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Master Thesis

Species richness and abundance of true bugs (Hemiptera: Heteroptera) in different grassland habitats in Austria

submitted by

Lukas STREISSELBERGER, BSc

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Supervisor:

Univ.-Prof. Mag. Dr. Thomas Frank
Institute of Zoology
Department of Integrative Biology and Biodiversity Research (DIB)

Co-supervisors:

DI Dr. Ronnie Walcher
Institute of Zoology
DIB

Dr. Raja Imran Hussain, MSc
Institute of Zoology
DIB

Affidavit

I hereby declare that I have authored this master thesis independently, and that I have not used any assistance other than that which is permitted. The work contained herein is my own except where explicitly stated otherwise. All ideas taken in wording or in basic content from unpublished sources or from published literature are duly identified and cited, and the precise references included.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree.

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

Vienna, 18.12.2023 Lukas STREISSELBERGER *(manu propria)*

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Abstract

The present master thesis investigated the effects of different grassland habitats on the species richness, abundance and assemblages of true bugs in the two Austrian biosphere reserves Wienerwald and Lungau/Nockberge. The research questions related to variations in the true bug abundance, species richness and assemblages in four grassland habitats – sown wildflower strips, extensively managed meadows, intensively managed meadows (adjacent to wildflower strips) and intensively managed control meadows without adjacent flower strips. Further, the effects of plant parameters on species richness and abundance of true bugs were analysed. The results revealed significant differences in true bug species richness and abundance in grassland habitats in Lungau/Nockberge between wildflower strips and intensively managed meadows adjacent to wildflower strips as well as intensively managed control meadows. The more extensively managed Wienerwald region exhibited higher overall species richness and abundance compared to Lungau/Nockberge. However, in Wienerwald no significant differences between the habitats were obtained regarding species richness and abundance of true bugs. Also, the species assemblages between the two regions differed significantly, emphasizing their distinct characteristics. Furthermore, in both regions, species assemblages of true bugs were significantly (Wienerwald) or even highly significantly (Lungau/Nockberge) different. Plant parameters, particularly plant height and vegetation structure, emerged as crucial factors influencing true bugs. The results showed that wildflower strips in intensively managed areas are effective agri-environmental schemes. However, they should probably be maintained over a longer period of time and possibly be established over larger areas to achieve sustainable positive effects on the local bug fauna. Contrary to expectations, the study found only slight differences in the abundance and diversity of bugs between extensively and intensively managed meadows. The results suggest that the high species diversity in the two regions could mitigate the effects of management schemes on the true bugs. Overall, the study provided valuable insights into different grassland habitats and the effect of sown wildflower strips on true bug fauna.

Zusammenfassung

Diese Masterarbeit untersuchte die Auswirkungen verschiedener Grünlandhabitate auf den Artenreichtum, die Abundanz und die Artengemeinschaften von Wanzen in den beiden österreichischen Biosphärenparks Wienerwald und Lungau/Nockberge. Der Schwerpunkt lag dabei auf der Intensivierung des Grünlandes und deren Auswirkungen auf die Artenvielfalt der Insekten und es wurde untersucht, wie wirksam Wildblumenstreifen und extensiv bewirtschaftete Wiesen den Rückgang der Wanzenpopulationen abmildern. Die Forschungsfragen beziehen sich auf Variationen in der Abundanz, dem Artenreichtum und den Artengemeinschaften von Wanzen in vier Grünlandhabitaten - Wildblumenstreifen, extensiv bewirtschaftete Wiesen, intensiv bewirtschaftete Wiesen (angrenzend an Wildblumenstreifen) und intensiv bewirtschaftete Kontrollwiesen, mit besonderem Augenmerk auf die Pflanzenparameter der Habitate. Die Ergebnisse zeigten signifikante Unterschiede im Artenreichtum und in der Abundanz von Wanzenarten in Grünlandhabitaten im Lungau/Nockberge zwischen Wildblumenstreifen und intensiv bewirtschafteten Wiesen (angrenzend an Wildblumenstreifen) und intensiv bewirtschafteten Wiesen. Die extensiver bewirtschaftete Region Wienerwald wies insgesamt einen höheren Artenreichtum und eine höhere Abundanz bei gleichmäßigerer Verteilung über die Grünlandhabitate auf. Im Wienerwald konnten keine signifikanten Unterschiede zwischen den Habitaten festgestellt werden. Auch die Artengemeinschaften in den beiden Regionen unterschieden sich signifikant, was ihre unterschiedlichen Eigenschaften unterstreicht. Darüber hinaus hatte in beiden Regionen das Grünlandhabitat einen signifikanten (Wienerwald) oder sogar hochsignifikanten (Lungau/Nockberge) Einfluss auf die Artenvielfalt, insbesondere auf die Wildblumenstreifen. Die Pflanzenparameter Pflanzenhöhe und Vegetationsstruktur erwiesen sich als entscheidende Einflussfaktoren auf die Wanzenpopulationen. Die Ergebnisse zeigten, dass Wildblumenstreifen in intensiv bewirtschafteten Gebieten wirksam sind, aber für eine nachhaltig positive Wirkung (auch in extensiveren Gebieten) eine längere Etablierung, eine größere Fläche und einen kollektiven Ansatz erforderlich ist. Entgegen den Erwartungen wurden in der Studie nur geringe Unterschiede zwischen extensiv und intensiv bewirtschafteten Wiesen in Bezug auf die Anzahl und Vielfalt der Wanzen festgestellt. Die Ergebnisse deuten darauf hin, dass die hohe Artenvielfalt in den beiden Regionen die Auswirkungen der Bewirtschaftung auf die Wanzen abmildern könnte. Insgesamt bietet die Studie wertvolle Einblicke in die Wechselwirkungen, die die Artenvielfalt von Insekten in unterschiedlichen Grünlandhabitaten bestimmen.

1. Introduction and problem statement

A recent warning from a group of leading conservation biologists highlighted the insect extinction humanity is facing (Cardoso et al., 2020). In 2017, a research article estimated that there had been a decline of more than 75% in insect biomass in protected areas in Germany over 27 years. Intensified agriculture and the associated changes in the landscape were identified as two of the main drivers of this harsh decrease (Hallmann et al., 2017). Furthermore, a report by Sánchez-Bayo & Wyckhuys (2019) concluded that the conversion and intensification of agriculture for food production accounted for 24% of the causes of global insect declines. Moreover, studies for Europe showed that the majority of the biodiversity loss occurred due to the industrialization of agriculture after World War II, from traditional to high-intensity land-use systems in simplified landscape (Robinson & Sutherland, 2002; Tscharntke et al., 2005). This is also evident in Austria as GLOBAL 2000 released their atlas of insects for the first time for Austria in 2020 and named agriculture as the biggest threat to insect diversity (GLOBAL 2000, 2020).

The industrialization of agriculture in most Western and Northern European countries as well as in Austria took place after 1945. This period was characterized by an increase in the size of agricultural fields, intensification of agriculture and a homogenization of agricultural landscapes (Bignal & McCracken, 1996; Jepsen et al., 2015; Tscharntke et al., 2005). This transition to intensified agriculture still takes place. In their research paper on changing land use intensity in Europe Van der Sluis et al. (2016) stated that Austria is one of two countries still intensifying their agriculture in the 21st century, albeit starting from a rather low level of intensification and with the third largest share of organic agriculture (23% of land is farmed organically) (Willer & Lernoud, 2019). This process of intensification is not limited to arable land, but also extends to grassland. The intensification of grassland is mainly driven by increased fertilization, intensive mowing and grazing and leads to a significant loss in grassland biodiversity (Batáry et al., 2015; Plantureux et al., 2005).

To combat biodiversity loss in grassland habitats, one effective strategy is through the extensification of intensively managed meadows, which has shown promising results in insect conservation (Marriott et al., 2004; Walker et al., 2004). Extensification involves reducing the number of annual cuttings, stocking density, and fertilizer use. But this extensification poses some challenges. First, it leads to a reduction in the total output of productive livestock and to a decrease in their performance as Marriott et al. (2004) found out. Second, restoring a habitat through conversion into extensive management takes approximately 10 to 20 years and in this for farm management long time span, socio-economic factors, such as low profitability and no successor to the farm, play a central role (Plantureux et al., 2005; Waldén & Lindborg, 2018).

In a survey of farmers who managed previously restored semi-natural grasslands, 10% of the restored area was already abandoned and 40 % of the farmers were unsure about the future management of the sites (Waldén & Lindborg, 2018). In Europe, the abandonment of semi-natural grasslands means overgrowth by trees leading to a lower conservation value (Bucharova et al., 2020; Rusterholz et al., 2020). Thus, transforming intensively used grasslands into extensively used results in a higher conservation value, but takes time and has some mid-term uncertainty.

Furthermore, another way to restore intensively managed grasslands is to establish wildflower strips (Potts et al., 2009). These strips play a crucial role in supporting higher biodiversity and are integral to preserving and restoring grassland insect communities (Ouvrard et al., 2018). In their review on sown wildflower strips, Haaland et al. (2011) identified them as probably the most suitable habitat for many insects in intensively used agricultural landscapes. The use of wildflower strips is part of the agri-environmental programme in many European countries (Schmidt et al., 2022). In Austria, the establishment of wildflower strips is part of the national agri-environmental program ÖPUL, which means Austrian Program for Environmentally Sound Agriculture. The strips have a positive influence on the diversity of farmland birds and indicator species, such as locusts and butterflies, in arable land. Kromp et al. (2004) and Weber (2020) showed a positive effect on species number and abundance of beetles in Austrian wildflower strips.

However, the impact of sown wildflower strips on nearby intensively managed meadows remains unclear, and the present master thesis is one of the first studies trying to answer this question. The present thesis evaluates the species richness, abundance and species assemblages of true bugs in wildflower strips, nearby intensive meadows, intensive meadows without wildflower strips (control sites) and extensive meadows. By analysing the species richness, abundance, and assemblages of true bugs in these four different grassland habitats, this work will provide further insight into how different management practices and grassland systems (extensive management, intensive management, and wildflower strips) affect true bugs in grassland ecosystems.

True bugs are suitable indicators and react sensitively to land-use changes (Duelli & Obrist, 1998). They represent a highly diverse insect taxa with both phyto- and zoophagous species (Hodkinson, 1992). True bugs often occupy key roles in ecosystems, serving as predators or herbivores, which further influences their importance as ecosystem engineers. Their abundance and diversity mean that they make up a significant part of the insect fauna in most ecosystems (Wolda, 1988). Their suitability as indicators is mainly due to the sensitivity to changes in environmental conditions (Duelli & Obrist, 2003; Fartmann et al., 2012; Frank & Künzle, 2006). This includes the sensitivity to microclimatic conditions and the strong relationship with vegetation parameters like plant richness and structure (Di Giulio et al., 2001; Zurbrügg & Frank, 2006).

The four different grassland habitats analysed within this thesis differ in their plant parameters. Plant parameters include vegetation structure, plant height, and flower cover. Tscharntke & Greiler (1995) demonstrated that invertebrate diversity in grassland ecosystems is strongly correlated with plant diversity and other vegetation parameters. Plant parameters can also influence true bugs. Many true bug species are herbivores or omnivores, feeding on plant material. Thus, the quality, composition, and structure of plant communities in grasslands can have impacts on true bug communities. The influence of plant parameters on true bugs is evident in various studies. For instance, Zurbrügg and Frank (2006) conducted a study which demonstrated that true bug assemblages, as determined by the number of individuals per species, were significantly influenced by both flower abundance and vegetation structure. In their study, Kőrösi et al. (2012) demonstrated a positive influence of mean vegetation height on true bug assemblages. Understanding the relationships between true bugs and plant parameters can help to develop conservation and management strategies.

This leads to the following research questions:

RQ 1: Are there significant differences in the abundance of true bugs between the four studied grassland habitats?

RQ 2: Are there significant differences in the species richness of true bugs between the four studied four grassland habitats?

RQ 3: Do the species assemblages of true bugs differ between the investigated grassland habitats?

RQ 4: Do plant parameters affect the species richness and abundance of true bugs?

This master thesis was conducted within the research project “DivRESTORE”, which started in 2019 and ended in 2021. The project aimed to convert intensively used meadows into species rich ones in order to conserve native insect species and improve the landscape beauty. This transformation was achieved through the establishment of wildflower strips along the edges of intensively managed meadows. The assessment of the impact of these wildflower strips on insect diversity focused on bumblebees, butterflies, grasshoppers, hoverflies, and true bugs.

2. Materials and Methods

I contributed to the project by collecting syrphids and true bugs using sweep netting and measuring plant parameters in various grassland habitats. Afterwards, I sorted the collected insects, counted them, and identified true bugs down to the species level.

Between June and August 2021, the sampling took place in two Austrian biosphere reserves. The study sites were located in the Wienerwald region in eastern Austria and the Lungau/Nockberge region at the Salzburg and Carinthia border in central Austria (Figure 1). In each region, 15 meadows were selected, forming four distinct habitat types, as later explained in the experimental setup. The selection of the study sites involved local stakeholders and the meadows were under the management of local farmers.

The true bugs were sampled via sweep netting, stored in plastic bags, and later identified at the species level, focusing on adults only. Additionally, plant parameters, including vegetation structure, plant height and flower cover were measured for each habitat. Version 4.2.2. of the statistics software “R” was used to for the statistical analysis of the results (R Core Team, 2020).

2.1. Study regions

Both the Wienerwald and Lungau/Nockberge regions are classified as “biosphere reserves”. The concept of biosphere reserves extends beyond the well-known “national parks”, which primarily focuses on nature and the preservation of the natural environment. Biosphere reserves also consider the cultural, social and economic needs of the local population, expanding the reserve concept to include the cultural landscape. An important distinction is that national parks are managed by the respective government and can therefore vary in their standards, while biosphere reserves fall under the umbrella of the UNESCO and must adhere to certain global standards (Biosphärenparks Österreich, 2023; Lange, 2005; UNESCO, 1996).

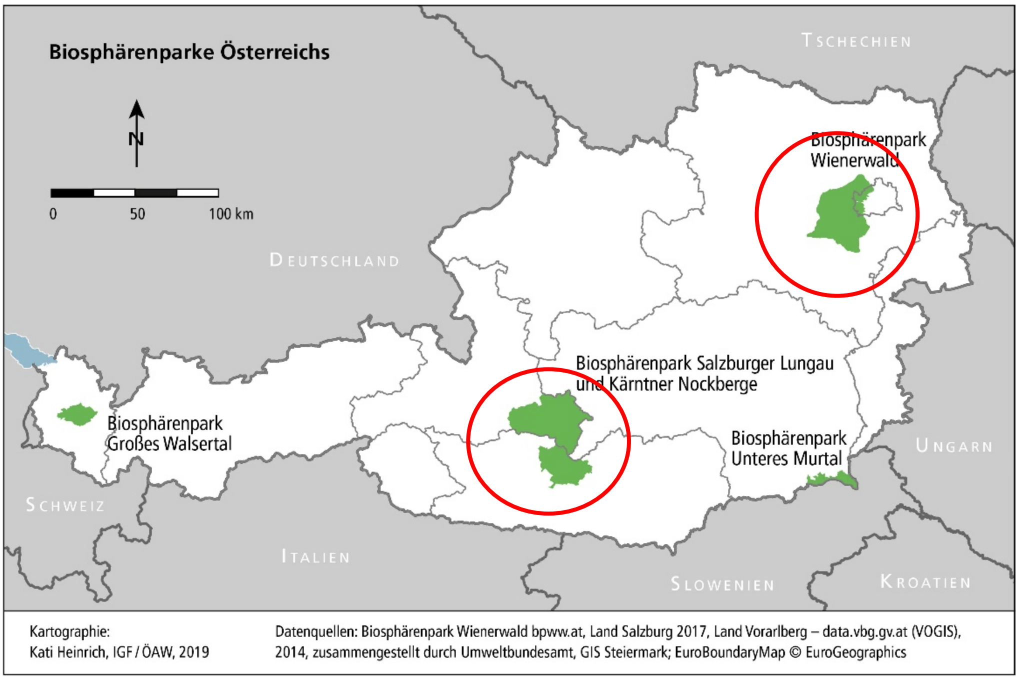

Figure 1: https://www.biosphaerenparks.at/index.php/de/modellregion - own illustration.

Both regions vary in climate and geography due to their distinct locations in Austria. The sites sampled in the Wienerwald, below 600 m altitude, fall into the submontane elevation zonation. The sites in Lungau/Nockberge are situated in the montane altitudinal zone (Herzberger et al., 2020).

Table 1: Climate data for the two study regions. Source: (*Klimamittelwerte 1991-2020 — ZAMG*, 2023).

	Wienerwald (Wolfsgraben)	**Lungau/Nockberge (St. Michael)**
Altitude	350-400m	1000-1100m
Mean annual temp.	10,0°C	6,2°C
Precipitation	759mm	860mm
Mean temp. January	-1,5°C	-4,7°C
Mean temp. July	+24,8°C	+15,9°C

2.2. Experimental setup

In each of the two study regions Wienerwald and Lungau/Nockberge, four different grassland habitats were studied, namely extensively managed meadows, intensively managed meadows with adjacent wildflower strips, intensively managed meadows without adjacent wildflower strips (control sites) and the wildflower strips (Figure 3). Each habitat was present five times (Site I-V) in each of the two regions, which is shown in Figure 2 (example given for

Lungau/Nockberge). To account for different seasonal activities of the studied insects, three runs (June, July, August) were performed (RUN I June; RUN II July; RUN III, August).

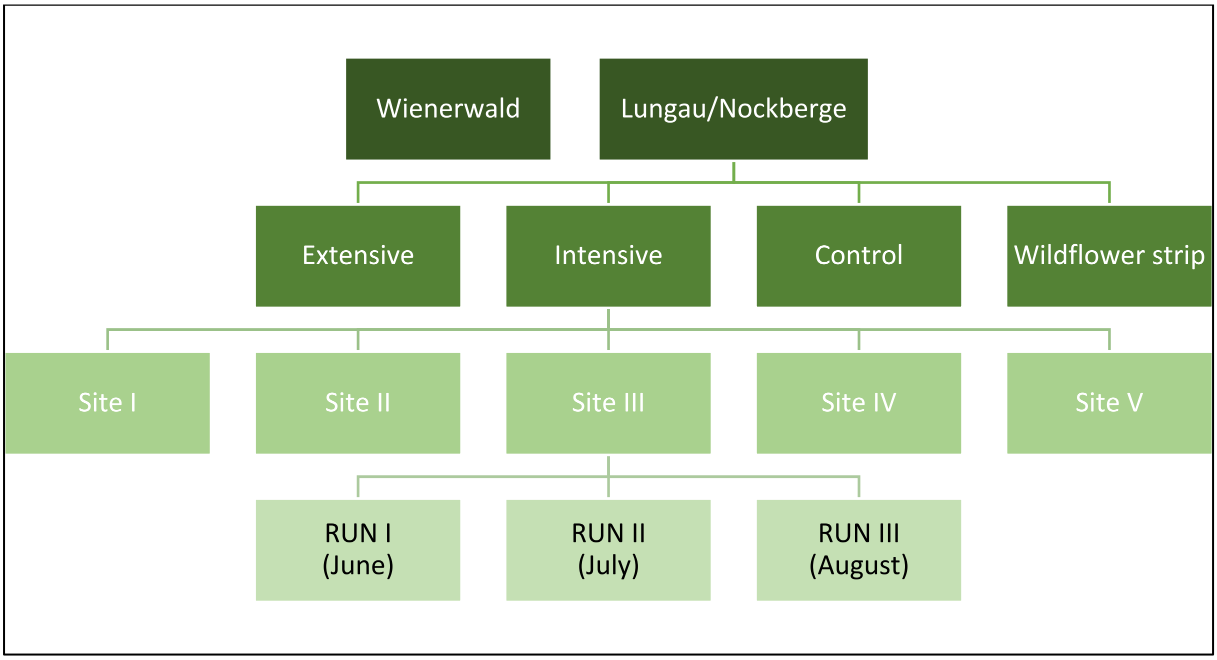

Figure 2: Experimental setup (exemplary illustration for Lungau/Nockberge, Intensive, Site III) - own illustration.

The intensive meadows were mown at least twice a year and fertilized, mostly with organic fertilizers such as manure or slurry. Intensive meadow is another word for permanent grassland, which is mown more than once a year (Greif et al., 2005). Extensive meadows are permanent grasslands, which were mown once a year and not fertilized.

			
• Mown once a year • No fertilization	• Mown > 2 times a year • + fertilization • Adjacent wildflower strip	• Mown >2 times a year • + fertilization	• Sown wildflower strip

Figure 3: Description of the four habitats - own illustration.

2.2.1. Wildflower strips

The selection of the appropriate seed mixture for the establishment of the wildflower strips was based on native plants and suitability for present flower visitors, in this case bees and hoverflies.

The seeding date of the wildflower strips was in September 2019, providing a satisfactory plant establishment before the first survey in June 2020 and the for thesis relevant survey in 2021. Experts from the Federal Agriculture Research and Education Center (AREC) in Raumberg Gumpenstein helped to plan and establish the wildflower strips. In Wienerwald, the experts also helped with the selection of the wildflower species. In Lungau/Nockberge the seed mixture for the establishment of wildflower strips was harvested from local extensively managed meadows.

Each wildflower strip, which was always located on one side of an intensively used meadow, was 3 m wide and 50 m long, leading to a size of 150 m^2 per wildflower strip (Figure 4).

Figure 4: Wildflower strips in Lungau from June to August 2021.

2.2.2. True bug sampling and identification

To survey the species richness and abundance of true bugs, sweep-netting was conducted. The minimum temperature for the field work was 17°C, sunshine, dry vegetation, and not too strong wind.

The sweep net was approximately 35 cm in diameter, with a mesh size of 1 mm and a wooden rod of 1 m length. Sweep netting was performed along three defined transects per meadow with 15 m distance between the transects. Within each transect 30 sweeps were conducted. The collection along three transects was chosen to empty the net after 30 sweeps into a labelled plastic bag. Ethyl acetate ($C_4H_8O_2$) was added to promptly kill the captured true bugs and other caught insects. The plastic bags were then stored in a freezer, sorted in the following weeks, and placed in small glass vials containing 70% ethanol.

The identification was done in the following months up to the species level with a stereomicroscope, identification keys (Deckert & Wachmann, 2020; Wagner, 1952, 1966, 1967) and the “CORISA” CD from Gerhard Strauß (Strauss, 2020). While larvae were counted as individuals for abundance data, they were not identified up to the species level. The sorting and identification process is illustrated in Figure 5.

Sorting of collected insects according to grasshoppers, syrphids, true bugs and the rest.

Bottle of ethanol for conservation of insects.

Result of the sorting process and the storage in small glass vials filled with ethanol.

Identification of true bugs up to species level.

Carpocoris fuscispinus

Kalama tricornis

Figure 5: Sorting of insects collected via sweep netting and identification of true bugs.

2.2.3. Plant parameter sampling

The plant parameters, including vegetation structure, plant height and flower cover, were assessed in five randomly selected 1x1m study plots per sampling site. To measure vegetation structure, an iron rod was inserted vertically into the soil and every leaf touching the rod was counted from the top. This method represents a simplified version of the modified point quadrat method, as employed by Frank & Künzle (2006) and Zurbrügg & Frank (2006). Plant height was measured using a tape, and flower cover was estimated following Karrer (2015), which involved placing a 1x1 m frame on the ground. In Figure 6, the wooden frame can be seen, which was used to choose the five study plots per sampling site and to calculate the flower cover in percent. The whole frame was separated in 25 squares, whereby one flower in one square stood for a flower cover of 4%. This means for example, that 20 squares with flowers led to a flower cover of 80% for the respective plot.

Figure 6: A wooden frame to measure plant parameters.

2.3. Data analysis

The statistical analysis was conducted using “R” version 4.2.2 (R Core Team, 2020). Initially, normal distribution of the data was assessed using Shapiro-Wilk tests and Q-Q plots. The dependent variables, abundance, and species richness were found not to follow a normal distribution, a common characteristic in ecological count data. Following the paper from O’Hara & Kotze (2010), the count data was not log-transformed.

To evaluate the effect of habitat type on true bug species richness and abundance Generalized Linear Models (GLMs) were performed. Due to an overdispersion in all GLM models, the quasipoisson family was chosen. Post hoc testing using Tukey’s range test identified significant differences between habitats. Additionally, plant parameters, namely vegetation structure, plant height, and flower cover, were analysed using GLMs.

Differences in true bug species assemblages between habitat types were assessed using Nonmetric Multidimensional Scaling (NMDS), and a PERMANOVA was conducted with log10-transformed data. The pairwise adonis function was used to examine habitat effects and differences between habitats, with separate analyses for the two regions. The adjusted p-value from the pairwise adonis test was obtained, and the Bonferroni correction was applied for multiple comparisons to mitigate type one errors (Jafari & Ansari-Pour, 2018).

Effect of regional differences:

Considering the dissimilarity in climate and geography between the Wienerwald and Lungau/Nockberge regions, it was evident that separate analyses were needed. A GLM with quasipoisson as a family was employed to evaluate the effect of region on species richness and abundance. The subsequent ANOVA indicated a tendency ($p = 0.0961$ for species richness, $p = 0.0925$ for abundance) but no significant effect. Given these differences, separate datasets for Wienerwald and Lungau/Nockberge were created.

3. Results

The results section is structured based on the main research questions formulated in the Introduction section. In chapter 3.1, the results of the analysis regarding abundance of true bugs in the four habitats are presented. Chapter 3.2 shows the results regarding species richness in the four habitats. Chapter 3.3 answers the question whether the species assemblages of true bugs differ between the studied grassland habitats. Chapter 3.4 deals with the influence of plant parameters (plant height, flower cover and vegetation structure) on species richness and abundance of true bugs.

For chapters 3.1, 3.2 and 3.3, a further important subdivision was undertaken. Based on the tests described in chapter 2.3 (data analysis), it was decided to analyse the two regions separately (also considering differences in climate and geographical location). Therefore, the results are always presented first for the Lungau/Nockberge and then for the Wienerwald. In the joint chapters 3.1.3, 3.2.3 and 3.3.3 the research questions are then answered.

3.1. Abundance of true bugs

Overall, 3.056 true bugs, including larvae, were captured. 1.450 were caught in Wienerwald and 1.606 in Lungau/Nockberge. The highest number of individuals was recorded in a wildflower strip in Lungau/Nockberge (July) with 271 individuals. Distribution across habitats revealed that 39% of true bugs were found in wildflower strips, 30% in extensive meadows, 17% in intensive meadows and 14% in the control habitat (both regions).

Figure 7 presents a boxplot illustrating the abundance of true bugs in Lungau/Nockberge and Wienerwald, with significance letters indicating the results of a post-hoc Tukey Range Test. Further details of these results will be discussed in the following chapters.

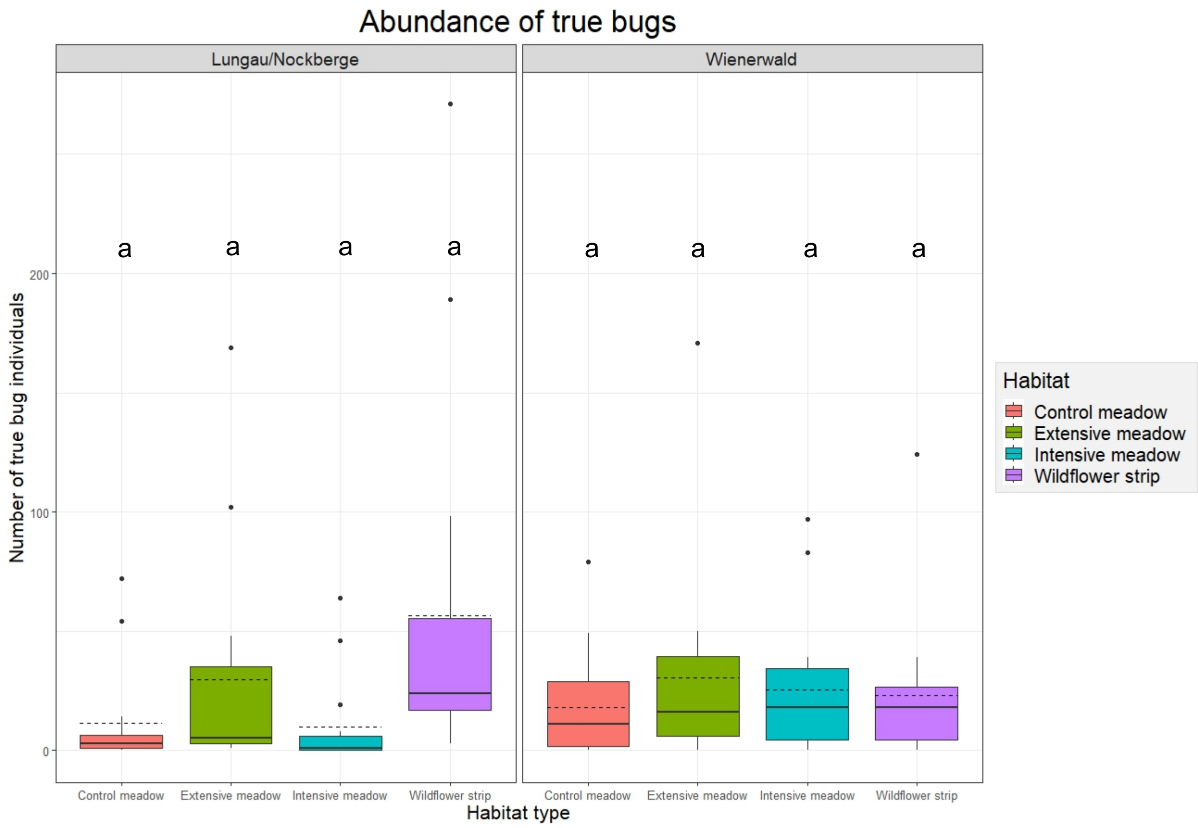

Figure 7: Boxplot of the abundance of true bugs in Lungau/Nockberge and Wienerwald. Boxplots show the median (solid line in box), mean (dotted line) and the 25% and 75% quartile. 50% of the data lies within the box (interquartile range). The Whiskers show the maximum and minimum, or 1,5 times the interquartile range. Black points indicate outliers. Indicator letters (a) show the result of a post-hoc Tukey Range Test. Same letters indicate no significant differences.

Note: Abundance data includes larvae of true bugs.

3.1.1. Abundance of true bugs in Lungau/Nockberge

For the control meadow, the mean was 11.33 (median = 3), for the extensive meadow, the mean was 29.6 (median = 5), for the wildflower strip, the mean was 56.4 (median = 24) and for the intensive meadow, the mean was 9.73 (median = 1). The highest recorded abundance was 271 in a wildflower strip. The data looks more heterogeneous than in Wienerwald (Figure 7). To assess significant differences between the four grassland habitats (RQ1) a GLM was performed (Table 2). The GLM reveals a significant difference for the wildflower habitat in Lungau/Nockberge.

Table 2: GLM results of true bug abundance in Lungau/Nockberge

* → p-value < 0.05;

*** → p-value < 0.001

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
Intercept	2.4277	0.6168	3.936	0.001 ***
Habitat Extensive	0.9600	0.7254	1.323	0.191
Habitat Flower	1.6047	0.6760	2.374	**0.021 ***
Habitat Intensive	-0.1522	0.9075	-0.168	0.867

To assess potential significant differences between individual habitat types (e.g., intensive meadow vs. extensive meadow, wildflower strip vs. control meadow), a post-hoc Tukey Range Test was performed (Table 3). All p-values were > 0.05, indicating no significant differences between the four habitat types. Nevertheless, there was a marginally significant difference between wildflower strips and control meadows (p = 0.078 .) and wildflower strips and intensive meadows (p = 0.066 .). The results are also presented with significance letters in Figure 7.

Table 3: Post-hoc Tukey Range Test for true bug abundance in Lungau/Nockberge

. → p-value < 0.1

	Estimate	*Std. Error*	*z value*	*Pr(>|z|)*
Extensive - Control == 0	0.9600	0.7254	1.323	0.536
Flower - Control == 0	1.6047	0.6760	2.374	0.078 .
Intensive - Control == 0	-0.1522	0.9075	-0.168	0.867
Flower - Extensive == 0	0.6447	0.4713	1.368	0.507
Intensive - Extensive == 0	-1.1122	0.7673	-1.450	0.456
Intensive - Flower == 0	-1.7569	0.7207	-2.438	0.066 .

3.1.2. Abundance of true bugs in Wienerwald

The highest number of individuals in Wienerwald was recorded in an extensive meadow with 171 individuals. Specifically, for the control meadow, the mean was 17.87 (median 11), for the extensive meadow, the mean was 30.47 (median = 16), for the wildflower strip, the mean was 23 (median = 18) and for the intensive meadow, the mean was 25.33 (median = 18).

The abundance data appears quite similar across the habitats (Figure 7). To evaluate significant differences between the four grassland habitats (RQ1), a GLM was conducted for the Wienerwald data, revealing no significant differences (Table 4). A following post-hoc test (Tukey Range Test) confirmed the absence of significant differences between the habitats, as expected. The results are further illustrated with significance letters in Figure 7.

Table 4: GLM results of true bug abundance in Wienerwald

*** → p-value < 0.001

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
Intercept	2.8829	0.3909	7.375	8.3e-10 ***
Habitat Extensive	0.5337	0.4924	1.084	0.283
Habitat Flower	0.2526	0.5211	0.485	0.630
Habitat Intensive	0.3492	0.5105	0.684	0.497

3.1.3. Answering research question 1

Based on the conducted tests and the results presented (chapter 3.1.1 and 3.1.2), research question 1 is now answered.

RQ 1: Are there significant differences in the abundance of true bugs between the four studied grassland habitats?

In Lungau/Nockberge, the GLM revealed a significant effect of habitat type on true bug abundance. However, the following post-hoc Tukey Range Test indicated only marginal differences between single habitat types for abundance. In Wienerwald, no effect of habitat type on true bug abundance was obtained, meaning that there are no significant differences between the true bug abundance in the four different habitat types.

In summary, RQ1 can be answered with a marginal yes in the Lungau/Nockberge region and a no in Wienerwald.

3.2. Species richness of true bugs

Larvae were excluded from the species richness analysis.

A total of 75 distinct species, belonging to 14 different families, were detected, with 57 found in Wienerwald and 41 found in Lungau/Nockberge. The species *Stenotus binotatus* dominated with 379 occurrences, accounting for 19,8% of all identified true bugs, followed by *Leptopterna dolabrata* with 375 identifications (19,6%). Thirty-six of the 75 species were identified 3 times or less, accounting for 48% of all identified species (see Table 7).

The majority of the identified true bug species belonged to the family of *Miridae* (87%), followed by *Lygaeidae* (5%) and *Pentatomidae* (2,3%). Nine of the 14 families found accounted for less than 1% of the total number of species, which is mostly due to the dominance of the *Miridae*. The highest species diversity within a single habitat was observed in a control meadow (intensive) in Wienerwald in July, where 15 species were recorded.

Table 5: Number of individuals of the 35 most abundant species of true bugs, sorted by frequency.

Species	**Family**	**Control**	**Extensive**	**Flower**	**Intensive**	**Total**
Stenotus binotatus	Miridae	8	14	340	17	379
Leptopterna dolabrata	Miridae	6	109	237	23	375
Megaloceroea recticornis	Miridae	2	165	75	3	245
Trigonotylus caelestialium	Miridae	106	20	13	33	172
Polymerus unifasciatus	Miridae	18	2	10	51	81
Stenodema laevigata	Miridae	14	5	46	4	69
Spilostethus saxatilis	Lygidae	16	21	3	26	66
Notostira elongata	Miridae	7	9	23	14	53
Adelphocoris lineolatus	Miridae	23	8	2	16	49
Lygus rugulipennis	Miridae	27	2	10	9	48
Plagiognathus chrysanthemi	Miridae	2	28	1	0	31
Amblytylus nasutus	Miridae	1	18	2	2	23
Aelia accuminata	Pentatomidae	2	8	13	0	23
Lygus pratensis	Miridae	5	2	5	10	22
Orthops kalmii	Miridae	0	7	4	6	17
Nabis flavomarginatus	Nabidae	0	10	5	1	16
Rhopalus parumpunctatus	Rhopalidae	3	0	4	9	16
Lygus wagneri	Miridae	1	2	10	0	13
Stenodema calcarata	Miridae	2	1	10	0	13
Nithecus jacobaeae	Lygidae	0	0	12	0	12
Polymerus brevicornis	Miridae	1	3	3	5	12
Nabis ferus	Nabidae	3	3	3	3	12
Oxycarenus pallens	Lygidae	0	1	0	10	11
Carpocoris fuscispinus	Pentatomidae	0	6	1	2	9
Charagochilus spiralifer	Miridae	1	2	1	4	8
Grypocoris sexguttatus	Miridae	0	8	0	0	8
Eurygaster maura	Scutelleridae	0	7	1	0	8
Coreus marginatus	Coreidae	2	0	3	2	7
Carpocoris purpureipennis	Pentatomidae	0	3	3	0	6
Adelphocoris seticornis	Miridae	1	2	0	2	5
Charagochillus gyllenhali	Miridae	0	1	0	4	5
Deraeocoris ruber	Miridae	1	0	4	0	5
Stictopleurus punctatonervosus	Rhopalidae	0	4	0	1	5
Polymerus carpathicus	Miridae	0	0	1	3	4
Stenodema sericans	Miridae	2	0	2	0	4

Figure 8 displays the boxplot of the species richness of true bugs in Wienerwald and Lungau/Nockberge, with significance letters showing the result of a post-hoc Tukey Range Test. More details about these results will be explained in the following chapters.

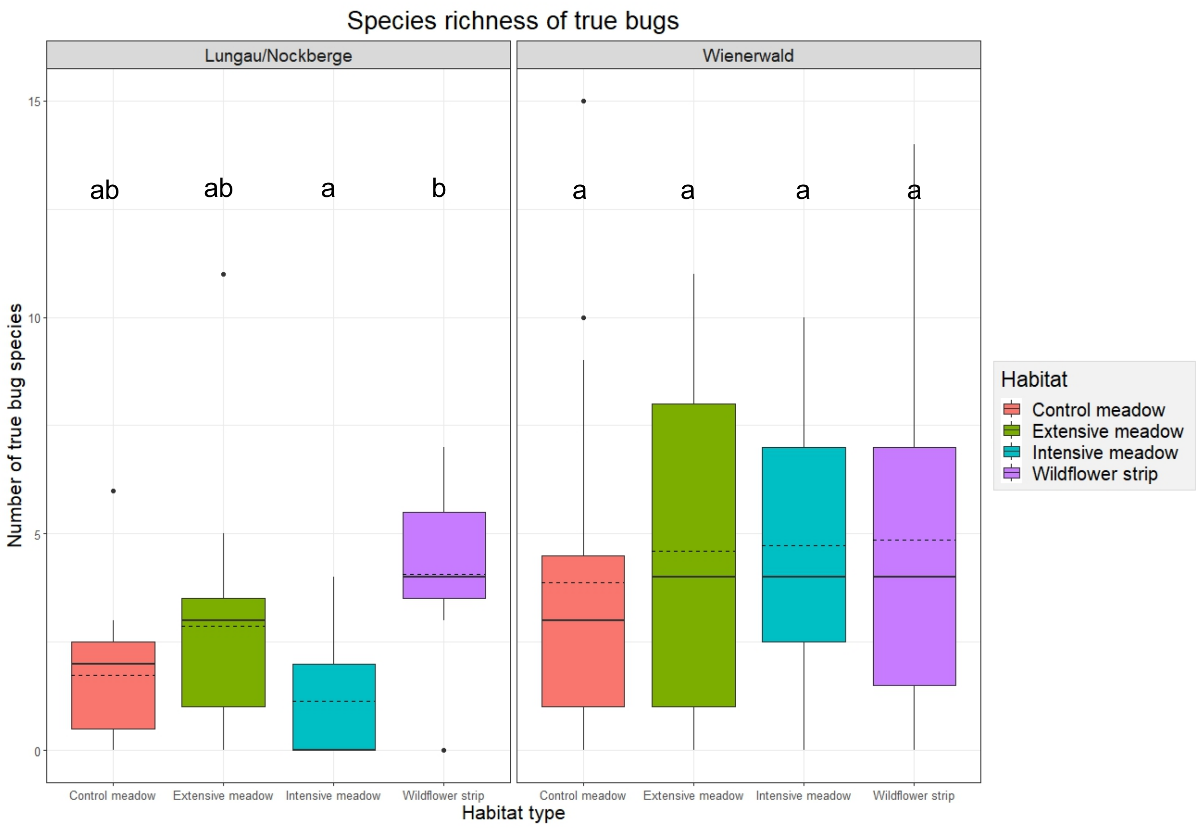

Figure 8: Boxplot of the species richness of true bugs in Wienerwald and Lungau/Nockberge.
Boxplots show the median (solid line in box), mean (dotted line) and the 25% and 75% quartile. 50% of the data lies within the box (interquartile range). The Whiskers show the maximum and minimum, or 1,5 times the interquartile range. Black points indicate outliers.
Indicator letters (a, ab, b) show the result of a post-hoc Tukey Range Test. Same letters indicate no significant difference. Different letters indicate significant differences.
Note: species richness data does not include true bug larvae.

3.2.1. Species richness in Lungau/Nockberge

Descriptive statistics revealed that, for the control meadow, the mean was 1.73 (median = 2), for the extensive meadow, the mean was 2.87 (median = 3), for the wildflower strip, the mean was 4.07 (median = 4) and for the intensive meadow, the mean was 1.13 (median = 0). In the Lungau/Nockberge region, the maximum number of species found was 11 in an extensive meadow.

Again, a GLM was computed (Table 6), followed by a post-hoc Tukey Range Test (Table 7). The GLM reveals a significant effect of the wildflower habitat on species richness in Lungau/Nockberge (Table 6).

Table 6: GLM results of true bug species richness in Lungau/Nockberge.
* → p-value < 0.05

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
Intercept	0.5500	0.2802	1.963	0.055
Habitat Extensive	0.5031	0.3550	1.417	0.162
Habitat Flower	0.8528	0.3347	2.548	**0.014 ***
Habitat Intensive	-0.4249	0.4457	0.953	0.345

There was a highly significant difference between the intensive meadow adjacent to the wildflower strip and the wildflower strip (see Table 7 for post-hoc Tukey Range Test; p = 0.006). The difference between the control meadow and the wildflower strip was marginally significant with a p-value of 0.051. No significant differences were found among the other habitat types. The results are further illustrated with significance letters in Figure 8.

Table 7: Post-hoc Tukey Range Test for true bug species richness in Lungau/Nockberge.
. → p-value < 0.1
** → p-value < 0.01

	Estimate	*Std. Error*	*z value*	*Pr(>|z|)*
Extensive - Control == 0	0.5031	0.3550	1.417	0.482
Flower - Control == 0	0.8528	0.3347	2.548	**0.051 .**
Intensive - Control == 0	-0.424	0.4457	-0.953	0.772
Flower - Extensive == 0	0.3497	0.2845	1.22	0.602
Intensive - Extensive == 0	-0.9280	0.4094	-2.267	0.103
Intensive - Flower == 0	-1.2777	0.3919	-3.260	**0.006 ****

3.2.2. Species richness in Wienerwald

The maximum number of species found was 15 in a control meadow. Specifically, for the control meadow, the mean was 3.87 (median = 3), for the extensive meadow, the mean was 4.6 (median = 4), for the wildflower strip, the mean was 4.87 (median = 4), and for the intensive meadow, the mean was 4.73 (median = 4). The high degree of similarity of the four habitats is also evident in the boxplot presented in Figure 8.

There was no significant difference in species richness among the habitat types (GLM Table 8). The result of the post-hoc Tukey Range Test can be seen as significance letters in Figure 8.

Table 8: GLM results of true bug species richness in Wienerwald.
*** → p-value < 0.001

	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
Intercept	1.3524	0.2497	5.416	1.33e-06 ***
Habitat Extensive	0.1737	0.3388	0.513	0.610
Habitat Flower	0.2300	0.3345	0.688	0.495
Habitat Intensive	0.2022	0.3366	0.601	0.550

3.2.3. Answering research question 2

Following the conducted tests and the results presented in chapters 3.2.1 and 3.2.2, a comprehensive answer to research question 2 is now available.

RQ 2: Are there significant differences in the species richness of true bugs between the four studied grassland habitats?

In Lungau/Nockberge, habitat had a significant effect on true bug species richness. The post-hoc test revealed significant differences between the wildflower strips and the intensive meadows adjacent to the wildflower strips (p = 0.006 **) and a marginally significant effect between the control meadow and the wildflower strip (p = 0.051 .). In Wienerwald, no effect of habitat type on true bug species richness was obtained. With this result, RQ2 can be answered with yes in the region Lungau/Nockberge and with a no in Wienerwald.

3.3. Species assemblages of true bugs

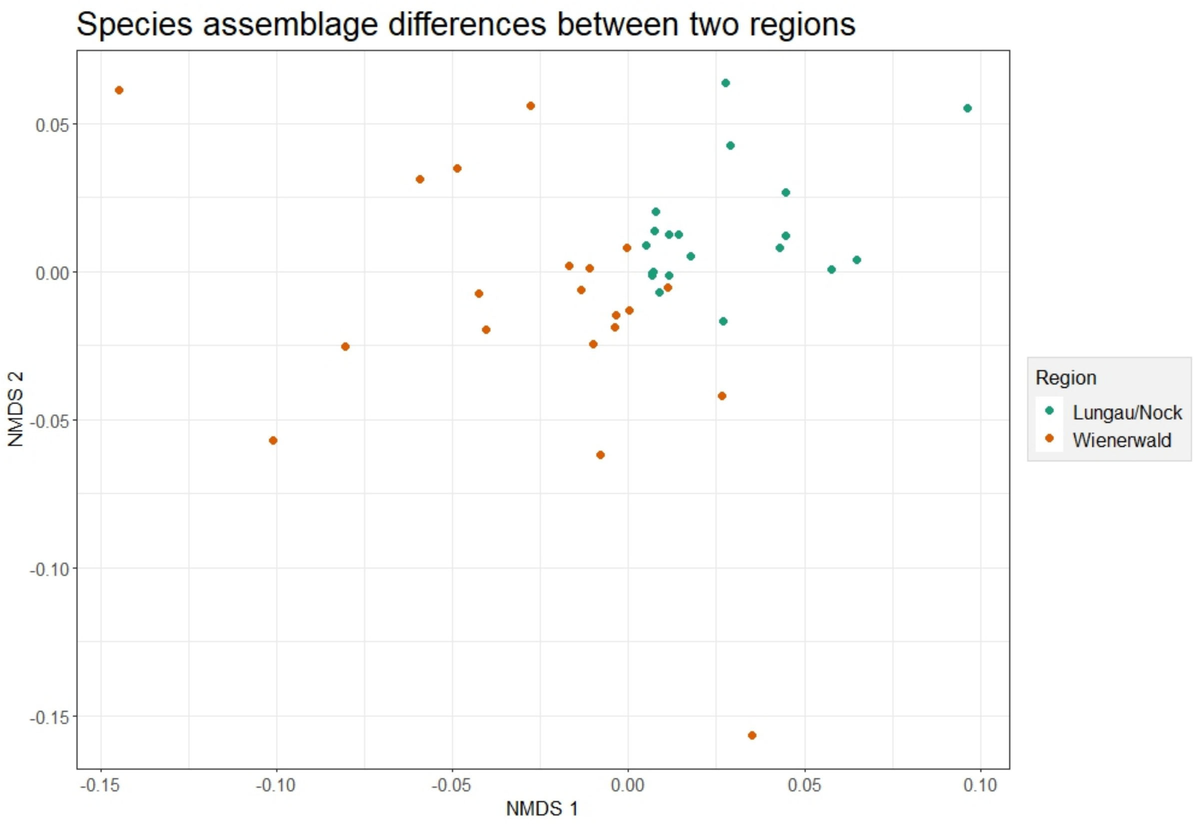

Figure 9: NMDS of species assemblage differences between Lungau/Nockberge and Wienerwald

Figure 9 illustrates the differences in species assemblages of true bugs between Wienerwald and Lungau/Nockberge in a non-metric multidimensional scaling (NMDS) plot, where the multiple characteristics of the species assemblages are shown on the two axes NMDS 1 and NMDS 2. It is evident that the species assemblages in Wienerwald significantly differ from those in Lungau/Nockberge.

The PERMANOVA analysis with the Adonis function in “R” produced a p-value of 0.001. The difference in the species assemblages was therefore highly significant between the two study regions (Table 9).

Table 9: PERMANOVA of species assemblage differences between Lungau/Nockberge and Wienerwald.
*** → p-value < 0.001

	Df	SumOfSqs	R2	F	**Pr(>F)**
Region	1	0.04583	0.13798	6.0824	**< 0.001 *** **
Residual	38	0.28632	0.86202		
Total	39	0.33215	1		

3.3.1. Species assemblages in Lungau/Nockberge

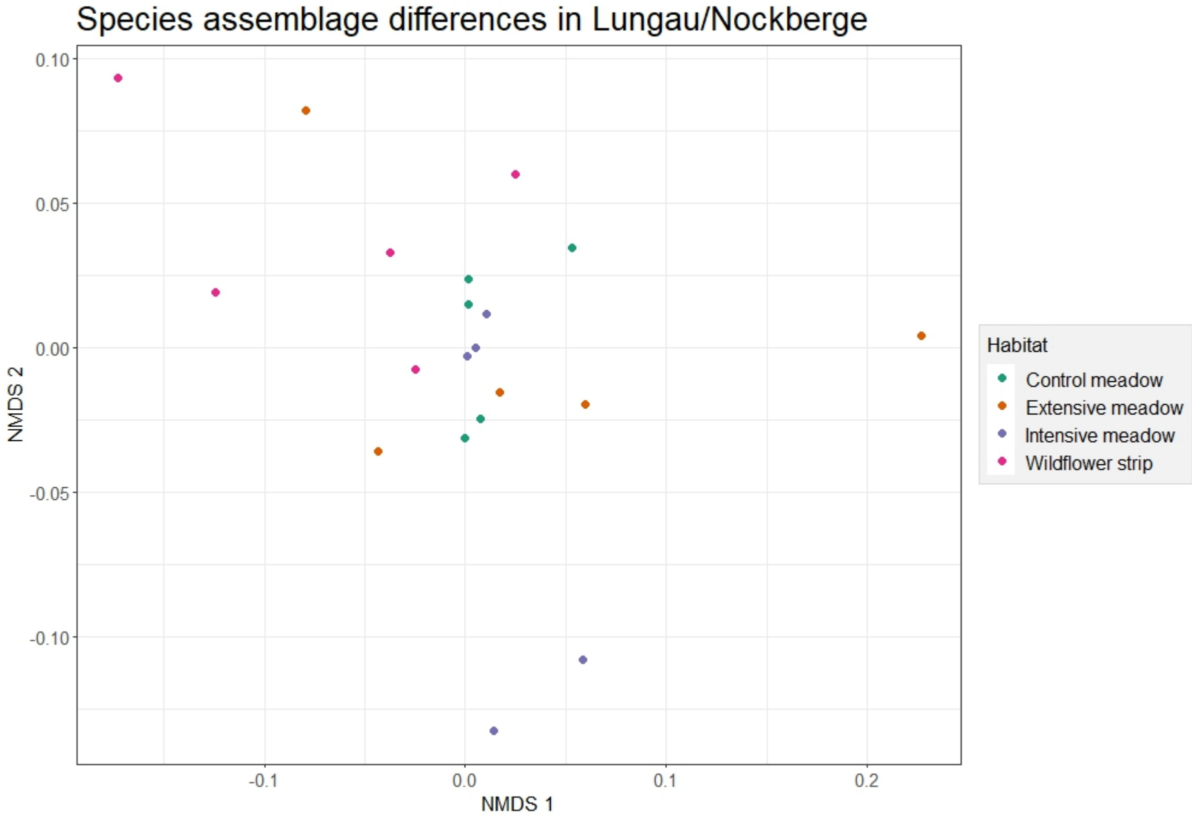

Figure 10: NMDS of species assemblages differences between habitats in Lungau/Nockberge.

In figure 10, the NMDS data is presented, plotted with the two axes NMDS 1 and NMDS 2 for the biosphere reserve Lungau/Nockberge. The distinction between the habitat types was confirmed by the Adonis Test (Table 10), where the p-value for the effect of the habitat in the region Lungau/Nockberge was 0.001 and therefore highly significant. Regarding the different habitats, the true bug species found in intensive and control meadows indicated significant differences from those in wildflower strips (Table 11).

Table 10: PERMANOVA of species assemblage differences between habitats in Lungau/Nockberge. ** → p-value < 0.01

	Df	SumOfSqs	R2	F	**Pr(>F)**
Region	3	0.08434	0.26054	1.8791	**0.001 ****
Residual	16	0.23938	0.73946		
Total	19	0.32373	1		

Table 11: Pairwise adonis test for differences in the species assemblages in Lungau/Nockberge. * → p-value < 0.05

Pairs	DF	SumsofSqs	F.Model	R2	p.value	p.adjusted
flower vs extensive	1	0.3394983	1.8678567	0.1892870	0.029	0.174
flower vs intensive	1	0.7932624	3.0806028	0.2780176	0.006	**0.036** *
flower vs control	1	0.8254418	3.5798351	0.3091439	0.007	**0.042** *
extensive vs intensive	1	0.5582927	1.6138045	0.1678633	0.058	0.348
extensive vs control	1	0.6349972	1.9904198	0.1992328	0.091	0.546
intensive vs control	1	0.3208181	0.8126691	0.0922160	0.631	1.000

3.3.2. Species assemblages in Wienerwald

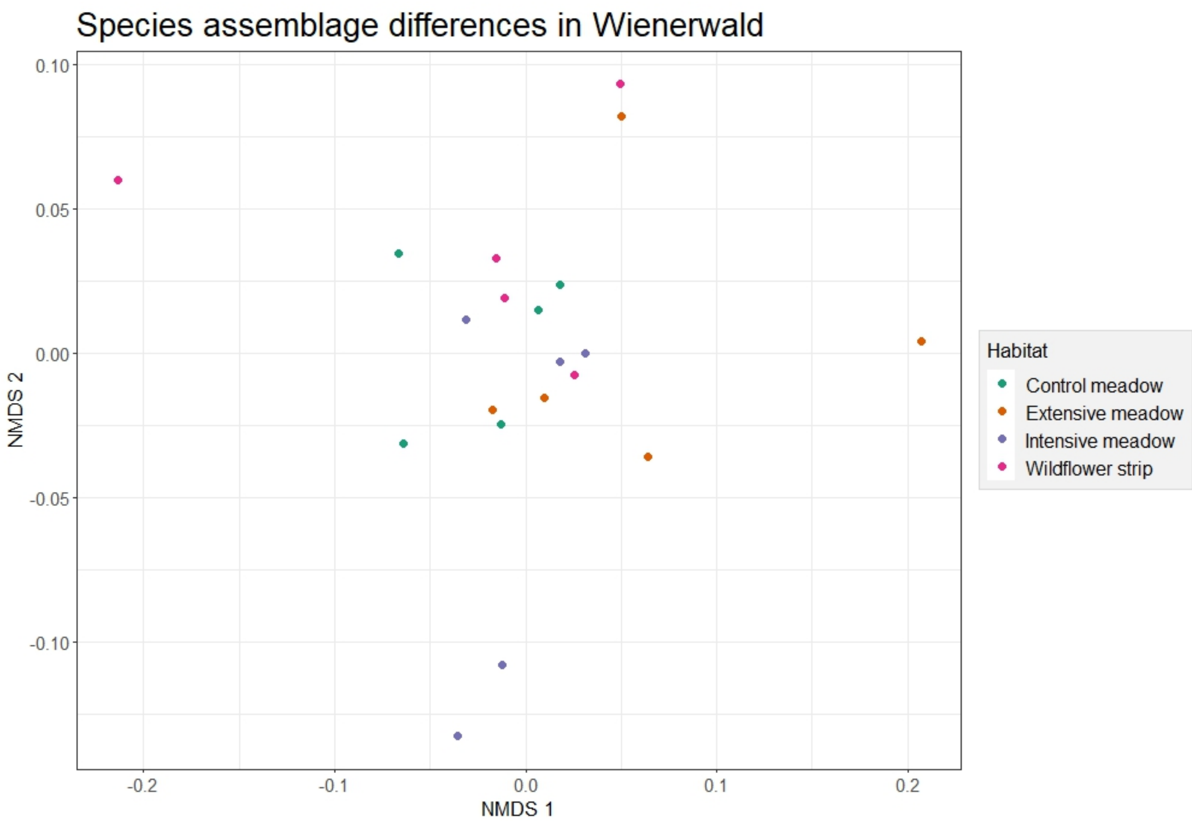

Figure 11: NMDS of species assemblage differences between habitats in Wienerwald.

Figure 11 illustrates the species assemblage differences between the four habitat types in the biosphere reserve Wienerwald. The result of the PERMANOVA (Table 12) using the Adonis function revealed a p-value of 0.021, signifying significant differences in species assemblages between the four habitat types in Wienerwald. The following post-hoc test for pairwise differences (Table 13) indicated marginally significant differences between the two habitats wildflower strip and extensive meadow.

Table 12: PERMANOVA of species assemblage differences between habitats in Wienerwald.
* → p-value < 0.05

	Df	SumOfSqs	R2	F	**Pr(>F)**
Region	3	0.10098	0.21693	1.4775	**0.021 ***
Residual	16	0.36452	0.78307		
Total	19	0.46551	1		

Table 13: Pairwise adonis test for differences in the species assemblages in the Wienerwald.
. → p-value < 0.1

Pairs	DF	SumsofSqs	F.Model	R2	p.value	**p.adjusted**
flower vs extensive	1	0.6324240	2.2727979	0.2212443	0.014	0.084 **.**
flower vs intensive	1	0.5059554	1.9451786	0.1955901	0.048	0.288
flower vs control	1	0.4136251	1.2898184	0.1388422	0.251	1.000
extensive vs intensive	1	0.4136251	1.3747680	0.1466455	0.189	1.000
extensive vs control	1	0.4250534	-1.4266655	0.1513436	0.144	0.864
intensive vs control	1	0.2551904	0.9120966	0.1023437	0.491	1.000

3.3.3. Answering research question 3

Considering the tests and results in chapters 3.3.1 and 3.3.2, research question 3 is now addressed.

RQ3: Do the species assemblages of true bugs differ between the investigated grassland habitats?

In Lungau/Nockberge, according to the Adonis test, habitat type had a significant influence on the species assemblages of the true bugs. Therefore, RQ3 can be answered with yes. As far as the individual habitats are concerned, the species assemblages found in intensive and control meadows differed significantly from those in wildflower strips. In Wienerwald, the habitat also had a significant influence on the species assemblages of the true bugs according to the Adonis test. Therefore, RQ3 can be answered with yes and states that the species assemblages differed significantly between the four habitats in Wienerwald. When looking at the different habitats, a significant difference was found between wildflower strips and extensive meadows as well as wildflower strips and intensive meadows adjacent to wildflower strips.

3.4 Plant parameters

The effect of plant parameters on species richness and abundance of true bugs was analysed for both regions combined. First a GLM was performed, followed by an ANOVA.

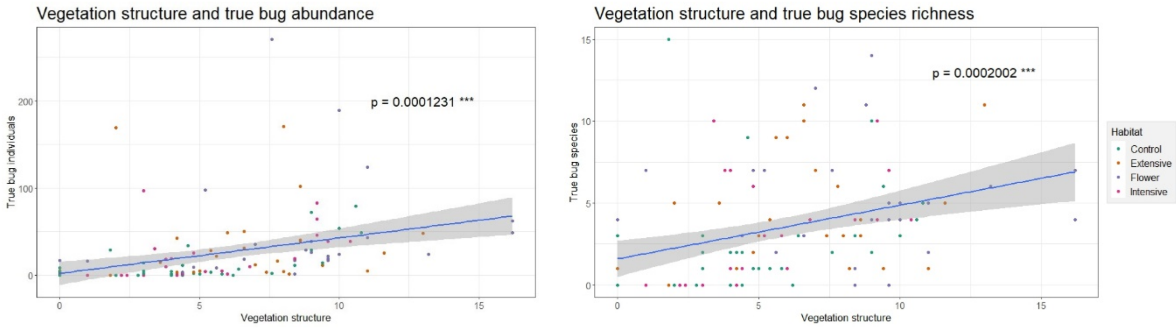

Figure 12: Effect of vegetation structure on true bug abundance and species richness.
*** → p-value < 0.001

Vegetation structure had a highly significantly positive effect on both abundance (p = 0.001 ***) and species richness (p = 0.002 ***) of true bugs (Figure 12).

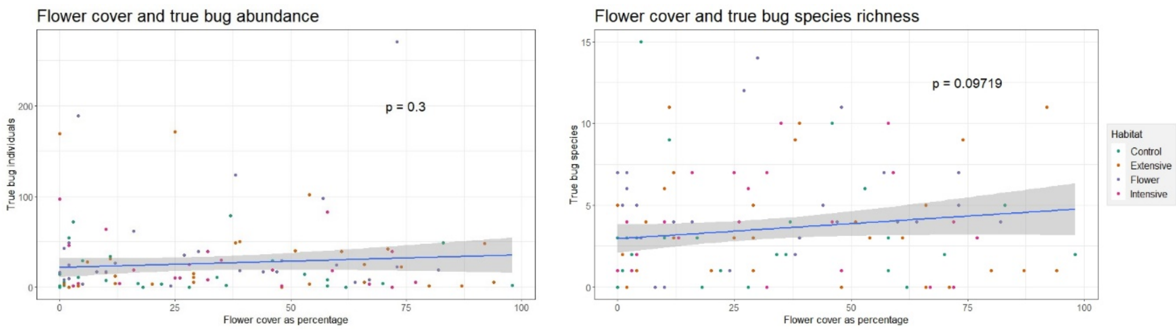

Figure 13: Effect of flower cover on true bug abundance and species richness.

Flower cover had no significant effect on true bug species richness an abundance (Figure 13).

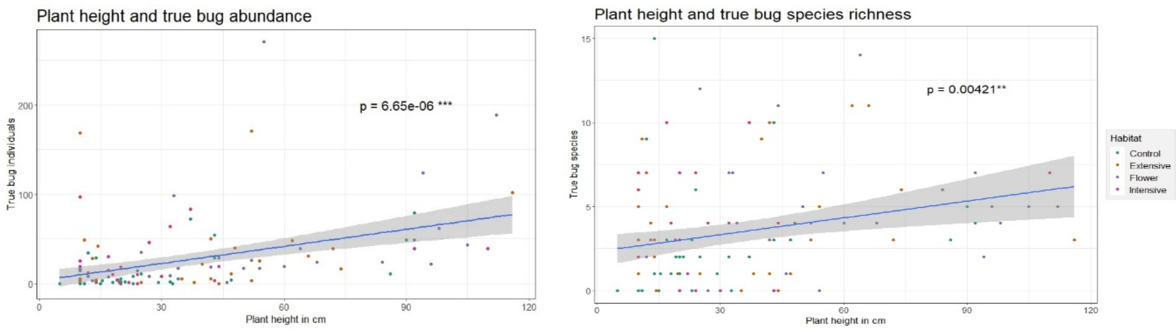

Figure 14: Effect of plant height on true bug abundance and species richness.

*** → p-value < 0.001

** → p-value < .0.01

Plant height influenced both species richness and abundance of true bugs. A highly significant positive effect on abundance (p <0.001 ***) and species richness (p = 0.005 **) of true bugs was obtained (Figure 14).

3.3.4. Answering research question 4

Drawing from the conducted tests and presented results in chapters 3.3.1 and 3.3.2, research question 3 is now addressed.

RQ 4: Do plant parameters affect the species richness and abundance of true bugs?

The results proved that vegetation structure and plant height had a significant or highly significant positive effect on both species richness and abundance of true bugs. Thus, the answer for those two plant parameters is yes. Regarding the flower cover, no significant effect was found, neither on true bug abundance nor species richness. Thus, the answer for the research question four regarding the plant parameter flower cover is no.

4. Discussion

In Lungau/Nockberge, habitat type had a marginally significant ($p < 0.1$) effect on true bug abundance. No effect of habitat type on true bug abundance was identified in the Wienerwald region. Regarding species richness, habitat type had a significant effect in Lungau/Nockberge, while in Wienerwald, no significant effect was observed. Thus, the results were quite similar within the regions for species richness and abundance and will therefore be discussed together.

The differences between the two regions will be first discussed in more detail, as this also has implications for the further discussion.

Comparison of Wienerwald and Lungau/Nockberge

Except for the abundance of true bugs in wildflower strips (which was higher in Lungau/Nockberge), all habitat types in Wienerwald contained more true bug species as compared to the Lungau/Nockberge region. Overall, the species richness of true bugs was higher in Wienerwald compared to Lungau/Nockberge. Thus, the region had a significant influence on the habitat effects on true bugs discussed in the present thesis.

One explanation for the existing regional differences could be that the management of meadows were different between Lungau/Nockberge and Wienerwald. Intensively managed meadows in the Lungau/Nockberge region were mowed around 5 times a year, while intensively managed meadows in the Wienerwald region were only mowed 3 times per year. Thus, the intensity of cultivation of intensively managed meadows was therefore different in the two regions. Overall, intensive grassland is characterized by a high management intensity, including frequent mowing (three or more times a year) and increased fertilizer application (mainly manure). In contrast, extensively managed grasslands are cut once or twice a year and are less or non-fertilized (Kemp & Michalk, 2007). Different climatic conditions and different soil properties across the Austrian cultural landscape lead to varying grassland yields and forage quality, and also significantly influence the present management intensity in the respective region (Buchgraber, 2018). In Wienerwald, the prevailing soil properties would be suitable for intensive grassland management, but the precipitation is too low during the growing season (especially in the more western parts of the Wienerwald region) (Hülber et al., 2017; Suske et al., 2003). Thus, the intensive meadows in the study region Wienerwald received only three cuts a year and could have therefore been considered as more extensively managed than those in Lungau/Nockberge with around five cuts per year. Another reason for an extensive management in the Wienerwald region can be due to several socioeconomic factors. In this context, Suske et al. (2003) found out that an important factor for the predominant form of farming, which could have been characterised as extensive in the

Wienerwald region, is the proximity to the city of Vienna. The resulting attractive work situation for many farmers in the surrounding of a city combined with a low income from agriculture leads to a high proportion of part-time farms. For example, 87% of farms in the municipality of Wolfsgraben (one of the two municipalities in the Wienerwald region in which the study took place) are part-time farms (Statistik Austria, 2022). However, most of the farmers in the Wienerwald region are increasingly aware of their role as landscape managers. They show a predominantly positive attitude towards landscape and biodiversity conservation and therefore maintain extensive farming (Suske et al. 2003). Furthermore, the predominant type of animal husbandry determines the type of farming. Horse husbandry is widespread in the Wienerwald region in the studied area. For example, in the Wienerwald region there are twelve horses per farm, whereas in the Lungau/Nockberge region there are only five horses per farm (Statistik Austria, 2013). Compared to cows, horses have a higher demand for hay in their diet (Stangl et al., 2014; Suske et al., 2003). The production of food for cows differs significantly from that for horses, for which a higher crude fibre content is required. Hay production for horse husbandry leads to a later mowing time and fewer cuts per year, which leads to a more extensive management and consequently to the preservation of biodiversity rich meadows. This is also confirmed by Zechmeister et al. (2003) who stated that agricultural practices such as small part-time farms and horse husbandry positively influence the conservation value of grasslands.

In comparison to Wienerwald, Lungau/Nockberge is a region with better production conditions for grassland farming especially in the valleys, while only the surrounding mountain slopes are extensively farmed. Thus, the meadows in the valley are mainly intensively managed (Greif et al., 2005; Lendl, 1953; Stifter, 2020). This is necessary because cattle husbandry is widespread in the study area of Lungau/Nockberge. For example, each farm in the study area has an average of 25 cows. Thus, the meadows are used very intensively to provide sufficient fodder for livestock farming. Unfortunately, no data was available for the municipalities in Wienerwald regarding the cattle stock (Statistik Austria, 2013, 2022), however, it can be assumed to be very low in the studied area. Further, Suske et al. (2003) described cows and especially dairy farming do not play an important role in the Wienerwald region, especially not in the more western part near Vienna.

Effect of Wildflower strips

In Wienerwald there were no significant differences between wildflower strips and the other studied habitats, while In Lungau/Nockberge, there was a marginally significant difference of true bug abundance between wildflower strips and control meadows as well as between wildflower strips and intensive meadows. Regarding species richness in Lungau/Nockberge, there was a significant difference between wildflower strips and intensive meadows, as well as a marginally significant difference between wildflower strips and control meadows. The effect of the sown wildflower habitat on true bugs was therefore greater in the more intensively managed Lungau/Nockberge region. This is in line with Haaland et al. (2011) and Uthes & Matzdorf (2013), reporting that agri-environmental schemes (such as the implementation of wildflower strips, fallow land, or hedges) are most effective in more intensively managed areas. It must be said, however, that in reality most of the semi-natural areas that promote insect conservation are located in extensively farmed areas, because of low adaptation costs compared to intensively managed areas (Kleijn & Sutherland, 2003).

An important aspect of schemes to protect and enhance insect diversity in the agricultural landscape is the duration from the introduction of the measures to the realisation of an effect on biodiversity. The wildflower strips in this study were sown in September 2019 and the collection of true bugs took place in 2021, which indicated a rapid effect on true bugs, at least in Lungau/Nockberge. This is in line with the existing literature, which points in particular to a rapid positive effect of sown wildflower strips on insects (Bretzel et al., 2016; Haaland et al., 2011). However, older wildflower strips appear to further encourage bugs. Frank et al. (2009) observed a significant increase in the density of zoophagous bugs in older wildflower habitats adjacent to wheat fields, with the highest density in 4-year-old flower strips. In the extensively managed study region in Wienerwald, effects of flower strips on nearby habitats may only materialise after a longer period of time. It would therefore be important to study the flower strips in the long term in order to assess their impact on biodiversity and especially their effect on the true bug fauna.

Another important aspect of semi-natural habitats such as wildflower strips is their effect on adjacent habitats in terms of increasing biodiversity. In this thesis, the effect of wildflower strips on true bugs did not extend to other habitats. This could have been seen in the intensive meadows, which were adjacent to the wildflower strips. They did not differ from the intensively managed control meadows (no adjacent wildflower strips) in both regions regarding true bugs (see Figures 7 and 8). Albrecht et al. (2010) found in their study about ecological compensation meadows (ECM) near intensive meadows an increase of arthropod abundance (including true bugs) by 40% in the adjacent intensively managed meadows. The 90% decrease of insect abundance was achieved at 117m (± 18m) distance from the ECM, meaning that the effect of the ECM on true bugs declined by 90% after 117m. In the study by Albrecht et al. (2010), the average size of the semi-natural habitats was 8,600m², compared to the 150m² of wildflower strips investigated in the present thesis. The wildflower strips investigated in this master thesis were probably too small to trigger spill-over effects on nearby intensive meadows. To maximise the effect of wildflower strips on adjacent habitats an increase in size of the flower strips might be necessary.

The dispersal of true bugs to other habitats could lead to corridor-like effects, in which the insects move from wildflower-strip to wildflower-strip in the agricultural landscape. To therefore maximize the effect these strips, a network of connected areas would be the best option. This is a common suggestion regarding environmentally beneficial habitats (Buhk et al., 2018; Dover et al., 2000; Korányi et al., 2023).

However, it should be noted that the establishment of flower strips in intensively used meadows always means a loss of land for the farmer and the establishment of large flower strips can lead to high yield losses which must be compensated for. Finding the appropriate size of flower strips is a major challenge that still requires a lot of future research.

Effect of management

In the following discussion of the effects of management on bugs, I focus on extensively managed meadows and the differences between them and the two intensively managed meadows (control and intensive meadows). The extensively managed meadows were only mowed once a year and never received any fertilizer application.

In a study by Di Giulio et al. (2001), the effect of landscape structure and management (intensive or extensive) on true bug diversity was investigated. Management accounted for almost 30% of the variance in the species richness of true bugs. Also Torma et al. (2019), in accordance with Badenhausser & Cordeau (2012), emphasised the importance of management practice on orthopterans and true bugs, especially on the abundance. This could not have been observed in the present master thesis. Extensively managed meadows did not differ statistically significant from the other investigated habitats regarding species richness and abundance of true bugs. Only the mean and median of species richness and abundance of true bugs were higher in the extensively managed meadows in Lungau/Nockberge than in the intensive meadows and control meadows. This was not the case in Wienerwald, where no differences in mean and median of species richness and abundance were observed.

One reason for this non-existing effect of extensive management on true bugs could be, that both regions are quite extensively managed on a landscape scale. This is supported by the fact, that both are in an UNESCO biosphere region with certain management conditions, whereby biosphere reserves are extensively managed on a landscape scale per definition. (Biosphärenparks Österreich, 2023; Lange, 2005; UNESCO, 1996). And as already mentioned in the discussion about the differences of the two regions, both regions are overall more extensive, as the geographical and climatic conditions are not ideal for intensive farming. This is very much in line with the hypothesis from Tscharntke et al. (2005). In a landscape with high biodiversity (important is the landscape scale), the effects of management on biodiversity is lower, than in a landscape with lower biodiversity on a landscape scale. Biodiversity in this context includes insects. This means for this thesis, that both intensive management (intensive and control meadows) and extensive management (extensive and wildflower strips) did not affect species richness and abundance of true bugs in the same way, as it would be in a simpler landscape.

A limitation in assessing the impact of management on true bugs was the lack of detailed records on management practices and its timing, as previously mentioned in the discussion of the two regions. These records would have facilitated a more accurate evaluation of the actual intensity of grassland habitats. Importantly, having such records would help avoid conducting insect surveys immediately after cutting or fertilization. However, this limitation was known but could not be completely avoided, which is why, among other things, three surveys were carried out each year (June, July and August).

Effect of plant parameters

Among the plant parameters measured, plant height and vegetation structure had a highly significant influence on the species richness and abundance of true bugs, while flower cover had no influence. True bugs, which are often found on flowers or flower buds, use them differently than pollinators. In addition to the vegetative parts of the plant, many true bugs also feed on flowers or flower buds. They also like to get into the upper layers of vegetation to warm up (Deckert & Wachmann, 2020). Most of the literature on this topic revealed a positive influence of flower cover on true bugs (Frank & Künzle, 2006; Zurbrügg & Frank, 2006). Only Walcher et al. (2017) observed the opposite, namely a negative relationship between species richness and flower cover. In the present thesis, also no effect of vegetation cover was observed. Zurbrügg & Frank (2006) identified vegetation structure as a key factor for true bugs in agricultural landscapes. As also Kőrösi et al. (2012, p. 57), which said: "*We conclude that vegetation structure is the primary factor shaping Hemiptera communities*..". Greater vegetation height and structure influence the microclimate in a habitat (Karrer, 2015). The altered microclimatic conditions in turn have an influence on true bugs, as shown by Di Giulio et al. (2001), Otto (1996) and Stoutjesdijk & Barkman (2014). Higher vegetation structure and plant height usually lead to a decrease in temperature and higher humidity, which are factors influencing the appearance of true bugs (Deckert & Wachmann, 2020). Especially predatory species benefit from the higher complexity of the plant architecture and the greater potential surface for colonisation, which also leads to a higher availability of suitable prey species (Lawton, 1983; Murdoch et al., 1972; Price et al., 1980). Availability of diverse plant communities are further important for the maintenance of various phytophagous species. The two species *Stenotus binotatus* and *Leptopterna dolabrata* alone accounted for 39,4%. Both true bug species, belong to the family of *Miridae* and feed on tall grasses. *Leptopterna* *dolabrata* on for example Dactylis, Phleum and Alopecurus. *Stenotus binotatus* prefers developing grass seeds.

Extensive meadows and wildflower strips were mowed once or twice a year. Because the first mowing date was very late, the vegetation could have grown very tall. Further, due to their usually higher plant species richness, they also showed higher vegetation structure (Marriott et al., 2004). In view of this information, it was not to be expected that extensive meadows in both regions would show no significant difference to intensive and control meadows.

Effect of habitat on species assemblages:

In terms of species diversity, there were highly significant differences between the two regions. This is in line with Batáry et al. (2007), who described regional effects as very influential on the assemblages of true bugs. Climatic and geographical differences between the two regions are very different (mean annual temperature in Wienerwald 10°C, in Lungau/Nockberge 6.2°C, altitude Wienerwald 350-400m, Lungau/Nockberge 1000-1100m). These factors most likely contribute significantly to the differences in species assemblages of true bugs, together with another important reason, the large distance between the experimental areas of the two regions. The distance in a straight line is just over 200 km.

In both regions, species assemblages were significantly (Wienerwald) or even highly significantly (Lungau/Nockberge) different between the four habitat types investigated. In Wienerwald, species assemblages of wildflower strips were marginally significant different from extensive meadows and in Lungau/Nockberge. The wildflower strips contained significantly different species assemblages than intensive and control meadows. It could therefore be shown that there are differences between wildflower strips and the other habitat types investigated in both regions. Gessé et al. (2014) named specific plant communities as the main drivers of different true bugs assemblages. There is therefore a strong correlation between plant species assemblages and the true bug species assemblages. The wildflower strips in the present thesis were sown either with a seed mixture specially selected for the region (Wienerwald), or the seeds were harvested from local, extensively managed meadows (Lungau/Nockberge).This difference in the seed selection could be an explanation, why there was no significant difference in true bug assemblages between wildflower strips and extensive meadows in Lungau/Nockberge, because in Wienerwald there was a marginally significant difference between these two habitats. This non existing difference in Lungau/Nockberge was a positive aspect, indicating that the wildflower strips provided an attractive habitat for true bugs which benefitted from the extensive management within the intensively managed meadows. Without the presence of wildflower strips, these species might not be found in intensively managed meadows. But plant communities were not the only factor driving these variations in true bug assemblages. Differences in the character and complexity of the surrounding grassland habitats are according to Kőrösi et al. (2012) and Woodcock et al. (2007) important factors shaping heteropteran communities.

The varying outcomes concerning true bug assemblages in the two regions underline the assumptions discussed earlier about the distinctions between these regions. In the more intensively managed region of Lungau/Nockberge, true bugs species assemblages in wildflower strips differed from those in intensive and control meadows. In the more extensively managed Wienerwald, no significant difference between wildflower strips and intensively managed meadows (intensive and control) was detected.

5. Conclusion

The aim of this master's thesis was to evaluate the impact of four grassland habitats and their plant parameters on true bug species richness, abundance, and species assemblages in two Austrian biosphere reserves.

The results of this thesis showed significant and marginally significant differences in true bug species richness and abundance across different grassland habitats in two Austrian regions. Wildflower strips had a more significant impact on the true bug species richness and abundance in the more intensively managed region of Lungau/Nockberge. In contrast, the more extensively managed region of Wienerwald exhibited higher overall species richness and abundance, with a more even distribution across habitats, resulting in greater homogeneity. The observed effect of the sown wildflower strip within two years indicated potential benefits, but an extension of the temporal conservation of the wildflower strips (2 years) and size of the strips (150m²), as suggested by Albrecht et al. (2010) and Frank et al. (2009), would probably lead to greater effects, especially in adjacent intensive meadows and overall in extensively managed regions. Considering the corridor-like effects of the strips, the new Common Agriculture Policy of the European Union (2023-2027) emphasizes "collective measures" in several member states, such as the Netherlands. Implementing wildflower strips collectively, connecting them across different fields, aligns with this approach (Barghusen et al., 2021; van Dijk et al., 2015). In conclusion, wildflower strips have proven to be effective agri-environmental measures with an immediate impact in intensively managed regions. Maximizing their positive effects, particularly in extensive regions, requires long-term establishment, bigger areas and a collective approach to ensure sustainable positive effects.

The effect of management did not result in the expected changes in true bug numbers and diversity. Despite some differences in certain areas, extensively managed meadows did not significantly differ from other habitats. The broader landscape management, influenced by factors like geography and climate, probably challenges the usual expectations, as both regions are quite extensive on a landscape level. This can easily be seen by the fact, that UNESCO biosphere reserves are extensive regions by definition. The results support the idea from Tscharntke et al. (2005) that high biodiversity in the landscape can lower the impact of implemented management schemes, such as extensification and establishment of wildflower strips, on insect diversity.

The significant differences in species assemblages between the two regions were influenced by regional factors affecting the assemblages of true bugs. Climatic and geographical variations, as well as the large distance between the experimental areas most likely contributed to these differences. The impact of specific plant communities, most likely contributed to variations in true bug assemblages. In the present thesis regional differences confirmed assumptions about the influence of management on wildflower strips and meadows. In Lungau/Nockberge regarding species assemblages, intensively managed meadows (intensive and control) significantly differed from wildflower strips, while in Wienerwald, extensive meadows differed from wildflower strips.

The plant parameters plant height and vegetation structure significantly influenced true bug species richness and abundance, while flower cover had no influence. The thesis underlines the central role of vegetation structure on true bugs and emphasizes the importance of considering plant parameters for understanding and managing true bug populations and their occurrence in agricultural landscapes.

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List of abbreviations

ANOVA: Analysis of Variance

GLM: Generalized Linear Model

PERMANOVA: Permutational multivariate analysis of Variance

ÖPUL: Österreichisches Programm für umweltgerechte Landwirtschaft

UNESCO: United Nations Educational, Scientific and Cultural Organization

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