BACHELOR'S THESIS

Influence of environmental parameters on diurnal Lepidopteran diversity and abundance on an artificial levee in the National Park Donau-Auen

Magdalena Sophie Riedl
12123735
a12123735@unet.univie.ac.at

Supervisor: Univ.-Prof. Mag. Dr. Konrad Fiedler
300186 PP Forschungspraktikum Ökologie (2025S)
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Abstract

The loss of biodiversity through climate change, land-use intensification and environmental degradation have made the effective protection of species and their habitats more relevant than ever. Especially species rich semi-natural grasslands, which are steadily declining in Europe, are dependent on appropriate management strategies for long-term conservation. The Marchfeldschutzdamm runs through the Nationalpark Donau-Auen and protects the surrounding areas from inundation while simultaneously providing conditions for the existence of dry grasslands in a wetland landscape. In this study, diurnal Lepidoptera ("butterflies"), which are ideal biological indicators, were recorded from the end of June to July 2025. The aim was to investigate the influence of environmental factors on butterfly diversity and abundance which may result in better management recommendations. Nectar-flower abundance and vegetation height positively correlated with the number of individuals observed, but not the number of species. Cloud coverage had no noticeable impact on recording success. I also compared the local diversity and number of individuals between surveys in mid and high summer and contrasted the gamma diversity of the two study years 2023 and 2025. The number of species as well as the number of individuals were higher in midsummer. Species richness and Shannon diversity of butterflies showed no significant difference between 2023 and 2025.

Keywords: Butterfly diversity, diurnal moths, Lepidoptera, gamma diversity, species richness, grasslands, Shannon Diversity, mowing regime

Zusammenfassung

Der Verlust der biologischen Vielfalt durch den Klimawandel, die Intensivierung der Landnutzung und die Umweltzerstörung machen den wirksamen Schutz von Arten und ihren Lebensräumen wichtiger denn je. Insbesondere artenreiche naturnah bewirtschaftete Wiesen, die in Europa stetig zurückgehen, sind für ihren langfristigen Erhalt auf geeignete Bewirtschaftungsstrategien angewiesen. Der Marchfeldschutzdamm verläuft durch den Nationalpark Donau-Auen und schützt die umliegenden Gebiete vor Überschwemmungen, während er gleichzeitig die Voraussetzungen für das Bestehen von Trockenwiesen schafft. In dieser Studie wurden von Ende Juni bis Juli 2025 tagaktive Lepidoptera („Tagfalter") erfasst, die sich als biologische Indikatoren eignen. Ziel war es, den Einfluss von Umweltfaktoren auf die Vielfalt und Häufigkeit von Tagfaltern zu untersuchen, um daraus eventuell bessere Managementstrategien ableiten zu können. Die Häufigkeit von Nektarblüten und die Vegetationshöhe korrelierten positiv mit der Anzahl der Individuen, jedoch nicht mit der Anzahl der Arten. Die Bewölkung hatte keinen erkennbaren Einfluss auf den Nachweiserfolg. Ebenfalls wurde die lokale Vielfalt und die Anzahl der Individuen zwischen den Erhebungen im Frühsommer und im Hochsommer verglichen und die Gamma-Diversität in den beiden Untersuchungsjahren 2023 und 2025 gegenübergestellt. Die Anzahl der Arten sowie die Anzahl der Individuen waren im Frühsommer höher. Der Artenreichtum und die Shannon-Diversität der Tagfalter zeigten keinen signifikanten Unterschied zwischen 2023 und 2025.

Schlüsselwörter: Schmetterlingsvielfalt, tagaktive Motten, Lepidoptera, Gamma-Diversität, Artenreichtum, Grasland, Shannon-Diversität, Mähregime

Introduction

Biodiversity has been rapidly deteriorating for several decades with some of the main drivers being habitat loss, climate change and land use change (IPBES, 2019). According to the EU Grassland Butterfly Index, there has been a decline of butterflies of over 50% since 1991, which in Europe is mainly accredited to nitrogen deposition in nature reserves and habitat loss accompanying the intensification of agricultural grasslands or the loss of grasslands by abandonment and resulting forest succession (Van Swaay, et al., 2025). National Parks act as islands of preservation in a sea of increasingly intensively used and fragmented landscapes. Austria's six national parks only comprise 2.8% of the Austrian total land area, but due to their unique topographies and wide variety of habitat types they still cover a high percentage of Austria's biodiversity and therefore play an important role in national biodiversity conservation (Zulka, et al., 2022).

The Nationalpark Donau-Auen, established in 1996 under Category II Protected Areas of the IUCN (International Union for Conservation of Nature and Natural Resources), spans 9,600 hectares, constituting of 65% riparian forest and 15% meadows, with the remaining area being covered by water. It protects the largest complete riverine wetland in Central Europe and aims to preserve natural processes and protect endangered species and their habitats, some of which are man-made structures (Nationalpark Donau Auen, n.d.) (Manzano, 2019). One of these anthropogenic structures is the Marchfeldschutzdamm (Marchfeld protective dam), an artificial levee running in West-East direction through the Nationalpark Donau-Auen, built during the Danube regulation in the 19th century to shield areas to the left side of the Danube, such as the Marchfeld, from inundation (Wesner, 2006). Aside from flood protection, it is now also used recreationally, as a cycling path runs along the top, connecting Vienna and Bratislava.

The relatively nutrient poor soil and high ground temperatures of the dam allows for the existence of semi-dry grasslands (Wesner, 2016), which belong to the most species-rich ecosystems found in Europe and provide an increasingly rare habitat for many species, especially regarding heliophilic or xerophilic organisms such as butterflies and grasshoppers (Depisch & Fiedler, 2023) (Almásy, et al., 2021). To prevent the deterioration of this habitat through vegetation succession, anthropogenic management is required. Here, the type of land use management, and the overall land-use intensity such as mowing or grazing intensity and frequency, as well as the impact of fertilizer have been shown to have an impact on species abundance, assemblages and diversity (Almásy, et al., 2021) (Bubová, et al., 2025) (Mangels, et al., 2017). A combination of management strategies such as extensive mowing and grazing, as is being conducted on the Marchfeldschutzdamm, has been shown to lead to a high species diversity in nectar plants and visiting butterflies (Fiedler, Wrbka, & Dullinger, 2018) (Depisch & Fiedler, 2023).

Butterflies are well-documented, widely distributed and sensitive to environmental change due to their relatively high mobility and species interactions, which makes them ideal biological indicators for the health status of ecosystems. Because of their beauty and distinctive appearance, they are also well liked by the public as well as relatively easy to identify in the field, without the need to harm them (Habel, et al., 2021) (Zhang, 2023).

The aim of this study was to explore the influence environmental attributes such as vegetation height and nectar-flower availability have on local butterfly species diversity, whether the species diversity or number of individuals differs between mid and high summer, and whether there is a difference in accumulated species diversity between studies conducted in the same area in the years 2023 and 2025. This may ultimately have implications for the ecological importance of the levee as well as the significance of different mowing regimes as a conservation tool. Furthermore, it might bring an insight on how similar biodiversity patterns have been over the years, or whether they have shifted. Based on these goals, the following hypothesis were tested:

(1) The locally observed number of species (and individuals) per transect stretch is influenced by the relation to/dependence on "environmental factors" such as nectar flower supply, vegetation height, mowing condition, wind and cloud coverage.

(2) The (mean) local diversity (= "alpha diversity") per transect, differs in comparison between the surveys conducted in mid and high summer.

(3) The accumulated species diversity (= "gamma diversity"), differs in comparison of the two study years 2023 and 2025.

Materials and Methods

Study site

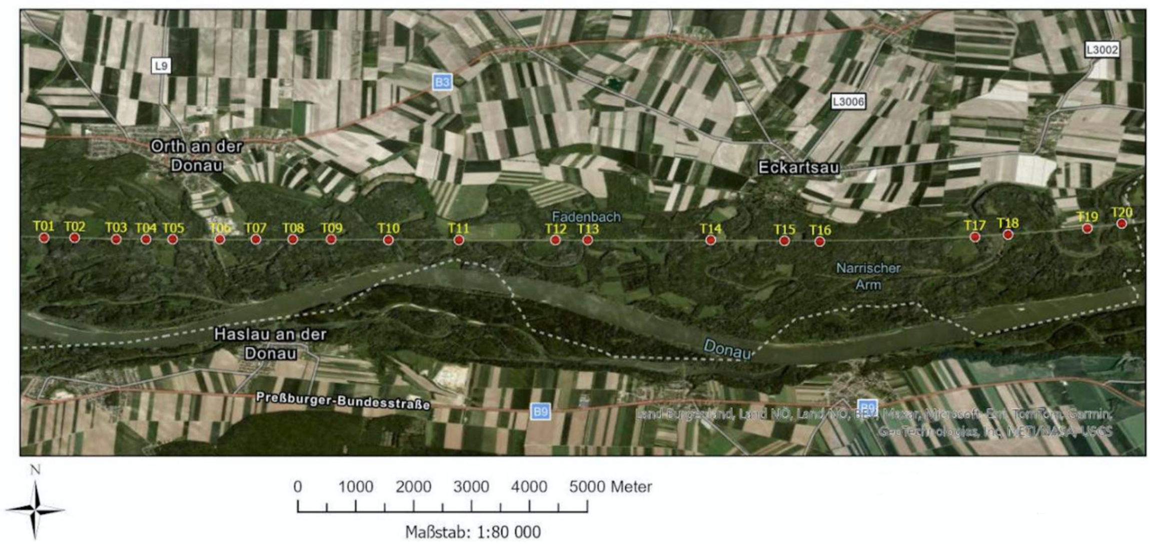

Figure 1 Location of the 20 transects chosen for butterfly sampling. The exact coordinates can be found in the Supplementary Information. (Map created in ArcGIS. Photo source: ESRI, 08/2025).

Sampling was conducted along the Marchfeldschutzdamm, an artificial levee in the Nationalpark Donau-Auen east of Vienna, approximately between the villages Orth an der Donau in the west and Witzelsdorf in the east. Due to its exposition, slope inclination and management concept, such as the removal of mown material to prevent high nutrient concentrations of the soil, the dam is characterized by a species rich, dry grassland, which serves as an important secondary habitat and stands in stark contrast with the surrounding woodland vegetation (Wesner, 2016). The embankment is maintained by viadonau through extensive mowing and, in some sections, supplemented by sheep grazing, which aims to preserve structural and species diversity (viadonau, 2023) (viadonau, 2022). 20 transects, each with a length of 100m, were selected along the northern side of the levee (Fig. 1), where a dirt road runs between the cycling path on the crown and the forest at the bottom of the slope of the embankment, which allowed for convenient sampling. There were at least 200m between each transect.

Butterfly collection/sampling

For sampling, diurnal Lepidoptera (belonging to the superfamily Papilionoidea), as well as diurnal moths (to increase data volume), hereafter rereferred to as “butterflies” for simplicity, were chosen for sampling. Sampling was done in the manner of so-called “Pollard walks” (Barkmann, et al., 2023) by walking the transects at a slow, constant pace, recording all butterflies up to about five metres in front of the observer and from to the edge of the forest up to the cycling path, which runs along the top of the levee.

Butterflies which were unidentifiable in flight were caught with a butterfly net and identified in the field (then released immediately) or photographed and identified later with appropriate literature (Slamka, 2004) (Ulrich, 2018). The two cryptic species pairs *Leptidea* *sinapis/juvernica* and *Colias hyale/alfacariensis,* were recorded as operational taxonomic units (OTU), since their reliable identification is not possible in the field.

Each transect was surveyed four times from June to July 2025 with one survey round being completed in two to four days and separated at least by one week. Sampling took place between 10am and 5pm CEST, only on days with suitable weather conditions, meaning temperatures above 17°C and no rain or strong winds (above 5 on the Beaufort scale) as recommended by Butterfly Conservation Europe (Van Swaay, et al. 2012). Alongside the butterfly counts, the following environmental attributes were recorded: cloud coverage (estimated in eights), wind intensity using the Beaufort scale for land conditions (from 0 = no wind to 5 = moving branches and whole trees, audible wind), nectar flower availability on a rank scale from 1 to 5 (1 = no flowers available; 5 = very high flower density), vegetation height (<10; 10-30; 30-70; >70cm) as well as mowing status (0/1; not recently mowed/recently mowed).

Statistical analysis

For the analysis of the influence of environmental parameters on species diversity and abundance, Jamovi version 2.7.4 was used (The jamovi project, 2025). Generalized Linear Models (GLMs), assuming a Poisson distribution, were fitted to analyze the potential correlation between the number of species or of individuals (as dependent variables) and cloud coverage, vegetation height, nectar-flower availability as well as wind (as predictors). For all statistical tests, a significance level of 5% was chosen. In some graphs, star symbols have been used to show the risk of a Type I error: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

To compare the gamma diversity between 2023 and 2025 iNEXT was used (Chao A. G., 2014) (Chao A. M., 2016). Here, I looked at the accumulated species richness across all temporal and spatial replications within the year 2023 in comparison to the year 2025 in reference to only true butterflies, diurnal moths, and the aggregated data. The data from 2023 was extracted from (Scanferla, 2023). Species accumulation curves were estimated with iNEXT, which is based on rarefaction and extrapolation (R/E) sampling curves of Hill numbers. The accumulation curves were estimated at q=0 for species richness and q=1 for (exponential) Shannon diversity.

Results

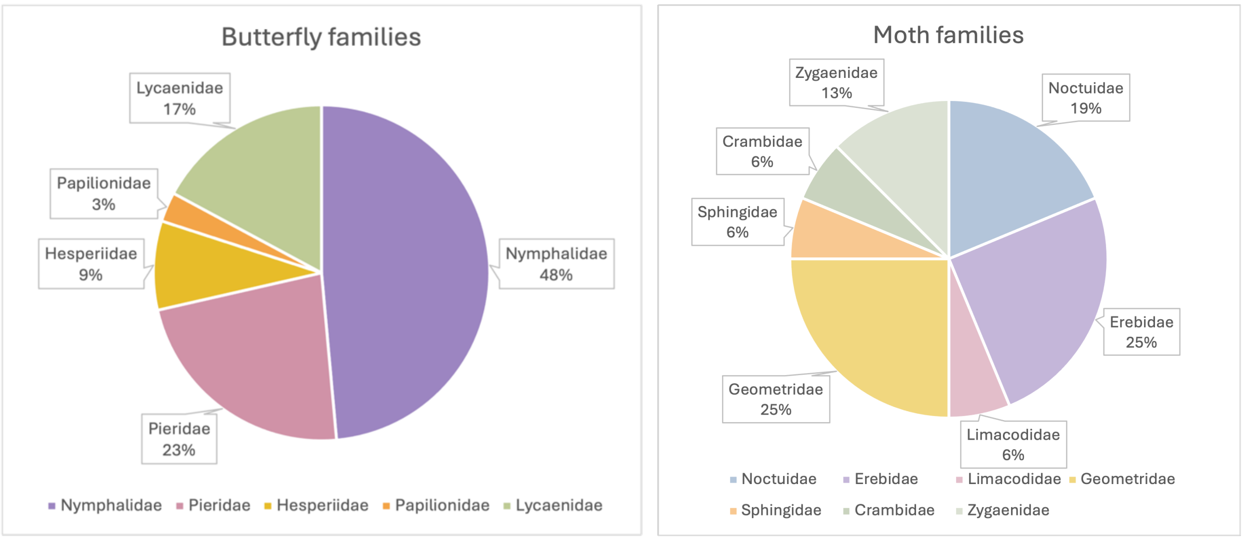

Figure 3 Frequency distributions of butterfly species (left) or diurnal moth species (right) across families

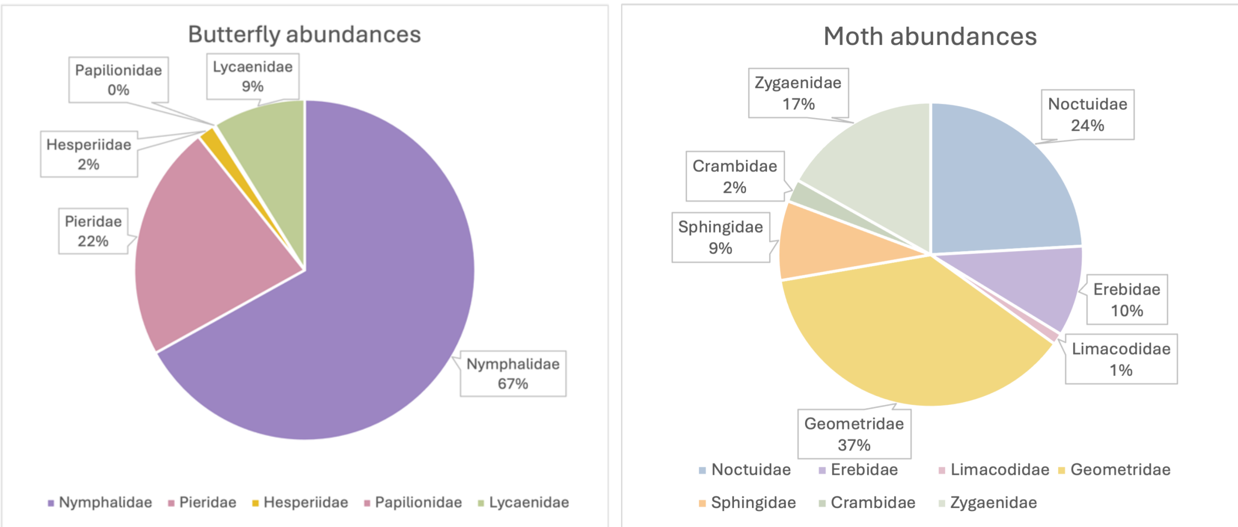

Figure 2 Frequency distribution of butterfly individuals (left) or diurnal moth individuals (right) across families.

In total, 1353 individuals belonging to 51 species were recorded. Most individuals, namely 1270 individuals representing 35 species belonged to the true butterflies, while 83 individuals representing 16 species were diurnal moths. The highest number of species within the true butterflies belonged to the family Nymphalidae (48 %, Fig. 2), which also constituted the highest number of individuals of true butterflies (67 %, Fig. 3). The Nymphalidae were followed by Pieridae, Lycaenidae and Hesperiidae. The Papilionidae were represented by a single species

(*Iphiclides podalirius*) on the levee, found three times during the sampling period. The most frequent species was *Maniola jurtina* with 516 individuals (38 %) followed by *Melanargia galathea* with 172 individuals (13 %), *Colias hyale/alfacariensis* with 116 individuals (9 %), *Issoria lathonia* with 78 individuals (6 %) and *Leptidea sinapis/juvernica* with 75 individuals (6 %).

The most common moth families were Erebidae and Geometridae (25% each, Fig. 2), with the most individuals belonging to the Geometridae (37 %, Fig. 3). The most common moth species found were *Idaea serpentata* with 14 individuals (1 %), *Ematurga atomaria* with 13 individuals (1%) *and Autographa gamma* with 12 individuals (1%).

Environmental parameters

When looking at the relationship between the parameters that describe the availability of resources (i.e. vegetation height and nectar-flower availability) and the number of species or individuals, they all positively correlated, though only the GLMs for the number of individuals were significant ($p < 0.001$, Table 1). The correlation between the number of species and nectar-flower availability was not significant ($p = 0.079$, Fig. 4, left), neither was the correlation between the number of species and vegetation height ($p = 0.180$, Fig. 5, left). The correlation between the number of individuals seen (as well as the number of species) and cloud coverage was also not significant ($p = 0.837$, Fig. 6). In contrast, the number of individuals and wind speed did significantly and negatively correlate ($p< 0.001$; Fig. 7).

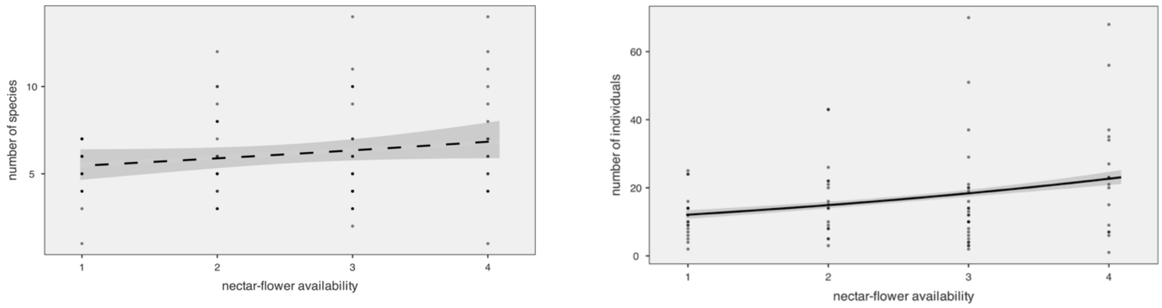

Figure 4 Results of Generalized Linear Models of the number of butterfly species (left) or individuals (right) and the nectar flower availability. The result on the left was not significant ($p = 0.079$), as indicated by the dashed line. The result on the right was highly significant ($p < 0.001$).

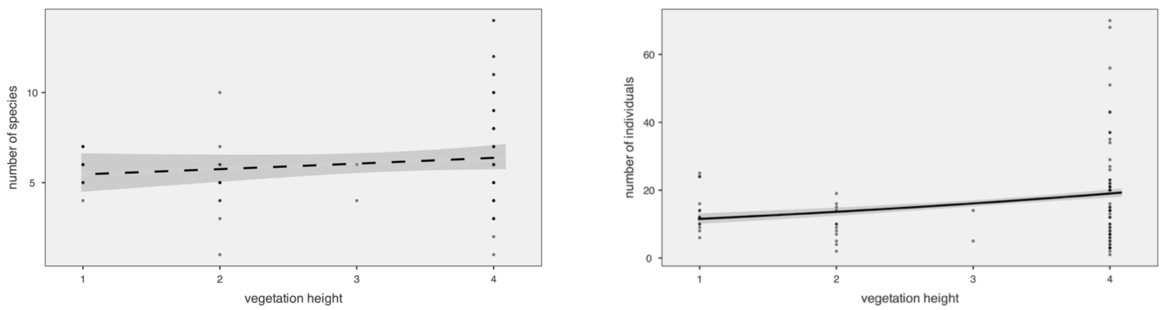

Figure 5 Results of Generalized Linear Models of the number of species (left) or individuals (right) and vegetation height. The result on the left was not significant ($p = 0.180$), as indicated by the dashed line. The result on the right was highly significant ($p < 0.001$).

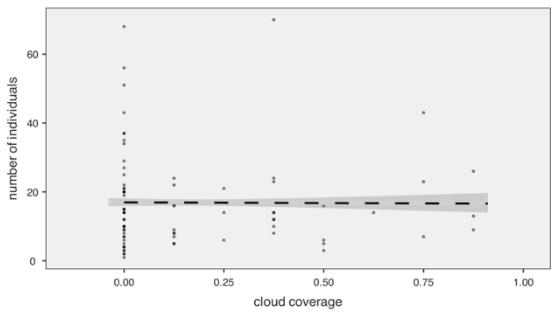

Figure 6 Results of a Generalized Linear Model of the number of individuals and cloud coverage. The result was non-significant ($p = 0.837$).

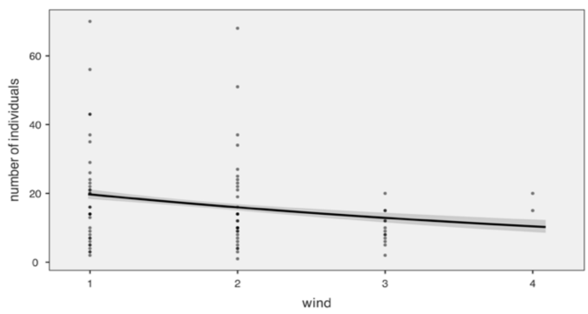

Figure 7 Results of a Generalized Linear Model of the number of individuals and wind speed. The result was highly significant ($p < 0.001$).

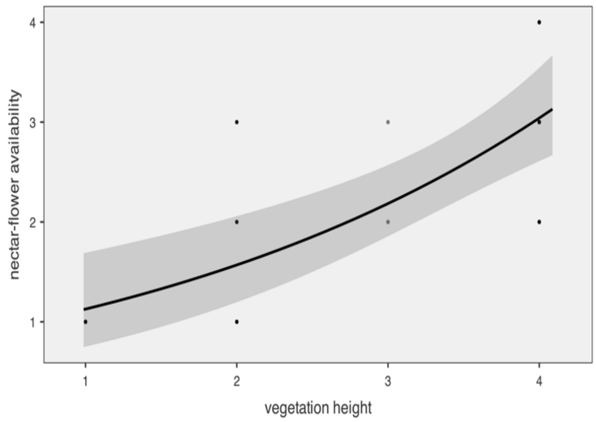

Figure 8 Relationship (Generalized Linear Model) between the nectar-flower availability and vegetation height. The result was highly significant (p < 0.001).

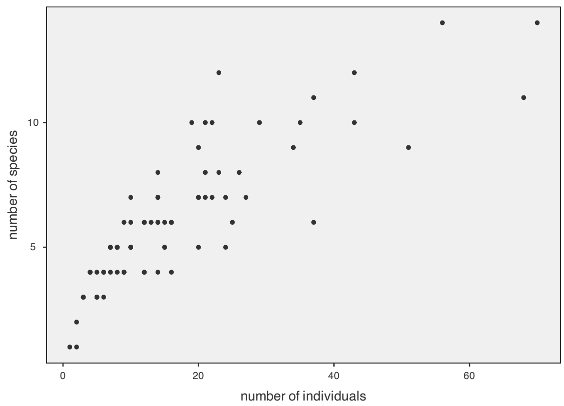

Figure 9 Scatter plot of the number of butterfly species in relation to the number of individuals. The result was highly significant (p<0.001)

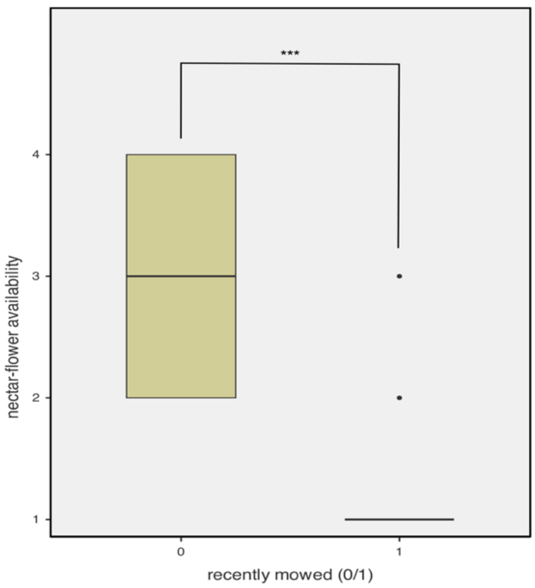

Figure 10 Box Plot of nectar-flower availability depending on the mowing status. 0 = the transect has not been mowed recently. 1 = the transect has been mowed recently. The result was significant (p < 0.001).

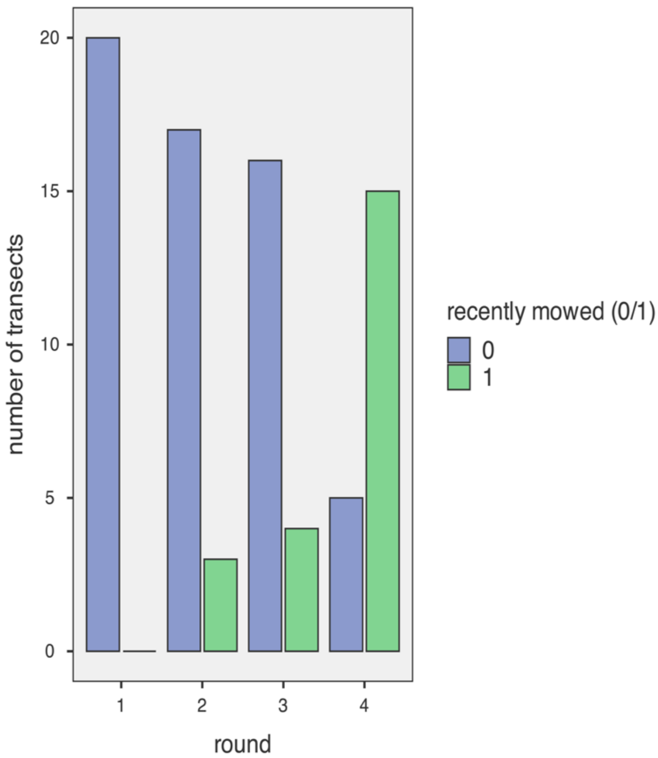

Figure 11 Bar Plot of the number of recently mowed (1) vs. not recently mowed (0) transects per round.

It is also worth mentioning that, although this may be expected, nectar-flower availability and vegetation height strongly correlated ($p < 0.001$, Fig. 8), as did nectar-flower availability and mowing status ($p < 0.001$, Fig. 10), with recently mown transects having significantly fewer nectar-flowers available than those not recently mown. During the sampling period, some of the transects were mown. During our first visit (round 1, Fig. 11), none of the transects had been mown whereas during our last visit (round 4, Fig. 11) 15 of the 20 transects were mown. Furthermore, the number of species recorded on each transect was highly significantly and positively related to the number of individuals ($p < 0.001$; Fig. 9), meaning the locally observed number of butterfly species depended heavily on the number of sightings of all butterflies.

Table 1 Overview of statistical key figures of the Generalized Linear Models. Significant values are highlighted in bold print.

Dependent variable	**Covariate**	**p**	**R^2 adj**	**df**	**χ^2**
Number of individuals	nectar-flower availability	**<.001**	0.0824	1	65.2
Number of species	nectar-flower availability	0.079	0.0217	1	3.08
Number of individuals	vegetation height	**<.001**	0.0586	1	46.6
Number of species	vegetation height	0.180	0.0084	1	1.80
Number of individuals	cloud coverage	0.837	0.0000	1	0.04
Number of species	cloud coverage	0.569	0.0000	1	0.32
Number of individuals	wind	**<.001**	0.0450	1	36.1
Number of species	wind	**0.041**	0.0333	1	4.18
Number of species	mid- vs. high summer	**0.030**	0.0388	1	4.71
Number of individuals	Mid- vs. high summer	**<.001**	0.0809	1	64.0
Nectar-flower availability	Vegetation height	**<.001**	0.5670	1	23.0
Nectar-flower availability	Recently mowed (0/1)	**<.001**	0.5490	1	22.3
Number of individuals	Number of species	**<.001**	0.5890	1	57.2

Differences in abundance and species diversity mid- to high summer

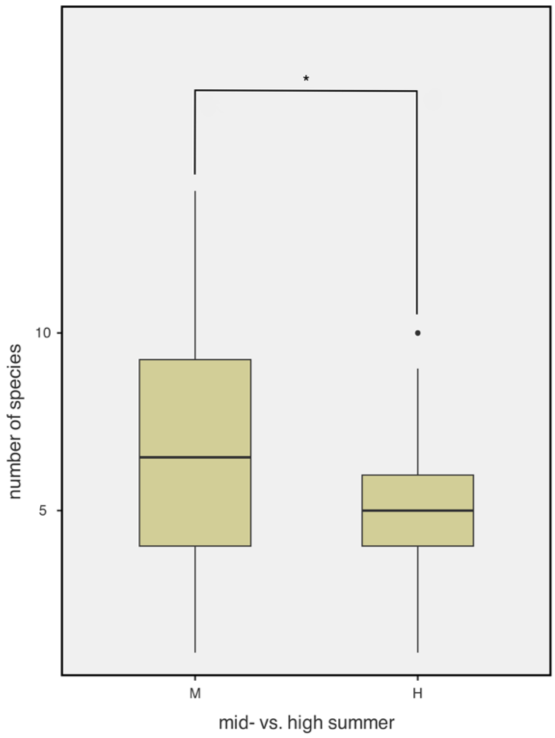

Figure 12 Boxplot of the number of species in mid- vs. high summer. The result has been significant (p = 0.030).

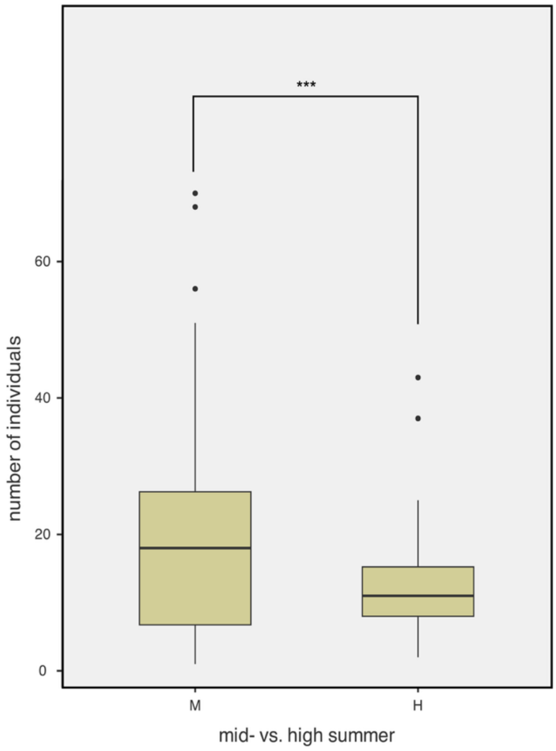

Figure 13 Boxplot of the number of individuals in mid- vs. high summer. The result has been significant (p < 0.001).

Next, the species richness and abundance in midsummer and high summer was compared. Sampling rounds one and two (between 21st June and 14th July 2025) were combined to represent midsummer, while sampling rounds three and four (between 21st July and 30th July 2025) represented high summer. Both differences between the number of species as well as the number of individuals in mid to high summer were significant ($p = 0.03$ for species, $p < 0.001$ for individuals). As visualized in Fig. 12 and Fig. 13, a greater number of species and individuals was found in midsummer than in high summer.

Comparison between 2023 vs 2025

Species accumulation curves with Hill numbers at q = 0 and q = 1 were calculated for the year 2023 and 2025, once for true butterflies (Fig. 14 and 15), once for diurnal moths (Fig. 16 and 17), and once for the aggregated data (Fig. 18 and 19). Regarding true butterflies alone, estimated sample coverage (SC) for the year 2023 was 0.9988, for 2025 it was 0.9953. In 2025 (blue line; Fig. 14), the species richness was somewhat higher than in 2023 (orange line; Fig. 14), though it should be noted that the confidence intervals overlap considerably, thus this prediction is not statistically significant and might just be due to differences in sample size rather than differences in actual diversity. Conversely, the Shannon Diversity was distinctly higher in 2025 (blue line; Fig. 15) than in 2023 (orange line; Fig. 15), without overlapping confidence intervals. Moreover, both curves reach a plateau, indicating that the sampling effort was sufficient and that in the selected sampling time frames, additional sampling sites would not have resulted in recording a higher number of species (Chao A. M., 2016). A quite different pattern is seen when considering only the diurnal moths. Here, the species richness in 2023 was noticeably higher than in 2025, without overlapping confidence intervals (Fig. 18). The Shannon Diversity also seemed to be higher in 2023 than in 2025, regarding diurnal moths, though there is a slight overlap of confidence intervals (Fig. 19). The estimated sample coverage for 2023 was 0.9361, for 2025 it was 0.9527. Given the relatively low absolute number of observations, this is a remarkably high value, which indicates that in both years, the expectable diurnal moths were recorded almost completely. Lastly, species accumulation curves for the aggregated data (true butterflies and diurnal moths) were computed. The estimated sample coverage of 2023 was 0.9922, for 2025 it was 0.9926. This time, the species richness was somewhat higher in 2023, with a slight overlap of the confidence intervals (Fig. 16), whereas the Shannon diversity was slightly higher in 2025 (Fig. 17), though here the confidence intervals overlap considerably which is why any apparent differences are not significant. Evidently, when utilizing both data sets, there is no significant difference between the years. Regarding the true butterflies, there was a noticeably greater diversity in 2025 than two years ago, while in the case of moths the opposite was true. This largely "neutralizes" the overall effect.

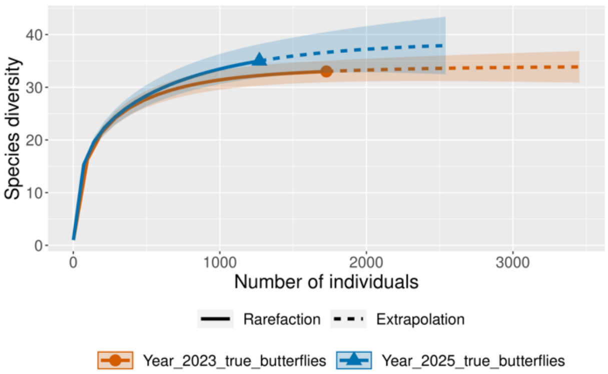

Figure 14 Species accumulation curves of true butterflies in comparison of 2023 and 2025, p = 0.

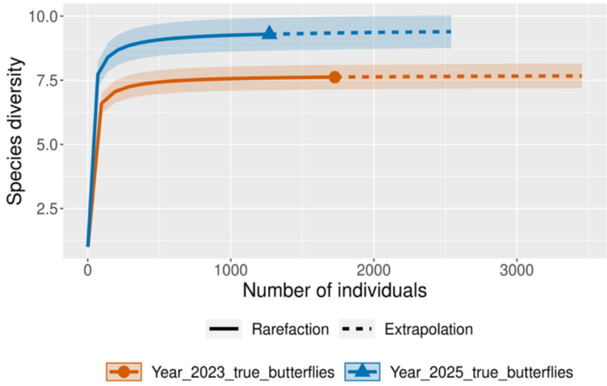

Figure 15 Species accumulation curves of true butterflies in comparison of 2023 and 2025, p = 1.

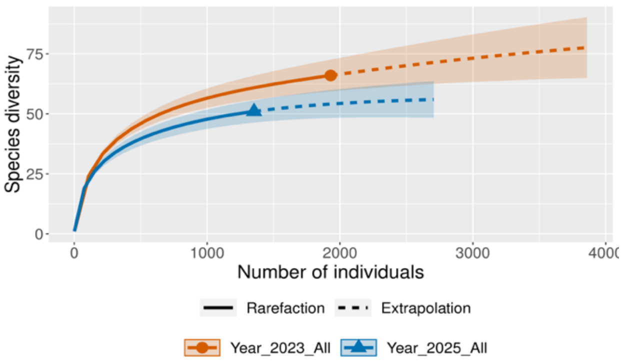

Figure 16 Species accumulation curves of aggregated data in comparison of 2023 and 2025, p = 0.

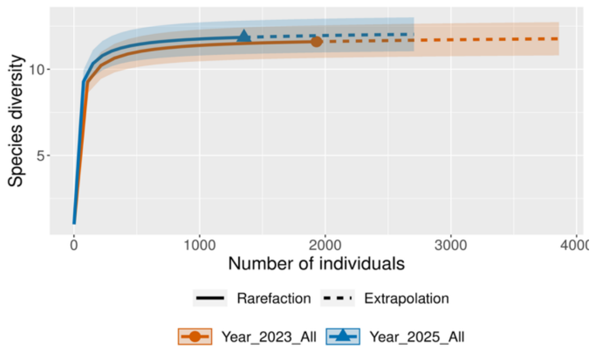

Figure 17 Species accumulation curves of aggregated data in comparison of 2023 and 2025, p = 1.

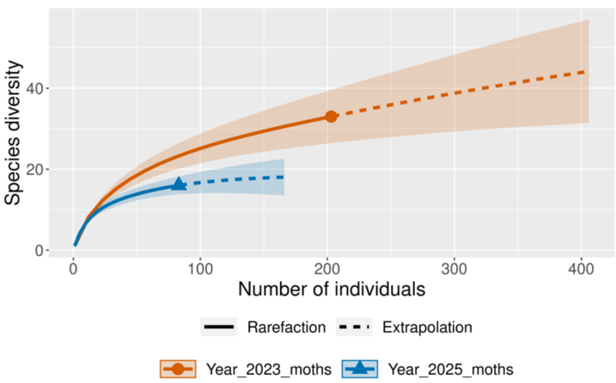

Figure 18 Species accumulation curves of diurnal moths in comparison of 2023 and 2025, p = 0.

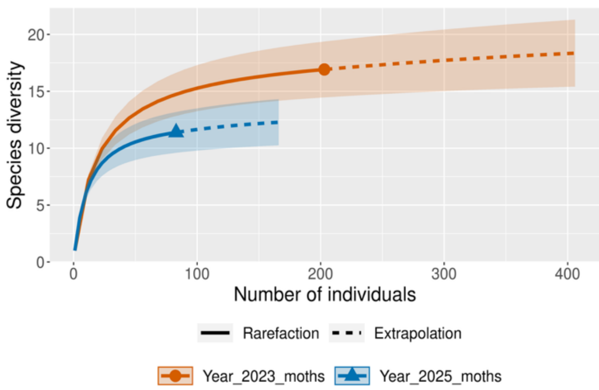

Figure 19 Species accumulation curves of diurnal moths in comparison of 2023 and 2025, p = 1.

There were twelve species which were found in 2025 but not 2023, ten of which belonged to the true butterflies (*Aglais io, Araschnia levana, Argynnis pandora, Cupido argiades, Cupido decolorata, Pararge aegeria, Pieris mannii, Polygonia c-album, Spialia sertorius, Vanessa cardui)*, the other two (*Apoda limacodes* and *Paratalanta pandalis*) being diurnal moths. Conversely, twenty-seven species had been recorded in 2023, that were not noted in 2025 with eight species of true butterflies (*Anthocharis cardamines, Brintesia circe, Celastrina argiolus, Lycaena tityrus, Lysandra coridon, Melitaea cinxia, Ochlodes sylvanus* and *Pyrgus malvae*) and nineteen species of diurnal moths (*Chiasmia clathrata, Camptogramma bilineata, Diaphora mendica, Chrysocramboides cratarella, Homoeosoma sinuella, Hemaris tityus, Idaea humiliata, Pechipogo strigilata, Ostrinia nubilalis, Pyrausta nigrata, Pseudopanthera macularia, Scopula immutata, Scopula nigropunctata, Scopula ornata, Scopula virgulata, Siona lineata, Thisanotia chrysonuchella, Zygaena angelicae* and *Zygaena minos/purpuralis*) (Scanferla, 2023).

Discussion

Sampling method

Line transect counts ("Pollard walks") are a common survey method for quantitative butterfly monitoring (Barkmann, et al., 2023). However, it has been shown that a substantial proportion of butterflies are not detected by transect counts, as factors such as wing size and apparency, as well as adult behavior may influence detectability and therefore create a bias (Dennis, Shreeve, & Isaac, 2006). In this study, this might have created a bias towards more conspicuous species, most of which belong to the true butterflies, and may have led to an underrepresentation of diurnal moths, many of which are much more unobtrusive in coloration as well as behavior (Pellet, et al., 2012). Possibly, area-time counts, which do not follow a fixed path, may have allowed for better detectability of sedentary or inconspicuous species via disturbance

(Barkmann, et al., 2023). Furthermore, it should be noted, that two different observers collected the data, both of which were relatively unexperienced. It has been suggested that the level of experience relates to the ability to find species that are difficult to see or such that exhibit distinctive flight patterns, though further research is needed (Isaac, et al., 2011). Since none of the students involved had conducted butterfly sampling before, and therefore had the same experience level, this should not pose a problem for the analyses presented here. However, if the collected data were to be compared with data recorded by more experienced observers in the future, this should be taken into consideration.

Influence of wind speed and cloud coverage

Adult butterflies are mobile, ectothermic species, that rely on solar radiation and environmental temperature for thermoregulation. Consequently, environmental conditions, such as wind speed, temperature and time of day influence butterfly behavior (Wittman, Stivers, & Larsen, 2017). The degree of cloudiness as well as wind speed have been shown to influence activity patterns in butterflies, with higher cloudiness and higher windspeeds negatively impacting the duration of flying bouts (Cormont, et al., 2011). It has also been suggested that wind speed may negatively affect the number of butterflies (Nurhayati, et al., 2025), perhaps because of butterflies being easily displaced due to their lightweight bodies, so more of them tend to seek shelter during stronger winds (Turshak, et al., 2023) as well as wind making it harder to identify butterflies, especially during flight. This correlation therefore may not reflect a "true" reduction in abundance, but rather the fact that butterflies are much harder to spot (and thus record) when in hiding. In our case, wind speed significantly correlated with the number of individuals, with fewer individuals observed at higher wind speed, while cloud coverage had no significant impact on recording success. This is in line with much of the literature, though not all studies have found a significant correlation between wind speed and butterfly abundance (Lang, et al.,

2025) (Wikström, Milberg, & Bergmann, 2009). It should also be noted that the wind speed was only estimated visually (and roughly) using the Beaufort scale, which makes it subjective and therefore not completely accurate. Nonetheless, these findings highlight the importance of recording variables such as weather conditions during butterfly monitoring, so butterfly counts may reflect “actual” changes in abundance instead of variance due to changing environmental conditions (Wikström, Milberg, & Bergmann, 2009).

Influence of vegetation height, nectar-flower availability and mowing status

To give recommendations for effective nature conservation, it is crucial to understand what drives population abundances. Especially semi-natural grasslands which are steadily decreasing need appropriate management strategies, particularly when considering the protection of invertebrates, not just vascular plants (Milberg, et al., 2016). Local habitat quality (i.e. nectar-flower abundance and vegetation height) is of utmost importance in explaining fluctuations in butterfly diversity and can be heavily influenced by the type of management (Farruggia, et al., 2011). The Marchfeldschutzdamm is managed by viadonau as ongoing maintenance of the flood protection dam. Taking into consideration the small-scale requirements of unique locations, they aim to preserve the valuable habitat for protected wildlife through extensive mowing and removing the cuttings to prevent eutrophication of the soil. In some sections sheep grazing as a rotational pasture which compared to mowing keeps the vegetation shorter is currently being tested (Nationalpark Donau-Auen GmBH, 2009). During our sampling period we did come across sheep, though they were always located on the southern side of the levee and therefore did not influence the vegetation on our transects directly. It would certainly be an interesting topic for future research, how grazing vs mowing influences butterfly abundance and diversity, since a study from 2021 (Almásy, et al., 2021) showed the influence different grassland management types had on grasshopper communities on the Marchfeldschutzdamm. Accordingly, differences in species abundance and composition in response to various management strategies may be expected from other insect families as well.

In our case, the number of individuals correlated significantly with both nectar-flower availability and vegetation height, with a greater number of individuals recorded alongside larger nectar abundance and higher vegetation. The connection between butterfly- and nectar-abundance, implying that a higher availability of nectar-flowers leads to greater butterfly numbers, has often been shown previously (Lang, et al., 2025). However, it has also been pointed out that role of nectar availability in butterfly abundance should not be overstated too hastily, as the nutrients obtained from the larval host plants may play just as an important role as the adult diet (i.e. nectar) for adult fecundity (Curtis, et al., 2015). During the first visit, all transects had a vegetation height of over 70cm. Later on, variation in vegetation height resulted from mowing and subsequent regrowth. Hence, shorter vegetation (below 10 cm) was recorded shortly after mowing, which resulted in a correlation between mowing status and nectar-flower availability (see below), as there had simply not passed enough time for flowers to regrow. This might be one possible explanation for the influence of vegetation height on the number of individuals. Another may be that the breakdown of vegetation structure may lead to the area becoming unsuitable for egg-laying (Valtonen, Saarinen, & Jantunen, 2006) (Milberg, et al., 2016).

Contrastingly, species number did not significantly correlate with nectar flower availability nor vegetation height. We did show, however, that more individuals correlated with more species, so on a larger scale increasing the feeding resources and therefore the number of individuals may still have a positive impact on species diversity. Additionally, vegetation height was only scored coarsely, and in cases of varying vegetation height within a transect, the average was used. Possibly, by recording the vegetation height more precisely, different patterns might have been located.

Two interesting though expected correlations between environmental variables were found: nectar-flower availability and vegetation height as well as nectar-flower availability and mowing status (recently mowed or not) significantly correlated: Shorter vegetation and recent mowing meant less abundance of nectar-flowers. This may have implications not just for butterflies but flower visitors in general, as more vegetation correlated with more resources, or conversely, mowing lead to a temporary drastic shortage of food supply and therefore may increase competition with other flower visitors. Reducing mowing frequency, varying mowing times and mosaic-like mowing regimes have shown to increase floral abundance and ensure continuous availability of nectar and pollen (Halbritter, Daniels, & Whitaker, 2015) (Johansen, et al., 2019) (Valtonen, Saarinen, & Jantunen, 2006). A resulting nature conservation recommendation may be that the dam should only be mowed partially at a time, leaving strips of vegetation unmown. However, one should always keep in mind that different species have different, often conflicting habitat and resource requirements, which is why it is difficult to find one "perfect" management method. Not even just different species, but one single individual may have varying demands throughout their life. Butterflies can be viewed as a collection of "semaphoronts", a term referring to the characteristics of specific life stages of an individual, such as in this case the imago, the pupae and the larvae (Spektrum.de, n.d.). Focusing on nectar-availability alone may therefore not be enough, as the demands of the larvae on their environment may be different than those of the adults (Ernst, et al., 2025). Depending on the mowing time and the varying life-histories, different butterfly species might be affected more strongly than others. For example, a more frequent mowing regime may lead to rare specialist species being replaced by generalists (Mangels, et al., 2017). Currently, the levee is mowed in sections, though these sections are relatively long and leave wide stretches of the dam "bare" of flowers at the same time. Possibly, mowing in smaller sections, varying the mowing frequencies as well as continuing with low-intensity grazing may be beneficial for creating a heterogenous habitat for a wide variety of organisms and support greater species diversity.

Differences in abundance and species diversity mid to high summer

The number of species and individuals significantly differed between mid to high summer, with a larger number of species and individuals being recorded in midsummer. In our case, a major reason for this may have also been that during the latter two sampling rounds (“high summer”), a much larger proportion of transects (47.5%) had been mown than during the first two rounds (“midsummer”, 7.5%). As discussed above, this resulted in a drastic reduction of nectar-flower availability and vegetation height, which may be the underlying factor at play here. Another reason may be species turnover, which may result in an overlap of species occurring on early summer (such as *Pentophera morio* (Novák & Severa, 1985) and *Zygaena loti* (Ulrich, 2018)*),* and those arriving later during the summer. Another factor might be a “gap” created between the occurrence of the first and second generation of some species such as *Boloria dia* and *Araschnia levana* (Höttinger, et al., 2013), which produce another generation later in the year.

Gamma diversity 2023 vs 2025

Species accumulation curves showed different patterns in 2023 vs 2025, depending on whether one considered only the true butterflies (Papilionidaea), only the diurnal moths or the aggregated data. A greater diversity of true butterflies was found this year than two years ago, while the opposite was true for moths. It cannot be ruled out, whether events since last time could have had the potential to lead to shifts in diversity. For example, the catastrophic flood in

September 2024 (Nationalpark Donau Auen, n.d.) or the fact that climate change is now setting new all-time temperature records almost every year (NOAA National Centers for Environmental Information, 2025). Rising temperatures and more extreme weather patterns have been shown to lead to biodiversity loss and changes in migration patterns (Thakur & Jagani, 2025). The occurrence of *Argynnis pandora,* a rare immigrant in Austria, may already indicate an effect of climate change. Over the past two decades, early seasonal sightings in June have become more frequent in years with above-average temperatures (Höttinger, 2018). It seems likely however, that in our case differences arose at least partly form annual fluctuations rather than as a direct result of climate change, since there passed only two years between the two studies. To see trends more clearly, more data over a longer period of time should be collected.

Another reason for differences in species abundance may be species turnover, as the sampling periods differed. In 2023 the sampling started in May and lasted until July, with longer periods between each sampling round (approximately three weeks), while in 2025 the sampling started by the end of June and concluded at the end of July, with only about a week between each survey. For example, some species, such as *Zygaena angelica* and *Anthocharis cardamines* both of which were found in 2023 but not 2025, are usually gone by July (Wagner, 2005-2025) (Höttinger, et al., 2013) and since we started sampling only by the end of June we might have missed them. Potential differences might have also been caused by biases unintentionally created due to different observers conducting the sampling during the two years, as well as the fact that more transects were mown this year, which as discussed before correlated with less individuals.

When regarding the combined data, there seemed to be a greater "absolute" species richness in 2023, compared to 2025, although this effect vanished when regarding Shannon Diversity. This is because with species richness each individual find contributes to an increase in apparent "diversity", while Shannon Diversity emphasizes the "normally expected" species in a community with individual findings playing a lesser role. Therefore, the hypothesis that the accumulated species diversity (= "gamma diversity") differs in comparison of the two study years 2023 and 2025 has proven in line with some of the findings, though the effect largely disappears when looking at the aggregated data.

Conclusion

Some environmental parameters, such as vegetation height and nectar-flower availability had a significant positive impact on the number of individuals. This supports the recommendation of an extensive mowing regime, with mowing being done in smaller sections, which results in a heterogenous landscape that continuously provides food supply for nectar-flower visitors. The sheep grazing project which is currently underway may also lead to future exciting research as to the potential benefits on species richness and abundance. Furthermore, the occurrence of xerothermophilic species which prefer warm, open terrain such as *Plebejus argyrognomon, Pontia edusa* and *Colias alfacariensis* (Höttinger, et al., 2013) or those which according to Austria's Red Lists (umweltbundesamt, 2005) are near threatened (NT) e.g. *Iphiclides podalirius*, *Apatura ilia* and *Plebejus argus* or vulnerable (VU) e.g. *Melitaea didyma* and *Spialia sertorius* underline the importance of the levee as an important habitat that deserves protection.

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Supplementary Information

Table 2 Coordinates of the twenty transects used as sampling locations.

Transect ID	Coordinates (starting points of the transects)
T01	48.1342763N, 16.6802611E
T02	48.1342279N, 16.6850470E
T03	48.1340517N, 16.6914759E
T04	48.1339927N, 16.6960850E
T05	48.1339852N, 16.7002930E
T06	48.1339595N, 16.7075755E
T07	48.1339803N, 16.7130853E
T08	48.1339447N, 16.7189101E
T09	48.1339552N, 16.7248545E
T10	48.1339199N, 16.7337360E
T11	48.1339299N, 16.7446531E
T12	48.1338412N, 16.7596610E
T13	48.1338300N, 16.7646764E
T14	48.1338379N, 16.7837099E
T15	48.1337199N, 16.7951675E
T16	48.1336390N, 16.8006794E
T17	48.1343678N, 16.8247041E
T18	48.1347606N, 16.8298152E
T19	48.1357333N, 16.8421488E
T20	48.1364022N, 16.8474902E

Table 3 Numbers of individuals of true butterfly species, per transect.

Species/ Transect	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	Gesamtergebnis
Aglais io					2																2
Apatura ilia	1				1																2
Aphantopus hyperantus				1																	1
Araschnia levana				1																	1
Argynnis pandora						1															1
Argynnis paphia		2	3	1	3			7		2					3						21
Boloria dia																		1			1
Coenonympha glycerion											2										2
Coenonympha pamphilus		1		1	1	1			1	1	3	1	1		2	1	3	1	1	1	20
Colias hyale/alfacariensis	3	3	3	5	9	5	5	5	5	7	5	3	5	8	3	9	9	2	11	11	116
Cupido argiades					1	1							1	1							4
Cupido decolorata																	1				1
Cupido minimus	5	2	2	4	2	1			1				1			2	1				21
Erynnis tages						1				1			2				1	1			6

Species/ Transect	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	Gesamtergebnis
Gonepteryx rhamni	2	1	2	1	1		1	1	1	2	1		6		1		2	1			23
Iphiclides podalirius		1																1		1	3
Issoria lathonia		2	4	2	1	6	1	6	3	5	2		3	9	3	6	6	8	6	5	78
Leptidea sinapis/juvernica	9	5	3	7	9	3	3	3	1	3	4	1	7	3		8	2	2	2		75
Maniola jurtina	46	55	21	52	43	40	15	18	15	31	27	16	25	9	11	29	5	26	19	13	516
Melanargia galathea	10	2	10	20	16	42	6	1	5	5	18	7	11	4			6	3	2	4	172
Melitaea didyma	2		1			2					1			1							7
Pararge aegeria						1						1		1							3
Pieris brassicae						1															1
Pieris mannii				2																	2
Pieris napi		2	2		2	3	2	1	4				1	1	2						20
Pieris rapae	1	1	4	1	1	5	2	2		3		1	2	1	1	3	4	2	2	4	40
Plebejus argus										1					1	1					3
Plebejus argyrognomon		2	2		1		2			2		2	1	7	2	1	3	2	2	4	33
Polygonia c-album	1	1	1			1															4
Polyommatus icarus	1	5	8	4	1	1	1	3	3	1	1		4	3	1	1	3	3	2	4	50
Pontia edusa					1											1			2	3	7
Spialia sertorius												1							1		2
Thymelicus lineola	1	1	1	3					1	1			1		1	1				2	13
Vanessa atalanta			3	1	1	1															6
Vanessa cardui			3	2	1	3		1		1		1		1							13
Gesamt	82	86	73	108	97	119	38	48	40	66	64	34	71	49	31	63	46	53	50	52	1270

Tabelle 4 Numbers of individuals of diurnal moth species, per transect.

Species/Transect	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	Gesamtergebnis
Acontia trabealis	2					1		1	1					1							6
Amata phegea	1	1							1		1										4
Apoda limacodes															1						1
Autographa gamma	5		2	1		2				1							1				12
Ematurga atomaria	5		1	3		1				1				1					1		13
Euclidia glyphica										1								1			2
Idaea rufaria					1															2	3
Idaea serpentata	7	4			1	1				1											14
Macroglossum stellatarum	1	1								1			4								7
Minoa murinata	1																				1
Paratalanta pandalis							1				1										2
Penthophera morio									1												1
Polypogon tentacularia		1																			1
Tyta luctuosa		1							1												2
Zygaena filipendulae		1	1		3	2							1								8
Zygaena loti		1		2				1			1		1								6
Gesamtergebnis	22	10	4	6	5	7	1	2	4	5	3	0	6	2	1	0	1	1	1	2	83