

# **Pollination, wild bee communities and seed development in apple orchards of Sogn and Hardanger in Western Norway**



**Sandra Kaasen Vestheim**

**Master of Science in Biology**  
Biodiversity, Evolution and Ecology



Department of Biological Sciences  
University of Bergen  
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**Supervisors:**

Bjørn Arild Hatteland, Department of Biological Sciences, University of Bergen and NIBIO  
Anders Nielsen, NIBIO

Front page:

Apple orchards in Djønno, Norway, June 2020. Photo: Sandra Kaasen Vestheim

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## **Abstract**

Human progression has led to and is still creating massive land use changes. This is the main driver of biodiversity loss, and we are currently living in the sixth mass extinction. Increased human populations need increased food production, which rely heavily on ecosystem services. Pollination is estimated to be crucial for 70% of food crops used directly for human consumption, and especially fruit and berry crops such as apples are dependent on animal pollination often provided by insects. Several studies have shown that wild bees often are more effective pollinators than managed honeybees. In this study, I explore pollination in ten apple orchards in Sogn and Hardanger in Western Norway. These areas have not been extensively sampled since the 1950s, I found that the species common at that time still are common today. The abundance and diversity of wild bees varied greatly between sites.

For wild bees to thrive in an area, they also need floral resources outside of the intense apple flowering period. I mapped the surrounding vegetation in a 200m radius of each orchard focusing on potential floral resources. Bumblebees seem to be positively affected by woodlands in the area, but I did not find definite effects from floral resources such as meadows. Managed honeybees can affect wild bees, I did not find any clear signs of competition but there were more bumblebees at sites further away from beehives. Apple seed set was also studied, of which the main difference in seed set were found between cultivars. Gravenstein apples contained a much smaller proportion of developed seeds than Aroma and Summerred apples.

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## ***Introduction***

The human race has changed and is still changing the Earth according to their needs, with only 5% of the land cover untouched by human activity (Kennedy et al, 2019). Moreover, to sustain further populational and welfare growth of humans, food production must also increase. For this to happen, large wild areas are transformed into agricultural land. These land use changes, both for agriculture and other societal development, has been shown to be the main driver of biodiversity loss (Vié et al, 2009; Sánchez-Bayo & Wyckhuys, 2019).

The biodiversity loss is so great that we by definition are living in the sixth mass extinction (Ceballos et al, 2017). When discussing the sixth mass extinction, there is a large focus on extinctions of species but before a species is completely extinct, there are declines in populations as well as local extinctions. Ceballos et al. (2017) estimate that as much as 50% of the vertebrate individuals that humans used to share the world with are gone. This is more complicated to estimate for invertebrates, but there is no doubt that the situation for these animals is also alarming, with “The Insect Apocalypse” making headlines in newspapers worldwide (Jarvis, 2018).

Nonetheless, as humans shape the earth to their needs, we are still very much dependent on ecosystem services. It is estimated that as many as 70% of food crops used directly for human consumption are dependent on pollination, with insect pollination being the most common form (Klein et al, 2007). These crops are dependent on insect pollination to varying degrees, with e.g. avocados, many nuts, and fruits like apples, kiwi and plums having a reduced yield of more than 40% without pollinators (Aizen et al, 2019; Klein et al, 2007).

The most important pollinators for apple flowers are bees and hoverflies (Pardo and Borges, 2020). The western honeybee *Apis mellifera* is the most important pollinator species for crop pollination in general (Garibaldi et al, 2013) and it is common practice to supply the orchards with managed honeybees in addition to pollination provided by wild bees in the area.

Apples are especially dependant on pollinators as most cultivars are self-incompatible and require cross-fertilisation (Ramírez & Davenport, 2013). In Pardo and Borges (2020) review on pollination on apples, they found that several studies using open and closed treatments (excluding flowers from pollinators) show that insect pollination leads to higher seed set, fruit set and fruit quality.

Blitzer et al. (2016) found that wild bee richness had a positive effect on pollination services in a study on 17 apple farms in the state of New York, showing that the number of developed seeds within the apples significantly increased with abundance and diversity of wild bees but did not show a significant relationship with honeybee abundance. This corresponds with the review by Garibaldi et al. (2011) on other pollinated crops such as cherry, strawberries, almond and blueberries among others.

For the wild bees to thrive in the area, they are dependent on food sources all season long, not just during the apple blossoming. The apple flowers bloom for a very short period of time and is not enough to sustain the wild bee community. Garibaldi et al. (2011) reviewed how access to natural areas, and thereby access to wild pollinators, affects pollination service stability in several different crops. They found that even with an abundance of honeybees present, isolation from natural areas correlates with lower mean rates and stability of seed and fruit set, suggesting that managed honeybees are not a full replacement for wild pollinators (Garibaldi et al., 2011).

Apple production has a long history in the fjords of Western Norway and is a part of the area's cultural identity. In spring, tourists gather to see the beautiful blossoming and in fall the harvest is the main event. Apple production is an important income for the area and would not be possible without the thousands of bees buzzing about pollinating the apple flowers during spring. The wild bees of Norway can be grouped into bumblebees and solitary bees; *A. mellifera* is not found in the wild but commonly supplied in the main fruit growing regions.

Despite the important ecosystem service wild bees provide, there are only a few studies on wild bee communities and apple pollination in Norway. The last extensive field collections in Western Norway's fjord areas were done in the 1950s by Astrid Løken (GBIF data; Løken, 1958).

In this study, I explore wild bee diversity and activity in apple flowers, and how the surrounding landscape may influence bee communities within the orchards. Finally, I measure the ecosystem service provided by the bees and analyse seed set and compare it among cultivars.



In this thesis I try to answer these three questions:

- I) Are the wild bee species found in Sogn and Hardanger similar to what was recorded by Astrid Løken in the 1950s?
- II) How does the orchards' surrounding vegetation affect what bees are visiting apple flowers?
- III) How does wild bee diversity affect apple seed set/development?

I predict that:

- a) There are some changes in what wild bee species are found in Sogn and Hardanger have occurred since the 1950s.
- b) Areas with more floral resources will attract more wild bees leading to higher proportions of wild bees visiting apple flowers.
- c) A higher wild bee diversity has a positive effect on seed development in apples.

## ***Material and methods***

### **Study area**

This study took place in ten apple orchards located along Sognefjorden and Hardangerfjorden in the Vestland county of Western Norway. There were four sites in Sogn and six in Hardanger, details of the sites can be found in Table 1 and Figure 1. The orchards were chosen using aerial photos from NIBIO's online map programme Kilden ([kilden.nibio.no](http://kilden.nibio.no)). The minimum distance between two orchards was 2 km, to limit the interactions between fields as this is a further distance than bees typically fly to forage (Zurbuchen et al, 2010). The minimum area of each orchard was 3000 m<sup>2</sup>, to ensure that the localities were comparable. When selecting which orchards to sample, we made sure there was variation in what landscapes surround them. Both orchards in intensely farmed areas and more isolated areas were included, with varying proximity to natural and semi-natural vegetation. We also ensured that some fields were on the north and some on the south side of the fjords.

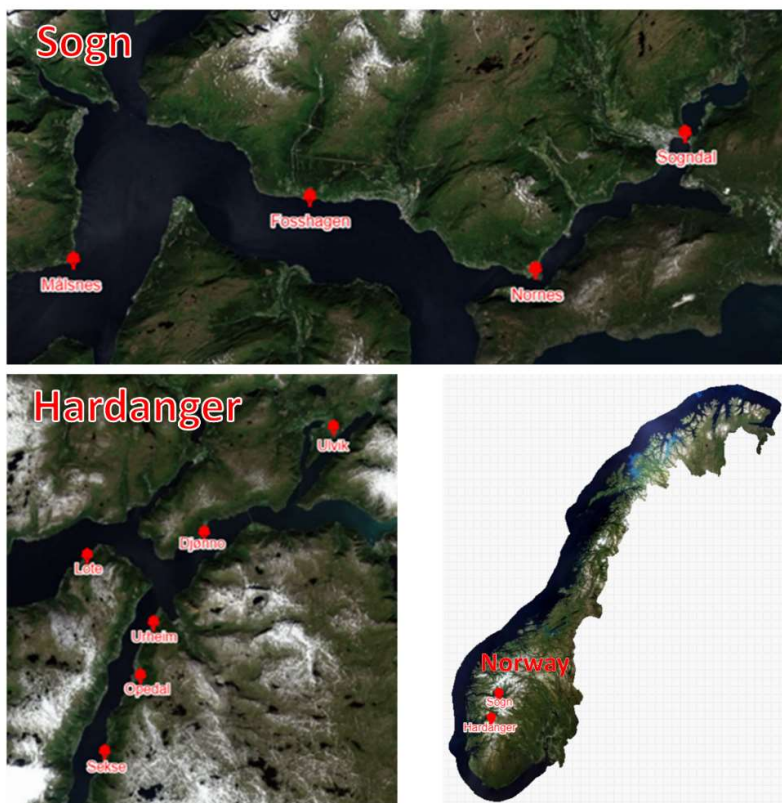


Figure 1: Study sites, maps retrieved from NIBIO Kilden (<http://nibio.kilden.no>)

<b>Table 1: Visited sites, cultivar, size, and sampling effort</b>						
Region	Site	Coordinates	Cultivar	Orchard size (m <sup>2</sup> )	# net sessions	# pantrap sessions
Sogn	Målsnes	6.543164°E, 61.139394°N	Aroma	5448	4	3
	Fosshagen	6.763193°E, 61.182544°N	Summerred	3204	3	2
	Nornes	6.988959°E, 61.161956°N	Summerred	8980	4	2
	Sogndal	7.117421°E, 61.234397°N	Aroma	6768	2	1
Hardanger	Djønno	6.750213°E, 60.458129°N	Aroma	4039	4	2
	Ulvik	6.963327°E, 60.567082°N	Gravenstein	7161	6	3
	Urheim	6.679178°E, 60.371199°N	Aroma	12728	6	3
	Opedal	6.668369°E, 60.322430°N	Gravenstein	3821	6	3
	Sekse	6.620804°E, 60.250084°N	Aroma, Discovery	6717	6	3
	Lote	6.544342°E, 60.424482°N	Aroma, Discovery	8975	4	2

### Collection of bees

Bees were collected in May and June 2020, during the flowering season of the apple orchards using two different trapping techniques. Active trapping was performed by doing netting walks capturing bees using butterfly nets, while pan traps were deployed as a passive collection method. We only collected bees on days with no precipitation and a higher temperature than 10°C. Sampling was done between 1-3 days at each site.

Each netting walk lasted 90 minutes and covered the entire field. One walk was done by one person. In most of the fields, we walked along every row of trees, but in the fields with a more challenging (very steep) landscape, every other row was inspected. During these walks, only bees visiting apple flowers were captured. These walks were done in the morning (often starting around 9 AM) and in the afternoon (often around 14 PM). Each bee was captured in a separate tube and euthanized by being put in a freezer.

For each field, nine pan traps were put out before the first netting walk of the day and emptied after the last walk. There is variation between how long the traps were out for, most were out for 5-8 hours, but four of the total 24 sets of traps were out through the night. The traps were of three fluorescent colours: yellow, blue, and white (500ml plastic bowls primed with white

Motip primer, spray-painted with blue Liquitex paint and yellow and white Rocol paints). Three sets of three traps, one of each colour, were placed in different locations of the field. One group of traps was placed in the middle of the field, the other two were placed in opposite corners of the field. For each group, the traps were placed approximately 2m away from each other. The collected bees and other captured insects were dried and placed in a freezer.

### **Identification of bees**

All the captured bees were identified to species level using identification keys (Falk and Lewington, 2015; Løken, 1985) and samples from the University Museum of Bergen. The three species *Bombus lucorum*, *B. cryptarum* and *B. magnus* were separated using morphological traits but should ideally be distinguished using DNA barcoding (Bossert, 2014).

### **Comparison with older data**

To compare the species assemblages with earlier data, I used the Norwegian Biodiversity Information Centre and GBIF Norway's web programme Species Map ([artskart.artsdatabanken.no](http://artskart.artsdatabanken.no)). In addition to this I used literature by Løken (1958) describing common species and data from 2019 from some of the same sites (Hatteland, B.A, unpublished data).

### **Vegetational data and beehives**

To study how the surrounding vegetation affects the bee diversity, the vegetation in a 200m radius of the fields was recorded. I mapped the vegetation surrounding the ten fields between the 12<sup>th</sup> and 23<sup>rd</sup> of June 2020. I chose to collect vegetational data in June as this is after the apple flowering and most Norwegian wildflowers have blossomed by this time, meaning that we get a good picture of what floral resources are available in the areas.

I recorded the vegetational data by mapping vegetational types on printed aerial photos of the areas. The vegetation was described in categories, such as “ditch/road verge”, “pasture” and “urban areas”. For all flowering vegetation (ditches, edges, meadows) a score of 1-3 was given to represent the density of the flowering vegetation compared to other plants like grasses.

These maps were then reproduced in the web programme gmapgis.com, an online GIS program that uses data from Google Maps. This allowed me to digitalise the hand drawn maps and measure the areas in square meters using polygons. The vegetational data was

summarised into seven categories: forest, urban areas, orchards, three cover levels of floral areas and “other” (Table 2; Appendix A). The three floral levels are based on density of flowering plants, defined as floral “sparse”, “medium” and “high”. The category “other” includes all green areas that does not contain flowers, such as mowed grass fields and bushy areas with tall grasses.

All areas with floral resources that did not fall under the categories forest, orchards or urban areas are included in the “floral” categories. This was typically road verges, pastures etc. Some smaller open areas of deciduous forest with low floral vegetation were included in both the “floral low” and “forest” categories.

<b>Table 2: Explanation on recorded vegetational categories</b>	
<b>Category</b>	<b>Explanation</b>
Orchard	Rows of cultivated fruit trees and berries
Urban areas	Gardens, houses, private parking lots (does not include roads)
Forest	Decidious and corniferous forest
Floral – high	Densely covered road ditches, raspberry bushes, meadows
Floral – medium	Any area with wildflowers of a medium coverage
Floral – sparse	Åastures (with sheep and sparsely spread white clover), low covered meadows or road ditches
Other	Green areas without floral vegetation, such as pastures, mowed grass fields, chopped forest, tall grasses

The number of beehives were also recorded inside the area of 200m radius. I also used gmapgis.com to measure the distance to the nearest hive of each site, from the centre of the orchard to the nearest hive.

### **Temperature**

Temperatures were recorded from Norwegian Centre for Climate Services at seklima.met.no, Table 3 shows the location of the weather stations used. I used the records of mean air temperature per hour fitted to when the sites were sampled.

<b>Table 3: Locations of weather stations</b>	
<b>Site</b>	<b>Weather station</b>
Målsnes	Balestrand
Fosshagen	Njøs
Nornes	Njøs
Sogndal	Njøs
Djønno	Ulvik
Ulvik	Ulvik
Urheim	Ullensvang
Opedal	Ullensvang
Sekse	Ullensvang
Lote	Ullensvang

### **Apple seed set**

A total of 100 apples from each orchard were collected in the following harvest season of September 2020. Apples were collected from 10 trees per orchard, for every tree the apples were collected from several branches. For the site Sekse and Lote, where there were two different cultivars (Table 1), only Aroma apples were picked. I counted the number of seeds in each apple and classified the seeds into three categories: fully developed, partly developed, and not developed. The fully developed seeds are hard and have a white inner mass, undeveloped seeds only consist of a shell and partly developed seeds fall somewhere in between these descriptions, often with a softer, see-through inner mass (Figure 2).



*Figure 2: Apple seed of each category, top left: fully developed seed, right: partly developed seed, bottom: undeveloped seed.*

## **Data analysis**

All statistical analyses were done in R (R Core Team, 2019) and using RStudio (RStudio Team, 2020). I also used the packages *vegan* (Oksanen et al, 2019), *nnet* (Venables and Ripley, 2002) and *ggplot2* (Wickham, 2016) for particular analyses.

### Species accumulation curves

Species accumulation curves were created based on the solitary bees caught in pan traps and of bumblebees caught in netting walks to investigate how likely it was to find more species in the two regions Sogn and Hardanger. For bumblebees each netting walk was used as one sample, for solitary bees each pan trap was one sample. I created separate accumulation curves for the two regions. This analysis was done using the *specaccum* function in the *vegan* package, with the method “exact” and 100 permutations.

### Ordinations

To visualise the differences in species composition between sites I made two correspondence analysis ordination plots, one of solitary bees and bumblebees caught in nets and an equivalent plot for pan traps. The species data was square root transformed to prevent heavily represented species from dominating the analyses.

### Multinomial analyses of netting data

A multinomial regression analysis was used to study how the surrounding landscape affects which bees are visiting apple flowers. Each netting walk was used as one sample. It can be difficult to standardize sweep netting when there are several people doing the sampling, so counts in such surveys can be driven by observer differences (Cooper et al, 2017). The multinomial regression analysis is suitable for this situation as I investigate the ratio between captured bees, not the abundance.

This analysis was done using the *multinom* function in the *nnet* package. The bees captured in the netting walks were honeybees, solitary bees, and bumblebees. These were used as the three response variable categories. I used honeybees as the reference class such that the regression coefficients are interpreted as effects on proportional change from honeybee to solitary or bumble bees.

The vegetational predictor variables were area of forest, orchards, urban areas, and flowering vegetation within the 200m radius of each orchard (Table 4). In addition to the vegetational

variables, I included time of day (early or late), number of honeybee hives within the 200 m radius, distance to closest honeybee hive and temperature in the analyses.

<b>Table 4: Explanation of predictor variables used in community model</b>	
<b>Predictor variable</b>	<b>Explanation</b>
Time of day	When was the netting walk executed, early: before 12, late: after 12 (a few exceptions)
Temperature	Air temperature during each walk
Nearest hive	Distance from the closest hive to the orchard, measured from the centre of the orchard to the hive (meters)
Number of hives	Number of hives inside of a 200m radius of the orchard
Orchards	All vegetational are in m <sup>2</sup> inside of a 200m radius of each orchard (see Table 2 for explanation on categories)
Urban areas	
Forest	
Floral – high	
Floral – medium	
Floral – sparse	

I made a Spearman correlation matrix (Appendix B) before conducting the analysis. The matrix showed that there were no correlations above 0.75. To visualise the results, I made marginal response curve plots. These plots were made using a model that also included squared versions of the predictor variables.

#### Multinomial analyses of seed data

When counting the seeds, they were sorted into the three categories: fully developed, partly developed, and not developed. To investigate how the seed development is affected by pollination, I conducted a multinomial regression analysis with these three categories as response variables. The category “fully developed seeds” was used as the reference class such that the regression coefficients are interpreted as effects on proportional change from fully developed seeds to partly or undeveloped seeds.

For each site I calculated different measures of the wild bee community, and registered proximity to beehives and number of beehives within a 200m radius of each orchard (Table 5). These variables are the same for every apple picked within one site, resulting in 10 “sets” of 100 observations (apples) having identical potential predictor variables. This results in a large site effect, with only cultivar being a variable that is the same for more than one site. Because of this, the only predictor variables used for this analysis were cultivar and site.



After doing the multinomial regression analysis, I compared the site and cultivar effects on seed development proportions with the measures of wild bee community (Table 5). I also made a correlation plot of these variables (Appendix A).

<b>Table 5:</b> Variables used for seed analyses; every variable is at site level. Bee proportions are measures of bees caught in netting walks.	
<b>Variable</b>	<b>Explanation</b>
Number of hives	Number of hives inside a 200m radius of the orchard
Nearest hive	Distance from the closest hive to the orchard, measured from the centre of the orchard to the hive (meters)
R solitary bees	Total number of solitary bee species
R bumblebees	Total number of bumblebee species
Solitary bees per hour	Number of solitary bees caught in all pan traps divided by how many hours in total the pan traps were out for, for each site. Hours between 21:00 and 07:00 were not included (a few traps were out over night)
Wild bee proportion	% of caught bees in nets that are wild bees (not honeybees)
Bumblebee proportion	% of caught bees in nets that are bumblebees
Solitary bee proportion	% of caught bees in nets that are solitary bees

## Results

### Bees in the area

In the ten apple orchards, we found a total of 23 species of solitary bees and 14 species of bumblebees. In total we collected 881 honeybees, 289 solitary bees and 97 bumblebees. The netting walks resulted in a high proportion of honeybees (81%), while the pan traps almost solely caught solitary bees (94%). Table 6 shows presence of species in the ten sites, shaded cells marks species found in 2019 but not in 2020. The number of individuals of each species can be found in Appendix C.

The bumblebee found in most sites was *B. pascuorum*, being present in eight sites (Table 6). Other common bumblebees were *B. lucorum* and *B. hortorum* (5 sites), *B. hypnorum* and *B. pratorum* (4 sites). Five bumblebee species were found only once. *Bombus cryptarum* and *B. magnus* are difficult to distinguish from *B. lucorum*, this especially applies to workers. The specimen identified as a *B. cryptarum* queen showed black hairs in the collar band (Figure 3), corresponding to Bertsch et al (2014) claiming that this is a morphological trait for this species. The specimen we identified as *B. magnus* queen was relatively paler yellow compared with a typical *B. lucorum* with a collar that went further past the wing basis of the bee.

*B. lapidarius* was found in Ulvik. The only previous observations of this species in Hardanger are “human observations” further towards the coast in Kvinnherad municipality (GBIF data). The *B. lapidarius* observation by Løken is nearby Målsnes, from 1935. *B. campestris* and *B. norvegicus* are cuckoo bumblebees, parasites on *B. pascuorum* and *B. hypnorum*, respectively.



Figure 3: The recorded *Bombus cryptarum* queen, black hairs in the collar band indicated with the red circle

Moreover, five other bee genera were also found representing solitary bees. *Lasioglossum* spp. (172), followed by *Andrena* spp. (108) were the most common solitary bees found. The three other genera were *Halictus* (3 *H. rubicundis* and 1 *H. tumulorum*), three *Nomada* singletons and 2 *Osmia* singletons. *Lasioglossum albipes* was present in eight out of ten sites. *L. calceatum* was also very common, found at seven sites. In total, five different *Lasioglossum* species were identified. *Andrena* was the genera with most species identified. Of the eleven different *Andrena* species, the most common were *A. haemorrhoea*, *A. scotica* and *A. fucata*, each present at six sites. There were four *Andrena* species found only at one site each. *A. nigroaenea* has not previously been recorded in the area.

**Table 6:** Wild bee community of Sogn and Hardanger, 2019 and 2020 compared to 1950s. x = present at site, found by Løken in the same area, shaded = found in 2019 but not 2020, \* = described as common by Løken (1956), □ = not found by Løken, but registered in later years, ! = not previously found in the area.

Species	Sogn				Hardanger						total sites present in (2020)	Previous observations
	Målsnes	Fosshagen	Nornes	Sogndal	Djønno	Ulvik	Urheim	Opedal	Sekse	Lote		
<b><i>Bombus</i></b>												
<i>B. pascorum</i>	x	x	x		x	x	x	x	x		8 (8)	*
<i>B. pratorum</i>	x	x	x		x	x	x	x	x		8 (4)	*
<i>B. lucorum</i>		x		x		x	x		x	x	6 (5)	*
<i>B. hypnorum</i>	x		x			x		x	x	x	6 (4)	*
<i>B. hortorum</i>	x	x				x	x				4 (4)	*
<i>B. soroensis</i>		x	x	x		x					4 (3)	x
<i>B. bohemicus</i>		x				x	x				3 (3)	x
<i>B. terrestris</i>						x			x		2 (2)	□
<i>B. sylvestris</i>						x				x	2 (2)	x
<i>B. campestris</i>						x					1 (1)	x
<i>B. cryptarum</i>									x		1 (1)	x
<i>B. lapidarius</i>						x					1 (1)	x
<i>B. magnus</i>		x									1 (1)	x
<i>B. norvegicus</i>						x					1 (1)	x
<i>B. monticola</i>								x			1 (0)	x
<b><i>Andrena</i></b>												
<i>A. haemorrhhoa</i>	x	x			x	x	x	x	x	x	8 (6)	*
<i>A. scotica</i>				x	x	x		x	x	x	6 (6)	x
<i>A. fucata</i>	x		x		x	x	x			x	6 (6)	x
<i>A. helvola</i>					x	x	x	x		x	5 (5)	x
<i>A. cineraria</i>		x			x	x		x			4 (3)	x
<i>A. semilaevis</i>	x				x						2 (2)	x
<i>A. subopaca</i>				x		x					2 (2)	x
<i>A. lapponica</i>						x					1 (1)	x
<i>A. nigroaenea</i>						x					1 (1)	!
<i>A. similis</i>					x						1 (1)	x
<i>A. intermedia</i>		x									1 (1)	x
<b><i>Halicus</i></b>												
<i>H. rubicundis</i>					x	x					2 (2)	x
<i>H. tumulorum</i>				x							1 (1)	x
<b><i>Lasiglossum</i></b>												
<i>L. albipes</i>		x	x	x	x		x	x	x	x	8 (8)	*
<i>L. calceatum</i>	x	x			x	x	x	x	x	x	8 (7)	*
<i>L. rufitarse</i>				x	x		x	x	x		5 (5)	x
<i>L. fratellum</i>					x	x		x	x		4 (4)	x
<i>L. leucopus</i>		x			x						2 (2)	x
<b><i>Nomada</i></b>												
<i>N. marshamella</i>						x					1 (1)	x
<i>N. panzeri</i>						x					1 (1)	x
<i>N. ruficornis</i>						x					1 (1)	x
<b><i>Osmia</i></b>												
<i>O. bicornis</i>				x							1 (1)	□
<i>O. uncinata</i>		x									1 (1)	x

### Differences in bee communities between sites

There was a big difference in the number of bees caught at the ten sites. This was largely due to differences in sampling effort (Table 1). In addition to the sampling effort, there was a difference in experience and skill among the participants of netting walks. It is therefore more interesting to use proportions of bee groups caught in nets (Figure 4). The highest proportions of solitary bees were found in Hardanger, in the two sites Lote and Ulvik, while the two sites with the highest proportion of bumblebees are Ulvik and Sekse, also in Hardanger.

The number of solitary bees caught per hour in the pan traps was calculated for each site as a measure of the solitary bee abundance in the areas, since the total trapping period varied between sites. Djønnø clearly stands out with 5-6 bees/hour (Table 7). There is also a larger abundance of solitary bees at Opedal and Ulvik with 2 and ~1 bees/hour, respectively.

The total wild bee richness is by far highest in Ulvik (Table 7), where we found 12 species of bumblebees and 14 solitary bee species. Djønnø also stands out, with 13 solitary bee species. Opedal, which had a large proportion of solitary bees also contained a high solitary bee richness, with eight different species recorded.

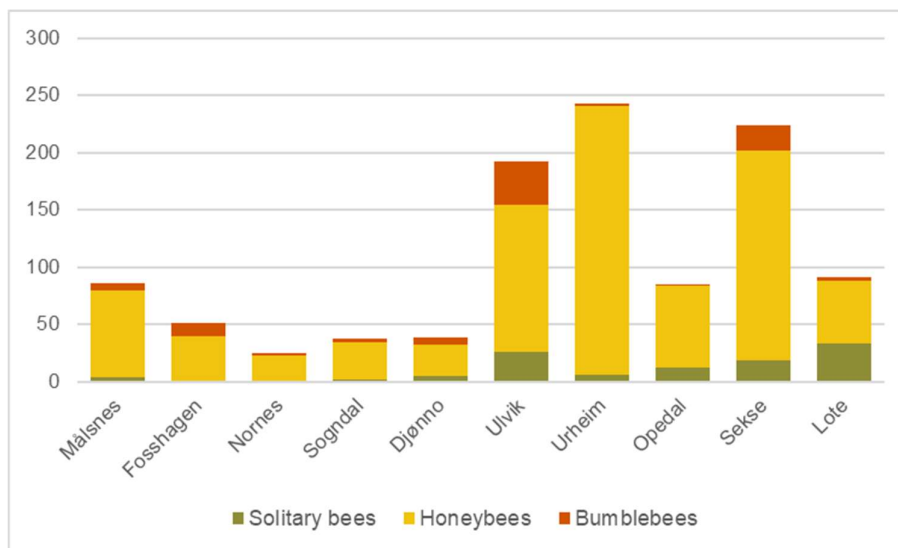


Figure 4: Bee groups caught in the netting walks at the ten sites

**Table 7:** Recorded bee community variables. Solitary bees per hour is marked with parentheses for Lote as we suspect something was wrong with the pan traps.

Site	Number of hives	Neares hive	R Bombus	R solitary bees	Solitary bees per hour
Målsnes	3	125	3	4	0.148
Fosshagen	4	46	6	4	0.208
Nornes	14	83	1	2	0.140
Sogndal	4	62	2	6	0.5
Djønno	0	376	2	13	5.628
Ulvik	0	380	12	14	0.914
Urheim	9	63	3	5	0.523
Opedal	9	149	2	8	2
Sekse	0	318	6	6	0.619
Lote	6	84	3	6	(0.09)

### Species accumulation curves

Species accumulation curves were created for solitary bees caught in the pan traps and for bumblebees caught in nets for each region, Sogn and Hardanger (Figure 5). The solitary bee curve for Hardanger is flattening, showing that it is not likely to find many more species doing more replicas of the method. In Hardanger, 96 out of the total of 269 solitary bee specimens were found in Djønno. Thus, this orchard could have a large influence on the curve, so I made an accumulation curve just for Djønno and one for Hardanger excluding Djønno (Appendix D). However, no noteworthy difference was found when excluding Djønno. For Sogn the curve does not show the same tendency to flatten, indicating that there is a good chance we would catch more species by doing more replicates. The accumulation plots for bumblebees are similar for the two regions, showing that there is some chance of finding more bumblebee species in both regions.

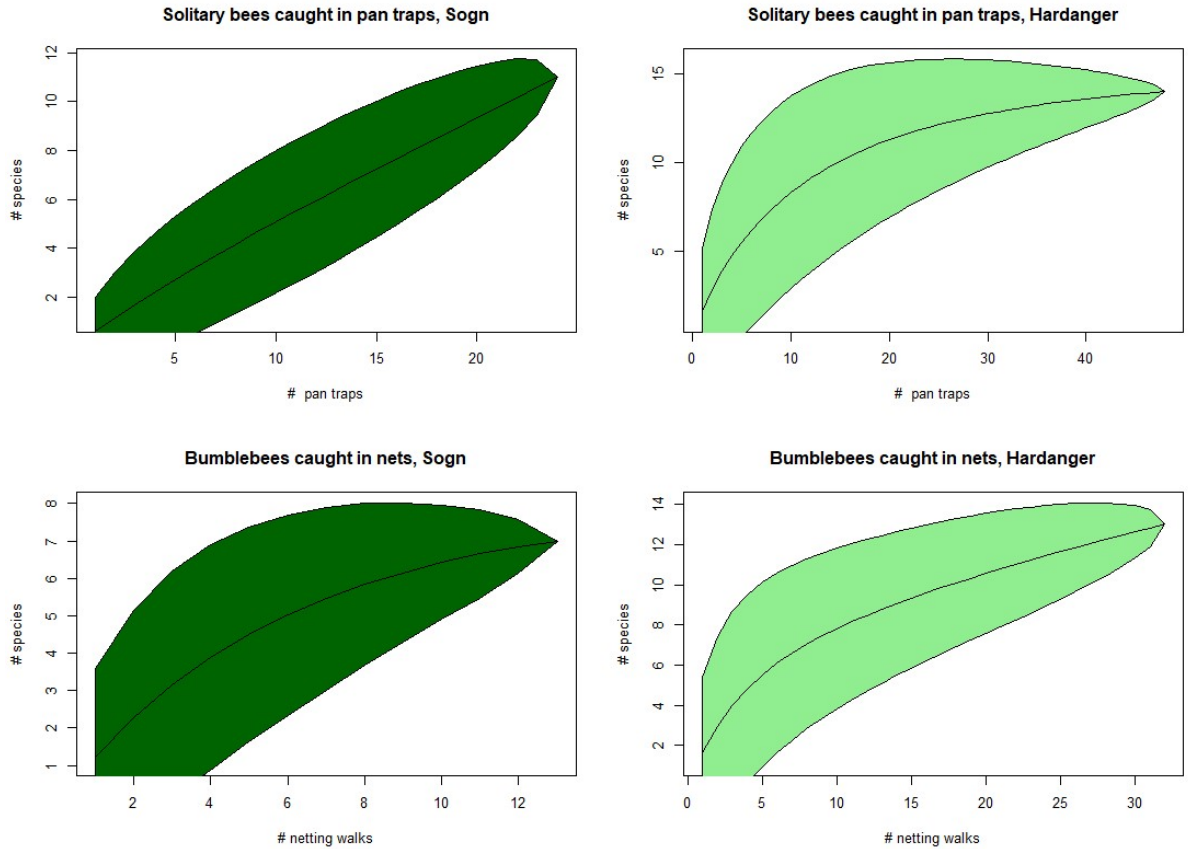


Figure 5: Species accumulation curves for Hardanger and Sogn

## Ordinations

The correspondence analysis ordination plots show a larger spread in the species composition in Sogn compared with Hardanger, both for the bees captured in nets (Figure 6) and bees caught in pan traps (Figure 7). This is at least partially due to singletons that only are in Sogn. Ulvik in Hardanger is the site with the most singletons, eight species. Fosshagen in Sogn has three singletons, Sogndal in Sogn has two, and Djönno and Sekse in Hardanger have one each. The species plots can be found in Appendix G. The site Lote in Hardanger was not included in the ordination for trap data, as we suspect that there was something wrong with the pan traps at this site. We suspect this because there was a large proportion of solitary bees caught in nets, while only one was caught in the pan traps.

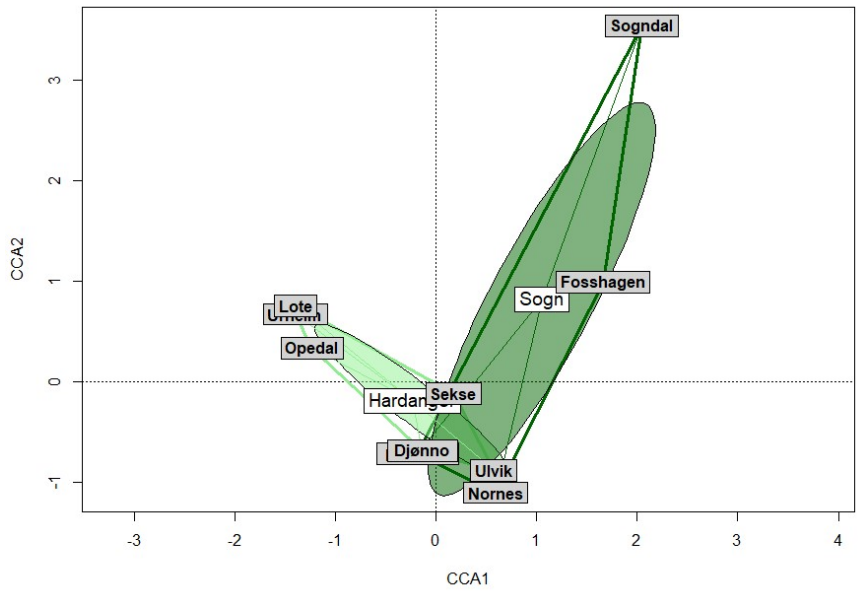


Figure 6: Correspondence analysis ordination plot for netting walks

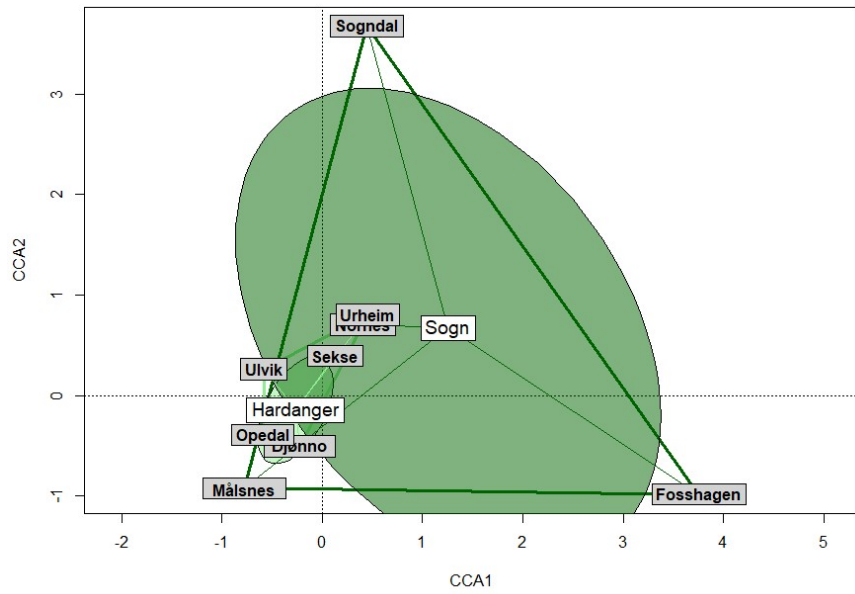


Figure 7: Correspondence analysis ordination plot for pan traps



## Comparison with data from the 1950s

The bees Løken (1958) described as common were also found at most sites in 2019 and 2020 (Table 6). Three species were not found by Løken: *Bombus terrestris*, *Andrena nigroaenea* and *Osmia uncinata*.

## Vegetational differences between sites

The ten orchards varied greatly in vegetational composition. Table 8 and Figure 8 shows the amount of each vegetational category inside the 200 m radius of each site. Figure 9 shows the digitally reproduced map of Målsnes, with explanations on labels in Table 9, the rest of the maps can be found in Appendix E.

Djønno and Målsnes are the two sites with a lot of forest. Apart from Nornes, the sites in Sogn have less orchards than the sites in Hardanger. Ulvik, Lote and Sekse have the most floral areas. These sites contained large fields where sheep were grassing, of which white clovers were common.

Site	Floral high	Floral medium	Floral sparse	Floral total	Orchards	Urban areas	Forest	Other green areas
Målsnes	1595	3917	1816	7328	14553	3741	52659	2493
Fosshagen	752	1241	2035	4028	28872	10207	38538	1090
Nornes	642	5790	542	6974	66784	9475	18248	16677
Sogndal	271	868	434	1573	19429	14340	14261	10611
Djønno	710	4872	2640	8222	17948	6387	81742	1409
Ulvik	5489	3100	21714	30303	40242	6538	11449	29130
Urheim	1160	1872	4681	7713	67008	8643	0	2596
Opedal	2263	5718	9414	17395	58197	17208	21615	3969
Sekse	1477	3031	39177	43685	40433	13510	6727	13161
Lote	2291	4805	22456	29552	40565	12010	16226	2105

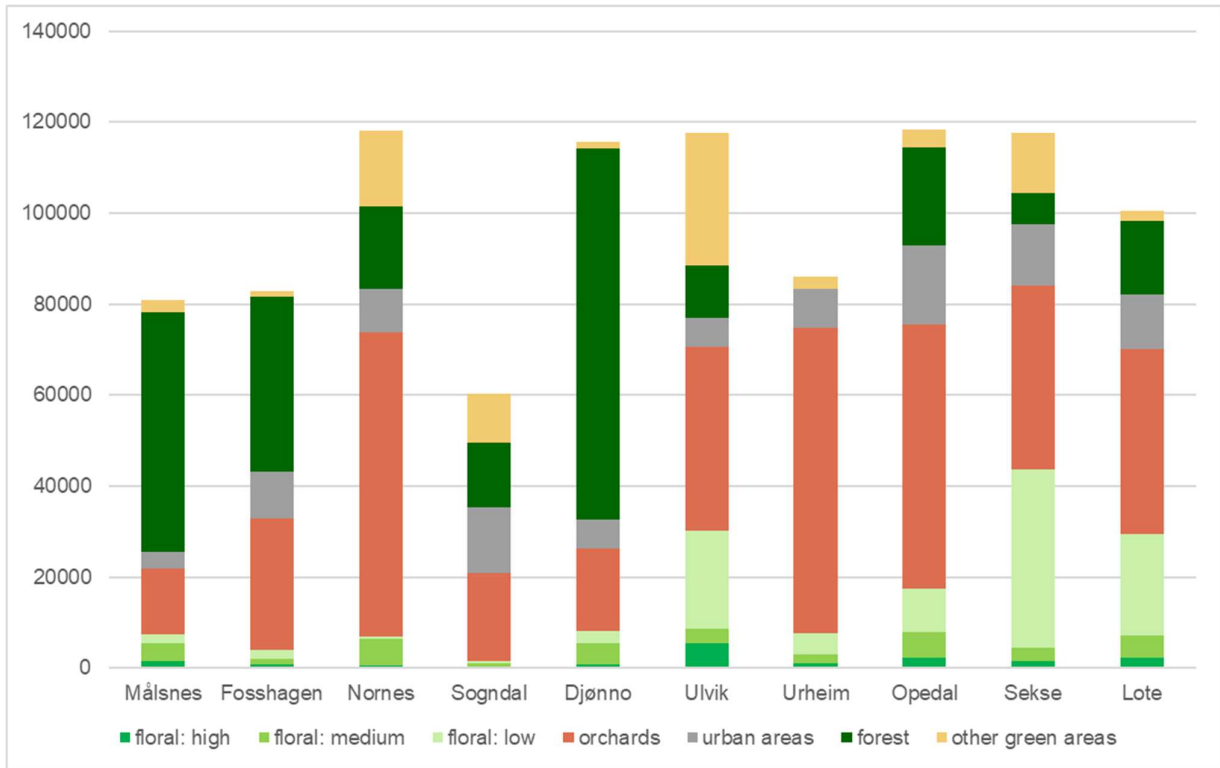


Figure 8: Vegetation assemblages inside a 200m radius of each site, each category is measured in m<sup>2</sup>. Most sites were located close to the fjord, sea is not included in the figure.



Figure 9: Vegetational map of Målsnes, Sogn

<b>Table 9:</b> Mapped vegetation in Målsnes, letters in area code correspond to handwritten notes.				
<b>Area</b>	<b>Type</b>	<b>Cover level</b>	<b>Area (m<sup>2</sup>)</b>	<b>category</b>
01	forest: pine and blueberry		24110	forest
02-S	apple orchard		1581	orchards
03	mixed forest		3135	forest
04-R	ditch	sparse	223	floral - sparse
05-Q	meadow	medium	950	floral - medium
06	forest: pine and blueberry		5269	forest
07-N	apple orchard		773	orchards
08	mowed grass		537	other green areas
09	urban area		3741	urban areas
10-O	ditch/meadow	high	1076	floral - high
11-P	meadow	medium	974	floral - medium
12	mixed forests		3018	forest
13-M	garden/meadow	medium	555	floral - medium
14-L	edge	sparse	152	floral - sparse
15-K	edge	medium	721	floral - medium
16-I	<b>apple orchard</b>		7452	orchards
17-L	edge	sparse	243	floral - sparse
18-J	slope with raspberried and some flowers	high	519	floral - high
19-G	edge	sparse	323	floral - sparse
20	grass		388	other green areas
21-F	gravel	sparse	437	floral - sparse
22-B	edge	medium	351	floral - medium
23-A	ditch	medium	366	floral - medium
24-H	edge	sparse	247	floral - sparse
25-E	mixed forest		2368	forest
26-D	edge	sparse	191	floral - sparse
27	apple orchard		663	orchards
28-C	grass		1568	other green areas
29	raspberry orchard		1059	orchards
30	apple orchard		3025	orchards
31	deciduous forest		14759	forest

### Community model

None of the predictors had significant effects on there being a higher proportion on solitary bees compared to honeybees (Table 10) Furthermore, the proportion of solitary bee is barely visible in some of the marginal response curves (Appendix F). For bumblebee proportion, there were several significant effects. The model shows that when the distance to the nearest honeybee hive increases, a larger proportion of bumblebees can be found (Table 10), this is also clearly shown in the marginal response curve (Figure 11). On the other hand, there is a

larger significant effect showing that areas with more honeybee hives also increases the proportion of bumblebees, however this effect is not visible in the marginal response curve (Figure 11).

For bumblebees, all vegetational variables except urban areas showed significant effects. When there was a larger area of orchards, the model predicts less bumblebees, whereas more forest predicts more bumblebees. The floral areas show variable effects. An increase in the “floral: high cover” category predicts a larger bumblebee proportion; the effect is even larger for sparsely covered areas. Floral areas with a medium floral cover however cause less bumblebees, with a slightly higher effect than that of sparse areas.

Lower temperatures seemed to increase the proportion of bumble bees, although this trend was not significant (Table 10) it is visible in the marginal response plot (Figure 10).

<b>Table 10:</b> Community model output. AIC: 1182.975 All quantitative variables are centred and scaled, all vegetational variables are within a 200m radius of each orchard.				
	Solitary bees		Bumblebees	
	Coefficient	p-value	Coefficient	p-value
Intercept (honeybee, early)	-2.68	0	-2.41	0
Time of day: late	0.23	0.44	-0.47	0.07
Temperature	0.05	0.75	-0.32	0.06
Distance to nearest hive	-1.80	0.23	3.50	<b>&lt;0.001</b>
Number of hives	-3.07	0.46	9.69	<b>&lt;0.001</b>
Orchards	0.98	0.55	-3.94	<b>&lt;0.001</b>
Urban areas	0.14	0.60	0.10	0.73
Forest	-0.21	0.89	3.40	<b>&lt;0.001</b>
Floral – high cover	0.47	0.39	1.71	<b>&lt;0.001</b>
Floral – medium	1.52	0.33	-3.93	<b>&lt;0.001</b>
Floral - sparse	-0.21	0.89	3.88	<b>&lt;0.001</b>

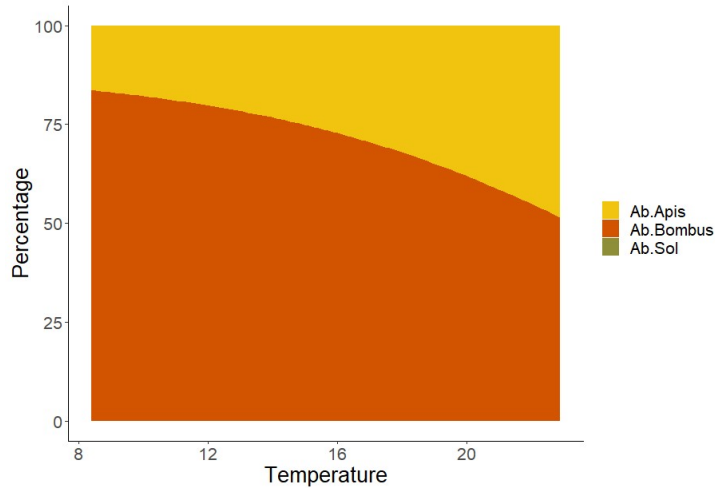


Figure 10: Marginal response curve for temperature on bee proportions caught in nets, solitary bee proportion is too low to be visible on the figure.

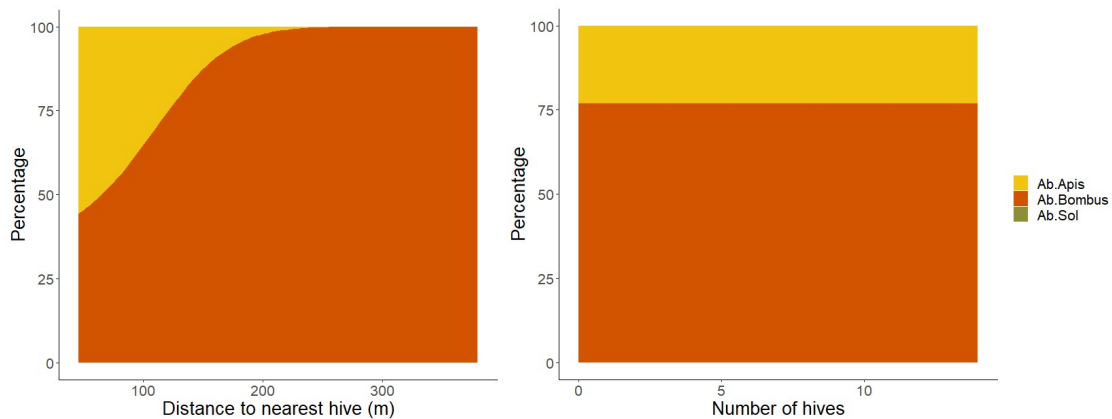


Figure 11: Marginal response curves for distance to nearest hive and number of hives within a 200m radius on bee proportions caught in nets, solitary bee proportion is too low to be visible on the figure.

### Apple seed set

For all three apple cultivars, most seeds were fully developed. There is a large variation between seed number in the apples. Aroma apples had the most seeds (a mean of 7,4 seeds per apple), while Gravenstein (~1,5 seeds per apple) and Summerred (~1,8 seeds per apple) had substantially less. The difference in seed development seems highly dependent on cultivar, with Gravenstein having a mean of 41% undeveloped seeds, Summerred 9% and Aroma 5% (Table 11, figure 12). The sites Lote and Sekse had a combination of Aroma and Discovery apples, but only Aroma apples were picked for seed counts, so these sites are treated as Aroma sites.

<b>Table 11: Mean percentages of seed development in different cultivars</b>			
	Developed	Partly developed	Undeveloped
Aroma	0.77	0.18	0.05
Summerred	0.87	0.03	0.09
Gravenstein	0.44	0.15	0.41

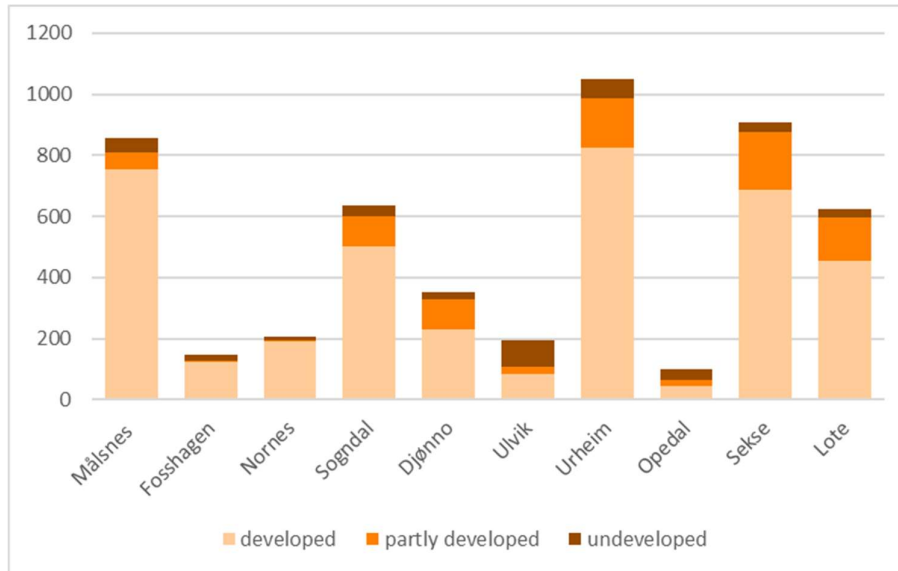


Figure 12: Seeds from 100 apples from each site, sorted into three developmental categories.

### Seed model

The model output for the multinomial regression analysis on seed development can be found in Table 12. The reference class was set to Aroma apples in Urheim, all effects were compared to apples in Urheim.

The model shows that there is a significantly larger proportion of undeveloped seeds in Gravenstein apples compared to Aroma apples (Table 12). This cultivar also tended to have a significantly larger proportion of partly developed seeds, though this effect is smaller. Summerred apples tended to have a significantly smaller proportion of partly developed seeds than Aroma apples. The marginal response plot (Figure 13) also shows a larger proportion of undeveloped seeds in Gravenstein apples, and less partly developed seeds in Summerred apples, compared to Aroma apples.

Site effects are visualised with a marginal response plot in Figure 14. Gravenstein orchards were used in the sites Ulvik and Opedal, of which the model also suggests that there is a significantly positive site effect on seeds being undeveloped for these sites (Table 12). Opedal also shows a significant positive effect on seeds being partly developed.

The sampled Summerred orchards were in Nornes and Fosshagen. The Summerred effects are not the same as the site effects (Table 12). For Fosshagen, a significantly larger proportion of seeds are undeveloped, than in Urheim apples. The Nornes site effect predicts both a significantly smaller undeveloped and partly developed seed proportion.

Among the Aroma sites, Djonno, Lote and Sekse have a significantly larger proportion of partly developed seeds, compared to Urheim. Målsnes has significantly less than Urheim. The effect on seeds being undeveloped is only significant for Sekse, where the effect is negative.

<b>Table 12: Seed multinomial regression model output. AIC: 6467.742</b>				
	Partly developed		Undeveloped	
	Coefficient	p-value	Coefficient	p-value
Intercept: Aroma, Urheim	-1.64	0	-2.57	0
Gravenstein	0.33	<b>&lt;0.05</b>	1.66	<b>&lt;0.001</b>
Summerred	-1.13	<b>&lt;0.001</b>	0.16	0.30
Fosshagen	-0.26	0.42	0.59	<b>&lt;0.01</b>
Nornes	-0.87	<b>&lt;0.01</b>	-0.44	0.05
Sogndal	0.03	0.80	-0.12	0.5960962
Ulvik	-0.05	0.78	0.92	<b>&lt;0.001</b>
Djonno	0.79	<b>&lt;0.001</b>	0.18	0.50
Lote	0.48	<b>&lt;0.001</b>	-0.25	0.29
Målsnes	-1.04	<b>&lt;0.001</b>	-0.16	0.40
Opedal	0.38	<b>&lt;0.05</b>	0.74	<b>&lt;0.001</b>
Sekse	0.34	<b>&lt;0.01</b>	-0.56	<b>&lt;0.05</b>

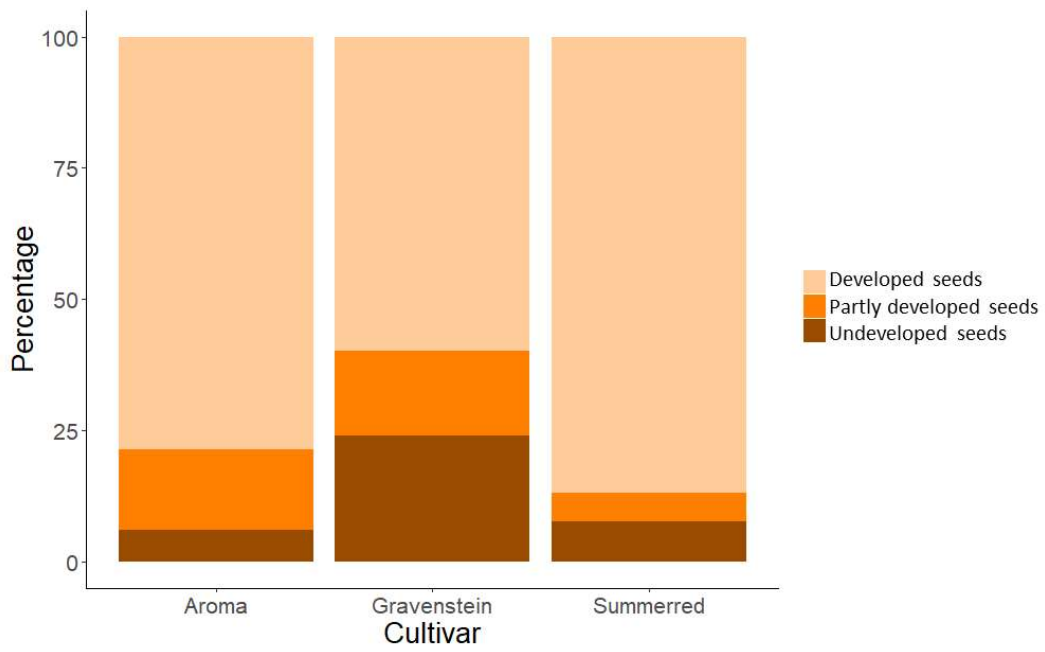


Figure 13: Marginal response plot for cultivar on seed development

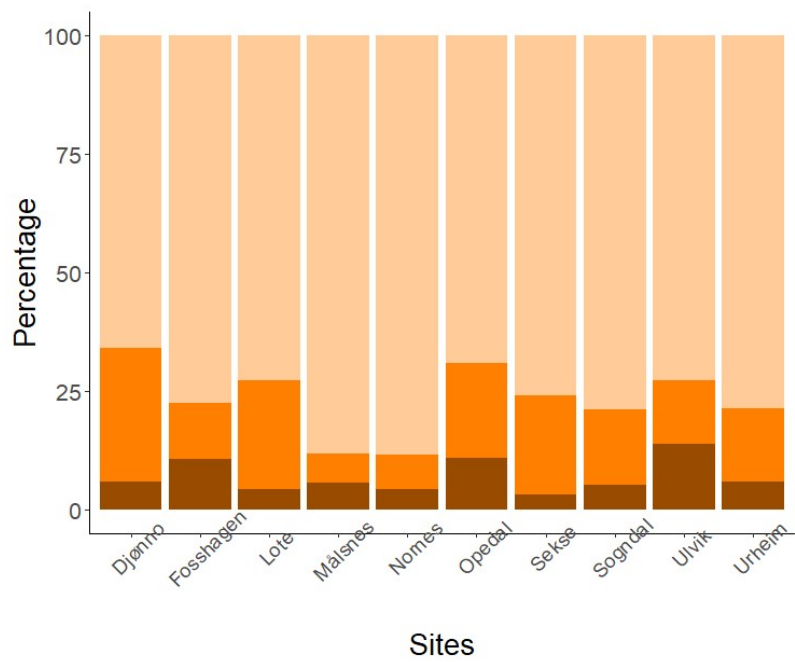


Figure 14: Marginal response plot for sites on seed development



## ***Discussion and conclusion***

In this study, we identified 23 solitary bee species and 14 bumblebee species. Hardanger had a generally richer wild bee diversity than Sogn. The species Løken (1958) described as common were also common today. The sites varied greatly in vegetational composition, with Hardanger generally being more intensely cultivated. Amount of forest had a positive effect on bumblebee proportions caught in nets, while amount of orchard affected this negatively. The effects of honeybee hives and floral areas on wild bee proportions is more uncertain. Apple seed set was highly affected by cultivar but did also vary within sites of the same cultivar.

## **Methods**

Pan traps are regarded as an effective method for sampling solitary bees, while larger species like bumblebees are more efficiently sampled with nets (Hutchinson, 2022; Prendergast, 2020). In crops where there are important pollinators in both groups, pan traps and transect walks can complement each other to give a more complete measure of the pollinator community composition in the area (Hutchinson, 2022). When we combined these methods, there was still an important difference in what the two methods measure. The bees captured with nets were inside apple flowers they potentially pollinated. On the other hand, bees captured in pan traps were not necessarily visiting apple flowers, but maybe rather the dandelions close to the traps. Bees caught in nets are a measure of bees that were visiting apple flowers, but bees caught in pan traps were rather a measure of the wild solitary bee community in the area. There is however a correlation of 0.85 (Appendix B) between solitary bees per hour caught in pan traps and the proportion of solitary bees caught using nets, suggesting that when there are more solitary bees in the area, they do visit the apple flowers. The pan traps caught almost solely solitary bees (94%), while the netting walks caught 81% honeybees, 10% solitary bees and 9% bumblebees.

Netting walks are regarded as an effective method for sampling bee communities, but there is a bias towards catching larger bees, as smaller species are difficult to spot (Hutchinson, 2022). Some implications come from the walks being done by six different people, who have different skills when it comes to catching. There was a large variation in the abundance of bees caught in each walk depending to some extent on who did the sampling. Because of this, proportions of the different pollinator groups caught were used instead of absolute abundance to reduce the effect of sampling skills. The ability to spot solitary bees might have varied between samplers, but not to the extent that overall sampling skill does. We also experienced

that honeybees were easier to catch than bumblebees, and that if we did not catch the honeybee on the first attempt it moved to a nearby flower whereas bumblebees often went further away after one attempt. Johansen (2022) observed foraging behaviour in bumblebees and honeybees in two of the orchards used in this study and did not find a difference in frequency of tree and row change. However, the methods in Johansen's study did not interfere with the bees in the same way a capturing attempt does.

### **Bee communities**

The species accumulation curves (Figure 5) clearly show that there is a chance of finding additional solitary bee species with more pan trap samples in Sogn, but not as likely in Hardanger. However, almost twice as many pan traps were used in Hardanger compared to Sogn. There is some chance of finding more bumblebee species in both regions.

The ordination plots (Figure 6 and 7) show a large variation between the sites in Sogn. As mentioned, singletons are placing the Sogn sites far apart, this is also visible when comparing the ordination plots (Figure 6 and 7) with the species plots (Appendix G). Ulvik was the site with the highest richness of 26 species, so even though Ulvik had eight singletons the more common species are placing Ulvik nearby other sites in the ordination plot. The singletons found in Ulvik are more likely to be rare than the ones found in Sogn, as Ulvik was more sampled than the Sogn sites (Table 1). The low sampling effort at for instance Sogndal in Sogn makes it difficult to know whether singletons were found only once because of sampling effort or that they truly are rare in this area.

All species described by Løken (1958) as common were found in more than half of the ten sites, except *B. hortorum* that was identified in just four sites (Table 6). *Bombus pratorum* was present in four sites in 2020, but eight sites when including 2019. This is one of the species Løken (1958) described as common and is from these observations still common in the area today. Four species were not found in the area by Løken. Three of these species (*B. terrestris*, *B. cryptarum*, *Osmia bicornis*) have been registered in the Hardanger and/or Sogn area more recently (GBIF data). The only one of these three that were of preserved specimens was *B. terrestris*, while the other two were only observations. *Andrena nigroaenea* has not been registered in this area earlier. *Andrena similis* is classified as endangered on the IUCN Red List (Ødegaard et al, 2021), all other identified species are classified as "least concern".

Bumblebees pollinate at lower temperatures and tolerate more wind than honeybees (Nayak et al, 2020). The marginal response curve for temperature (Figure 10) shows that the trend in

bumblebee proportions follows this pattern. Temperature varies throughout the apple blossoming period the bumblebees' ability to pollinate at times when honeybee activity is low demonstrates the importance of not solely relying on honeybees to pollinate.

### **Vegetation**

More forest results in larger bumblebee proportions, and more orchards causes less bumblebees, according to the multinomial regression model on bee communities (Table 10). This is in line with the prediction that natural habitats benefit the wild bee community. However, the effects of floral areas are not as clear.

When mapping the vegetation, I used the density of flowering vegetation as a defining category. This resulted in grass fields with some white clovers being placed in the category "floral: sparse" and other grass fields being placed in the category "other green areas". Each site was only visited once and a grass field that did not have any clovers the day I mapped it could have some two weeks later, or a day earlier if it had been recently mowed. It is therefore not possible to be sure of what grassy areas should be defined as areas with floral resources. Another approach to this could be to instead look at categories where there is likely to be floral resources, categories could for example be "edge", "meadow", "grass field" and so on instead of levels of floral density the day the site was visited. This also makes it possible to analyse potential nesting sites and not just floral resources.

None of the variables tested in the multinomial regression analysis on wild bee proportions caught in nets showed significant effects on solitary bee proportion. Johansen (2022) analysed the bee diversity and abundance data from this study with vegetation on various scales from 0-250 meters to 2500-3000m surrounding the orchards. He found that solitary bee abundance and richness was positively affected by forest area in the 0-250m scale, but no significant effects of forest on bumblebees. However, his study showed that bumblebee abundance was significantly affected by area of pasture on the 1500-2000m scale.

### **Beehives**

Managed honeybees have been suggested to be competing with wild bees for food resources (Goulson, 2003). In my study the proportion of bumblebees increased with longer distances to honeybee hives. However, the proportion of bumblebees also increased with higher numbers of hives. The effect size of number of hives was larger than that of distance to nearest hive (Table commodel). Only beehives inside a 200m radius of each orchard were included, which is a low distance compared to how far bees typically forage (Zurbuchen et al, 2010).

Looking at beehives on a larger scale could be more useful. One example of 200m being a low distance is the site Sekse, where there were no beehives in the 200m radius. The other two sites with no honeybee hives within this radius was Ulvik and Djonno. Sekse is located in a more intensely cultivated area and probably has more honeybee hives in a 1000m radius than Ulvik and Djonno, if we rather looked at a different scale. An experimental study done in the south of Sweden showed that bumblebee abundance was negatively affected by adding honeybee hives in homogenous landscapes, but not in heterogenous landscapes (Herbertsson et al, 2016), suggesting that bumblebee and honeybee competition is complex.

There is no clear pattern between sites with more honeybee hives and seed development. The sites with most hives were Nornes (14), Urheim (9) and Opedal (9), looking at the site marginal response plot (Figure 14) these sites are not similar in predicted seed development proportions. Number of honeybee hives was recorded for the 200m radius, but bees typically forage in a much larger distance than this (Zurbuchen et al, 2010), suggesting that hives outside of this radius could affect the apple seed set as much as the ones within the area.

### **Apple seed set**

The multinomial regression model clearly illustrates the large probability of Gravenstein apples having less developed seeds compared to Aroma apples. Gravenstein is a triploid cultivar, causing a larger self-fertility (Sedov, 2018). Gravenstein is an old cultivar in Norway and the larger self-fertility could potentially cause inbreeding and a lower genetic variation, that might again affect seed development.

We sampled one orchard per site and each orchard represented one apple cultivar. Due to this, it is difficult to distinguish site and cultivar effects. Both cultivars and sites had significant effects on seed set, but looking at the Gravenstein sites Opedal and Ulvik, the site and cultivar effects are similar. There being only two sites of this cultivar means there is a low basis of comparison within this specific cultivar.

There were six Aroma sites, the site effects among Aroma orchards can be compared. The multinomial model predicts that all Aroma sites except Målsnes have a larger proportion of partly developed seeds than Urheim (Table 12). Målsnes is the only site that has organic production. The marginal response plot (Figure 14) shows there being the most developed seeds in Målsnes and Nornes, when not including the cultivar effect. These sites do not have much in common, except that they are both in Sogn.

The model does not seem to predict a higher proportion of developed seeds with higher wild bee diversity. Ulvik and Djonno had the highest diversities, but do not show any higher proportion of developed seeds than other sites (Figure 12). The abundance measured in solitary bees per hour was largest in Djonno and Opedal (Table 7), the sites effects from these do not predict a higher proportion of fully developed seeds.

### **Conclusions and future studies**

The species that were recorded as common by Astrid Løken (1958) were also commonly found today. Hardanger had an overall higher wild bee diversity than Sogn. The proportion of bumblebees visiting apple flowers was positively affected by amount of forest and negatively affected by amount of orchards, showing that natural habitats are beneficial for wild pollinators. Overall, most apple seeds were fully developed, but this varied greatly between cultivars, with Gravenstein apples containing a much smaller proportion of developed seeds than Aroma and Summerred apples.

Both the species accumulation curves, and the ordinations show that Sogn should be sampled more intensively if we want a more complete idea of the wild bee communities in this area. In this type of studies, all sites should ideally be sampled equally, but due to the short apple flowering period over a relatively large geographical area, this requires resources in shape of many people doing the sampling.

This study did not show clear effects from floral resources in the areas, future studies would benefit from analysing areas that could potentially have floral resources (such as categories “road ditch”, “meadow” and “pasture”) instead of areas that visibly have floral resources at one point in time, like I did. The effect of honeybee hives should also be assessed at larger distances than in this study, due to how far bees typically forage. The overlap in site and cultivar effects can be avoided by sampling more than one orchard of more than one cultivar at each site. Doing a different statistical approach to look closer at the effects of the wild bee community on seed development could also be beneficial.

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## *Appendix*

### **Appendix A: Examples of vegetation at sites**



Ulvik, area 21-S: White clover meadow, category: floral – high



Ulvik, area 40-ø: Raspberry bushes, category: floral – high



Ulvik, area 13-G: Edge, category: floral – medium



Ulvik, area 32-W: road ditch, category: floral – sparse



Sekse, area 19-B: pasture with some clover, category: floral – sparse



Ulvik, area 7-K: deciduous forest, category: forest

## Appendix B: Correlation matrixes

	Nearest hive	Number of hives	Temp	Orchards (m <sup>2</sup> )	Urban areas (m <sup>2</sup> )	Forest (m <sup>2</sup> )	Floral: sparse (m <sup>2</sup> )	Floral: medium (m <sup>2</sup> )	Floral: high (m <sup>2</sup> )
Nearest hive		-0.69	0.16	-0.34	-0.20	0.06	0.53	0.33	0.53
Number of hives	-0.69		-0.21	0.73	0.33	-0.02	-0.41	0.29	-0.26
Temp	0.16	-0.21		-0.21	-0.43	-0.01	0.02	-0.08	0.25
Orchards (m <sup>2</sup> )	-0.34	0.73	-0.21		0.42	-0.57	0.17	0.12	-0.03
Urban areas (m <sup>2</sup> )	-0.20	0.33	-0.43	0.42		-0.19	0.33	0.03	0.02
Forest (m <sup>2</sup> )	0.06	-0.02	-0.01	-0.57	-0.19		-0.49	0.53	-0.14
Floral: sparse (m <sup>2</sup> )	0.53	-0.41	0.02	0.17	0.33	-0.49		-0.08	0.66
Floral: medium (m <sup>2</sup> )	0.33	0.29	-0.08	0.12	0.03	0.53	-0.08		0.13
Floral: high (m <sup>2</sup> )	0.53	-0.26	0.25	-0.03	0.02	-0.14	0.66	0.13	

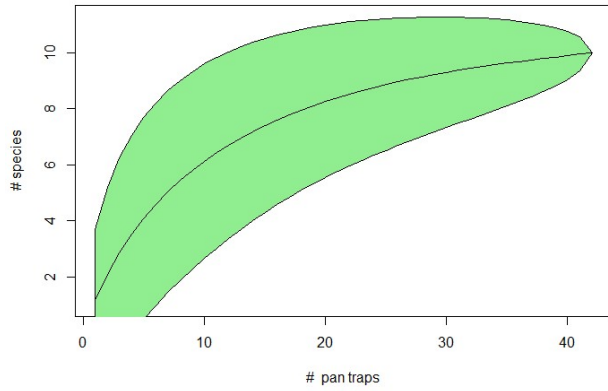
	Nearest hive	Number of hives	Solitary bees per hour in pan traps	R Bombus	R solitary bees	Wild bee proportion	Bombus proportion	Solitary bee proportion
Nearest hive		-0.69	0.63	0.37	0.65	0.74	0.41	0.68
Number of hives	-0.69		-0.58	-0.37	-0.71	-0.53	-0.27	-0.66
Solitary bees per hour in pan traps	0.63	-0.58		0.13	0.91	0.60	0.13	0.85
R Bombus	0.37	-0.37	0.13		0.24	0.48	0.47	0.10
R sol	0.65	-0.71	0.91	0.24		0.68	0.26	0.90
Wild bee proportion	0.74	-0.53	0.60	0.48	0.68		0.83	0.54
Bombus proportion	0.41	-0.27	0.13	0.47	0.26	0.83		0.025
Solitary bee proportion	0.68	-0.66	0.85	0.10	0.90	0.54	0.02	

## Appendix C: Wild bee community

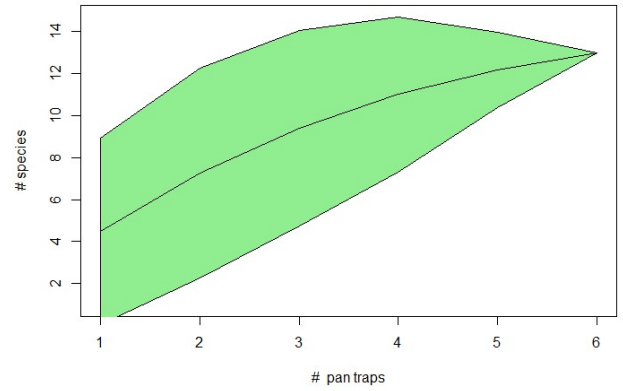
Species	Målsnes	Fosshagen	Nornes	Sogndal	Djønno	Ulvik	Urheim	Opedal	Sekse	Lote	Abundance	Sites present in
<i>B.pas</i>	3	2	2	0	2	13	1	1	4	0	28	8
<i>L.alb</i>	0	2	1	1	2	0	8	1	5	3	23	8
<i>L.cal</i>	1	0	0	0	58	12	3	14	20	8	116	7
<i>A.fuc</i>	1	0	1	0	1	2	1	0	0	5	11	6
<i>A.hae</i>	4	0	0	0	2	4	0	19	1	4	34	6
<i>A.sco</i>	0	0	0	1	3	8	0	1	2	2	17	6
<i>A.hel</i>	0	0	0	0	1	1	2	9	0	12	25	5
<i>B.luc</i>	0	4	0	2	0	5	0	0	12	1	24	5
<i>L.ruf</i>	0	0	0	1	2	0	3	2	1	0	9	5
<i>B.hor</i>	1	1	0	0	0	4	1	0	0	0	7	4
<i>B.hyp</i>	0	0	0	0	0	3	0	1	2	1	7	4
<i>B.pra</i>	2	0	0	0	4	4	0	0	2	0	12	4
<i>L.fra</i>	0	0	0	0	4	2	0	1	2	0	9	4
<i>A.cin</i>	0	0	0	0	2	4	0	2	0	0	8	3
<i>B.boh</i>	0	1	0	0	0	3	1	0	0	0	5	3
<i>B.sor</i>	0	2	0	1	0	1	0	0	0	0	4	3
<i>A.sem</i>	1	0	0	0	3	0	0	0	0	0	4	2
<i>A.sub</i>	0	0	0	1	0	2	0	0	0	0	3	2
<i>B.syl</i>	0	0	0	0	0	1	0	0	0	1	2	2
<i>B.ter</i>	0	0	0	0	0	2	0	0	1	0	3	2
<i>H.rub</i>	0	0	0	0	1	2	0	0	0	0	3	2
<i>L.leu</i>	0	1	0	0	14	0	0	0	0	0	15	2
<i>A.int</i>	0	1	0	0	0	0	0	0	0	0	1	1
<i>A.lap</i>	0	0	0	0	0	1	0	0	0	0	1	1
<i>A.nig</i>	0	0	0	0	0	1	0	0	0	0	1	1
<i>A.sim</i>	0	0	0	0	3	0	0	0	0	0	3	1
<i>B.cam</i>	0	0	0	0	0	1	0	0	0	0	1	1
<i>B.cry</i>	0	0	0	0	0	0	0	0	1	0	1	1
<i>B.lap</i>	0	0	0	0	0	1	0	0	0	0	1	1
<i>B.mag</i>	0	1	0	0	0	0	0	0	0	0	1	1
<i>B.nor</i>	0	0	0	0	0	1	0	0	0	0	1	1
<i>H.tum</i>	0	0	0	1	0	0	0	0	0	0	1	1
<i>N.mar</i>	0	0	0	0	0	1	0	0	0	0	1	1
<i>N.pan</i>	0	0	0	0	0	1	0	0	0	0	1	1
<i>N.ruf</i>	0	0	0	0	0	1	0	0	0	0	1	1
<i>O.bic</i>	0	0	0	1	0	0	0	0	0	0	1	1
<i>O.unc</i>	0	1	0	0	0	0	0	0	0	0	1	1
Richness	7	10	3	8	15	26	8	10	12	9		

## Appendix D: Species accumulation curves

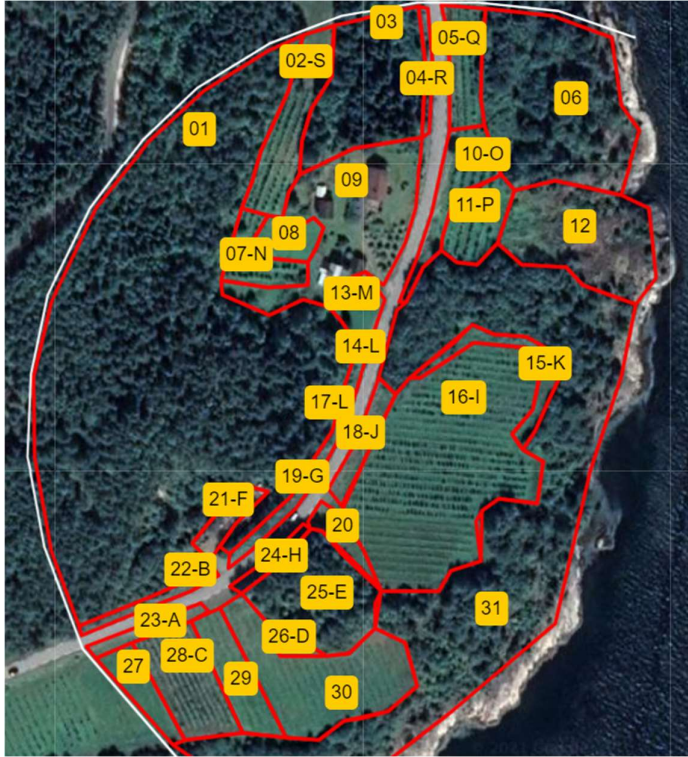
Solitary bees caught in pantraps, Hardanger, not including Djønno



Solitary bees caught in pantraps, Djønno



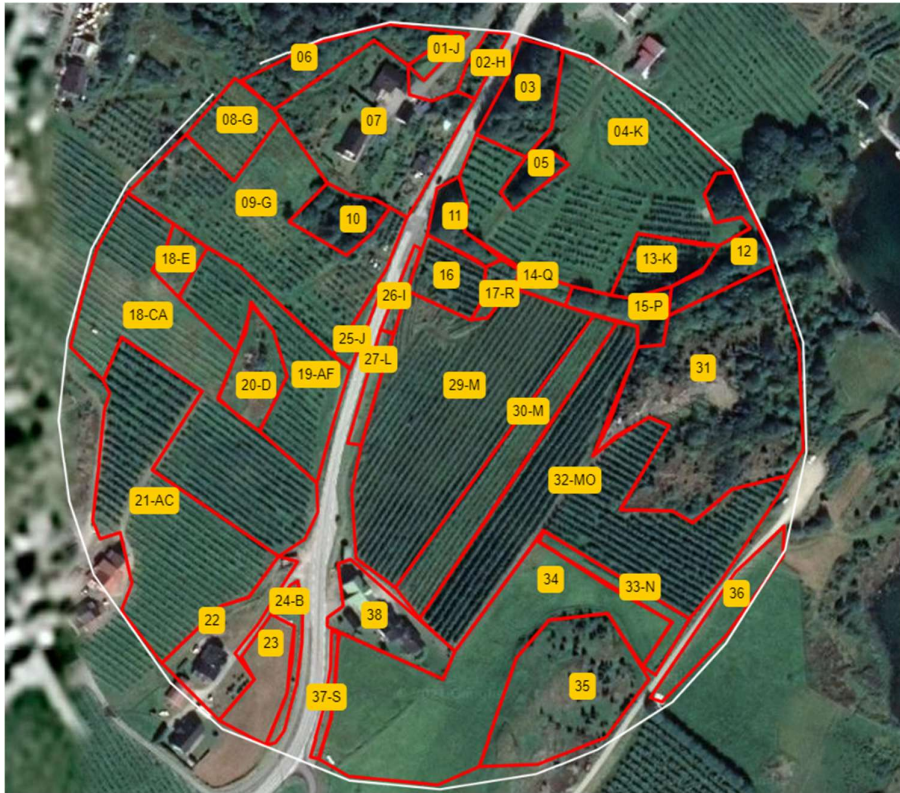
## Appendix E: Vegetation



Målsnes



Fosshagen

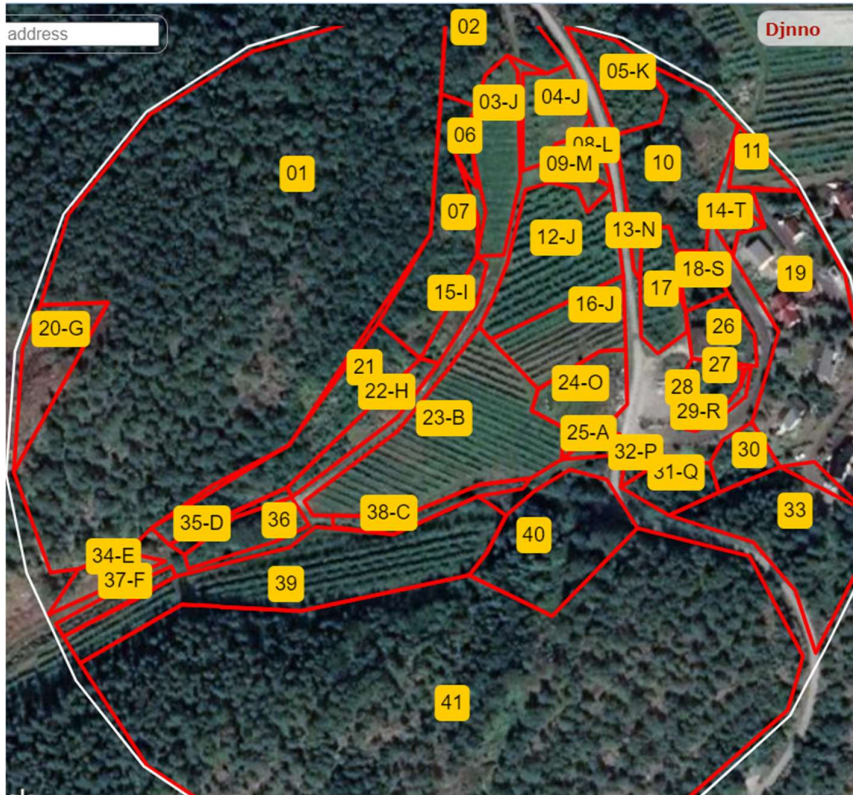


Nornes



Sogndal

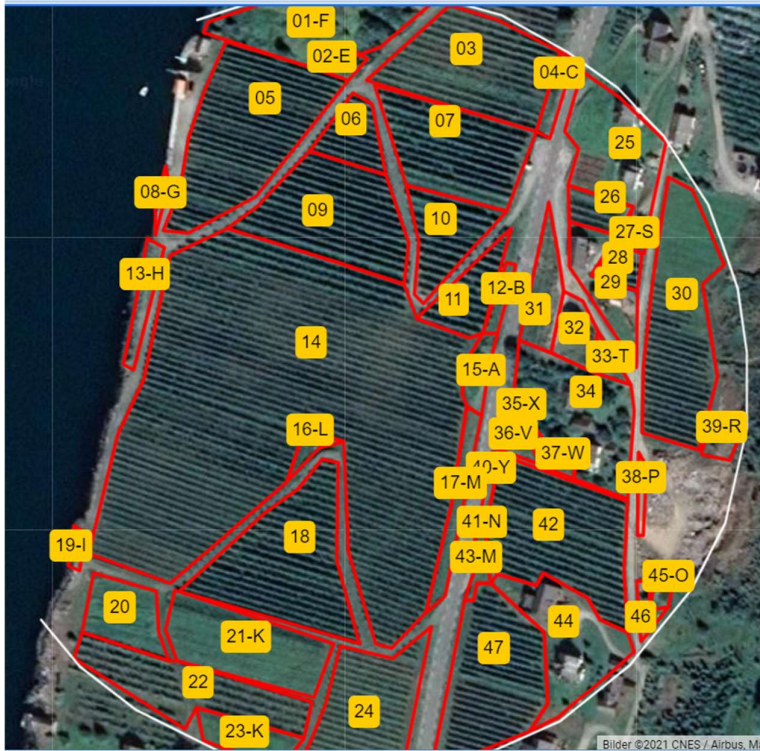




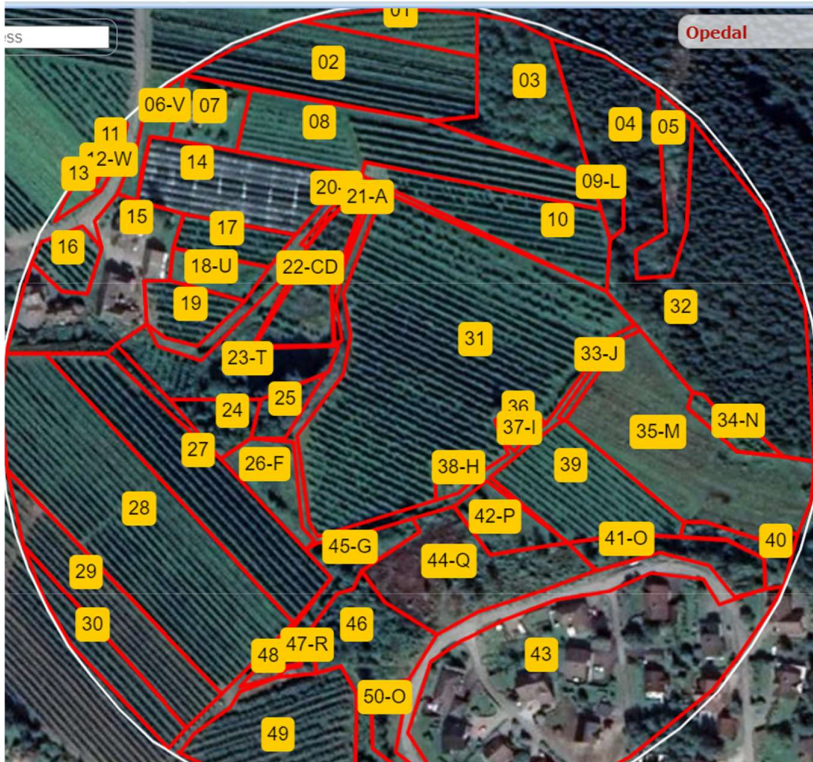
Djønno



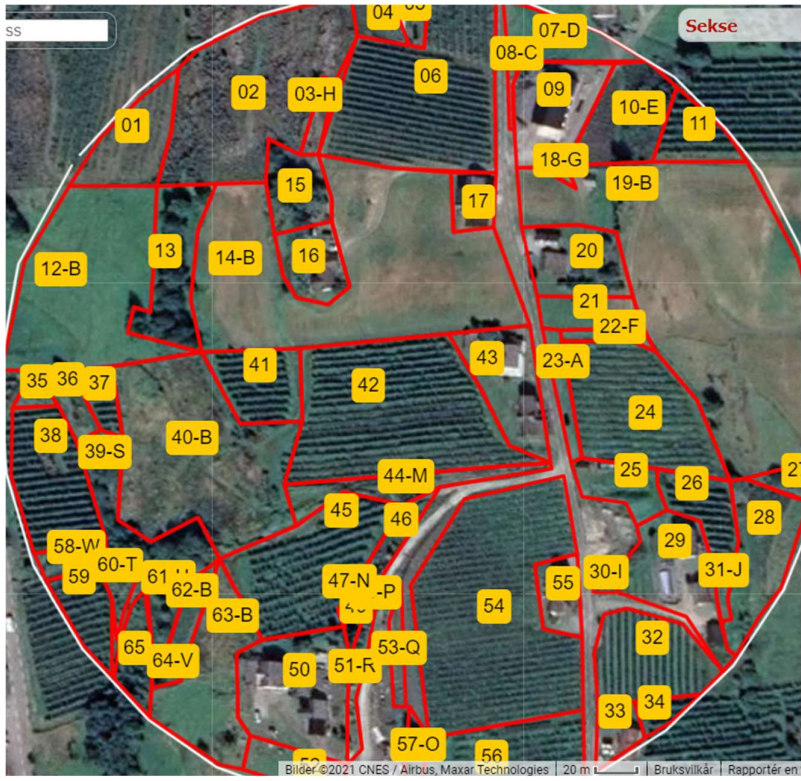
Ulvik



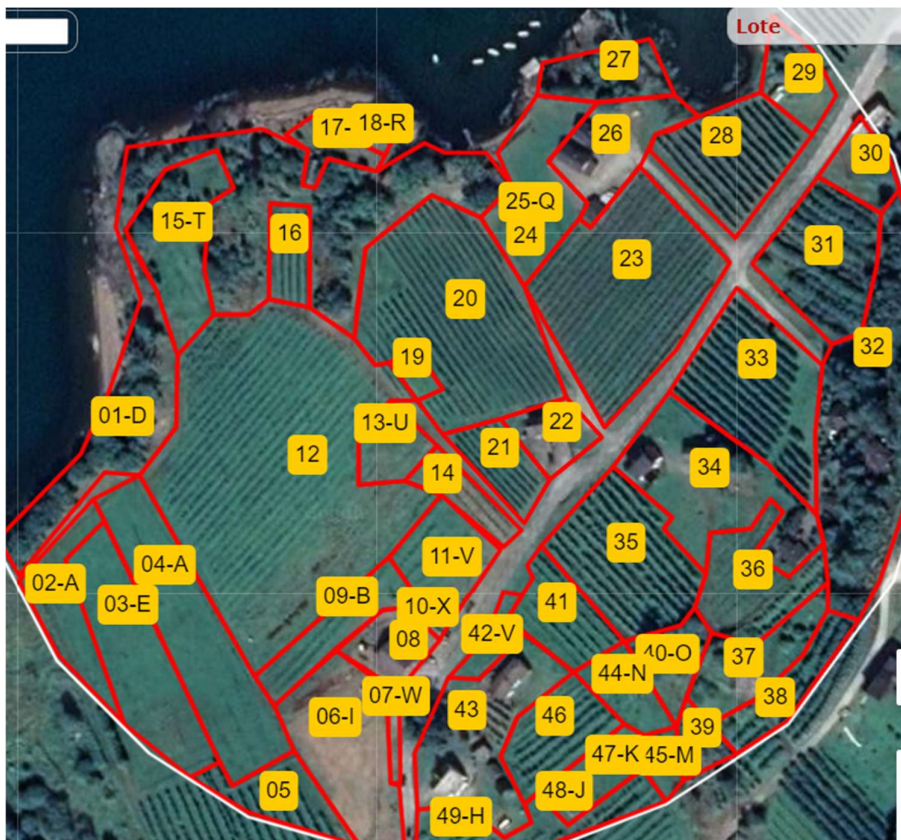
Urheim



Opedal



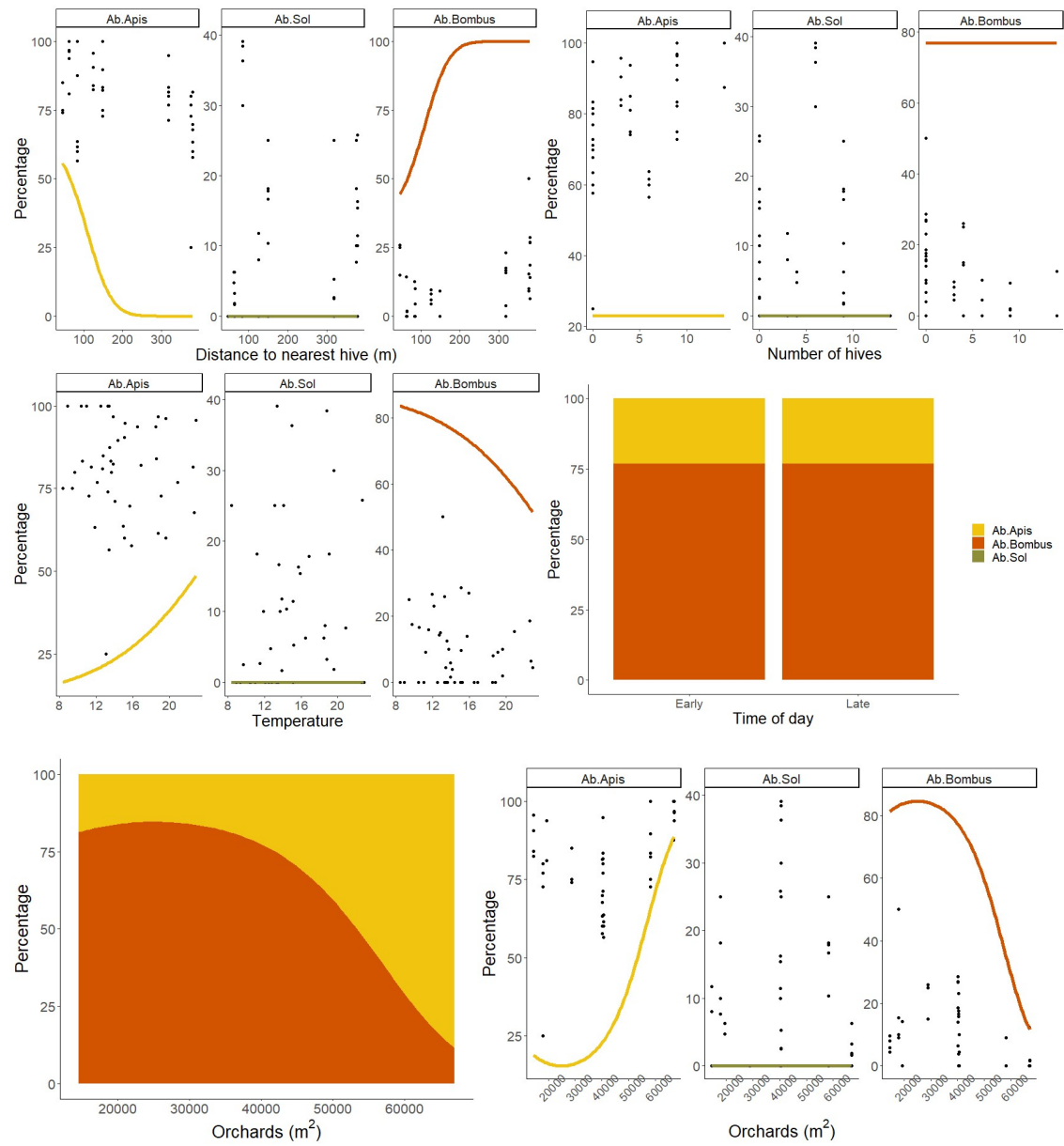
Sekse

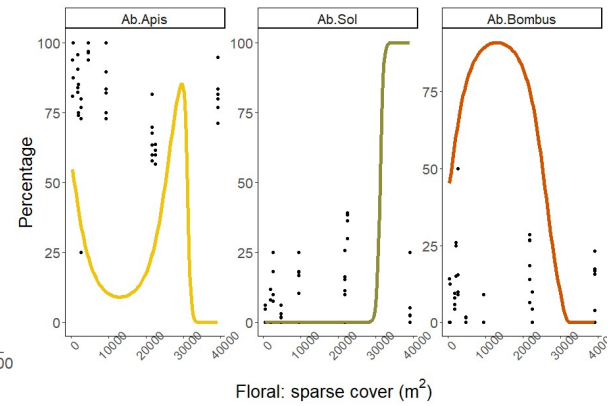
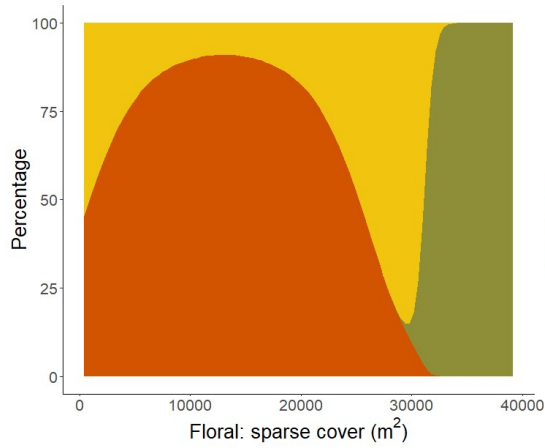
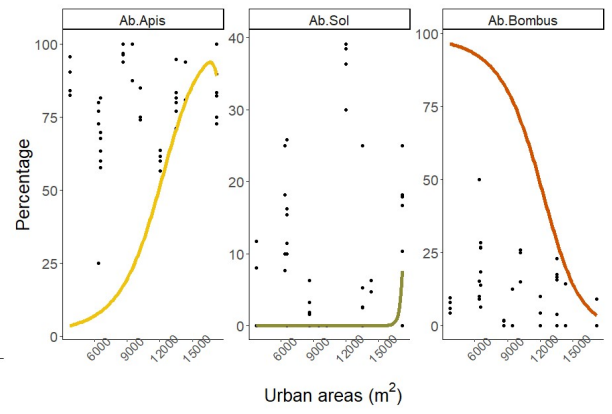
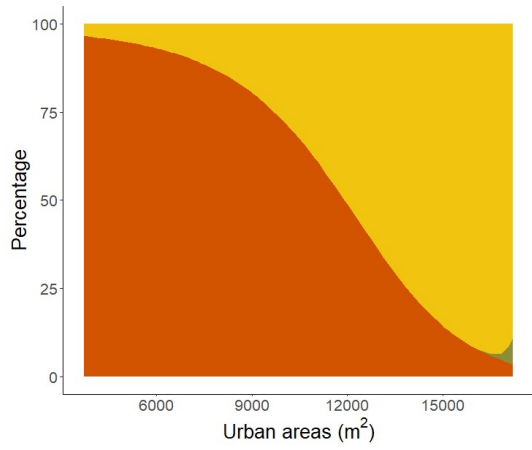
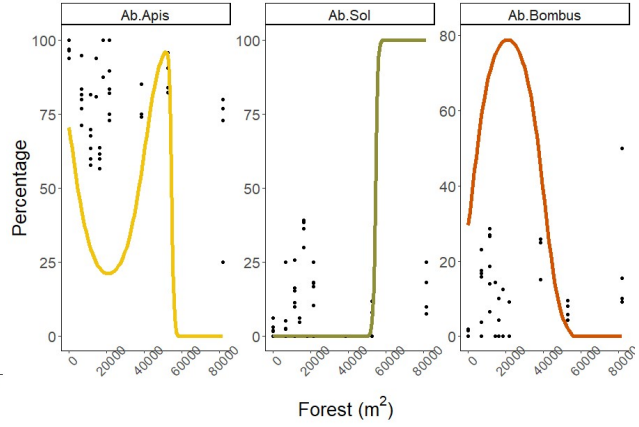
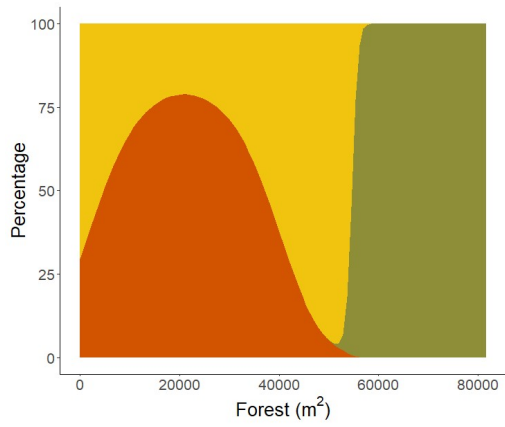


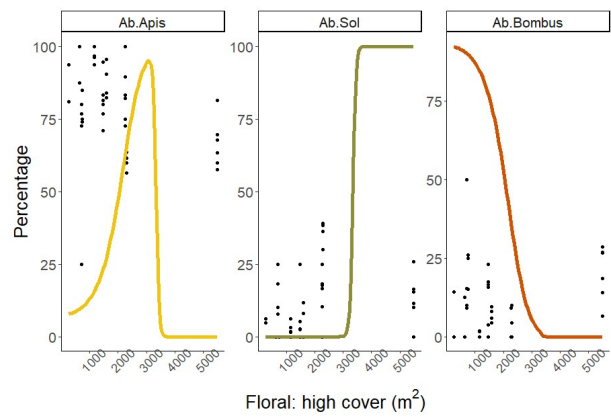
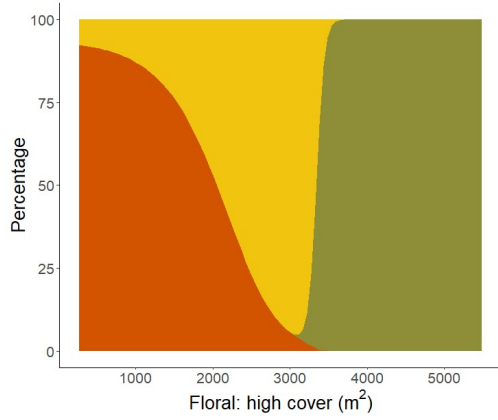
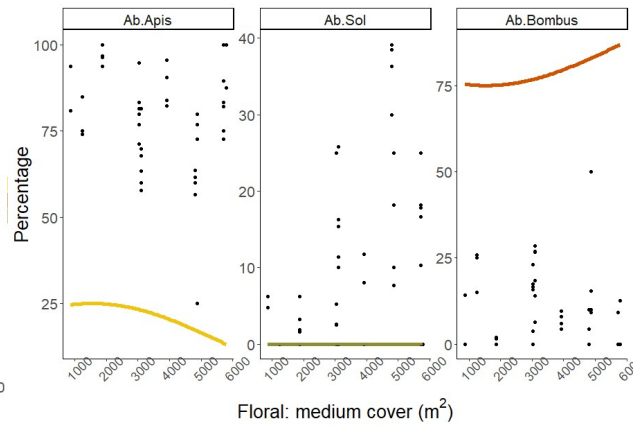
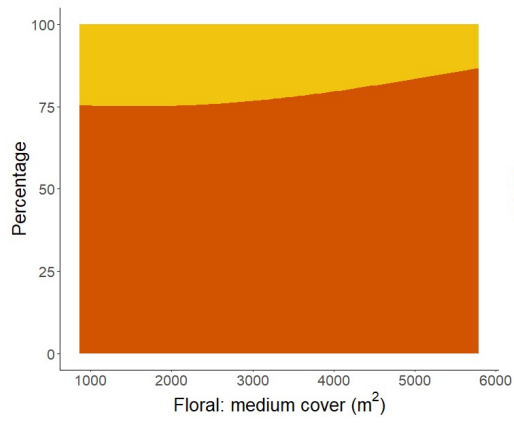
Lote

Table E1: Overview of vegetational maps. Numbers correspond to maps (see previous pages)								
site	floral - high	floral - medium	floral - sparse	orchards	urban areas	forest	other green areas	Notes
Målsnes	10,18	05,11,13,15,22,23	04,14,17,19,21,24,26	02,07,16,27,29,30	09	01,03,06,12,25,31	08,20,28	
Fosshagen	09,15,18,22,25,34	27	01,03,12,13	02,04,05,06,08,14,17,20,23,24,32,33,36	07,10,19,26,28,31	01,11,12,16,29,30,35	21	
Nornes	14,25	01,02,15,17,18,20,26,27,33,37	24	04,08,09,13,16,19,21,28,29,30,32	07,22,38	03,05,06,10,11,12,15,31	23,34,35,36	
Sogndal	13,23	14,18,19	17	06,08,09,11,12,22	07,16,20,24	01,02,03,05,15	04,10,21	
Djønno	13,25,37	08,09,14,18,22,24,28,32,34,35,38	05,06,15,29,31	03,04,11,12,16,17,23,39	19,26	01,02,05,07,10,21,27,30,33,36,40,41	-	Area 20-G is chopped forest
Ulvik	01,04,05,14,20,21,33,40,42,47	07,09,13,15,29,30,34,37,39,44	02,06,23,24,27,32,43	08,22,25,28,36	03,10,18,26,35,45,46	11,16,27,38	12,17,19,31,41	
Urheim	02,15,16,27,45	04,12,13,35,36,38,41	01,08,17,19,33,37,39,40,43	03,05,06,07,09,10,11,14,18,22,24,26,28,30,31,42,47	25,32,34,44	-	20,21,23,29,46	
Opedal	26,42,47	12,18,20,21,22,23,33,37,38	09,34,35,41,45,50	01,02,08,10,11,13,14,16,17,19,27,28,29,30,31,39,49	07,15,36,43,48	03,04,05,24,25,40,45,46	06,44	
Sekse	22,31,47,60,61,64	03,18,23,44,51,53,58	07,08,12,14,19,30,40,48,57,62,63	01,06,11,24,26,32,34,37,38,41,42,45,54,56,59	05,09,16,17,20,29,33,43,50,55	13,15,27,35,39,49,57,65	04,21,25,36,52	Area 02, 10-E, 28 and 46 are christmas trees
Lote	09,10,44,48	07,13,15,18,25,45,49	01,02,03,04,06,11,17,40,42,47	05,12,14,16,20,21,23,28,31,33,35,36,38,41,46	08,22,26,29,30,34,37,43	01,27,32,39,40	19,24	

## Appendix F: Community plots







## Appendix G: Ordinations

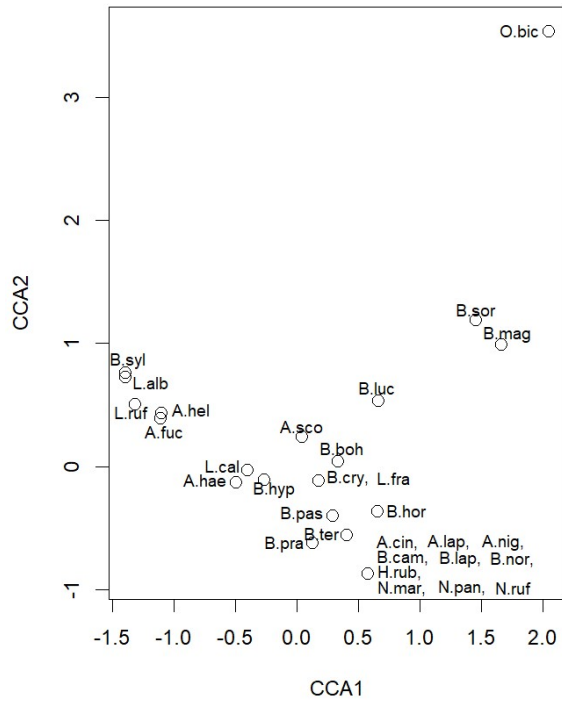


Figure G1: Species correspondence analysis ordination plot for netting walks

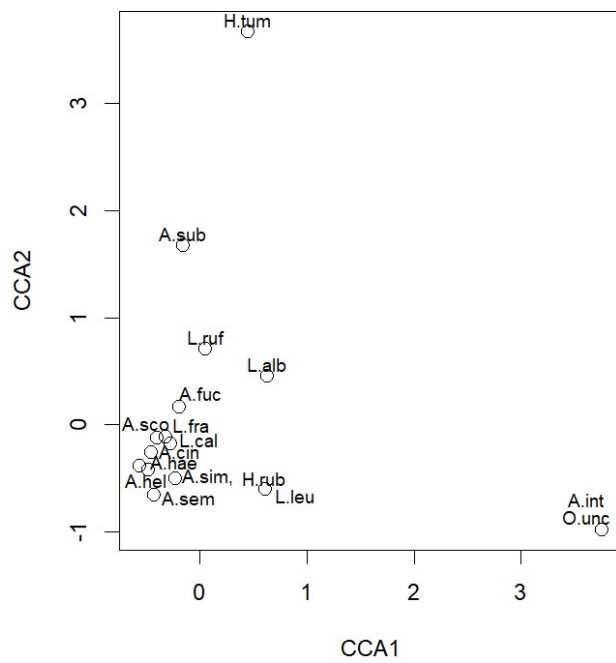


Figure G2: Species correspondence analysis ordination plot for pan traps