergent reduces surface tension and causes the bee to sink (Survey Protocols FAO).

The collected specimens were stored in 70 % ethanol before identification using Artsdatabanken and British museums webpages for identifying bumblebees. To identify honeybees I used wing vein drawings based on the book “The bees of the world” (Michener 2000) from “honeybeedrawwing.org” and drawings of honeybees from the same webpage. There were few individuals of wild pollinators in the traps, therefore the species were only identified to the same group level as in the transects and observations which was honeybee, bumblebee, wild solitary bee and hoverfly.

The catch of the traps was not very successful, but the data is reported in the Appendices (Appendix 2).

Method 4: Species distribution models for pollinators in a fruit growing landscape

In May 2014 I made four transects designed to cover all the landcover types and a large part of the area that was visited during fieldwork (Figure 7). I walked each of the transects a total of five times. I recorded the geographic positions and number of honeybees and bumblebees observed when walking the transects. The first transect was parallel to a paved road next to farms and grassland. The second transect started by the farms and continued through the cropland and ended up in a forest area. The third transect went through the cropland from south to north. The fourth transect was in forest, wooded grassland and grassland. These data were used in the Species Distribution Modelling.

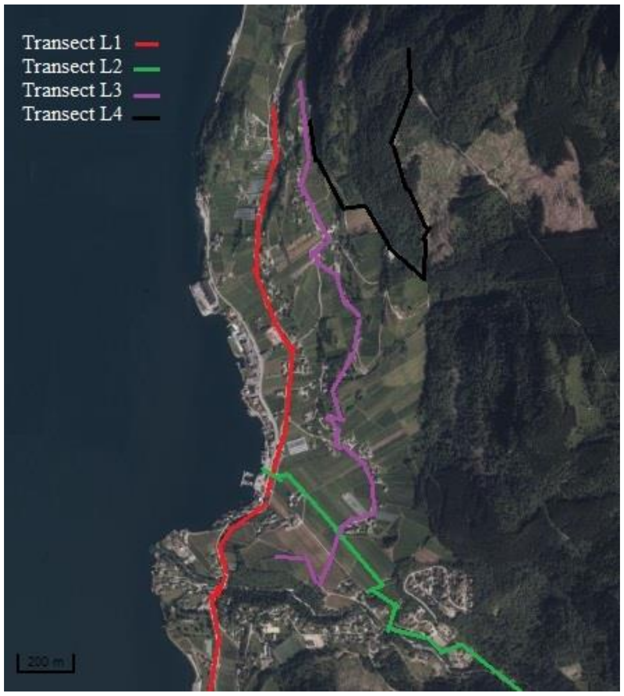


Figure 7: The transect walks conducted in different landscape types**.**

Statistical Methods

All statistical analyses were performed using R, version 3.1.0.

Method 1: Pollinator abundance along transects

To assess the variation of pollinator abundance and density between farms I inspected descriptive statistics and plots of the raw data of the different species groups from the transects, observations and the traps.
This was done both for the farm level and the total level. Boxplots were constructed from the transect walks from each single farm displaying the number of observed individuals from each species group, the median and the range of each farm of each species group. The mean, variation, standard deviation and confidence interval was calculated for each species group at each farm and for the transect walks to display the variation between species groups.

I constructed a boxplot with the honeybee abundance and bumblebee abundance from each of the farms to compare between farms. I conducted a post-hoc comparison test to test which farms had a significant effect on honeybee and bumblebee abundance. In order to show which farms were significantly different from each other I made groups of superscripts to show the difference and similarities between the farms.

I assessed the pollinator species groups' response to weather by constructing a boxplot of their abundance in different weather types. The mean, variation, standard deviation and confidence interval was calculated for each species group according to each weather type. I also included weather as an environmental factor in the models used to test the effect of environmental factors on the pollinators.

The impact of farm and habitat quality factors and environmental factors such as distance to forest, number of honeybee hives within 1 and 3 km, distance to closest honeybee hives and elevation on the total abundance of pollinators, honeybee abundance, bumblebee abundance and other pollinators in the transects was studied by means of negative binomial regression and generalized linear models.

The four response variables used were: total abundance of pollinators, abundance of honeybees, abundance of bumblebees and abundance of other pollinators. According to the Shapiro-Wilks test, the pollinator abundance data of all pollinators, honeybees and bumblebees was non-normally distributed (p-value < 0.05).

To model the abundance of all pollinators, honeybees and bumblebees, a negative binomial regression with a logarithmic link was used due to the high overdispersion of the response variable (Zuur et al. 2009). A quasipoisson generalized linear model was used to explore the relationship between the predictors and response variables of the other pollinators, because these other pollinators were not overdispersed. All explanatory variables were included in the primary model, and the best models were then identified by means of backwards selection with the z statistic, analysis of variance tables (Anova, Chi and Anova, F) and model selection AIC to find the best model.

The predictor variables tested for all response variables were: weather, distance to closest honeybee hive, numbers of honeybee hives within 1000 and 3000 meters, elevation of the transect, the quadratic elevation of the transect, and the distance to the closest forest. For the abundance of honeybees, bumblebees and other pollinators the other observed species groups were also included as predictors.

Pearson's r-correlation indices was used to test for correlation between the fixed variables.

I made a negative binomial regression model with farm as a predictor and the pollinator groups as response variables to assess the variation in pollinator abundance and density between the farms. The farm identity was a fixed factor in the regression models because the farms were chosen according to my stratified sampling design (i.e. they were not sampled randomly). I did a comparison between models that had only farm as predictor, and environmental factors as predictors to see what had the largest impact on the pollinator groups.

Method 2: Observations at apple tree branches

To assess the variation of flower clusters and fruit set I looked at the descriptive statistics and plots of the flower clusters and fruit set between the different branches. The raw data and data comparing the flower clusters and fruit set between the farms are included in the Appendices (Appendix 3). This was done both for the farm level and the total level. The mean, standard deviation and confidence interval was calculated for the pollinator observations, flower cluster observations and fruit set at the branches. The species abundance was quite low here compared to the transect records thus single farm boxplots were not made.

I tested the impact of visits to branches and the number of flower clusters on the fruit set. The response variable was percent fruit set which was calculated by dividing the number of apples counted on the branches by the flower cluster count (x5) and multiplying the result by 100. The predictor variables tested were: the pollinator abundance, environmental variables and farm. The Shapiro Wilks test suggests that the percent fruit set was non-normally distributed ($p\text{-value}<0.05$). Overdispersion was taken into account by using a quasipoisson generalized linear model to explore the relationship between the predictor and response variables.

The data on apple yield from the area in which the transects and observations were obtained from the landowners from October to December 2013. I constructed a histogram of the yield from the farmers that were able to give me the information. I also calculated the mean and ranges of the yield.

I tested the impact of pollinator richness and habitat quality factors such as, honeybee hives and elevation on yield. Overdispersion was taken into account in the by using a negative binomial model with a logarithmic link. The response variable used was yield in kilograms per decare. The predictor variables included was the number of honeybee hives within 1000 and 3000 meters, insects richness observed at the branches, insect diversity at the transects and the type of apple tree. The distance variables from the middle of the transect walks were used. In the farms where I had walked transects of the same apple type I averaged the predictor variables.

Method 3: Traps along transects

I had planned to use the traps assess the community composition of pollinator species and how it varied at different elevations and at different distances from forest and hives. If some bowls were lost or destroyed during the experiment I would only account for the bowls that I could use.

For species group distribution I will add the observations from the traps that were kept both over the summer and the traps that were kept for two days to my results.
Due to the low pollinator catch in the traps, I was not able to make a suitable statistical model with the trap data. I had planned to carry out a mixed effects model with traps nested in site and farm as a random variable. The fixed predictor variables would have been defined as the color of the traps, elevation of the traps and the distance to the closest forest. For the catch of honeybees I would also have included distance to closest hives and the numbers of hives within 3 and 1 km as predictor variables. The response variables would have been the catch of the different species. I would have made different models for the different species.

Method 4: Species distribution models for pollinators in a fruit growing landscape
I used the recorded high quality coordinates (latitude, longitude) of species occurrence to build a Species distribution model for the study area using Maxent.

I decided to use Maxent to perform species distribution modeling (SDM), because it is especially useful as it can be applied to analyze small and presence-only datasets (Giannini et al. 2012, Wisz et al. 2008). The use of Maxent in ecology is recent (Phillips et al. 2006) and has been shown to perform well using small datasets (Wisz et al. 2008) .We used Maxent to predict the geographic ranges of the pollinators in Lofthus in terms of occurrence probability and habitat suitability (Franklin et al. 2009, Peterson 2011). The map output of Maxent represents the occurrence probability for the pollinators in each of the grid cells that are used in the model (Giannini et al. 2012).

The SDMs were developed using detailed maps of the study area with environmental layers that included landcover type, slope, aspect and elevation.

We used area under the receiver operating characteristics (ROC) curve or (AUC) to evaluate the model performance (Fielding and Bell 1997). The AUC value is threshold independent measure that varies from 0 to 1, where a value closer to 1 represents a model’s ability to discriminate suitable from unsuitable areas for the species (Anderson and Gonzalez Jr 2011). AUC values of 0.5 shows that the model predictions are not better than random, values below 0.5 are worse than random and values higher than 0.5 shows that the model performs better than random. Values from 0.5 to 0.7 exhibit poor performance, 0.7-0.9 show moderate performance and values higher than 0.9 show high performance (Anderson and Gonzalez Jr 2011, Elith et al. 2002).

Model validation was performed using the subsampling procedure in Maxent. I used 25 percent of the data as a random sample for statistical testing when I ran the model. I used 75 percent of the *Apis mellifera* data for model calibration (training data: 126 points) and the remaining 25 % for model validation (test data: 41 points). I used 75 percent of the *Bombus sp* data for model calibration (training data: 21 points) and the remaining 25 % for model validation (test data: 7 points). Jackknife and percent variable contribution was used to investigate the importance of the different predictor variables.

Results

Climate data

The temperatures in Ullensvang in March were colder than the mean temperature while, in April and May, the temperatures were similar to the mean that is measured from 1960-1990 (Table 2). The precipitation in March 2013 was very low compared to the normal while the precipitation in April and May was higher than the normal (Table 2).

Table 2: Average temperatures and total precipitation in spring 2013 in Ullensvang compared to the normal temperatures and precipitation (1960-1990)

Climate variable	Month	Min ^oC/mm	Max ^oC/mm	Total (mm)	Mean (2013)	Normal (1960-1990)	Deviance (^oC/mm)	%
Temperature	March	-5.4	3.4		-0.7	1.7	-2.4	
	April	0.7	8.7		4.7	5.2	-0.5	
	May	0.1	19.5		10.7	10.2	0.5	
Precipitation	March	0	10.8	42.5		110	-67.5	38.6
	April	0	41.7	211.2		51	160.2	414.1
	May	3.7	18.2	134.2		50	84.2	268.4

Method 1: Pollinator abundance along transects

In the 22 apple orchards a total of 1167 individuals of pollinating insects were observed during the transect walks, 1074 of which were honeybees. In 80 bumblebees, 25 hoverflies and 4 solitary bees were recorded. There was considerable variation in the number of observed individuals of the different species groups between the farms (Appendix 4).

There is a clear difference between the numbers of observed individuals of the four species groups (Figure 8). Honeybees were both the most prevalent and locally abundant pollinators, observed at 42 of the 44 transects (Appendix 4), and ranged from 0 to 100 observations per transect, with an average per transect of 24.4 and a 95 % confidence interval of [17.7, 31.3]. Bumblebees were the most prevalent and locally abundant wild pollinator, and they were observed in 28 of the 44 transects where their abundance ranged from 1 to 14 per transect. The mean number of observed bumblebees per transect was 1.8 with 95% confidence interval of [0.96, 2.66]. Hoverflies ranged from 0 to 3 per transects and was observed at 13 of the 44 transects. The mean was 0.56 per transect and the confidence interval spanning 0. The solitary bees were uncommon in the transect walks, and this is very well represented by the mean of 0.09 observations per transect.

Farm is an important predictor of the honeybee abundance. Figure 9 depicts at which farms the honeybee abundance is significantly different from each other. It shows that the abundance is similar at many of the farms, but farm 4, farm 12 and farm 14 has a lower abundance than the other farms. Figure 10 depicts the bumblebee abundance at each farm. The abundance was not significantly different between any of the farms.

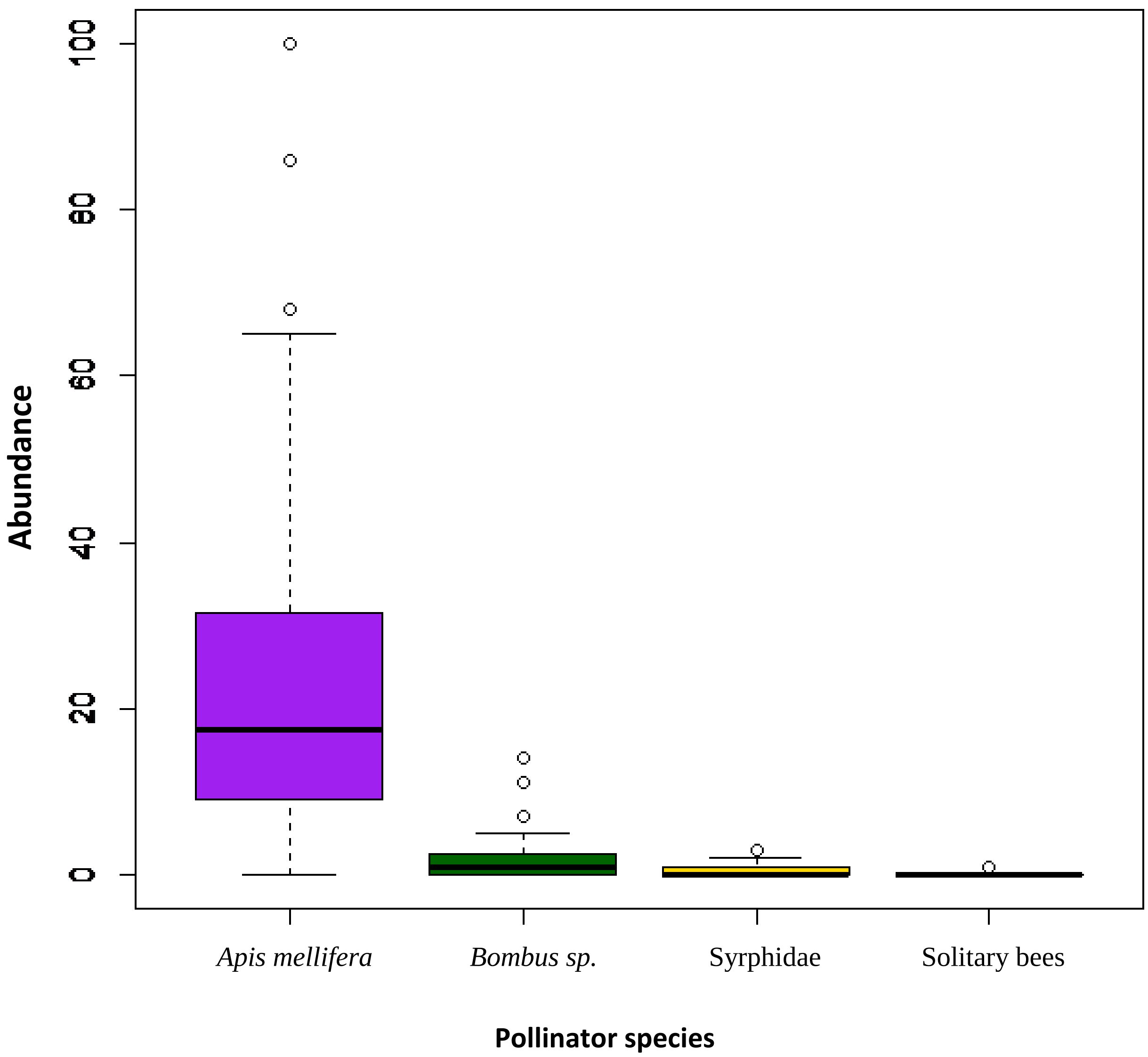


Figure 8: Pollinator species abundance at the transects. The boxes represent the first quartile, the median and the third quantile and display the distribution of the different species groups. The whiskers extend out to the minimum and maximum and the outliers are represented with dots.

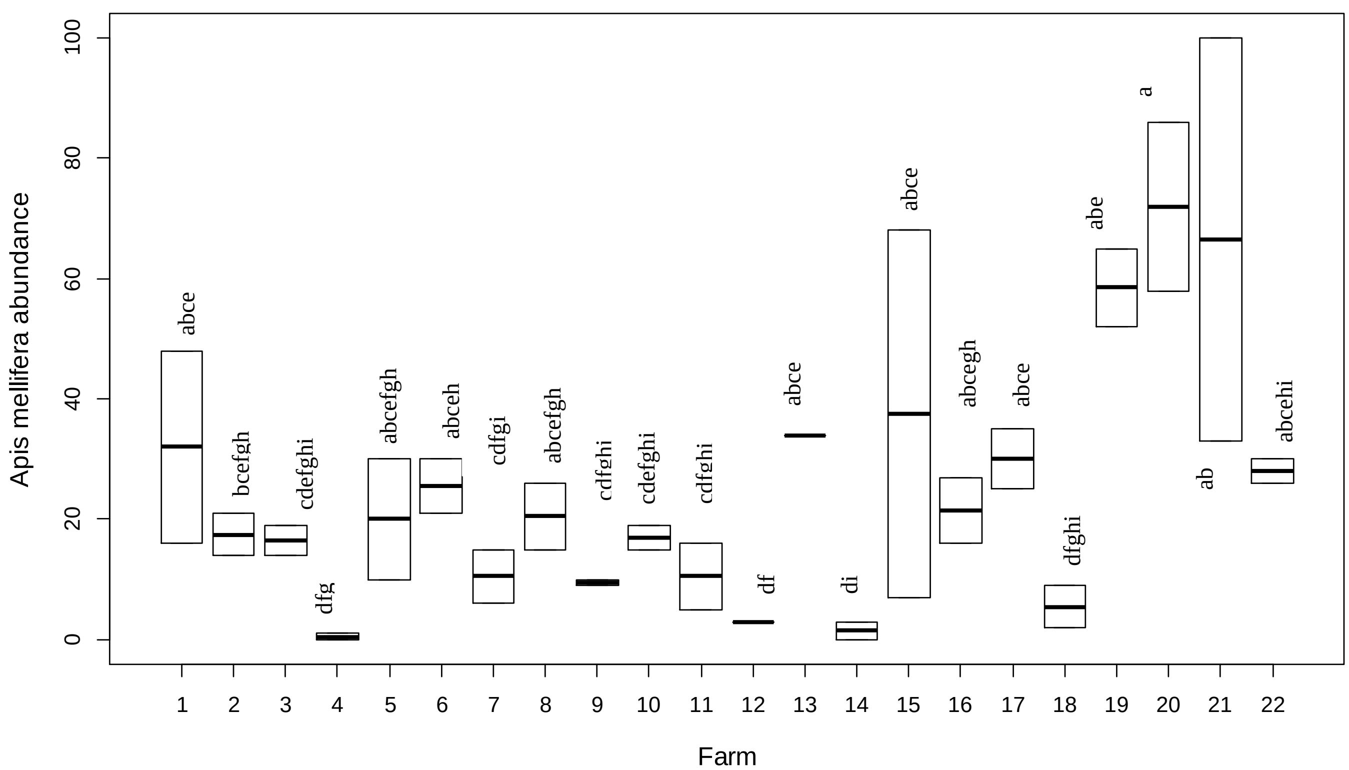


Figure 9: A boxplot depicting the honeybee abundance at each farm. Same letters mean that the farms have similar honeybee abundance

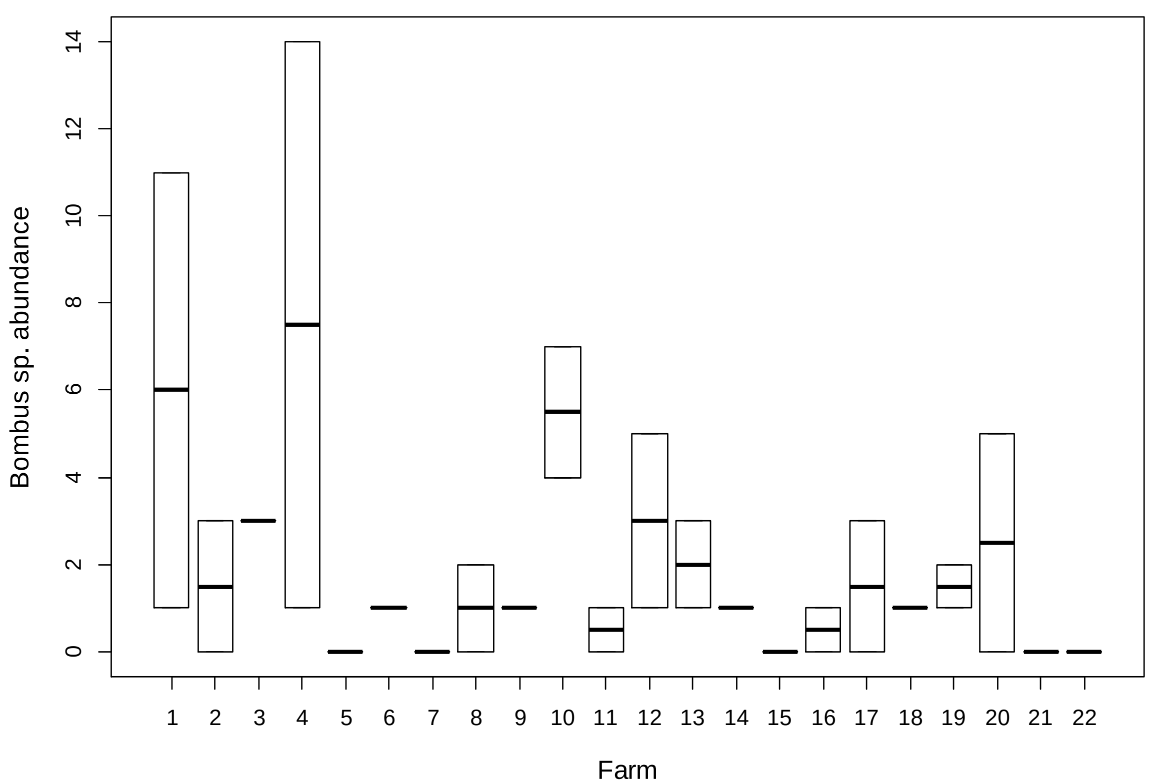
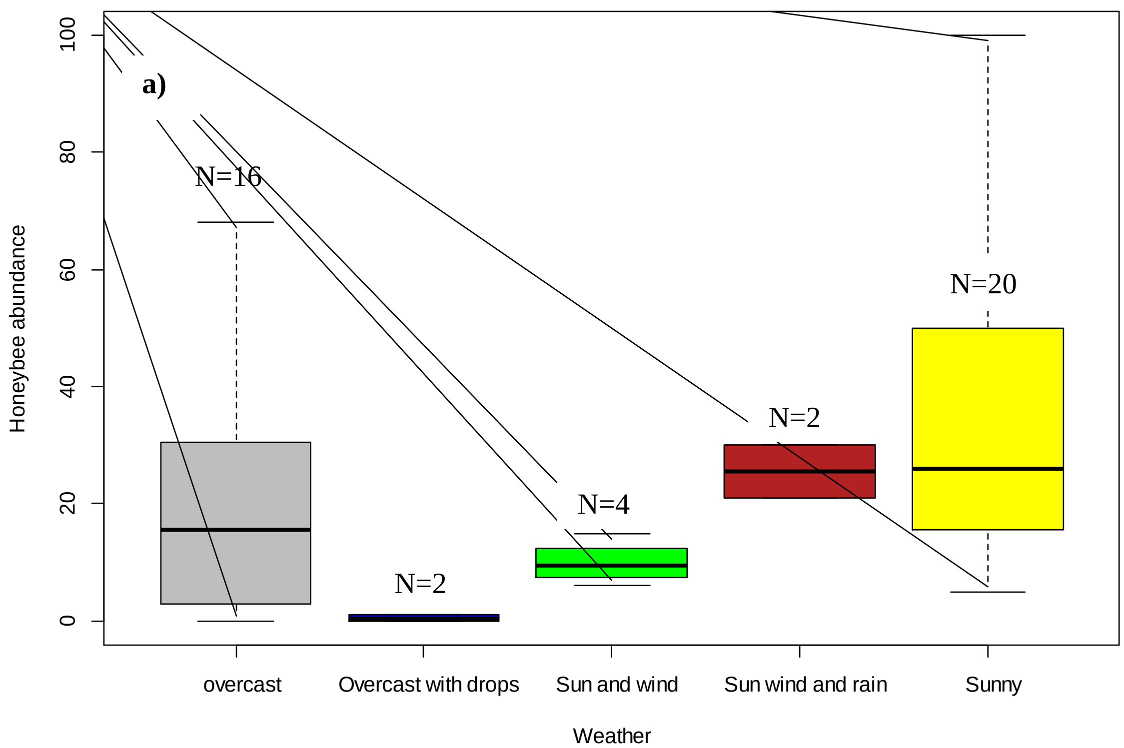


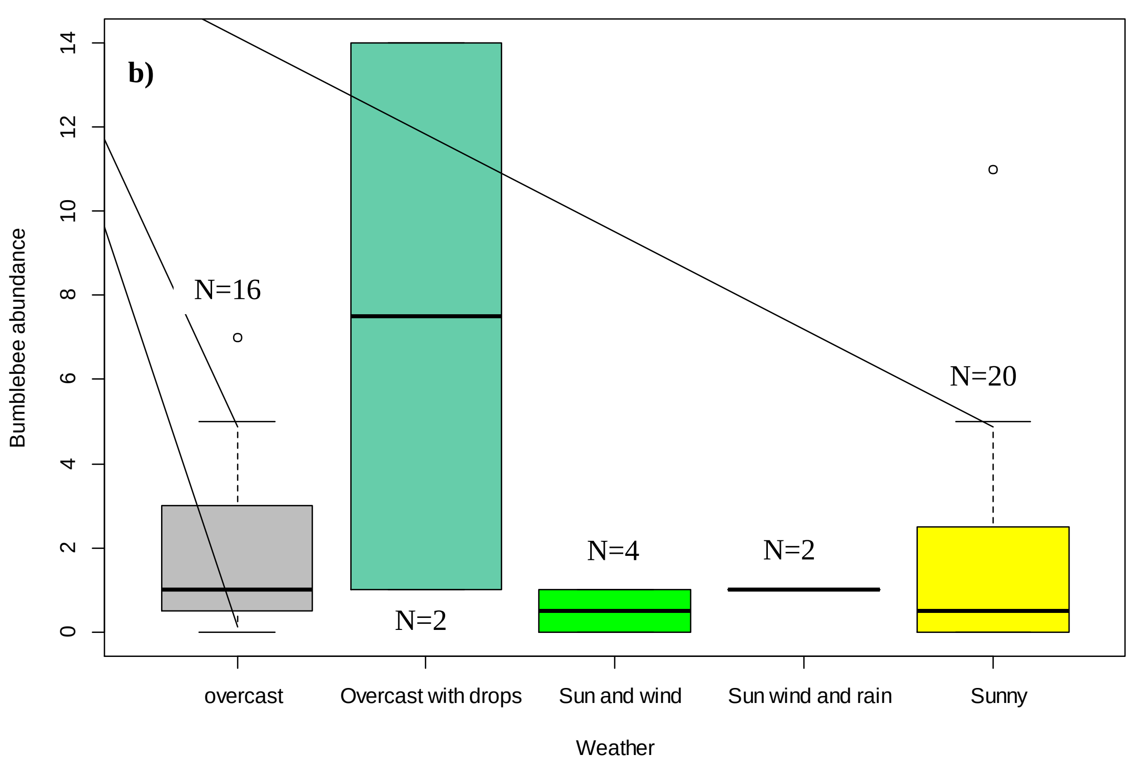
Figure 10: A boxplot depicting the bumblebee abundance at each farm

Honeybees were observed pollinating in all types of weather, but they were more prevalent in sunny weather (Figure 11a). Honeybees were observed in all transects except two, but this is most likely due to the overcast weather at the day these transect walks were performed. In overcast weather the observations ranged from 0 to 68 of the honeybees with an average of 18.75. In sunny weather the observations ranged from 5 to 100, but the 100 data point was removed before calculating the average here because it represent a row with high blooming when almost all blooming in the surrounding orchard had already finished. The average number of honeybees for sunny days was 30.73. For the two overcast transects with rain the average was 0.5 honeybees. For the four transects with registrations done in windy and sunny weather the average was 10. The two transects with sun, rain and wind had an average of 25.5.

Bumblebees were also pollinating in all types of weather (Figure 11b). The number of bumblebees observed in overcast weather ranged from 0 to 7. The average for overcast days was 1.81. For sunny days the observations ranged from 0 to 11 and the average was 1.45. For the two overcast transects with raindrops the average observation was 7.5 bumblebee. For the four registrations carried out in windy and sunny weather the average was 0.5 and for the transects with sun, rain and wind the average was 1.

Other pollinators were also pollinating in all of the weather types that occurred during my fieldwork (Figure 11c). The number of other pollinators observed in overcast weather ranged from 0 to 3. The average for overcast days was 0.68. For sunny days the observations ranged from 0 to 3 and the average was 0.6. For the two overcast transects with rain the average observation was 0.5. For the two transects with registrations done in windy and sunny weather the average was 0.25 and for the transects with sun, rain and wind the average was 0.5.


a)
Honeybee abundance
0
20
40
60
80
100
N=16
N=2
N=4
N=2
N=20
overcast
Overcast with drops
Sun and wind
Sun wind and rain
Sunny
Weather


b)
Bumblebee abundance
0
2
4
6
8
10
12
14
N=16
N=2
N=4
N=2
N=20
overcast
Overcast with drops
Sun and wind
Sun wind and rain
Sunny
Weather

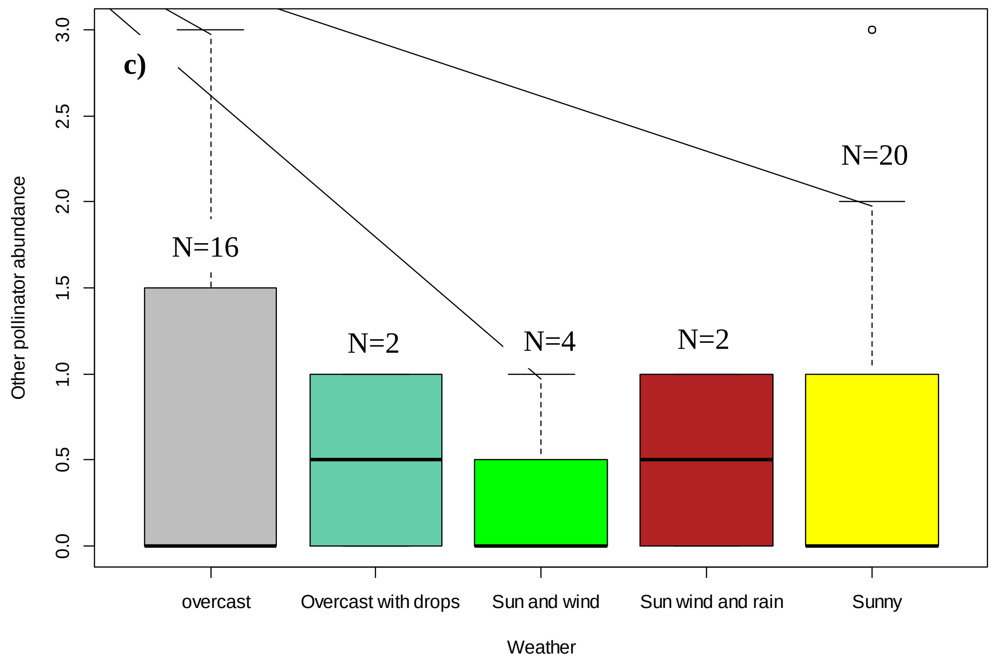


Figure 11: a) Abundance of honeybees b**)** abundance of bumblebees c) abundance of other pollinators in the five types of weather at the transects. N=x explains the number of transects the weather type was observed in. The boxes represent the first quantile, median and upper quantile and display the distribution of pollinators in the different weather types. The whiskers extend to the minimum and maximum of observed pollinators and the outliers are represented by dots**.**

The pollinator abundance per transect was best explained in a negative binomial regression that included honeybee hives within 3 km, elevation in meters above sea level, weather and distance to forest as explanatory variables. This model explained 44% of the variance in the data. The number of honeybee hives within 3 km had a significant positive effect on the pollinator abundance (Table 3). The distance to forest (Figure 12) had a significant negative effect on the polliantor abundance (Table 3). Overcast weather had a significant positive effect on the pollinators and overcast with drops, and sun and wind had a significant negative effect on pollinator abundance (Table 3).

The Pearson's correlation test shows which of the habitat quality related explanatory variables are correlated (Appendix 5). Distance to closest hive and hives within 3 km of the transects were positively correlated, hives within 1 km and hives within 3 km of the transects were positively correlated and distance to closest forest and elevation was negatively correlated (Appendix 5).

For honeybee abundance the best explanatory variables were weather, number of honeybee hives within 3 km, elevation, distance to forest and bumblebees. The model explains 49 % of the variation in the data. Honeybee hives within 3 km had a significant positive effect on honeybee abundance (Table 3). The distance to forest had a significant negative effect on honeybee abundance (Table 3). Overcast weather had a significant positive effect on honeybees and overcast with rain and sun and wind has a significant negative effect on honeybee abundance (Table 3).

For bumblebee abundance the best explanatory variables were weather, elevation, honeybee hives within 3 km, honeybee hives within 1 km, honeybee abundance and abundance of other pollinators (Table 3). There was a significant positive effect from the honeybee hives within 3 km and elevation on the abundance of bumblebees (Table 3, Figure 13). There was also a significant negative effect from honeybee abundance on bumblebee abundance (Table 3). The weather types sun and wind, and overcast had a significant negative effect on the bumblebee abundance. The model explains 50% of the variation in the data.

Hoverflies and wild bees that were not bumblebees have been merged as “other pollinators” due to a low number of observations in the transect walks.

There was a significant positive effect from distance to closest honeybee hive, elevation and distance to closest forest on other pollinators (Table 3). The model explains 27.1 % of the variation in the data.

Table 3: Results from negative binomial regression models and a generalized linear model (glm) analyzing which predictors have a significant effect on abundance of the response variables: all pollinators, honeybees, bumblebees and other pollinators. Significant variables are marked with a *

	Estimate	SE	Z	P
All pollinators				
(Intercept): Weather overcast	3.32	0.456	7.28	3.63e-13*
Weather: Overcast with rain	-1.695	0.55	-3.04	0.002*
Weather: Sun and wind	-0.8	0.37	-2.17	0.03*
Weather: Sun,wind and rain	0.232	0.51	0.46	0.65
Weather: Sunny	0.26	0.24	1.05	0.29
Distance to forest	-0.003	0.0009	-3.181	0.0014*
Elevation	-0.007	0.004	-1.94	0.052
#Honeybee hives within 3 km	0.014	0.006	2.064	0.039*
Honeybee				
(Intercept): Weather overcast	3.32	0.53	6.28	3.42e-10*
Weather: Overcast with rain	-4.171	1.2	-3.48	0.0005*
Weather: Sun and wind	-0.862	0.44	-1.962	0.049*
Weather: Sun, wind and rain	0.268	0.58	0.46	0.644
Weather:Sunny	0.28	0.28	0.994	0.32
Distance to forest	-0.003	0.001	-3.2	0.0015*
Elevation	-0.008	0.004	-1.78	0.074
# Honeybee hives within 3 km	0.016	0.008	2.04	0.0042*
Bumblebees	-0.08	0.05	-1.49	0.13
Bumblebee				
(Intercept:): Weather overcast	-2.1	0.788	-2.663	0.0078*
Weather: Overcast with rain	-0.11	0.835	-0.136	0.9
Weather: Sun and wind	-2.14	0.884	-2.416	0.016*
Weather: Sun, wind and rain	0.088	0.999	0.088	0.923
Weather:Sunny	0.054	0.471	0.116	0.91
Elevation	0.017	0.006	2.893	0.003*
Honeybee hives within 3 km	0.05	0.016	3.049	0.002*
Honeybee abundance	-0.019	0.009	-2.016	0.044*
Other pollinators	-0.4	0.211	-1.846	0.06
Honeybee hives within 1 km	-0.03	0.018	-1.551	0.12
Other pollinators				
(Intercept):	-5.711	1.62	-3.526	0.0004*
Distance to closest honeybee hive	0.003	0.0035	3.292	0.001*
Distance to closest forest	0.007	0.002	3.141	0.0017*
Elevation	0.067	0.028	2.35	0.019*
Elevation^2	-0.0003	0.00016	-1.72	0.085

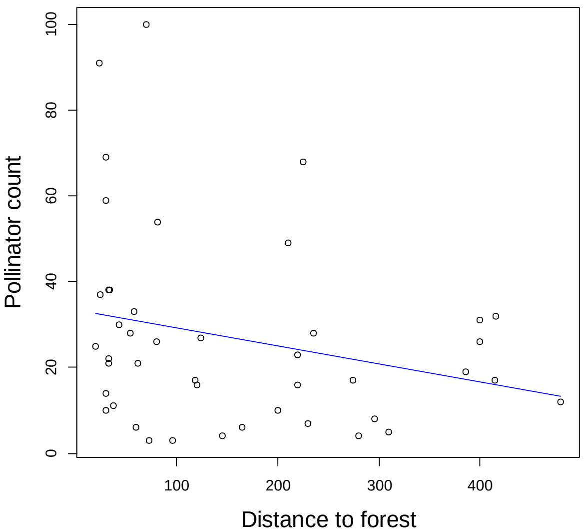


Figure 12: Relationship between pollinator count and distance to forest in meters

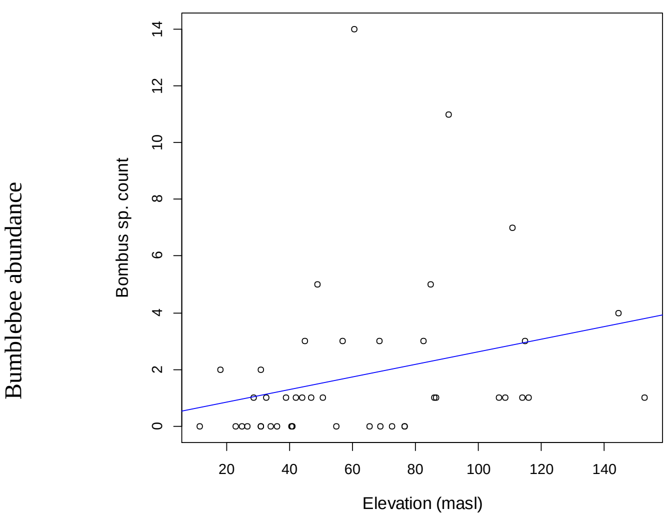


Figure 13: Relationship between bumblebee abundance and elevation (masl)

To disentangle the importance of the different types of predictor variables, I carried out a set of analyses for each response variable. I first tested farm as the only predictor variable using a negative binomial regression for all pollinators, honeybees and bumblebees. I obtained an AIC score and a pseudo r2 for each of the species groups. I then we tested the model with all environmental variables and carried out backward selection to determine which variables were the most important of the environmental variables. I then tested a model containing the farm and environmental variables together. For these I obtained an AIC score and a pseudo r2 that were used to compare the strength of the models (Table 4). This showed that for honeybees the best model was farm and environmental variables, in other words all variables. For bumblebees the AIC score shows that environmental factors are the most important while the pseudo r2 shows farm and environmental variables to be the most important (Table 4). For the other pollinators the AIC score and pseudo r2 were also different. AIC score shows environmental variables to be the most important while the r2 shows farms to be most important.

Table 4: Table comparing farm with environmental factors as predictor variable of pollinator abundance

Response variable	Predictor groups	Environmental variables included	AIC	Pseudo r2
All pollinators	Farms		351.2	0.784
	Environmental variables	Weather, hives within 3 km, elevation, distance to forest	364.88	0.436
	Farm +Environmental variables	Distance to closest hive, hives within 3 km	348.31	0.812
Honeybees	Farms		335.44	0.8255
	Environmental variables	Weather, hives within 3 km, elevation, distance to forest, bumblebee abundance	357.7	0.49
	Farm +Environmental variables	Hives within 1 km, distance to closest forest and distance to closest hive	330.46	0.865
Bumblebees	Farms		162.22	0.6722
	Environmental variables	Weather, elevation, honeybee abundance, honeybee hives within 3 km, honeybee hives within 1 km, other pollinators	153.85	0.504
	Farm + Environmental variables	Elevation, unimodal elevation, other pollinators	152.65	0.802
Other pollinators	Farms		96.174	0.735
		Distance to closest forest, distance to closest hive, elevation and elevation (^2)	90.503	0.27

<u>Method 2: Observations at apple tree branches</u>

At the 44 branches the number of the flowerclusters ranged from 2 to 37 and the average was 16.77

flowerclusters per branch. A higher number of flower clusters usually led to a higher count of unripe apples or fruit set (Appendix 3).

The number of counted unripe apples ranged from 3 to 36. The average applecount per branch was 11.9 and the confidence interval was [9.65, 14.13]. Few pollinators were observed during the five minute observation period at the branches compared to the transect walks (Appendix 3). The response variable for the fruit set model was % apple count of the flowers observed. Here I tested a model with environmental variables. Of the environmental variables tested diversity was positive and hives within 3 km was a negative significant predictor of the percent fruit set (Table 5). The model explained 20.1 % of the variation in the fruit set.

The yield per decare area varied from 0 to 2470 (Figure 14, Appendix 1). The yield had a normally distributed shaped curve. The mean kg yield per decare area was 1119.84 and the confidence interval was [912.4, 1326.5].

The best model to explain the distribution of the yield was a negative binomial model with a log-link function and honeybee and other wild pollinator abundance at the transect, pollinator diversity, distance to closest forest, hives within 3 km and distance to closest hive as predictors. There was a significant positive effect from honeybees abundance at the transect, distance to the closest forest, diversity and distance to closest hive (Table 5). There was a significant negative effect from hives within 3 km and abundance of other pollinators at the transects (Table 5). The AIC value obtained was high and the predictor variables explained 30.1 % of the variation in the yield.

Table 5: Results from a quasipoisson general linear model and a negative binomial model with a log link function. The response variables were fruit set and yield and the predictors of Fruit set was diversity and hives within 3 km while the predictors of yield were honeybee and other pollinators abundance at the transects, pollinator diversity, distance to closest forest, distance to closest hive and the number of hives within 3 km. T measures a raw score's distance from the mean while a Z score is a measure of the standard deviation

Factor	Estimate	SE	T/Z	P
Fruit Set				
Intercept	2.96	0.41	7.257	7.16e-09
Diversity	0.431	0.161	2.674	0.01*
Hives within 3 km	-0.01	0.007	-2.293	0.027*
Yield				
Intercept	6.2	0.64	9.722	<2e-16
Honeybees	0.01	0.005	2.073	0.038*
Other pollinators	-0.43	0.19	-2.247	0.024*
Diversity	0.667	0.22	2.979	0.0029*
Distance to forest	0.003	0.0009	3.266	0.00011*
Hives within 3 km	-0.028	0.009	-3.068	0.0021*
Distance to closest hive	0.0017	0.0006	2.905	0.00368*

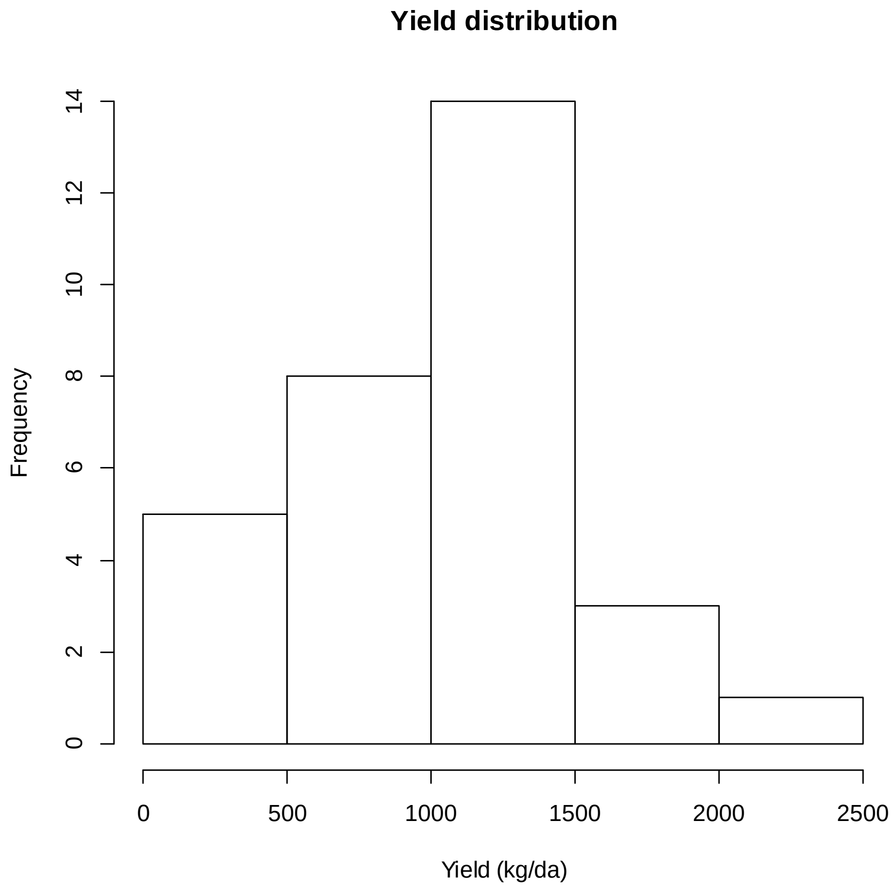


Figure 14: Distribution of yield per decare in the transects at the farms

<u>Method 3: Traps along transects</u>

The traps were not as successful as the other methods so the catch is not presented and analyzed to as great of an extent as the data from the transects and observations. The data of the catch in the traps are included in Appendix 2. Except for the honeybees and flies this catch is quite low.

In the 16 traps that were in the orchards for 2 days during the blooming season, the total catch was 30 pollinators, of which 28 was honeybees. In the traps that stayed over summer and that was distributed among varying landscape types 29 of 42 pollinators was honeybees, while the remainder consisted of wild bees (6), bumblebees (4) and hoverflies (3) (Appendix 2).

Method 4: Species distribution models for pollinators in a fruit growing landscape

Inside the area covered by the transect walks we observed a total of 555 pollinators at 327 coordinates, of which 520 were honeybees and 35 were bumblebees (Appendix 6)

For honeybees we see that suitable conditions are predicted for a large part of the lowland area (Figure 15, Figure 16)

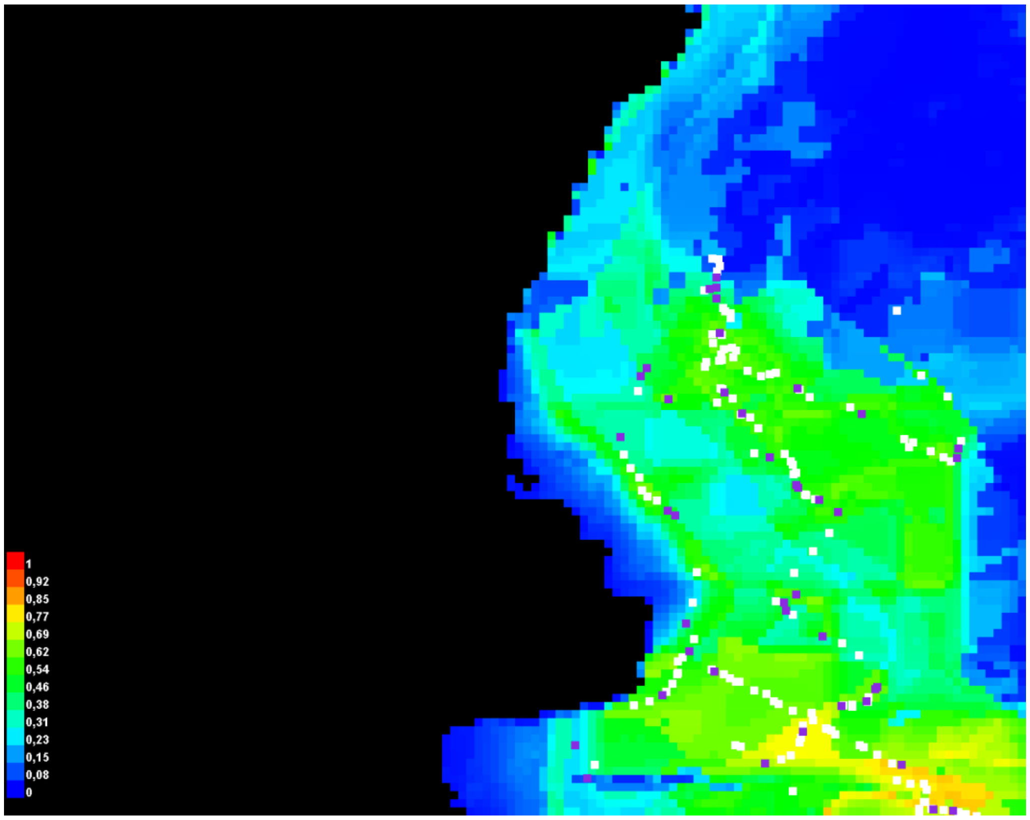


Figure 15: *Apis mellifera* output map from Maxent. The image uses colors to indicate predicted probability that colors are suitable. Warmer colors indicate more suitable areas for the species; red indicates a high probability of suitable conditions for the species (Phillips 2005). Green indicates conditions of where the species are found and blue and lighter shades of blue indicate low predicted probability of suited conditions (Phillips 2005).

Figure 16: Aerial photo of the same area used in the output map. H marks locations of honeybee hives.

Maxent predicted the potential distribution of honeybees (*Apis mellifera)* with moderate accuracy with an average test AUC value of 0.782 and an average training AUC value of 0.843.

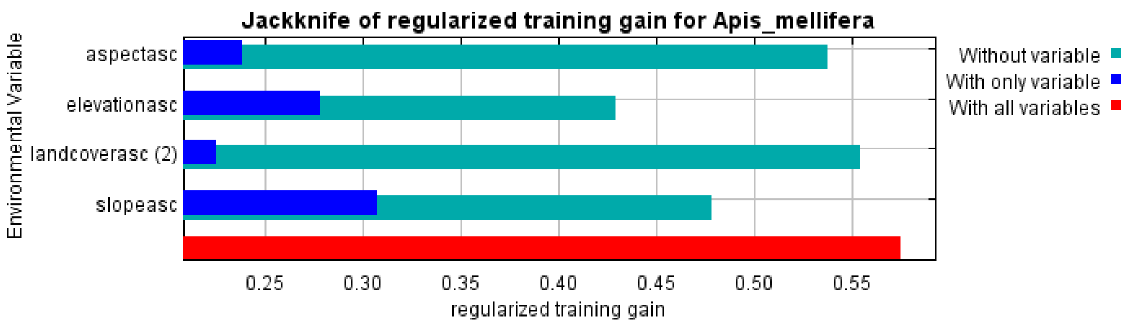
Elevation and slope were the strongest predictors of honeybees, where distribution contributed with 40.4 percent (Table 6). Jackknife also showed that slope and elevation had the highest predictive power (highest regularized training gain and AUC) (Figure 17a and 17b). The variable that has the most information which is not present in the other variables is elevation (Figure 17a).

Response curves for the variables were created, and they show how the logistic prediction change as each environmental variable is varied, while keeping all other environmental variables at their average sample value. The predicted probability of presence of honeybees was lowest at south-facing aspects and higher closer to north facing aspects, but the patterns were complex (Figure 18a). The probability of honeybee presence increased sharply up to 40 meters above sea level, and reached a maximum between 100 m and 230 m and thereafter decreased with altitude (Figure 18b). The probability of honeybee presence is highest for landcover type 2: agricultural areas, second highest in landcover type 3: wooded grassland and lowest in landcover type 4: forest (Figure 18c). The predicted probability of honeybee presence generally decreases with an increasing slope (Figure 18d).

Table 6: Relative contribution of the environmental variables to Maxent model for *Apis mellifera*

Variable	Percent contribution	Permutation importance
Elevation	40.4	38.4
Slope	40.3	38.
Aspect	19.3	8.7
Landcover	0	14.4

(a)



(b)

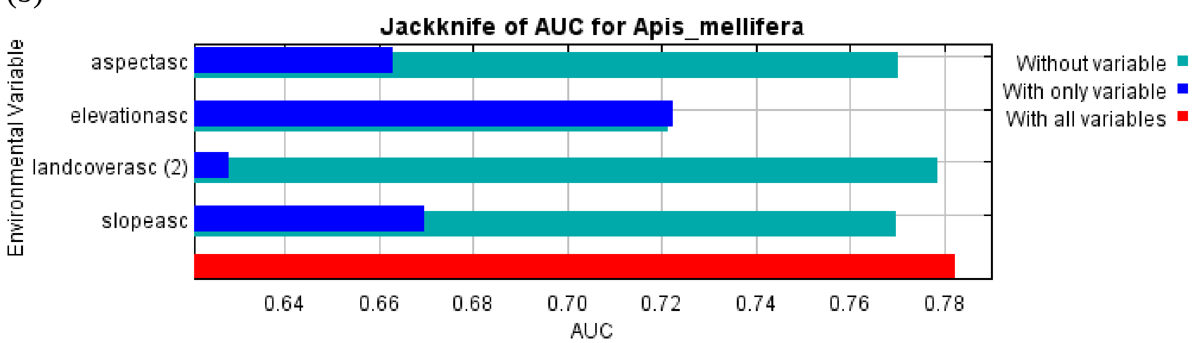


Figure 17: Relative importance of the different environmental variables based on results from jackknife test in Maxent. Graphics show variable contributions to a) reguralized training gain and b) AUC (area under the ROC curve)

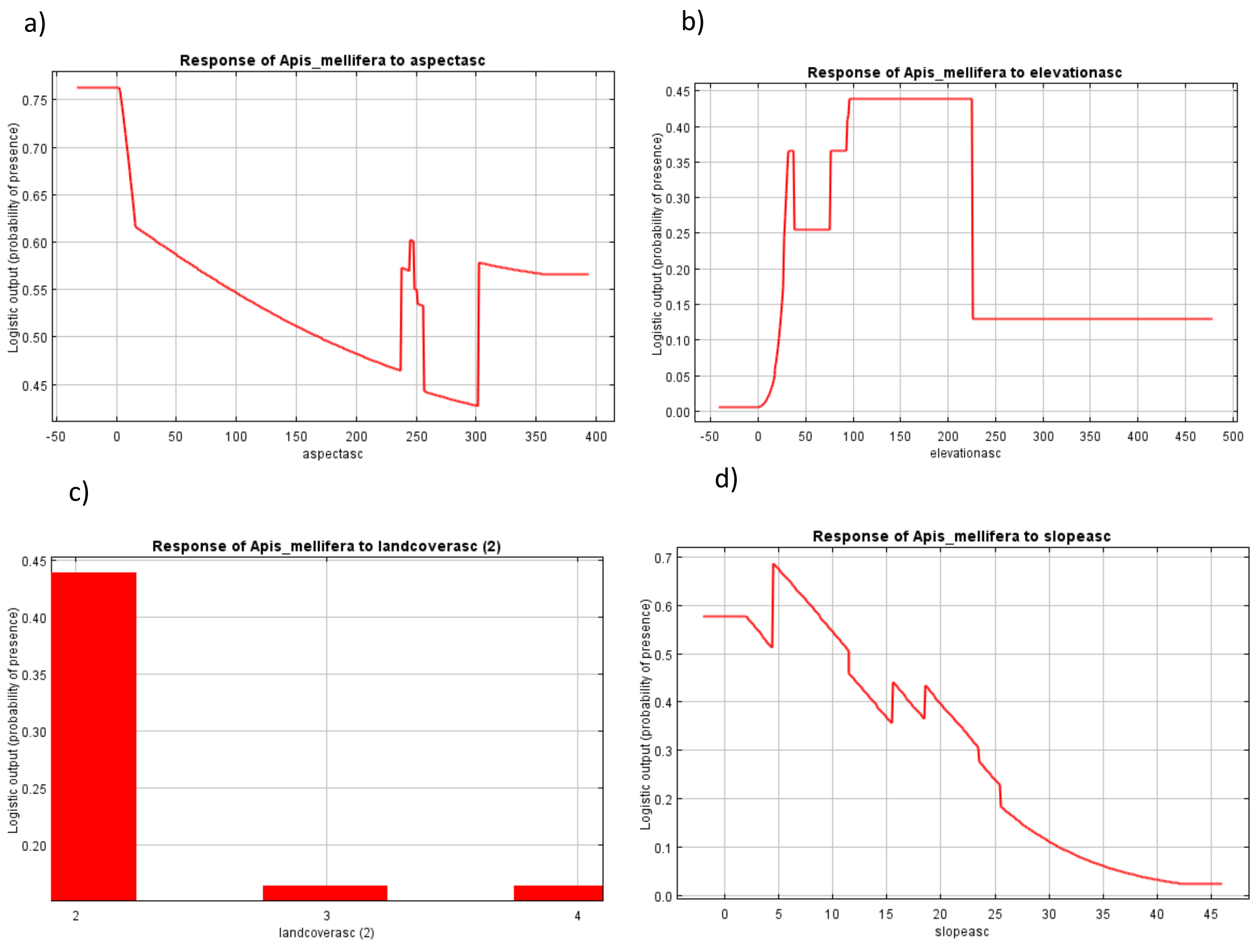


Figure 18: The relationship between environmental predictors and the probability of presence of Apis mellifera in Lofthus according to; (a) aspect; (b) elevation (meters); (c) landcover type; and (d) slope.

Suitable conditions for bumblebees are predicted for a large part of the sampled area in Lofthus, but not much presence is predicted in the more urban areas and along the main road which are located at the lower parts of the map (near the black area). The map shows that the bumblebees are more likely to be present at higher elevation towards more natural areas compared to the more urban areas (Figure 19).

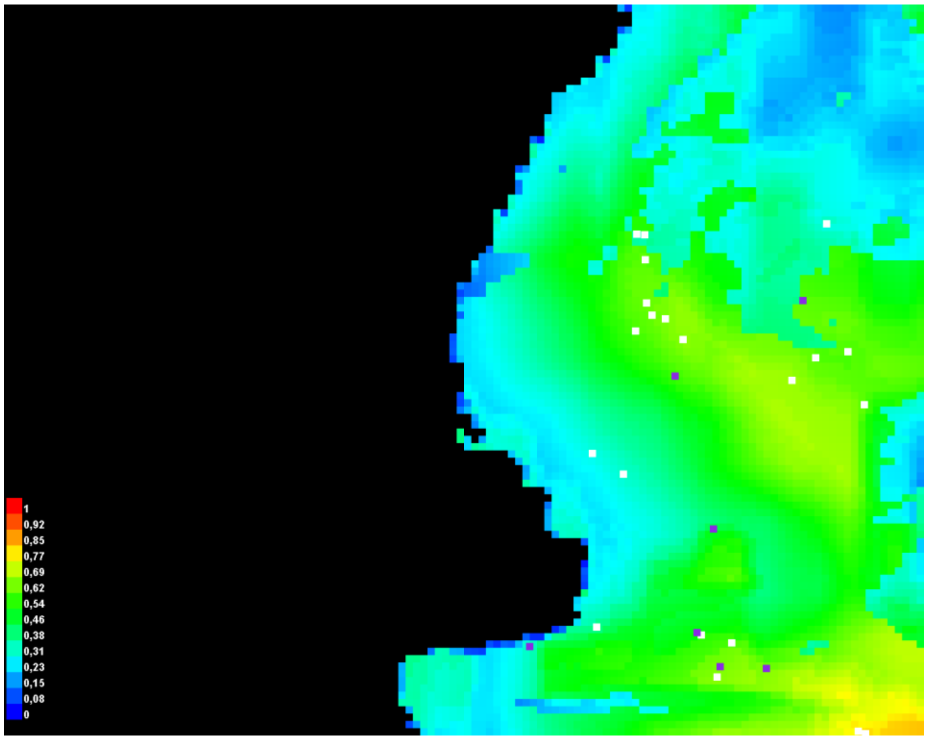


Figure 19: Bombus sp. output map from Maxent. Warmer colors indicate more suitable areas for the species

Maxent predicted the potential distribution of *Bombus sp* with poor-moderate accuracy with an average test AUC value of 0.656 and an average training AUC value of 0.747.

Elevation and slope were the strongest predictors of *Bombus s*p. distribution with 48 and 47.4 percent contribution (Table 7). Jackknife results showed that elevation, slope and landcover all had high predictive power (high regularized training gain and AUC) (Figure 20a and b). The variable that has the most information which is not present in the other variables is elevation (Figure 20a).

Response curves for the variables were created, and they show how the logistic prediction changes as each environmental variable are varied, while keeping all other environmental variables at their average sample value. The predicted probability of presence of *Bombus* sp. is stable to 250^{o}N, then decreases sharply (Figure 21a). The probability of *Bombus* sp. presence increases sharply to 140 metres, then decreases (Figure 21b). The probability of *Bombus* sp. presence is highest for landcover type 2: agricultural habitat, second highest in landcover type 4: forest and lowest in landcover type 3: wooded grassland (Figure 21c). The predicted probability of *Bombu*s sp. presence decreases from 0 to 10 degrees slope, is stable to 23 then decreases (Figure 21d).

Table 7: Relative contribution of the environmental variables to Maxent model for *Bombus sp.*

Variable	Percent contribution	Permutation importance
Elevation	48	52.4
Slope	47.4	41
Aspect	4.6	6.6
Landcover	0	0

a)

b)

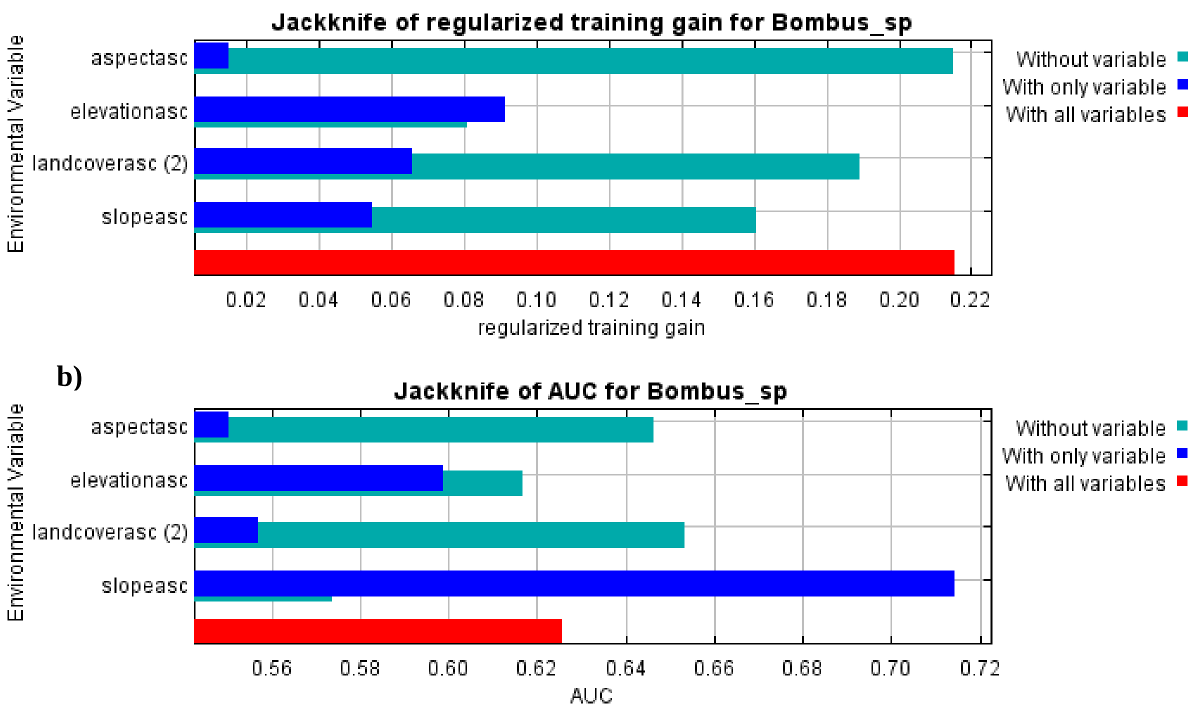


Figure 20: The relative importance of the different environmental variables based on results from jackknife test in Maxent. Graphics show variable contributions to a) reguralized training gain and b) AUC(area under the ROC curve).

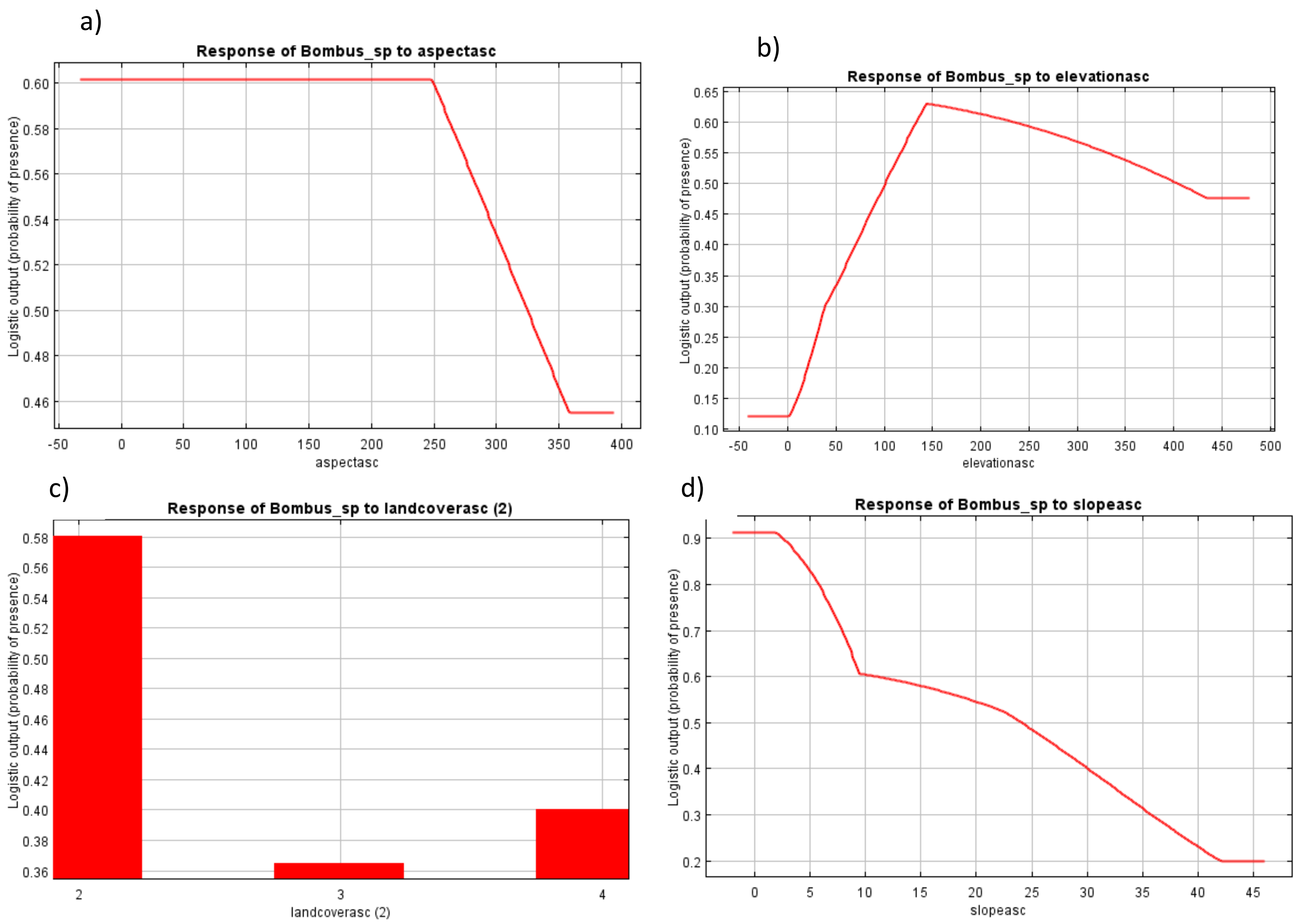


Figure 21: The relationship between environmental predictors and the probability of presence of Bombus sp. in Lofthus according to: (a) aspect; (b) elevation (meters); (c) landcover type and; (d) slope

Discussion

Pollinator community response to environmental and external factors

The majority of the pollinators I found were honeybees from managed colonies which represented 92 % of all observations at the farm transect walks. Growers often rely on honeybees from cultivated hives and they are often the dominating species in orchards (Klein et al. 2007, Potts et al. 2010b). In Sweden a study of pollinators on oilseed rape from of their observations they found: 79.1 % honeybees, 10.5 % hoverflies and 5.1 % bumblebees (Bommarco et al. 2012). However in studies from watermelon fields (Kremen et al. 2004) and apple orchards (Watson et al. 2011) in the United States there were a more similar amount of observed honeybees and wild bees. In a study across land use gradients in New Jersey and Pennsylvania there were more visiting wild bees observed than honeybees (Winfree et al. 2007a). This suggests that there is a large variation in the pollinator species composition and relative abundance between different systems. This may be due to agricultural practices in terms of natural habitat (Kennedy et al. 2013). Kennedy et al (2013) conducted a literature review where their results suggested that a 10 % increase in high quality habitats for the bees the wild bee abundance and richness will increase with 37 %. This could be a good idea in farm areas that are managed intensively. Norway on the other hand contains extensive natural habitats compared to farming landscapes in many other countries meaning that there must be another suggestion on how to increase the low wild pollinator abundance that was shown in my study.

Bumblebees were the most common wild pollinator in my study. They were still not very common in comparison to honeybees which is in accordance with findings from apple orchards in Wisconsin (Watson et al. 2011) and on oilseed rape fields in Sweden (Bommarco et al. 2012). The bumblebee queens are still building their colonies during the apple bloom, and therefore workers do not emerge in large numbers before, after the apple flowering (Vaughan and Black 2008, Gardner and Ascher 2006). This may explain why bumblebees were uncommon compared to honeybees in my study. Bumblebees need a constant supply of food throughout their growing season and they need places to nest (Vaughan and Black 2008). Thus a combination of a lack of undisturbed nesting sites, lack of food and colony building may explain why so few bumblebees were observed.

It has been shown that wild pollinators can be more efficient than honeybees in their pollination services of crops (Garibaldi et al. 2013). Honeybees are viewed as a replacement of natural pollinators, but it is shown that they cannot fully replace the contributions of wild pollinators or maximize pollination even in crops that are stocked with high density of honeybee hives for pollination (Garibaldi et al. 2013). In Lofthus, the apple orchards contained plenty of honeybee hives and it is likely that these have a large part in the provision of pollination as an ecosystem service towards the apple crops, but in accordance with Garibaldi et al. (2013) it is likely that the farmers also need to rely on wild pollinators. A possible reason why there were so few wild pollinators is a lack of nest places and alternative flowers in the area for the rest of the year (Vaughan and Black 2008, Kennedy et al. 2013). Bumblebees need small cavities in the ground or in trees to nest and to support a pollinator community the key is to have a rich plant community so that there is a source of pollen and nectar when the crops are not blooming (Vaughan and Black 2008).

The abundance of pollinators varied between the farms, and there was a significant difference in honeybee abundance, but not bumblebee abundance. When testing the significance between each of the farms it was shown that many of the farms have similar honeybee abundance, while some farms are very different from the other farms (Figure 9). Farm 4, 12 and 14 varied from the other farms, in that they had significantly lower honeybee abundance than most other farms. The reason for the low honeybee abundance at these farms may simply be a combination of cloudy/rainy weather at the time the transects were conducted and a long distance to the closest honeybee hive from the transects, and both farm 4 and 14 was located more than 400 meters from a honeybee hive. In overcast weather the farms with the lowest honeybee abundance were located farthest from honeybee hives. In addition the apple trees at farm 14 were almost finished blooming. Farm 12 also had cloudy weather when visited, but was not as far from hives as the other two. Other factors that might have impacted their low abundance are the amount of wildflowers, but this varied between all farms; farm 12 had few wild flowers, while farm 4 had many. There is likely to be complex patterns determining the abundance differences between the farms, but due to a high abundance at many of the farms, both weather and distance to honeybee hives were probably the most contributing factors. The reason why there was not a significant difference in bumblebee abundance between any farms may be that too few bumblebees were observed to make a significant difference.

There can be several reasons why farms, that are significant predictors of the pollinator abundance, have not been explained by the environmental variables. The weather on the day of data collection is an environmental variable that could explain the abundance of honeybees. I did not take into account the management at the farms, for example use of pesticides, insecticides and removal of wildflowers and weeds can have a large impact on the abundance of both honeybee and bumblebees in the orchards. The management at the farms and weather of the day may be the reason for the differences in pollinator abundance.

I did not predict that there would be a positive effect from distance to closest forest on the abundance of honeybees, but I did predict an effect on the pollinator abundance. The proportion of forest area did not have an effect on honeybee abundance in northeastern Wisconsin during apple bloom (Watson et al. 2011). However Marini et al (2012) showed that presence of forest had a positive effect on honeybee abundance in intensive apple orchards in Northern Italy. My prediction that distance to forest would have a significant positive impact on bumblebees was not supported by the data. There was however a significant positive impact on the presence of other wild pollinators. Marini et al (2012) showed that forest had a positive impact on presence of bumblebees. The extent of forest cover can have a negative effect on wild bee abundance and species richness (Winfree et al. 2007b). Winfree et al (2007b) showed that agricultural habitat and urban and suburban development had a greater abundance of bees than an extensive pine-oak forest. This suggests that the type of forest habitat may be of importance to the richness and abundance of pollinators. For instance a deciduous forest with many spring flowers that are blooming simultaneously as the crops can have a positive effect on the wild bee abundance and richness (Watson et al. 2011). None of the transects in the present study were farther than 480 meters from the forest, and this is known to be well within the maximum distance that many bumblebees fly daily for pollen (Steffan-Dewenter and Kuhn 2003, Dramstad 1996). Therefore the distance to forest from the farms I used may have been close enough that the distance would not have an impact on the bumblebees present.

Elevation had a positive effect on the presence of bumblebees and other wild pollinators, but no significant effect on honeybees. Increasing elevations have been associated with a decrease in species diversity and abundance in apple orchards in Italy where the orchards ranged from 150 to 1000 meters (Marini et al. 2012). The climate is often harsher at higher elevations and this may pose a higher risk for the apple orchards to be pollinator limited due to less wild species and less activity of honeybees (Marini et al. 2012). Marini et al (2012) showed that there was no apparent effect of elevation on bumblebees and the effect on honeybees was not as strong as predicted. The apple orchards in my study ranged from 0 to 150 meters so I did not expect a large difference in the species abundance and diversity. The significant effect on wild pollinators from increasing elevations suggests that the less disturbed habitats farther from farms has a positive effect on them. Habitats that are less disturbed than agricultural land may have more available substrates for nesting (Osborne et al. 2008) and potentially more resources.

My prediction that honeybee hives would have a significant effect on pollinator abundance was supported by the data. There were more honeybees observed when there was a high number of hives within 3 km, which supports my prediction that there would be a higher abundance of honeybees in areas with hives. This is in accordance with Vicens and Bosch (2000) who state that the high number of honeybees in apple orchards is most likely caused by honeybee hives. There is no effect from the hives within 1 km of the orchards or from the closest hive. However most of the farms have honeybee hives within 400 meters of the orchards and the overall number of honeybee hives in the area is quite high. This information indicates that honeybees fly farther than 1 km to pollinate which is in accordance with Steffan-Dewenter and Kuhn (2003) who showed their overall mean foraging distance to be 1.5 km. There was also an effect on the bumblebees from hives within 3 km which is in accordance with Steffan-Dewenter and Tsharntke (2000) who showed a positive correlation between bumblebee abundance and presence of honeybee hives. The reason why both honeybees and bumblebees were affected by honeybee hives within 3 km might be that all of the pollinator groups are attracted to areas with the most intensive flowering at a given time.

The negative impact from honeybee abundance on bumblebee abundance may indicate that the bees are territorial or that there are differences in the conditions in which they thrive. However it is surprising that density of honeybee hives within 3 km has a positive effect on both honeybee and bumblebee abundance, but honeybee abundance has a negative impact on bumblebee abundance. It may have been an effect from weather as more bumblebees were observed in unfavorable weather and less honeybees.

The abundance of pollinators varied with weather conditions and in accordance with my hypothesis and observations in previous studies, fewer insects were observed in unfavorable weather, especially honeybees (Vicens and Bosch 2000, Brittain et al. 2013). The weather appeared to have a large, but varying effect on honeybees and bumblebees. Honeybees were more often seen in sunny than in overcast weather and this is in accordance with Vicens and Bosch (2000), where it was shown that honeybee activity was significantly dependent on temperature, solar radiation and wind speed in apple orchards. The bumblebees in the present study were less affected by the weather as a few raindrops and overcast weather did not have a negative effect on their activity. This suggests that bumblebees are less sensitive to weather change than managed honeybees. This is in accordance with studies showing that bumblebees forage in poorer weather than honeybees on raspberries in Scotland (Willmer *et al.* 1994) and on blueberries in Michigan (Tuell and Isaacs 2010) . The low number of other pollinators made it difficult to see an effect from weather.

The spring apple blooming period is short and the pollination of apple flowers may be limited by unstable weather at the time of the bloom (Watson et al. 2011). Therefore the capability of some wild pollinators such as *Bombus sp.* to handle lower temperatures and lower solar radiation and the low abundance of honeybees in lower temperature and lower solar radiation (Vicens and Bosch 2000, Gardner and Ascher 2006) suggest that it is important to have a higher diversity of pollinator species (Brittain et al. 2013). This is in accordance with my results that indicated that diversity of pollinators had a positive impact on crop yield and fruit set which indicates that a high diversity of pollinator species are important for the apple. This is to ensure adequate pollination during the short blooming season and vice versa: it is important to have other foraging resources that can be provided by high-quality habitats for wild pollinators to enhance their abundance and diversity (Kennedy et al. 2013).

A mixture of farm and environmental variables was the best predictors of honeybee abundance, and the environmental predictors were changed depending on whether farms were included as part of the model. This indicates that some of the environmental variables are masked by the farm. Farm is a powerful variable with 21 degrees of freedom and the two variables hives within 3 km and elevation seems to act through farm. It shows that both farm and the environmental variables are important predictors of honeybee abundance.

The AIC and pseudo r2 score are conflicting as the predictors of bumblebees. The best model here is also the mixed one, but due to a low number of bumblebee observations and a high number of predictor variables; I did not use it in my study. The AIC score and pseudo r2 shows that both farm and environmental variables are good predictors of the bumblebee abundance. I prefer environmental variables due to the AIC score.

The comparisons between farm as the only predictor variable, both environmental variables and farm and environmental variables alone show that farms most likely contains important information that is not present in the environmental variables. This shows that farm is an important predictor of the species abundance.

Variables that were not measured may be related to the management of the farm as the same farm including wildflowers, semi natural habitat, insecticides and pesticides can all have a significant impact on the pollinator abundance. This shows the conflict between choosing to do a study with fewer farms and more repetitions per farm, or as in my study with many farms, but few areas per farms. We choose more farms and fewer repetitions because we wanted to study the effect from environmental factors.

<u>Effect of pollinator communities and landscape factors on crop yields</u>

The yield varied between the farms and apple cultivars. The average yield was slightly low this year at 1119 kg/decare, where a good yield represents at least 1400 kg/decare area (pers. comm farmers). However this differed between the farms and apple cultivars, and some farmers said their yield was OK, while others were dissatisfied.

The yield was affected by honeybee abundance and other pollinator abundance at the transects. The positive effect from honeybee abundance on yield is in accordance with my prediction that abundance of pollinating insects enhances the yield. This is in contrast with Holzschuh et al (2012) who showed that only wild pollinators had an effect on the fruit set and final yield of cherries. It is in accordance with Bommarco et al (2012) who showed that honeybees as the most abundant pollinator in oilseed rape in fields in Sweden had a positive impact on seed yield. However Holzschuh et al (2012) suggested that the honeybee effect on the fruit set and yield was masked by the more efficient wild pollinators. In accordance with my prediction the diversity of pollinators at the transect walks also had a positive effect on the yield, which is also in accordance with the positive effect from diversity on fruit set in the present study. It is also in accordance with a report by Garibaldi et al (2013) where it was suggested that diversity of wild insects has a potential to improve global yield of animal-pollinated crops. In the present study the pollinator abundance and diversity recorded during a 15 minute transect walk may not be representative of the visitation at the orchards during the full bloom period. I only recorded four species group for the diversity factor and therefore the effect surprises me. The yield is measured from all the trees of the same apple cultivar on the farm. Thus the predictor variables measured from the transects may not be good predictors of the yield at the farm. However the results indicate that honeybee abundance and pollinator diversity at the transects have a positive impact on the yield.

The surrounding factors that impacted the yield were distance to closest forest, distance to closest hive and number of hives within 3 km. However they had a negative impact on the yield and so the yield was higher farther from forest and hives and also when there was fewer hives within 3 km. This suggests that forest and hives have a negative impact on the yield or that variables measured from transects are not the best method to measure what impacts the yield. This shows that there may be other factors that were not measured that may be affecting the yield. It has been shown that there is a negative effect from environmental conditions such as frost, precipitation and temperature on apple pollination (Ramírez and Davenport 2013). Apples are also affected by the yield in previous years (pers. comm farmers and Mekjell Meland) and because 2012 had a very good yield this may have limited the yield in 2013.

Fruit set was affected by the diversity of pollinators and the number of hives within 3 km. There was no effect from the pollinators observed on the branches, but it is known that successful pollination leads to apple fruit set (Ramírez and Davenport 2013). The negative effect from hives within 3 km suggest that honeybees has a negative effect on the fruit set. This is in conflict with a review Free et al (1993) where it was shown that honeybees enhance fruit set and that there are often not sufficient wild pollinators to give an adequate fruit set in apples. A study from Sweden on pollinators of oilseed rape showed that pollination is required for a high fruit set (Bommarco et al. 2012). However my results are in accordance with a new report (Garibaldi et al. 2013) suggesting that wild pollinators enhance fruit set regardless of honeybee abundance and that honeybees merely supplement the wild pollinators. They found an increase in fruit set from honeybee visitation in 14 % of the systems surveyed; however their study did not include apples. The positive effect from diversity is also in accordance with Garibaldi et al (2013). The negative effect from the number of honeybee hives within 3 km may be a coincidence as it is a large area. However the positive effect from diversity coupled with the negative effect from the number of hives within 3 km suggests that it is important with a diversity of pollinators to enhance the fruit set of apples.

Optimizations of field methods

I wanted to test which methods worked best for obtaining data on pollinators in apple orchards and which factors affect them. The methods used for data collection at the farms were transect walks, observations at branches, traps, and in addition transect walks were carried out in different habitat types for modeling the species distribution. The data from the first three methods were used for statistical analysis, while the data obtained from the transect walks in different landscape types were used for Species Distribution Modeling. Of these methods, transect walks, both at farms and in different landscape types was one of the most successful methods. Similar methods have also been used by Bommarco et al (2012) who carried out transects walks with successful observations and Watson et al (2011) and Vicens and Bosch (2000) who recorded bee visitors in trees along transects. The fruit set count from the observational data in my study worked for its purpose. Bommarco et al (2012) performed bagging and control treatment to look at the success of pollination on the seed set of oilseed rape. Winfree et al (2007) conducted a bagging experiment to study the efficiency of the per-flower deposition between native bees and honeybees. The traps in the present study were very unsuccessful and were also quite time consuming. This is surprising since they are highly recommended by Westphal et al (2008) and many studies have been able to use them successfully. For instance Watson et al (2011) who placed the traps beneath the trees, and Marini et al (2012) who placed the traps on wooden poles used the traps successfully. The low abundance of wild pollinators in the area may have explained my low catch in this study. Compared to the count in the transects and in other studies such as Watson et al [2011] where they caught an average of 56.9 bees per trap the catch in my traps is a very low number. The traps over summer were the most successful and maybe an improvement in their conditions could have led to a positive impact.

Most of the natural area was forested and there was often a distinct border between the cropland and forest. I could have measured distances to more other types of natural habitats such as patches of wildflowers in addition to forest in my study. To do this I would find the most nearby semi-natural or natural habitats that were not forests and also test how these would affect the honeybee and bumblebee abundance. I could have walked transects along wild flowers, either in the crops or natural and semi-natural areas to assess the flower cover and the pollinator abundance in areas with more flowers. However, because the apple-blooming season is very short, limiting the available time for fieldwork, this would have taken away time that I could have used in the orchards. I also partly carried this out in my transects used for the SDM, where I walked along varying landscape types to study the pollinator abundance.

One factor that needs to be taken into consideration is that for the fruit set, some of the branches had been thinned while others had not before the field work was repeated. When the branches are thinned the workers remove small apples so that there are fewer apples per branch (pers comm. farmers). However I still found an effect from surrounding factors on apples which indicate that even if some apples are removed the percent fruit set will still be highest at places with best conditions, for example high pollinator diversity.

The low catch in the traps suggests that the trapping method was not optimal and should have been improved. The temperature measurers that were placed out over summer were not used due to low catch, but it would have been interesting to see how temperature affects both the catch and the yield.

Because of the large number of zeros of pollinators and the low catch I did not construct a model of the catch in the traps. The problem is most likely that there is not enough data on pollinator species. If I made a model of the caught pollinator species over the summer with the low catch, I probably would have had to make a zero inflated model which is currently under development (Zuur et al. 2009). If I had caught more in the traps I would have had more data for which I was planning to test a generalized linear mixed model with traps nested in farm.

To improve the trap methodology I could have hanged up the traps before the apple blooming started. I could have dropped the different colors of the traps, and kept the bowls white since this is the color of the apple flowers.

The main limitation of my methods has been time. The apple flowering season lasted for around two weeks, and exactly when it starts is uncertain, and covering this entire area using three methods within such a limited timeframe was challenging.

The SDM predicted that the habitats that are most suitable for the honeybees are located in the orchards and on the way towards the river valley. On the other hand the habitat SDM predicted to be most suitable for bumblebees are the upper parts of the apple orchards and the natural and semi-natural habitats above the orchards, especially towards the river valley. The AUC score showed that the SDM had good predictive power for the presence of honeybees, but not as good for the bumblebees. The lower predictive power of the SDM for the bumblebees is probably because of the relatively low number of observed bumblebees. In the statistical modeling only the honeybee abundance from the farm was used which makes it difficult to compare to their preferred habitats. The honeybees were more attracted to agricultural land, grassland and edge habitat than they were to forests and more urban areas. A reason for the honeybees preference for agricultural land, grassland and edge habitat may be that flowering weeds such as *Taraxum sp.*, in which honeybees were often observed, are very common in these areas. It was also shown that the bumblebees' preferred agricultural areas rather than forest, but forest before wooded grassland. The upper parts of the orchards are often closer to natural habitats situated on the border of the forest. This may explain why there is a higher predicted presence of bumblebees in these areas. However there was no significant effect from distance to forest on the presence of bumblebees in the apple orchards. This may be because they fly to their preferred foraging sites in orchards and that a distance between 100 and 400 meters does not make a significant difference to them.

Elevation and slope were the two strongest predictors of the predicted honeybee presence in the SDM. The SDM showed elevation to have a positive effect on honeybees to around 230 meters. Elevation did not have a significant effect on honeybee abundance in the negative binomial model. On the other hand elevation, slope and land cover were the strongest predictors of bumblebee presence. Bumblebee presence is predicted to peak around 150 meters above sea level. This is in accordance with my prediction that the SDMs would support the statistical findings on environmental predictors of pollinator abundance on the farms, even though none of the orchard transects were located above 160 masl. The bumblebees seem to prefer elevations between 100 and 300 masl, which are in areas with less disturbances and more natural areas. The transect walks used for the negative binomial regression were done only in apple orchards, while the SDM transects were carried out in three land cover types: wooded grassland, agricultural land and forest. Thus the landscape used for the SDM walks were more heterogeneous than for the orchard landscape, and in addition there were more natural areas with wild flowers at higher elevations. This changes at around 230 meters in the transect walks where the landscape is forested. It may be the case that honeybees and bumblebees are attracted to flowers and weeds which are more common in the orchards, edge habitats and grassland and/or a low diversity and amount of flowering plants in pine forest. Therefore it may be the case that bumblebees and honeybees prefer a more heterogeneous landscape than found in the orchards.

The predicted response from honeybees to slope was shown to vary up to 16 degrees and then decrease, while predicted bumblebee response decreased continuously from 0 to 45. The host plants may have certain preferences of slope conditions due to factors such as drainage or extreme colds. This may lead to fewer plants which honeybees and bumblebees are attracted to on the steeper slopes. When there are fewer plants this may lead to fewer pollinators due to lower availability of nectar and pollen. It may also be the case that slope affects the distribution of land use, and in fact it has been shown steeper slopes are more often used for forest than for farming (Fu et al. 2006).

The north facing slope has a higher presence and prediction of honeybee observations, but there is also a peak in the western facing slopes. Lofthus does not receive direct sunlight before around 10 AM in June because of the Hardangervidda mountain plateau located east of the village. The lack of sunlight in the morning means that it does not get warm early, but there is direct sunlight until around 8 PM. Honeybees need temperatures of 12-14^{o}C and 300w/m^{2} solar radiation to start foraging (Vicens and Bosch 2000). The lack of sunlight in early mornings and therefore the lower temperature may be why the honeybees are predicted to be more present in west and towards north facing slopes. The bumblebees' reaction to the aspect differs from the honeybees and that they are more common from 0 to 250^{o}N, which indicates that they are not as dependent on sunlight and temperature as honeybees and that they have different foraging preferences from honeybees.

<u>Implications for the fruit orchards in Lofthus, Hardanger</u>

My results suggest that there is support for decline in pollinator abundance with increasing distance to natural habitat in Lofthus, which is in accordance with Ricketts et al (2008). Ricketts et al (2008) argue that this is because native pollinators are occurring more often at lower abundance in isolated fields due to a large distance to their nests in natural habitats. The interesting finding in my study is that honeybee abundance declines with increasing distance to natural habitat, while there is no significant effect from distance to forest on bumblebees. However this may be because the distance to natural habitats was not far enough for there to be an effect on bumblebees.

There is a lack of synchrony between fruit flowering and wild bee colony building in Norway. This leads to a potentially lower number of wild pollinators, especially in the number of bumblebees compared to what would have been expected. The low number of other wild pollinators observed in the field suggests that honeybee hives are very important for the apple production in Lofthus, Hardanger.

It is of great risk to rely on one pollinator species only, especially considering the fact that honeybees seem to have a low tolerance for cloudy and rainy weather and that diversity had a positive impact on fruit set and yield. A year with poor weather conditions during flowering may limit pollination success. It could therefore be a good idea to enhance habitat for natural pollinators, especially in case of unfavorable weather conditions. It has been suggested managed bumblebees to support pollinators (Velthuis and van Doorn 2006), but I have not studied this.

The effect of many farms in a small area may lead to a lower pollination service on each farm from the wild pollinators, especially since they may need to distribute their contribution due to the abundance of floral resources for a short time period. Lofthus has many apple orchards which are all situated very close to one another and there are two dominating cultivars: aroma and discovery. Thus a large apple growing area requires pollination more or less in the same period depending on the cultivar. The fruit-blooming has an extreme amount of flowers that needs to be pollinated in a very short time period. The low amount of wild bees observed at each transect suggests that there is not sufficient pollination from wild pollinators to the apple trees. The abundance of flower resources could have led to more wild pollinators. However the wild pollinators also need pollen and nectar resources the rest of their active season. I did see that many of the farms had flowers between the crop rows, but this is not necessarily flowers preferred by wild pollinators. Alternative food supplies for wild pollinators could possibly be improved by using set aside areas with planted flowers known to be attractive to wild pollinators as bumblebees that are known to be efficient to be able to rely less on honeybees. For instance, I observed that the pollinators, especially honeybees were very attracted to *Taraxum sp*. To set aside areas for nectar-yielding flowers would be in accordance with Kennedy et al (2013) who shows that farms with high quality habitat surrounding the field has a higher bee abundance and richness. This could also have a potential impact on the fruit set and yield of the apples by enhancing the wild bee abundance and diversity.

Future management

It is well known that semi-natural habitats can have a positive influence on pollination of agricultural crops by increasing the amount of pollinators (Klein et al. 2007). The distance from the orchards to the natural habitat in Lofthus was close; however it might not have been the right type of natural habitat as it consisted primarily of pine forest. The agriculture in Norway has been modernized since the 1950s and this has had a large impact on the presence of species rich semi-natural habitats such as pasture and semi-natural meadows (Norderhaug 2011). Semi-natural meadows with a high diversity of plants and insects have declined and is now considered a threatened habitat type in Norway (Norderhaug 2011). The habitat type can still be recovered if the right type of conservation action is implemented, and there is a plan to conserve these in Norway (Norderhaug 2011). The occurring natural fragments in farms in Lofthus are small parts of edge habitats, flowers in the crop rows and forests, which is also the case according to a study in Sweden (Öckinger and Smith 2007). Enhancement of pollinator abundance and diversity, for cropland and orchards, can be done by introducing flowers that are pollinated by the common pollinator groups of the crops and to ensure constant availability of forage when the pollinators are active (Totland 2013).

Conclusions

I have shown that honeybees are the most abundant pollinators of apple flowers in Lofthus, Norway. This supports the knowledge that growers often rely on managed honeybee hives in orchards. Wild pollinators were not nearly as abundant as honeybees, but bumblebees were the most common wild pollinators. Honeybee hives within 3 km had a positive impact on honeybee and bumblebee presence. Weather had a large, but varying impact on honeybee and bumblebee abundance. While honeybees were limited by poor weather, bumblebees were not as dependent on sunny weather. Norwegian spring weather can be unfavorable and therefore limit the pollination service performed by honeybees.

The abundance of honeybees and pollinator diversity had a positive impact on the yield, while only pollinator diversity had a positive impact on the fruit set. The significant effect of pollinator diversity on yield indicates that natural pollinators are important despite their low abundances. My results add to the evidence that pollinator diversity is important for the yield and fruit set of crops. There was however negative effects on the yield from landscape scale factors such as distance to honeybee hives and forest.

The most successful field method for collecting this data in Lofthus was transect walks, performed both in agricultural landscape and in other landscape types. A species distribution model supported and strengthened the results from the statistical analyses by showing which habitat types were preferred by the pollinators. There was an effect from elevation, which on honeybees was only shown in particular landscape types, while the effect on bumblebees was constant at farms and in different habitat types. Honeybees and bumblebees were both present in agricultural landscapes, but bumblebees preferred semi-natural landscape at higher elevations.

This highlights the importance of enhancing the diversity and abundance of wild pollinators in Lofthus, Norway. In accordance with other studies on the subject I suggest to invest in habitat types such as semi natural meadows that are known to be attractive to pollinators. I also suggest ensuring that plenty of nectar-yielding wildflowers are available throughout the season of the wild pollinators.

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Appendices

Appendix 1: Yield from the apple cultivars from the subareas at the farms.

Figure A1: Yield in kilograms per decare from the farmers that were able to provide me the yield. The yield is the high quality apples that were sold

Farm	Yield
1	750, 625
2	1250, 1000
3	800, 625
4	500, 1302
6	1500, 2000
7	254, 0
8	2470, 906
9	1207, 1342
10	350, 1250
11	1467, 641
12	1167
13	1275
15	2000, 1400
16	1200
17	1390
19	1500, 2000
20	940, 320
22	1250

Appendix 2: Traps and catch from the traps over summer and for two days

2 days

Table A2a: Information about the catch in traps, farm location and elevation of trap in traps left outside for two days

Trap location and color	Elevation	Recorded species
F1 S1 434: White	50 m	2 honeybees
F1 S1 434: Blue	50 m	2 honeybees
F1 S2 437: White	63 m	-
F1 S3 435: White	65 m	1 honeybee
F1 S3 435: Blue	65 m	-, 1 wild bee
F1 S4 436: White	68 m	2 honeybees
F1 S5: 101 White	101 m	1 bumblebee
F2 S3 White	19 m	2 honeybees
F2 S4 483: Red	11 m	2 honeybees
F3 S1 477: White	47 m	1 honeybee
F3 S2 478: White	58 m	2 honeybees
F3 S2 478: Blue	58 m	1 honeybee
F4 S1 515: White	41 m	1 honeybee
F4 S2 516: Whte	31 m	4 honeybees
F4 S3 517: White	37 m	4 honeybees
F4 S3 517: Yellow	37 m	3 honeybees
F4 S4 518: Blue	36 m	3 honeybees

Table A2b) Information about which farm the traps are located on, trap color, elevation of trap, location of trap when considering landscape variables and catch in traps from the traps left outside over the summer.

Traps location and color	Elevation	Location	Observed species
F1 S1 –White	93 m	Close to forest	Diptera
F1 S1 Blue	93 m	Close to forest	Diptera
F1 S1 Yellow	93 m	Close to forest	-
F1 S2 White	95 m close to forest	Close to forest	Diptera, 6 honeybees
F1 S2 Blue	95 m	Close to forest	Beetle, flies, 1 apis mellifera, 1 small bumblebee
F1 S2 Yellow	95 m	Close to forest	-ruined insects
F2 S1 610: White	30 m	Close to road	Ruined flies, 5 honeybees
F2 S1 610: Yellow	30 m	Close to road	-
F2 S1 610: Blue	30 m	Close to road	-
F2 S2 611: White	10 m	Close to road, centre and fjord	104 flies, 5 Beetles, ants
F2 S2 611: Yellow	10 m	Close to road, centre and fjord	5 honeybees
F2 S2 611: Blue	10 m	Close to road,	-

		centre and fjord	
F3 S1 608: White	44 m	Middle of farms	. 2 hymenoptera (wild), other
F3 S1 608: Blue	44 m	Middle of farms	-dipteras, moth, ants
F3 S2 609: White	52 m	Middle of farms	-insect parts
F3 S2 609: Yellow	52 m	Middle of farms	-1 Coleoptera + Dipteras
F4 S1 593: White	31 m	By forest, far from centre	1 honeybee, Dipteras, 1 Coleoptera
F4 S1 593: Yellow	31 m	By forest, far from centre	-coleotera, diptera
F4 S2 594: White	32 m	By forest, far from centre	Ruined insects, 1 honeybee
F4 S2 594: Blue	32 m	By forest, far from centre	-ruined insects
F4 S2 594: Yellow	32 m	By forest, far from centre	Ruined flies, Diptera, 1 bombus (terrestris/lucorum)
F5 S1 599: White	53 m	Middle of farms	-
F5 S1 599: Blue	53 m	Middle of farms	-
F5 S1 599: Yellow	53 m	Middle of farms	-1 hoverfly
F5 S2 600: White	47 m	Middle of farms	Ruined insects, diptera , hoverfly
F5 S2 600: Yellow	47 m	Middle of farms	Diptera
F5 S2 600: Blue	47 m	Middle of farms	-
F6 S1 597: White	46 m	Middle of farms	Flies, ant, 10 honeybees, 1 hymenoptera (wild bee)
F6 S1 597: Blue	46 m	Middle of farms	-ruined, also a bumblebee
F6 S1 597: Yellow	46 m	Middle of farms	-coleoptera
F6 S2 598: White	38 m	Middle of farms	-Diptera, 2 hoverflies, 2 wild bees, 2 B. terrestrs/lucorum
F6 S2 598: Blue	38 m	Middle of farms	-ruined
F6 S2 598: Yellow	38 m	Middle of farms	-
F7 S1 596: White	53 m	Close to forest and camping area	-
F7 S1 596: Blue	53 m	Close to forest and camping area	-squeezed bee
F7 S1 596: Yellow	53 m	Close to forest and camping area	Diptera
F7 S2 594: White	61 m	Close to forest and camping area	-
F7 S2 594: Blue	61 m	Close to forest and camping area	-1 wild bee
F7 S2 594: Yellow	61 m	Close to forest and camping area	-

Appendix 3: Raw data from observations at branches including a table with count of flower clusters and apples at the branch at each farm, and a table with recorded bees.

Table A3a: Flowerclusters and apple count at the branches. The percent fruit set is included and the mean, variance and confidence interval of the flowerclusters and apple recordings was also calculated.

Farm number	Flowerclusters branch t1 and t2	Mean flower obs	Variance and sd flower obs	Confidence interval flower obs	Apples branch t1 and t2	Mean apple obs	Variance and sd apple obs	Confidence interval apple obs	Procent fruit set
1	31, 12	21.5	180.5, 13.43	[2.88, 40.12]	17, 19	19.5	4.5, 2.12	[16.6, 22.4]	30, 13.5
2	30, 31	30.5	31.48, 0.707	[29.52, 31.48]	4, 7	5.5	4.5, 2.12	[2.56, 8.44]	2.6, 4.5
3	18, 14	16	8, 2.82	[12.08, 19.92]	12, 6	9	18, 4.24	[3.12, 14.88]	13.3, 10
4	10, 11	10.5	0.5, 0.707	[9.52, 11.48]	7, 12	9.5	12.5, 3.53	[4.6, 14.4]	14, 25
5	19, 14	16.5	12.5	[11.6, 21.4]	20, 36	28	68, 8.25	[16.57, 39.42]	14.7, 36
6	13, 14	13.5	0.5	[17.16, 32.84]	8, 24	16	128, 11.3	[0.32, 31.68]	12.3, 34.3
7	14, 5	9.5	40.5	[0.68, 18.32]	6, 5	5.5	0.5, 0.707	[4.52, 6.48]	8.6, 20
8	20, 11	15.5	40.5, 6.36	[6.7, 24.3]	12, 7	9.5	12.5, 3.53	[4.6, 14.4]	17, 12.7
9	15, 19	17	8, 2.82	[13.02, 20.92]	7, 8	7.5	0.5, 0.707	[6.52, 8.48]	9, 8.4
10	7, 9	8	2, 1.4	[6.04, 9.96]	5, 14	9.5	40.5, 6.36	[0.68, 18.32]	25.7, 64
11	24, 12	18	72, 8.48	[6.24, 29.76]	12, 9	10.5	4.5, 2.12	[7.56, 13.44]	10, 15
12	20, 6	13	98, 9.9	[0, 26.72]	10, 5	7.5	12.5, 3.53	[2.6, 12.4]	12, 23.3
13	31, 41	36	50, 7.07	[26.2, 45.8]	21, 16	18.5	12.5, 3.53	(13.6, 23.4]	13.5, 7.8
14	9, 6	7.5	4.5, 2.12	[4.56, 10.44]	30, 4	17	338, 18.4	[0, 42.5]	66.7, 16.7
15	31, 37	34	18, 4.24	[28.12, 39.88]	29, 11	20	162, 12.7	[2.36, 37.64]	25.2, 5.95
16	8, 2	5	18, 4.24	[0, 10.88]	17, 5	11	157, 12.5	[0, 28.4]	55, 50
17	17, 22	19.5	12.5, 3.53	[14.6, 24.4]	8, 7	7.5	0.5, 0.707	[6.52, 8.48]	7.2, 8.2
18	11, 16	13.5	12.5, 3.53	[8.6, 18.4]	14, 23	18.5	40.5, 6.36	[9.68, 27.32]	29.1, 28.7
19	8, 24	16	128, 11.31	[0.32, 31.68]	3, 7	5	8, 2.82	[1.08, 8.92]	6, 7.5
20	25, 9	17	128, 11.31	[1. 32, 32.68]	7, 8	7.5	0.5, 0.707	[6.52, 8.48]	5.6, 13.3
21	8, 12	10	8, 2.82	[6.08, 13.92]	10, 5	7.5	12.5, 3.53	[2.6, 12.4]	35, 8.3
22	13, 31	22	162, 12.72	[4.36, 39.64]	13, 13	13	0, 0	[13]	20, 8.4

Table A3b: Pollinator observations from both branches at each of the 22 farms. Mean, variance, standard deviation and confidence interval is calculated for each of the three species groups.

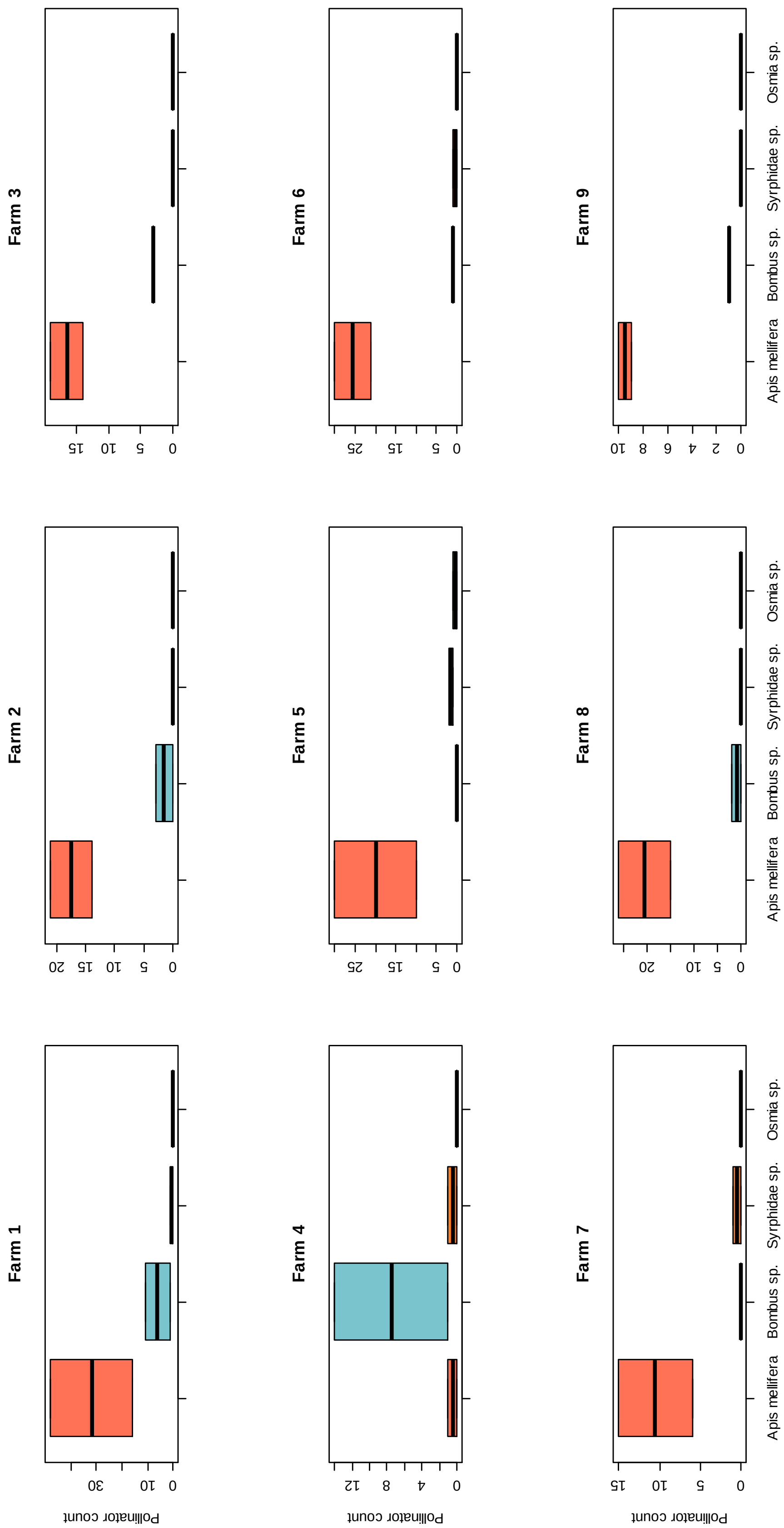
Farmnumber	B1 , B2 honeybees, bumblebees and hoverflies	Mean Honeybees, Bumblebees. Hoverflies	Variance Honeybees, Bumblebees. Hoverflies	Standard deviation Honeybees, Bumblebees. Hoverflies	Confidence interval Honeybees, Bumblebees. Hoverflies
1	1, 1 , 0, 4, 0, 0	2.5, 0.5, 0	4.5, 0.5, 0	2.12, 0.7	[0, 5.44], [0,1.48], [0]
2	3, 1, 0, 0, 0, 0	2, 0, 0	2, 0, 0	1.41, 0, 0	[0.04, 3.96], [0], [0]
3	1, 1, 0, 0, 0, 0	1	0	0,0	[1], [0], [0]
4	0, 2, 0, 0, 0, 0	0, 1, 0	0, 2, 0	0, 1.41, 0	[0], [0, 2.96], [0]
5	1, 0, 0, 1, 0, 0	1, 0, 0	0, 0, 0	0, 0, 0	[1], [0], [0]
6	0, 0, 0, 1, 0, 0	0.5, 0, 0	0.5, 0, 0	0.707, 0, 0	[0, 1.48], [0], [0]
7	3, 0, 0, 0, 0, 0	1.5	2.25, 0, 0	1.5, 0 , 0	[0, 3.6]
8	1, 0, 0, 4, 0, 0	2.5, 0, 0	4.5, 0, 0	2.12	[0, 5.44]
9	2, 0, 2, 0, 0, 0	1, 0, 1	2, 0, 2	1.41, 0 ,1.41	[0, 2.96], [0], [0, 2.96]
10	0, 0, 0, 0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	[0], [0], [0]
11	0, 0, 0, 0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	[0], [0], [0]
12	0, 0, 0, 0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	[0], [0], [0]
13	0, 0, 0, 2, 0, 0	1, 0, 0	2, 0, 0	1.41, 0, 0	[0, 2.96], [0], [0]
14	1, 0, 0, 0, 0, 0	0.5, 0, 0	0.5, 0, 0	0.7, 0, 0	[0, 1.48], [0].,[0]
15	2, 0, 0, 0, 0, 0	1, 0, 0	2, 0, 0	1.41, 0, 0	[0, 2.96], [0], [0]
16	0, 0, 0, 3, 0, 0	1.5, 0, 0	4.5, 0, 0	2.12, 0, 0	[0, 4.44], [0], [0]
17	1, 0, 0, 2, 0, 0	1.5, 0, 0	0.5, 0, 0	0.7, 0, 0	[0.52, 2.48], [0], [0]
18	0, 0, 0, 2, 0, 0	1, 0, 0	2, 0, 0	1.41, 0, 0	[0, 2.96], [0], [0]
19	6, 0, 0, 1, 0, 0	3.5, 0, 0	12.5, 0, 0	3.53, 0, 0	[0, 8.4], [0], [0]
20	2, 0, 1, 1, 0, 0	1.5, 0, 0.5	0.5, 0, 0.5	0.707, 0, 0.707	[0.52, 2.48], [0], [0, 1.48]
21	4, 0, 0, 4, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	[4], [0], [0]
22	1, 0, 0, 6, 0, 0	3.5, 0, 0	12.5, 0, 0	3.53, 0, 0	[0, 8.4], [0], [0]

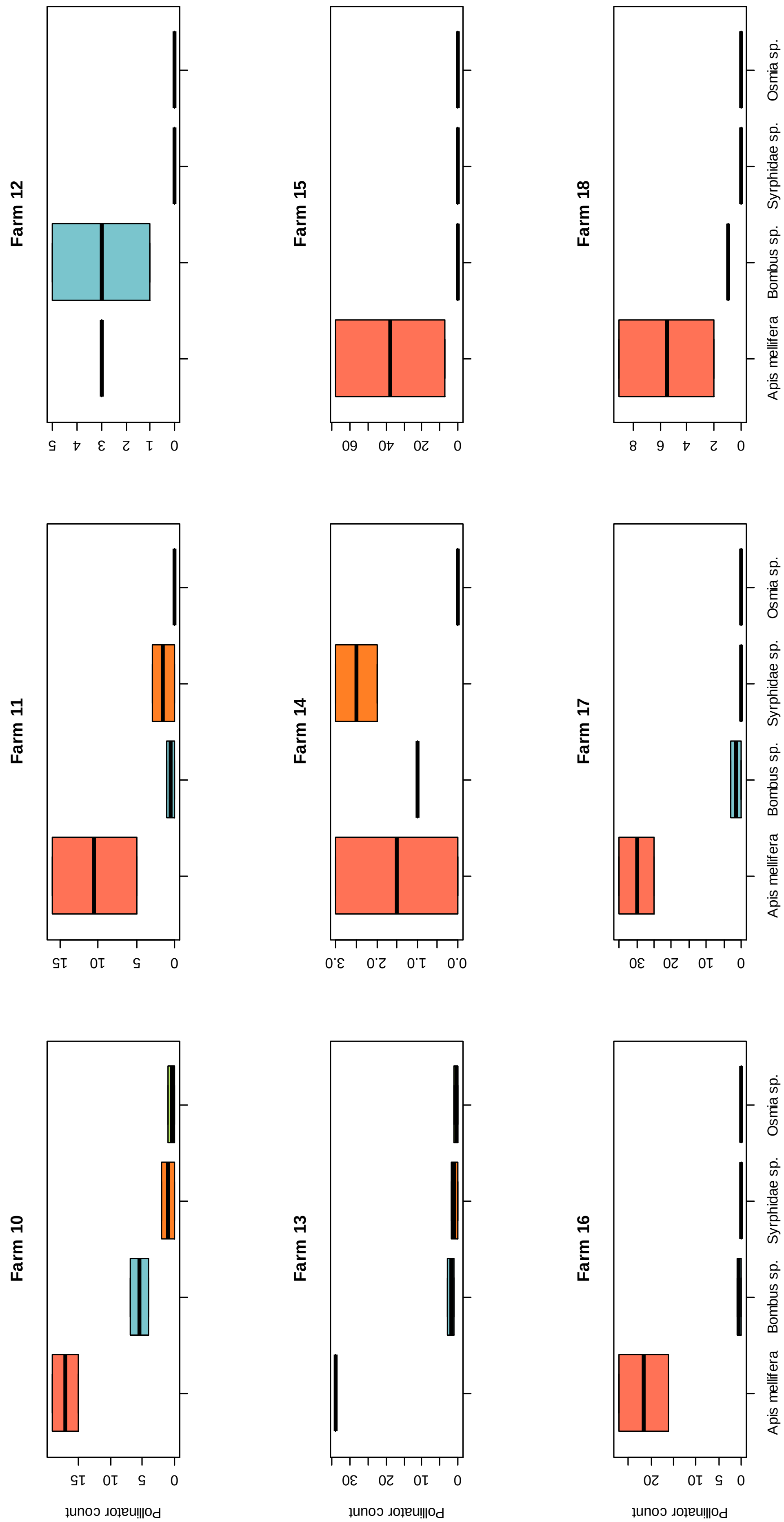
Appendix 4: raw data on insect observations from the transect at the farms and boxplots from each farm showing the distribution of the different pollinator species groups across the farms.

Table A4a: Recorded pollinators at the transects at each farm and calculations on the mean, variance, standard deviation and confidence interval of the pollinator species group at each transect

Farm number	Total Honeybees, Bumblebees, Hoverflies and Solitary bees: T1 and T2	Mean Honeybees, Bumblebees, Hoverflies and Solitary bees	Variance Honeybees, Bumblebees, Hoverflies and Solitary bees	Standard deviation Honeybees, Bumblebees, Hoverflies and Solitary bees	Confidence interval Honeybees, Bumblebees, Hoverflies and Solitary bees
1	16, 11, 1, 0, 48, 1, 0, 0	32, 6, 0.5, 0	512, 50, 0.5, 0	22.63, 7.07, 0.707, 0	[0.64, 63.36], [0, 15.8], [0, 1.48], [0, 0]
2	21, 0, 0, 0, 14, 3, 0, 0	17.5, 1.5, 0, 0	24.5, 4.5, 0, 0	4.95, 2.12, 0, 0	[10.64, 24.36], [0, 4.44], [0], [0]
3	14, 3, 0, 0, 19, 3, 0, 0	16.5, 3, 0.5, 0	12.5, 0, 0.5, 0	3.55, 0, 0.707, 0	[11.6, 21.4], [3], [0, 1.48], [0]
4	0, 14, 0, 0, 1, 1, 1, 0	0.5, 7.5, 0.5, 0	0.5, 84.5, 0.5, 0	0.707, 9.19, 0.707, 0	[0, 1.48], [0, 20.24], [0, 1.48], [0]
5	30, 0, 2, 0, 10, 0, 1, 1	20, 0, 1.5, 0.5	200, 0, 0.5, 0.5	14.14, 0.707, 0.707 (?)	[0.4, 39.6], [0], [0.52, 2.48], [0, 1.48]
6	30, 1 , 0, 0, 21, 1, 0, 1	25.5, 1, 0, 0.5	0, 40.5, 0, 0.5	6.36, 0, 0, 0.707	[16.7, 34.3][1], [0], [0, 1.48]
7	15, 0, 1, 0, 6, 0, 0, 0	10.5, 0, 0.5, 0	40.5, 0, 0.5, 0	6.36, 0, 0.7	[1.68, 19.3], [0], [0.5, 1.48], [0]
8	26, 0, 0, 0, 15, 2, 0, 0	20.5, 1, 0, 0	60.5, 2, 0, 0	7.77, 1.41	[9.72, 31.2]. [0, 2.96], [0], [0]
9	10, 1, 0, 0, 9, 1, 0, 0	9.5, 1, 0, 0	0.5, 0, 0, 0	0. 707, 0, 0, 0	[8.52, 10.48], [1], [0], [0]
10	15, 4, 2, 0, 19, 7, 0, 1	17, 5.5, 1, 0.5	8, 4.5, 2, 0.5	2.83, 2.12, 1.41, 0.707	[13.08, 20.92], [2.56, 8.44], [0, 2.96], [0, 1.48]
11	5, 0, 0, 0, 16, 1, 3, 0	10.5, 0.5, 1.5, 0	60.5, 0.5, 4.5, 0	7.77, 0.707, 2.12, 0	[0, 21.28], [0, 1.48], [0, 4.44], [0]
12	3, 5, 0, 0, 3, 1, 0, 0	3, 3, 0, 0	0, 8, 0, 0	0, 2.82, 0, 0	[3], [0, 6.92], [0], [0]
13	34, 3, 0, 1, 34, 1, 2, 0	34, 2, 1, 0.5	0, 2, 4, 1	0, 1.41, 2, 1	[34], [0.04, 3.96], [0, 2.77], [0, 1.38]
14	3, 1, 2, 0, 0, 1, 3, 0	1.5, 1, 2.5, 0	4.5, 0, 0.5, 0	2.12, 0, 0.707, 0	[0, 4.44], [1], [1.52, 3.48], [0]
15	68, 0, 0, 0, 7, 0, 0, 0	37.5, 0, 0, 0	186, 0.5, 0, 0, 0	43.1, 0, 0, 0	[0, 97.28], [0], [0], [0]
16	27, 1, 0, 0, 16, 0, 0, 0	21.5, 0.5, 0, 0	60.5, 0.5, 0, 0	7.77, 0.707, 0, 0	[10.72, 32.28], [0, 1.48], [0], [0]
17	35, 3, 0, 0, 25, 0, 0, 0	30, 1.5, 0, 0	50, 4.5, 0, 0	7.07, 2.12, 0, 0	[20.2, 39.8], [0, 4.44], [0], [0]
18	2, 1, 0, 0, 9, 1, 0, 0	5.5, 1, 0, 0	24.5, 0, 0, 0	4.94, 0, 0, 0	[0, 12.36], [1], [0], [0]
19	65, 1, 3, 0, 50, 2, 0, 0	57.5, 1.5, 1.5, 0	112.5, 0.5, 4.5, 0	10.6, 0.707, 2.12	[42.8, 72.2], [0.52, 2.48], [0,

					4.44], [0]
20	86, 5, 0, 0, 58, 0, 1, 0	72, 2.5, 0.5, 0	392, 12.5, 0.5, 0	19.8, 3.53, 0.707, 0	[44.56, 99.44], [0, 7.4], [0, 1.48], [0]
21	33, 0, 0, 0, 100, 0, 0, 0	66.5, 0, 0, 0	2244.5, 0, 0, 0	47.37, 0, 0, 0	[0.84, 132.16]
22	26, 0, 0, 0, 30, 0, 3, 0	28, 0, 1.5, 0	8, 0, 4.5, 0	2.82, 0, 2.12, 0	[24.08, 31.92], [0], [0, 4.44], [0]


Farm 1
Farm 2
Farm 3
Farm 4
Farm 5
Farm 6
Farm 7
Farm 8
Farm 9
Apis mellifera
Bombus sp.
Syrphidae sp.
Osmia sp.
Pollinator count


Farm 10
Farm 11
Farm 12
Farm 13
Farm 14
Farm 15
Farm 16
Farm 17
Farm 18
Apis mellifera
Bombus sp.
Syrphidae sp.
Osmia sp.
Pollinator count

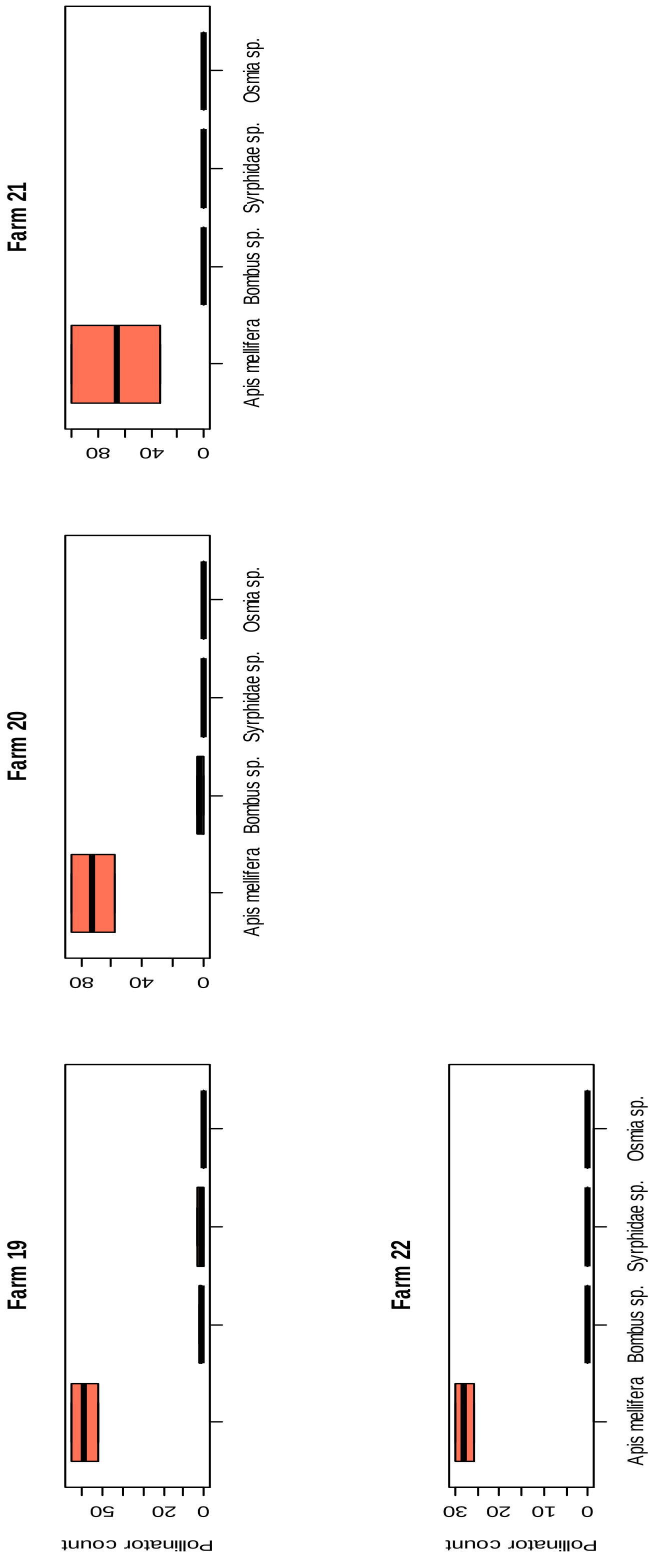


Figure A4a: Boxplot from each farm showing the distribution of the four species group per farm

Appendix 5: Pearson's correlation indices of correlated continuous predictor variables

Table A5: Pearson's correlation indices showing which continuous predictors are correlated. * means that correlation is significant at the 0.05 level while ** means that the correlation is significant at the 0.05 level

		Distance to closest hive	Hives within 1 km	Hives within 3 km	Elevation	Distance to closest forest
Distance to closest hive	Pearson's correlation p-value	1 .	-0.261 0.087	0.355* 0.018	0.0538 0.7287	-0.294 0.053
Hives within 1 km	Pearson's correlation p-value	-0.261 0.087	1 .	0.501** 0.0005	0.228 0.136	0.146 0.343
Hives within 3 km	Pearson's correlation p-value	0.355* 0.018	0.501** 0.0005	1 .	0.155 0.313	-0.127 0.411
Elevation	Pearson's correlation p-value	0.054 0.729	0.228 0.136	0.155 0.313	1 .	-0.6*** 0.00001628
Distance to forest	Pearson's correlation p-value	-0.294 0.053	0.146 0.343	-0.127 0.411	-0.6*** 0.00001628	1 .

Appendix 6: Recorded honeybees and bumblebees in the transect walks in the different landscape types, used for Species distribution modeling.

Table A6: Number of honeybee and bumblebee abundance recorded at the four transects routes in the different landscape types

	L01a	L02a	L03a	L04a
Apis mellifera	1	15	46	25
Bombus sp.	2	3	8	5
	L01b	L02b	L03b	L04b
Apis mellifera	8	13	65	30
Bombus sp.	1	0	4	3
	L01c	L02c	L03c	L04c
Apis mellifera	14	44	11	7
Bombus sp.	0	1	0	1
	L01d	L02d	L03d	L04d
Apis mellifera	1	31	22	9
Bombus sp.	0	0	0	1
	L01e	L02e	L03e	L04e
Apis mellifera	94	21	44	19
Bombus sp.	2	1	1	2