

Frida Slettan

# Investigating the effect of different land use types on the presence of, and interaction between flowering plants and their pollinators in Budalen

Master's thesis in Natural Resource Management

Supervisor: James D. M. Speed (Department of Natural History)

Co-supervisor: Gunnar Austrheim (Department of Natural History)  
and Beatrice Trascau (Department of Natural History)

May 2024



Photo: Frida Slettan



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Norwegian University of Science and Technology  
Faculty of Natural Sciences  
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# Abstract

Animal pollination is vital for ecosystem function and services, and especially important is the role of insects. There is a global decline in pollinator diversity, and groups such as the bumblebees are heavily affected. Semi-natural grasslands are of big importance for pollinators because of their high floral diversity, but land use change such as intensification and abandonment, has caused a decrease in area and numbers, both globally and in Norway.

The objective of this thesis is to study the effects of three land use types on the richness and abundance of flowering plants and pollinators, as well as their interaction. The land use types assessed were: "former haymaking" (FH), "extensive grazing" (EG), and "intensive grazing" (IG). This was done over the summer of 2023 at subalpine semi-natural grasslands in Budalen, Central Norway.

The species richness and abundance of plants in flower, as well as the pollinator abundance were significantly different between the land use types. When looking at the composition of the plants in flower, the IG areas were significantly different from the EG and FH areas who had many of the same species.

IG had the highest total flower richness and abundance. These areas were open grasslands close to the farms that were fenced and grazed at low intensity at given times. For the pollinators, IG had the highest abundance in early and midsummer, but due to it decreasing at the onset of grazing, FH was higher in late summer. Excluding the flies from the data, made the difference between the land use types very small, and when looking at bumblebees only, IG had the highest abundance, FH was in the middle, and EG had the lowest. IG had the highest connectivity in interaction networks. The species composition for both plants and pollinators differed between land use types. This suggests that different land use at the landscape scale could increase the large-scale diversity.

The results showed the importance of maintaining low-scale farming activity in the mountainous regions of Norway to maintain all three land use types, and the environmental diversity that it creates. In addition, advise to the farmers would be to leave a portion of the intensive grazing land undisturbed from grazing to create a refuge for the pollinators throughout the summer.



# Sammendrag

Dyrepollinering er avgjørende for økosystem funksjoner og tjenester, deriblant er insektenes rolle spesielt viktig. Det er en global nedgang i pollinator diversitet, og spesielt arter som humler er vist å være kraftig påvirket. Semi-naturlige grasmarker er svært viktig for pollinatorer grunnet naturtypens høye abundanse -og blomster diversitet. Grunnet endringer i landbruket som blant annet intensivering og opphør av bruk, minker områder som disse i størrelse og antall. Dette gjelder både i Norge og globalt.

Målet med denne avhandlingen er å undersøke hvilke effekter ulike semi-naturlige arealbrukstyper har på artsrikheten og abundansen til planter i blomstring, heretter kalt blomster, pollinatorer samt interaksjonen dem imellom. Arealbrukstypene som ble undersøkt var; "former haymaking" (FH), "extensive grazing" (EG) and "intensive grazing" (IG). Studiet ble utført over sommeren 2023 i Budalen i Norge.

Artsdiversiteten og abundansen av blomster, samt pollinator abundansen viste en signifikant forskjell mellom alle de ulike landbrukstypene. Komposisjonen av blomster var også signifikant forskjellig fra IG sammenliknet med EG og FH som hadde mange av de samme artene.

IG hadde den høyeste artsrikheten og abundansen av blomster. Disse områdene var åpne inngjerdede grasmarker nærliggende til gården som ble beitet kun til bestemte tider av sommeren. IG hadde høyeste pollinator abundansen i juni og juli, frem til beitingen startet og en sank betydelig. Etter dette tok FH over med høyest abundanse. Fjernet man fluer fra dataen, ble forskjellen i pollinator abundanse betydelig mindre. Ved å se på kun humler, hadde IG den høyeste abundansen, etterfulgt av FH. EG hadde færrest humler. Interaksjons-nettverket viste også at IG hadde flest interaksjoner. Artssammensetningen for både blomster og pollinatorer var ulik mellom alle arealbrukstypene. Dette viser at ulik arealbruk på landskapskala kan øke diversiteten på et større nivå.

Resultatene viser viktigheten av å fortsette et lite intensivt landbruk i de subalpine områdene i Norge for å vedlikeholde alle tre arealbrukstypene samt viktigheten av hver av dem for å opprettholde mangfoldet av økosystem som de skaper. Grunnet dette, kan det anbefales til bønder å beskytte deler av IG områdene slik at det ikke beites for å skape et leveområde for pollinatorene gjennom hele sommeren.





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# 1 Introduction

## 1.1 Pollinators

Pollinators provide important ecosystem services that the well-being of both humans and nature depends on (Gallai et al., 2009; IPBES, 2016). By moving from flower to flower, they aid the reproduction of the plants, thereby maintaining the native flora and plant diversity (IPBES, 2016; Khalifa et al., 2021; Porto et al., 2020). About 90% of all wild flowering plant species, as well as close to 35% of the world's overall crop production volume, depend on animal assisted pollination (IPBES, 2016; Ollerton et al., 2011). This makes them very important for ecosystem functions and services, maintaining both the stability and diversity of plants which also is highly important for human welfare (Artsdatabanken, 2021a; Galen et al., 2017).

Most pollinators use the flowers as a food source or shelter and spend their life moving between them to get this (Simonsen & Nylén, 2022; Willmer, 2011). Consequently, their behavior offers valuable insights into their role as pollinators. When looking into their role as a pollinator, it is often focused on their diet concerning whether they are generalists or specialists. The generalists are flexible and interact with flowers from a broad range of species, while specialists collect only from a narrow range of species often based on their anatomy (Willmer, 2011).

Out of the many pollinating insects, *Bombus* (bumblebees), *Apis* (honeybee), *Syrphidae* (hoverflies), *Lepidoptera* (butterflies), *Brachycera* (flies), *Heterocera* (moths) and *Culicidae* (mosquitos) are seen as important for flower pollination (Doyle et al., 2020; Galen et al., 2017; Khalifa et al., 2021; Klecka et al., 2018; Larson et al., 2001; Ødegård, 2023; Peach & Gries, 2020; Rader et al., 2016; Willmer, 2011). Out of these, *Bombus*, who belongs to the *Apidae* family, is often seen as the most efficient one. This is due to its furry body and way of living (Artsdatabanken, 2021b). Sadly, out of the 23 405 assessed pollinating species from all taxonomic groups, 21.2% are on the Norwegian Red List, where the endangered ones make up 11.8%. When considering only bees and bumblebees, 30.6% are on the Red List, and 17% are threatened (Artsdatabanken, 2021a).

### 1.1.1 Bombus

*Apis*, are considered significant pollinators due to their high number, wide range, and effectiveness in collecting pollen (Ødegård, 2022a; Willmer, 2011). The family *Apidae* contains both solitary and social bees and the last one includes the *Bombus* which is one of the most important genera of pollinators in this family (Khalifa et al., 2021). Most of the *Bombus* species are generalists, though there are some more specialized as well (Ødegård, 2022a). One good example also present in Norway is the *B. consobrinus* with its long tongue adapted for feeding on the *A. septentrionale* (Ødegård, 2022a).

Out of the world's more than 250 *Bombus* species, 35 of them have been observed in Norway (Ødegård, 2022a). In the recent decades, they have been found to decline in numbers globally, but also in Europe. In Norway, all but four species of *Bombus* are assessed as endangered (Artsdatabanken, 2021a). This is mainly due to changes in land use, climate changes, the use of pesticides, and the introduction of alien *Bombus* species (Artsdatabanken, 2021a; Totland et al., 2013).

### 1.1.2 Lepidoptera

The order *Lepidoptera* (butterfly) serve as relatively important pollinators, and includes many specialist pollinators, which links their diversity to the diversity and composition of flowering plants (Totland et al., 2013; Willmer, 2011). *Lepidopterans* are heat-loving insects that are mostly found in open meadows, and the most species-rich areas in Norway are known to be in the inner and continental areas (Elven et al., 2021). Areas at higher elevation with birch forests are known for having low species diversity but high abundance. Despite their fragile body, *lepidopterans* often travel big distances, making them important for preventing inbreeding in plants (Elven et al., 2021).

Globally, there are about 175 000 known *Lepidoptera* species whereas 2300 of them are found in Norway, covering 73 families. 5 of these are dayflying, called *Papilionidea*, and contain 100 different species (Elven et al., 2021). Many of these species are associated with open areas abundant in flowering plants, such as natural grazing fields or open, lowland dry meadows (Artsdatabanken, 2018).

Europe has witnessed significant declines in *Lepidoptera* populations (IPBES, 2016; Wagner, 2020), particularly grassland *Lepidoptera*, although woodland species experienced a decline in the 1990s followed by a recent resurgence (IPBES, 2016; Van Swaay et al., 2020; Wagner, 2020).

The decline is mostly caused by increased urbanization, overgrowth of meadows, intensification of land use areas, reducing the size, and fragmenting their preferred habitat (Elven et al., 2021; Willmer, 2011). Their specialized nature can make them even more vulnerable to changes. About 22% of the *Papilionidea* in Norway are on the red list, where 17% are assessed as threatened (Artsdatabanken, 2018; Elven et al., 2021).

### 1.1.3 Other pollinators

Brachycera is a diverse taxonomic group where many are generalists. As pollinators, each individual is not that effective, but because of their high number they collectively do a considerable amount of pollen transportation, making them an important group (Larson et al., 2001; Rader et al., 2016). Especially the suborder *Syrphidae* are important pollinators (Larson et al., 2001; Willmer, 2011).

*Culicidae* are seen as nectar thieves but also pollinate many plants (Larson et al., 2001; Peach & Gries, 2020). Same as for the Brachycera, they are important due to their high number of individuals as well as some being generalists and other specialists. They also tolerate cold temperatures well, which many pollinators don't. This makes them important, especially in the colder areas (Galen et al., 2017; Larson et al., 2001; Peach & Gries, 2020).

## 1.2 Plant pollinator interaction

Plants and pollinators rely on each other through a mutualistic relationship where the pollinator gets nutrition in the form of nectar and pollen, and in return, the pollinator transfers pollen between flowers while foraging allowing the plant to reproduce (Totland et al., 2013; Willmer, 2011). Therefore, declines in one will then affect the other negatively.

In Norway, there are 1, 133 species of pollinating insects recorded. Alarmingly, 24.2% of these species are on the red list, while 13.8% are deemed threatened, underscoring the urgent need for conservation efforts (Artsdatabanken, 2021a).



### 1.3 Semi-natural landscapes

Semi-natural areas are known for having high flower density, which makes them good areas for pollinators to nest and feed (Aune et al., 2018; Bullock et al., 2011; IPBES, 2016; Öckinger & Smith, 2006). By creating mosaics of small habitats flourishing with flowers, they are highly favorable for insects such as bees, butterflies, and bumblebees (Elven et al., 2021; Öckinger & Smith, 2006).

Semi-natural areas are defined as meadows that depend on correct type and intensity of management to persist, as for example small scale farming (Aune et al., 2018; Bullock et al., 2011; Hovstad et al., 2018). In Norway, Semi-natural ecosystems can be found in coastal heathlands, grasslands, forests, and mountainous terrains where summer dairy farming is or has been present (Hovstad et al., 2018).

Humans have used the Norwegian mountains for farming for resources and having livestock since 4000-3500 BP (Olsson et al., 2000). In later times, the land use methods changed. General farming in Norway started transitioning from traditional small-scale farming to more intensive and effective in the 1950s (Stoate et al., 2009). Since then, the number and size of these semi-natural areas has gone down. The main causes for this decrease are changes in agricultural practices such as modernization and streamlining of the most productive areas, and abandonment of the less productive ones. This has then resulted in fragmentation, overgrowing, and reforestation of some areas, and can potentially reduce the density of plants in flower and thereby threaten pollinators (Elven & Berggren, 2021; IPBES, 2016; Johansson et al., 2011; Kearns et al., 1998; Potts et al., 2010; Squires et al., 2018; Wagner, 2020).

In Norway, all semi-natural areas are assessed as vulnerable, and mowed grasslands are critically threatened because of a substantial decrease over the past fifty years (Hovstad et al., 2018). When knowing the importance of pollinator abundance and species richness, the focus on sustaining them is highly important in the cause of maintaining the pollinators in these areas.

To find out how drivers such as agricultural intensification and abandonment of alpine grasslands affects the abundance and diversity of pollinators, we must look into certain groups of pollinators, and combine this with the abundance and diversity of flowering plants for different types of land use.

Even though there is a lot of research pointing out this decreasing trend in pollinators, there are surprisingly few long-term studies. Our understanding of how land use impacts pollination is also limited, especially when looking at previous history of areas.

There is no precise information regarding the area of the assessed semi-natural ecosystem types in Norway. There is also a lack of surveys or monitoring in these areas, seeing the changes, or the forest regrowth conditions in Norway (Hovstad et al., 2018; Johansen et al., 2019). For the period 2014 -2017, Nature in Norway NiN surveying carried out on behalf of the Norwegian Environment Agency, provided information on the forest regrowth in amongst others the semi-natural grasslands and old fields for haymaking (Johansen et al., 2017) It stated that more than 80% of old hayfields have been lost during the last 50 years (Hovstad et al., 2018).

## 1.4 Aim and Hypothesis

This study aims to understand how land use affects abundance and species richness of flowering plants, and the interactions between them and their pollinators in subalpine grasslands in Budalen. We are looking into the land use types named "former haymaking" (FH), "extensive grazing" (EG) and "intensive grazing" (IG). These will be closely defined in the methods.

### Hypothesis

In assessing the effects of land use on the interaction between flowering plants and their pollinators in Budalen, we seek to address the following hypotheses:

**(1)** The (a) species richness, (b) abundance and (c) composition of plant species in flower will show a change between the three semi-natural areas studied. Partly due to the open land in IG sites, these are expected to get the highest species richness and abundance. The openness is also thought to make the species composition of IG somehow different from EG and FH.

Prediction 1a: (richness) The greatest number of plant species will occur at intermediate levels of disturbance (Petraitis et al., 1989). This means that seminatural areas that are prone to continuous disturbance through grazing or mowing, such as IG sites, will have a significantly higher diversity of flowering plants than former haymaking areas that are currently prone to encroachment.

Prediction 1b: (abundance) Plant abundance is higher in open and sunny areas (Dormann et al., 2020), and the presence of grazing and trampling animals is negative for the abundance (Albon et al., 2007). This means that the areas of IG will have a higher abundance than the others, at least until grazing onsets.

Prediction 1c: (composition) The difference in growing conditions, such as light and soil moisture will make the land use types fitting for different plant species (Dormann et al., 2020; Hettenbergerová et al., 2013). These are abiotic factors that are changing with amongst others the presence of trees casting shadows and cows trampling down an area. Therefore, it is thought that the composition of flowering plants will differ between the different land use types.

**(2)** There will be a difference in pollinator abundance between the three semi-natural areas studied. If hypothesis 1 is supported, the difference in abundance and species richness of flowers will affect the number of pollinators, making IG the most pollinator-rich land use.

Prediction 2: Different pollinators have different niches, so different flowering plant compositions will attract different pollinators. A more heterogenous area will also therefore support a wider range of pollinators (Galen et al., 2017). A higher abundance of flowers means more nutrition offered for the pollinators. So, combined with the prediction from 1a and b, the difference in present flowering plant species and abundance will lead to a difference in pollinators present.

**(3)** There will be a difference in plant-pollinator interaction between the three semi-natural areas studied. If both hypotheses 1 and 2 are supported, this will give different combinations of flowering plants and pollinators.

Prediction 3: Flower diversity and pollinator diversity are found to be positively correlated, especially for the specialists (Biesmeijer et al., 2006; Fründ et al., 2010). Areas with lower plant diversity will have more specialized pollinators that interact with fewer plants compared to areas with higher plant diversity (Fründ et al., 2010).

## 2 Methods

### 2.1 Area and Study Sites

Budalen is a subalpine landscape conservation area (33km<sup>2</sup>) laying at 600-900 m.a.s.l. (Solem et al., 2011, fig. 1). The area is in the northern boreal zone (Moen, 1999) and as Figure 1 shows, the vegetation consists of semi-natural grasslands, forest, heathlands, and some mire patches (Austrheim, Gunilla, et al., 1999; Olsson et al., 1995, 2000; Tretvik et al., 2015, pp. 81–114).

Budalen has annual precipitation is 760 mm, a mean annual temperature of 2.5 degrees Celsius, and a growing season limited to 140-160 days (Austrheim et al., 1999; Pålsson, 1984).

Budalen has a high number of semi-natural land use areas where many have different uses throughout history (Figure 1). A Figure 1 shows, they have been used for wood cutting, hay making and grazing fields, whereas the use depended on the characteristics of the area as well as distance to the farm.

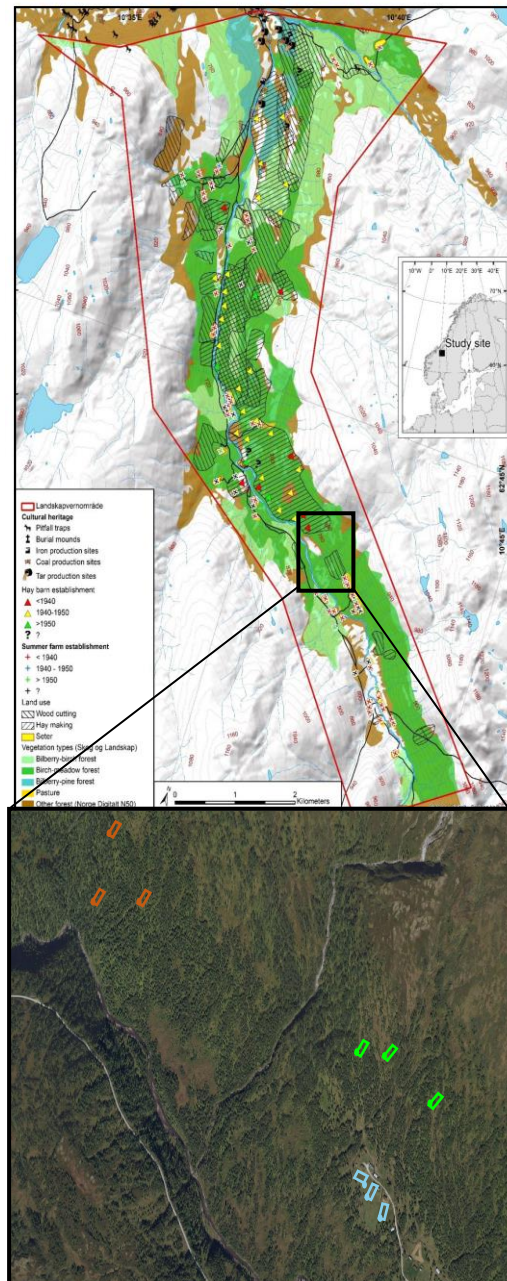
Today, some areas are still in use, while others are left and overgrown. This variety makes Budalen a suitable area for this study.

### 2.2 Data collection

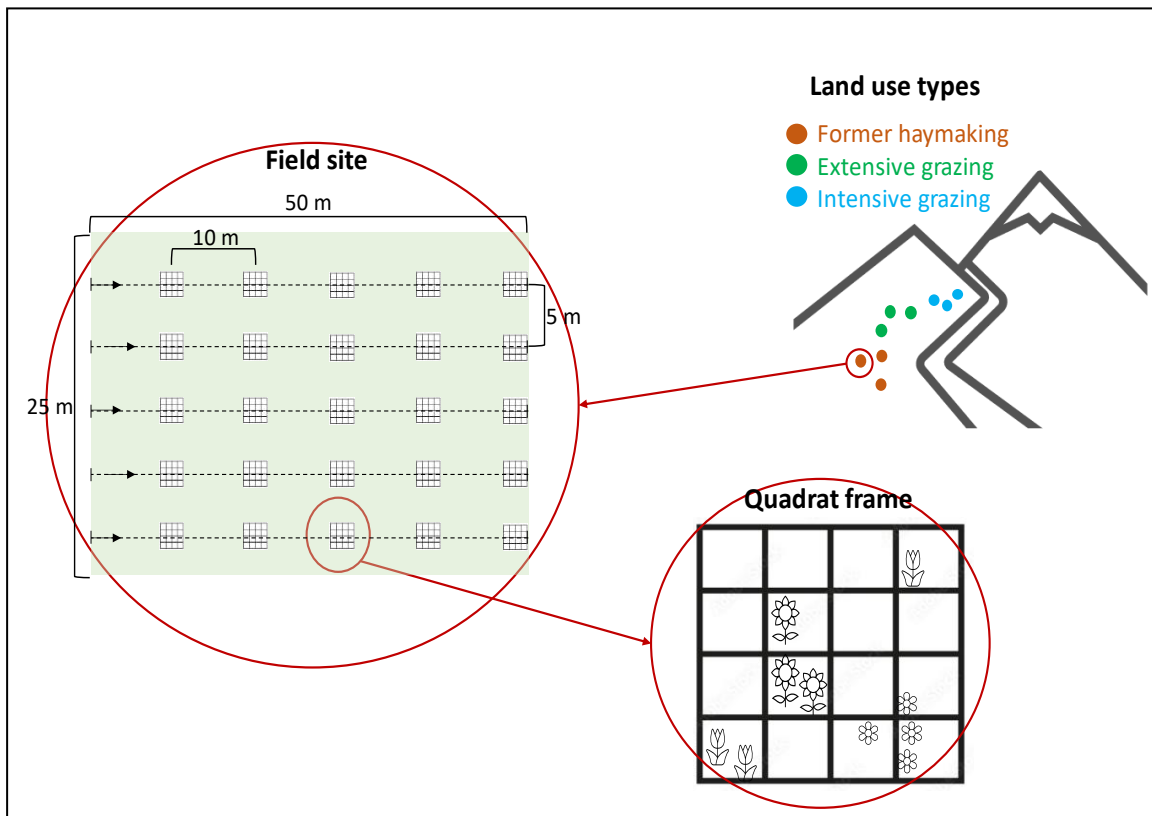
To include the whole pollinator season as well as both before and after grazing, the study was done in three rounds throughout the summer of 2023. Starting in June (18.-21.), then July (07.-10.) ending in August (01.-03).

#### 2.2.1 Sampling area

To get three different types of semi natural grassland representing different land use, I chose to use the land use types called "former haymaking" (FH), "extensive grazing" (EG), and "intensive grazing" (IG) shown in Figure 1. The coordinates for all sites are shown in Table 1. FH are areas that previously have been used for haymaking until the 1950s, but then later been abandoned and turned into birch forests (Austrheim, Gunilla, et al., 1999).



**Figure 1:** Map over Budalen (10°33′–10°41′ E and 62°42′62°48′ N) (Austrheim, 2015, s. 81–114). Black rectangle marks the study area, containing all study sites shown as colored rectangles where orange = FH, green = EG, and blue = IG. The study area is located between Skarpmoen and Bakkvollen.



**Figure 2:** Study design of with the transects (dashed line) and quadratic frames (squares).

These areas are visited by some sheep, but due to the long distance to the farms, the grazing pressure is very low. EG areas are located closer to the farms and therefore used by both cows and sheep for continuous low intensity grazing and staying through the whole season. Areas like this were dominated by trees, but not as dense as in FH, as well as many trampled areas and animal-constructed paths which made them appear wetter than most of the other sites. IG are fenced grassland areas of pasture, close to the farmhouses and have no trees present. These are unavailable for the grazing animals until later in the season when cows are let in. IG is therefore the area with the highest intensity of grazing, although only at certain parts of the season.

### 2.2.2 Data collection of plants in flower

The data from plants in flower was collected by using a quadrat frame (0.5 x 0.5 m containing 4 x 4 sub-quarters) along the transect at every 10 m interval, as shown in Figure 2. Any ramet of plant in flower, one or several, within one of the 16 sub-quarters was counted as one observation of this species. When covering several sub-quarters, the number of sub-quarters covered, was the number of observations of that species of plants in flower. If possible, all flowering plants were identified down to species or genus level.

### 2.2.3 Data collection of pollinators and interactions

To ensure representative pollinator observations, all fieldwork concerning pollinators was limited to between 10.00 and 16.00, only on sunny/partly sunny days with minimal wind and a temperature above 15°C. The diverse mountain conditions, combined with minimal or no phone connectivity and a restricted timeframe, posed challenges in keeping up with all restrictions, but despite a few cloudier days, no restrictions were skipped.

The pollinator data was recorded by walking along the 50 m long transects observing 2.5 m out from the transect on both sides. All pollinators observed were noted in the sheet in Appendix B. Most of the *Bombus* and *Papilionidea* were identified down to species level, but when not possible they were registered as *Bombus sp.* or *Papilionidea sp.* Due to some difficulties differentiating between some *Bombus* species, some were grouped together. Other pollinator taxa such as hoverflies, moths, honeybees, and stinging wasps were only registered at the taxonomic levels *Syrphidae*, *Heterocera*, *Apis*, and *Vespidae*.

Plant-pollinator interaction was defined as a pollinator sitting on the flower of a plant. This means that every interaction registered was a visitation from a pollinator with a chance of pollination. Every interacting pollinator and plant individual observed within 2.5 m on both sides of the transect was registered. This was noted down meanwhile doing the pollinator observation.

## 2.3 Statistical analysis

All analyses were conducted in the R-environment version 4.3.1. Base R and the package "*ggplot2*" were used for general visualizing of the data. When analyzing the effect of different variables on species richness and abundance of the plants and pollinators, it was fitted a *lm* or *glm*, assuming a negative binomial distribution. NMDS ordination was used for looking at the plant community composition. For visualizing the plant-pollinator interactions, "*plotweb*" from the package "*bipartite*" was used. Here, all 3 moths of field work were nested within every site due to too few interactions in each period. Then, the network parameters "connectivity" and "links per species" were calculated for all pollination networks to check for significance. "Links per species" is defined as the mean number of links per species (qualitative) and give us the level of specialization or generalization of the network. The higher the value, the more specialized it is. The "connectivity" measures the proportion of realized interactions out of all possible interactions within the network and thereby provides an indication of the density of each network and how well it is connected. A high value indicates a dense network with more interactions (Blüthgen et al., 2006).

## 3 Results

### 3.1 Plants in flower – richness and abundance

#### 3.1.1 Plants in flower – species richness

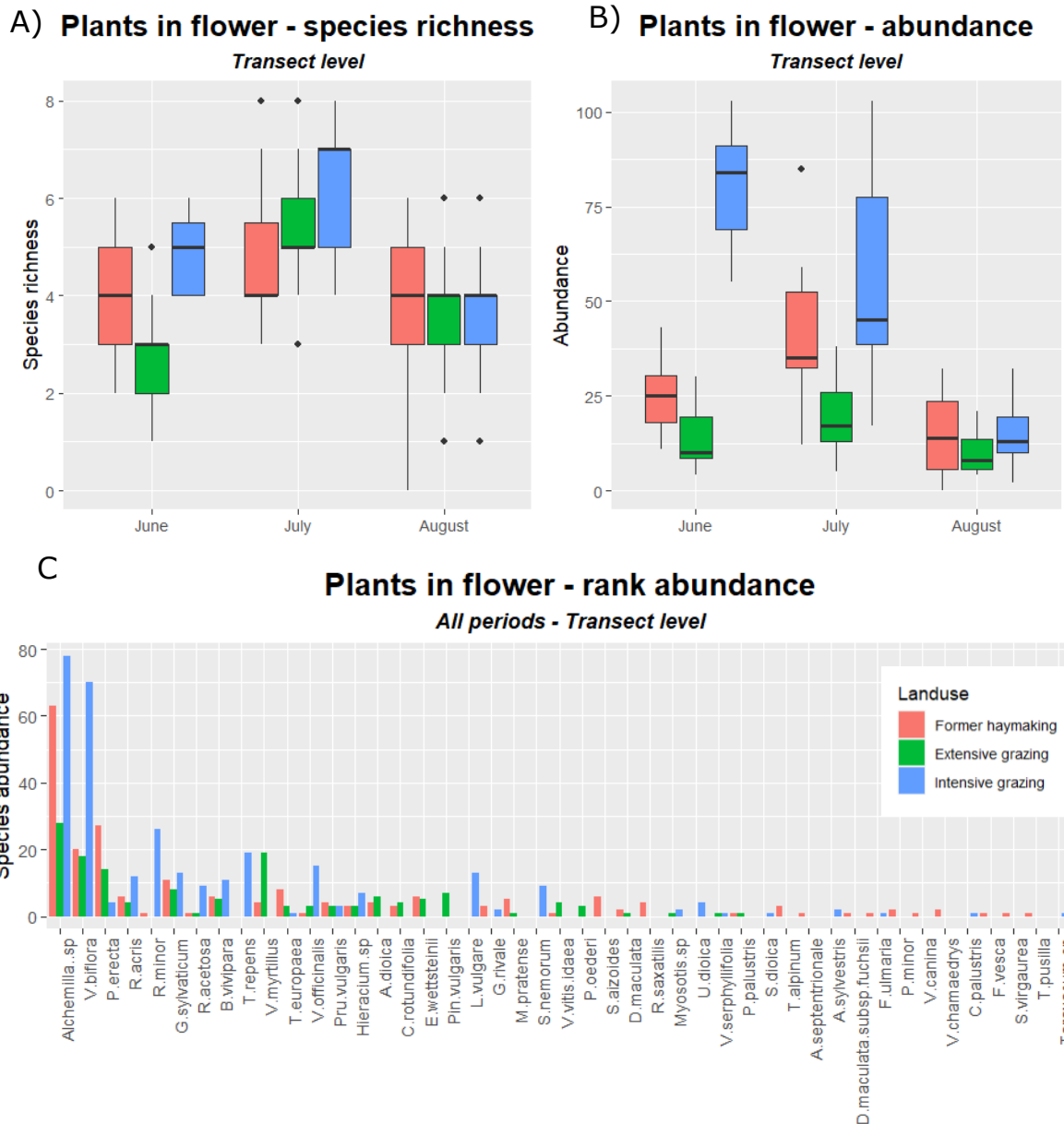
There were registered 46 species of herbs in flower in total: 33 in FH, 23 in EG, and 25 in IG. 22 species were exclusive to one type of land use, 13 were shared between several land uses, and 11 species were found in all three land uses (Appendix A). In June, there were registered 19 species, 27 in July, and 20 in August. Out of them, 11 were exclusive to June, 10 to July, and 8 to August. *Alchemilla sp.*, *R. acris*, and *A. dioica* were present throughout the whole season (Appendix A).

It was found a significant difference in the richness between all the land use types, both with and without the interaction of time, always with transect nested within the sites (chi-square = 18.276, df = 4, p = 0.001, Appendix A). Species richness at the transect level for all the sites throughout all seasons is shown in Figure 3a. IG peaked in July having a median of 7 (IQR 5-7) species present and EG with 5 (IQR 5-6). FH had little variation throughout the season, with a constant median of 4 (IQR 3-5.5) with some variation in standard deviation.

#### 3.1.2 Plants in flower – abundance

It was found a significant difference in the abundance of plants in flower between the different land uses, both with and without the interaction of time, but always keeping transects nested within sites (chi-square = 44.305, df = 4, p < 0.001, Appendix C). At the land use level in all seasons together, the abundance of plants in flower was 2268 for IG, 1231 for FH, and 650 for EG (Appendix A). At the transect level, this was 5 (IQR 4-6) for IG and 4 (IQR 3-5) for both FH and EG. (Appendix A). Throughout the season IG had the highest abundance in June, at 84 (IQR 69-91) but decreased drastically through the summer, as the grazing started. FH and EG peaked in June, FH at 35 (IQR 32.5-52.5) and EG at 17 (IQR 13-26) but FH was constantly a bit above EG (Figure 3b).

Figure 3c shows that *Alchemilla sp.* was the most abundant group for all land uses, even though it has to be mentioned that this is only at genus level, not species as most of the others in this figure. This was followed by *V. biflora*, *V. myrtillus*, *P. erecta*, and *R. minor* as the most abundant. More details about the abundance and species richness of plants in flower can be found in Appendix A.



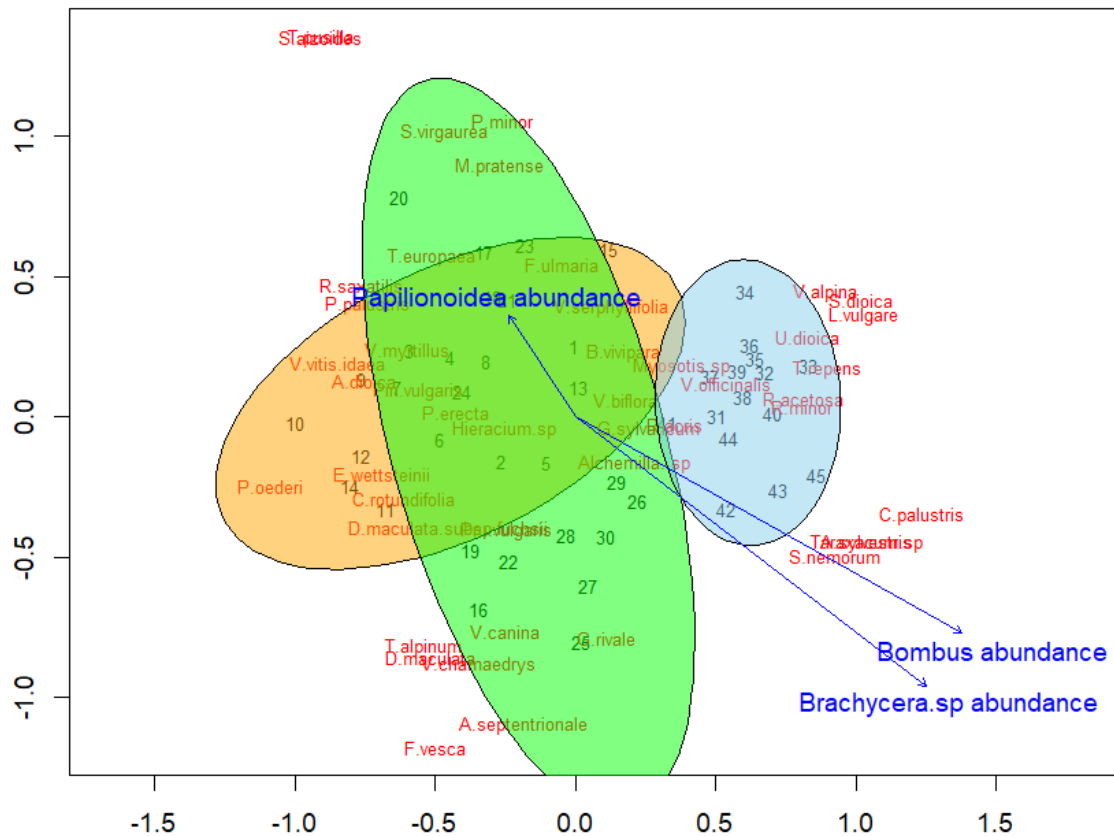
**Figure 3:** Mean flower species richness (A) and mean flower abundance (B) across the land use types, Former haymaking (FH), Extensive grazing (EG), and Intensive grazing (IG) for each month. Error bars represent standard error. Figure C shows rank-abundance for flowering species abundance for all species

### 3.1.3 Plants in flower – composition:

As Figure 4 shows, the plant communities in FH and EG are overlapping, and IG is almost totally separated from them. This shows that the plant composition is significantly different from IG to the other land use types, containing amongst others *C. palustris*, *L. vulgare*, *S. dioica*, *V. alpina*, *Taraxacum sp* and *A. sylvestris*, that were only found here. It showed that *P. oderi* was most connected to FH only, while species such as *F. vesca*, *A. septentrionale*, *P. minor*, *S. virgaurea* and *M. pratense* for EG only.



The stress, which represents the amount of distortion that happens when taking highly dimensional data and combine it into two dimensions, is 0.200. The vectors with each their r<sup>2</sup>-value, represents the correlation between each variable and the difference between the land uses, and indicates that there is a significant effect of the abundance of *Bombus* (r<sup>2</sup> = 0.302), *Brachycera* (r<sup>2</sup> = 0.303), but not for *Papilionidea* (r<sup>2</sup> = 0.023).



**Figure 4:** Ordination plot of sites (Former haymaking (FH) = yellow, Extensive grazing (EG) = green, Intensive grazing (IG) = blue) and plant species (red) along a non-metric multidimensional scaling (NMDS) with axis 1 (MDS1) and 2 (MDS2). The vectors show the abundance of *Papilionidea*, *Bombus* and *Brachycera.sp*, and the length represents the value of r<sup>2</sup>.

## 3.2 Pollinator species and abundance

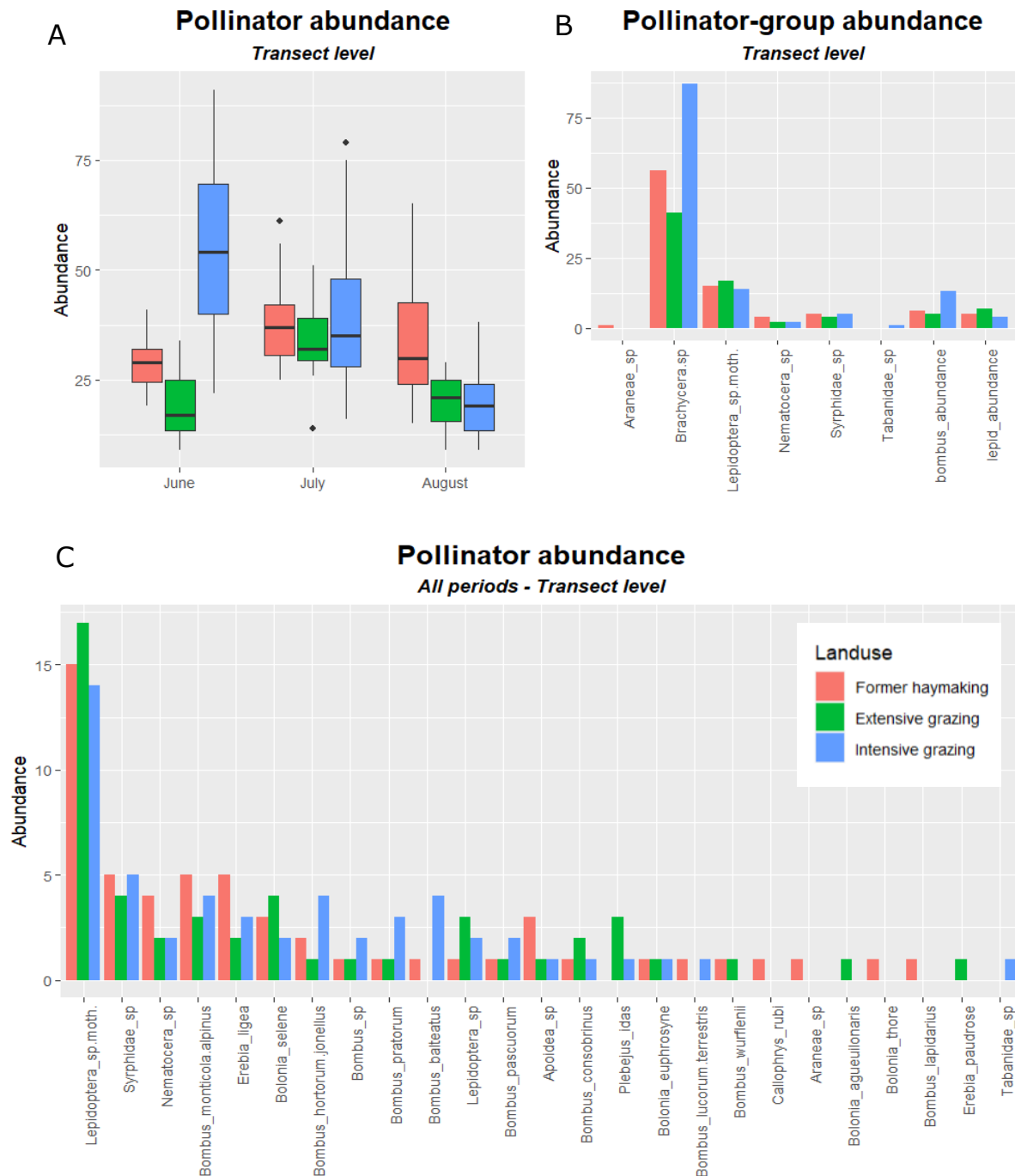
### 3.2.1 All pollinators

In total, 4340 pollinators were registered: 1730 in IG, 1500 in FH, and 1110 in EG. *Bombus* included 178 individuals from ~9 species, and 86 *Papilionidea* individuals from 8 species. It was registered 9 *Bombus* species in FH, 7 in IG, and 6 in EG. For the *Papilionidea*, 7 were registered in EG, 6 in FH, and 5 in IG. IG had the highest abundance of *Bombus* and all pollinators as well as *Bombus*, but the lowest abundance and species richness of *Papilionidea*. EG had the highest species richness of *Papilionidea*, but the lowest *Bombus* abundance and species richness as well as pollinator abundance in total (Appendix B). At some sites and seasons it was also recorded individuals of various *Brachycera*, *Syrphidae*, *Apis*, and *Araneae* (Appendix B).

It was found a significant difference in the pollinator abundance between the land uses, both with and without including the interaction of time, always nesting transect within site (chi-square = 71.123, df = 4,  $p < 0.001$ , Appendix C). The pollinator abundance estimated as flower visitors throughout the seasons, is shown in Figure 5a. IG started with the highest pollinator abundance with a median of 54 (69.55/40) but decreased for every month, ending with the lowest abundance at 19 (IQR 13.5-24) in August. FH and EG peaked in July. FH with a median of 37 (IQR 30.5-42) and EG with a median of 32 (IQR 29.5-39). They had the same seasonal change, but FH was always rising a bit above EG in number (Figure 5a).

As Figure 5b shows, a big part of the observed pollinators are *Brachyceans*. Apart from *Brachycera*, moth and *Bombus* were highly abundant, both peaking in abundance in July. The *Papilionidea* increased in number every month, but there was a change in the species present throughout the season (Appendix B). Changes in their abundance throughout the season and in the different land uses are shown closer in Appendix B.

The flies are important to include in the data, but they also make up a big percentage of the total observations. Therefore, the same calculations and plots were also made for pollinators excluding *Brachycera*. When excluding them, all land uses decreased in pollinator abundance, IG the most as *Brachycera* abundance was extremely high there. There was still a significant difference between the land uses when including time, but not without (Appendix B).



**Figure 5:** Pollinator abundance (A) across the land use types, Former haymaking (FH), Extensive grazing (EG), and Intensive grazing (IG), in different seasons. Error bars represent standard error. Pollinator group abundance (B). Figure C shows rank-abundance for pollinator group abundance for all groups across the

### 3.2.2 Bombus

There was a significant difference in the *Bombus* abundance between the land uses without time interacting but transect nested within site (chi-square = 10.315, df = 2, p = 0.006, Appendix C), but not when including time (chi square = 8.295, df = 4, p = 0.081, Appendix C). *Bombus* species richness gave the same results regarding significance with (chi-square = 6.138, df = 4, p = 0.190, Appendix C) and without time interacting (chi-square = 8.004, df = 2, p = 0.018, Appendix C).

When looking at the total numbers from the table in Appendix B, the total abundance started on 4 individuals in June, peaked at 103 in July, and then decreased to 62 in August. When grouped by land use, IG had the highest abundance of 91 in total, compared to FH which had 46, and EG with 32. The total species richness increased every month, starting at only 2 species in June, 7 in July, and 8 in August. 9 were registered in FH, 7 in IG, and 6 in EG. *B. lapidarius* were only found in FH, *B. wulflenii* were not found in IG, and *B. balteatus* and *B. lucorum/terrestris* were not in EG.

### 3.2.3 Papilionidea

For the *Papilionidea*, the abundance increased every month, so the drop was never registered. In total, FH had the highest abundance with 32 individuals, followed by EG with 31 and IG with 23. The total species richness was not that varying, showing 7 species in EG, 6 in FH, and 5 in IG, even though the composition had big changes. For all land uses, *E. ligea* and *B. selene* were the most numerous, but dominating in different months. *B. euphrosyne*, *E. ligea* and *B. selene* were present in all land uses. *C. rubi* and *B. thore* were only found in FH, and *B. aquilonaris* and *E. paudrose* were only in EG (Appendix B).

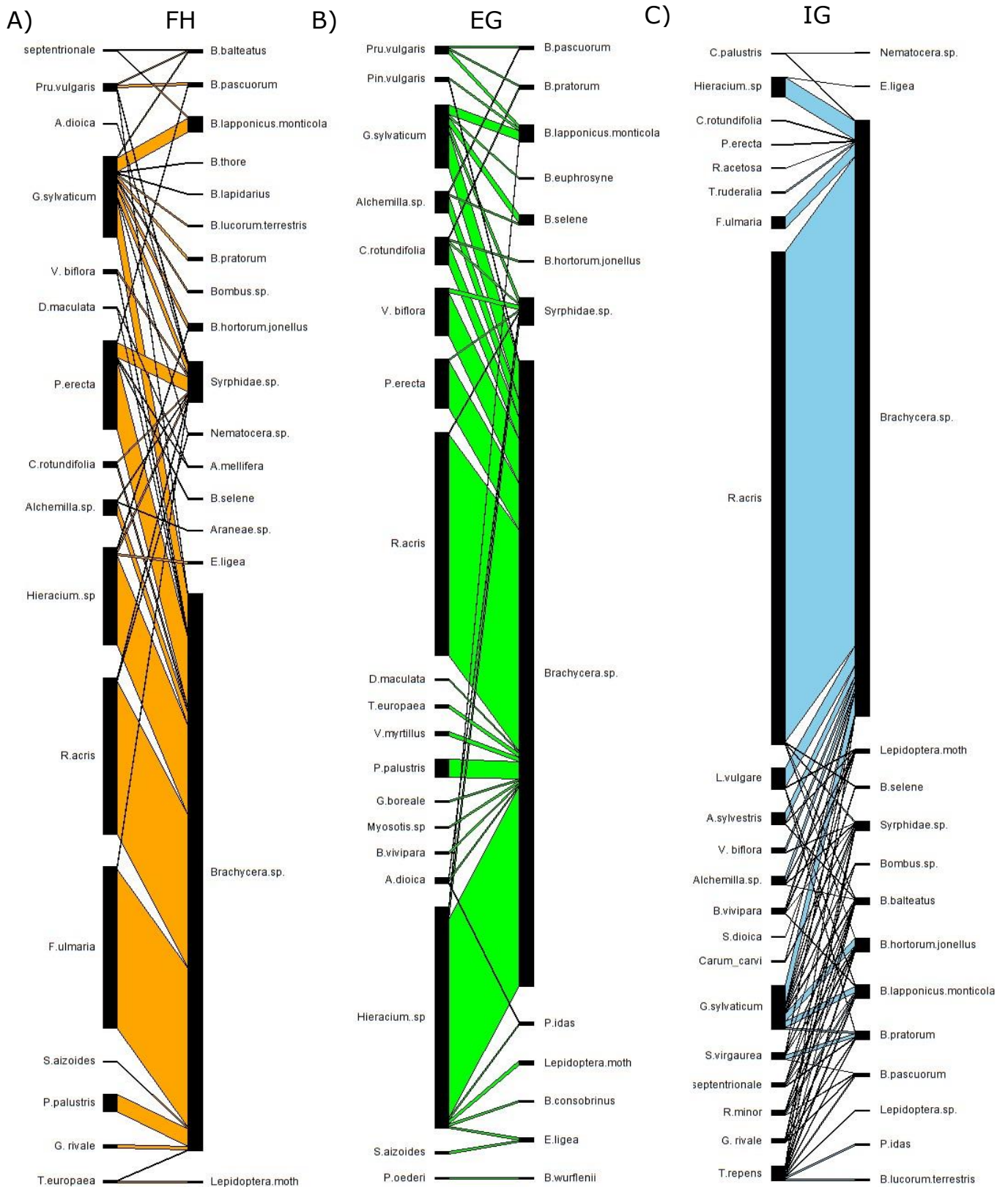
## 3.3 Plant-pollinator interaction network

In total, *R. acris*, *Hieracium sp.*, *G. sylvaticum*, *F. ulmaria*, and *P. erecta* were the most visited plants. *Brachycera* was by far, the most interacting pollinator, mostly interacting with *Ranunculus acris* (buttercup) and *Hieracium* (Figure 6). To get a better view of the rest of the pollinators, there is an interaction web excluding the *Brachycera* in Appendix D. *Syrphide* was the second most registered visitor to the flowers, mostly interacting with *G. sylvaticum*, *P. erecta*, and *Hieracium amongst* others (Figure 6).

The flowers most visited by *Bombus* were *G. sylvaticum*, *P. vulgaris*, *Hieracium sp.*, *C. rotundifolia*, *T. repens*, *A. septentrionale*, *S. virgaurea*, *R. minor* (Figure 6). *G. sylvaticum* was the most visited in all three land use types, while the species further down varied more between the different land uses. Among the three land uses, the interaction was most complex in IG, and least complex in EG. FH and IG shared the same 7 *Bombus* species. EG had 6 species, but the two species *B. consobrinus* and *B. wulflenii* were not present in FH and IG (Figure 6).

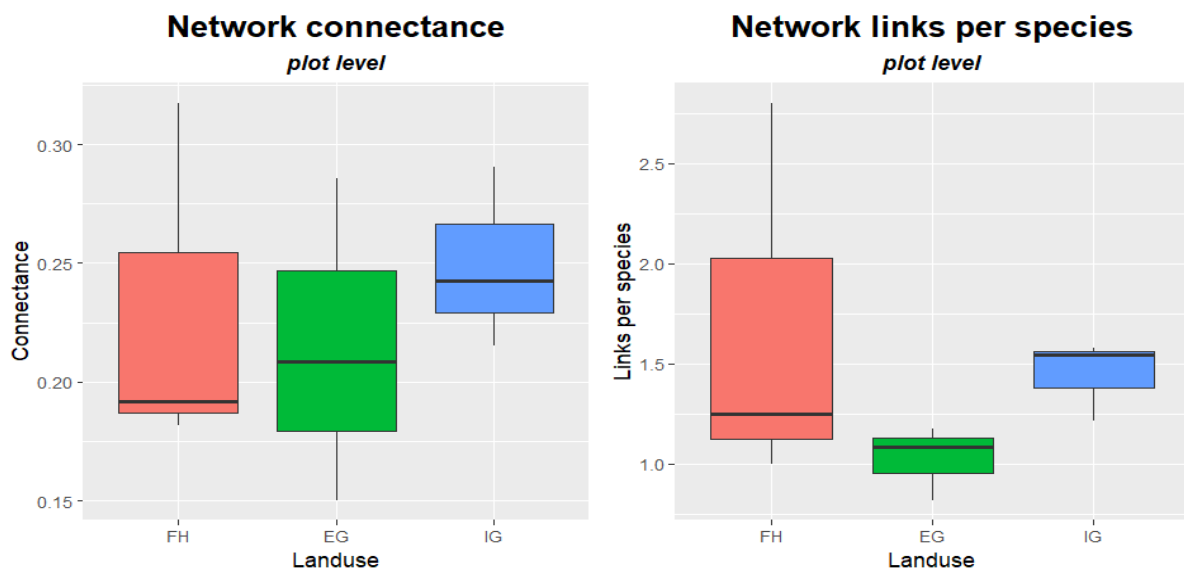
The flowers most visited by *Papilionidea* were *Hieracium sp.*, *P. erecta*, *G. sylvaticum*, and *Trifolium repens*. In FH, *Hieracium* was the most visited, *T. repens* was the most visited in IG, and *G. sylvaticum* was by far the most visited in EG. There was little interaction in general, but EG had 4 interacting *Papilionidea* species while IG and FH had 3.

*B. selene* and *E. ligea* were found interacting in all land uses, while *B. thore* were only found interacting in FH, *B. euphrosyne* only in EG, while *P. idas* not in FH (Figure 6). Among the other pollinators, excluding *Papilionidea*, *Bombus* and *Brachycera*, *G. sylvaticum*, *P. erecta*, *Hieracium sp.*, and *V. biflora* were the plants most visited (Figure 6).



**Figure 6:** Interaction networks for pollinator groups and plants in flower for former haymaking (A), extensive grazing (B) and intensive grazing (C) with all field periods summarized.

The web analysis was made with all 3 field seasons grouped within land use, just as the web itself. With a value of 0.243 (lower = 0.229, upper = 0.267) IG had the highest connectance, while FH has 0.192 (lower = 0.187, upper = 0.255) and EG has 0.208 (lower = 0.179, upper = 0.247) (Figure 7). For the links per species, IG has a value of 1.545 (lower = 1.381, upper = 1.561), followed by FH at 1.250 (lower = 1.125, upper = 2.026) (Figure 7). More information can be found in Table 2. For the web excluding *Brachycera*, the result was not that different, except that "links per species" decreased for all land uses and the differences within FH got smaller (Appendix D).



**Figure 7:** Plotted network indices of connectance and links per species from interaction network for the different land uses. Former haymaking (FH), Extensive grazing (EG), and Intensive grazing (IG).

## 4 Discussion

This study aims to investigate the effects of three different land use types on the interaction between flowering plants and their pollinators. Abundance and species richness of plants in flower, pollinator abundance, and their interactions were studied in Budalen through 3 field periods over the summer 2023. I looked at 3 different land use areas of seminatural grassland named; "former haymaking" (FH), "extensive grazing" (EG) and "intensive grazing" (IG), which were all parted into 3 sites each.

### 4.1 Flowering plant abundance and species richness

#### 4.1.1 Flowering plant abundance

There was a significant effect of land use on the abundance of flowering plants, which supports hypothesis 1b. IG had the highest abundance in early, and mid-summer before drastically decreasing when grazing started. FH and EG had only slight differences, peaking in July, but FH was a bit higher all summer.

The lack of trees and shrubs in IG due to the grazing, made the area open and sunny with low stress level until the gazing started. This high availability of sunlight makes it an area supporting a high plant abundance in early summer, which was also shown in the results, as well as others research (Dormann et al., 2020). This also goes the opposite way, as there were more trees in FH and EG, allowing less sunlight to reach the forest floor and therefore less energy supporting a lower abundance.

Grazing intensity is also associated with less flowering plant resources and lower plant recruitment due to the direct removal of parts of the plant (Eldridge et al., 2016; Tadey, 2015; Wissman, 2006). This coincides with the results of FH having consistently very low grazing intensity and a relatively even low abundance throughout summer. The same applied to EG where there was more grazing, though still consistent, resulting in an even abundance, but lower than FH. IG, on the other hand, experienced no grazing until late summer, leading to high abundance initially, followed by a sharp decline by the end of summer. The presence of big herbivores is also known to decrease plant abundance by trampling the area (Augustine & McNaughton, 1998; Côté et al., 2004; Jefferies et al., 1994). This can then help explain the lower abundance in EG, as there were cows in EG and only a few sheep in FH, giving a lower grazing pressure. The high abundance of plants makes IG a very important energy source for pollinators in the early and mid-part of the summer. The grazing prevents reforestation by removing the sprouting trees, but it also decreases the abundance of flowering plants drastically when present. Therefore, IG areas have both pros and cons for the abundance of flowering plants.

The site named IG3 was never grazed during this study due to the owner selling the farm. Here, the plant abundance was higher than the two others in August after grazing onset. This highlights the effects of grazing on flowering plant abundance, even in late summer, which is supported by the papers from Tadey (2015) and Wissman (2006).

#### 4.1.2 Flowering plant species richness and composition

The flowering species richness was significantly affected by land use, supporting hypothesis 1a. Still, the significance was only present between some of the land uses, as well as none in August. This may be because there were only slight differences between them. Throughout the summer, IG always had the highest species richness. The confidence interval was much bigger for EG than IG and FH. Species composition was

significantly different between IG and the two other land uses, which partly supports hypothesis 1c concerning different species composition for the different land uses.

Even though IG had the highest richness of plants in flower when looking throughout the season, the differences were small. But, when grouping all months, FH had the highest and EG the lowest (Appendix A). This means that FH had more change in species composition than IG during the season, thus supporting a higher number of different species than IG throughout the summer. This may be because of a bigger variety of niches and microclimates in FH than in IG. This is also supported by the results for the flowering plant composition, which will be more discussed later.

22 of the 46 registered species that were registered in total across all land uses and all field periods were specific to a certain land use type. 9 in IG, 11 in FH, and 2 in EG. This states the importance of heterogeneity in the land use types within an area to maintain the presence of all plant species. IG was very different from EG and FH regarding the composition. This can imply that when grazing ceases over a longer time, species such as *S. dioica*, *L. vulgare*, *C. palustris*, and *S. nemorum* will eventually disappear since they were highly connected to only this one land use type. Even though these species were not found to be most visited by pollinators, they can still be important for the ecosystem.

It is known that light availability affects the vegetation composition of an area (Bohner et al., 2019; Gilhaus et al., 2017), and that an increasing cover of trees has a negative effect on the total species richness (Pykälä et al., 2005). Both FH and EG had trees that covered parts of the forest floor with shadow, which IG did not have at all. This may help explain the common plants shared between FH and EG. Others have found that light availability is positive related to plant species richness (Dormann et al., 2020), which also aligns with IG having the highest species richness. However, it is important to say that the effect of tree density on field layer composition is complex. In addition to casting shadows, trees also reduce the nutrient level and lower the water table, which also affects what plants find these areas favorable.

A higher number of habitat types and environmental gradients within an area should increase the amounts of different niches available, thereby allowing a higher species richness (Austrheim, Ollson, et al., 1999; Stein et al., 2014). The areas of IG were very homogenous in structure as everything was flat and open terrain. This gave fewer varying niches, supporting less varying plant species to thrive. FH and EG had more variation in light availability and steepness, and moisture within, which then supported a higher species richness within these land use types.

What herbivore species are present can also affect the composition of plants in an area (Eldridge et al., 2016; Milberg et al., 2020; Socher et al., 2013). At FH it was a few grazing sheep, while FH and IG had mostly cows of different ages. Cows and sheep are different in the way they eat as well as in body weight, making them affect the plants and soil differently. For example, the sheep are a more selective grazer than the cow, and the cow is way heavier, giving more impact on the ground it treads on (Abaye et al., 1997). A lower grazing pressure is also known to alter the plant composition by giving an increased species diversity (Dorrough et al., 2012; Lunt et al., 2007).

All flowering plants that were registered in this study, are grouped as LC in the Norwegian red list (Artsdatabanken, 2021a), and common all over Norway. Still, other studies have found threatened species in the same area. Tretvik et al., (2015) did



register *Primula Scandinavica* which is assessed as NT, and *B. multifidum* which is assessed as threatened VU, whereas both are associated with semi-natural grasslands and mainly threatened by the overgrowing of these areas (Solstad et al., 2021a, 2021b). In addition, Austheim et al (1999) found *G. campestris* and *G. conopsea*, which were then decreasing in abundance, but both are now registered as LC.

## 4.2 Pollinator abundance and species richness

### 4.2.1 All pollinators

The pollinator abundance showed a significant effect of land use. IG had the highest abundance, followed by FH and then EG. This can be linked to flowering plant abundance as pollinators rely on the presence of flowers as a food resource, therefore one working positively on the other (Fontaine et al., 2005; Roulston & Goodell, 2011; Winfree et al., 2011)

*Brachycera* and *Heterocera* were the most abundant out of all pollinator groups. Even though this may be because they are more species-rich groups than *Bombus* and *Papilionidea*. Their high abundance supports their function as pollinators due to their high number, despite their low efficiency (Rader et al., 2016; Willmer, 2011).

In addition to flowers, many pollinators also rely on trees and shrubs at certain life stages for resting or shelter (Doyle et al., 2020; Ødegård et al., 2014; Semb-Johansson & Paus-Knudsen, 2023). IG areas had sparse vegetation and would therefore not fulfill these needs from the pollinators without the surrounding other areas. This again highlights the importance of heterogeneity in land use types for an area, to support the presence of these pollinators.

### 4.2.2 *Bombus*

There was a significant effect of land use on the *Bombus* abundance when not including time. They were most abundant in IG and least in EG and peaked in July for all. The species richness was highest in IG and lowest in EG, but the difference was rather small. Neither was the composition. These results are supported by others finding that *Bombus* species richness and abundance were significantly higher in managed meadows (Walcher et al., 2017) and that both their abundance and species richness was positively correlated with flowering plant abundance and richness (Åström et al., 2019; Fründ et al., 2010; Walcher et al., 2017).

*B. lapidarius* was only registered in FH, but apart from that, all other 8 species were present in several land use types. This shows that the presence of each specific *Bombus* species does not depend strongly on a certain type of these three land uses, but rather the number of flowers in them. Furthermore, this is also supported by most of them being generalists.

Even though *B. monticola* and *B. alpinus* were grouped due to difficulties identifying them, they were by far the most abundant group in all land uses. *B. pratorum*, *B. hortorum/jonellus*, and *B. balteatus* were all some of the most abundant species in all land use types, with the highest abundance in IG. This again shows the importance of IG areas, even though the presence of FH and EG do increase the *Bombus* diversity.

*Bombus*, like many other pollinators, often makes nests in old wood structures, which was only present in EG and FH. Others have found that non-managed meadows that are at the start of becoming overgrown, are favored by *Bombus*, as they are then relatively

open but at the same time include good nesting sites (Söderström et al., 2001; Svensson et al., 2000).

*B. consobrinus* is known for being adapted to feed on the *A. septentrionale* but was never observed feeding on it. Several other *Bombus* species were interacting with this plant. This may be due to the low number of observations in general, which makes the results less representative for all possible interactions between *Bombus* and flowering plants.

When looking at both abundance and species richness spread over each field period, the differences between land use were very small. The low amount of data may explain why the results weren't significantly different.

#### 4.2.3 Papilionidea

The *Papilionidea* abundance was mostly the same in FH and EG, but lower in IG, while the species richness was highest in EG and lowest in IG, but only with slight differences. The seasonal abundance showed that their activity was low in June and then increased throughout summer, while no decrease was registered. This is probably because it happened after my last field round. Together with a change in species abundance throughout the summer, it implies that some of the species rely more on late-blooming flowers and others on early-blooming ones.

The low abundance in IG, can be explained by the grazing onset. As the abundance increased every month, the grazing of IG destroyed its resource availability in parts of the summer (Åström et al., 2019). Many *Papilionidea* also depend on vegetation such as trees and bushes in the larval stage, which makes them dependent on several nature types during their life.

In accordance with the literature, the species composition was different between the land use, highlighting their specialized nature (Elven et al., 2021).

In total, the most abundant species was by far *E. ligea* and *B. selene*, while *P. idas* comes third. The rest were only in low numbers. The same abundance-patterns in species are found by others as well (Åström et al., 2019). It was also a clear change in species activity throughout the summer. *Apoidea* and *B. selene* were most active in early summer and both were most abundant in FH. Late summer, *P. idas* and *E. ligea* had the highest abundance, whereas *P. idas* was most abundant in EG and *E. ligea* stayed in FH mostly. It is hard to tell if the late summer species did not use IG areas because of the lack of resources after grazing, or if it is just not their preferred habitat. This can be an interesting topic for later research.

*E. pandrose* and *B. aquilonaris* were only found in EG. These are species that are common in all of Norway (GBIF Secretariat, 2023d, 2023a) and are active from June to September (GBIF Secretariat, 2023d, 2023a). This coincides with both being found in June. *E. pandrose* is known for staying in open forests as well as alpine areas, having a larva that eats different grass types (GBIF Secretariat, 2023d). *B. aquilonaris* is more common in swamps and alpine areas and its larva depends on *V. oxycoccus* (GBIF Secretariat, 2023a). These are characteristics that overlap with those for EG areas concerning the presence of trees as well as wet areas as well as being located a bit higher than FH and IG. Even though not registered in my results, *V. oxycoccus* is a species known for growing in moist alpine areas (Simonsen & Nyléhn, 2022), and both *Festuca* and *Poa* are found in all types of nature types in Norway (Store norske leksikon,

2023, 2024). This makes these two species highly fitted for the EG areas, and less for FH and IG.

*C. rubi* and *B. thore* were only found in FH. They are both fairly early active whereas *C. rubi* is active from May to end of June (GBIF Secretariat, 2023c, 2023b), and was found in June, while *B. thore* is active from end of June to July (GBIF Secretariat, 2023b), and was found in July. *C. rubi* is common for the whole of Norway, but not that much in alpine areas (GBIF Secretariat, 2023c). As a larva, it depends on various types of berries, while as a grownup it eats *Rubus*, *V. uliginosum*, and *Trifolium* (GBIF Secretariat, 2023c). *Rubus* was only in FH, and different berries were found in both FH and IG, but species of *T. repens* were only found in IG. This makes it best fitting for FH and IG. *B. thore* is a species that is very local and rare in Norway, as individuals have only been found in Sør-Trøndelag, some in Nordland, and Troms and Finnmark (GBIF Secretariat, 2023b). It is known for staying in the birch belt, where the larva depends on *Viola*, especially *V. biflora*, while *G. sylvaticum* as an adult (GBIF Secretariat, 2023b). Both FH and EG lay in the birch belt, and both *V. biflora* and *G. sylvaticum* were found in all land use areas, although the last one less in EG. *B. thore* should therefore be best fitting to both FH and EG. Since there were only found 3 individuals of these two species, it is also important to not rely too much on the registrations when looking at their preferred habitat.

*P. idas* was found in both EG and IG. This is a species that is common for the whole of Norway (GBIF Secretariat, 2023e), and lives in both grassland, forest, swamp, and alpine areas (GBIF Secretariat, 2023e). It is active from the end of June to September and was found in August. It is known to rely on both *Vaccinium uliginosum* and *Vaccinium oxycoccos* as larva and *Trifolium repens* as grown up (GBIF Secretariat, 2023e). Altogether, this makes it best fitting with IG, but also possible with both EG and FH.

*B. selene*, *E. ligea*, and *B. Euphrosyne* were found in all three land uses, although *B. selene* was a bit less in EG, while *E. ligea* was most abundant in FH and least in IG. Both *Boloria* are flying from June to July while *E. ligea* is from July to September (Artsdatabanken, 2014a, 2014b, 2014c). This coincides with my findings as both *Boloria* were found in July and *E. ligea* in July and August. Both of the *Boloria* species are common in open grasslands and forests as well as alpine areas, but *B. euphrosyne* also for swamps. Both rely on *Viola* as larva (Artsdatabanken, 2014a, 2014b, 2014c). This supports the theory that both the *Boloria* are fitted for all three land uses. *E. ligea* is also told to stay in open grasslands and forest as well as alpine areas, but their larva rely on different types of grass, while as an adult they eat *S. virgaurea* (Artsdatabanken, 2014b) which I only registered in FH. This then supports it being fitting for all land uses, but most for FH.

It also has to be mentioned that even though much of the findings coincide with the theory, it is also important to highlight the low amount of data, which makes it less trustworthy.

### 4.3 Plant-pollinator interactions and interaction webs

The results showed that IG had the most plant-pollinator interactions, while EG had the fewest. By measuring the "linkage per species" and "connectance", I found that IG had the highest value of links per species and connectance, while EG had the lowest links per species and FH had the lowest connectance, supporting hypothesis 3. IG also had the highest abundance and species richness of both plants and pollinators, which can then

impact this, as flower diversity and flower visitor diversity often are positively correlated (Ollerton, 2017).

For the connectance, IG had the highest value, suggesting a greater level of interaction for this land use. EG had a higher median than FH, but both had big confidence intervals, making the difference less confident. This is probably due to the sparse amount of data. The lower value for FH and EG can be both because of fewer species in general and fewer interactions. A higher connectance might suggest a more robust ecosystem in terms of resource availability and redundancy. Conversely, a lower connectance might indicate vulnerability to disturbances or species loss. Yet, it can also be that the high abundance of plants and pollinators in some sites in these areas gives that just by chance, more interactions will be observed.

The calculated value of links per species, showed that IG had the highest value, indicating more generalists, while EG was lowest, indicating more specialists. Having more specialist pollinators in an area supports a bigger variety of flowering plant species and interactions, but it also makes every species more dependent on a few pollinators, and therefore more vulnerable to changes (Willmer, 2011). In this way, the presence of both EG and IG in an area will support the species richness of pollinators and flowering plants through the specialists, as well as assure stability and safety by having generalists. Still, by having more species in total, the "linkage per species" will increase automatically since every pollinator has more flowers to choose between. A higher number of individuals of each species also increases the chances for visitation for every species. This has to be taken into consideration.

The analysis showed that *Brachycera* had the highest level of interaction among the pollinators, followed by *Syrphidae*, both highly interacting with *R. acris*. It's noteworthy that most of the interaction between these two species simply was the insect sitting on the petals. This implies the multifunctional function of the flower for visitors, as pollinators use the flowers not just for getting food, but also for other uses, such as for basking or shelter (Willmer, 2011). This is highly important to take into consideration when looking at all pollinators registered, especially those including *Brachycera*.

Plants such as *T. repens*, *R. minor*, and *L. vulgare* were notably favored by pollinators, particularly in IG. Consequently, a reduction in IG areas would lead to fewer available resources for the pollinators. The most visited flowers in EG were common for all land use types. In FH, *A. spetentrionale* was exclusive for this land use, and *F. ulmaria* was not found in IG. This then states the importance of this variation in land use areas for a good diversity of both flowers and pollinators. Pollinators that depend on these species that are specific to a land use type, would then be negatively affected by the disappearance of any of these land uses, especially IG leading to a change in species composition.

Interestingly, the most popular flowers amongst the pollinators weren't always the most abundant ones. Several other studies have been finding the same (Herrera, 1989; Souza-Silva et al., 2001). This shows the existence of different flower preferences for the different pollinators, also called syndromes. It also states the fact that the most abundant plant in an area is not necessarily the one with the most resources available for pollinators, so plant abundance is maybe not the best way to see the availability of resources (Souza-Silva et al., 2001). It is also important to say that these are interactions found in one summer, and as network structure varies through time (Alarcón

et al., 2008; Dupont et al., 2009), one year of data is not enough to give any clear statements for every link between each species.

There are both generalists and some specialists in the *Bombus* family and different preferences are found for different species (Ødegård et al., 2015; Willmer, 2011). But even though a species is given the nametag of a specialist or generalist, it is also shown that the same species can show generalization and specialization levels at different periods and depending upon the availability of flower resources (Biesmeijer et al., 2006; Fründ et al., 2010; Willmer, 2011). Each *Bombus* species appeared to be more specialized in FH, with many of them interacting with *G. sylvaticum* only. When comparing the most visited plants to their abundance, *G. sylvaticum* is highly abundant in all land uses, implying that this may be visited not only due to preferences but also for it being very accessible. *P. vulgaris* and *Hieracium* were also popular in all land uses but not the most abundant. *A. septentrionale* was only registered as present in FH but was still one of the most visited for both FH and IG. This then tells that those three plant species are highly preferred by the *Bombus*. This is also supported by various studies. Others have found that *G. sylvaticum* is mostly pollinated by *Bombus* and *Syrphids* (Asikainen & Mutikainen, 2005), while *P. vulgaris* is also found to be popular among species of *Bombus* (Brian, 1951; Kuriya et al., 2015). The same was for *Hieracium* (Dramstad, 1995; Ødegård et al., 2014). Even though *A. septentrionale* has a shape allowing only long thunged *Bombus* such as *B. consobrinus* to visit, it is also visited by other *Bombus* that get their reward through nectar stealing (Ødegård, 2022b; Thøstesen et al., 1996).

And as FH was the only land use where *A. septentrionale* was registered, it makes FH a highly important land use for the *Bombus*. As for the other most popular plant species, they are not that connected to a certain type of land use. EG displayed slightly more links per *Bombus* species, while IG had the most, suggesting a higher level of generalized *Bombus* here. However, this can simply be explained by the *Bombus* having a higher number of flowers in IG, leading to more interactions.

*Papilionidea* had just a few recorded interactions, which aligns with their overall abundance, so the results can therefore only be used for making assumptions. The *Hieracium* and *G. sylvaticum* were visited in all land uses. *S. aizodes*, *A. dioica*, and *Alchemilla* were only visited in EG, and *T. repens* and *R. acris* were only in IG. Interestingly, some species that were present in all land uses were only visited by certain *Papilionidea* species. For example, *P. erecta*, *Alchemilla*, and *R. acris* were only visited by *B. selene* even though both this *Papilionidea* and the plant species were present in all land uses. This highlights the presence of flower preference within this species. When looking at the already mentioned preferences of the *Papilionidea* species, *B. thore* was found interacting with *G. sylvaticum* and *P. idas* with *T. repens*, which coincides with the theory.

For comparison, except for *G. sylvaticum* being highly visited by both groups, the most popular plants among *Bombus* were far from the most popular for *Papilionidea*. The lack of overlap therefore increases the importance of each group for spreading the pollen from the flower species. Literature do say that *Papilionidea* and *Bombus* have different preferences when it comes to flowers, but the preferences also vary between and within the species (Aarvik & Elven, 2022; Ødegård et al., 2014; Tiple et al., 2009; Tudor et al., 2004; Willmer, 2011). The results can therefore only give us indications on these preferences.

The focus on semi-natural grassland as an important source for biodiversity is increasing. As land use change such as abandonment and overgrowing of these areas has been recognized as a common threat, research has now started looking closer at this. However, there is a lack of long-term studies. The same accounts for land use change in terms of intensification. When focusing on sub-alpine areas, the amount of research on species abundance and richness decreases drastically, which is worrying as these are areas that are especially threatened due to global warming. Our understanding of how land use change and intensity impacts pollination is still limited, especially when looking at previous history of areas. After finding that some of the plants and pollinators registered in Budalen are seen as rare in Norway, it raises the importance of more study on their abundance here.

## 4.4 Limitations and method

Some of the sites of the three land use types were placed very close to each other, which increases the chance of pseudo-sampling. Especially for IG sites. Due to farming history, the placement of the farms was decided by the landscape and what was best for the people. Therefore, many were placed in the same areas. The same accounts for FH and EG as this followed the placement of the farms combined with the quality of the area. Even though a random spread and distribution of the sites would be the most optimal, this was not possible. This highlights the challenges when working with land use as a driver for biodiversity.

When recording the pollinators, we decided to make the transects cover 5m in total, which I think is too wide to get a representative observation of all pollinators present, as it is too broad to see everything. For later I would recommend having more and narrower transects.

The chance for double sampling a pollinator while walking the transects was big. To prevent this, the best would be to keep the caught insects while doing all transects for each site and then release them. Sadly, the high temperatures gave bad conditions for keeping the pollinator in the jars for too long, so this was not doable. Our knowledge regarding species recognition also increased during our time in the field. Therefore, we kept fewer insects in the jars later in the fieldwork to increase work efficiency. This made the chances of double sampling increase during the summer. Even though the recording of the same individual might be bad for the abundance results, it also might increase the plant-pollinator interactions, leaving more important information and therefore actually aiding the results.

While doing pollinator observations, the weather conditions varied to some extent. This can have affected the results due to higher pollinator activity when full sun versus slightly cloudy or windy. But because of the limited intervals with nice weather, we did not dare to take the risk of waiting for better weather.

It was planned to do 3-4 rounds of fieldwork, but only 3 were done due to bad weather conditions. This did affect our results, as we did not get to record the decrease in the *Papilionidea* abundance and not the grazing onset for all three sites of IG, but it is also a natural consequence of sampling in montane areas, which is hard to plan for.

Some species of *Bombus*, as well as all *Brachycera* and *Heterocera*, were grouped because of difficulties identifying them, which made the results less accurate for the species diversity. This is because we did not want to do any destructive sampling that would allow identification to the species level.

As stated earlier, all pollinators visiting a flower were registered as pollinators, which is not correct. If possible, distinguishing between pollinating insects and just visiting can be recommended for later studies.

## 4.5 Management implications

This study shows the importance of grazing and farming in the mountains for maintaining all the semi-natural grasslands and the environmental diversity that it creates. It suggests a late onset of low-intensity grazing in IG areas for balancing farming productivity with ecological conservation. I would also recommend setting off a portion of the grazing land as an undisturbed refuge for pollinators, either for the season or just for some weeks more than the rest of the area. I would also recommend that FH and EG stay the same. For FH, it is important to leave it as it is, not chopping down the forest or having more grazers to maintain the shadows from the trees as well as the low stress from the absent grazers. Chopping would probably increase the flowering plant abundance but also make the shadow-loving plants disappear, which would decrease its species diversity which we know is important for the pollinators. EG is also important and should just stay the way they are as being used for residence and grazing areas for the cows.



## 5 Conclusion

This study examined the effect of three different land use types on the interaction between flowering plants and their pollinators in Budalen, Norway.

The difference in land use types significantly impacted the richness and abundance of plants in flower, as well as the abundance of pollinators. The species composition of the flowering plants also differed from IG compared to both FH and EG. Regarding the plant-pollinator network, both network connectance and links per species were significantly different for the different land uses.

Given the differences in species composition for both plants and pollinators in all land uses, FH, EG and IG represents different semi-natural grasslands which all contributes to biodiversity at a landscape level. Amongst other, IG contributes with a high abundance of both plants and pollinators, while FH and EG have vegetation which is important for many pollinators in certain life stages. Especially EG and FH are also important for the presence of certain Papilionoidea species.

This emphasizes the value of heterogeneity in land use in an area, as well as the importance of maintaining every single type for preventing the loss of specific species of both plants and pollinators.

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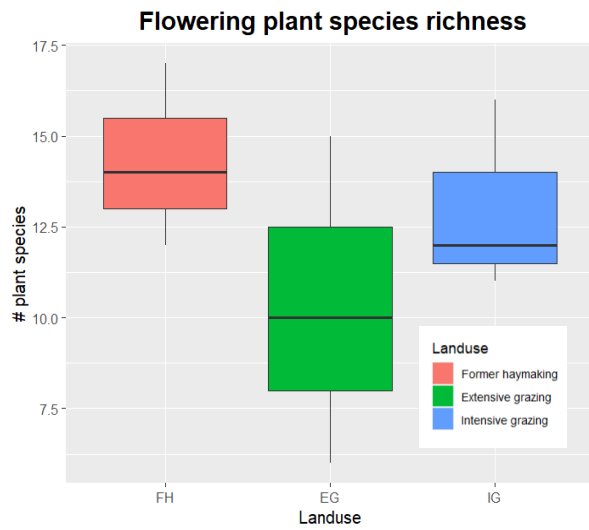
# Appendixes

## Appendix A: Supplementary flower data

Sp. Name	Flowering plant abundance								
	June			July			August		
	FH	EG	IG	FH	EG	IG	FH	EG	IG
Viola biflora	150	122	541	0	0	0	0	0	0
Rubus saxatilis	5	0	0	0	0	0	0	0	0
Geum rivale	4	0	1	6	0	4	0	0	0
Fragaria vesca	1	0	0	0	0	0	0	0	0
Alchemilla sp.	153	20	479	363	126	442	149	58	52
Trientalis europaea	26	7	1	0	8	0	0	0	0
Ranunculus acris	7	1	94	25	15	59	1	0	0
Thalictrum alpinum	3	0	0	0	0	0	0	0	0
Viola canina	2	0	0	0	0	0	0	0	0
Vaccinium myrtillus	12	45	0	0	0	0	0	0	0
Antennaria dioica	4	0	0	0	21	0	0	4	0
Geranium sylvaticum	14	0	42	37	18	37	0	0	0
Pedicularis oederi	0	7	0	0	0	0	0	0	0
Rumex acetosa	0	0	41	1	1	69	0	0	0
Silene dioica	0	0	2	0	0	1	0	0	0
Urtica dioica	0	0	4	0	0	0	0	0	0
Veronica alpina	0	0	1	0	0	0	0	0	0
Taraxacum sp.	0	0	1	0	0	0	0	0	0
Caltha palustris	0	0	1	0	0	0	0	0	0
Potentilla erecta	0	0	0	161	71	4	15	5	0
Hieracium sp.	0	0	0	5	0	8	5	14	1
Tofieldia pusilla	0	0	0	1	0	0	0	0	0
Melampyrum pratense	0	0	0	11	1	0	0	0	0
Veronica chamaedrys	0	0	0	2	0	0	0	0	0
Dactylorhiza maculata subsp. Maculata	0	0	0	2	0	0	0	0	0
Dactylorhiza maculata	0	0	0	3	2	0	0	0	0
Pyrola minor	0	0	0	2	0	0	0	0	0
Vaccinium vitis-idaea	0	0	0	1	9	0	0	0	0
Bistorta vivipara	0	0	0	6	2	37	0	24	38
Rhinanthus minor	0	0	0	1	0	159	2	0	3
Aconitum septentrionale	0	0	0	1	0	0	1	0	0
Veronica serpyllifolia	0	0	0	0	2	2	0	0	0
Pinguicula vulgaris	0	0	0	0	21	0	0	0	0
Myosotis sp.	0	0	0	0	1	3	0	0	0
Prunella vulgaris	0	0	0	0	1	3	18	13	4
Trifolium repens	0	0	0	0	0	6	0	0	64
Leucanthemum vulgare	0	0	0	0	0	1	0	0	15
Stellaria nemorum	0	0	0	0	0	1	0	0	9
Euphrasia wettsteinii	0	0	0	0	0	0	10	11	0
Filipendula ulmaria	0	0	0	0	0	0	1	0	1
Solidago virgaurea	0	0	0	0	0	0	1	0	0
Campanula rotundifolia	0	0	0	0	0	0	10	13	0
Parnassia palustris	0	0	0	0	0	0	2	1	0
Veronica officinalis	0	0	0	0	0	0	1	6	35
Saxifraga aizodes	0	0	0	0	0	0	6	0	0
Anthriscus sylvestris	0	0	0	0	0	0	0	0	2
Floral abundance	381	202	1208	628	299	836	222	149	224
Floral abundance pr. month		1791			1763			595	
Floral sp. richness pr. month		19			27			20	
	FH	EG	IG						
Floral abundance	1231	650	2268						
Floral sp. richness	33	23	25						

Table A1: Flowering plant abundance per species observed in former haymaking, extensive grazing, and intensive grazing in June, July, and August.

Figure A1: Boxplot showing plant species richness in each land use, grouped by land use.



## Appendix B: Supplementary pollinator data

Sp. Name	Pollinator abundance and richness								
	June			July			August		
	FH	EG	IG	FH	EG	IG	FH	EG	IG
Brachycera sp.	345	241	775	349	347	365	401	181	209
Nematocera sp.	7	8	6	15	12	10	3	2	2
Syrphidae sp.	24	18	27	35	21	14	21	17	8
Tabanidae sp.	0	0	0	0	0	1	0	0	0
Drepanoidea	53	26	18	119	109	126	43	64	53
Araneae sp.	1	0	0	0	0	0	0	0	0
Lepidoptera sp.	0	0	0	1	3	2	3	4	2
Plebejus idas	0	0	0	0	0	0	0	6	2
Callophrys rubi	2	0	0	0	0	0	0	0	0
Bolonia thore	0	0	0	1	0	0	0	0	0
Bolonia euphrosyne	0	0	0	1	1	1	0	0	0
Erebia ligea	0	0	0	1	0	0	13	9	5
Erebia poudrose	0	0	0	0	1	0	0	0	0
Bolonia agueuilonaris	0	0	0	0	1	0	0	0	0
Bolonia selene	0	0	0	10	6	11	0	0	0
Apoidea sp.	0	1	1	6	0	1	0	0	0
Bombus sp.	1	0	0	3	4	5	3	3	4
Bombus pratorum	0	0	0	3	0	5	1	2	6
Bombus hortorum/jonellus	0	0	0	3	0	19	1	1	2
Bombus monticola/alpinus	0	0	0	16	8	20	3	6	6
Bombus lapidarius	0	0	0	1	0	0	0	0	0
Bombus lucorum/terrestris	0	0	0	1	0	0	0	0	2
Bombus pascuorum	0	0	0	0	1	3	4	1	4
Bombus balteatus	0	0	0	0	0	11	2	0	3
Bombus consobrinus	1	0	0	0	0	0	2	4	1
Bombus wurflenii	0	2	0	0	0	0	1	0	0
Pollinator abundance	434	296	827	565	514	594	501	300	309
Bombus abundance	2	2	0	27	13	63	17	17	28
Bombus sp. richness	1	1	0	5	2	5	7	5	7
Lepid abundance	2	0	0	14	12	14	16	19	9
Lepid sp. richness	1	1	1	5	4	3	1	2	2
Poll abundance pr. month	1557			1673			1110		
Bombus abundance pr. month	4			103			62		
Bombus sp. richness pr. month	2			7			8		
Lepid abundance pr. month	2			40			44		
Lepid sp. richness pr. month	2			7			2		
	FH	EG	IG						
Poll abundance	1500	1110	1730						
Bomubs abundance	46	32	91						
Bombus sp. Richness	9	6	7						
Lepid abundance	32	31	23						
Lepid sp. Richness	6	7	5						

Table B1: Pollinator abundance and richness observed in former haymaking, extensive grazing, and intensive grazing in June, July, and August.

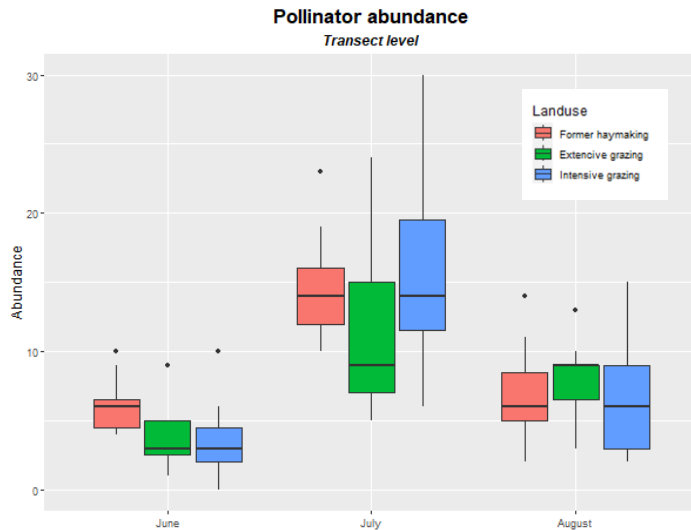


Figure B1: Boxplot showing poll wasps for each month in each land use.

## Appendix C: Supplementary model information from generalized mixed models

### C1: Plant abundance

	Chisq	Df	Pr(>Chisq)
<b>Landuse</b>	38.203	2	5.061e-09
<b>Field_period</b>	125.321	2	<2.2e-16
<b>Landuse:Field_period</b>	44.305	4	5.545e-09

Table C1.1: Anova from generalized linear mixed effect model (GLMM) on how land use and field period affected the abundance of plants in flower. Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

	contrast	estimate	SE	df	z.ratio	p.value
<b>Field_period1</b>						
	FH-EG	0.673	0.232	Inf	2.901	0.0104
	FH-IG	-1.169	0.222	Inf	-5.270	<.0001
	EG-IG	-1.842	0.228	Inf	-8.079	<.0001
<b>Field_period2</b>						
	FH-EG	0.759	0.226	Inf	3.361	0.0022
	FH-IG	-0.291	0.221	Inf	-1.316	0.3860
	EG-IG	-1.050	0.226	Inf	-4.656	<.0001
<b>Field_period3</b>						
	FH-EG	0.372	0.240	Inf	1.553	0.2665
	FH-IG	-0.048	0.235	Inf	-0.204	0.9772
	EG-IG	-0.420	0.239	Inf	-1.753	0.1855

Table C1.2: Pairwise post hoc comparison from generalized linear mixed effect model (GLMM) on how land use and field period affected the abundance of flowering plants. Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

## C2: Plant species richness

	Chisq	Df	Pr(>Chisq)
<b>Landuse</b>	9.0584	2	0.01079
<b>Field_period</b>	47.9749	2	3.823e-11
<b>Landuse:Field_period</b>	18.2761	4	0.00109

Table C2.1: Anova from generalized linear mixed effect model (GLMM) on how land use and field period affected the species richness of plants in flower. Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

	contrast	estimate	SE	df	z.ratio	p.value
<b>Field_period_1</b>						
	FH-EG	1.467	0.492	39.4	2.982	0.0133
	FH-IG	-0.667	0.492	39.4	-1.355	0.3739
	EG-IG	-2.133	0.492	39.4	-4.337	0.0003
<b>Field_period_2</b>						
	FH-EG	-0.667	0.492	39.4	-1.355	0.3739
	FH-IG	-1.333	0.492	39.4	-2.711	0.0262
	EG-IG	-0.667	0.492	39.4	-1.355	0.3739
<b>Field_period_3</b>						
	FH-EG	-0.133	0.492	39.4	-0.271	0.9603
	FH-IG	0.133	0.492	39.4	0.271	0.9603
	EG-IG	0.267	0.492	39.4	0.542	0.8511

Table C2.2: Pairwise post hoc comparison from generalized linear mixed effect model (GLMM) on how land use and field period affected the species richness of plants in flower. Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

## C3: All pollinators

	Chisq	Df	Pr(>Chisq)
<b>Landuse</b>	9.6568	2	0.007999
<b>Field_period</b>	42.2099	2	6.827e-10
<b>Landuse:Field_period</b>	71.1233	4	1.315e-14

Table C3.1: Anova from generalized linear mixed effect model (GLMM) on how land use and field period affected the pollinator abundance. Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).



	contrast	estimate	SE	df	z.ratio	p.value
<b>Field_period1</b>						
	FH-EG	0.3970	0.168	Inf	2.363	0.0476
	FH-IG	-0.6162	0.161	Inf	-3.817	0.0004
	EG-IG	-1.0132	0.165	Inf	-6.146	<.0001
<b>Field_period2</b>						
	FH-EG	0.1041	0.162	Inf	0.643	0.7966
	FH-IG	-0.0160	0.161	Inf	-0.099	0.9946
	EG-IG	-0.1201	0.162	Inf	-0.742	0.7387
<b>Field_period3</b>						
	FH-EG	0.5003	0.167	Inf	2.994	0.0078
	FH-IG	0.4658	0.167	Inf	2.792	0.0145
	EG-IG	-0.0345	0.171	Inf	-0.202	0.9778

Table C3.2: Pairwise post hoc comparison from generalized linear mixed effect model (GLMM) on how land use and field period affected the pollinator abundance. Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

#### C4: Pollinators except for *Brachycera*

	Chisq	Df	Pr(>Chisq)
<b>Landuse</b>	feb.85	2	0.245554
<b>Field_period</b>	150.8185	2	<2.2e-16
<b>Landuse:Field_period</b>	14.3435	4	0.006276

Table C4.1: Anova from generalized linear mixed effect model (GLMM) on how land use and field period affected the pollinator abundance (except for *Brachycera*). Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

	contrast	estimate	SE	df	z.ratio	p.value
<b>Field_period1</b>						
	FH-EG	0.483229	0.198	Inf	2.435	0.0395
	FH-IG	0.536539	0.201	Inf	2.669	0.0208
	EG-IG	0.053310	0.218	Inf	0.245	0.9675
<b>Field_period2</b>						
	FH-EG	0.264232	0.144	Inf	1.836	0.1578
	FH-IG	-0.058525	0.138	Inf	-0.425	0.9051
	EG-IG	-0.322757	0.143	Inf	-2.257	0.0620
<b>Field_period3</b>						
	FH-EG	-0.172730	0.168	Inf	-1.026	0.5605
	FH-IG	0.000979	0.173	Inf	0.006	1.0000
	EG-IG	0.173709	0.168	Inf	1.031	0.5570

Table C4.2: Pairwise post hoc comparison from generalized linear mixed effect model (GLMM) on how land use and field period affected the pollinator abundance (except for *Brachycera*). Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

### C5: *Bombus* abundance

	Chisq	Df	Pr(>Chisq)
<b>Landuse</b>	10.3151	2	0.005756
<b>Field_period</b>	36.0420	2	1.491e-08
<b>Landuse:Field_period</b>	8.2952	4	0.081345

Table C5.1: Anova from generalized linear mixed effect model (GLMM) on how land use and field period affected the *Bombus* abundance. Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

	contrast	estimate	SE	df	z.ratio	p.value
<b>Field_period1</b>						
	FH-EG	-0.40704	0.950	Inf	-0.429	0.9037
	FH-IG	0.68844	1.252	Inf	0.550	0.8466
	EG-IG	1.09548	1.184	Inf	0.925	0.6243
<b>Field_period2</b>						
	FH-EG	0.94344	0.420	Inf	2.246	0.0637
	FH-IG	-0.67722	0.339	Inf	-2.000	0.1121
	EG-IG	-1.62067	0.403	Inf	-4.018	0.0002
<b>Field_period3</b>						
	FH-EG	-0.00294	0.432	Inf	-0.007	1.0000
	FH-IG	-0.50672	0.405	Inf	-1.252	0.4225
	EG-IG	-0.50378	0.405	Inf	-1.245	0.4266

Table C5.2: Pairwise post hoc comparison from generalized linear mixed effect model (GLMM) on how land use and field period affected the *Bombus* abundance. Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

### C6: *Bombus* species richness

	Chisq	Df	Pr(>Chisq)
<b>Landuse</b>	8.0040	2	0.01828
<b>Field_period</b>	26.4853	2	1.773e-06
<b>Landuse:Field_period</b>	6.1376	4	0.18911

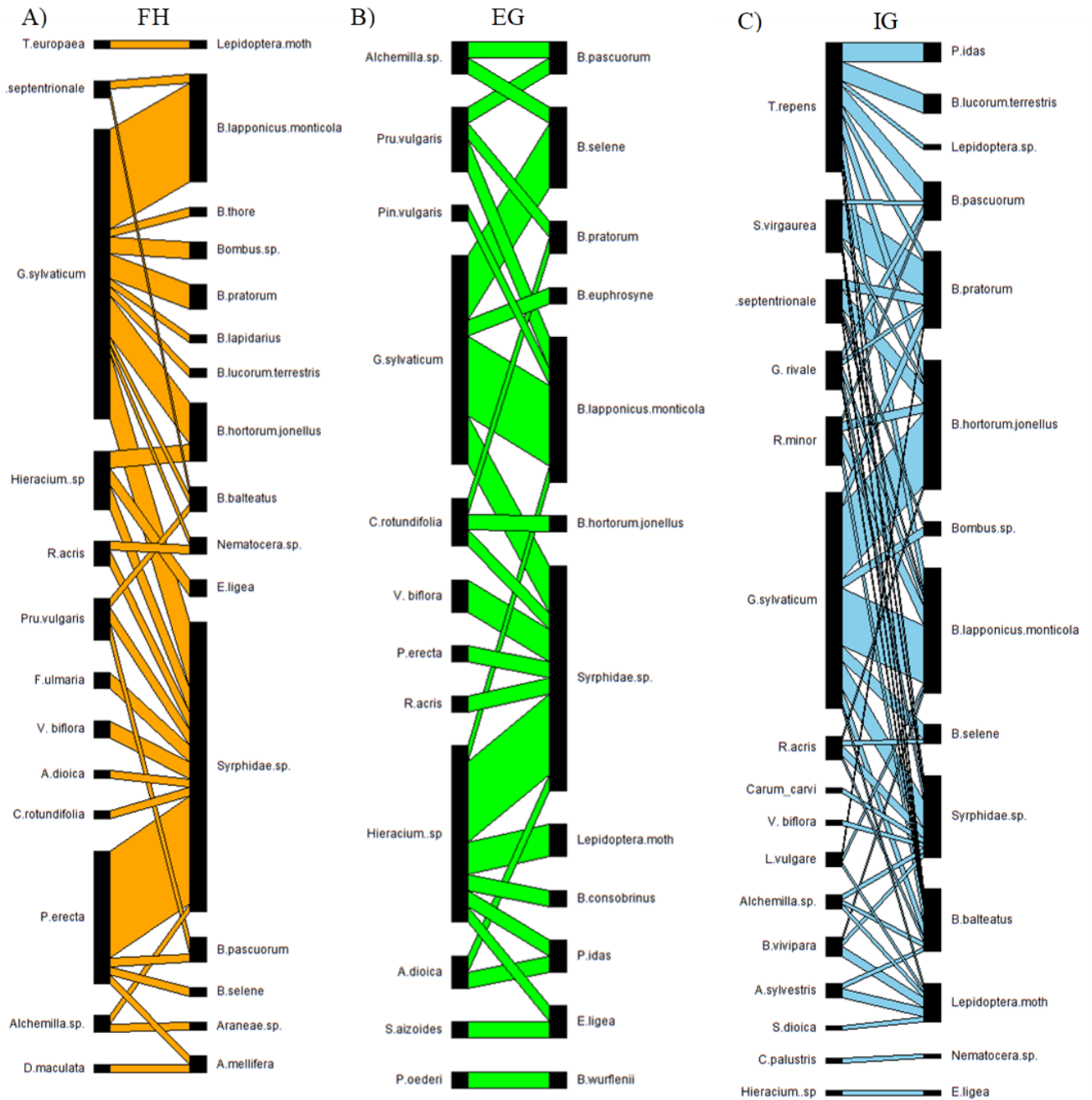
Table C6.1: Anova from generalized linear mixed effect model (GLMM) on how land use and field period affected the *Bombus* species richness. Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

	<b>contrast</b>	<b>estimate</b>	<b>SE</b>	<b>z.ratio</b>	<b>p.value</b>
<b>Field_period1</b>					
	FH-EG	-0.411	0.929	-0.442	0.8978
	FH-IG	0.682	1.236	0.552	0.8456
	EG-IG	1.093	1.167	0.936	0.6173
<b>Field_period2</b>					
	FH-EG	0.782	0.424	1.845	0.1549
	FH-IG	-0.587	0.325	-1.806	0.1677
	EG-IG	-1.369	0.400	-3.426	0.0018
<b>Field_period3</b>					
	FH-EG	0.127	0.410	0.309	0.9486
	FH-IG	-0.378	0.375	-1.008	0.5720
	EG-IG	-0.504	0.386	-1.307	0.3912

Table C6.2: Pairwise post hoc comparison from generalized linear mixed effect model (GLMM) on how land use and field period affected the *Bombus* species richness. Values indicate estimate, standard error (SE), z-value, and p-value. (Seasonal repetitions = 3, Land use types = 3, Sites = 9, transects = 45).

## Appendix D: Plant-pollinator network

Figure D1: Interaction networks for pollinator groups (except for Brachycera) and flowering plant species for former haymaking (A), extensive grazing (B), and intensive grazing (C) with all field periods summarized.



Network indices			
Land use	Site	Connectence	Links per species
Former haymaking	FH1	0.1818	1.0000
	FH2	0.3174	1.2500
	FH3	0.1919	2.8015
Extensive grazing	EG1	0.2857	1.1764
	EG2	0.2083	1.0869
	EG3	0.1500	0.8181
Intensive grazing	IG1	0.2426	1.5769
	IG2	0.2153	1.2173
	IG3	0.2905	1.5454

Table D1: Calculated network indices of connectance and links per species from the interaction network for the different sites.  $p$ -value(connectance) = 0.001,  $p$ -value (links per species) = 0.020.

Network indices (without flies)			
Land use	Site	Connectence	Links per species
Former haymaking	FH1	0.2000	0.7500
	FH2	0.3095	1.0000
	FH3	0.1919	0.9500
Extensive grazing	EG1	0.3055	0.9166
	EG2	0.2619	0.8461
	EG3	0.1587	0.6250
Intensive grazing	IG1	0.2500	1.4347
	IG2	0.2962	1.0666
	IG3	0.3125	1.38888

Table D2: Calculated network indices of connectance and links per species from the interaction network for the different sites when excluding flies.

## Appendix E: Field coordinates and survey forms

Land use type	Cordinates	Elevation (m.o.h)
Former Haymaking 1 (FH1)	62.734964N, 010.683115E	755
Former Haymaking 2 (FH2)	62.734905N, 101.686017E	789
Former Haymaking 3 (FH3)	62.736355N, 010.683845E	819
Extensive grazing 1 (EG1)	62.732242N, 010.700742E	843
Extensive grazing 2 (EG2)	62.731253N, 010.705989E	871
Extensive grazing 3 (EG3)	62.732208N, 010.702540E	858
Intensive grazing 1 (IG1)	62.728650N, 010.702922E	778
Intensive grazing 2 (IG2)	62.728993N, 010.702122E	781
Intensive grazing 3 (IG3)	62.729156N, 010.701814E	782

Table E1: Coordinates and elevation data for study site





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