Graduate thesis

NTNU
Norwegian University of Science and Technology
Faculty of Natural Sciences
Department of Biology

Pooja Subedi

Mowing Impacts on Urban Biodiversity

A study of plant-pollinator dynamics in mowed vs unmowed grasslands

Graduate thesis in Natural Resource Management
Supervisor: Gunnar Austrheim
Co-supervisor: Frode Ødegaard
May 2024

NTNU
Norwegian University of Science and Technology

Pooja Subedi

Mowing Impacts on Urban Biodiversity

A study of plant-pollinator dynamics in mowed vs unmowed grasslands

Graduate thesis in Natural Resource Management
Supervisor: Gunnar Austrheim
Co-supervisor: Frode Ødegaard
May 2024

Norwegian University of Science and Technology
Faculty of Natural Sciences
Department of Biology

NTNU
Norwegian University of
Science and Technology

Abstract

Mowing, as a management practice, can impact the species richness and abundance of both plants and pollinators and the interaction between them by altering the plant-pollinator dynamics and their relationship. The main aim of the study is to compare the species diversity, abundance, and interactions of flower resources and pollinators between mowed and unmowed grassland plots in an urban setting. The study was conducted in Trondheim, Norway across six sites in 4 different seasons from mid-June to mid-August with mowed and unmowed plots. The results showed that both plants, pollinators, and the interaction between them were significantly higher in unmowed grasslands than mowed grasslands. Total pollinators counts were approximately 8 times, bumblebees approximately 7 times and butterflies approximately 3 times more in unmowed grasslands compared to mowed grasslands. Seasons also significantly impacted plants and pollinator's species richness and abundance. The flowering plant's interaction with pollinators peaked in late July (3rd season), contrasting with its lowest point in mid-June (1st season), showcasing distinct seasonal effects on their interaction. The mowed grassland plots had a notably low count of bumblebees, butterflies, and other pollinator groups. Mowing should be scheduled to avoid periods of peak flowering and high pollinator activity. Aligning the mowing frequency with these seasonal patterns is important. This strategy helps maintain favorable conditions for both the flowering plants and pollinators in grassland environments.

Acknowledgments

Firstly, I would like to express my gratitude to my supervisor, Gunnar Austrheim, and co-supervisor Frode Ødegaard for their invaluable guidance and suggestions throughout my study- from fieldwork and analysis to writing. I want to thank Gro Lefstad from the section for property maintenance, NTNU, and Andreas Pedersen from Trondheim municipality for their collaboration throughout the study.

I would also like to thank my colleague Hedda for her assistance during fieldwork and her continual support when needed, as well as my colleague Peter for his companionship and insightful suggestions while writing my thesis.

I am grateful to my family for their patience and trust in my decision to study overseas, and my friends who have supported and encouraged me in every possible way.

Table of Contents

List of Figures

List of tables

1. Introduction

1.1 Land Use Impact on Biodiversity

Land use is a significant driver of global biodiversity loss (IPBES 2019; De Baan et al., 2013), and poses the greatest threat to nature causing a decrease in the species richness and abundance of plants and pollinators around the world (Davison et al., 2021). Changes in land use can disrupt the mutualistic relationship between plants and pollinators which can lead to fewer flower resources, fewer places for them to live, and fewer pollinators (Dalsgaard, 2020). These land use changes can also affect the economy by reducing the productivity of crops (Dalsgaard, 2020). Changes in land use can impact pollinators in two main ways: indirectly by altering the types and availability of flowers they rely on, and directly by affecting their life cycles, such as disrupting where they can nest or the habitats where their larvae grow (Weiner et al., 2014).

1.2 Urbanization and Green Urban Habitats

Urbanization is regarded as one of the most significant drivers of land use change in addition to agricultural expansion and intensification, resulting in the loss of resources and pollinator habitats (Potts et al., 2016). Urban environments are important for preserving biodiversity within cities (Deák et al., 2016). Urban areas can support a diverse range of plant and animal life which is essential for sustainable development and enhancing the quality of life for city residents (Petersen et al., 2020). Important ecosystem services that cities provide to society include pollination services, air and water purification, temperature control, and water retention (Cervelli et al., 2013) along with provisioning and cultural ecosystem services (Kowarik et al., 2020). Maintaining and increasing biodiversity in urban habitats is crucial for maintaining ecosystem services (Onandia et al., 2019). The extent, isolation, and fragmentation of urban green spaces vary, and they are often separated by hostile environments (Fattorini et al.,2018). Although environmental changes in urban areas frequently have a negative impact on the range and abundance of insects, research demonstrates that more bee species can be found in cities than in rural areas(Rahimi et al., 2022). The high species diversity of bees in urban areas as compared to rural areas may be due to the surrounding landscapes urban areas continue to support habitat for a variety of species (Wenzel et al., 2020). Urban environments could serve as appealing habitats for pollinators (Lizée et al., 2011). Diverse habitats in urban areas might influence pollinators differently, because of the variety of plant types and how people manage these landscapes (Banaszak-Cibicka et al., 2016). The connection of urban landscapes and proximity between habitat patches may be crucial for maintaining plant-pollinator communities and their interaction in urban spaces (Potts et al., 2016).

1.3 Grassland ecosystem and grassland management in urban settings

Grasslands cover a significant portion of urban areas around the world (Onandia et al., 2019). Urban grasslands are a diverse group of green spaces that include playgrounds, parks, residential meadows, historic wastelands, and other habitat types in densely populated places (Klaus, 2013). Urban grasslands offer a wide range of benefits including social, economic, recreational, and environmental services and are also capable of maintaining a wide range of species (Klaus, 2013). Urban grasslands can sustain large and diverse pollinator populations. Because of this, it's necessary to preserve valuable urban green spaces while also working to enhance intensively managed urban ecosystems through new management techniques (Dylewski et al., 2019). The specific characteristics and composition of the local plant and pollinator community can be significantly influenced by the management practices used in grasslands (Politi Bertoncini et al., 2012). Urban grasslands are often subjected to various management practices, such as mowing, which can influence the diversity and abundance of plant and pollinator species (Gros et al., 2023). Mowing generally refers to chopping down or leveling grass. Lawns, or short-cut grasslands that are cropped periodically, are a popular type of vegetation in urban settings (Sehrt et al., 2020). Grassland biodiversity can be maintained with regular annual mowing (Valkó et al., 2012). For thousands of years, mowing has played a crucial role in the management of semi-natural grasslands in Europe (Hansson & Fogelfors, 2000). However, if done frequently or early in the growing season, mowing might reduce biodiversity (Socher et al., 2012), and influence the pollinator species abundance and richness (Lerman et al., 2018). The abundance and diversity of endangered or rare species including wild bees, beetles, butterflies, and true bugs, were positively impacted by a reduced mowing regime in urban grasslands(Wastian et al., 2016). Overall negative impacts of "intense" mowing on both plant and invertebrate communities (i.e., abundance, richness, and diversity combined) were revealed by combining the results from unpublished and published datasets, according to the meta-analysis conducted by (Watson et al., 2020).

1.4 Pollinators

Pollinators are an important part of the world's biodiversity. Increasingly, studies indicate large-scale declines in pollinators globally, with the strongest evidence available from Europe and North America (Potts et al., 2010). Insects are the primary pollinators in northern ecosystems (Tøtland et al., 2013). 25% of pollinating insects in Norway are on the Red List (Tøtland et al., 2013).

Various groups of insects, including bees, butterflies, flies, and beetles show different levels of efficiency as pollinators. Bees (series Apiformes) are the primary and most frequent visitors to flowering plants among other insect pollinators (Neff & Simpson, 1993; Winfree et al., 2011). The second most visitors to flowers are flies: order Diptera (Winfree et al., 2011); (Torrez et al., 2023). Though flies are less effective as pollinators than bees and bumblebees, they contribute to the pollination process due to their high numbers (Tøtland et al., 2013). Butterflies efficiency as pollinators is generally lower compared to more specialized pollinators such as bees (Tøtland et al., 2013). Honeybees are economically the most important pollinators because they help pollinate vast areas of single-crop farmlands worldwide, serving as substitutes for wild bees to maintain pollination in agricultural fields (Klein et al., 2006). Bumblebees are capable of transferring more pollen from anthers to stigmas compared to other insects and can gather nectar and pollen over longer periods of the day, even during adverse weather conditions(Abrol, 2012). Therefore, they are considered more efficient and active pollinators among various bee species Bumblebees are naturally found in cooler and temperate climates, primarily throughout the northern hemisphere (Abrol, 2012)..

1.5 Effect of seasonal variation on plants and pollinators

Seasonal changes can have impacts on pollinators, their foraging patterns, species richness, and interaction with flowering plants (Oertli et al., 2005). The variability in seasons affects the species richness and abundance of flowering plants as well as of pollinators (Groven, 2023). The number of pollinators like bumblebees goes up during the summer, with the most seen in July and August compared to earlier months and this increase happens at the same time when more flowers bloom, especially in July, across different types of grasslands (Groven, 2023). The plant-pollinator interaction networks are more complex and specialized during the peak summer months i.e June to August (Dhukuchhu, 2021). Higher species richness of insect pollinators is known during the dry season when rain does not restrict their activities (Abrahamczyk et al., 2011).

1.6 Plant Pollinators Interaction

Plant-pollinator interaction involves a mutual process where insects transfer the reproductive gametes, and in return, plants provide the insects with energy and protein in the form of nectar and pollen (Dar et al., 2017) . Pollination directly influences the production of biomass, fruit, and seed production in flowering plants (Gunnarsson & Federsel, 2014). Ecological relationships among plants and pollinators are essential and possess great importance in ecosystem services. A global estimate of the economic worth of pollination as an ecosystem activity is 153 billion euros per year (Gallai et al., 2009). Pollination by insects (biotic pollination) and other animals is more prevalent and typically more efficient than other abiotic pollen movement methods like wind and water (Willmer, 2011). Insect pollination is essential for the production of fruit and seeds in 80% of wild plant species (Potts et al., 2010).

Insects move pollen grains from stamens to stigmas to either the same or different flowers, starting the seed formation process in the receptive flower. Thus, insect pollination is a significant interaction between plants and animals (Tøtland, Ø., Hovstad, K.,A., Ødegaard, F., & Åstrom, J.(2013). These biotic pollinators play a crucial role in the success of urban gardening.

1.7 Objectives

The main objective of this study is to compare the species diversity, abundance, and interactions of flower resources and pollinators between mowed and unmowed grassland plots in an urban setting from mid-June to mid-August. This study is designed to investigate: (a) the effect of mowing on the species richness and abundance of flower resources and pollinators, (b) Is the effect mediated by season? (c) How are plant-pollinator networks affected?
The study aims to explore the hypothesis that:

- First Hypothesis: Mowing reduces the species richness and abundance of plant flowering resources and pollinators.
- Second Hypothesis: Different seasons influence the richness and abundance of plants and pollinators within urban grasslands. There will be an increase in plant and pollinator richness and abundance as the season progresses to July (season 2 and season 3) and a decline at the end of the growing season (season 4).
- Third hypothesis: Bumblebee species richness and abundance vary with mowed and unmowed grassland types and also with different seasons.
- Fourth hypothesis: Mowing practices and seasons have a significant impact on the plant-pollinator interactions. The plant-pollinator network will be more complex in unmowed grasslands. Season 2 and Season 3 will witness more interactions.

The findings of this study could provide valuable recommendations to landowners on how to manage grassland sites effectively.

2. Methods

2.1 Description of Study Site

The research was conducted in Trondheim, Trøndelag county(63º26´24´´N 10º24´0´´E), which lies in central part of Norway. Trondheim, located in the northern hemisphere, experiences the start of summer towards the end of June, lasting until September (*Trondheim Climate: Average Temperature by Month, Trondheim Water Temperature*, n.d.). The climate in this region is characterized by a cool and moist atmosphere with mild summers featuring mild temperatures and moderate levels of rainfall (*Trondheim Climate: Average Temperature by Month, Trondheim Water Temperature*, n.d.).

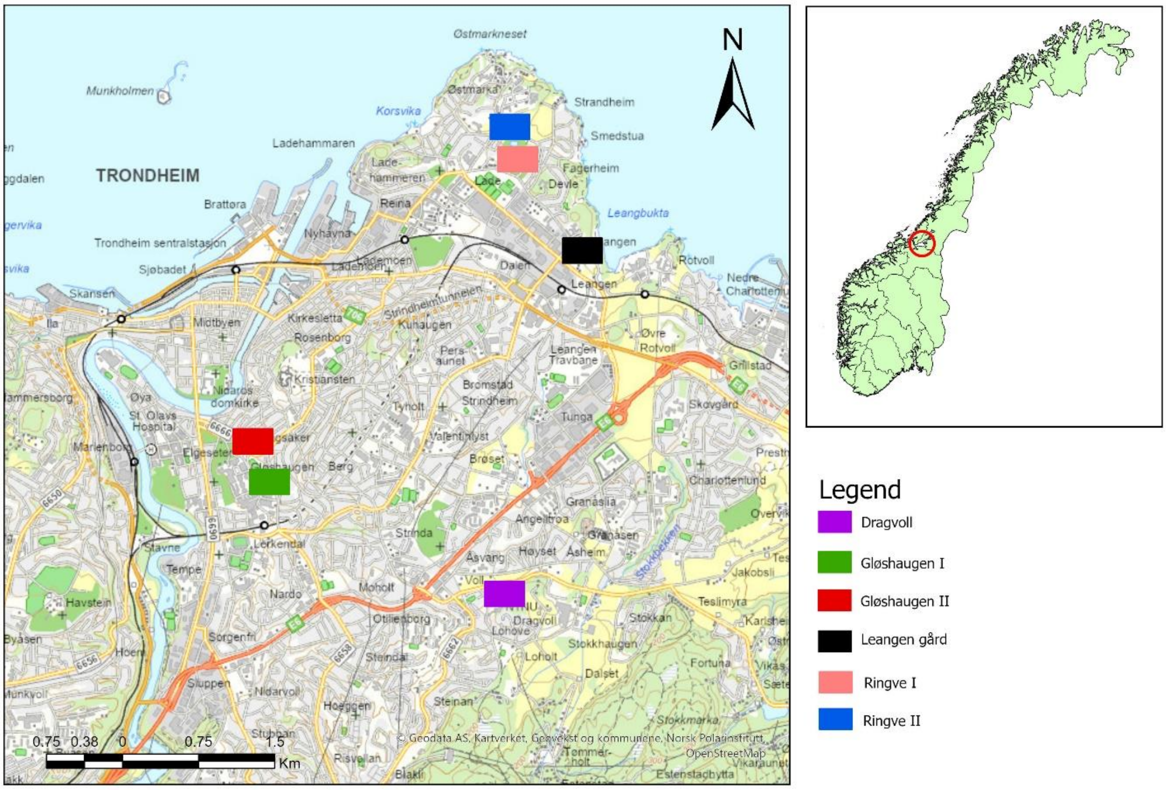


Figure 2.1: Map of the selected study sites (six unmowed and mowed) in Trondheim municipality

For the study, six sites of paired mowed and unmowed grassland habitats were selected. The study sites were situated in the different parts of Trondheim. The sites were selected based on the area of mowed and unmowed grassland types within proximity to each other. Trondheim municipality and NTNU are the large landowners of Trondheim. In recent years, these landowners have changed the management regimes towards more low-frequency mowing and leaving certain areas unmowed to promote pollinator activities and to create a more biodiversity-friendly urban space in Trondheim. They have not used fertilizers in any of the study sites. NTNU has an ambitious plan for sustaining biodiversity within their area(Betten, n.d.) also Trondheim municipality has an action plan for maintaining and conserving biodiversity. Suggestions for the selection of study sites were taken from Trondheim municipality- Trondheim bydrift (*Trondheim Bydrift*, n.d.) and NTNU- Eiendomsavdeling ((*Property Department - NTNU*, n.d.)). I had one more study site in Saupstad, managed by Trondheim municipality. It was mistakenly mowed by the municipality which prevented me from collecting data in the last two field periods so I excluded this site. Table 2.1 below describes the study sites.

Table 2.1 An overview over the management details of the study sites in mowed and unmowed grasslands

S.N	Sites	Grassland Type	Start of Management practice	Mowing Frequency	Human use of grassland
1	Gløshaugen I	Unmowed	4 years	1-2 times per year	Rarely used
		Mowed		2-4 times per month	Rarely used
2	Gløshaugen II	Unmowed	4 years	1-2 times per year	Rarely used
		Mowed		2-4 times per month	Often used
3	Dragvoll	Unmowed	4 years	1-2 times per year	Rarely used
		Mowed		Almost daily by robots	Often used
4	Ringve I	Unmowed	19 years	2 times per year for past 5 years	No use
		Mowed		1 time per week	Often used
5	Ringve II	Unmowed	3 years	2 times per year	No use
		Mowed		1 time per week	No use
6	Leangen gård	Unmowed	4 years	1-2 times per year	Rarely used
		Mowed		2 times per week	Often used

(a) (b)

Figure 2.2: (a) Ringve II, one of the unmowed grasslands(mowed 1-2 times a year), (b) Leangen gård, one of the mowed grassland; both plots included in the study

2.2 Data Collection

The sampling was conducted during the summer of 2023 in four rounds: season 1 (mid-June), season 2 (early-July), season 3 (late-July), and season 4 (mid-August). The data were collected on sunny and partly sunny days with a minimum temperature of 15ºC between the time 10:00 and 17:00. The approximate average duration spent on each plot ranged between 20 to 30 minutes. Each grassland plot was standardized to a size of 20 meters by 10 meters, and the dimensions were fixed using a measuring tape. Two fixed transects (20 meters) were set up in parallel at each site. The same observer registered plants and pollinators for the duration of the field season. Pollinators and flowering plants were registered in the field using a standardized form that included sections for date, site, time, plant/pollinator name, wind, temperature, transects, and quadrats.

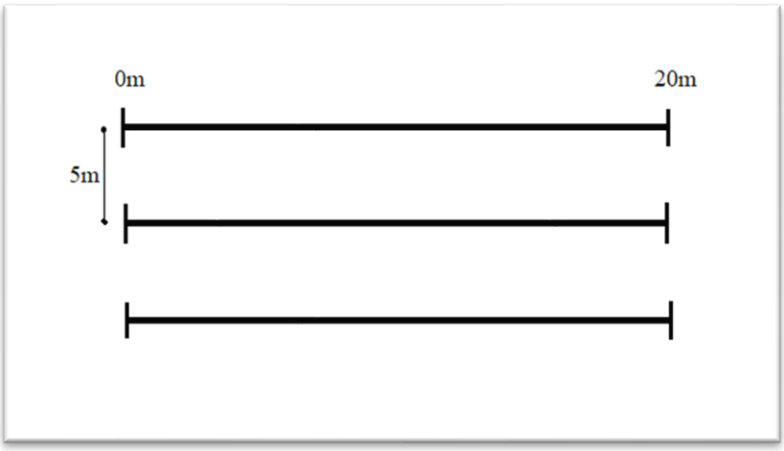


Figure 2.3: Dimension and position of transect lines

Figure 2.4: Measuring and fixing the unmowed grassland plot of Gløshaugen I, during the first field period before recording the data (Photo: Gunnar Austrheim)

2.2.1 Pollinator data

Pollinator data was recorded by walking at a slower pace along the fixed transects, observing pollinator activity and their visitation within 2.5 m on either side of the transect line. The amount of time spent on each plot was dependent on the level of pollinator activity observed; notably, when a higher amount of pollinator activity was encountered, the duration taken to complete the transect increased accordingly. Temperature, cloud cover, and wind speed observations were recorded at the beginning of each sampling day at each site.

Both pollinators (when they are flying or resting) and the flowering plant species they were visiting were recorded. Only when a pollinator is spotted on the flower's reproductive part, the pollinator was counted as a floral visitor. Bumblebees and butterflies were recorded at the species level . Other pollinators: flies, hoverflies, honeybees, wild bees, wasps, beetles, and green lacewings were identified and recorded at broad taxonomic group. “Humler i Norge”(Ødegaard et al., 2015) and “Sommerfulger i Norge (forenklet)” was used to identify the bumblebee and butterfly species respectively. The other pollinators and bumblebees which were hard to identify in the field were captured by a sweeping net and transferred in a glass jar and a picture of it was taken and sent to an insect expert(Frode Ødegaard) for the correct identification.

It was challenging to differentiate between *Bombus lucorum, Bombus terrestris, Bombus cryptarum, Bombus magnus,* and *Bombus sporadicus*, so they were noted in the *Bombus lucorum* group. Bumblebees and butterflies that were observed flying across the transect line, which could not be captured and identified were recorded as *Bombus species* and *Lepidoptera species* respectively.

(a)

(b)

Figure 2.5: (a) Pollinator individuals captured in a glass jar for easier identification (Photo: Pooja Subedi), (b) Walking at a slow pace along with transects for recording pollinator data in a trial round before the field season (Photo: Gunnar Austrheim)

2.2.2 Plant data

When recording plant data, a quadrat frame (50 cm*50 cm) with 16 sub-quadrats (4*4) was placed systematically every 5 m along the fixed transect line (4 quadrats in each transect). The flowering herbs that were present within the quadrat were noted to assess the richness of flowering plant species. For flower abundance, I counted and recorded the number of flowers in each sub-quadrat, including multiple counts of flowers from the same plant species. This pattern of positioning quadrats was consistently followed each time. The grasses and the plant species that were not flowering at the time of recording were not noted. Flowering species that were not identified on the field were pictured and identified later. Furthermore, the average height(cm) of plants within each quadrat frame was documented.

(a)

(b)

Figure 2.6: (a) A quadrat frame placed for registrations of the flowering plants in one of the unmowed grasslands (b)Registration of plant data in one of the mowed grassland (Photo: Gunnar Austrheim)

2.3 Statistical analysis

The analysis was performed in software R version 4.3.1 (R Core Team, 2023). Generalized Linear Models and Generalized Linear Mixed Effect Models were prepared for the analysis. The explanatory variables used for the model selection for flowering plant species richness and flower abundance were: Grassland type, Season, Site, and Quadrats. Grassland type and Season were chosen as the fixed explanatory variables whereas Site and quadrats nested within the Site as random variables. "ggplot 2" package from R was used to generate figures.

For testing the relationship between the flowering plant richness and explanatory variables, a generalized linear model and a generalized linear mixed effect model with "Poisson" distribution were used. "Poisson" distribution was chosen because of the appropriateness of the count data and the right-skewed distribution of the response variable observed in preliminary data analysis. Models for richness were made with the function "glmer" of the "lme 4" package. The relationship between flower abundance and explanatory variables was tested using zero-inflated generalized mixed models to account for the excess zero with " negative binomial" distribution to address the overdispersion of the flower abundance responses. Models for abundance were made with the function "glmmTMB" which stands for "Generalized Linear Mixed Models using Template Model Builder". This function was chosen for its robustness in handling the complexities of the data and for its extra flexibility for the mixed models to account for count data with overdispersion and zero inflation.

For pollinator richness, season, grassland type, and site were used as the main explanatory variables. Site was not used as a random variable here because the model was not able to address the random effects of Site with the warning as the random effects were very small. For the final model, Season and Grassland type were used as main predictor variables in a GLM with a "poisson " distribution. The differences in the Sites were visualized separately. The relationship between pollinator abundance and explanatory variables was tested using generalized mixed models using "glmer.nb" function. A negative binomial distribution was used to account overdispersion of the response variable. Season and grassland type were chosen as fixed explanatory variables and Site as a random variable for the final model.

For analysis of both bumblebee species richness and bumblebee abundance, the explanatory variables Season and Grassland type as fixed and Site as random, were chosen and a generalized mixed effect model was used. For models of bumblebee species richness "glmmTMB" function was used with "poisson distribution" and for models of bumblebee abundance "glmer.nb" function was used.

The final model for all the response variables was selected based on checking model diagnostic plots (distribution of residuals Q-Q plot and residual vs predicted plot) by "dHARMA" package, and the relevance of the variables within models with the study. The diagnostic plots for the chosen models are shown in Appendix D.

Post-hoc analysis was performed on the selected models of all response variables to compare the level of seasons to each other to see if there are significant differences between them by doing pairwise comparisons. For this, "emmeans" package was used with the function "emmeans". Tukey's adjustment method was used to control the risk of Type I errors(false positives).
To show the interaction between flowering plants and pollinators through interaction networks, the "plotweb" function from the "bipartite" package (Dormann et al., 2023) was used. The interaction network was prepared for different Seasons and different grassland types.

3. Results

3.1 Flowering plant species richness

A total of 37 distinct species of flowering herb species were recorded in the entire field period. Specifically, within unmowed grassland types, 34 species were identified whereas 12 species were observed in mowed grassland types. The analysis identified 9 species that were present in both mowed and unmowed areas of grassland. A detailed list of the flowering plant species is provided in Appendix A.

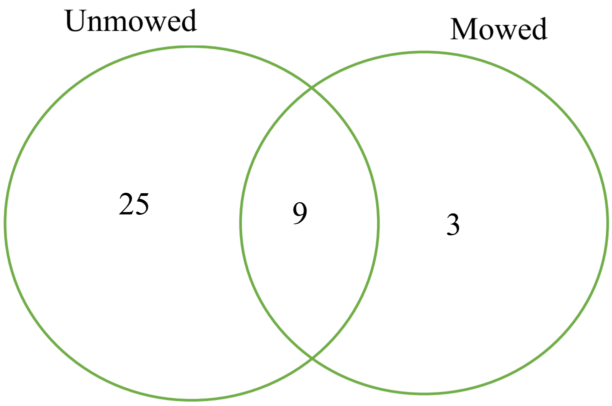


Figure 3.1: Venn diagram showing the presence of flowering plant species between unmowed and mowed grasslands

Effect of Grassland Management and Season on Flowering Plant Species richness

The fitted GLMM model analysis showed a significant effect of both grassland type and Season within the study sites. Site variability was treated as a random effect, to account for differences within each site. Unmowed grassland showed significantly higher species richness ($p < 2e-16$) compared to mowed grassland.

Seasonal variations showed a distinct impact on plant species richness. Compared to season 1, season 2 was associated with a significant increase in plant richness ($p < 0.01$), suggesting that early July conditions are particularly favorable for a higher diversity of plant species. Season 3 also exhibited a positive trend, although this was not statistically significant ($p = 0.09775$), whereas season 4 was characterized by a significant decrease in plant richness($p < 0.05$). Site variability indicated an estimated variance of 0.04515 and a standard deviation of 0.2125, which suggests notable variations among Sites that are not explained by these fixed factors.

Post-hoc analysis between seasonal pairs confirmed significant differences in plant richness. Specifically, season 1 was significantly lower in richness compared to season 2 ($p = 0.0241$), while season 2 and season 3 both showed significantly higher richness compared to season 4 ($p < 0.0001$ and $p = 0.0015$, respectively). No significant differences were found between season 1 and season 3 or between season 2 and season 3.

Table 3.1: Results from fixed effects of GLMM predicting plant richness. Values include estimate, standard error, z-value, and p-value

Predictors	Estimate	Std. Error	z value	p value
Intercept	-0.7204	0.1592	-4.524	<0.001***
Season 2	0.3801	0.1343	2.830	0.00465**
Season 3	0.2296	0.1386	1.656	0.09775
Season 4	-0.3279	0.1599	-2.051	0.04032*
Grasslandtype Unmowed	1.0634	0.1124	9.459	<0.001***

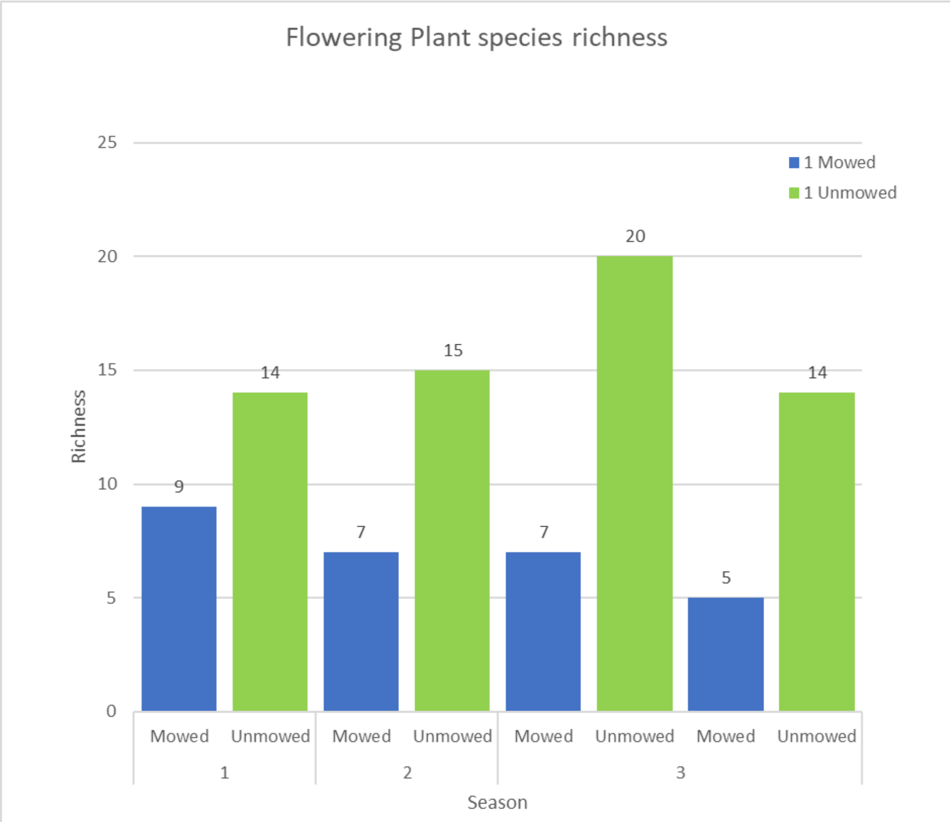


Figure 3.2: Total flowering plant species richness across seasons in mowed and unmowed grassland type

3.2 Flower Abundance

Overall, the most abundant flower present in mowed was *Trifolium repens* and the most abundant species in unmowed was *Alchemilla vulgaris*. The detail on the abundant species on each Season is given in Table 3.2.

Table 3.2: Most abundant flowering plant species with their total count with each season and grassland type

Season	**Grassland Type**	**Most Abundant Flowering Plant**	**Count**
1	Mowed	*Alchemilla vulgaris*	44
1	Unmowed	*Alchemilla vulgaris*	163
2	Mowed	*Trifolium repens*	111
2	Unmowed	*Stellaria graminea*	185
3	Mowed	*Trifolium repens*	58
3	Unmowed	*Stellaria graminea*	105
4	Mowed	*Leontodon autumnalis*	11
4	Unmowed	*Leontodon autumnalis*	78

Effect of Grassland Management and Season on Flower Abundance

The fitted GLMM model analysis revealed a significant effect of both grassland type and season on flower abundance. Site variability was incorporated as a random effect to account for intra-site variability. Unmowed grassland exhibited a significantly higher flower abundance($p < 2e\text{-}16$) compared to mowed grass indicating that management practices have a substantial effect on flower abundance.

Seasonal variations also showed a distinct impact on flower abundance. Season 2 was associated with a significant increase in flower abundance ($p < 0.01$) compared to season 1. Although season 3 showed an increase in flower abundance, it was not statistically significant ($p = 0.73822$), whereas season 4 was marked by a significant decrease in plant abundance ($p < 0.001$). The random effect of the site showed some variance (var = 0.1007, std. dev = 0.3173)

Post-hoc analysis between seasonal pairs confirmed significant seasonal differences in flower abundance. Season 1 showed significantly lower plant abundance compared to season 2 ($p = 0.0028$) and higher abundance compared to season 4 ($p < 0.0001$). Season 2 showed markedly higher abundance than both season 3 ($p = 0.0083$) and season 4 ($p< 0.0001$). Season 3 was found to have significantly more abundance than season 4 ($p < 0.0001$).

Table 3.3: Results from fixed effects of GLMM predicting flower abundance. Values include estimate, standard error, z-value, and p-value

Predictors	**Estimate**	**Std. Error**	**z value**	**p value**
Intercept	0.39310	0.20678	1.901	0.057295
Season 2	0.57328	0.16485	3.478	<0.001***
Season 3	0.05733	0.17189	0.334	0.73822
Season 4	-0.94773	0.18436	-5.141	<0.001***
Grasslandtype Unmowed	1.59366	0.12999	12.259	<2e-16***

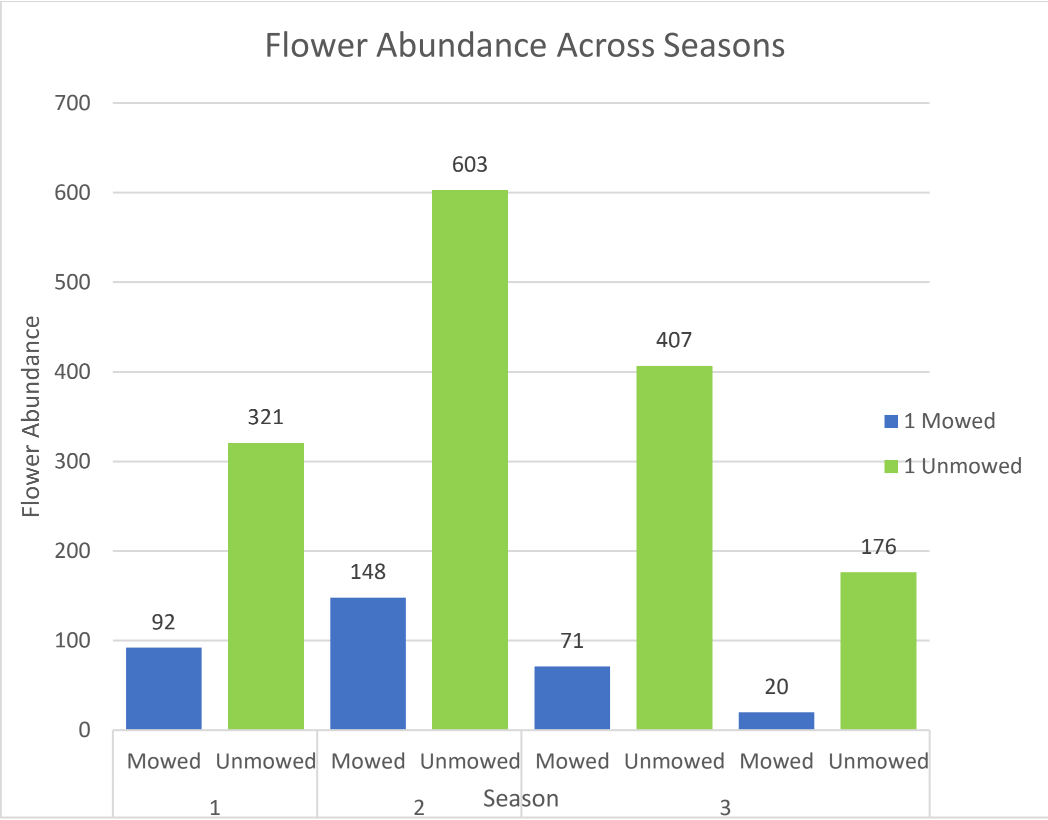


Figure 3.3:Total flower abundance across different seasons in mowed and unmowed grassland types

3.3 Pollinator Richness

A total of 9 distinct groups of pollinators were recorded throughout the field period: Bumblebees, Lepidoptera, wasps, hoverflies, honeybees, wild bees, flies, beetles, and green lacewings. Within unmowed grassland types, 9 were identified, whereas in mowed grassland types, 7 pollinator groups were observed. Seven pollinator groups were present in both mowed and unmowed plots of grassland whereas two pollinator groups were exclusively found in unmowed grassland.

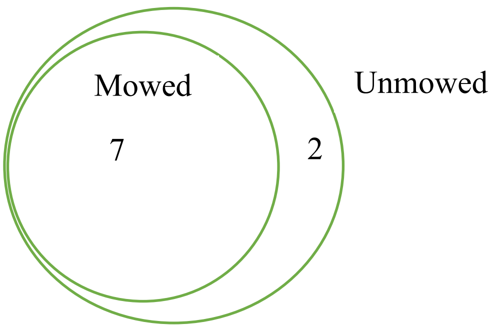


Figure 3.4: Venn diagram showing the presence of pollinator richness between mowed and unmowed grasslands

The presence of pollinators in mowed and unmowed grassland types Table 3.4.

Table 3.4: Presence or absence of pollinators in mowed and unmowed grassland type.

Pollinators(Species)	Mowed Grassland	Unmowed Grassland
Bombus lucorum	✓	✓
Bombus hypnorum	✓	✓
Bombus lapidarius	✓	✓
Bombus pascuorum	✓	✓
Bombus sylvestris	✓	✓
Bombus hortorum		✓
Pieris napi	✓	✓
Anthocharis cardamines		✓
Callophyrus rubi		✓
Pollinators(Groups)		
Moth	✓	✓
Wasp	✓	✓
Hoverflies	✓	✓
Honeybees	✓	✓
Wildbees		✓
Flies	✓	✓

Effect of Season and Grassland management on Pollinator Richness

Statistical analysis with the fitted GLM model revealed a significant effect of grassland management on pollinator richness. Unmowed grassland type had substantially higher pollinator richness ($p < 2.21e-12$) in comparison to mowed grassland.

Seasonal changes were also found to significantly affect pollinator richness. However, only one of the seasons, season 3, showed a statistically significant increase in pollinator richness ($p=0.128$) when compared to season 1, whereas season 2 and season 4 did not show a statistically significant difference in pollinator richness with p values 0.810 and 0.349 respectively suggesting no large fluctuation in pollinator richness due to seasonal changes.

The post-hoc analysis revealed no significant differences in pollinator richness between any of the season pairs compared. No significant variations were found between season1 and seasons 2,3, and 4 (p-values: 0.9951, 0.4245, 0.7854) also between season 2 and seasons 3 and 4 (p values: 0.5738, 0.8986), nor between season 3 and season 4 (p value: 0.9353).

Table 3.5: Results from fixed effects of GLM predicting pollinator richness. Values include estimate, standard error, z-value, and p-value

Predictors	Estimate	Std. Error	z value	p value
Intercept	0.65456	0.14113	4.638	<0.001***
Season 2	0.03871	0.16067	0.241	0.810
Season 3	0.23361	0.15354	1.522	0.128
Season 4	0.14660	0.15659	0.936	0.349
Grassland type unmowed	0.82910	0.11809	7.021	<0.001***

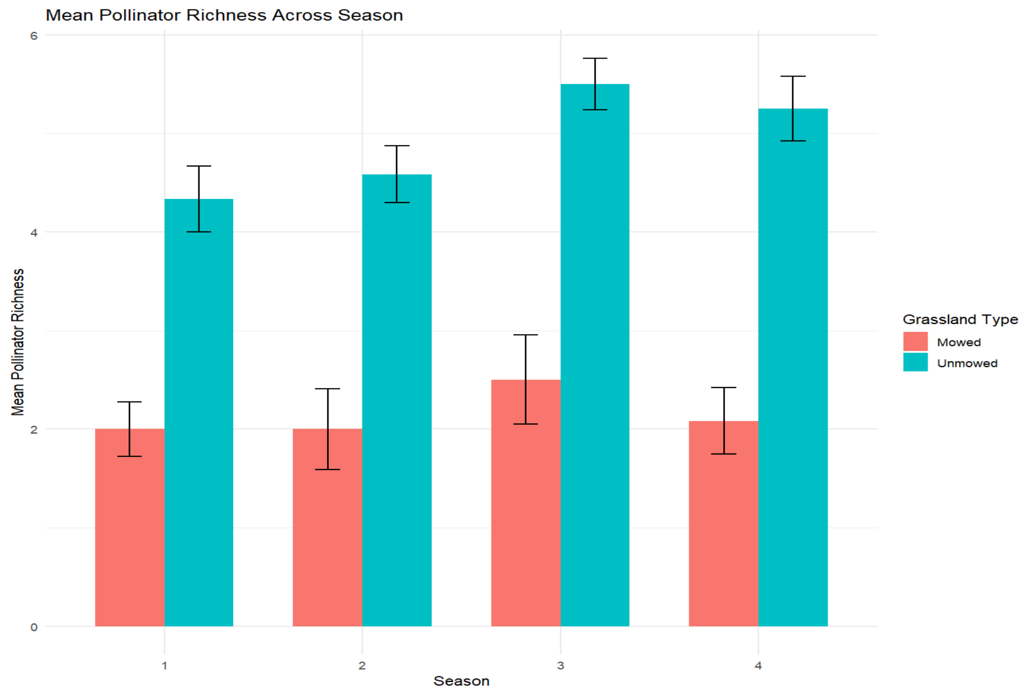


Figure 3.5: Mean pollinator richness across different seasons in mowed and unmowed grassland types

3.4 Pollinator abundance

A total of 1,473 pollinator individuals were counted in the unmowed areas and 190 pollinator individuals in the mowed areas. Specifically, bumblebee individuals accounted for 320 of the pollinators in unmowed areas and 47 in mowed areas. 31 butterfly individuals were found in unmowed grasslands, while 10 were found in mowed grasslands. The most abundant pollinators for each Season and grassland type are given in the table below:

Table 3.6: Most abundant pollinators with their total count in each season and grassland types

Season	Grassland type	Most abundant Pollinator	Count
1	Mowed	Flies	25
1	Unmowed	Flies	79
2	Mowed	Bumblebees	19
2	Unmowed	Bumblebees	87
3	Mowed	Flies	16
3	Unmowed	Hoverflies	432
4	Mowed	Flies	16
4	Unmowed	Bumblebees	108

Effect of Season and Grassland management on Pollinator abundance

The fitted GLMM model revealed a significant effect of grassland management on pollinator abundance. In comparison to mowed grassland, the unmowed grassland type had significantly higher pollinator abundance ($p < 2.21e-12$).
In terms of seasonal impact, season 2 ($p = 0.591$) and season 4 ($p = 0.170$) did not show a significant change in pollinator abundance when compared to season 1. The third season, on the other hand, showed a significant rise in pollinator abundance ($p < 6.10e-07$). The random

effects of sites showed some minimal variation (variance= 0.01192, std dev.= 0.1092). The post-hoc analysis showed significant differences in the pollinator abundance between several seasons. Notably, season 1 showed significantly lower abundance than season 3 ($p < 0.0001$), and season 2 also had significantly less abundance compared to season 3 ($p = 0.0001$). Season 3 showed greater abundance compared to season 4($p = 0.0013$). No significant differences were observed between season 1 and season 2 ($p < 0.9500$), season 1 and season 4 ($p < 0.5174$), season 2 and season 4 ($p < 0.8398$).

Table 3.7: Results from fixed effect of GLMM predicting pollinator abundance. Values include estimate, standard error, z-value, and p-value.

Predictors	**Estimate**	**Std. Error**	**z value**	**p value**
Intercept	1.0356	0.1721	6.016	<0.001***
Season 2	0.1096	0.2040	0.537	0.591
Season 3	0.9537	0.1912	4.988	<0.001***
Season 4	0.2731	0.1991	1.371	0.170
Grasslandtype Unmowed	1.8973	0.1432	13.247	<0.001***

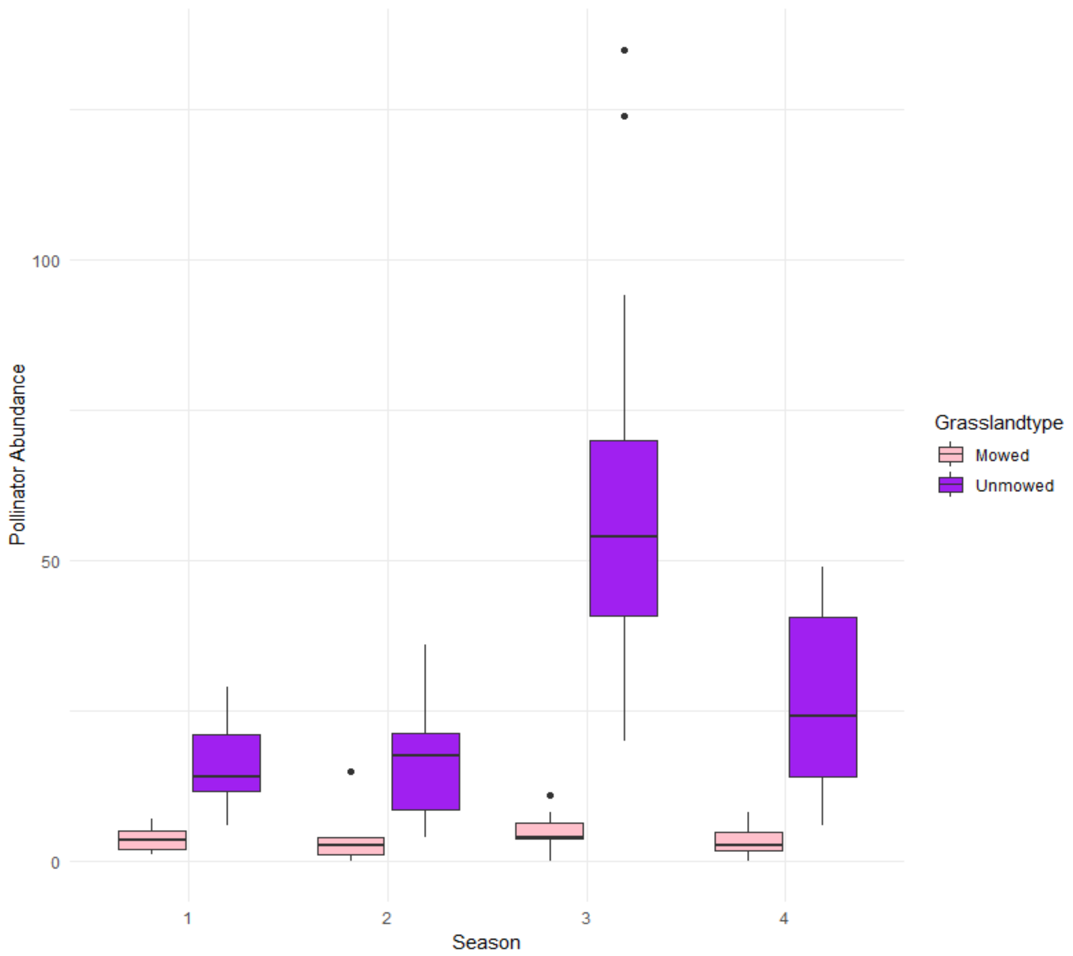


Figure 3.6: Transect level pollinator abundance across seasons with mowed and unmowed grassland types

3.5 Bumblebee Species Richness and Abundance

Bumblebee species richness

Total 6 bumblebee species: *Bombus lucorum, Bombus hypnorum, Bombus lapidaries, Bombus pascuorum, Bombus sylvestris* and *Bombus hortorum* were observed over all field periods. Within unmowed grassland types, all 6 species were identified, whereas in mowed grassland types 5 species were observed except *Bombus hortorum*.
The presence and absence of each bumblebee species in mowed and unmowed grassland types are shown in Table 3.4 and across the four seasons are shown below in Table 3.8:

Table 3.8: Presence or absence of bumblebee species in different seasons

Species	Season 1	Season 2	Season 3	Season 4
Bombus lucorum	✓	✓	✓	✓
Bombus hypnorum		✓	✓	✓
Bombus lapidaries	✓	✓	✓	✓
Bombus pascuorum	✓	✓	✓	✓
Bombus sylvestris		✓	✓	
Bombus hortorum		✓	✓	✓

Effect of Season and Grassland Management on Bumblebee Species Richness

The statistical finding on bumblebee species richness showed that the species richness was significantly higher in unmowed grasslands ($p < 1.51e-07$) compared to the mowed grasslands. Seasonal effects on bumblebee richness were also notable. Each season compared to season 1, showed a statistically significant increase in bumblebee species richness. Season 2 recorded a significant rise ($p < 2.65e-05$), and this pattern continued to be significant in season 3 ($p < 3.57e-05$) and season 4 ($p < 0.000168$). The effects are slightly stronger in season 2 and season 3. Site variability indicated some differences in bumblebee richness between sites (variance=0.1318, Std deviation= 0.363).

The post-hoc test on comparing seasons 2, 3 and 4 with each other, revealed there are no evidence to suggest that the bumblebee richness is significantly different when comparing Season 2, 3, 4 with each other.

Table 3.9 : Results from fixed effects of GLMM predicting bumblebee species richness. Values include estimate, standard error, z-value, and p-value

Predictors	Estimate	Std. Error	z value	p value
Intercept	-2.1879	0.4673	-4.682	<0.001***
Season 2	1.8458	0.4393	4.202	<0.001***
Season 3	1.8192	0.4401	4.133	<0.001***
Season 4	1.6740	0.4449	3.763	<0.001***
Grasslandtype Unmowed	1.1585	0.2206	5.252	<0.001***

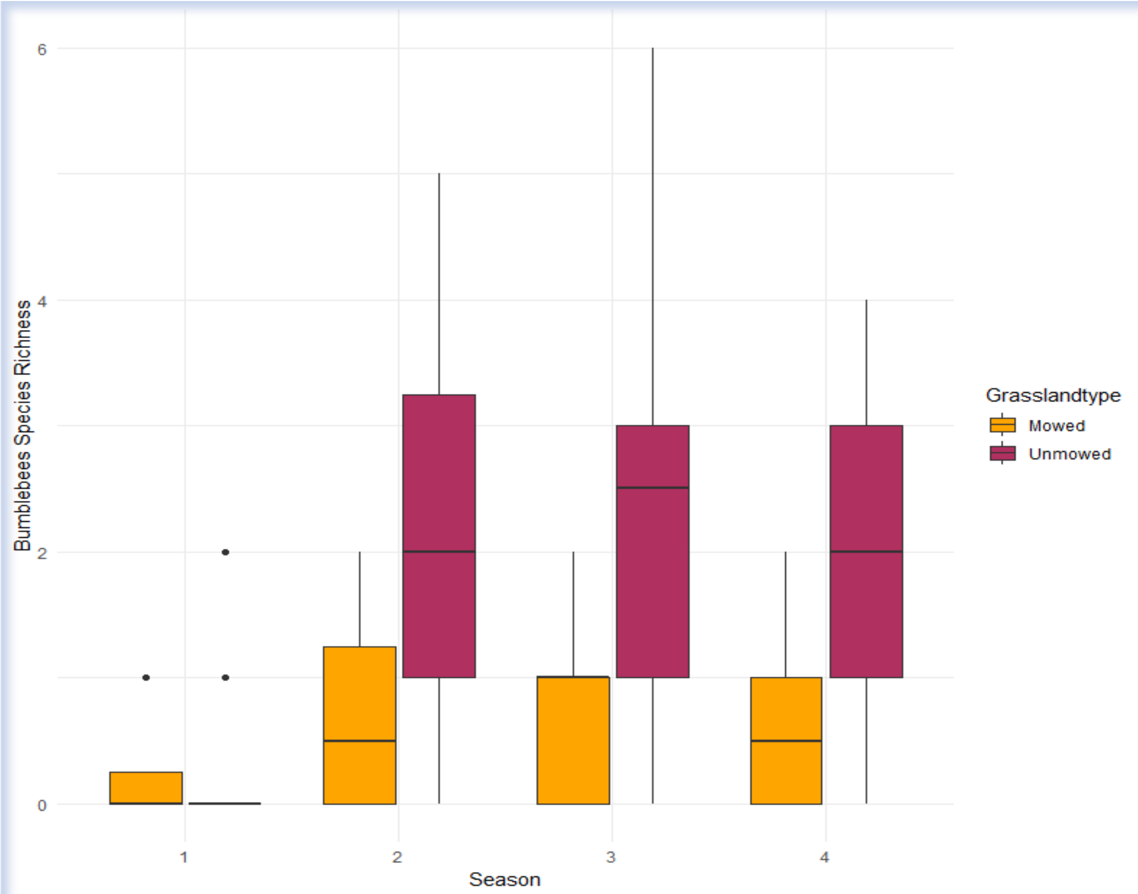


Figure 3.7: Transect level bumblebees species richness across different seasons for mowed and unmowed grassland types

Bumblebee Abundance

The most abundant bumblebee species for each combination of Season and grassland type are given below:

Table 3.10:Most abundant bumblebee species and their count with each season and grassland types

Season	Grassland Type	Most abundant species	Count
1	Mowed	*Bombus_lucorum*	3
1	Unmowed	*Bombus pascuorum*	3
2	Mowed	*Bombus lucorum*	14
2	Unmowed	*Bombus lucorum*	43
3	Mowed	*Bombus lucorum*	5
3	Unmowed	*Bombus lucorum*	48
4	Mowed	*Bombus lucorum*	5
4	Unmowed	*Bombus lucorum*	47

Effect of Season and Grassland Management on Bumblebee Abundance

Statistical analysis revealed that both the grassland management type and season significantly influence the bumblebee abundance. Unmowed grassland areas support a higher abundance of bumblebees ($p < 1.51e-07$) compared to the mowed grasslands. Seasonal effects were also significant with each season exhibiting an increase in bumblebee abundance compared to season 1. Season 3 ($p < 3.34e-07$) and season 4 ($p < 5.56e-07$) show the strongest effects. Post-hoc tests revealed that there is no evidence to suggest that the bumblebee abundance is significantly different when comparing seasons 2, 3, 4 with each other. The results indicated that there is some variability in bumblebee abundance between sites (variance= 0.3947, Std deviation 0.6282).

Table 3.11: Results include fixed effects of GLMM predicting bumblebee abundance. Values include estimate, standard error, z-value, and p-value

Predictors		**Estimate**	**Std. Error**	**z value**	**p value**
Intercept		-1.9941	0.4942	-4.035	<0.001***
Season 2		2.1823	0.4386	4.976	<0.001***
Season 3		2.2170	0.4344	5.103	<0.001***
Season 4		2.1633	0.4322	5.006	<0.001***
Grasslandtype Unmowed		1.5952	0.2575	6.195	<0.001***

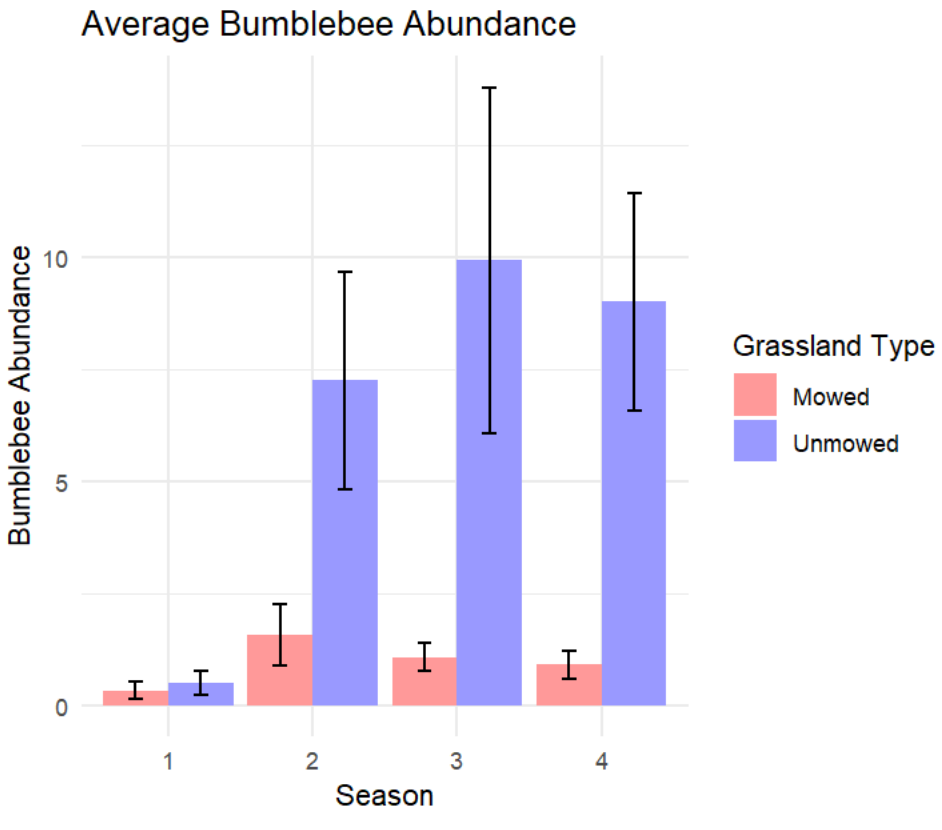


Figure 3.8: Transect level average bumblebee abundance with standard errors across seasons for mowed and unmowed grassland types

3.6 Plant-Pollinator Interaction

Overall, the most abundant flower visitor is Hoverflies, with a total 523 visits recorded in all seasons. There were no visits by hoverflies in season 1 but they interacted in Season 2 with most preferred *Leucanthemum vulgare*, the number of visits exceptionally peaked in season 3 with with most preferred *Stellaria graminea* and then the visits dropped in season 4 with most preferred *Leontodon autumnalis*.

In mowed grasslands, the pollinator's interaction with flowers is somewhat consistent with certain pollinators favoring specific plant species throughout the year. The most notable interactions includes:
Season 1: Honeybees were most frequent visitors of *Trifolium repens* and Flies on *Ranunculus bulbosus.*
Season 2: Honeybees continued their preference for *Trifolium repens* and also showed strong preference on *Prunella vulgaris*.
Season 3: Honeybees were observed predominantly on *Leontodon autumnalis*, with Hoverflies primarily visiting *Trifolium repens*.
Season 4: Hoverflies become the most visitors to *Leontodon autumnalis*

In unmowed grasslands, more complex interactions were noted, with different pollinators preferring different plant species across the seasons. The most notable interactions include:
Season 1: Flies were the primary visitors to the variety of flowers of plant including *Achillea millefolium, Alchemilla* and *Cardamine*. Honeybees showed a significant preference for legume species such as *Trifolium repens* and various *Vicia* species.
Season 2: Honeybees dominating the interactions with most of the plant species, with Hoverflies visiting *Leucanthemum vulgare* among others.
Season 3: Season 3 witnessed exceptionally high plant-pollinator interactions. Hoverflies became more prevalent, visiting a wide range of plants specially *Stellaria graminae*, whereas honeeybees continued their frequent visits to species like *Anthyllis vulneraria* and *Cirsium arvense.*
Season 4: With honeybees and hoverflies, wasps beginning to show significant interactions particularly with *Cirsium arvense* and *Euphrasia stricta.*

Total plant-pollinator interaction was highest in Ringve I site, followed by Dragvoll site whereas lowest in Ringve II. Site wise visualization on plant-pollinator interaction across seasons is provided in Appendix C.

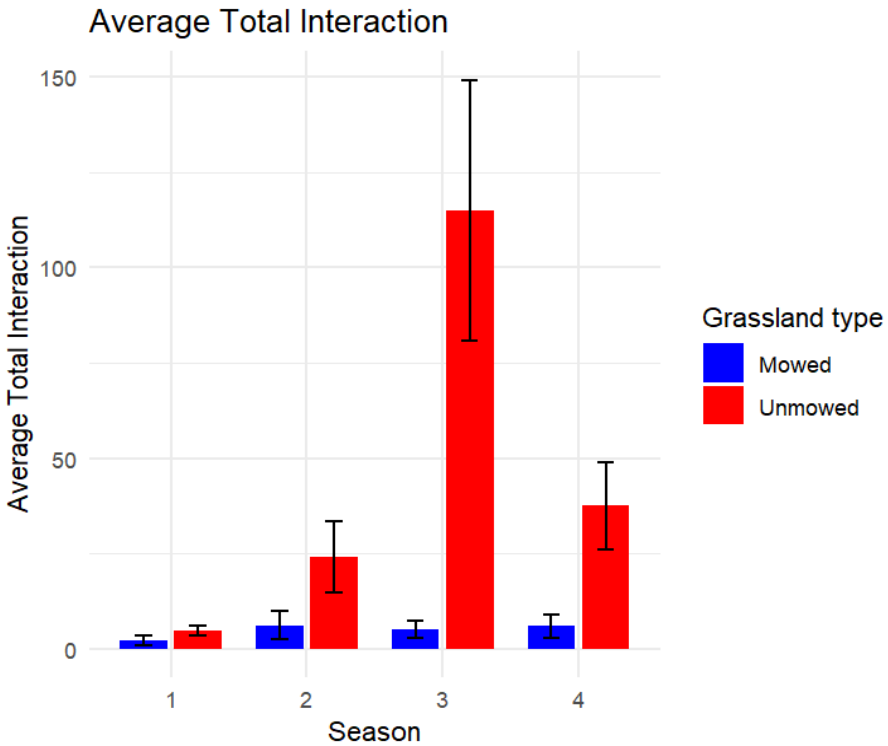
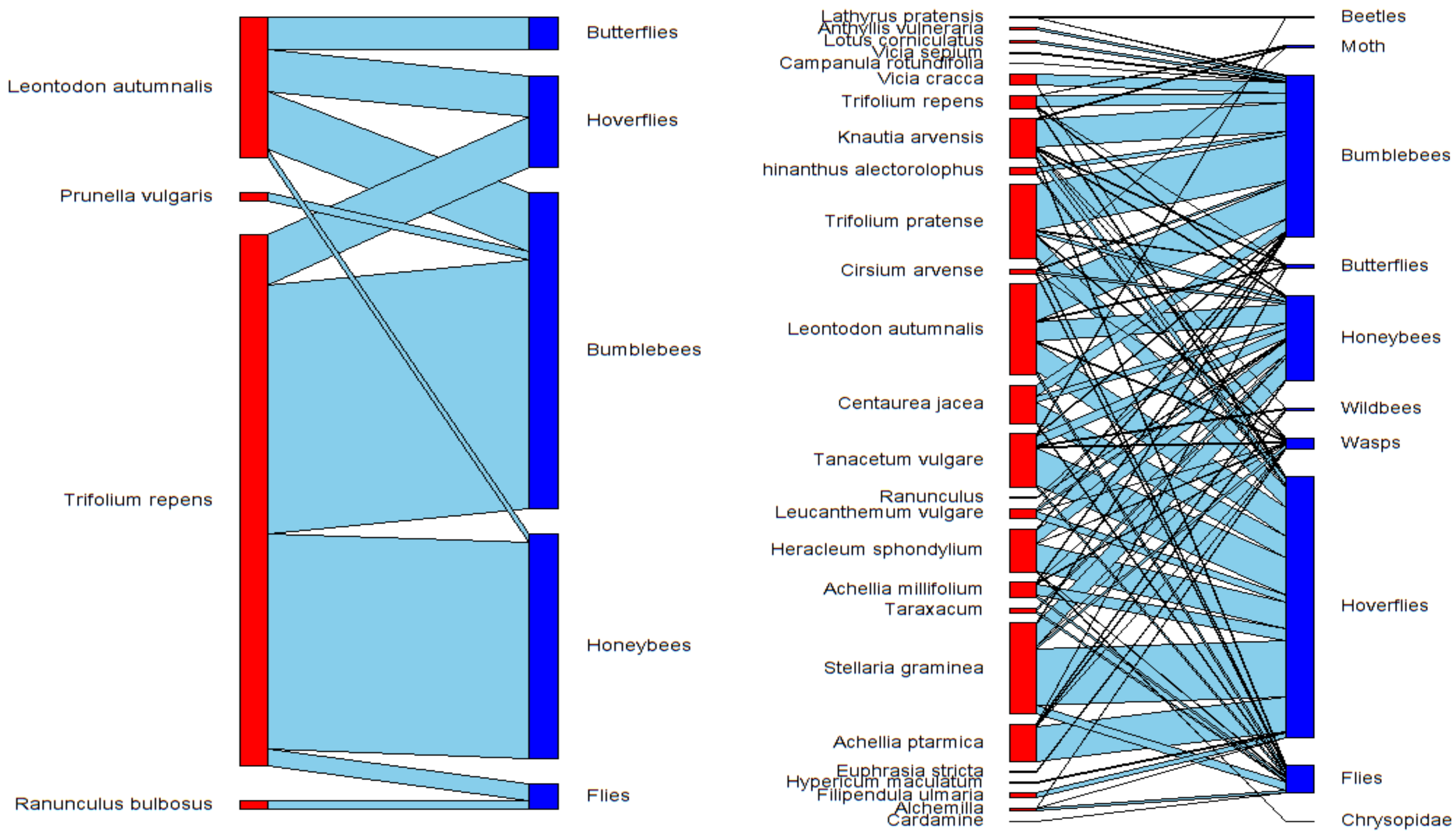


Figure 3.9: Site level average total plant-pollinator interactions with standard error across different seasons for mowed and unmowed grassland types

The plant-pollinator interaction networks in mowed and unmowed grasslands as well as season wise networks are shown in *Figure 3.10* and *Figure 3.11* respectively.



(a)

(b.)

Figure 3.10: Plant-pollinator interaction network in a.Mowed grasslands b. Unmowed grasslands. Size of each species is relative to proportion of observations. Size of connecting lines are relative to proportion of interaction with the connected species

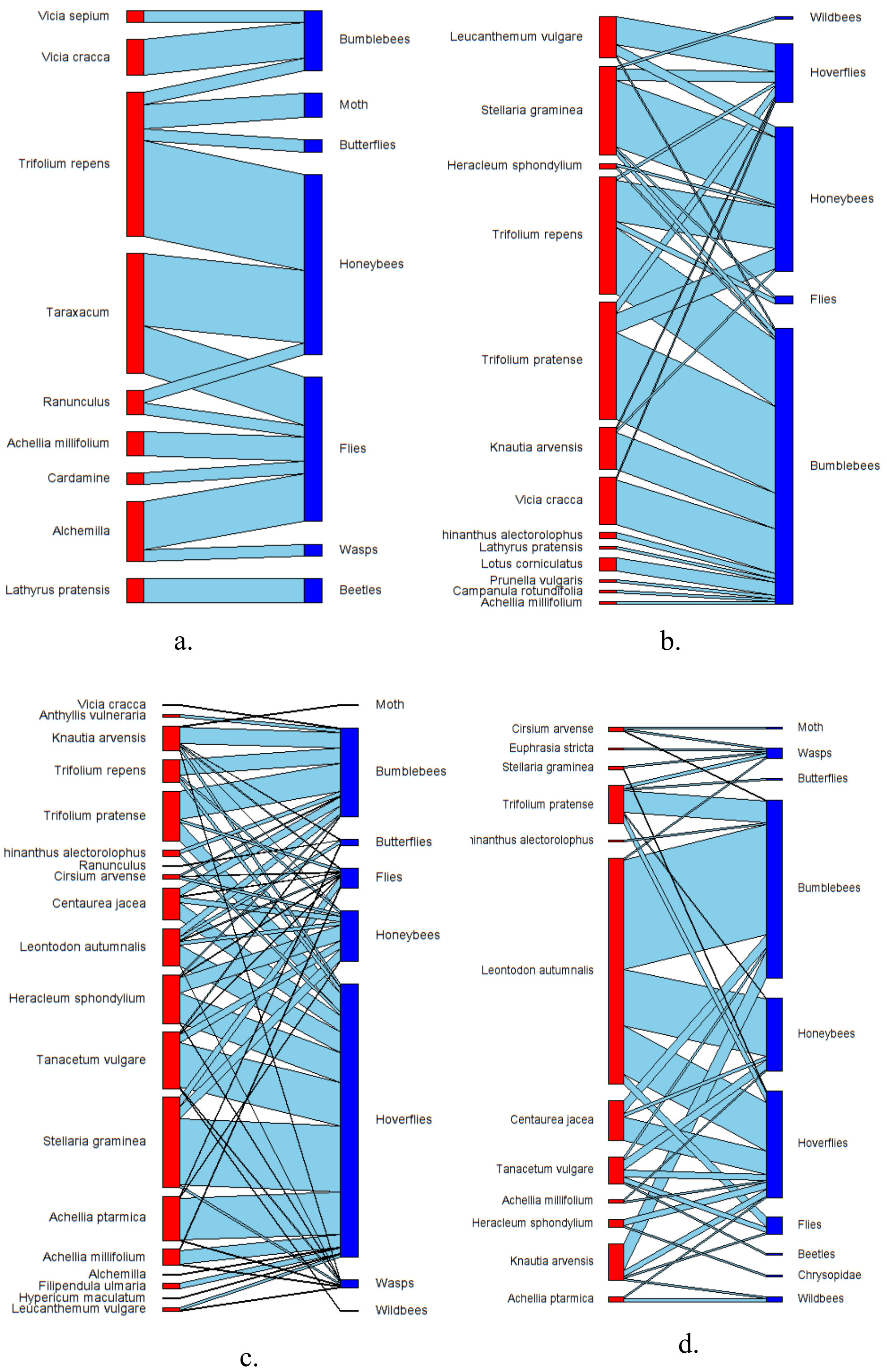


Figure 3.11: Plant-pollinator interaction network of both mowed and unmowed grasslands in a. Mid-June, b. Early-July, c.Late-July, d. Mid-August. Size of each species is relative to proportion of observations. Size of connecting lines are relative to proportion of interaction with the connected species

4. Discussion

This study aimed to investigate the impact of mowing practices on species richness and abundance of flowering plants and pollinators within urban grasslands and to determine how these change with seasons. The results showed as hypothesized that unmowed grasslands have much higher richness and abundance of both plants and pollinators compared to those that are regularly mowed. Additionally, the research found that there are seasonal fluctuations in species richness, abundance, and interaction between pollinator activity. These findings highlight that plant-pollinator richness, abundance and their interaction are greatly influenced by grassland management practice and season.

Influence of Grassland Management and Season

Flowering plants

Flowering plant species richness was significantly affected by grassland type and season. As hypothesized, unmowed grassland type was associated with significantly high plant richness. Unmowed grassland tends to support high biodiversity because it provides a variety of microhabitats and structural heterogeneity. Also, the unmowed grasslands are less disturbed allowing flowering plants to complete their entire life cycle from germination to seed dispersal. Unmowed areas typically accumulate a richer seed bank as seeds are allowed to fall naturally and are less likely to be removed or destroyed by mowing equipment. Findings from this study align with the previous studies indicating that grasslands subjected to less frequent mowing exhibited a 30% increase in plant species diversity compared to those under intensive management (Sehrt et al., 2020). Another study highlighted that mowing reduced herbaceous flowering plant richness while only improving the grass species richness (Fynn et al., 2004). However, the study on the grassland management practice by (Bonari et al., 2017) suggests that regular mowing, particularly when combined with mixed management strategies like temporary abandonment of certain patches appears to support high plant species richness. Another study of meta-analysis concluded that once-a-year mowing practice increases species richness by approximately 32 % compared to no mowing at all, but the response can vary significantly depending on specific environment and management contexts (Piseddu et al., 2021).

Season 2 (early July) showed a higher number of plant richness followed by season 3 (late July) and lowest on season 4 (mid-August). This might be because early to late July might be the peak growing season for many flowering plant species to flower where conditions such as temperature and daylight hours are optimal for growth and reproduction. In contrast, some species might be senesced as the season progresses towards Autumn. The study by (Yan et al., 2023) supports that plant species richness was highest in spring, then in summer, and lowest in autumn. Grasslands may show peak species richness under conditions of moderate resource availability, which could vary seasonally depending on rainfall and temperature (Cornwell & Grubb, 2003). Flowering plant species richness was relatively similar across the Leangen gård, Dragvoll, Gløshaugen II and Ringve I sites, with Ringve I exhibiting the highest flowering plant richness. In contrast, Gløshaugen I and Ringve II had lower plant richness than the other mentioned sites.

Flower abundance followed a similar pattern as flowering plant richness since flower abundance and flowering plant richness were correlated. It was impacted by grassland types and seasons. Unmowed grassland had significantly higher flower abundance than mowed. The significant increase in flower abundance in unmowed is because unmowed grassland had higher flowering plant richness that ultimately led to higher numbers of flowers to bloom. According to Noordijk et al., 2009, mowing once or twice a year with hay removal resulted in the highest levels of flower abundance throughout the growing seasons. The flower abundance was significantly high in season 2 followed by season 3 and lowest in season 4. There was some variance in flower abundance across Sites. Dragvoll and Ringve I site had a higher flower abundance whereas Gløshaugen I and Ringve II had a lower flower abundance. This might be because of different sites facing in different directions which might affect the amount of sunlight each site receives, also maybe because of the shading effect of tall trees in the Ringve II site.

Pollinators

Pollinator richness varied significantly with grassland type. Consistent with the hypothesis, the unmowed grassland type had higher pollinator richness than the mowed ones. The mixture of grasses, flowers, and layered vegetation structure favors pollinators with nesting opportunities. The increased structural diversity in unmowed grasslands supports a wider range of pollinators which play a crucial role in pollination. Mowing less frequently and not mowing the entire area rather mowing partially in the area on urban lawns attracts more diverse insects as well as improves their reproduction (Wintergerst et al., 2021). Sections of lawns that are left unmowed have higher species richness of pollinators like bees, butterflies, and moths (Bonari et al., 2017). Seasonal variation in pollinator richness showed the highest richness in season 3, with not much variability in other seasons. This is because many flowering plants were at their peak flowering period with maximum bloom in late July, especially in unmowed areas, which directly corelates with higher pollinator activity. According to (Glaum et al., 2021), the temporal overlap of peak flowering periods with peak pollinator activity is a critical factor in maximizing pollinator richness. This might be because of the moderate temperature and relatively lower rainfall in late July, which are important conditions for pollinators like bees and butterflies. May pollinators have life cycles that are synchronized with specific flowering periods. Late July may coincide with the adult phase of several pollinators, who are actively foraging to gather food and resources for reproduction. There was not much variability in pollinator richness across different sites. Dragvoll and Ringve-I had maximum pollinator richness with 7 distinct types of pollinator groups whereas all other sites 6 distinct types of pollinator groups.

Pollinator abundance showed consistent trend where unmowed grasslands had a significantly higher abundance of all pollinator groups and it varied with Seasons. Frequent mowing disrupts the natural habitats of many pollinators, removing food sources and nesting materials, whereas less disturbed unmowed grassland type allows pollinator to complete their life cycles. Greater availability of floral abundance and flowering plant species richness lead to higher pollinator abundance in Unmowed grasslands. The decreased habitat disturbance correlates with increased biodiversity, particularly for pollinator species (Lerman et al., 2018). Studies have documented that plant species richness enhances pollinator richness and abundance by providing diverse habitats and extended blooming periods (Potts et al., 2003).

Flies were more abundant in the earlier season; bumblebees were dominant pollinators in season 2 and season 4 and hoverflies showed an extraordinary peak in season 3 in unmowed grasslands, which might be linked to specific environmental conditions and their floral preference during late July. The total butterflies count was less than expected. Only 41 individuals of three species of butterflies were encountered during all field seasons.

Interestingly all the other sites had very little butterfly activity except Leangen gård. Leangen gård seems to be a hotspot for butterflies, particularly in the 3rd season. This might be because Leangen gård lies a little far away from the main city spot and the surrounding spaces with shrubs, trees, and open space might have created a favorable place for butterflies.

Bumblebees

As hypothesized, unmowed grassland types support a significantly higher richness and abundance of bumblebees compared to mowed grasslands. The complex and continuous variety availability of more floral resources in unmowed grasslands might have provided optimal conditions for nesting and foraging of bumblebees and therefore more bumblebees were found. The seasonal variations in bumblebee richness with peaks during mid to late summer (season 2 and 3) highlight how bumblebee life cycles coincide with the times when flowers are most abundant. The availability of flowering plants is crucial for growth and establishment of bumblebee colonies (Glaum et al., 2021). The bumblebee's abundance fluctuates over different seasons, it showed an increasing trend along the seasons with more abundance in seasons 3 and 4. This is quite interesting because flower abundance decreased in season 4, and bumblebees were still more abundant. This finding coincides with the finding by (Lerman et al., 2018) reveals that higher floral abundance resulting from less mowing doesn't necessarily lead to higher bee abundance, which was observed in lawn mowed every two weeks. *Bombus_lucorum* was the most found bumblebee species whereas *Bombus_sylvestris* was least found bumblebee species. Both bumblebee's abundance and richness varied greatly with the sites. The highest richness and abundance were found in Ringve I site which was followed by Leangen gård and Dragvoll respectively. This might be because these Sites had a consistently great variety of colorful flowers favored by bumblebees throughout the seasons, unlike other sites.

Plant-Pollinator Interaction

As hypothesized, more complex interactions were found in unmowed grasslands. A greater variety of flowering plants such as *Achillea millefolium, Cardamine pratensis* attracted different pollinators such as flies early in the season, and more honeybees, hoverflies, and bumblebee's interactions with different flowers became more prevalent as the season progressed. These findings align with previous studies suggesting that less disturbed areas can support more plant-pollinator interactions (Norfolk et al., 2015), due to the diversity of flower resources and pollinators.

In mowed grasslands, *Trifolium repens*, commonly known as white clover was consistently the most visited plant by honeybees and also bumblebees, suggesting that regular mowing might restrict other flowering plants to grow but fast recovering plants like clover dominate and continuously attract pollinators.

As the seasons changed, the variety of plants being visited also shifted. For example, later in season 3, plants like *Stellaria graminea* in unmowed grasslands became hotspots for hoverflies and bees reflecting seasonal changes in plant blooming can affect pollinator preferences.
Mowed grasslands, with their fewer types of flowering plants, mainly supported pollinators that can thrive in more uniform environments, such as honeybees. On the other hand, unmowed grasslands with their higher flower diversity and flower abundance supported a wider range of pollinators across the season. This suggests that mowing reduces the diversity of plant-pollinator interactions.

Management Implications and Recommendations

Norway encourages homeowners to reduce lawn mowing to support biodiversity, especially pollinators like bees and butterflies, and also encourages to keep gardens wilder (WWF, n.d.) The findings of this study show that urban grasslands that are unmowed (mowed only once or twice a year) enhance both plant and pollinator diversity. It is important to let grass grow longer by mowing less and not de-weeding the gardens which can benefit bees and other pollinators and support biodiversity (WWF, n.d.). Urban green space managers should consider adopting less frequent mowing schedules and strategically leaving more areas unmowed to promote biodiversity. This practice not only enhances biodiversity but is also cost-effective. This study also highlighted the seasons like- early and late July(season 2 and season 3) are important, where there is higher species richness and abundance of both plants and pollinators. Avoiding mowing at this peak season can be more effective. Since there should be a balance between aesthetic perspective and biodiversity enhancement perspective, rotational mowing of the larger green space could be an option, where certain selected areas are rotationally mowed in patches. Additionally, educating the public about the benefits of biodiversity in urban settings potentially increases community involvement in biodiversity conservation practices. Collaborative approaches between landowners, environmental organizations, and academic institutions could encourage joint research initiatives, funding for biodiversity projects, and shared management plans so that the management efforts from all levels align and also could establish long-term monitoring programs to track the outcomes of modified mowing practices on biodiversity. This would allow for the refinement of management strategies to more effectively support urban biodiversity in the long run.

Limitations

This study did not account for the habitats surrounding the areas like- buildings, or open space of the adjoining areas which can affect the microclimate and the movement and survival of the of the species. A large number of sites could have made the study stronger. Unfortunately, one of the proposed Sites was not included due to a misunderstanding with Trondheim municipality. Some of the countings on the pollinators might have been overestimated or underestimated because while walking along the transects for pollinator recording, some pollinator individuals might have been counted twice, whereas others might have been missed.

5. Conclusion

This study explored the impact of grassland management type and seasonal changes on the biodiversity of urban grasslands in Trondheim, Norway. Both grassland type and season significantly impacted the richness and abundance of plants, pollinators, and their interactions. Particularly, unmowed grasslands displayed much higher species richness and abundance of both flowering plants and pollinators. Mid-summer months, season 2 (early July) and season 3 (late July) exhibited higher richness and abundance of flowering plants and pollinators. Plant-pollinator interactions peaked in season 3 (late July).This research demonstrated that reducing mowing frequency (1 or 2 times a year) and avoiding mowing during peak seasons when there is higher plant-pollinator interaction enhances ecosystem functions like pollination, which is essential for urban green spaces. Urban landscape can greatly benefit from integrating these findings into management practices, such as modifying mowing schedules.

In summary, adopting less intensive grassland management practices such as reduced-frequency mowing and leaving certain areas unmowed can transform urban areas into biodiversity-rich areas, which eventually improves urban life quality and ecological resilience.

References

Abrahamczyk, S., Kluge, J., Gareca, Y., Reichle, S., & Kessler, M. (2011). The Influence of Climatic Seasonality on the Diversity of Different Tropical Pollinator Groups. *PLoS ONE*, *6*(11), e27115. https://doi.org/10.1371/journal.pone.0027115

Abrol, D. P. (2012). *Pollination Biology*. Springer Netherlands. https://doi.org/10.1007/978-94-007-1942-2

Banaszak-Cibicka, W., Ratyńska, H., & Dylewski, Ł. (2016). Features of urban green space favourable for large and diverse bee populations (Hymenoptera: Apoidea: Apiformes). *Urban Forestry & Urban Greening*, *20*, 448–452. https://doi.org/10.1016/j.ufug.2016.10.015

Betten, T. (n.d.). *Miljøutviklingsplan 2020-203*.

Bonari, G., Fajmon, K., Malenovský, I., Zelený, D., Holuša, J., Jongepierová, I., Kočárek, P., Konvička, O., Uřičář, J., & Chytrý, M. (2017). Management of semi-natural grasslands benefiting both plant and insect diversity: The importance of heterogeneity and tradition. *Agriculture, Ecosystems & Environment*, *246*, 243–252. https://doi.org/10.1016/j.agee.2017.06.010

Cervelli, E. W., Lundholm, J. T., & Du, X. (2013). Spontaneous urban vegetation and habitat heterogeneity in Xi'an, China. *Landscape and Urban Planning*, *120*, 25–33. https://doi.org/10.1016/j.landurbplan.2013.08.001

Cornwell, W. K., & Grubb, P. J. (2003). Regional and local patterns in plant species richness with respect to resource availability. *Oikos*, *100*(3), 417–428. https://doi.org/10.1034/j.1600-0706.2003.11697.x

Dalsgaard, B. (2020). Land-Use and Climate Impacts on Plant–Pollinator Interactions and Pollination Services. *Diversity*, *12*(5), 168. https://doi.org/10.3390/d12050168

Dar, S. A., Hassan, G. I., Padder, B. A., & Wani, A. R. (2017). *Pollination and evolution of plant and insect interaction*.

Davison, C. W., Rahbek, C., & Morueta-Holme, N. (2021). Land-use change and biodiversity: Challenges for assembling evidence on the greatest threat to nature. *Global Change Biology*, *27*(21), 5414–5429. https://doi.org/10.1111/gcb.15846

De Baan, L., Alkemade, R., & Koellner, T. (2013). Land use impacts on biodiversity in LCA: A global approach. *The International Journal of Life Cycle Assessment*, *18*(6), 1216–1230. https://doi.org/10.1007/s11367-012-0412-0

Deák, B., Hüse, B., & Tóthmérész, B. (2016). *Grassland vegetation in urban habitats – testing ecological theories* [PDF]. https://doi.org/10.14471/2016.36.017

Dhukuchhu, A. (2021). *Effects of land use and season on flowering plants and plant-pollinator networks in urban grasslands* [NTNU]. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2782478

Dormann, C. F., Fruend, J., Gruber, B., Beckett, S., Devoto, M., Felix, G. M. F., Iriondo, J. M., Opsahl, T., Pinheiro, R. B. P., Strauss, R., & Vazquez, D. P. (2023). *bipartite: Visualising Bipartite Networks and Calculating Some (Ecological) Indices* (2.19) [Computer software]. https://cran.r-project.org/web/packages/bipartite/index.html

Dylewski, Ł., Maćkowiak, Ł., & Banaszak-Cibicka, W. (2019). Are all urban green spaces a favourable habitat for pollinator communities? Bees, butterflies and hoverflies in different urban green areas. *Ecological Entomology*, *44*(5), 678–689. https://doi.org/10.1111/een.12744

Fynn, R. W. S., Morris, C. D., & Edwards, T. J. (2004). Effect of burning and mowing on grass and forb diversity in a long-term grassland experiment. *Applied Vegetation Science*, *7*(1), 1–10. https://doi.org/10.1111/j.1654-109X.2004.tb00589.x

Gallai, N., Salles, J.-M., Settele, J., & Vaissière, B. E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*, *68*(3), 810–821. https://doi.org/10.1016/j.ecolecon.2008.06.014

Glaum, P., Wood, T. J., Morris, J. R., & Valdovinos, F. S. (2021). Phenology and flowering overlap drive specialisation in plant–pollinator networks. *Ecology Letters*, *24*(12), 2648–2659. https://doi.org/10.1111/ele.13884

Gros, C., Bulot, A., Aviron, S., Beaujouan, V., & Daniel, H. (2023). Both management practices and landscape influence plant communities in urban grasslands. *Frontiers in Ecology and Evolution*, *11*, 1151913. https://doi.org/10.3389/fevo.2023.1151913

Groven, I. S. (2023). *The Buzz on Grassland Management: Effects of management on pollinators and their flower resources in semi-natural grasslands* [Master thesis, NTNU]. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/3080581

Gunnarsson, B., & Federsel, L. M. (2014). Bumblebees in the city: Abundance, species richness and diversity in two urban habitats. *Journal of Insect Conservation*, *18*(6), 1185–1191. https://doi.org/10.1007/s10841-014-9729-2

Hansson, M., & Fogelfors, H. (2000). Management of a semi-natural grassland; results from a 15-year-old experiment in southern Sweden. *Journal of Vegetation Science*, *11*(1), 31–38. https://doi.org/10.2307/3236772

Klaus, V. H. (2013). Urban Grassland Restoration: A Neglected Opportunity for Biodiversity Conservation. *Restoration Ecology*, *21*(6), 665–669. https://doi.org/10.1111/rec.12051

Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2006). *Importance of pollinators in changing landscapes for world crops*. https://doi.org/10.1098/rspb.2006.3721

Kowarik, I., Fischer, L. K., & Kendal, D. (2020). Biodiversity Conservation and Sustainable Urban Development. *Sustainability*, *12*(12), 4964. https://doi.org/10.3390/su12124964

Lerman, S. B., Contosta, A. R., Milam, J., & Bang, C. (2018). To mow or to mow less: Lawn mowing frequency affects bee abundance and diversity in suburban yards. *Biological Conservation*, *221*, 160–174. https://doi.org/10.1016/j.biocon.2018.01.025

Lizée, M.-H., Mauffrey, J.-F., Tatoni, T., & Deschamps-Cottin, M. (2011). Monitoring urban environments on the basis of biological traits. *Ecological Indicators*, *11*(2), 353–361. https://doi.org/10.1016/j.ecolind.2010.06.003

Noordijk, J., Delille, K., Schaffers, A. P., & Sýkora, K. V. (2009). Optimizing grassland management for flower-visiting insects in roadside verges. *Biological Conservation*, *142*(10), 2097–2103. https://doi.org/10.1016/j.biocon.2009.04.009

Norfolk, O., Eichhorn, M. P., & Gilbert, F. S. (2015). Contrasting patterns of turnover between plants, pollinators and their interactions. *Diversity and Distributions*, *21*(4), 405–415. https://doi.org/10.1111/ddi.12295

Ødegaard, F., Staverløkk, A., Gjershaug, J. O., Bengtson, R., & Mjelde, A. (2015). *Humler i*

Norge. Kjennetegn, utbredelse og levesett. Norsk institutt for naturforskning.

Oertli, S., Müller, A., & Dorn, S. (2005). Ecological and seasonal patterns in the diversity of a species-rich bee assemblage (Hymenoptera: Apoidea: Apiformes). *European Journal of Entomology*, *102*(1), 53–63. https://doi.org/10.14411/eje.2005.008

Onandia, G., Schittko, C., Ryo, M., Bernard-Verdier, M., Heger, T., Joshi, J., Kowarik, I., & Gessler, A. (2019). Ecosystem functioning in urban grasslands: The role of biodiversity, plant invasions and urbanization. *PLOS ONE*, *14*(11), e0225438. https://doi.org/10.1371/journal.pone.0225438

Petersen, T. K., Speed, J. D. M., Grøtan, V., & Austrheim, G. (2020). Urban aliens and threatened near-naturals: Land-cover affects the species richness of alien- and threatened species in an urban-rural setting. *Scientific Reports*, *10*(1), 8513. https://doi.org/10.1038/s41598-020-65459-2

Piseddu, F., Bellocchi, G., & Picon-Cochard, C. (2021). Mowing and warming effects on grassland species richness and harvested biomass: Meta-analyses. *Agronomy for Sustainable Development*, *41*(6), 74. https://doi.org/10.1007/s13593-021-00722-y

Politi Bertoncini, A., Machon, N., Pavoine, S., & Muratet, A. (2012). Local gardening practices shape urban lawn floristic communities. *Landscape and Urban Planning*, *105*(1–2), 53–61. https://doi.org/10.1016/j.landurbplan.2011.11.017

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology & Evolution*, *25*(6), 345–353. https://doi.org/10.1016/j.tree.2010.01.007

Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., Aizen, M. A., Biesmeijer, J. C., Breeze, T. D., Dicks, L. V., Garibaldi, L. A., Hill, R., Settele, J., & Vanbergen, A. J. (2016). Safeguarding pollinators and their values to human well-being. *Nature*, *540*(7632), 220–229. https://doi.org/10.1038/nature20588

Potts, S. G., Vulliamy, B., Dafni, A., Ne'eman, G., & Willmer, P. (2003). Linking Bees and Flowers: How Do Floral Communities Structure Pollinator Communities? *Ecology*, *84*(10), 2628–2642. https://doi.org/10.1890/02-0136

Property department—NTNU. (n.d.). Retrieved 4 May 2024, from https://www.ntnu.no/adm/eiendomsavdelingen

Rahimi, E., Barghjelveh, S., & Dong, P. (2022). Amount, distance-dependent and structural effects of forest patches on bees in agricultural landscapes. *Agriculture & Food Security*, *11*(1), 10. https://doi.org/10.1186/s40066-022-00360-x

Sehrt, M., Bossdorf, O., Freitag, M., & Bucharova, A. (2020). Less is more! Rapid increase in plant species richness after reduced mowing in urban grasslands. *Basic and Applied Ecology*, *42*, 47–53. https://doi.org/10.1016/j.baae.2019.10.008

Socher, S. A., Prati, D., Boch, S., Müller, J., Klaus, V. H., Hölzel, N., & Fischer, M. (2012). Direct and productivity-mediated indirect effects of fertilization, mowing and grazing on grassland species richness. *Journal of Ecology*, *100*(6), 1391–1399. https://doi.org/10.1111/j.1365-2745.2012.02020.x

Torrez, V. C., B. Beauzay, P., McGinnis, E. E., Knudson, A. H., Laschkewitsch, B., Hatterman-Valenti, H., & Knodel, J. J. (2023). Pollinators and Other Insect Visitations on Native and Ornamental Perennials in Two Landscapes. *HortScience*, *58*(8), 922–934. https://doi.org/10.21273/HORTSCI17146-23

Tøtland, Ø., Ødegaard, F., & Åström, J. (2013). *Kunnskapsstatus for insektpollinering i Norge– betydningen av det komplekse samspillet mellom planter og insekter*. https://www.nina.no/archive/nina/pppbasepdf/B%C3%B8ker/%C3%98degaard%20Pollineringsrapporten%20Artsdatabanken%202013.pdf

Trondheim bydrift. (n.d.). Trondheim Kommune. Retrieved 4 May 2024, from https://www.trondheim.kommune.no/org/byutvikling/trondheim-bydrift/

Trondheim climate: Average Temperature by month, Trondheim water temperature. (n.d.). Retrieved 4 May 2024, from https://en.climate-data.org/europe/norway/s%C3%B8r-tr%C3%B8ndelag/trondheim-707/

Valkó, O., Török, P., Matus, G., & Tóthmérész, B. (2012). Is regular mowing the most appropriate and cost-effective management maintaining diversity and biomass of target forbs in mountain hay meadows? *Flora - Morphology, Distribution, Functional Ecology of Plants*, *207*(4), 303–309. https://doi.org/10.1016/j.flora.2012.02.003

Wastian, L., Unterweger, P. A., & Betz, O. (2016). Influence of the reduction of urban lawn mowing on wild bee diversity (Hymenoptera, Apoidea). *Journal of Hymenoptera Research*, *49*, 51–63. https://doi.org/10.3897/JHR.49.7929

Watson, C. J., Carignan-Guillemette, L., Turcotte, C., Maire, V., & Proulx, R. (2020). Ecological and economic benefits of low-intensity urban lawn management. *Journal of Applied Ecology*, *57*(2), 436–446. https://doi.org/10.1111/1365-2664.13542

Weiner, C. N., Werner, M., Linsenmair, K. E., & Blüthgen, N. (2014). Land-use impacts on plant–pollinator networks: Interaction strength and specialization predict pollinator declines. *Ecology*, *95*(2), 466–474. https://doi.org/10.1890/13-0436.1

Wenzel, A., Grass, I., Belavadi, V. V., & Tscharntke, T. (2020). How urbanization is driving pollinator diversity and pollination – A systematic review. *Biological Conservation*, *241*, 108321. https://doi.org/10.1016/j.biocon.2019.108321

Willmer, P. (n.d.). *Pollination and Floral Ecology*.

Winfree, R., Bartomeus, I., & Cariveau, D. P. (2011). Native Pollinators in Anthropogenic Habitats. *Annual Review of Ecology, Evolution, and Systematics*, *42*(1), 1–22. https://doi.org/10.1146/annurev-ecolsys-102710-145042

Wintergerst, J., Kästner, T., Bartel, M., Schmidt, C., & Nuss, M. (2021). Partial mowing of urban lawns supports higher abundances and diversities of insects. *Journal of Insect Conservation*, *25*(5–6), 797–808. https://doi.org/10.1007/s10841-021-00331-w

WWF. (n.d.). *5 tips on turning your garden into a wildlife haven*. https://www.wwf.org.uk/updates/5-tips-turning-your-garden-wildlife-haven

Yan, P., Lu, X., Li, W., Zhang, J., Li, P., Li, Y., Wang, K., & Ding, S. (2023). Seasonal Variations in Plant Species Diversity and Phylogenetic Diversity in Abandoned Farmland of China's Huang–Huai Plain. *Diversity*, *15*(8), 922. https://doi.org/10.3390/d15080922

Appendices

Appendix A: Supplementary flowering plant data

Table A1: List of the flowering plants with their abundance in mowed and unmowed areas

Period	Site	Flowering plant name	Family	Unmowed	Mowed
Mid-June	Gløshaugen I	*Alchemilla vulgaris*	Rosaceae	1	2
Mid-June	Gløshaugen I	*Cerastium fontanum*	Caryophyllaceae	2	9
Mid-June	Gløshaugen I	*Taraxacum officinale*	Asteraceae	0	1
Mid-June	Gløshaugen I	*Vicia sepium*	Fabaceae	7	0
Early-July	Gløshaugen I	*Cerastium fontanum*	Caryophyllaceae	0	4
Late-July	Gløshaugen I	*Achillea millefolium*	Asteraceae	3	0
Late-July	Gløshaugen I	*Alchemilla vulgaris*	Rosaceae	6	0
Late-July	Gløshaugen I	*Cirsium heterophyllum*	Asteraceae	1	0
Late-July	Gløshaugen I	*Stellaria graminae*	Caryophyllaceae	19	0
Late-July	Gløshaugen I	*Tanacetum vulgare*	Asteraceae	1	0
Late-July	Gløshaugen I	*Trifolium pratense*	Fabaceae	2	0
Late-July	Gløshaugen I	*Trifolium repens*	Fabaceae	0	10
Mid-August	Gløshaugen I	*Achillea millefolium*	Asteraceae	7	0
Mid-August	Gløshaugen I	*Cirsium arvense*	Asteraceae	1	0
Mid-August	Gløshaugen I	*Leontodon autumnalis*	Asteraceae	1	9
Mid-August	Gløshaugen I	*Tanacetum vulgare*	Asteraceae	5	0
Mid-June	Gløshaugen II	*Alchemilla vulgaris*	Rosaceae	99	0
Mid-June	Gløshaugen II	*Cardamine pratensis*	Brassicaceae	7	0
Mid-June	Gløshaugen II	*Cerastium fontanum*	Caryophyllaceae	0	6
Mid-June	Gløshaugen II	*Geum rivale*	Rosaceae	2	0
Mid-June	Gløshaugen II	*Potentilla erecta*	Rosaceae	2	0
Mid-June	Gløshaugen II	*Ranunculus bulbosus*	Ranunculaceae	10	3
Mid-June	Gløshaugen II	*Rumex acetosa*	Polygonaceae	12	0
Mid-June	Gløshaugen II	*Taraxacum officinale*	Asteraceae	2	0
Mid-June	Gløshaugen II	*Trifolium repens*	Fabaceae	0	9
Early-July	Gløshaugen II	*Alchemilla vulgaris*	Rosaceae	19	0
Early-July	Gløshaugen II	*Cerastium fontanum*	Caryophyllaceae	0	3
Early-July	Gløshaugen II	*Prunella vulgaris*	Lamiaceae	0	13
Early-July	Gløshaugen II	*Ranunculus bulbosus*	Ranunculaceae	0	1
Early-July	Gløshaugen II	*Rumex acetosa*	Polygonaceae	20	0
Early-July	Gløshaugen II	*Stellaria gramінea*	Caryophyllaceae	27	0
Early-July	Gløshaugen II	*Trifolium repens*	Fabaceae	2	70
Early-July	Gløshaugen II	*Vicia cracca*	Fabaceae	1	0
Late-July	Gløshaugen II	*Achillea ptarmica*	Asteraceae	1	0
Late-July	Gløshaugen II	*Alchemilla vulgaris*	Rosaceae	12	0

Late-July	Gløshaugen II	*Stellaria graminae*	Caryophyllaceae	7	0
Late-July	Gløshaugen II	*Trifolium repens*	Fabaceae	0	2
Mid-August	Gløshaugen II	*Achillea ptarmica*	Asteraceae	6	0
Mid-August	Gløshaugen II	*Alchemilla vulgaris*	Rosaceae	2	0
Mid-August	Gløshaugen II	*Leontodon autumnalis*	Asteraceae	16	1
Mid-August	Gløshaugen II	*Stellaria graminae*	Caryophyllaceae	3	0
Mid-June	Dragvoll	*Alchemilla vulgaris*	Rosaceae	32	21
Mid-June	Dragvoll	*Rumex acetosa*	Polygonaceae	1	0
Mid-June	Dragvoll	*Taraxacum officinale*	Asteraceae	0	0
Mid-June	Dragvoll	*Vicia sepium*	Fabaceae	12	0
Early-July	Dragvoll	*Alchemilla vulgaris*	Rosaceae	39	0
Early-July	Dragvoll	*Campanula rotundifolia*	Campanulaceae	1	0
Early-July	Dragvoll	*Stellaria graminea*	Caryophyllaceae	68	0
Early-July	Dragvoll	*Trifolium pratense*	Fabaceae	3	0
Early-July	Dragvoll	*Trifolium repens*	Fabaceae	25	8
Early-July	Dragvoll	*Vicia cracca*	Fabaceae	2	0
Late-July	Dragvoll	*Achillea millefolium*	Asteraceae	3	0
Late-July	Dragvoll	*Achillea ptarmica*	Asteraceae	9	0
Late-July	Dragvoll	*Alchemilla vulgaris*	Rosaceae	33	2
Late-July	Dragvoll	*Campanula rotundifolia*	Campanulaceae	6	0
Late-July	Dragvoll	*Cerastium fontanum*	Caryophyllaceae	0	1
Late-July	Dragvoll	*Euphrasia stricta*	Orobanchaceae	7	0
Late-July	Dragvoll	*Leontodon autumnalis*	Asteraceae	0	0
Late-July	Dragvoll	*Stellaria graminae*	Caryophyllaceae	72	0
Late-July	Dragvoll	*Trifolium repens*	Fabaceae	1	25
Mid-August	Dragvoll	*Achillea millefolium*	Asteraceae	6	0
Mid-August	Dragvoll	*Achillea ptarmica*	Asteraceae	10	0
Mid-August	Dragvoll	*Alchemilla vulgaris*	Rosaceae	0	3
Mid-August	Dragvoll	*Euphrasia stricta*	Orobanchaceae	5	0
Mid-August	Dragvoll	*Leontodon autumnalis*	Asteraceae	17	0
Mid-August	Dragvoll	*Stellaria graminae*	Caryophyllaceae	17	0
Mid-August	Dragvoll	*Trifolium repens*	Fabaceae	0	1
Mid-June	Ringve I	*Alchemilla vulgaris*	Rosaceae	2	1
Mid-June	Ringve I	*Cerastium arvense*	Caryophyllaceae	0	3
Mid-June	Ringve I	*Taraxacum officinale*	Asteraceae	61	2
Mid-June	Ringve I	*Veronica serpyllifolia*	Plantaginaceae	1	0
Early-July	Ringve I	*Leucanthemum vulgare*	Asteraceae	36	0
Early-July	Ringve I	*Lotus corniculatus*	Fabaceae	22	0
Early-July	Ringve I	*Stellaria media*	Caryophyllaceae	0	9
Early-July	Ringve I	*Trifolium pratense*	Fabaceae	25	0
Early-July	Ringve I	*Trifolium repens*	Fabaceae	0	21

Early-July	Ringve I	*Vicia cracca*	Fabaceae	40	0
Late-July	Ringve I	*Anthyllis vulneraria*	Fabaceae	11	0
Late-July	Ringve I	*Centaurea jacea*	Asteraceae	10	0
Late-July	Ringve I	*Knautica arvensis*	Caprifoliaceae	10	0
Late-July	Ringve I	*Leucanthemum vulgare*	Asteraceae	15	0
Late-July	Ringve I	*Stellaria media*	Caryophyllaceae	0	11
Late-July	Ringve I	*Tanacetum vulgare*	Asteraceae	3	0
Late-July	Ringve I	*Trifolium pratense*	Fabaceae	53	0
Late-July	Ringve I	*Trifolium repens*	Fabaceae	0	11
Late-July	Ringve I	*Vicia cracca*	Fabaceae	2	0
Mid-August	Ringve I	*Centaurea jacea*	Asteraceae	7	0
Mid-August	Ringve I	*Lotus corniculatus*	Fabaceae	2	0
Mid-August	Ringve I	*Rhinanthus alectorolophus*	Orobanchaceae	1	0
Mid-August	Ringve I	*Trifolium pratense*	Fabaceae	9	0
Mid-June	Ringve II	*Alchemilla vulgaris*	Rosaceae	29	20
Mid-June	Ringve II	*Cardamine pratensis*	Brassicaceae	15	0
Mid-June	Ringve II	*Cerastium arvense*	Caryophyllaceae	0	3
Mid-June	Ringve II	*Taraxacum officinale*	Asteraceae	6	1
Mid-June	Ringve II	*Veronica serpyllifolia*	Plantaginaceae	3	1
Early-July	Ringve II	*Alchemilla vulgaris*	Rosaceae	45	0
Early-July	Ringve II	*Stellaria graminae*	Caryophyllaceae	28	0
Early-July	Ringve II	*Trifolium repens*	Fabaceae	0	8
Late-July	Ringve II	*Alchemilla vulgaris*	Rosaceae	53	0
Late-July	Ringve II	*Heracleum sphondylium*	Apiaceae	6	0
Late-July	Ringve II	*Leontodon autumnalis*	Asteraceae	2	0
Late-July	Ringve II	*Prunella vulgaris*	Lamiaceae	0	2
Late-July	Ringve II	*Stellaria graminae*	Caryophyllaceae	1	0
Late-July	Ringve II	*Trifolium repens*	Fabaceae	0	2
Mid-August	Ringve II	*Heracleum sphondylium*	Apiaceae	3	0
Mid-August	Ringve II	*Leontodon autumnalis*	Asteraceae	2	0
Mid-June	Leangen gård	*Alchemilla vulgaris*	Rosaceae	29	0
Mid-June	Leangen gård	*Arabidopsis*	Brassicaceae	1	0
Mid-June	Leangen gård	*Brassica vulgaris*	Brassicaceae	1	0
Mid-June	Leangen gård	*Cerastium fontanum*	Caryophyllaceae	7	2
Mid-June	Leangen gård	*Myosotis arvensis*	Boraginaceae	1	0
Mid-June	Leangen gård	*Ranunculus bulbosus*	Ranunculaceae	8	0
Mid-June	Leangen gård	*Taraxacum officinale*	Asteraceae	0	1
Mid-June	Leangen gård	*Veronica serpyllifolia*	Plantaginaceae	1	0
Early-July	Leangen gård	*Alchemilla vulgaris*	Rosaceae	6	0
Early-July	Leangen gård	*Ranunculus flammula*	Ranunculaceae	1	0

Early-July	Leangen gård	*Stellaria graminea*	Caryophyllaceae	20	0
Early-July	Leangen gård	*Trifolium pratense*	Fabaceae	14	0
Early-July	Leangen gård	*Trifolium repens*	Fabaceae	85	4
Late-July	Leangen gård	*Leontodon autumnalis*	Asteraceae	7	1
Late-July	Leangen gård	*Lotus corniculatus*	Fabaceae	3	0
Late-July	Leangen gård	*Rumex acetosa*	Polygonaceae	2	0
Late-July	Leangen gård	*Stellaria graminae*	Caryophyllaceae	6	0
Late-July	Leangen gård	*Trifolium pratense*	Fabaceae	21	0
Late-July	Leangen gård	*Trifolium repens*	Fabaceae	15	9
Mid-August	Leangen gård	*Leontodon autumnalis*	Asteraceae	42	1
Mid-August	Leangen gård	*Stellaria media*	Caryophyllaceae	0	1
Mid-August	Leangen gård	*Trifolium pratense*	Fabaceae	2	0

Appendix B: Supplementary pollinators data

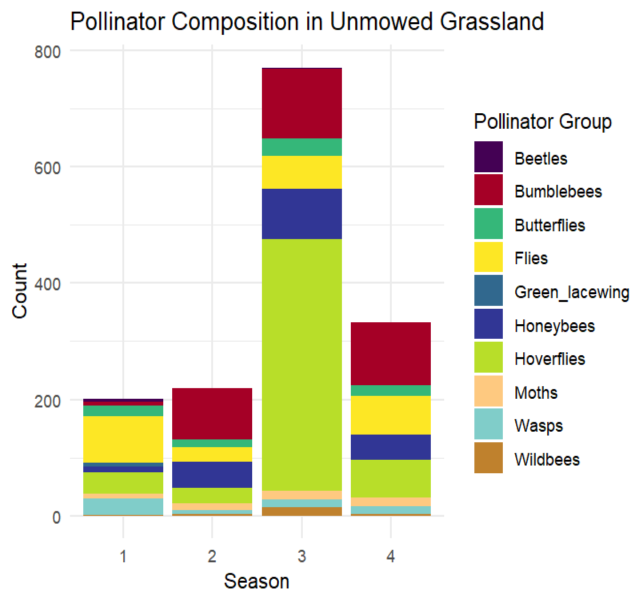


Figure B1: Total count of pollinators with their composition in unmowed grassland

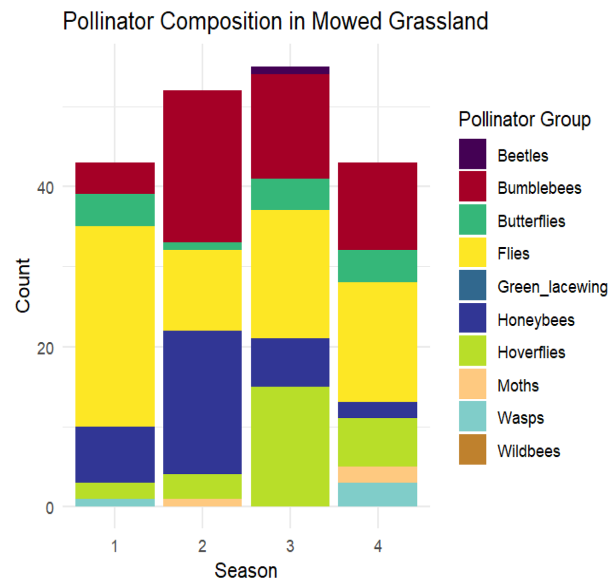


Figure B2: Total count of pollinators with their composition in mowed grassland

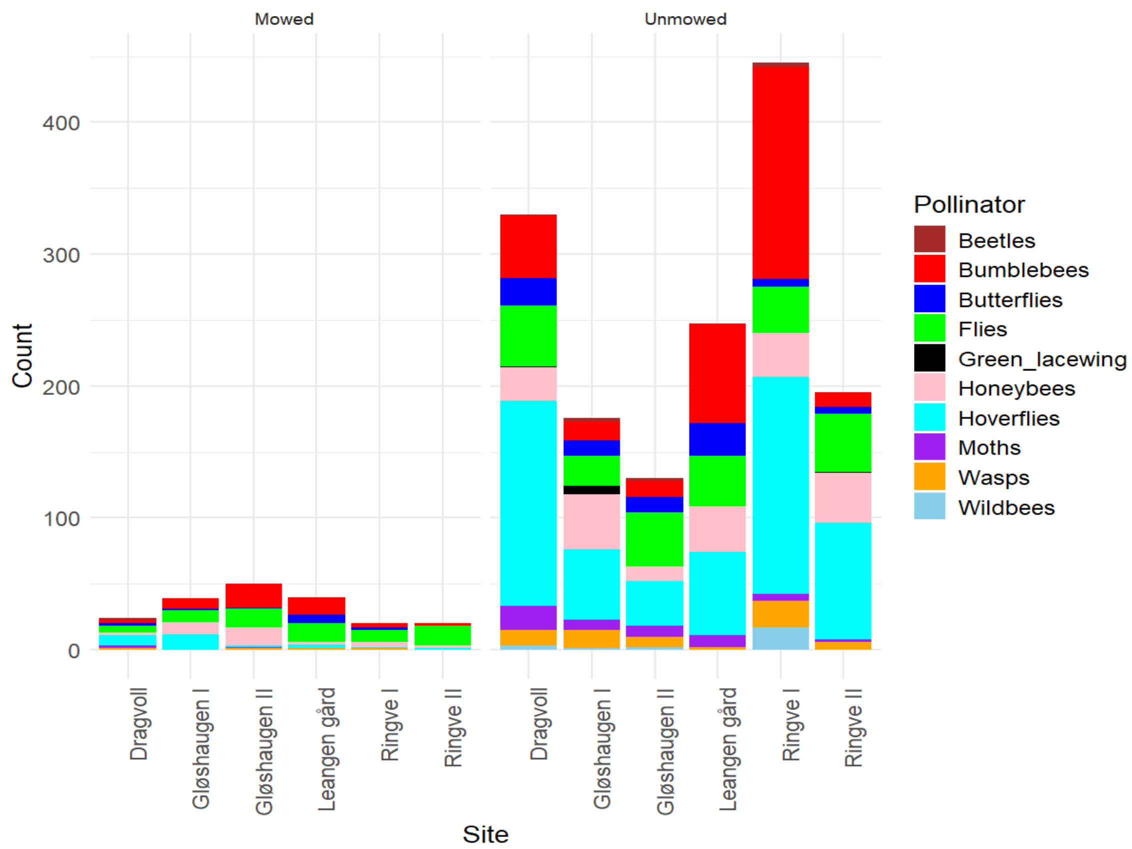


Figure B3: Total count of pollinators with their composition in each Site across all seasons

Table B1: Abundance of bumblebee species on mowed and unmowed grasslands in different field seasons

Bumblebee Species	Grassland Type	Mid-June	Early-July	Late-July	Mid-Aug
Bombus_species	Mowed	0	1	2	1
	Unmowed	2	0	2	1
Bombus_lucorum	Mowed	3	14	5	5
	Unmowed	1	43	48	47
Bombus_hypnorum	Mowed	0	1	2	0
	Unmowed	0	10	9	1
Bombus_lapidarius	Mowed	1	2	3	1
	Unmowed	0	8	24	28
Bombus_pascuorum	Mowed	0	0	1	4
	Unmowed	3	22	25	25
Bombus_sylvestris	Mowed	0	1	0	0
	Unmowed	0	0	5	0
Bombus_hortorum	Mowed	0	0	0	0
	Unmowed	0	4	6	6

Table B2: Abundance of bumblebee species on mowed and unmowed grasslands in different field seasons

Butterfly Species	Grassland Type	Mid-June	Early-July	Late-July	Mid-Aug
Anthocharis cardamines	Mowed	0	0	0	0
	Unmowed	2	0	1	0
Callophrys rubi	Mowed	1	0	0	0
	Unmowed	4	0	0	0
Pieris napi	Mowed	1	0	4	2
	Unmowed	2	1	15	3
Lipidoptera sp	Mowed	2	0	0	0
	Unmowed	2	1	0	0

Table B3: Abundance of other pollinators on mowed and unmowed grasslands in different field seasons

Other pollinators	Grassland Type	Mid-June	Early-July	Late-July	Mid-Aug
Beetles	Mowed	0	0	1	0
	Unmowed	5	0	3	1
Flies	Mowed	25	10	16	15
	Unmowed	79	25	57	66
Green lacewing	Mowed	0	0	0	0
	Unmowed	7	0	0	1
Honeybees	Mowed	7	18	6	2
	Unmowed	10	45	86	43
Hoverflies	Mowed	2	3	15	6
	Unmowed	36	26	432	65

Moth	Mowed	0	1	0	2
	Unmowed	9	12	14	15
Wasps	Mowed	1	0	0	3
	Unmowed	29	6	6	1

Appendix C: Total plant-pollinator interactions

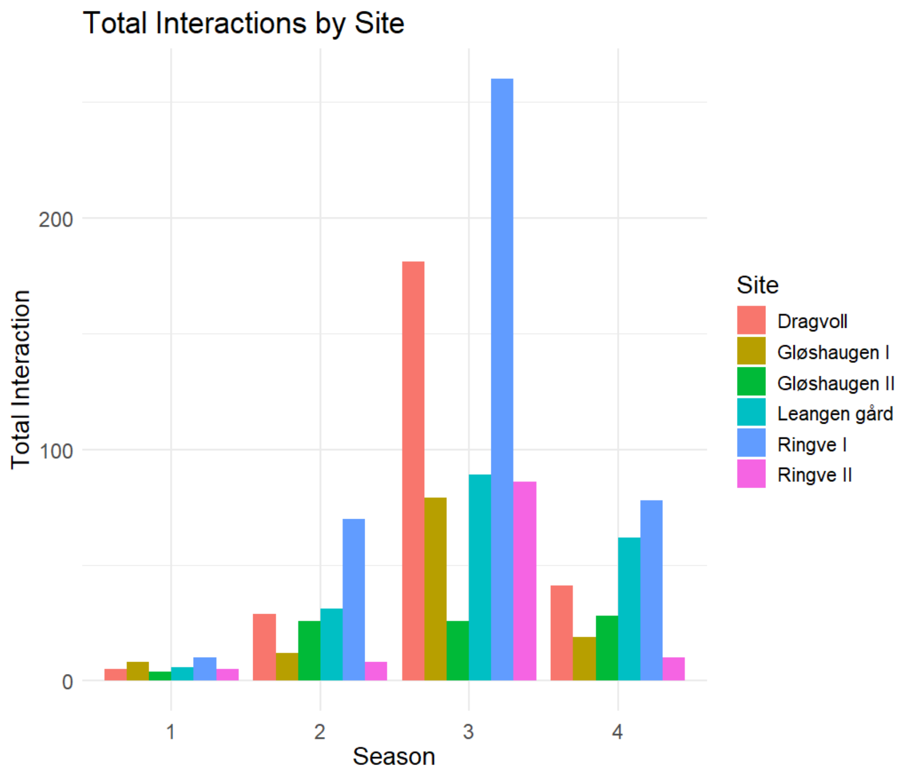


Figure C1: Total plant-pollinator interactions in each Site across all seasons

Appendix D: Diagnostic plots of models

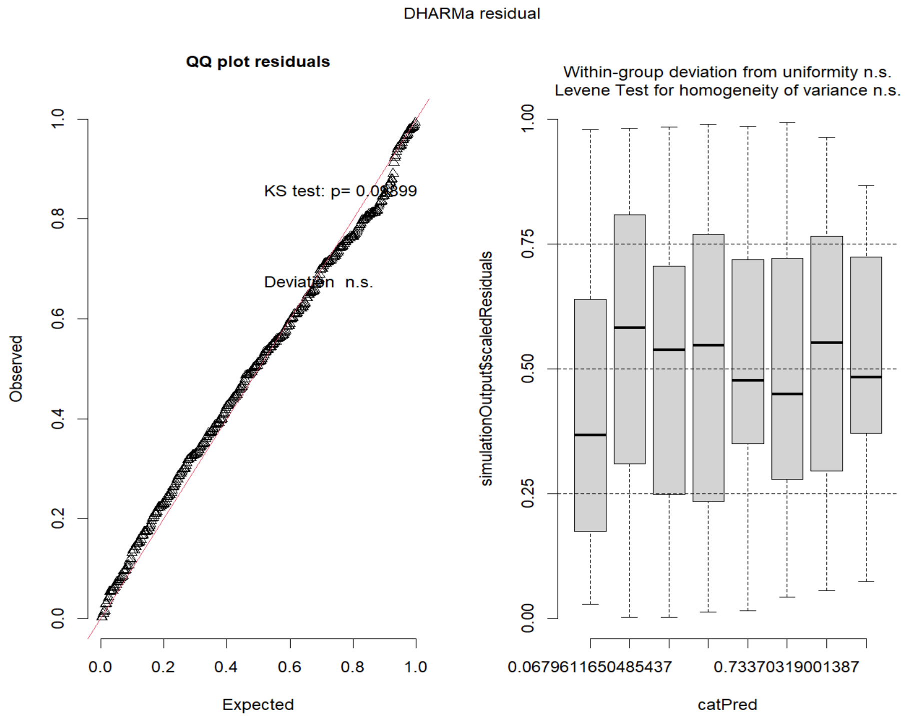


Figure D1: Diagnostic plots of the chosen model for flowering plant richness

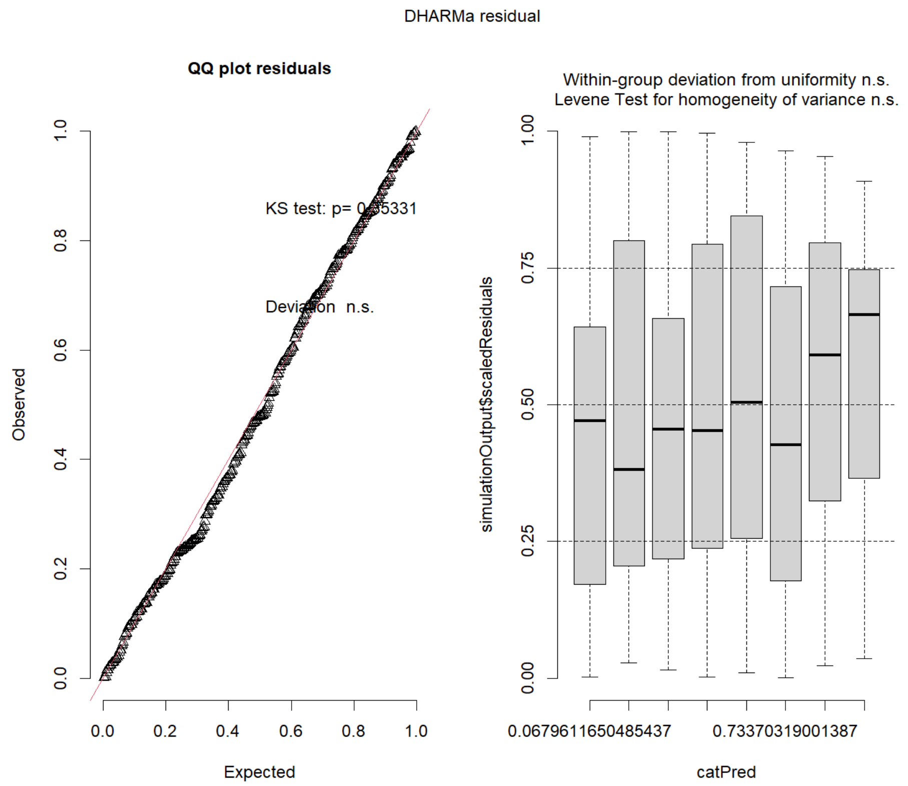


Figure D2: Diagnostic plot of the chosen model for flower abundance

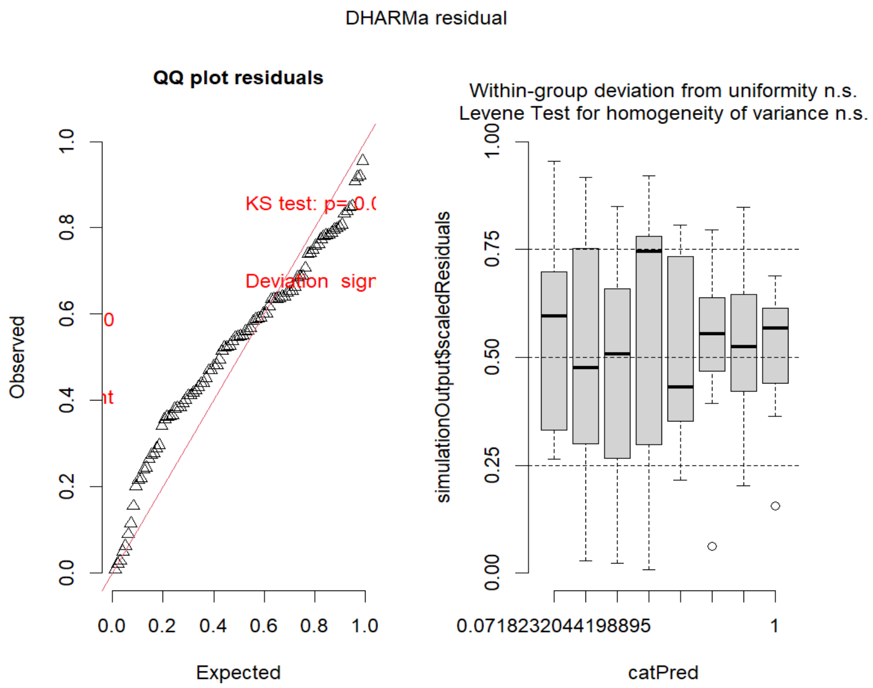


Figure D3: Diagnostic plot of the chosen model for pollinator richness

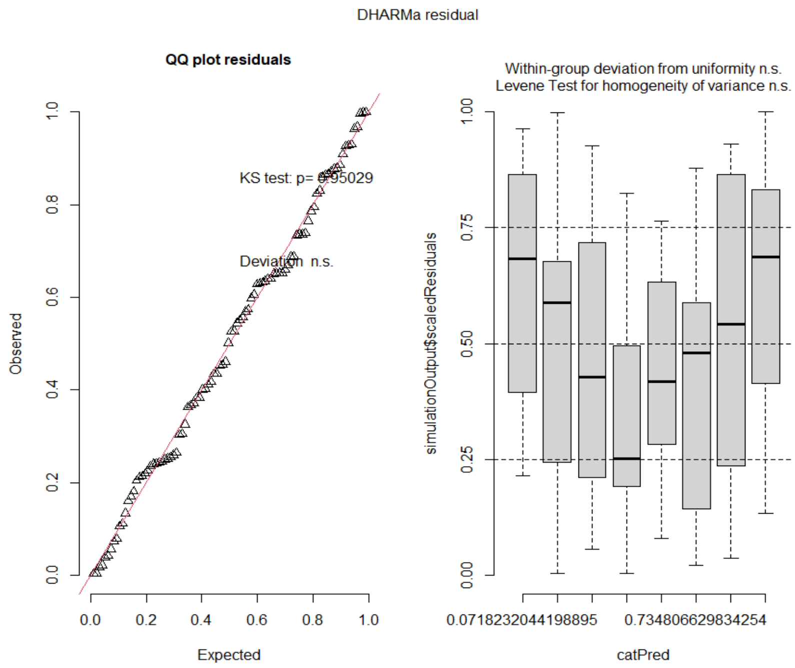


Figure D4: Diagnostic plot of the chosen model for pollinator abundance

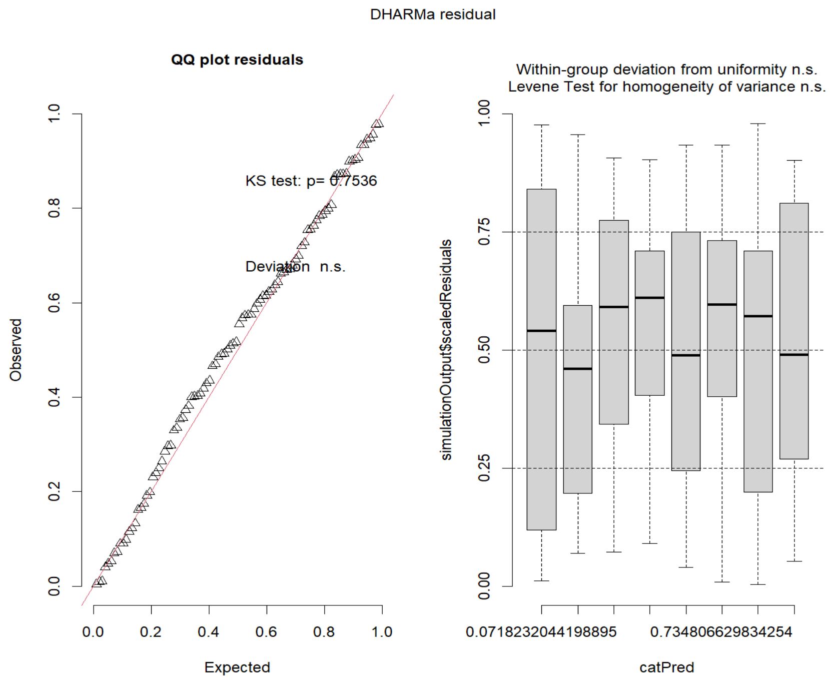


Figure D5: Diagnostic plot of the chosen model for bumblebee species richness

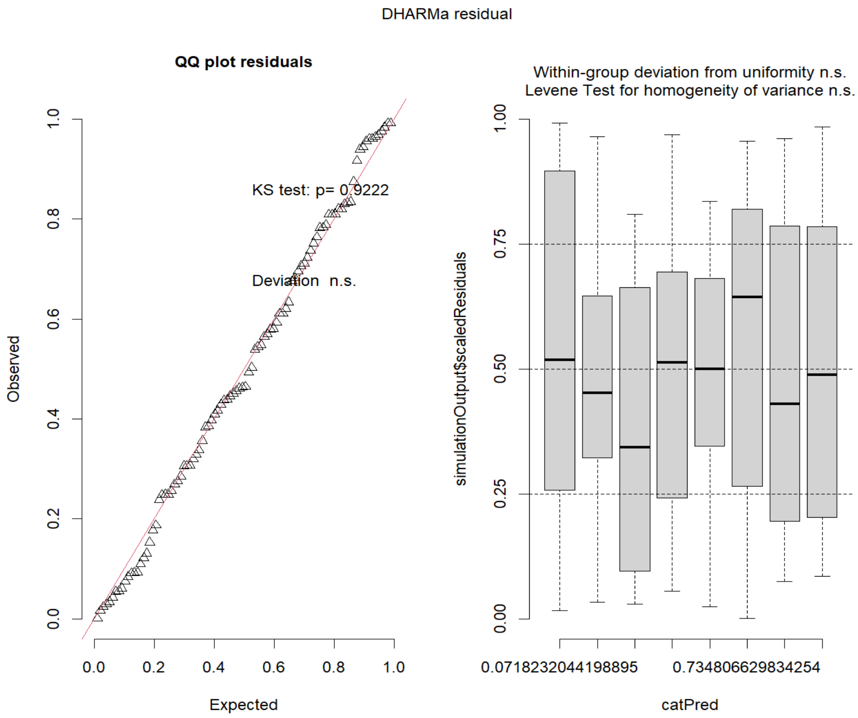


Figure D6: Diagnostic plots of the chosen model for bumblebee abundance

Appendix E: Site-wise results of the response variables

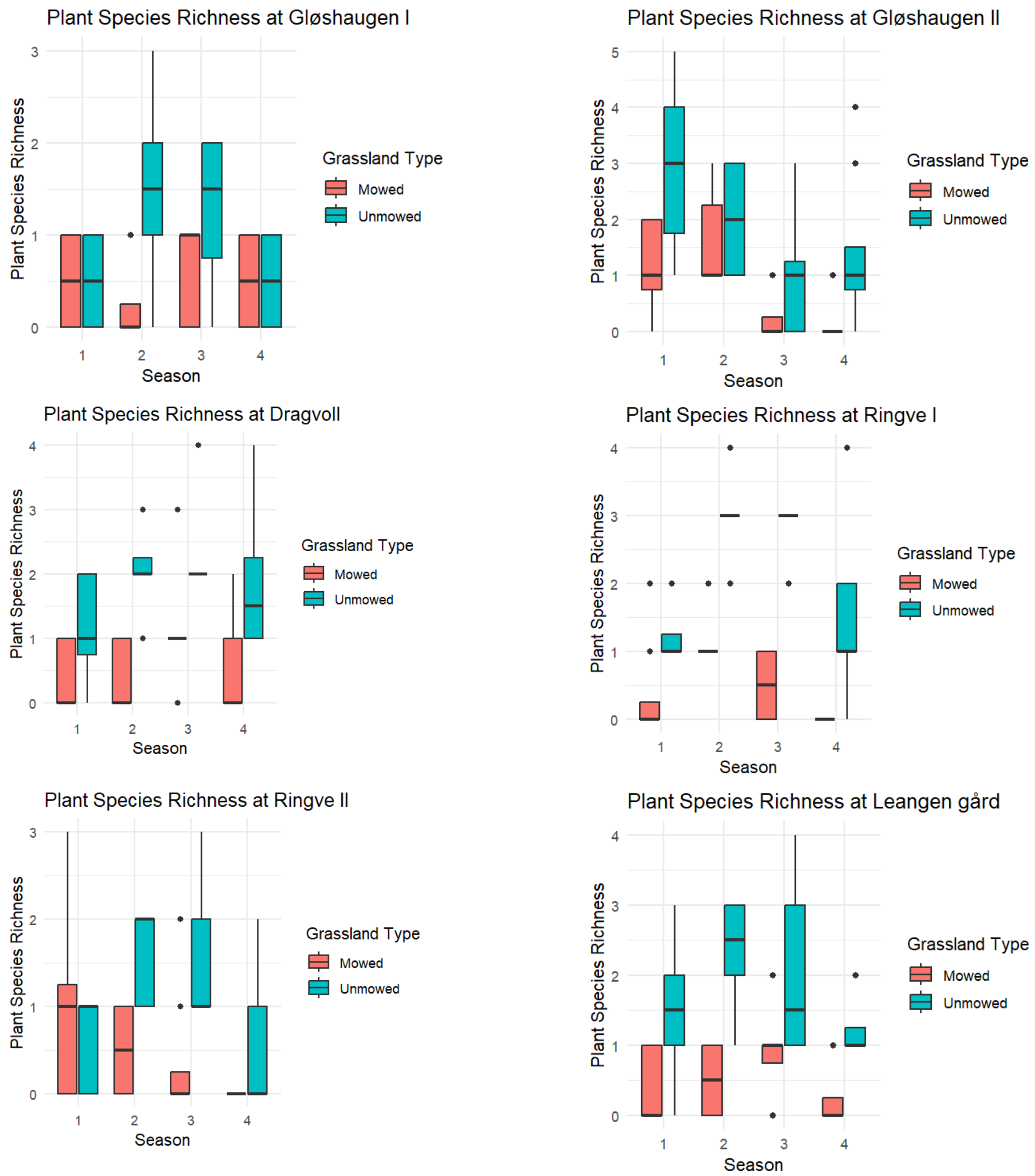


Figure E1: Quadrat level flowering plant species richness in each season at different sites

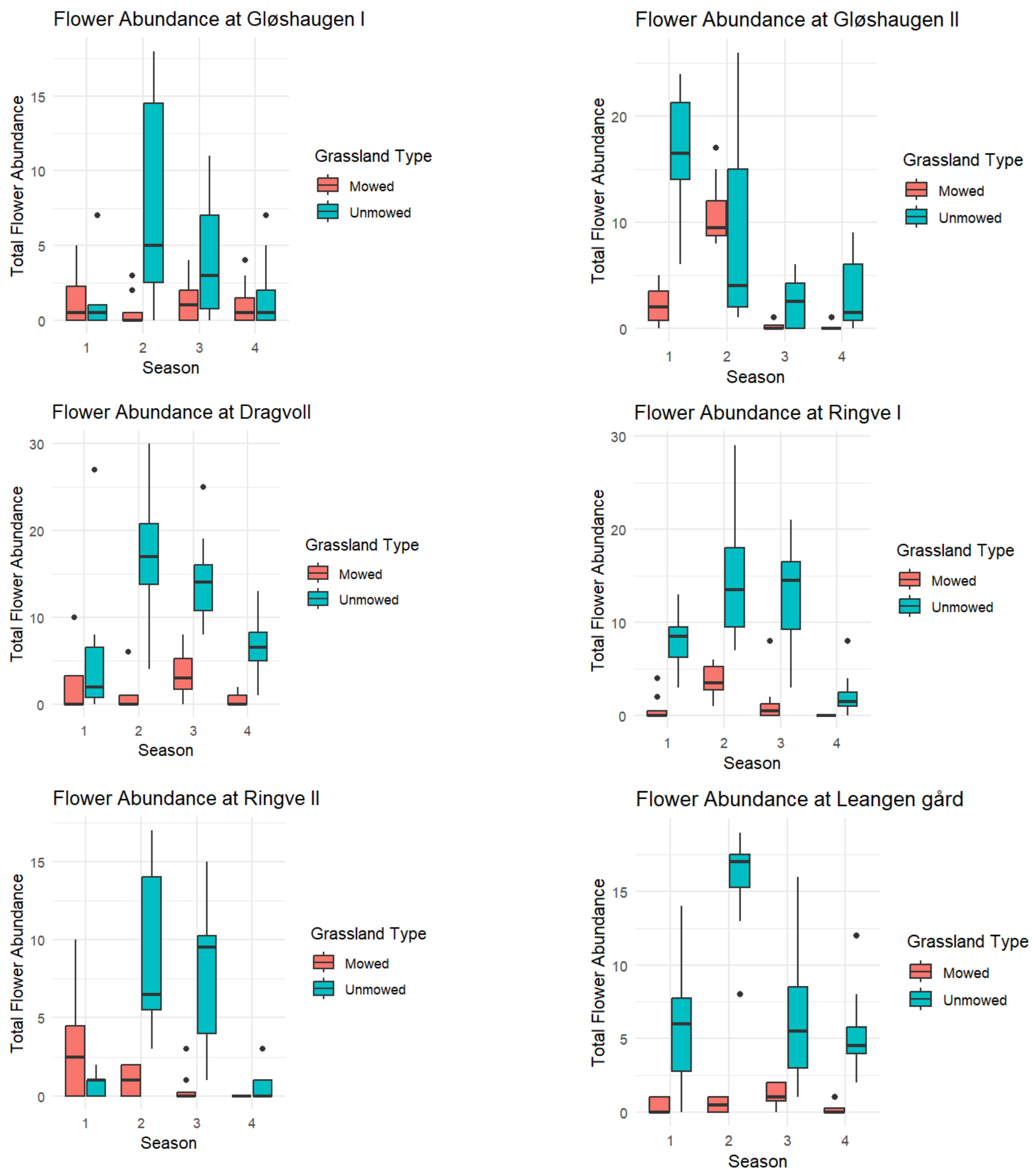
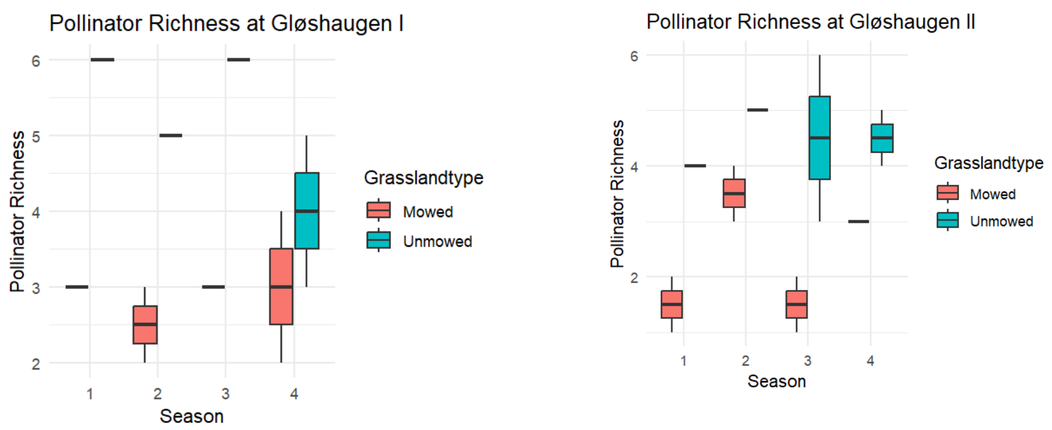


Figure E2: Quadrat level flower abundance in each season at different sites



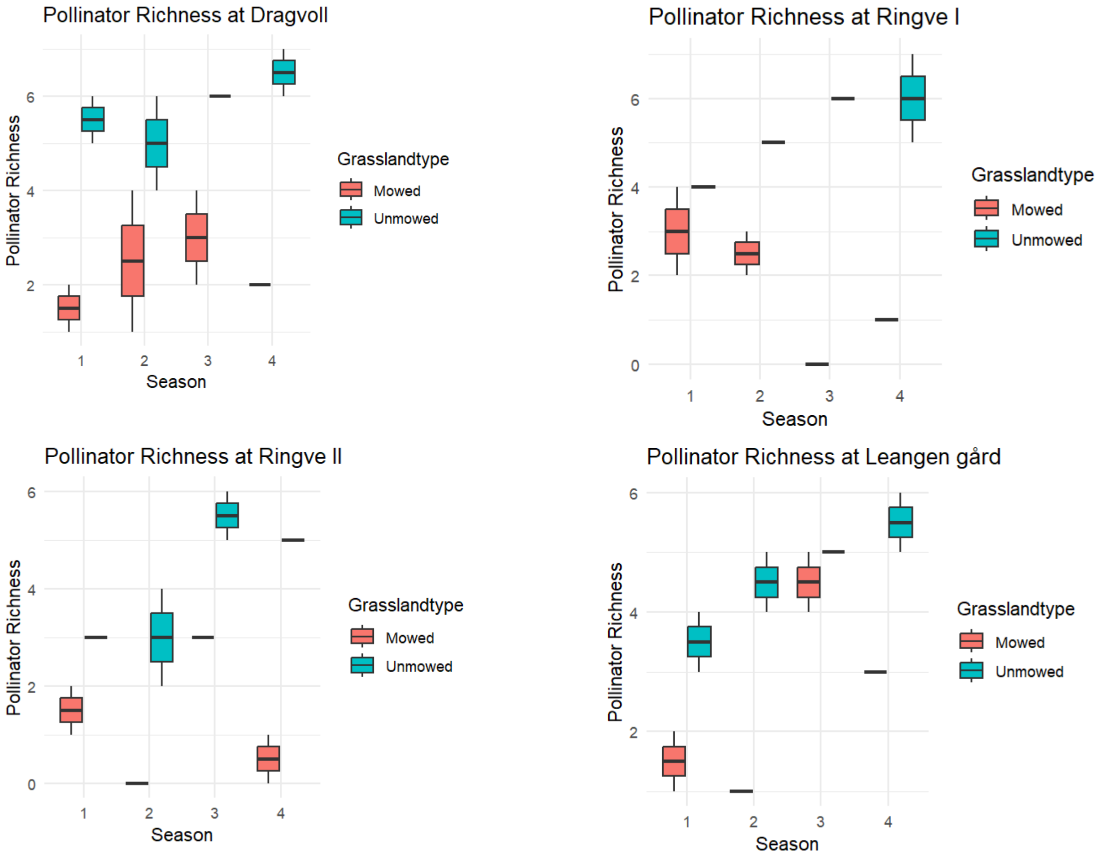
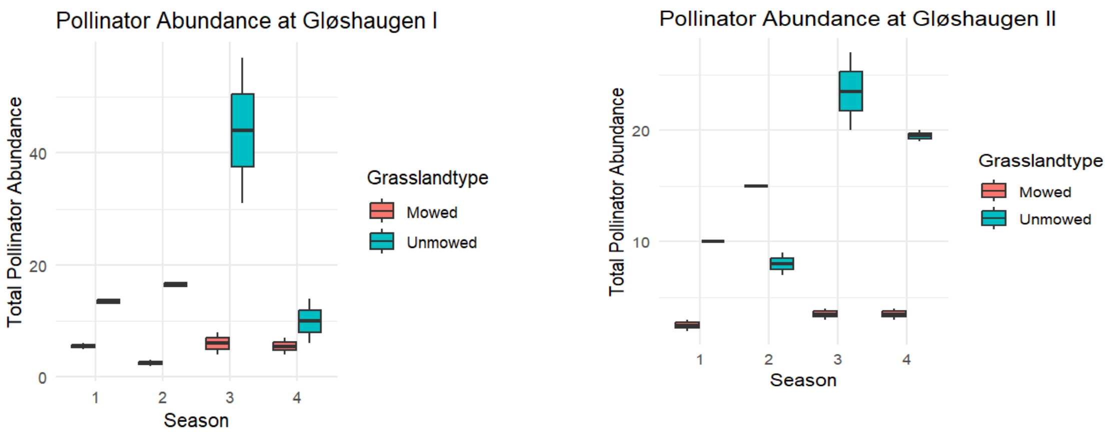


Figure E3: Transect level pollinator richness at different sites



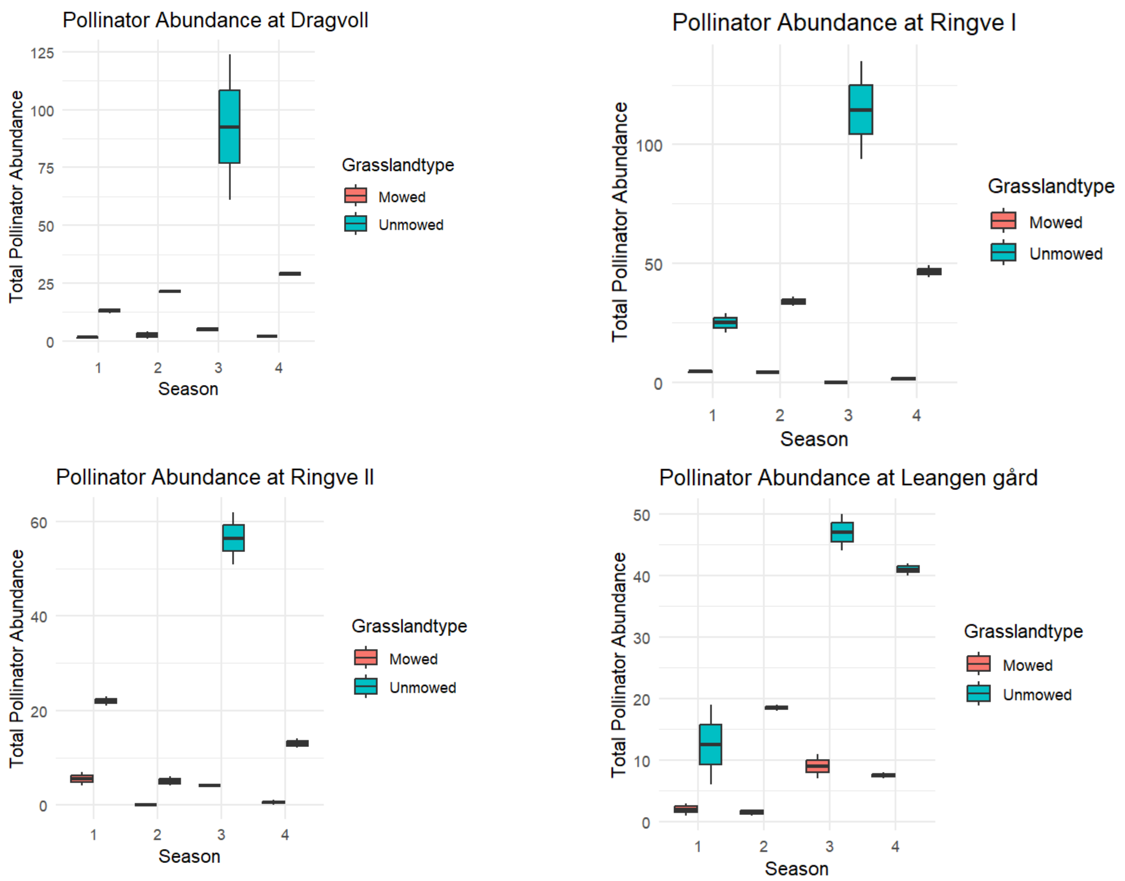
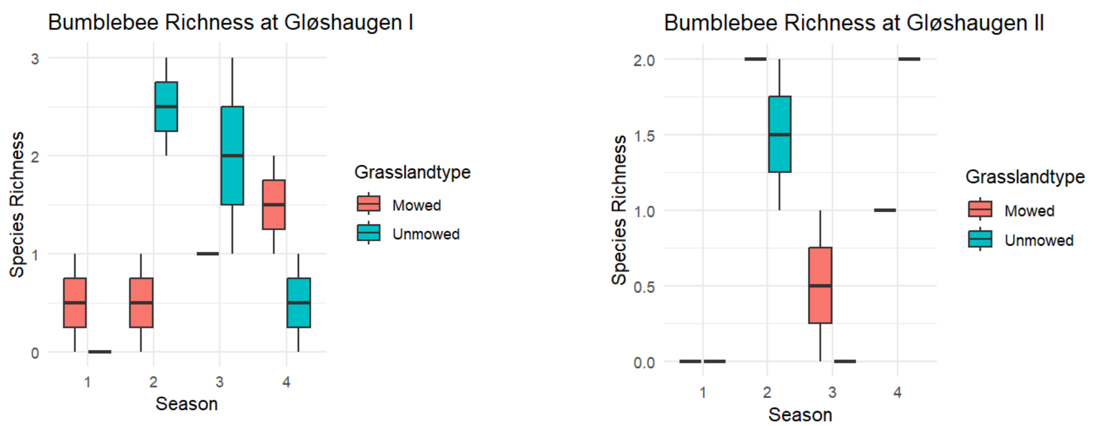


Figure E4: Transect level pollinator abundance at different sites



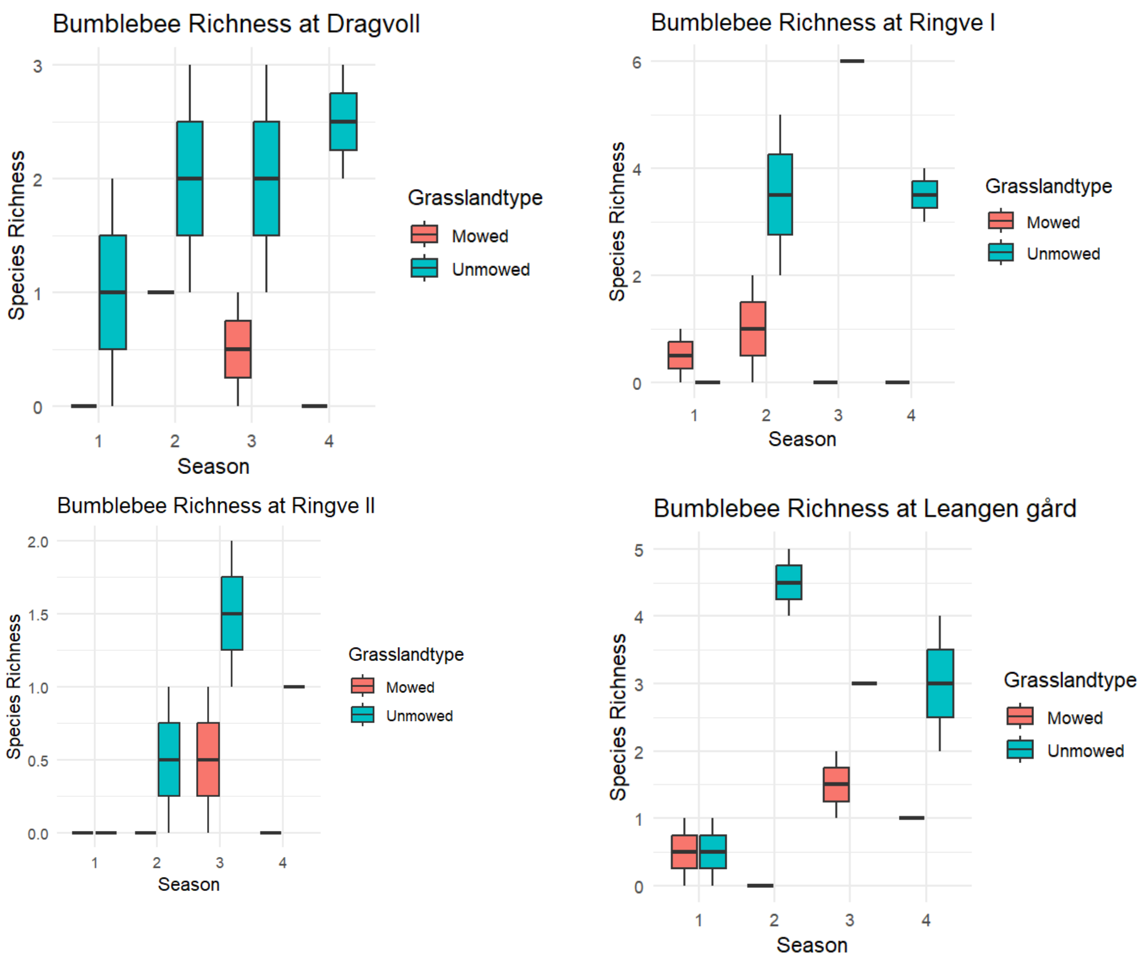
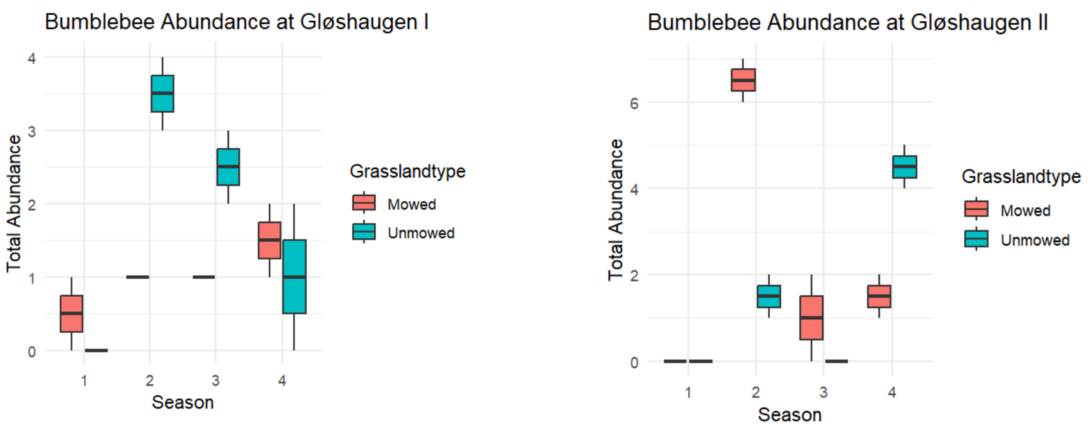


Figure E5:Transect level bumblebee richness at different sites



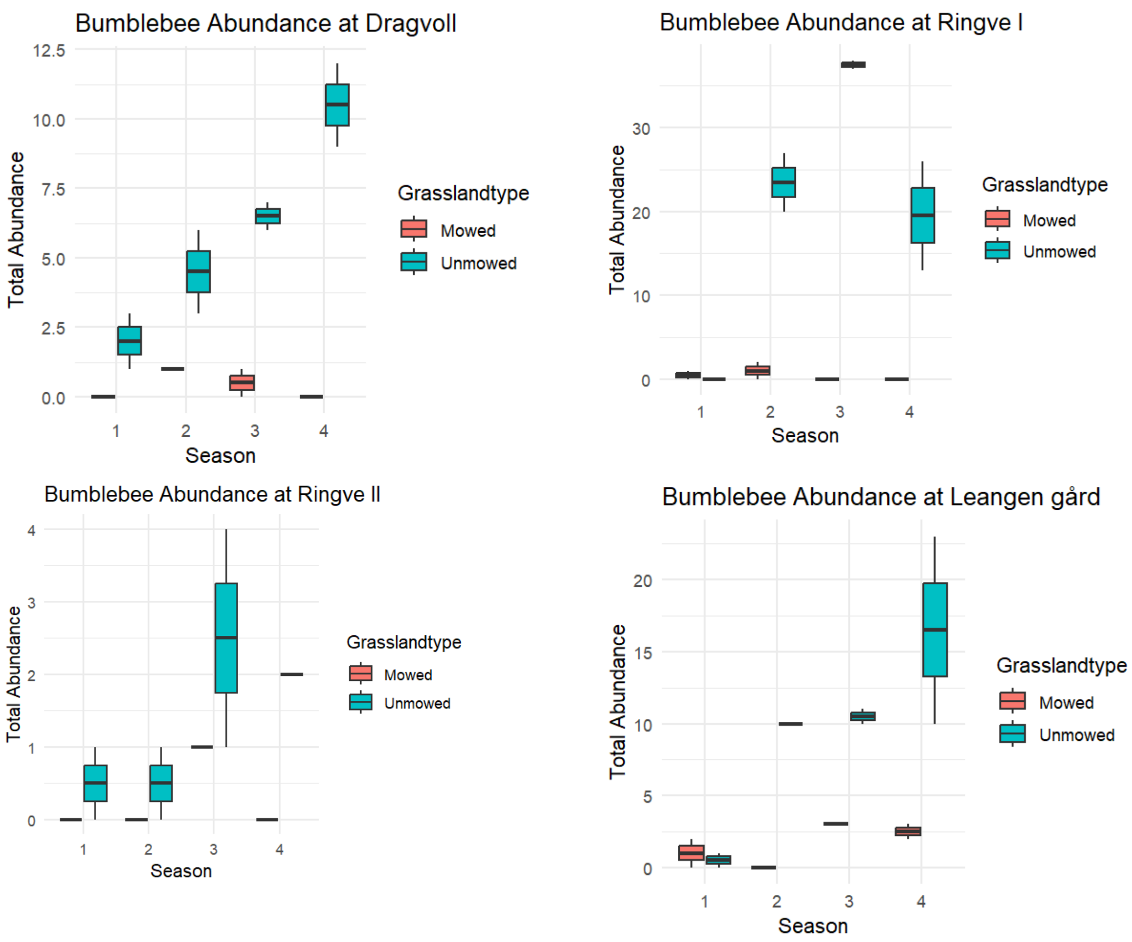


Figure E6: Transect level bumblebee abundance at different sites

Norwegian University of
Science and Technology