Zürcher Hochschule
für Angewandte Wissenschaften

Life Sciences und
Facility Management

IUNR Institut für Umwelt und
Natürliche Ressourcen

Report from the

# Master Summer School “Biodiversity Monitoring”

*Preda, Parc Ela, Switzerland, 12–22 August 2021*

*Edited by Jürgen Dengler & Hallie Seiler*

## Teachers

Jürgen Dengler, Regula Billeter, Roland Graf, Hallie Seiler, Stefan Widmer (Zurich University of Applied Sciences ZHAW); Patryk Czortek, Piotr Tykarski, Marta Wrzosek (University of Warsaw UW); Dieter Müller (Parc Ela)

## Participants

Miro Bergauer, Carina Kohler, Simon Meier, Melina Oldorf, Céline Schlatter, Ursula Schöni, Stefan Wild, Sharon Woolsey (ZHAW); Piotr Chibowski, Michał Gorczak, Michał Kochanowski, Igor Siedlecki, Martyna Wirwoska (UW)

## Recommended citation

Dengler, J. & Seiler, H. (eds.) 2022. *Report from the Master Summer School "Biodiversity Monitoring", Preda, Parc Ela, Switzerland, 12–22 August 2021*. Institute of Natural Resource Sciences (IUNR), Zurich University of Applied Sciences, Wädenswil, CH.

## Cover photo

Group photo at Lai Negr (2623 m a.s.l.) (Photo: J. Dengler).

## Disclaimer

The given authors are responsible for the content of the individual chapters.

This report is open access under the terms of the Creative Commons Attribution-ShareAlike 4.0 International License.

# Table of contents

# Preface

*Jürgen Dengler & Hallie Seiler*

The Summer School "Biodiversity Monitoring" is a joint international class for Master students in Environment and Natural Resources at the Zurich University of Applied Sciences in Wädenswil and the Master programs of the Faculty of Biology at the University of Warsaw (Dengler 2020b), with students and teachers from both universities. The two intended venues of the Summer School are Parc Ela, a regional nature park in Grisons, Switzerland, and in and around the Białowieża National Park in Eastern Poland. After two years of initial planning and coordination between the two universities, the first Summer School was conducted in August 2019 in Preda, a village at the southeastern edge of Parc Ela in Switzerland. Unfortunately, due to the COVID-19 pandemic and Poland-Belarus border crisis, the Summer School couldn't be conducted in Poland in 2020 or 2021 as planned. Instead, it took place in Preda during both of these years. Due to restrictions in international travel, only Swiss students could participate in 2020, but we were lucky enough to welcome Polish teachers and students again in 2021.

The main topics of the Summer School are sampling and monitoring biodiversity in a standardised manner. This is demonstrated for a range of different taxonomic groups with contrasting properties to provide the students with a broad set of skills, and to allow multi-taxon studies that are highly interesting scientifically (Allan et al. 2014; Zulka et al. 2014). Since one of the aims is "monitoring," permanent plots along one or two major environmental gradients will be resampled every second year, and the resulting time series will be analysed. Aside from imparting knowledge on species determination and standardised biodiversity sampling, the Summer School provides deeper insight into modern statistical analyses of such data and how to write up the results in the style of a scientific paper. As an international event, the Summer School is conducted in English.

The third Summer School "Biodiversity Monitoring" took place from 12–22 August 2021 at the Sonnenhof in Preda, Grisons. It was attended by 13 students and taught by eight teachers from both countries. As the permanent plots had already been established in 2019, they could be revisited for the second time during 2021. The first part of the Summer School was dedicated to exploring the surrounding habitats and resampling four taxonomic groups (vascular plants, orthopterans, small mammals and fungi) at some permanent plots on the transect. In the second part, students conducted five research projects in total, using data from the monitoring transect and / or additional sampling.

This reader mainly comprises the scientific reports from the five research projects, accompanied by some details on the permanent plots, a complete list of species recorded during the Summer School and some photographic impressions. It thus provides the participants with the product of their efforts, the teachers with material for the next Summer School and the conservation authorities (for the canton, Parc Ela and other partners) with documentation of the findings, complementing two earlier short reports (Dengler 2020; Dengler & Gehler 2021).

Enjoy reading!

## References

Dengler, J. (ed.) (2020a). *Report from the International Master Summer School "Biodiversity Monitoring", Preda, Parc Ela, Switzerland, 14–25 August 2019*. Institute of Natural Resource Sciences (IUNR). Zurich University of Applied Sciences, Wädenswil, CH.

Dengler, J. & Gehler, J. (ed.) (2021a). *Report from the International Master Summer School "Biodiversity Monitoring", Preda, Parc Ela, Switzerland, 10–20 August 2020* Institute of Natural Resource Sciences (IUNR). Zurich University of Applied Sciences, Wädenswil, CH.

Dengler, J. (2020b). Internationale Summer School "Biodiversity Monitoring": Lernen, wie man Biodiversität erfasst und ihre Veränderungen analysiert. *IUNR Magazin* 2020(1): 6–7.

# The permanent plots

*Jürgen Dengler & Hallie Seiler*

The sampling transect was established in a way that it matches the sampling strategy of two international plant biodiversity sampling initiatives. On the one hand, the plots correspond to the multi-scale "biodiversity plots" of the EDGG (Dengler et al. 2016), and the non-forested plots among them are contributed to the GrassPlot database (Dengler et al. 2018, 2020). On the other hand, these plots – combined with some additional co-occurrence plots sampled by I. Dembicz and J. Dengler – are part of the DarkDivNet (Pärtel et al. 2019), listed as site D095 (see https://www.botany.ut.ee/macroecology/en/darkdivnet).

In Preda, we established 13 permanent plots of 100 m², 11 of them along an elevational transect from Naz through the Val Mulix to the Lai Negr, placed in near-natural vegetation approximately every 100 m of elevation between 1750 and 2650 m a.s.l. (plots C01–C09 and N1C). In addition to plot N1C in near-natural forest, we established a second plot A1C at approximately 2050 m a.s.l. in a secondary grassland nearby, following the DarkDivNet protocol. Additionally, we established two permanent plots in the alluvial plain of the Albula river near the Sonnenhof, one in open vegetation (C10) and one in forested vegetation (C11). In 2020, we also established six new permanent plots approximately every 100 m of elevation between 1840 and 2440 m a.s.l. in the Val Zavretta (plots L01-L06). This is a valley to the north of Preda, consisting primarily of limestone. All 19 permanent plots were georeferenced with differential GPS and marked in two corners with coloured wooden poles and buried magnets to allow precise relocation in future sampling campaigns. Moreover, each of the 13 permanent plots installed in 2019 was equipped with a pair of tempurature loggers, one 10 cm below the soil surface and one 10 cm above the soil surface, to record the actual temperature in 30-minute intervals over the next years. Most of the loggers were still working in 2021 upon relocation of the plots, but some had been lost to rock fall, a stream changing its course and possibly due to removal by tourists. Following the protocol of Dengler et al. (2016), vascular plant species composition was recorded in each of all 19 100-m² plots and two nested subseries in two opposite corners of 0.0001, 0.001, 0.01, 0.1, 1 and 10 m². Additionally, coverage of each species in percent was estimated and some simple structural and environmental variables recorded in the 10-m² plots. During certain years, small mammals, orthopterans and fungi were systematically recorded for some of the permanent plots. In 2021, the vegetation-plot resampling was restricted to the 10-m$^2$ subplots of the main transect (without the additional plots in Val Zavretta).

## References

Dengler, J., Boch, S., Filibeck, G., Chiarucci, A., Dembicz, I., Guarino, R., Henneberg, B., Janišová, M., Marcenò, C., (…) & Biurrun, I. 2016. Assessing plant diversity and composition in grasslands across spatial scales: the standardised EDGG sampling methodology. Bulletin of the Eurasian Dry Grassland Group, 32, 13−30.

Dengler, J., Wagner, V., Dembicz, I., García-Mijangos, I., Naqinezhad, A., Boch, S., Chiarucci, A., Conradi, T., Filibeck, G., (…) & Biurrun, I. 2018. GrassPlot – a database of multi-scale plant diversity in Palaearctic grasslands. Phytocoenologia, 48, 331–347.

Dengler, J., Matthews, T.J., Steinbauer, M.J., Wolfrum, S., Boch, S., Chiarucci, A., Conradi, T., Dembicz, I., Marcenò, C., (…) & Biurrun, I. 2020. Species-area relationships in continuous vegetation: Evidence from Palaearctic grasslands. Journal of Biogeography, 60,: 72–86.

Pärtel, M., Carmona, C.P., Zobel, M., Moora, M., Riibak, K. & Tamme, R. 2019. DarkDivNet – A global research collaboration to explore the dark diversity of plant communities. Journal of Vegetation Science, 30, 1039–1043.

# Reports from student projects

The participants of the Summer School carried out five research projects in small teams of 2–4 students. These reports were prepared in the style of a scientific paper. Please note that the projects presented here are published as originally submitted by the students, except for minor adjustments in the layout. The responsibility for the content rests solely with the authors of the individual projects.

# Species and functional diversity drivers of herb layer flora in elevation gradient of Val Mulix

*Michał Kochanowski & Michał Gorczak*

## Abstract

Composition of plant communities may depend on many factors, including natural conditions, as well as management by humans. Mountainous regions are convenient field laboratories to study how elevation gradients may influence those communities. In our study we investigate which drivers may have a crucial influence on plant species and functional diversity. We reestablished 12 100 $m^2$ permanent plots set up in 2019 and examined one additional. Plots are set up in the Val Mulix every 100 m between 1750 and 2650 m a.s.l.. On our plots we were able to recognize 219 species of herb plants. Using multimodel inference we found that elevation, shrub cover and maximum microrelief may be significant predictors for explaining Shanon diversity index, species richness and certain functional traits such as specific leaf area or proportion of plant pollinated by wind or insects.

## Introduction

Elevation is an important factor shaping composition of plant communities (Körner, 2007; Theurillat et al., 2003; Wang et al., 2007). Higher elevations are characterized by colder, more humid climate. Mountainous regions, with high difference in elevation, can be considered as biodiversity islands, due to the stark differences to adjacent lowlands (Hoorn et al., 2018; Viterbi et al., 2013). Additionally, altitude difference creates a clear zonation of plant communities with a gradient change from forested lower altitudes, through shrublands and open areas to sparse vegetations atop the rocky summits (Ives & Barry, 2019; Väre et al., 2003). Thus mountains offer an opportunity to research the influence of abiotic factors on vegetation with high changes in climatic conditions on a relatively small geographic scale.

Although zonation of plant communities is naturally driven by abiotic conditions it can be drastically changed by human land use. In the Alps, the most important change is that subalpine forests have been transformed into open grasslands for cattle grazing (Maurer et al., 2006). Open grasslands (both natural and semi-natural) are the most species rich habitats in the Alps, with diversity of vascular herbs being especially well studied (Nagy et al., 2003; Pärtel et al., 2005).

In our study we explore what factors drive species diversity of herb layer flora in an alpine environment. Additionally we also explored the relationship between certain functional traits and recorded abiotic factors.

## Methods

### *Study site*

Study site was located in Val Mulix near the village of Preda, in Grisons, Switzerland. Area in which the study was conducted is located in the Ela Nature Park, which was established in order to protect regional biotopes and sustainable development of the region (Park Ela, 2021). We examined 13 permanent plots established in 2019 and one additional plot in the alluvial plane with open vegetation type (C12). The plots were set up according to the design of the European Dry Grassland Group (Dengler, 2016). The plots close to the natural vegetation (plots C01-C09 and N1C) are arranged in elevation gradient approximately every 100 m between 1750 and 2650 m a.s.l.. Additional plots were located in secondary grassland vegetation A1C at the same elevation as N1C (forest vegetation), and C10-C12 which are located in the alluvial plain of the Albula river.

### *Field sampling*

Data was collected between 13 and 19 of August 2021, by both Swiss and Polish students and teachers. All plant species were counted and their cover was estimated at two (NW and SE; 3,16 x 3,16m) subplots per plot. Furthermore, features as: microrelief, soil depth and vegetation height were measured. Additionally biomass was collected for further research on the grassland plots.

### *Data preparation*

Data collected from the field have been digitized using Excel and then compared and unified with datasets from two previous years of monitoring. Functional traits of plants were downloaded from different databases: BIEN, LEDA, Pladias and BiolFlor (Kühn et al. 2004; Kleyer et al. 2008; Maitner et al. 2018; Chytrý et al. 2021) and merged together. Every functional trait score for each plot is a sum of relative abundance of each species multiplied by that trait factor (from above mentioned databases). For pollination traits we lack data for over 40% species, so we decided to exclude those species from our analysis.

## Analysis

### *Biodiversity parameters*

All statistical analyses were performed using R (Version 4.1.0). Shannon Index was calculated for all plots using the function “diversity” and Richness was calculated using the function “decostand” from package vegan (Oksanen et al., 2019).

### *Multimodel inference*

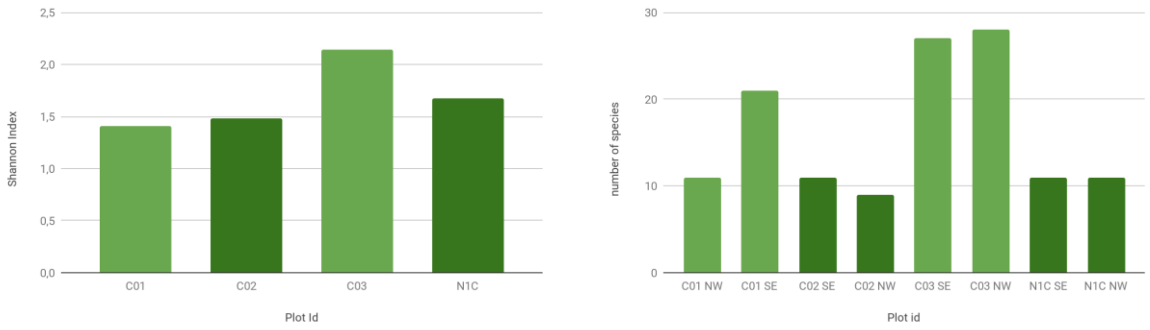
We started model inference, with preparing correlation matrix between predictors. Matrix was prepared with the function “cor” and visualized with the function “corrplot” from the library “corrplot” (Wei, 2021). We used correlation matrix to exclude strongly ($|r|>0,6$) correlating predictors. As predictors we chose: elevation, heat load index, maximum microrelief, litter percentage and shrub layer. With chosen predictors we prepared global models, which were tested with the “dredge” function (Rpackage MuMin, Barton 2019). The most parsimonious models were selected according to the AIC ($\Delta$ AIC ≤ 2, Burnham & Anderson 2002). For species richness we prepared a generalized linear model with Poisson distribution. Model visualization was performed in the R, and diversity and species richness plots were prepared in the Google Spreadsheets.

## Results

Altogether 218 vascular plant species were recorded in the herb layer of 14 plots sampled. The highest number of species was recorded on subplots in the alluvial plain C10_SE (55 species) and C11_SE (54 species). The lowest number of species was recorded on the subplot C02 NW (9 species).

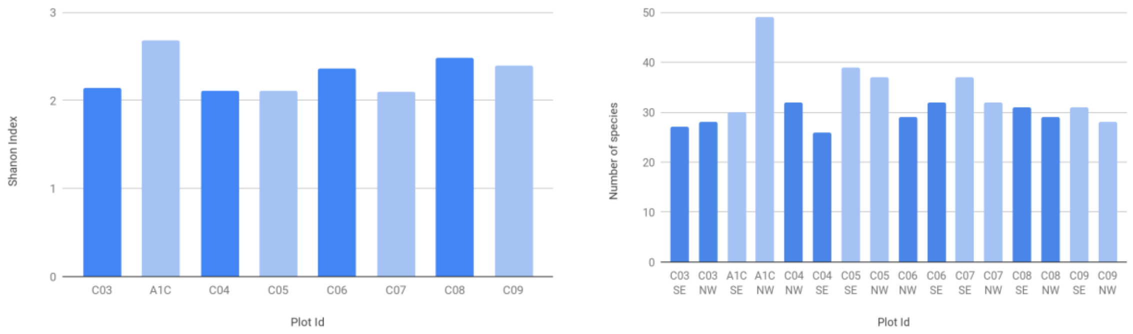
### *Species richness and diversity indices*

For better clarity of diagrams, plots were categorized by habitat type into two groups: forest and open vegetation. Forest plot with the highest biodiversity according to the Shannon Index was plot C03. Subplot with the highest number of species recorded was C03 NW, and with the lowest was C02 NW (Figure 1), however the differences are not significant (richness Kruskal Wallis test, p-value = 0.1259, and Shannon Index p-value = 0.1116) Blue bar plots represent biodiversity and richness on plots with open vegetation excluding alluvial plains. No significant difference was noticed on those plots between biodiversity (Kruskal-Wallis test, p-value = 0.1513), nor species richness (Kruskal-Wallis test, p-value = 0.2328). However, there are significant differences between those two groups, especially in the Shannon Index. Results calculated with the Pairwise Wilcoxon test are shown in table 1 and 2 in the appendix.



Diversity on forest plots in elevation gradient

Species richness in forest plots in elevation gradient



Diversity on open vegetation plots in elevation gradient

Species richness in open vegetation plots in elevation gradient

*Figure 1: Diagrams showing the diversity and species richness in the elevation gradient divided to forest and open vegetation plots.*

We tried to understand the variability of diversity, richness and chosen functional traits with a linear model using elevation, cover of shrub layer, maximum microrelief, heat load index and cover of the litter as predictors. Our results are shown in Table 3. Models with p<0,05 were visualized on figures below (Figure 2 - Figure 7). Biodiversity (Shannon Index) is significantly negatively correlated with percentage shrub cover (Figure 2). Species richness is significantly negatively correlated with elevation and with cover of shrubs (Figure 3).

| Predictor | Shannon Index | Richness | SLA | Conopy height | Seed mass | Insect-pollinated | Self-pollinated | Wind-pollinated |
|---|---|---|---|---|---|---|---|---|
| Elevation | - | 0.0308 | 0.0006 | 0.00114 | - | - | - | 0,030 |
| Shrub layer cover | 0.00027 | $8.83e^{-5}$ | - | - | 0.279 | $1{,}71e^{-5}$ | $9{,}11e^{-8}$ | - |
| Maximum microrelief | 0.06927 | 0.0815 | - | 0.23165 | 0.374 | 0,265 | 0,002 | - |
| Heat load index | - | - | - | 0.33234 | - | 0,272 | 0,244 | - |
| Litter cover | - | 0.4213 | - | 0.06139 | - | - | - | 0,031 |

*Table 3: p-value of models explaining: Shannon Index, richness and functional traits by different predictors, values < 0,05 are marked with green colour.*

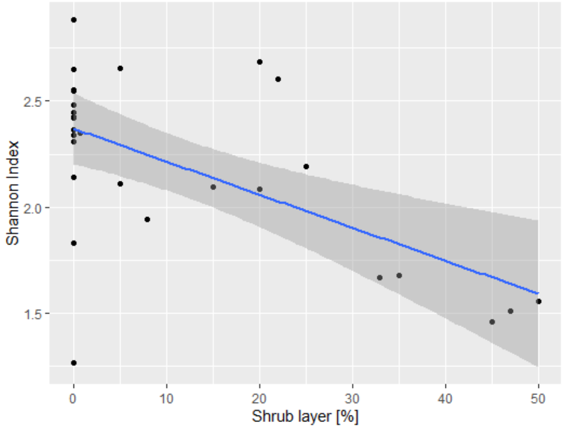


*Figure 2: Biodiversity in relation to maximum microrelief and cover of shrub layer*

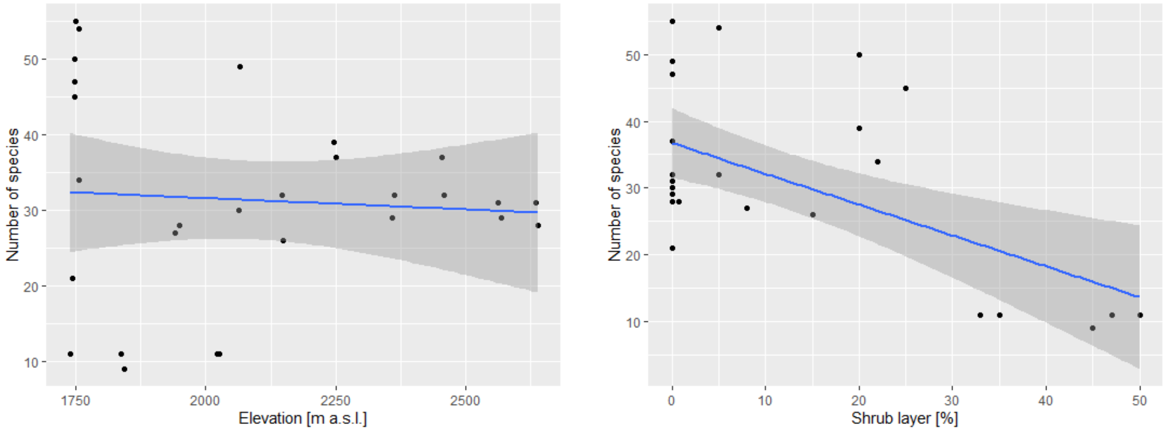


*Figure 3: Species richness in relation to elevation and heat load*

## *Functional traits analysis*

Specific leaf area (SLA), defined as the ratio of total leaf area to total leaf dry mass, has been shown to be one of the leaf traits best reflecting whole plant growth (Evans, 1972). In our data SLA is significantly negatively correlated with elevation (Figure 4). Another trait negatively correlated with elevation is herb layer height (Figure 4).

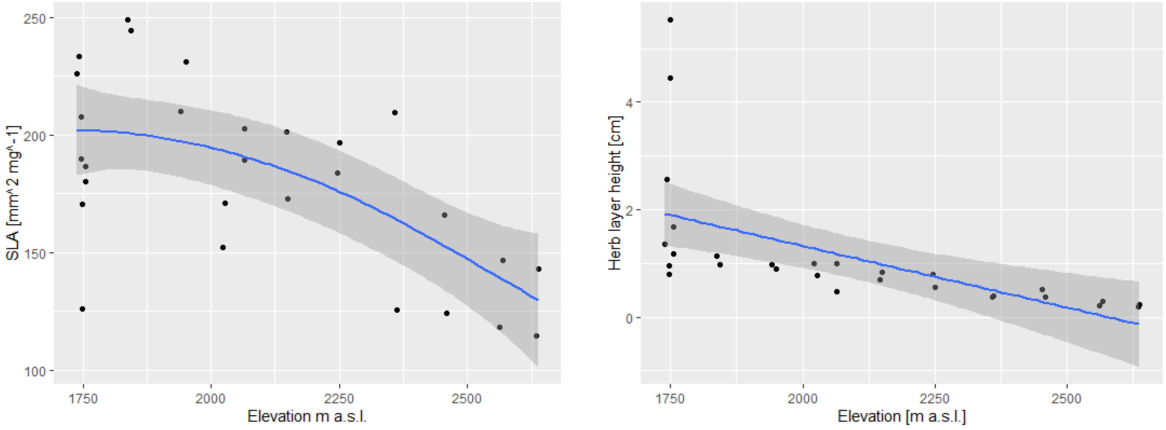


*Figure 4: Specific leaf area (SLA) and herb layer height in relation to elevation.*

## *Pollination traits*

Proportion of plants pollinated by insects is strongly positively influenced by shrub cover ($p = 1.71e-05$) (figure 5). Proportion of wind pollinated plants is positively influenced by litter cover ($p = 0.0295$) and negatively by elevation ($p= 0.0314$) (figure 6). Proportion of self pollinated plants is strongly positively influenced by microrelief ($p = 0.00165$) and shrub cover ($p = 9.11e-08$) (figure 7).

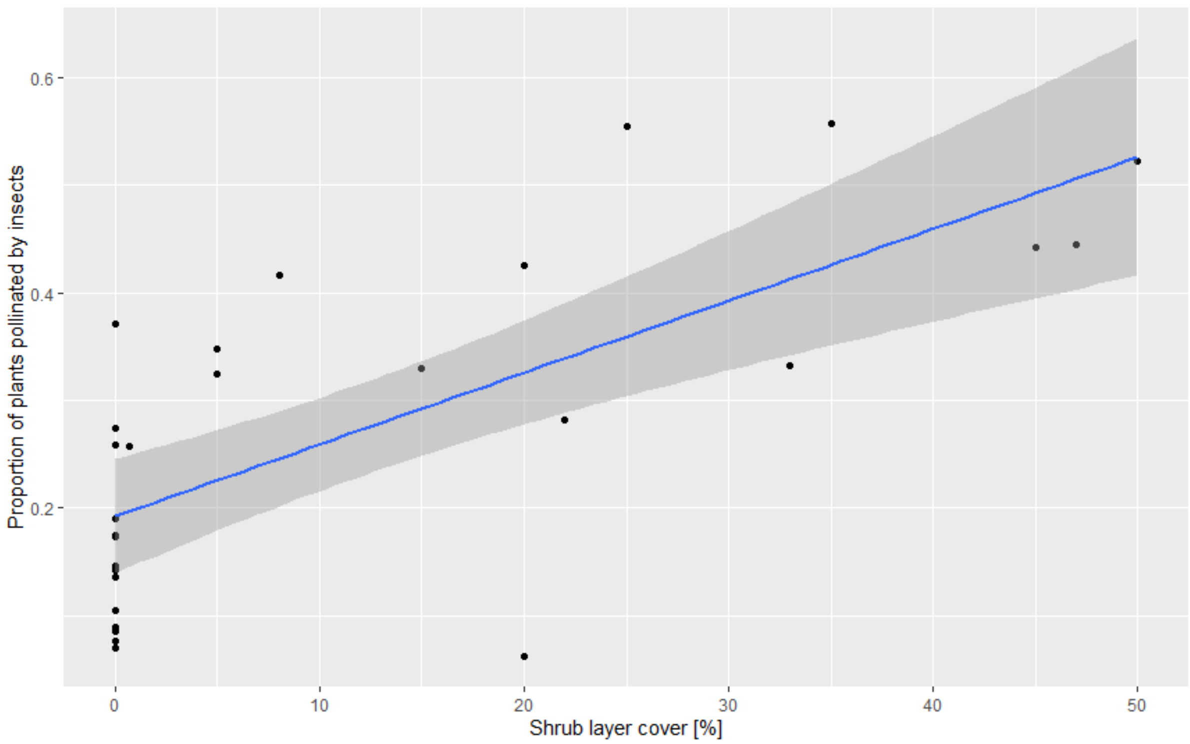


*Figure 5. Proportion of plants pollinated by insects in relation to shrub layer cover.*

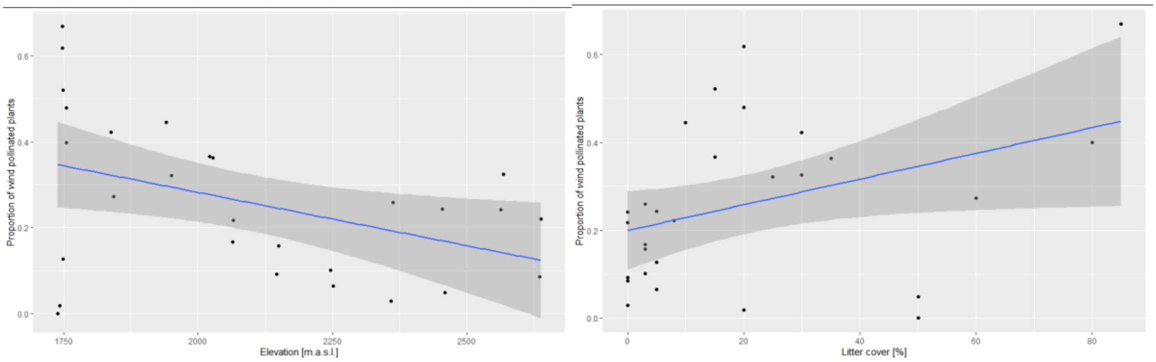


*Figure 6. Proportion of wind pollinated plants in relation to elevation, litter cover and shrub cover.*

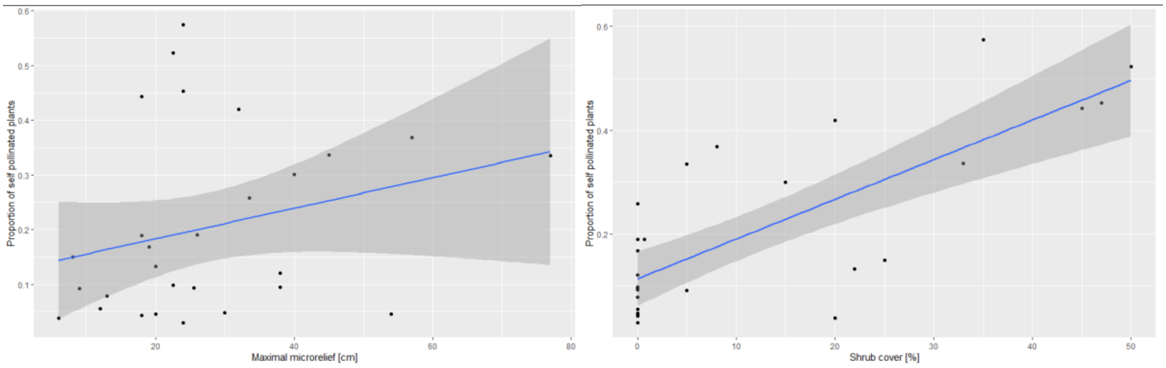


*Figure 7. Proportion of self-pollinated plants in relation to microrelief and shrub cover.*

## Discussion

### *Functional traits*

Elevation - the principal predictor we took into account - negatively influenced functional traits such as SLA, maximum canopy height and proportion of wind pollinated plants. This is to be expected as colder temperatures and shorter growth season in higher altitudes prevents plants from reaching as big sizes as in lowlands. It is also in line with previous research which found that lower temperatures results in lower SLA of at least some plant species (Prock & Körner, 1996; Rosbakh et al., 2015). The proportion of wind pollinated plants might not be directly driven by elevation itself. It could be an indirect effect of land use, as higher grasslands are usually under lower grazing pressure and harbour different plant communities from lower situated pastures (e.g. with less wind-pollinated grasses) (Kampmann et al. 2008).

Interestingly, the proportion of insects pollinated and self pollinated plants increased with increased shrub cover percent. This might be due to the fact that more shrubby areas (subalpine forests and heathlands) tend to have less wind-pollinated graminoid species in the herb layer (Dullinger et al., 2003). Additionally, the proportion of self pollinated plants increased with higher maximal microrelief, which may suggest that such plant species outcompetes plants with other pollination systems on steeper slopes or in crevices, possibly due to worse access to pollinators.

### *Species richness and diversity*

Negative influence of shrub layer cover on both Shanon index and total species richness, that we found in our data, can be also described as impact of vegetation type. Heathlands and forests have higher shrub layer cover than grasslands and this results in a lower area of herb layer, which in turn allows for less plant specimens but also plant species to be present (Nagy et al., 2003). Additionally maximal microrelief was found to be significantly negatively correlated with Shanon index, which suggest that steeper habitats are more homogenized. Such habitats may be more frequently disturbed - for example by avalanches - and have different flora than surrounding areas (Erschbamer, 1989). In line with previous research, we found a decrease of plant species with increasing altitude (Grabherr et al., 1995; Körner, 2000) . However in our data this effect was not pronounced, and shrub cover was much more important for species richness. Similar results were reported earlier for *Vaccinium myrtillus* shrub cover in Alps (Boscutti et al., 2018).

## References

Bartoń, K., 2020. MuMIn: Multi-Model Inference.

Boscutti, F., Casolo, V., Beraldo, P., Braidot, E., Zancani, M., Rixen, C., 2018. Shrub growth and plant diversity along an elevation gradient: Evidence of indirect effects of climate on alpine ecosystems. PLOS ONE 13, e0196653. https://doi.org/10.1371/journal.pone.0196653

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer-Verlag, New York. https://doi.org/10.1007/b97636

Chytrỳ, M., Danihelka, J., Kaplan, Z., Wild, J., Holubová, D., Novotnỳ, P., Řezníčková, M., Rohn, M., Dřevojan, P., Grulich, V., 2021. Pladias Database of the Czech flora and vegetation.

Dengler, J., Boch, S., Filibeck, G., Chiarucci, A., Dembicz, I., Guarino, R., Henneberg, B., Janišová, M., Marcenò, C., Naqinezhad, A., Polchaninova, N.Y., Biurrun, I., 2016. Assessing plant diversity and composition in grasslands across spatial scales: the standardised EDGG sampling methodology. Bulletin of the Eurasian Dry Grassland Group 18.

Dullinger, S., Dirnböck, T., Grabherr, G., 2003. Patterns of Shrub Invasion into High Mountain Grasslands of the Northern Calcareous Alps, Austria. Arctic, Antarctic, and Alpine Research 35, 434–441. https://doi.org/10.1657/1523-0430(2003)035[0434:POSIIH]2.0.CO;2

Erschbamer, B., 1989. Vegetation on avalanche paths in the alps. Vegetatio 80, 139–146. https://doi.org/10.1007/BF00048037

Evans, G.C., 1972. The Quantitative Analysis of Plant Growth. University of California Press.

Grabherr, G., Gottfried, M., Gruber, A., Pauli, H., 1995. Patterns and Current Changes in Alpine Plant Diversity, in: Chapin, F.S., Körner, C. (Eds.), Arctic and Alpine Biodiversity: Patterns, Causes and Ecosystem Consequences, Ecological Studies. Springer, Berlin, Heidelberg, pp. 167–181. https://doi.org/10.1007/978-3-642-78966-3_12

Home | Parc Ela - Naturpark Schweiz [WWW Document], n.d. URL https://www.parc-ela.ch/de/home (accessed 10.14.21).

Hoorn, C., Perrigo, A., Antonelli, A., 2018. Mountains, Climate and Biodiversity. John Wiley & Sons.

Ives, J.D., Barry, R.G., 2019. Arctic and Alpine Environments. Routledge.

Kampmann, D., Herzog, F., Jeanneret, P., Konold, W., Peter, M., Walter, T., Wildi, O., Lüscher, A., 2008. Mountain grassland biodiversity: impact of site conditions versus management type. Journal for Nature Conservation 12–25. https://doi.org/10.1016/j.jnc.2007.04.002

Kleyer, M., Bekker, R. m., Knevel, I. c., Bakker, J. p., Thompson, K., Sonnenschein, M., Poschlod, P., Van Groenendael, J. m., Klimeš, L., Klimešová, J., Klotz, S., Rusch, G. m., Hermy, M., Adriaens, D., Boedeltje, G., Bossuyt, B., Dannemann, A., Endels, P., Götzenberger, L., Hodgson, J. g., Jackel, A.-K., Kühn, I., Kunzmann, D., Ozinga, W. a., Römermann, C., Stadler, M., Schlegelmilch, J., Steendam, H. j., Tackenberg, O., Wilmann, B., Cornelissen, J. h. c., Eriksson, O., Garnier, E., Peco, B., 2008. The LEDA Traitbase: a database of life-history traits of the Northwest European flora. Journal of Ecology 96, 1266–1274. https://doi.org/10.1111/j.1365-2745.2008.01430.x

Körner, C., 2007. Körner C.. The use of ‘altitude’ in ecological research. Trends Ecol Evol 22: 569-574. Trends in ecology & evolution 22, 569–74. https://doi.org/10.1016/j.tree.2007.09.006

Körner, C., 2000. Why are there global gradients in species richness? Mountains might hold the answer [1]. Trends in Ecology and Evolution 15, 513–514. https://doi.org/10.1016/S0169-5347(00)02004-8

Kühn, I., Durka, W., Klotz, S., 2004. BiolFlor: A New Plant-Trait Database as a Tool for Plant Invasion Ecology. Diversity and Distributions 10, 363–365.

Maitner, B.S., Boyle, B., Casler, N., Condit, R., Donoghue II, J., Durán, S.M., Guaderrama, D., Hinchliff, C.E., Jørgensen, P.M., Kraft, N.J.B., McGill, B., Merow, C., Morueta-Holme, N., Peet, R.K., Sandel, B., Schildhauer, M., Smith, S.A., Svenning, J.-C., Thiers, B., Violle, C., Wiser, S., Enquist, B.J., 2018. The bien r package: A tool to access the Botanical Information and Ecology Network (BIEN) database. Methods in Ecology and Evolution 9, 373–379. https://doi.org/10.1111/2041-210X.12861

Nagy, L., Grabherr, G., Körner, Ch., Thompson, D.B.A., 2003. Alpine Biodiversity in Space and Time: A Synthesis, in: Nagy, Laszlo, Grabherr, Georg, Körner, Christian, Thompson, Desmond B. A. (Eds.), Alpine Biodiversity in Europe, Ecological Studies. Springer, Berlin, Heidelberg, pp. 453–464. https://doi.org/10.1007/978-3-642-18967-8_29

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O’Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E., Wagner, H., 2020. vegan: Community Ecology Package.

Pärtel, M., Bruun, H., Sammul, M., 2015. Biodiversity in temperate European grasslands: origin and conservation.

Prock, S., Körner, C., 1996. A Cross-Continental Comparison of Phenology, Leaf Dynamics and Dry Matter Allocation in Arctic and Temperate Zone Herbaceous Plants from Contrasting Altitudes. Ecological Bulletins 93–103.

Rosbakh, S., Römermann, C., Poschlod, P., 2015. Specific leaf area correlates with temperature: new evidence of trait variation at the population, species and community levels. Alpine Botany 125, 79–86.

Theurillat, J.-P., Schlüssel, A., Geissler, P., Guisan, A., Velluti, C., Wiget, L., 2003. Vascular Plant and Bryophyte Diversity along Elevation Gradients in the Alps, in: Nagy, L., Grabherr, G., Körner, C., Thompson, D.B.A. (Eds.), Alpine Biodiversity in Europe, Ecological Studies. Springer, Berlin, Heidelberg, pp. 185–193. https://doi.org/10.1007/978-3-642-18967-8_8

Väre, H., Lampinen, R., Humphries, C., Williams, P., 2003. Taxonomic Diversity of Vascular Plants in the European Alpine Areas, in: Nagy, L., Grabherr, G., Körner, C., Thompson, D.B.A. (Eds.), Alpine Biodiversity in Europe, Ecological Studies. Springer, Berlin, Heidelberg, pp. 133–148. https://doi.org/10.1007/978-3-642-18967-8_5

Viterbi, R., Cerrato, C., Bassano, B., Bionda, R., Hardenberg, A., Provenzale, A., Bogliani, G., 2013. Patterns of biodiversity in the northwestern Italian Alps: a multi-taxa approach. Community Ecology 14, 18–30. https://doi.org/10.1556/comec.14.2013.1.3

Wang, C.T., Long, R., Long, R., Wang, Q.J., Ding, L., Wang, M., 2007. Effects of altitude on plant-species diversity and productivity in an alpine meadow, Qinghai-Tibetan plateau. https://doi.org/10.1071/BT04070

Wei, T., Simko, V., Levy, M., Xie, Y., Jin, Y., Zemla, J., Freidank, M., Cai, J., Protivinsky, T., 2021. corrplot: Visualization of a Correlation Matrix.

## Appendix

*Table 1. Differences in Shannon Index between each plot, marked with colour are significant.*

| | A1C | C01 | C02 | C03 | C04 | C05 | C06 | C07 | C08 | C09 | C10 | C11 | C12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C01 | 0,000 | - | - | - | - | - | - | - | - | - | - | - | - |
| C02 | 0,001 | 1,000 | - | - | - | - | - | - | - | - | - | - | - |
| C03 | 0,490 | 0,071 | 0,149 | - | - | - | - | - | - | - | - | - | - |
| C04 | 0,336 | 0,105 | 0,229 | 1,000 | - | - | - | - | - | - | - | - | - |
| C05 | 0,359 | 0,099 | 0,211 | 1,000 | 1,000 | - | - | - | - | - | - | - | - |
| C06 | 1,000 | 0,007 | 0,016 | 1,000 | 1,000 | 1,000 | - | - | - | - | - | - | - |
| C07 | 0,311 | 0,112 | 0,248 | 1,000 | 1,000 | 1,000 | 1,000 | - | - | - | - | - | - |
| C08 | 1,000 | 0,002 | 0,005 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | - | - | - | - | - |
| C09 | 1,000 | 0,006 | 0,012 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | - | - | - | - |
| C10 | 1,000 | 0,007 | 0,014 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | - | - | - |
| C11 | 1,000 | 0,001 | 0,001 | 0,827 | 0,554 | 0,588 | 1,000 | 0,513 | 1,000 | 1,000 | 1,000 | - | - |
| C12 | 1,000 | 0,000 | 0,001 | 0,554 | 0,382 | 0,414 | 1,000 | 0,359 | 1,000 | 1,000 | 1,000 | 1,000 | - |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N1C | 0,005 | 1,000 | 1,000 | 0,933 | 1,000 | 1,000 | 0,109 | 1,000 | 0,031 | 0,083 | 0,103 | 0,007 | 0,005 |

*Table 2. Differences in richness between each plot, marked with colour are significant.*

| | A1C | C01 | C02 | C03 | C04 | C05 | C06 | C07 | C08 | C09 | C10 | C11 | C12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C01 | 0,146 | - | - | - | - | - | - | - | - | - | - | - | - |
| C02 | 0,024 | 1,200 | - | - | - | - | - | - | - | - | - | - | - |
| C03 | 1,200 | 1,200 | 0,719 | - | - | - | - | - | - | - | - | - | - |
| C04 | 1,200 | 1,200 | 0,508 | 1,200 | - | - | - | - | - | - | - | - | - |
| C05 | 1,200 | 0,227 | 0,037 | 1,200 | 1,200 | - | - | - | - | - | - | - | - |
| C06 | 1,200 | 1,200 | 0,353 | 1,200 | 1,200 | 1,200 | - | - | - | - | - | - | - |
| C07 | 1,200 | 0,569 | 0,107 | 1,200 | 1,200 | 1,200 | 1,200 | - | - | - | - | - | - |
| C08 | 1,200 | 1,200 | 0,403 | 1,200 | 1,200 | 1,200 | 1,200 | 1,200 | - | - | - | - | - |
| C09 | 1,200 | 1,200 | 0,460 | 1,200 | 1,200 | 1,200 | 1,200 | 1,200 | 1,200 | - | - | - | - |
| C10 | 1,200 | 0,007 | 0,001 | 0,196 | 0,309 | 1,200 | 0,460 | 1,200 | 0,403 | 0,353 | - | - | - |
| C11 | 1,200 | 0,037 | 0,007 | 0,971 | 1,200 | 1,200 | 1,200 | 1,200 | 1,200 | 1,200 | 1,200 | - | - |
| C12 | 1,200 | 0,010 | 0,002 | 0,309 | 0,460 | 1,200 | 0,634 | 1,200 | 0,569 | 0,508 | 1,200 | 1,200 | - |
| N1C | 0,032 | 1,200 | 1,200 | 0,971 | 0,634 | 0,049 | 0,460 | 0,146 | 0,508 | 0,569 | 0,002 | 0,009 | 0,003 |

# Temporal changes in herb layer vegetation of Val Mulix

*Piotr Chibowski & Martyna Wirowska*

## Abstract

Shifts in alpine habitats linked to climate change are already reported in long-term vegetation surveys. We explored data gathered throughout three years of vegetation sampling on permanent plots set in Val Mulix, Switzerdland in search of changes in taxonomical and functional diversity of herb cover. Only 38.4% of plot-species (species found in a given plot) occurred in all three studied years. The occurrence in years differed strongly among morphofunctional groups and habitats: most plot-species were present in all years among shrubs and on alpine grasslands. Species with higher cover were more likely to occur in all three years. The coefficient of variation of cover estimates between years was 58.65% (average for all plot-species) and did not differ between morphofunctional groups and habitats. We found positive effect of year on taxonomical diversity in alpine grassland vegetation type and graminoid morhphofunctional group. However, this results should be treated with caution, as three year study period is too short to distinguish between fluctuations and stable trends. Addintionaly to our analyses, we present a set of suggestions for future Summer School participants.

*Keywords: temporal changes, subalpine vegetation, permanent plots, observer error, functional diversity, taxonomical diversity*

## Introduction

The effect of climate change on vegetation in Alps, an unique region with many rare and endemic species, has been a topic of interest in the past years. Alpine habitats are nowadays met with many challenges: rise in temperature, glacier melting and shorter duration of snow cover, but also upward migrations of plants from different habitats (Begert et al. 2005, Pauli et al. 2012, Rixen & Wipf 2017). Alpine plants therefore fall into a kind of environmental trap: they are susceptible to higher temperature in the area of their occurrence, while the species already better adapted to warmer conditions may migrate upward to the stands that alpine species are occupying currently. Although occurrence of species in extreme summit habitats may start to shrink with delay, as they are characterised by high diversity of microhabitats, longevity of alpine plants and positive neighbour interactions (Rixen & Wipf 2017). In both examples of long-term studies undertook at Piz Linard, Swiss National Park area, rise in number of species was noted (Rixen & Wipf 2017) These findings are in line with temporal changes in species richness of plants detected in most of investigated European summits (Pauli et al. 2012)

A factor which can significantly alter the results of botanical studies is the observer error: each person responsible for a vegetation survey is more or less likely to make mistakes of a different type, or concerning different taxonomic groups. There are three main types of errors: 1) overlooking error – not observing species actually present, 2) misidentification error – not correctly identifying species 3) cover estimation error. A meta-analysis of studies of the observer error in vegetation surveys found significant differences between observers' results (Morrison 2015) in most studies. The mean amount of species overlooked by one observer but not another was between 10 and 30%. The species misidentification rate was 5-10%. The difference in cover estimates varied among cover values: up to several hundred percent in species with small cover, and about 25-50% in species with mean cover >50% (Morrison 2016). This summary gives a rough image of the size of the effect the observer error can have on vegetation results.

Here, we describe the results of vegetation survey in an alpine valley, done during the summer of 2021 on permanent plots established in 2019 and re-sampled in 2020. The plots are located along an elevation gradient. Due to the high diversity of species and habitats, further increased by human activity (forest logging and pasture), We divided the plant species data in two groups of categories: 1) into 6 types of habitats (see Methods and Figure Map) 2) into morphofunctional groups, not based on taxonomy, but on shape, life strategy and form (see Methods).

Based on personal observations in the field, we consider the observer effect to have a considerable effect on the data we produced during our study. In the first part of our study we try to: 1) Quantify the size of temporal changes in species composition and cover, whatever their reason 2) Look for differences in species turnover between different habitats and morphofunctional groups 3) Assess the size of observer error in cover estimation, based on plot characteristics, which probably do not drastically change from year to year, and are estimated similarly to plant species cover.

In the second part we wanted to assess whether differences in diversity of vegetation are connected only to habitat characteristics or were there any temporal changes observable from year 2019 to 2021. We decided to focus not only on taxonomical diversity, but also functional diversity, as it could probably carry more information about underlying reasons in potential shifts of vegetation communities than simply calculating number and abundance of species (Chun & Lee 2019). We hypothesize that diversity is dependent on rather stable habitat characteristics and won't show rapid temporal changes during three year period. As suggested in previous year, we wanted to control for observer effect and check if any kind of vegetation type or diversity index is especially susceptible to it.

Based on our experience, we prepared a set of comments and best practices for future studies on the permanent plots at Val Mulix.

## Methods

### *Study area*

Study sites were located on 13 already existing permanent plots, 100 m$^2$ each, established in Val Mulix in 2019 along the hiking trail. Each permanent plot was marked with poles and magnets to allow for resampling exactly in preestablished locations. Plots C1-C9 represented elevation gradient, with each plot located about 100 m higher than the previous one. Additional plots C10 and C11 were located in Albula river alluvial plain, and A1C and N1C near the edge of regular tree line, the former one representing anthropogenic habitat/secondary grassland and the latter one - near natural habitat/subalpine forest (Figure 1, Table 1). Inside each plot two 10 m$^2$ subplots were set in the opposite corners (NW and SE). On each 10 m$^2$ subplot we did vegetation sampling using shoot present method, following the EDGG sampling protocol (Dengler et al. 2016).

Sampling took place in August 2021 and involved species determination, estimating the percentage cover of vegetation and different types of surfaces (dead wood, gravel etc.), measuring maximum vegetation height and other subplot characteristics such as soil depth and maximum microrelief. For all included categories, see field sampling form attached in Appendix A. In our analyses, we included only herb layer (plants < 0.5 height).

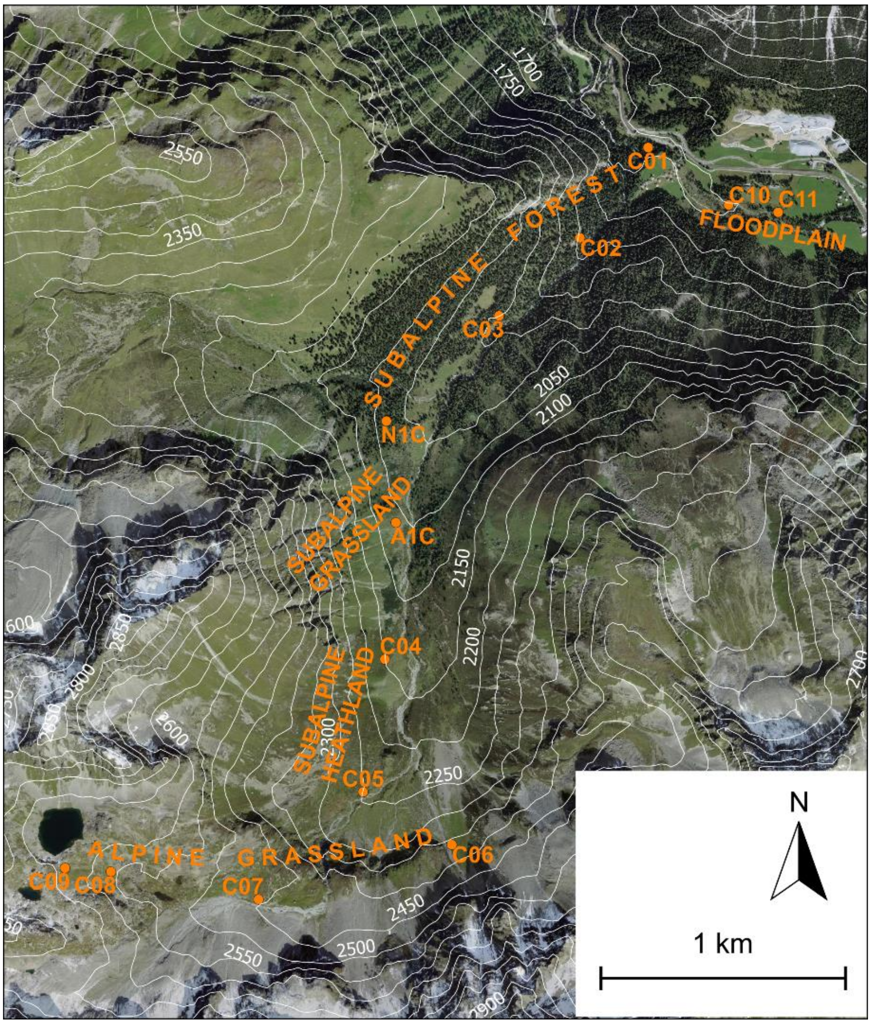


*Figure 1: Location of study sites at Val Mulix. Each dot represents a site where a 100 m² was established and vegetation survey was done in two 10 m² plots (NW and SE corner). Isolines are shown each 50 m. (Aerial photographs and elevation data downloaded from swisstopo.ch)*

*Table 1: Vegetation type represented by each 100 m2 plot and elevation (m a.s.l.) measured in two opposite corners (NW - north west, SE - south east).*

| Plot ID | Vegetation type | Elevation |
|---|---|---|
| C01 | subalpine forest | NW 1739 |
| | | SE 1743 |
| C10 | floodplain (habitat mosaic) | NW 1749 |
| | | SE 1749 |
| C11 | floodplain forest | NW 1755 |
| | | SE 1755 |
| C02 | subalpine forest | NW 1843 |
| | | SE 1838 |
| C03 | subalpine forest | NW 1950 |
| | | SE 1941 |
| N1C | subalpine forest | NW 2027 |
| | | SE 2022 |
| A1C | subalpine grassland | NW 2065 |
| | | SE 2064 |
| C04 | subalpine heathland | NW 2146 |
| | | SE 2150 |
| C05 | subalpine heathland | NW 2251 |
| | | SE 2247 |
| C06 | alpine grassland | NW 2359 |
| | | SE 2362 |
| C07 | alpine grassland | NW 2459 |
| | | SE 2455 |
| C08 | alpine grassland | NW 2569 |
| | | SE 2563 |
| C09 | alpine grassland | NW 2638 |
| | | SE 2635 |

## Statistical analysis

We carefully unified data from years 2019 and 2020 with our data from 2021, to omit situations such as that one species would be written down separately under different names. In case of two species (*Pedicularis rostratospicata* and *Senecio incanus*) we removed identification to subspecies level, as it has not been done in all three years. Having in mind that permanent plots were established along elevation gradient in many different habitats, additionally to analyses on whole dataset, we decided to divide all plots into different vegetation types and created separate data subsets for different morphofunctional groups (graminoids, herbs, ferns and shrubs).

## Species composition and cover estimation

In order to quantify the differences in plant species cover and composition (i.e. the species turnover) we established the term plot-species, which is a plant species, which occurs in certain plot at least in one year out of three. There are 1047 plot-species.

We divided the plot-species, based on the years they appeared, into 7 categories: Species found on a given plot 1) only in 2019 2) only in 2020 3) only in 2021 4) in 2019 and 2020 5) in 2019 and 2021 6) in 2020 and 2021 7) in all three years (2019, 2020, 2021). To test for differences in the proportions of plot-species in the categories mentioned above between habitats and morphofunctional groups, we arranged them in contingency tables and performed Chi-square tests, pooled and pairwise. Additionally, we performed the chi-squared test on plot-species divided only in two categories: those which occurred in all three study years and those which did not.

For all plot-species with occurrence in at least two years, we calculated the Pearson correlation coefficient (r) between cover values in both years. Plot-species which were present in three years, were assigned to all three possible measurements. Similarly, for plot-species which occurred in two or three years, we calculated the coefficient of variation (CV), which is the standard deviation expressed as a percentage of the mean ([standard deviation/mean] × 100). This method is used in most studies on observer error (Morrison 2016, Futschik et al. 2020).

We used ANOVA to test for differences 1) in cover estimates of plot-species which were present in one, two or three years 2) in the cover values of: total vegetation, herb layer, shrub layer, tree layer, moss layer, stones, gravel and fine soil between study years 3) in the coefficient of variation between morphofunctional groups and habitats. If ANOVA showed significant differences, we used Tukey's HSD post-hoc test to look for differences between pairs.

## Functional and taxonomical diversity

For each subplot, we calculated species richness, Shannon index and Pielou's evenness with vegan package (Oksanen et al. 2020). We also included functional traits in our analyses: specific leaf area (SLA), leaf dry matter content (LDMC), seed mass, maximum canopy height, and Ellenberg indicator values, which can be used as numerical system to classify in which habitat conditions a species has its peak occurrence (Bartelheimer & Poschlod 2016): EIV-L (light availability), EIV-T (temperature), EIV-M (soil moisture), EIV-R (soil reaction) and EIV-N (soil fertility). Functional traits for each recorded species were obtained from BIEN, LEDA, Pladias and BiolFlor, and in case of lack of data in these databases - from TTT dataset (available on github). Using dbFD function from FD package (Laliberté et al. 2014) we calculated diversity values for each plot: functional divergence – FDiv, functional dispersion – FDis, functional richness – FRic, functional evenness – FEve (Villéger et al. 2008, Laliberté & Legendre 2010) and CWMs of functional traits listed above. Species with most NAs in functional trait data (NAs ≥ 5) were excluded from analysis, because including them resulted in dbFD not working properly.

To examine not only if there were any temporal changes observable, but also to investige whether various habitat characteristics have an effect on functional and taxonomical diversity, we run GLMMs for each trait using lme4 package (Bates et al. 2015). Our initial predictor variables set consisted of following characteristics of the plots: elevation, heat load index, maximum microrelief, mean soil depth, litter coverage, dead wood coverage, stones coverage, gravel coverage, fine soil coverage, pH of the soil, conductivity of the soil. We rescaled two variables to avoid errors during model computing (heat load was multiplied by c = 10 and elevation was divided by c = 10). This changes are noted in results and one should consider them when analysing presented data (SD and Estimate values).

All of the analyses described below were performed separately on whole dataset, different morphofunctional groups and vegetation types. When a morphofunctional group wasn't noted on a plot at all, this plot was excluded from the analysis. We excluded ferns from functional and taxonomical diversity analysis due to small diversity of species on the plots (only 1 species per plot with attainable functional traits, max. 2 species per plot in general). Due to small sample size of some vegetation types, we were able to run models only for alpine grassland and subalpine forest subsets.

Using cor function we checked for strong correlations between predictor variables (Kendall $\tau > 0.7$). We detected such strong correlation for fine soil cover percentage and stone cover percentage in every subset of data. We decided to leave only stone cover percentage in our models. This step was repeated in case of deletion of NA data points and for analysis of different morphotypes and vegetation types. In alpine grassland subset elevation was correlated with both soil conductivity and pH. We decided to obtain pH in EIV-N and EIV-R models and for others we used elevation. In SLA and LDMC models we ommited litter and mean soil variables as litter decomposition is related to these parameters (Kazakou et al. 2006, Liu et al. 2018).

We builded global models for each diversity value and took semi-automatic approach by using dredge function from MuMIn package (Bartoń 2020) to select best-fitted models and chose variables only from these models that had Δ AICc < 2. In all final models, we also included year as fixed factor and main author of the form as random factor to control for observer error.

With the help of diagnostic plots, we checked our models for homogeneity of variances and normality of residuals. When needed, log transformation of response variable was performed. Then, utilizing methods provided by (Nakagawa & Schielzeth 2013) we used r.squaredGLMM function from MuMiN package to obtain $R^2$c (conditional) and $R^2$m (marginal) values.

## Results

In total, 301 plant species were identified in the herb layer during the three study years. There were 215 species found in 2019, 208 in 2020 and 218 in 2021.

### *Species composition and cover estimation*

In general, 412 plot-species were found only in one year, 248 in two years, and 412 in three years (Table 2). There were almost twice as much unique species in 2019 and 2021 than in 2020 (Table 2, Figure 2).

*Table 2: Number of plot-species (species, which were found in a given plot) in each year, two or three years in all types of habitat.*

| | | 2019 | 2020 | 2021 | 2019-2020 | 2019-2021 | 2020-2021 | All years | Sum |
|---|---|---|---|---|---|---|---|---|---|
| Habitat | Alpine grassland | 31 | 29 | 30 | 3 | 29 | 25 | 165 | 312 |
| | Floodplain | 43 | 33 | 42 | 19 | 35 | 20 | 91 | 283 |
| | Subalp. forest | 28 | 14 | 34 | 4 | 14 | 24 | 57 | 175 |
| | Subalp. grassland | 16 | 10 | 14 | 12 | 3 | 13 | 49 | 117 |
| | Subalp. heathland | 33 | 13 | 42 | 5 | 27 | 15 | 50 | 185 |
| Morpho - functional group | Herbs | 90 | 65 | 112 | 29 | 78 | 60 | 265 | 699 |
| | Graminoids | 47 | 25 | 35 | 8 | 18 | 30 | 80 | 243 |
| | Ferns | 2 | 0 | 3 | 1 | 0 | 0 | 4 | 10 |
| | Shrubs | 12 | 9 | 12 | 5 | 12 | 7 | 63 | 120 |
| | Total | 151 | 99 | 162 | 43 | 108 | 97 | 412 | |

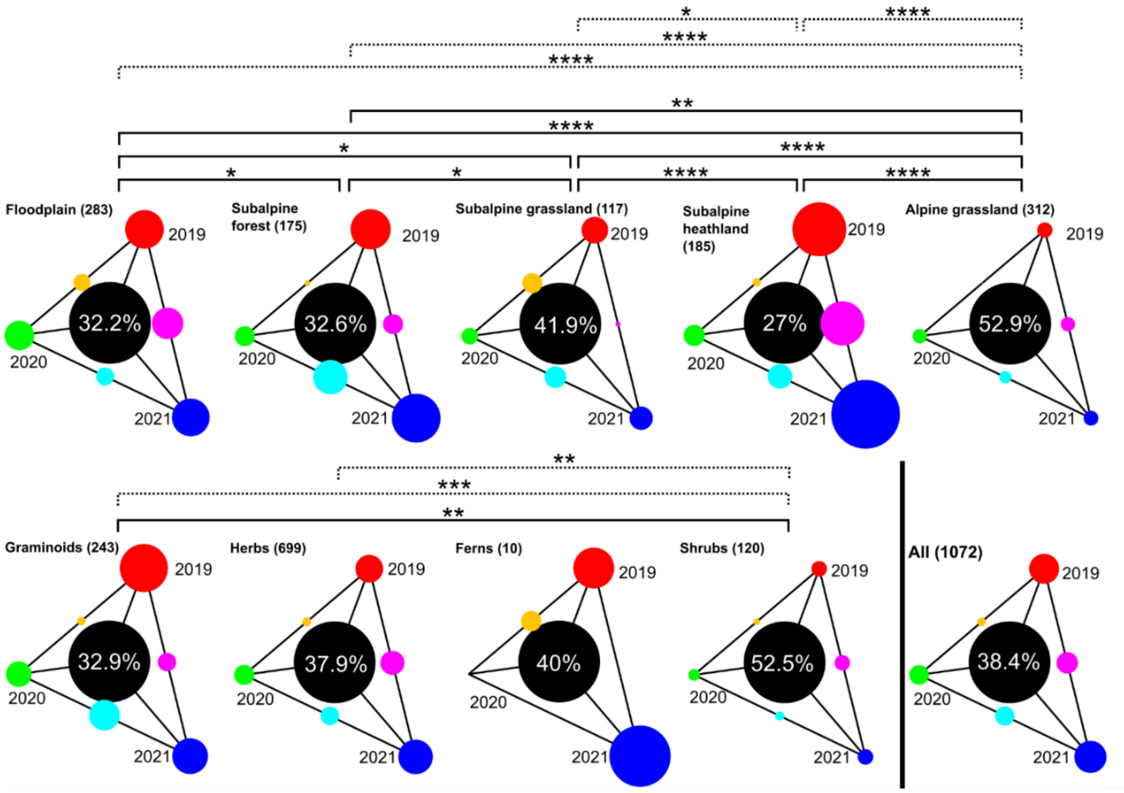


*Figure 2: The proportion of plot-species, which occur in only one year - 2019 (red), 2020 (green) or 2021 (blue), two years - 2019 and 2020 (yellow), 2020 and 2021 (turquoise), 2019 and 2021 (pink) and in all three years (black) in different habitats (upper row) and morpho - functional groups (bottom row). The size of the dot indicates the proportion of plot-species, each graph is re-scaled to an equal size of the all-years dot (dot size does not indicate absolute values). The percentage in the all-years dot is the percentage of plot-species found in all years. The number of plot-species in a given habitat or morphofunctional group is given in brackets. Above the graphs, the results of Chi-square test are visualized – results of paired tests between habitats and morphofunctional groups. Solid lines – comparison of all 7 categories of occurrence in*

*years, dotted lines – comparison only between occurrences in 3 years and less than 3 years. * - p<0.05, ** - p<0.01, *** - p<0.001, **** - p<0.0001. Only statistically significant results are shown (p<0.05).*

The proportion of plot-species which fall in each of the 7 categories of occurrence in years is different between habitats ($X^2$=98.89, df=24, p<0.0001) and between morphofunctional groups ($X^2$=31.08, df=18, p=0.028). When all plot-species which occur in less than 3 years are pooled and only two categories compared (present in 3 years and not), the proportions are also different both between habitats ($X^2$=45.55, df=4, p<0.0001) and morphofunctional groups ($X^2$=13.25, df=3, p=0.0041). Pairwise comparison of habitats and morphofunctional group of proportions both in 7 and in two categories of occurrence in years showed some significant differences (Figure 2)

All correlations between cover estimates of plot-species in two different years were statistically significant and Pearson's r coefficient values were very similar in all pairs (see Fig 3 for results). The mean coefficient of variation for all plot-species was 58.57%. When calculated separately in habitats, it was 58.76% in the floodplain, 54.04% in the subalpine forest, 62.45% in the subalpine grassland, 59.89% in the subalpine heathland and 58.52 in the alpine grassland. This values were not significantly different (F=0.76, df=4, p=0.55). The differences in the coefficient of variation were significantly different between morphofunctional groups (F=3.148, df=3, p=0.0246). Tukey HSD test showed only one difference between pairs of groups, between shrubs and herbs (p=0.013). In pooled data, the coefficient of variation was not correlated with mean cover (r=-0.25 df=658, p=0.099).

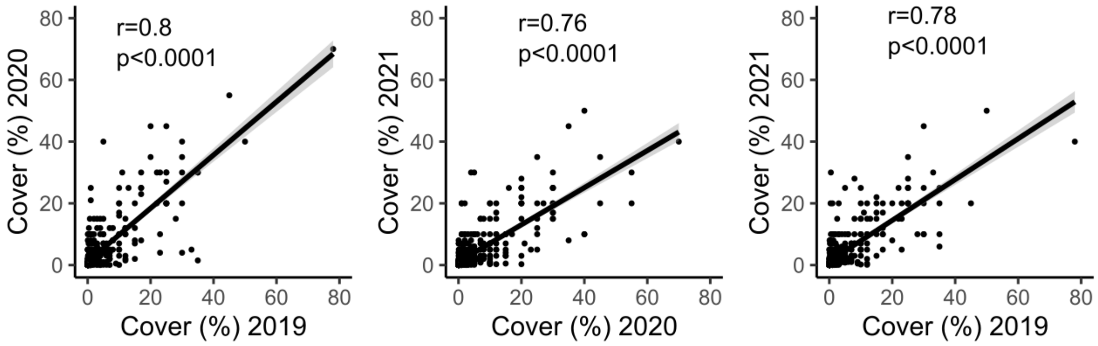


*Figure 3: Correlation between cover estimates of plot-species in two years, with Pearson correlation coefficient and p values*

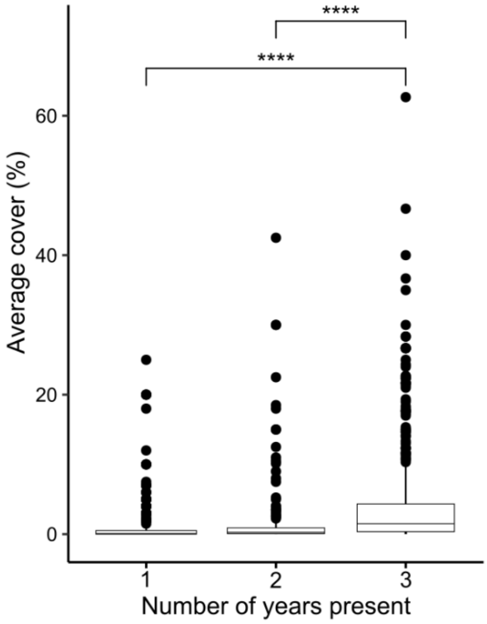


*Figure 4: Cover estimates of plot-species present in one (exact values), two and all three studied years (mean values). The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles). Whiskers extends from the hinge to the largest and smallest value no further than 1.5 * IQR from the hinge (where IQR is the inter-quartile range, or distance between the first and third quartiles). Dots indicate data points outside this range. Indication of results of Tukey HSD test, **** - p<0.0001.*

Plot-species which were present in all three years had higher average cover (4.38%) than those present only in two (1.66%) or one year (1.01%)(Figure 4) Closeness of species composition and cover, calculated with Sørensen-Dice and Bray-Curtis indices, is generally related to sharing the same plot (in time), 100 m$^2$ site or habitat (Figure 5).

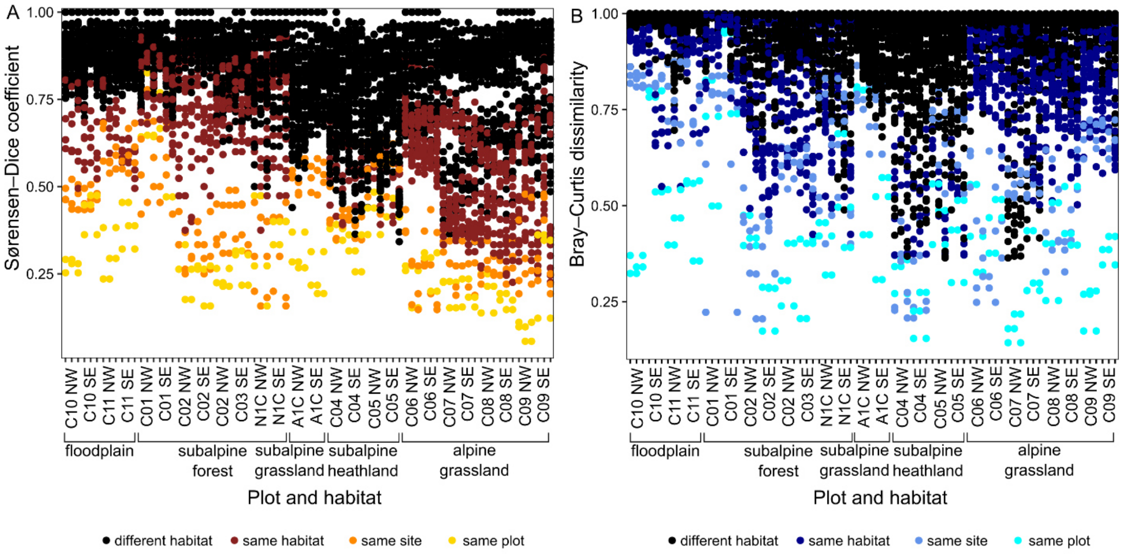


*Figure 5: Raw values of Sørensen-Dice coefficient (A) and Bryan-Dice dissimilarity index between each plot in each year and other plots in that year. Values between are differentiated, depending on whether the compared plots were in the same plot, the same 100 m$^2$ site (but different corners) or the same habitat.*

The differences in cover estimates of plant layers, stones, gravel and fine soil were high (up to 141.4% coefficient of variance, see Figure 6), but in none of the 8 analysed parameters were the differences between years significant, based on ANOVA results.

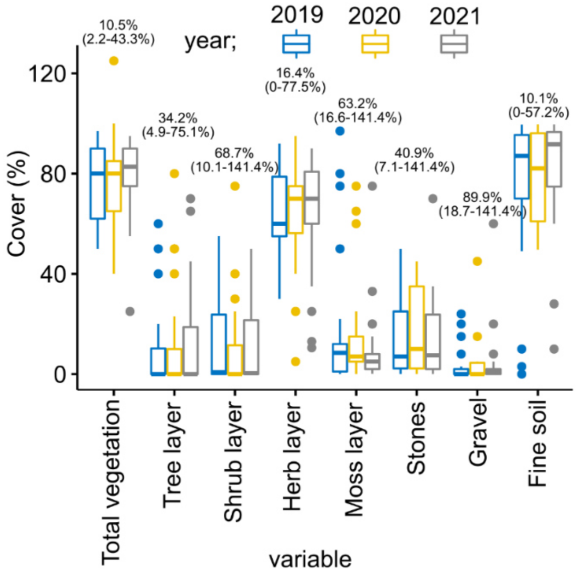


*Figure 6: Mean cover of different parameters in plots in three study years. For each variable, above the graphs, the mean coefficient of variation is given as well as the minimal and maximal values (in brackets).*

### *Functional and taxonomical diversity*

We extracted parameters of models with $R^2$m higher than 0.3 and listed them all in Appendix B. We detected a significant positive effect of year only for Shannon index in both graminoid morphofunctional group and alpine grassland vegetation type (Table 3). For alpine grassland, year had a signifficant positive effect also on Pielou's evennes. In every other model, year was an insignificant variable. All models with $R^2$m higher than 0.3 are shown in Appendix B. High effect of random effect was noted only in case of two GLMMs (Table 3).

*Table 3: Parameters of linear mixed-effect models showing temporal changes in taxonomical diversity parameters. Selected plot characteristics and year were set as fixed factors. Observer ID (name of the main author of the form) was set as random factor. SD – standard deviation; SE – standard error, t – t-statistic value, R2m – marginal coefficient of determination (the amount of variance explained by fixed effects only); R2c – (the amount of variance explained by both fixed and random effects). a – predictor variable values divided by c = 10*

| | | | | | | |
|---|---|---|---|---|---|---|
| **GRAMINOIDS** | **Shannon index** | **Random effects** | **Variance** | **SD** | **Mixed model parameters** | |
| | | Observer ID | 0.000 | 0.000 | $\mathrm{R}^2_\mathrm{m}$ | 0.402 |
| | | Residuals | 0.162 | 0.402 | $\mathrm{R}^2_\mathrm{c}$ | 0.402 |
| | | **Fixed effects** | **Estimate** | **SE** | **t** | **Pr(>\|t\|)** |
| | | (Intercept) | -1.697 | 0.691 | -2.458 | 0.016 |
| | | **Dead wood cover** | -0.030 | 0.013 | -2.367 | **0.021** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | **Elevation** [a] | 0.007 | 0.002 | 3.518 | **<0.001** |
| | | **pH** | 0.177 | 0.054 | 3.262 | **0.002** |
| | | **Year** | 0.117 | 0.056 | 2.066 | **0.042** |
| **ALPINE GRASSLAND** | **Shannon Index** | **Random effects** | **Variance** | **SD** | **Mixed model parameters** | |
| | | Observer ID | 0.000 | 0.000 | $R^2_m$ | 0.304 |
| | | Residuals | 0.051 | 0.226 | $R^2_c$ | 0.304 |
| | | **Fixed effects** | **Estimate** | **SE** | **t** | **Pr(>\|t\|)** |
| | | (Intercept) | 1.800 | 0.122 | 14.718 | **<0.001** |
| | | Year | 0.179 | 0.057 | 3.167 | **0.004** |
| | **Pielou's evenness** | **Random effects** | **Variance** | **SD** | **Mixed model parameters** | |
| | | Observer ID | 0.000 | 0.000 | $R^2_m$ | 0.390 |
| | | Residuals | 0.004 | 0.061 | $R^2_c$ | 0.390 |
| | | **Fixed effects** | **Estimate** | **SE** | **t** | **Pr(>\|t\|)** |
| | | (Intercept) | 0.533 | 0.034 | 0.092 | **<0.001** |
| | | **Dead wood cover** | -1.196 | 0.482 | -2.481 | **0.022** |
| | | Year | 0.059 | 0.016 | 3.636 | 0.002 |

*Table 4: Parameters of linear mixed-effect models showing temporal changes in taxonomical diversity parameters. Selected plot characteristics and year were set as fixed factors. Observer ID (name of the main author of the form) was set as random factor. SD – standard deviation; SE – standard error, t – t-statistic value, $R^2m$ – marginal coefficient of determination (the amount of variance explained by fixed effects only); $R^2c$ – (the amount of variance explained by both fixed and random effects). a – predictor variable values divided by c = 10*

| | | | | | | |
|---|---|---|---|---|---|---|
| **ALPINE GRASSLAND** | **Functional diversity** | **Random effects** | **Variance** | **SD** | **Mixed model parameters** | |
| | | Observer ID | 0.007 | 0.083 | $R^2_m$ | 0.381 |
| | | Residuals | <0.001 | 0.024 | $R^2_c$ | 0.951 |
| | | **Fixed effects** | **Estimate** | **SE** | **t** | **Pr(>\|t\|)** |
| | | (Intercept) | 0.772 | 0.031 | 25.262 | **<0.001** |
| | | **Litter cover** | 0.004 | <0.001 | 9.325 | **<0.001** |
| | | Year | -0.008 | 0.008 | -1.106 | 0.290 |
| **SUBALPINE FOREST** | **CWM of SLA** | **Random effects** | **Variance** | **SD** | **Mixed model parameters** | |
| | | Observer ID | 2893.000 | 53.790 | $R^2_m$ | 0.423 |
| | | Residuals | 535.900 | 23.150 | $R^2_c$ | 0.910 |
| | | **Fixed effects** | **Estimate** | **SE** | **t** | **Pr(>\|t\|)** |
| | | (Intercept) | 1028.973 | 120.583 | 8.533 | **<0.001** |
| | | **Elevation**$^a$ | -4.467 | 0.583 | -7.669 | **<0.001** |
| | | Year | 13.253 | 17.970 | 0.738 | 0.469 |
| | | **Elevation**$^a$ | -4.467 | 0.583 | -7.669 | **<0.001** |
| | | Year | 13.253 | 17.970 | 0.738 | 0.469 |

## Discussion

The differences in the distribution of plot-species in categories of occurrence in years between morphofunctional groups and habitats are somehow possible to explain. Shrubs are perennial and generally larger than herbs and graminoids, therefore less likely to disappear from a plot or not be found during vegetation survey. Different species groups of alpine plants have been found to differ in susceptibility to the observer error (Burg et al. 2015). Alpine grasslands in the nival zone are believed to have relatively stable species composition in short time scales, due to slow growth rates and extended live cycles (Pauli et al. 1999). However, this finding has been undermined (Cannone et al. 2007) and our results support it. The subalpine heathland seems to undergo the fastest changes, which may be a result of recent anthropogenic changes in this habitat.

The coefficient of variation in cover was similar among habitats and morphofunctional groups, which suggests that the observer error cover estimates was constant in our study. Contrary to most other findings (Morrison 2016), the coefficient of variation was not correlated with cover.

As expected, most of detected underlying variability in diversity was related to rather stable habitat characteristics, like pH, elevation or heat load (Appendix B). However, for alpine grassland and graminoids we detected a shift in taxonomical diversity with no observer error noted. This effect should be interpreted very carefully, as we run analyses for only three year period. It is important to not mistake a fluctuation with a trend and to avoid that, long-term collection of data is necessary (Magurran et al. 2010). Nonetheless, we still suggest checking for temporal changes in these vegetation type and morphofunctional group in the upcoming years.

High observer errors were noted for models with *FDiv ~ litter* interaction in alpine grassland vegetation type and *SLA ~ elevation* in subalpine forest vegetation type. Litter coverage might be indeed hard to assess precisely and it differed between years on the same subplots. In case of subalpine forest assessing coverage of some plants might play a role - some small plants growing in forest habitat on sampled plots, like *Viola biflora* and *Oxalis acetosella*, have high SLA values. Different assessment of coverage of such plants with small leaves doesn't seem unlikely, especially in forest habitat. Furthermore, the fact that we noted high observer effect only for models with functional diversity indices (which were obtained for each plot through plant cover estimation) suggests that differences in estimates in cover may be indeed the source of variability and that evaluating functional diversity might be more susceptible to observer effect than taxonomical diversity.

That said, we still should interpret these values of random effect with caution, because during three years of study as many as 22 people were signed as main authors of the form, and their initials were put into database. Nonetheless, we wanted to present a framework that could be utilised during upcoming Summer Schools to calculate observer error.

To omit this kind of problem in the future, we propose, when possible, to write down the name of most experienced person, who probably will be taking part in study in upcoming years and who took final decisions during field sampling. Putting down the name of one of supervisor teachers would be optimal. This would help with controlling for observer error to some extent.

We also suggest two possible solutions to minimize observer effect: analysing presence-absence data as it is carrying less noise (but also less information) or focusing more on standarised methods of cover estimation and cross-validating values obtained by different observers.

Additionaly to all described measurements, temperature sensors were previously set up on each plot, but due to technical problems and loss of one of the sensors we unfortunately couldn’t include temperature data in our analyses. It still will be important in the upcoming years to try to obtain data from temperature sensors to determine number of days with snow cover and detect potential variation in annual temperature. These are both seemingly important factors in temporal changes in plant diversity (Cannone et al. 2007, Choler 2018). Besides that, we also suggest revisiting plots established on the other side of Albula river, as recent report states there might be a difference in effects of climate change on vegetation growing on different bedrock types (Nicklas et al. 2021)

### *Data correction after fieldwork*

Apart from the three types of errors mentioned in the introduction, vegetation data are susceptible to writing/typing mistakes in each part of work. All kinds of errors, whatever their cause, can be sometimes traced back during data analysis. It is generally not a good practice to "repair" data after finishing fieldwork, apart from obvious typing mistakes in species names etc.

However, a pair of plots in a 100 m$^2$ site differs strongly from other plots in species turnover. Plots C01_NW and C01_SE have by far the lowest percentage of plot species observed in all three years (7.7% and 11.1%, respectively). We did not use any statistical tests to analyze this case, but visual inspection of the Bray-Curtis coefficient between those two plots in different years suggests that the NW and SE corner have been swapped in year 2019. C01_NW2019 is much more similar to C01_SE2020 and 2021, than to C01_NW 2020 and 2021. The same can be observed the other way round (Figure 7). We did not correct the raw data which we used in the analyses and added as an appendix to this report. But we did perform such a simulation for the sake of this section. Reversing the corners in plot C01 in 2019 somewhat increases the percentage of species observed on these plots in all three years, but they are still among the lowest values (Fig 8). Having described this observation, we leave the decision to those who will continue vegetation surveys at Val Mulix.

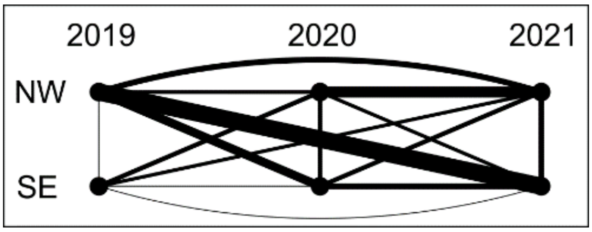


*Figure 7: Similarity between plots of the C01 site during the three study years, expressed as the reverse of the Bray-Curtis coefficient (1 – B-C), which is proportional to the thickness of the line linking two year-plots.*

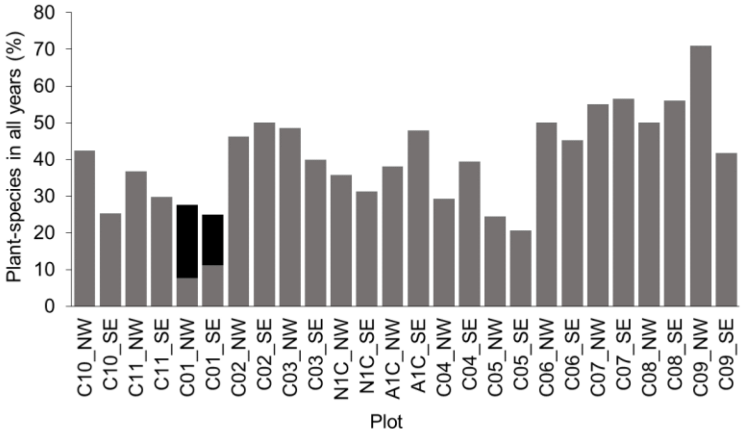


*Figure 8: The percentage of plant-species found in all three years in the studied plots, before (grey) and after (black) reversing the NW and SE corners in site C01 in the year 2019.*

## References

Bartelheimer M. & Poschlod P. 2016: Functional characterizations of Ellenberg indicator values – a review on ecophysiological determinants - *Functional Ecology* 30: 506–516.

Bartoń K. 2020: MuMIn: Multi-Model Inference. R package version 1.43.17. https://CRAN.R-project.org/package=MuMIn

Baselga A., Orme D., Villeger S., De Bortoli J., Leprieur F. & Logez M. 2021:. betapart: Partitioning Beta Diversity into Turnover and Nestedness Components. R package version 1.5.4. https://CRAN.R-project.org/package=betapart

Bates D., Maechler M., Bolker B. & Walker S. 2015: Fitting Linear Mixed-Effects Models Using lme4 - *Journal of Statistical Software* 67: 1-48

Begert M., Schlegel T. & Kirchhofer W. 2005: Homogeneous temperature and precipitation series of Switzerland from 1864 to 2000 - *International Journal of Climatology* 25: 65–80.

Burg S., Rixen C., Stöckli V. & Wipf S. 2015: Observation bias and its causes in botanical surveys on high-alpine summits - *Journal of Vegetation Science* 26: 191–200.

Cannone N., Sgorbati S. & Gugielmin M. 2007: Unexpected impacts of climate change on alpine vegetation - *Frontiers in Ecology and the Environment* 5: 360–364.

Choler P. 2018: Winter soil temperature dependence of alpine plant distribution: Implications for anticipating vegetation changes under a warming climate - *Perspectives in Plant Ecology, Evolution and Systematics* 30: 6–15. Elsevier.

Chun J.-H. & Lee C.-B. 2019: Temporal Changes in Species, Phylogenetic, and Functional Diversity of Temperate Tree Communities: Insights From Assembly Patterns - *Frontiers in Plant Science* 10.

Dengler J., Boch S., Filibeck G., Chiarucci G., Dembicz I., Guarino R., Henneberg B., Janišová M., Marcenó C. & Biurrun I. 2016: Assessing plant diversity and composition in grasslands across spatial scales: The standardised EDGG sampling methodology - *Bulletin of the Eurasian Dry Grassland Group* 32: 13–30.

Futschik A., Winkler M., Steinbauer K., Lamprecht A., Rumpf S. B., Barančok P., Palaj A., Gottfried M. & Pauli H. 2020: Disentangling observer error and climate change effects in long-term monitoring of alpine plant species composition and cover - *Journal of Vegetation Science* 31: 14–25.

Kazakou E., Vile D., Shipley, Gallet C. & Garnier E. 2006: Co-variations in litter decomposition, leaf traits and plant growth in species from a Mediterranean old-field succession - *Functional Ecology* 20: 21–30.

Laliberté E. & Legendre P. 2010: A distance-based framework for measuring functional diversity from multiple traits - *Ecology* 91: 299–305.

Laliberté, E., Legendre, P., & Shipley B. 2014: FD: measuring functional diversity from multiple traits, and other tools for functional ecology. R package version 1.0-12.

Liu G., Wang L., Jiang L., Pan X., Huang Z., Dong M. & Cornelissen J. H. C. 2018: Specific leaf area predicts dryland litter decomposition via two mechanisms - *Journal of Ecology* 106: 218–229.

Magurran A. E., Baillie S. R., Buckland S. T., Dick J. M., Elston D. A., Scott E. M., Smith R. I., Somerfield P. J. & Watt A. D. 2010: Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time - *Trends in Ecology & Evolution* 25: 574–582.

Morrison L. W. 2016: Observer error in vegetation surveys: a review - *Journal of Plant Ecology* 9: 367–379.

Nakagawa S. & Schielzeth H. 2013: A general and simple method for obtaining R 2 from generalized linear mixed-effects models - *Methods in Ecology and Evolution* 4: 133–142.

Nicklas L., Walde J., Wipf S., Lamprecht A., Mallaun M., Rixen C., Steinbauer K., Theurillat J.-P., Unterluggauer P., Vittoz P., Moser D., Gattringer A., Wessely J. & Erschbamer B. 2021: Climate Change Affects Vegetation Differently on Siliceous and Calcareous Summits of the European Alps - *Frontiers in Ecology and Evolution* 9.

Oksanen J., Blanchet F. G., Friendly M., Kindt R., Legendre P., McGlinn D., Minchin P.R, O'Hara R.B., Simpson G.L., Solymos P., Stevens M.H., Szoecs E & Wagner H. 2020: vegan: Community Ecology Package. R package version 2.5-7. https://CRAN.R-project.org/package=vegan

Pauli H., Gottfried M., Dullinger S., Abdaladze O., Akhalkatsi M., Alonso J. L. B., Coldea G., Dick J., Erschbamer B., Calzado R. F., Ghosn D., Holten J. I., Kanka R., Kazakis G., Kollár J., Larsson P., Moiseev P., Moiseev D., Molau U., Mesa J. M., Nagy L., Pelino G., Puşcaş M., Rossi G., Stanisci A., Syverhuset A. O., Theurillat J.-P., Tomaselli M., Unterluggauer P., Villar L., Vittoz P. & Grabherr G. 2012: Recent Plant Diversity Changes on Europe's Mountain Summits - *Science* 336: 353–355.

Pauli H., Gottfried M. & Grabherr G. 1999: Vascular plant distribution patterns at the low temperature limits of plant life - the alpine-nival ecotone of Mount Schrankogel (Tyrol, Austria) - *Phytocoenologia* 29: 297–325.

Rixen C. & Wipf S. 2017: Non-equilibrium in Alpine Plant Assemblages: Shifts in Europe's Summit Floras. In: pp. 285–303.

Villéger S., Mason N. W. H. & Mouillot D. 2008: New multidimensional functional diversity indices for a multifaceted framework in functional ecology - *Ecology* 89: 2290–2301.

# Vascular plant habitats in the alluvial plain in Preda: a comparison

*Carina Kohler & Ursula Schöni*

## Abstract

Alpine and subalpine ecosystems are biodiversity hotspots in Switzerland and alluvial plains are known to be very species rich. We therefore investigated the alluvial plain in Preda, located in the perimeter of Parc Ela, to identify and compare the various habitats. With a size of 548 km$^2$ Parc Ela is the largest nature park in Switzerland, 60% of which are protected area. The geology is characterized by quaternary unconsolidated rocks and alkaline biogenic sedimentary rocks. We sampled eight 1m$^2$ plots, prepared a species list for vascular plants and estimated the cover of each species. Furthermore, we recorded various environmental parameters. We integrated data available from previous surveys and used a modified TWINSPAN-algorithm to classify the sampled plots into clusters. We then compiled a vegetation table that allowed us to firstly identify the diagnostic species for each of the seven clusters and then to compare them against the classification by Delarze et al. (2015). Some allocations were unambiguous for some clusters, e.g. *Petasition paradoxi* and *Juniperon nanea*, others proved to be more difficult as no clear conclusions could be drawn based on the diagnostic species. One cluster could only be allocated to the superordinate habitat mountainous oligotrophic grassland. In order to see how the different habitats differ, various environmental parameters were compared. This work provides an overview of the diversity of potentially endangered habitats in the alluvial plain in Preda and contributes to develop conservation measures accordingly if deemed necessary.

*Keywords: alluvial plain, alpine, biodiversity, comparison, ecosystems, habitats, Parc Ela, subalpine, Switzerland, vascular plants*

## Introduction

The concept of biodiversity refers to the diversity of life on different levels (FOEN 2018). It includes the level of ecosystems, species as well as the genetic diversity. The geophysical diversity of Switzerland, i.e., differences in altitude, climate extremes and differences in soil as well as anthropogenic influences and centuries of traditional types of land use have led to the country's rich biodiversity, consisting of forests, open grasslands, water bodies and settlements. Different types of land use promote the diversity of flora and fauna. However, this mosaic of standard orchards, irrigated and dry meadows, wood pastures and other ecosystems is in decline. Since 1900, biodiversity in Switzerland has declined dramatically and it is generally in an unsatisfactory, even alarming state (FOEN 2018; Lachat et al. 2010). This is not only due to declining surfaces but also due to lesser quality of the habitats. It is therefore of utmost importance to protect the remaining valuable ecosystems and to interconnect these habitats better. Even in biotopes of national importance, ecological quality is declining because the natural dynamics are restricted, the areas are too small and fragmented, the management is not adapted to the site, the water balance is disturbed, or the nutrient input is too high (Guntern et al. 2013). According to the experts, the conservation and promotion of biodiversity on about one third of the country's area should be a priority.

600 species of vascular plants are to be found exclusively in alpine or subalpine zones or their dissemination focus lies within these ecosystems (Fischer et al. 2015). This is one-fifth of all native species. Alpine or subalpine zones are biodiversity hotspots and Switzerland as an alpine country has a responsibility to protect endemic species. The largest share of the mires, alluvial zones, dry meadows and pastures of national importance, with the species that call these habitats home, are found in the Alps (FOEN 2017).

Floodplain landscapes are complex ecosystems with a mosaic of different habitats. The dynamics that characterize floodplain landscapes create a mosaic of different habitats. Thus, in addition to wet and moist sites, dry and ruderal habitats are also found in floodplains. Thanks to this heterogeneity, floodplains are very species-rich landscapes (WWF 2007). However, these landscapes are threatened by the increasing presence of settlements and agricultural areas and have therefore a very large share of endangered habitats (Delarze et al. 2016). Currently, over 70% of Swiss habitats in waterbodies and wetlands are on the Red List (FOEN 2020).

To gain more knowledge about these floodplain habitats in Preda, eight vegetation surveys of 1m$^2$ plots were taken and analyzed along with data from previous years.

This work aims to define habitats according to Delarze et al. (2015) for the alluvial plain in Preda based on the vegetation records. In addition, different parameters are investigated to see to what extent these habitats differ.

This paper aims to investigate two research questions:

- Which vegetation types according to Delarze et al. (2015) do occur in the alluvial plain in Preda?
- How do these vegetation types differ from one another comparing different parameters?

## Methods

### *Study area*

Preda is in Parc Ela, the largest nature park in Switzerland (Parc Ela 2021). The park covers a size of 548 km$^2$, of which over a third is untouched landscape and 60% are protected area. Only 2% of the entire perimeter are covered with settlements. The altitude ranges from 745 to 3418 m.a.s.l. With its mires, mountain forests, hedges and glaciers the nature park is known to be a biodiversity hotspot.

As an inner alpine valley, the Albula valley is characterized by a continental climate (figure 1). Annual precipitation sums reach around 1000 mm and the annual mean temperature is approximately 3.5°C (MeteoSwiss 2021). The region has more than 180 frost days per year which shorten the vegetation period crucially to six months.

The study site is in the alluvial plain of the Alvra River and is delimited to the north by the railroad embankment (figure 2). The geological map of the Preda area (figure 3) shows that the alluvial plain both contains quaternary unconsolidated rocks and biogenic sedimentary rocks, which are mostly lime stones and therefore rather alkaline (Ludwig 2012). The locations of the eight plots were selected randomly. It was only ensured that the plots were in the nature conservation area, in open areas and between Veja Preda north to the group house and the hiking trail south to the Alvra river leading up to Naz.

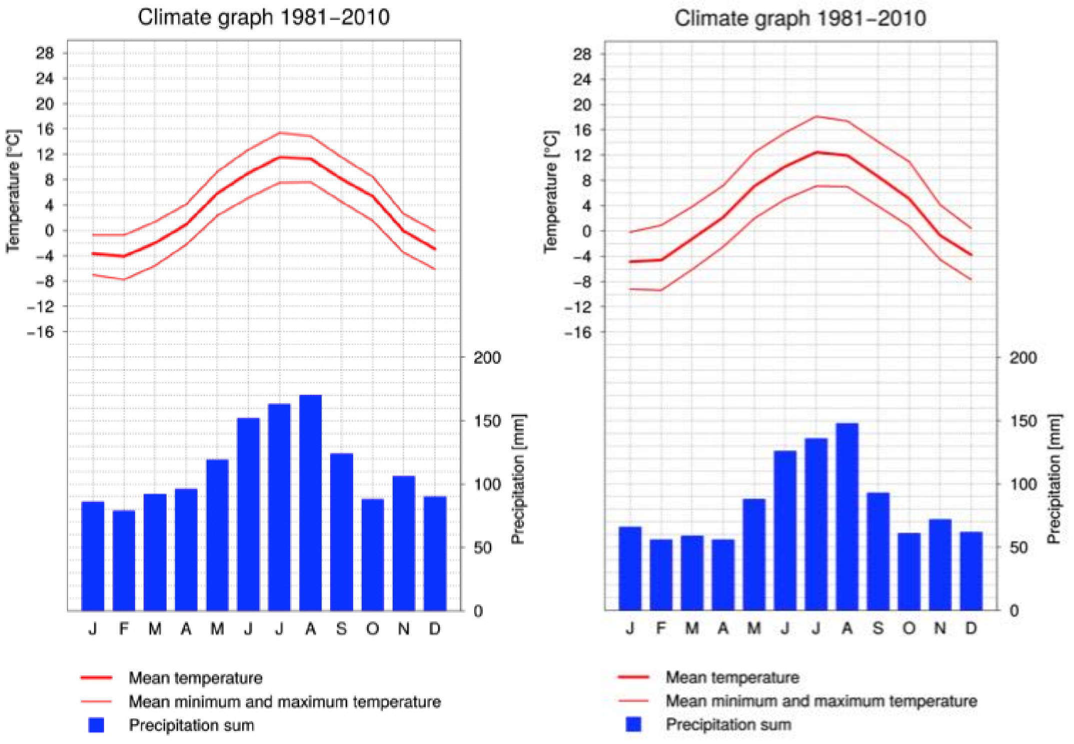


*Figure 1: The climate for Arosa (1878 m.a.s.l., left) and Davos (1594 m.a.s.l., right) is representative for the region. The two climate graphs show the mean values for the reference period 1981 – 2010. Precipitation sum for Arosa is 1365 mm, mean annual temperature 3.6°C, precipitation sum for Davos is 1022 mm, mean annual temperature 3.5°C (MeteoSchweiz 2021).*

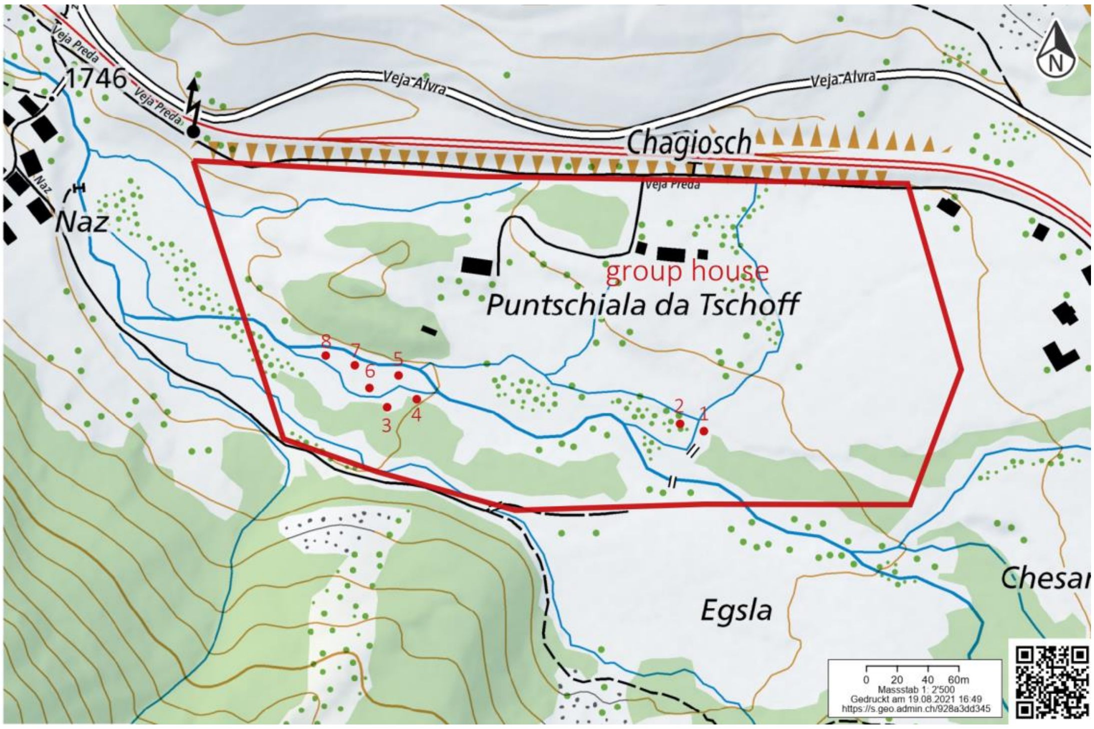


*Figure 2 shows the location of our group accommodation, the study site (red frame) as well as the eight 1m² plots that we sampled for this study on two days in August 2021 (Geo Admin 2021).*

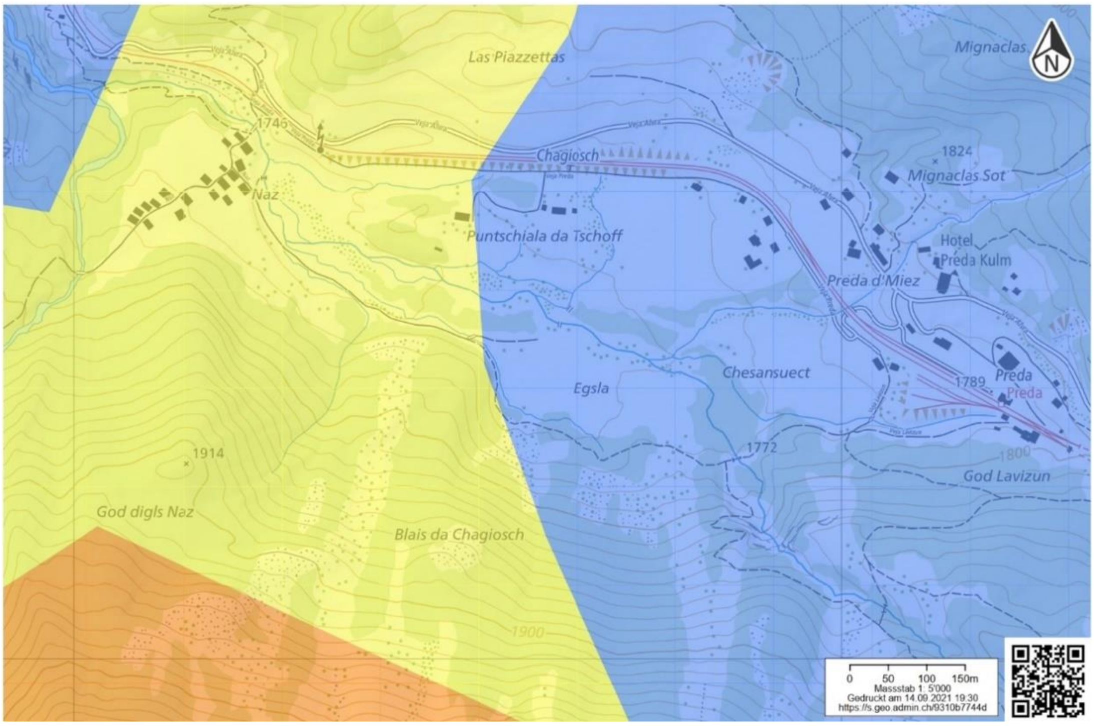


*Figure 3 shows the rock types that occur in the alluvial plain in Preda (GeoAdmin 2021). Light green marks the area with quaternary unconsolidated rocks, blue marks the area with biogenic sediments.*

### *Field sampling*

Sampling was performed on August 17 and 18, 2021. For each of the eight 1m$^2$ plots, a species list of vascular plants with percentage cover was prepared. Lichens and bryophytes were noted only for total vegetation cover. However, the individual species were not recorded.

The species determination was made according to the checklist 2017 of Info Flora (Info Flora 2021a). The Flora Helvetica app (Haupt 2021), the Flora Helvetica book (Lauber & Wagner 2009) and Flora Vegetativa (Eggenberg et al. 2020) were used as tools for species identification. The species lists for the first two plots were kept physically with standard forms. The following plots were documented with FlorApp (Info Flora 2021b), the online field book of Info Flora.

In addition to the species list, the following parameters were also included in the sampling process:

- pH-value from soil samples
- Max. Vegetation height [cm]
- Micro relief [cm]
- Soil depth at five points [cm]
- Total vegetation cover [%]
- Percentage cover of the individual layers [%]
- Rock and stones [%]
- Dead wood [%]

- Gravel [%]
- Fine soil [%]
- Exposure and slope [°]

In 2019 and 2021, soil samples were taken to measure the pH-value. In the 2020 survey, water samples were taken from the spring floodplains and pH-value was measured from the water. However, this methodological difference was neglected in the present analysis.

### *Data preparation*

In previous years, 1m$^2$ plots had already been sampled in the alluvial plain in Preda. Hochreutener et al. (2019) investigated a transect with 20 plots to find out which factors influence species diversity and Seiler (2021) recorded the vegetation of 60 spring-fed habitats in Parc Ela. Six of these 60 plots are in the area of the alluvial plain, which is as well subject of this study. Data of the previous studies were available and could as well be used in the study at hand.

In order to receive a complete species list, the data recorded in this year's Summer School were merged with those from previous years using a software called Vegedaz (WSL 2021). For the data recorded in 2019, four plots were removed as they were in the forest and thus outside the defined perimeter. For the vegetation surveys of Seiler (2021), only the six plots that were in the alluvial plain were considered. Thus, data from a total of thirty-six 1m$^2$ plots, all of which are in the alluvial plain, were available for further analysis.

Imprecise recordings in which only the family or the genus could be determined were excluded. In addition, species for which a subspecies was determined in previous years were combined on the level of the subspecies. It is assumed that only the subspecies occur in the perimeter. Vegedaz was used to simultaneously assign pointer values such as nutrient count, light count, temperature count and others for every plot. Vegedaz was also used to calculate the Shannon Index and Shannon Equitability. In addition, plots were assigned to a habitat according to Delarze et al. (2015) based on the species list. Allocation in Vegedaz is done through a bottom-up approach. This involves comparing the dominant character and associate species according to Delarze et al. (2015) with the cover of the species in the vegetation survey. It does not allow habitats to be uniquely assigned to a plot. Points are also assigned to the habitats to weight the classification (Krüsi & Widmer 2021). For the assignment three ranks were used. The habitats with the highest score are shown for the first rank.

### *Data analysis*

The different plots were classified using Juice software (Masaryk University 2021). The classification was done by a modified TWINSPAN-algorithm (Roleček et al. 2009) with the smallest possible Sørensen dissimilarity. Groups with only one recording were subsequently regrouped in the next higher level. In a next step, a vegetation table was compiled to get a better overview of which species occurred in which vegetation type. By determining the phi value, the diagnostic species for each group could be identified. Species with a phi value ≥ 0.7 were classified as highly diagnostic and species with a phi value ≥ 0.5 were classified as diagnostic. With these diagnostic species, the seven vegetation types could be classified according to Delarze et al. (2015).

After classification, the different vegetation types were compared using the software R (R Foundation 2021) and RStudio (RStudio 2021) to determine which parameters had an impact on the vegetation types. For this purpose, various ANOVA or Kruskal-Wallis tests were performed.

## Results

### *Which vegetation types do occur in the alluvial plain in Preda?*

In order to classify the sampled plots in the alluvial plain in Preda, a modified TWINSPAN algorithm was used. It resulted in eight different vegetation types (figure 4). As cluster 2 only contained one recording, clusters 2 and 3 were subsequently merged into one group. We could therefore identify seven different vegetation types in the sampled area.

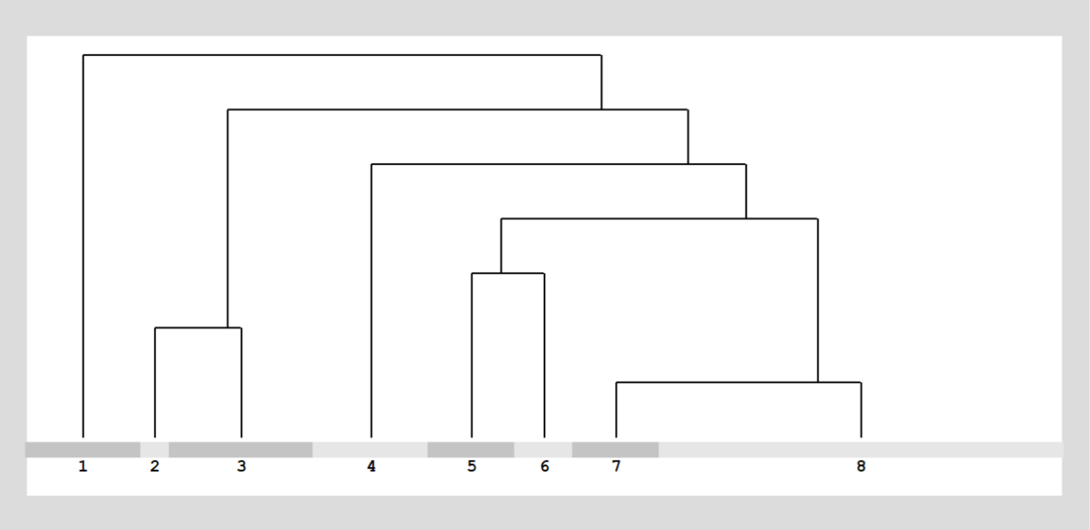
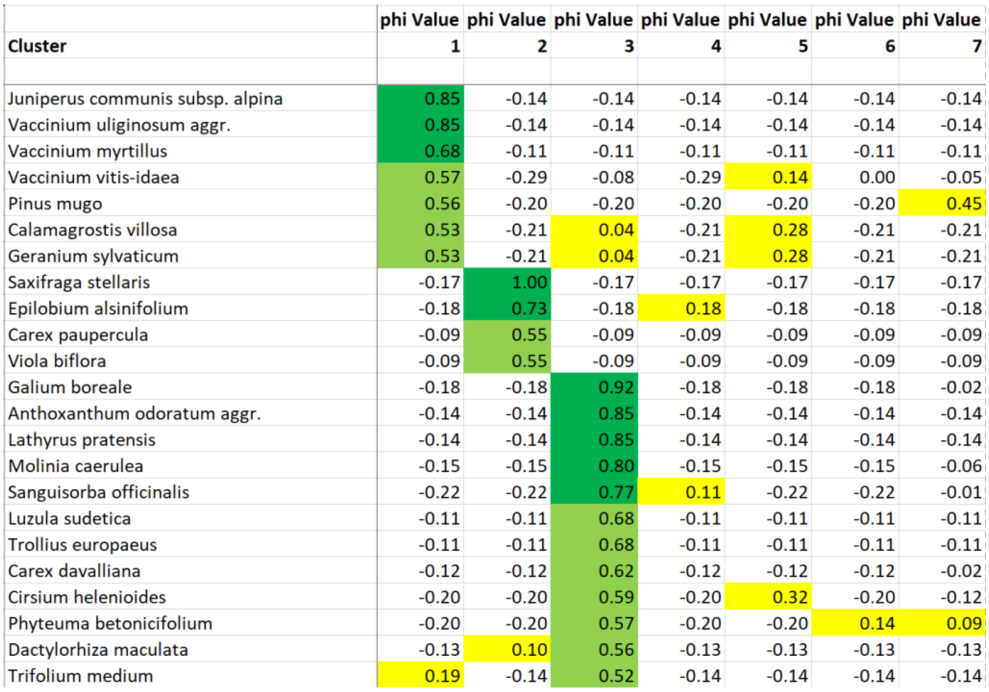


*Figure 4: Classification using the modified TWINSPAN algorithm resulted in eight different vegetation types. Clusters 2 and 3 were subsequently merged as cluster 2 only contained one recording.*

The vegetation table allowed us to get a better understanding of the flora and the vegetation types occurring in the alluvial plain in Preda (Tables 1 to 3). Darker green colored values mark highly diagnostic species whereas lighter green colored values stand for diagnostic species. Yellow colored values mark values >0.00. A value above zero means that the species is present in the clusters but is not considered diagnostic.

*Juniperus communis subsp. alpina, Vaccinium uliginosum aggr.* as well as *Vaccinium myrtillus* are found to be highly diagnostic species for cluster no. 1 whereas *Vaccinium vitis-idaea, Pinus mugo, Calamagrostis villosa* and *Geranium sylvaticum* are diagnostic species (table 1). The diagnostic species indicate that cluster no. 1 includes plots of dwarfshrub heathland. Cluster no. 2 is characterized by the highly diagnostic species *Saxifraga stellaris* and *Epilobium alsinifolium* with presence of diagnostic species *Carex paupercula* and *Viola biflora.* These species are indicative of springfed swamps. And in cluster no. 3 five species are found to be highly diagnostic: *Galium boreale, Anthoxanthum odoratum aggr., Lathyrus pratensis, Molinia caerulea* and *Sanguisorba officinalis* with presence of another seven diagnostic species. These are characteristic of wet meadows.

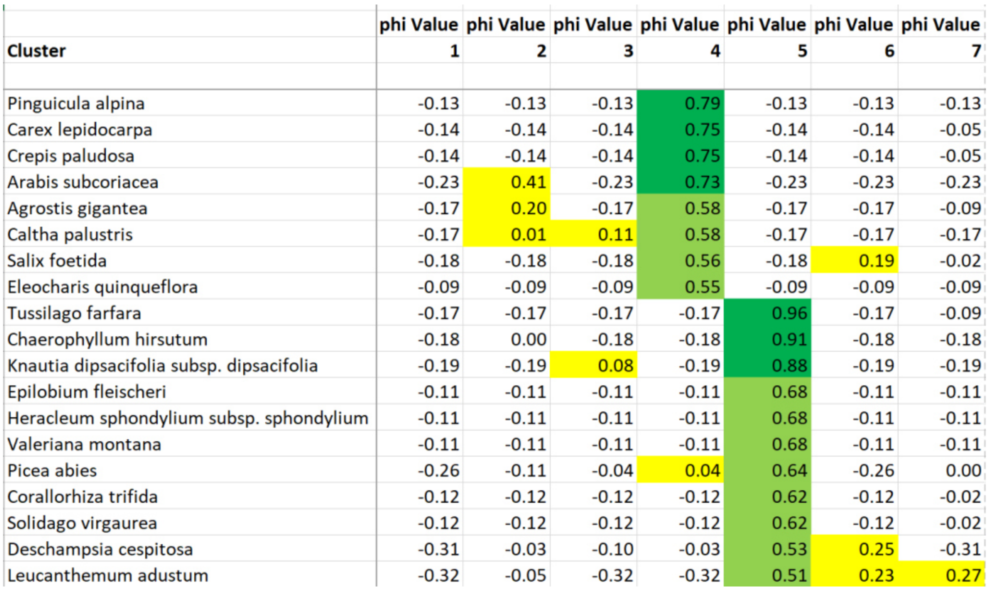
*Table 1: Vegetation table with highly diagnostic (darker green) and diagnostic (lighter green) species for clusters no. 1 to 3. Species that are present but not considered diagnostic are marked in yellow.*



| Cluster | phi Value 1 | phi Value 2 | phi Value 3 | phi Value 4 | phi Value 5 | phi Value 6 | phi Value 7 |
|---|---|---|---|---|---|---|---|
| Juniperus communis subsp. alpina | 0.85 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 |
| Vaccinium uliginosum aggr. | 0.85 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 | -0.14 |
| Vaccinium myrtillus | 0.68 | -0.11 | -0.11 | -0.11 | -0.11 | -0.11 | -0.11 |
| Vaccinium vitis-idaea | 0.57 | -0.29 | -0.08 | -0.29 | 0.14 | 0.00 | -0.05 |
| Pinus mugo | 0.56 | -0.20 | -0.20 | -0.20 | -0.20 | -0.20 | 0.45 |
| Calamagrostis villosa | 0.53 | -0.21 | 0.04 | -0.21 | 0.28 | -0.21 | -0.21 |
| Geranium sylvaticum | 0.53 | -0.21 | 0.04 | -0.21 | 0.28 | -0.21 | -0.21 |
| Saxifraga stellaris | -0.17 | 1.00 | -0.17 | -0.17 | -0.17 | -0.17 | -0.17 |
| Epilobium alsinifolium | -0.18 | 0.73 | -0.18 | 0.18 | -0.18 | -0.18 | -0.18 |
| Carex paupercula | -0.09 | 0.55 | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 |
| Viola biflora | -0.09 | 0.55 | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 |
| Galium boreale | -0.18 | -0.18 | 0.92 | -0.18 | -0.18 | -0.18 | -0.02 |
| Anthoxanthum odoratum aggr. | -0.14 | -0.14 | 0.85 | -0.14 | -0.14 | -0.14 | -0.14 |
| Lathyrus pratensis | -0.14 | -0.14 | 0.85 | -0.14 | -0.14 | -0.14 | -0.14 |
| Molinia caerulea | -0.15 | -0.15 | 0.80 | -0.15 | -0.15 | -0.15 | -0.06 |
| Sanguisorba officinalis | -0.22 | -0.22 | 0.77 | 0.11 | -0.22 | -0.22 | -0.01 |
| Luzula sudetica | -0.11 | -0.11 | 0.68 | -0.11 | -0.11 | -0.11 | -0.11 |
| Trollius europaeus | -0.11 | -0.11 | 0.68 | -0.11 | -0.11 | -0.11 | -0.11 |
| Carex davalliana | -0.12 | -0.12 | 0.62 | -0.12 | -0.12 | -0.12 | -0.02 |
| Cirsium helenioides | -0.20 | -0.20 | 0.59 | -0.20 | 0.32 | -0.20 | -0.12 |
| Phyteuma betonicifolium | -0.20 | -0.20 | 0.57 | -0.20 | -0.20 | 0.14 | 0.09 |
| Dactylorhiza maculata | -0.13 | 0.10 | 0.56 | -0.13 | -0.13 | -0.13 | -0.13 |
| Trifolium medium | 0.19 | -0.14 | 0.52 | -0.14 | -0.14 | -0.14 | -0.14 |

Cluster no. 4 contains four highly diagnostic species (Pinguicula alpina, Carex lepidocarpa, Crepis paludosa and Arabis subcoriacea) and as many diagnostic species (Agrostis gigantea, Caltha palustris, Salix foetida and Eleocharis quinqueflora, table 2). This indicates that plots from the fen belong to this cluster. In cluster no. 5 Tussilago farfara, Chaerophyllum hirsutum and Knautia dipsacifolia subsp. dipsacifolia are highly diagnostic with another eight diagnostic species. This indicates that the plots in this cluster are tall forb communities.

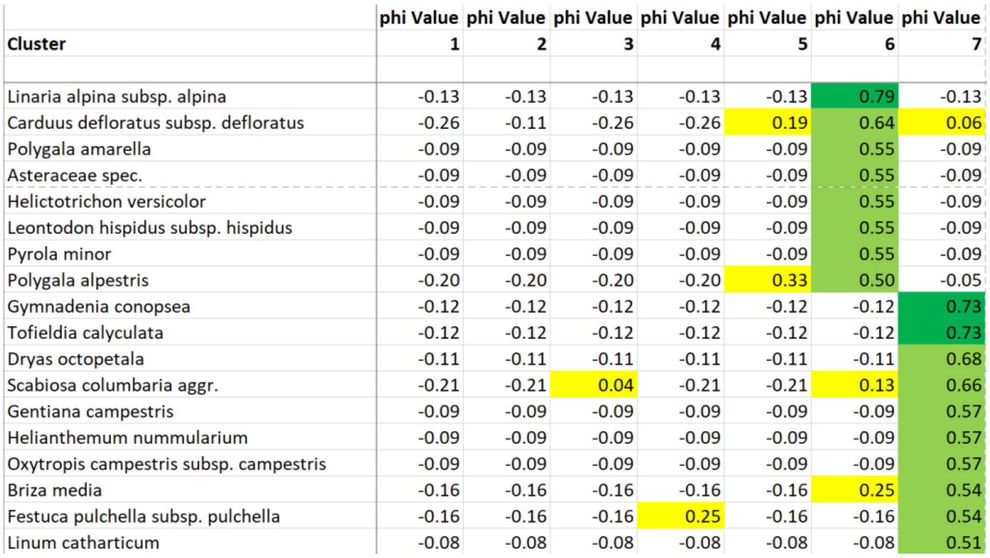
*Table 2: Vegetation table with highly diagnostic (darker green) and diagnostic (lighter green) species for clusters no. 4 and 5. Species that are present but not considered diagnostic are marked in yellow.*



| Cluster | phi Value 1 | phi Value 2 | phi Value 3 | phi Value 4 | phi Value 5 | phi Value 6 | phi Value 7 |
|---|---|---|---|---|---|---|---|
| Pinguicula alpina | -0.13 | -0.13 | -0.13 | 0.79 | -0.13 | -0.13 | -0.13 |
| Carex lepidocarpa | -0.14 | -0.14 | -0.14 | 0.75 | -0.14 | -0.14 | -0.05 |
| Crepis paludosa | -0.14 | -0.14 | -0.14 | 0.75 | -0.14 | -0.14 | -0.05 |
| Arabis subcoriacea | -0.23 | 0.41 | -0.23 | 0.73 | -0.23 | -0.23 | -0.23 |
| Agrostis gigantea | -0.17 | 0.20 | -0.17 | 0.58 | -0.17 | -0.17 | -0.09 |
| Caltha palustris | -0.17 | 0.01 | 0.11 | 0.58 | -0.17 | -0.17 | -0.17 |
| Salix foetida | -0.18 | -0.18 | -0.18 | 0.56 | -0.18 | 0.19 | -0.02 |
| Eleocharis quinqueflora | -0.09 | -0.09 | -0.09 | 0.55 | -0.09 | -0.09 | -0.09 |
| Tussilago farfara | -0.17 | -0.17 | -0.17 | -0.17 | 0.96 | -0.17 | -0.09 |
| Chaerophyllum hirsutum | -0.18 | 0.00 | -0.18 | -0.18 | 0.91 | -0.18 | -0.18 |
| Knautia dipsacifolia subsp. dipsacifolia | -0.19 | -0.19 | 0.08 | -0.19 | 0.88 | -0.19 | -0.19 |
| Epilobium fleischeri | -0.11 | -0.11 | -0.11 | -0.11 | 0.68 | -0.11 | -0.11 |
| Heracleum sphondylium subsp. sphondylium | -0.11 | -0.11 | -0.11 | -0.11 | 0.68 | -0.11 | -0.11 |
| Valeriana montana | -0.11 | -0.11 | -0.11 | -0.11 | 0.68 | -0.11 | -0.11 |
| Picea abies | -0.26 | -0.11 | -0.04 | 0.04 | 0.64 | -0.26 | 0.00 |
| Corallorhiza trifida | -0.12 | -0.12 | -0.12 | -0.12 | 0.62 | -0.12 | -0.02 |
| Solidago virgaurea | -0.12 | -0.12 | -0.12 | -0.12 | 0.62 | -0.12 | -0.02 |
| Deschampsia cespitosa | -0.31 | -0.03 | -0.10 | -0.03 | 0.53 | 0.25 | -0.31 |
| Leucanthemum adustum | -0.32 | -0.05 | -0.32 | -0.32 | 0.51 | 0.23 | 0.27 |

Cluster no. 6 contains only one highly diagnostic species with *Linaria alpina subsp. alpina* but another seven diagnostic species are present, among them *Carduus defloratus subsp. defloratus* with a consistency of 100% (table 3, details in the appendix). These diagnostic species are characteristic of gravel bedrock. In cluster no. 7 *Gymnadenia conopsea* and *Tofieldia calyculata* are found to be highly diagnostic with another eight diagnostic species. These indicate that the included plots are in alpine grasslands.

*Table 3: Vegetation table with highly diagnostic (darker green) and diagnostic (lighter green) species for clusters no. 6 and 7. Species that are present but not considered diagnostic are marked in yellow.*



| | **phi Value** | **phi Value** | **phi Value** | **phi Value** | **phi Value** | **phi Value** | **phi Value** |
|---|---|---|---|---|---|---|---|
| **Cluster** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| | | | | | | | |
| Linaria alpina subsp. alpina | -0.13 | -0.13 | -0.13 | -0.13 | -0.13 | 0.79 | -0.13 |
| Carduus defloratus subsp. defloratus | -0.26 | -0.11 | -0.26 | -0.26 | 0.19 | 0.64 | 0.06 |
| Polygala amarella | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | 0.55 | -0.09 |
| Asteraceae spec. | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | 0.55 | -0.09 |
| Helictotrichon versicolor | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | 0.55 | -0.09 |
| Leontodon hispidus subsp. hispidus | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | 0.55 | -0.09 |
| Pyrola minor | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | 0.55 | -0.09 |
| Polygala alpestris | -0.20 | -0.20 | -0.20 | -0.20 | 0.33 | 0.50 | -0.05 |
| Gymnadenia conopsea | -0.12 | -0.12 | -0.12 | -0.12 | -0.12 | -0.12 | 0.73 |
| Tofieldia calyculata | -0.12 | -0.12 | -0.12 | -0.12 | -0.12 | -0.12 | 0.73 |
| Dryas octopetala | -0.11 | -0.11 | -0.11 | -0.11 | -0.11 | -0.11 | 0.68 |
| Scabiosa columbaria aggr. | -0.21 | -0.21 | 0.04 | -0.21 | -0.21 | 0.13 | 0.66 |
| Gentiana campestris | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | 0.57 |
| Helianthemum nummularium | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | 0.57 |
| Oxytropis campestris subsp. campestris | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | -0.09 | 0.57 |
| Briza media | -0.16 | -0.16 | -0.16 | -0.16 | -0.16 | 0.25 | 0.54 |
| Festuca pulchella subsp. pulchella | -0.16 | -0.16 | -0.16 | 0.25 | -0.16 | -0.16 | 0.54 |
| Linum catharticum | -0.08 | -0.08 | -0.08 | -0.08 | -0.08 | -0.08 | 0.51 |

## *How do these vegetation types differ from one another comparing different parameters?*

In order to find out to what extent the individual clusters differ, various statistical tests were carried out. In some cases, significant differences were found comparing mean values of different parameters. First, the pH-value of the individual clusters was compared. The ANOVA test performed showed that there is a significant difference (p<0.001) between the pH-value. In the boxplot graph, it is noticeable that especially the pH-value of cluster no. 1 is significantly lower than those of other clusters (figure 5).

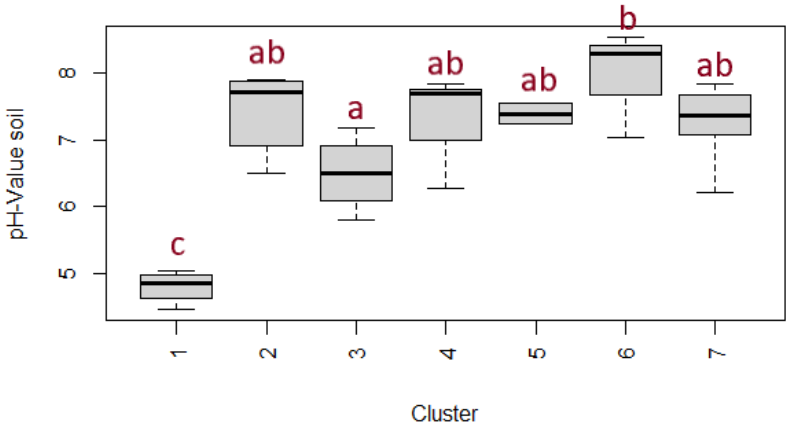


*Figure 5: Boxplot and ANOVA showing that the pH-value of cluster no. 1, containing plots of dwarfshrub heathland, differs significantly from the pH-value of other clusters.*

A significant difference could also be found comparing nutrients of the various clusters (p<0.001) with an ANOVA test. As with the pH-value, this is particularly noticeable with cluster no. 1 (figure 6).

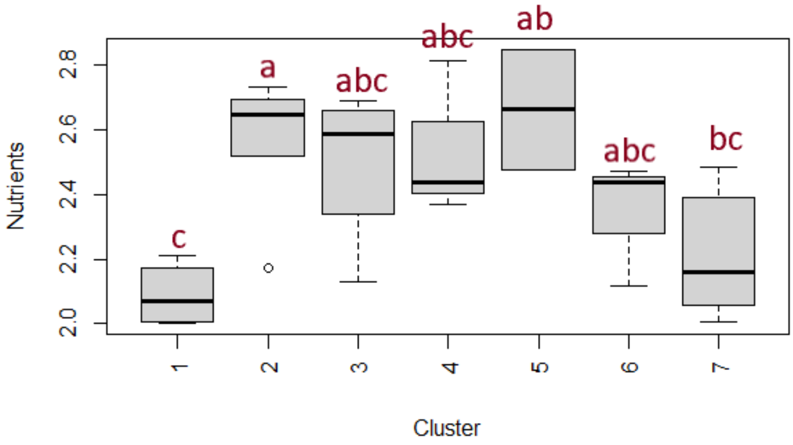


*Figure 6: Boxplot and ANOVA showing that also the nutrients of cluster no. 1, containing plots of dwarfshrub heathland, differ significantly from the those of other clusters.*

Comparing the Shannon Index of the various clusters, using an ANOVA, no evidence of any significant difference (p=0.041) could be detected. The coverage of the herb layer shows small but nevertheless significant differences between the seven clusters (p=0.003, figure 7). And there are also significant differences (p<0.001) when comparing the number of species of the various clusters as can be seen in figure 8.

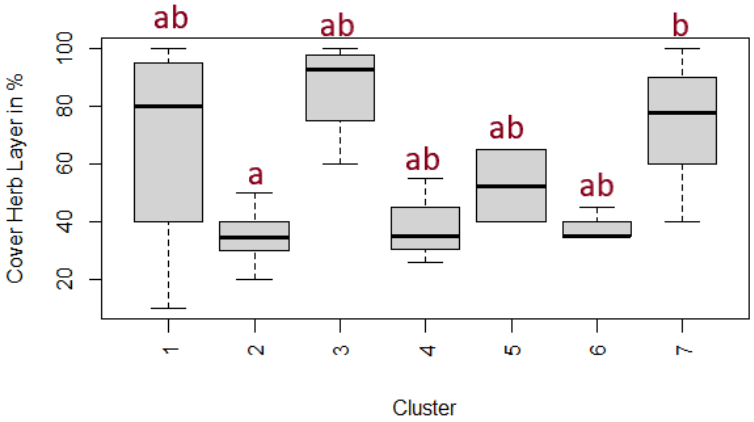


*Figure 7: Boxplot and ANOVA showing that the coverage of the herb layer of the different clusters does differ significantly.*

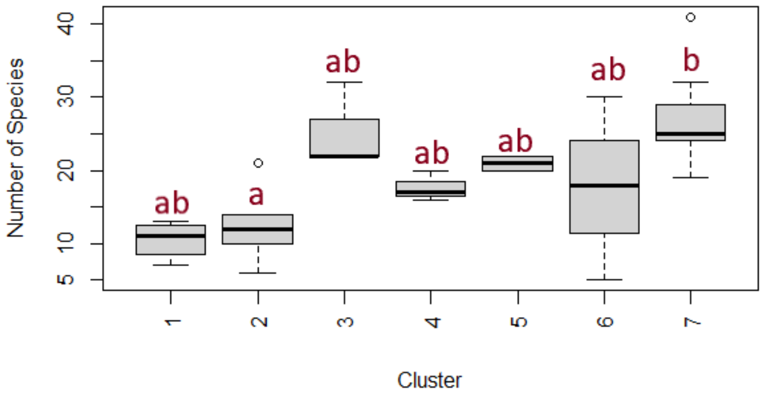


*Figure 8: Boxplot and ANOVA showing that the number of species differs significantly between different clusters.*

## Discussion

By determining the diagnostic species, each cluster could be assigned to a habitat by Delarze et al. (2015). Some vegetation types resulting from the modified TWINSPAN algorithm could be unambiguously assigned to a habitat based on the diagnostic species. However, for some clusters, the unambiguous classification into a habitat according to Delarze et al. (2015) was rather difficult. The classification will be discussed hereafter.

### *Which vegetation types do occur in the alluvial plain in Preda?*

#### Cluster no. 1: Juniperion nanae

According to Delarze et al. (2015), *Juniperion nanae* is widespread throughout the Alps. Where silicate rocks and subcontinental climate prevail, this habitat is particularly common. The authors define it by the predominance of small shrubs adapted to drought and by the presence of acidity pointers. They name *Juniperus communis subsp. nana, Arctostaphylos Uva-ursi* and *Calluna vulgaris* as diagnostic species in company with other heathers. *Juniperion nanae* grows on sunny rocky slopes of the subalpine and lower alpine levels. The plants also must withstand temperatures up to -40°C in winter, because they are often not protected by an insulating snow cover. The soil is acidic and poor in nutrients.

We could identify *Juniperus communis subsp. alpina, Vaccinium uliginosum aggr.* as well as *Vaccinium myrtillus* as highly diagnostic species for cluster no. 1 whereas *Vaccinium vitis-idaea, Pinus mugo, Calamagrostis villosa* and *Geranium sylvaticum* were diagnostic species. Cluster no. 1 could be assigned to this habitat rather clearly.

In Vegedaz, all plots included in the cluster were classified in the first rank as Mountain Coniferous Forests. When allocating habitats in Vegedaz, only the coverage of a species is considered. Whether a species is diagnostic or not does not play a role in the allocation in Vegedaz. Therefore, this may have led to a variance in comparison with our allocation.

In the Red List of Swiss habitats, Delarze et al. (2016) concluded that *Juniperion nanae* is not threatened and marked it with the Red List-status LC (Least Concern). Thus, *Juniperion nanae* does not need special attention when it comes to conservation measures in Switzerland.

### Cluster no. 2: Cardamino-Montion

Delarze et al. (2015) refer to permanently wet habitats in the immediate vicinity of low-limestone springs as *Cardamino-Montions*. These spring patches can occasionally be found along the banks of small mountain streams. The vegetation is like that of calcareous spring flats. In contrast, however, calcareous sinter crusts never occur. The soil is moist to marshy and acidic to neutral. Delarze et al. (2015) define *Saxifraga stellaris*, among others, as a species that characterizes this habitat. As the corresponding vegetation table (table 1) shows, the consistency of *Saxifraga stellaris* in cluster no. 2 is 100%. *Epilobium alsinifolium* is also common in this habitat (phi value 0.73). Based on the species and their consistency, cluster no. 2 could be identified as *Cardamino-Montion*.

A large part of the plots included in cluster no. 2 were assigned in the first rank to the *Cratoneurion* according to Vegedaz. Some diagnostic species like *Epilobium alsinifolium* occur in both habitats. Moreover, in the alluvial plain of Preda. In addition, the phi value of a species is not considered in Vegedaz, which can also lead to variance in the allocation. Furthermore, the strongly diagnostic species *Saxifraga stellaris* only occurs in *Cardamino-Montions* but not in *Cratoneurion.* For these reasons, the allocation *Cardamino-Montion* is comprehensible, although the Vegedaz evaluation has shown other results.

Delarze et al. (2016) marked the *Cardamino-Montion* with the Red List-status CR (Critically Endangered). This habitat therefore deserves special attention in nature conservation, especially in the Alps. This is because the *Cardamino-Montion* finds its optimum in the montane to alpine stage of the siliciclastic Alps (Delarze et al. 2015). At lower altitudes, this habitat occurs only occasionally and is also floristically impoverished.

### Cluster no. 3: Molinion

The *Molinion* is a particularly vulnerable habitat. Due to the intensification of agriculture or because these areas are no longer used in mountainous areas, many of the former reed meadows have already disappeared. According to Delarze et al. (2015), most of the characteristic species are threatened. Two species are considered extinct (*Viola pumila* and *Anagallis tenella*), 15 species are threatened with extinction. *Molinia caerulea* is common in wet meadows and can reach up to 1 meter in height of growth. *Molinion* grows mostly on calcareous, but sometimes superficially acidified soil. It contains a lot of organic material but is nevertheless always low in nutrients. If the soil has a higher nutrient content, the *Molinion* is replaced by the *Filipendulion* or the *Calthion*. Delarze et al. (2015) list many species that we also have identified as highly diagnostic or diagnostic in this cluster: *Molinia caerulea, Galium boreale, Sanguisorba officinalis* and *Daxtylorhiza maculata.* Cluster no. 3 could therefore be assigned rather clearly to the *Molinion*. In Vegedaz, most of the plots included in cluster no. 3 were also assigned to the *Molinion* in the first rank with a high score, which confirms our allocation.

Not surprisingly, Delarze et al. (2016) concluded that the *Molinion* in Switzerland is endangered (Red List-status EN). Further intensification of agriculture must be discouraged. Farmers should also be encouraged to continue moderate management of these valuable habitats, even when circumstances are sometimes difficult. The *Molinion* is remarkably species-rich and is home to rare plants of alternately humid sites (Delarze et al. 2015).

### Cluster no. 4: Caricion davallianae

Cluster no. 4 was very heterogeneous. With *Arabis subcoriacea* we identified a highly diagnostic species, which, however, is characteristic for the *Cratoneurion*. And *Pinguicula alpina*, which could also be identified as a highly diagnostic species, occurs in calcareous spring meadows. The proper assignment was accordingly difficult. Delarze et al. (2015) point out that a reliable habitat identification requires the identification of the dominant sedges and other sour grass species. These fens are base- and lime-rich, nutrient-poor, and are often home to many orchids. However, the assignment of cluster no. 4 to the habitat *Caricion davallianae* can be confirmed by Vegedaz. Most of the individual plots were also assigned to this habitat, but not all in the first rank. The difference in the weighting of the points between the individual ranks is rather small, which means that our allocation can still be confirmed.

According to Delarze et al. (2015) this habitat is home to several rare species and therefore needs protection, especially in the alpine regions as there the *Caricion davallianae* can still be found whereas it has vanished mostly in the lower regions of the country. In the Red List of Swiss habitats, the *Caricion davallianae* is classified as vulnerable (VU).

### Cluster no. 5: Filipendulion

According to Delarze et al. (2015), *Filipendulion* is a habitat consisting of tall, primarily dicotyledonous perennials. The vegetation occurs in striped stands along stream banks and margins of moist forests. It also extends to wet meadows that are no longer sufficiently cultivated. The soil is always moist, but not flooded for a long time. It contains many nutrients and much organic material but is less eutrophic than that of nutrient-rich wet meadows. Delarze et al. (2015) point out that the boundary with the *Calthion* is often difficult to draw. To be able to clearly determine the habitat, one is guided by the dominant species in the tall forbs' meadow. Especially for cluster no. 5, hardly any match could be found based on the diagnostic species. However, it contains only two recordings, which can explain the imprecise allocation due to too little data. Further recordings would be needed to be able to determine the habitat properly. Vegedaz allocation was not clear either. One of the plots was allocated to forest habitats whereas the other was allocated in the first rank to *Petasition paradoxi* and in the second rank to *Filipendulion. Petasition paradoxi,* however, is not an option due to insufficient debris. Thus, we remain with *Filipendulion*, but we are aware that this assignment is not entirely clear and can be objected. Delarze et al. (2016) classify this habitat as not threatened.

### Cluster no. 6: Petasition paradoxi

For cluster no. 6, only one strongly diagnostic species, *Linaria alpina subsp. alpina*, could be identified. Other diagnostic species include *Carduus defloratus subsp. defloratus* and *Leontodon hispidus subsp. hispidus*. These are characteristic of *Petasition paradoxi*. This habitat is characterized by calcareous debris and is rich in humus fine soil. The soil is mostly fresh to moist. *Petasition paradoxi* is a rather species-poor habitat, but some rare species may occur (Delarze et al. 2015). Most of the plots were allocated in the first rank to this habitat as well by Vegedaz. Thus, the classification can therefore be confirmed. Although these habitats contain some rare species, overall, they are not threatened (Delarze et al. 2015). In the Red List, the *Petasition paradoxi* is listed as a LC (Delarze et al. 2016).

### Cluster no. 7: Mountainous oligotrophic grassland

The exact assignment of this cluster to a habitat according to Delarze et al. (2015) proved to be difficult. The evaluation in Vegedaz also yielded very heterogeneous results.

Since no clear statement can be made, cluster no. 7 is assigned to the superordinate habitat mountainous oligotrophic grassland. The individual habitats from mountainous oligotrophic grasslands range from very alkaline (*Seslerion*) to neutral (*Caricion firmae*). As figure 5 illustrates, there is a large variance in pH-values in cluster no. 7. The pH-values of the individual plots range from neutral to alkaline. Thus, an exact classification of cluster no. 7 to a habitat according to Delarze et al. (2015) is not possible.

### *How do these vegetation types differ from one another comparing different parameters?*

In order to find out to what extent the individual habitats differ, various parameters were compared with one other using statistical tests. This will lead to a better understanding of the different habitats that were assigned.

The evaluations showed that especially cluster no. 1 differs significantly from the others in terms of pH-value. Cluster no. 1 is acidic, whereas the other habitats are more alkaline. According to Delarze et al. (2015), *Juniperion nanae* is characterized by acidic and nutrient-poor soil. Thus, the classification in this habitat can be validated. There is also a significant difference, with cluster no. 1 having a significantly lower nutrient value than other clusters. *Filipendulion* and *Cardamino-Montions*, on the other hand, tends to be more nutrient-rich (figure 6). Delarze et al. (2015) confirm that *Filipendulion* is a nutrient-rich habitat. For *Cardamino-Montions* no statements regarding the nutrients are made.

There are also significant differences between habitats with respect to the cover of the herb layer. Especially cluster no. 2 has a lower degree of cover than the other habitats. This confirms the assignment of cluster no. 2 to *Caramino-Montion*. This vegetation type belongs to the spring meadows that are characterized by flowing water, a factor that decreases the cover of the herb layer.

In a further test, the Shannon Index of the individual clusters was compared. The Shannon Index is used to determine the diversity of a habitat. It considers not only the number of species that occur in a habitat, but also the relative abundance of the species (Dušek & Popelková 2012). However, no significant difference could be detected. It can therefore be concluded that the individual plots did not differ in their diversity. The statistical evaluation showed that the number of species in each cluster differed significantly (figure 8). This means that clusters with a lower number of species must in turn have a higher relative abundance of the individual species.

## Conclusion

The classification by Delarze et al. (2015) is a very theoretical matter. In nature, however, habitats are influenced by many parameters, some of which are not clearly assignable. This made it sometimes difficult to clearly assign the individual clusters to a habitat according to Delarze et al. (2015). Especially for clusters that contain very little records the classification is not very representative. Nevertheless, this work provides an overview of the diversity of the floodplain landscape and the heterogeneity of the occurring habitats in this ecosystem. Considering that some of the habitats studied are endangered, hopefully this will be a reason for those responsible for Parc Ela to protect them or, if necessary, to restore them as far as possible.

The subsequent comparison of the different parameters revealed differences between the habitats, such as the pH-value or the number of species. But it only offers a small glimpse of the differences of the investigated habitats. The parameters listed above are only a selection of possible results. Various other parameters could be compared in future studies, which would help to distinguish the habitats more clearly from one another. However, this would have gone beyond the scope of this paper.

Furthermore, some parameters, e.g. soil depth, could not be examined in more detail because these values were not recorded for all plots. For this reason, it is important that the same method is used for further recordings so that the results can be compared.

In order to be able to distinguish the habitats more clearly and to make further statements about how they differ, it is important to collect more data in the same area in years to come. Thus, over time, a very detailed study of the diversity of the different habitats occurring in the alluvial plain in Preda can be conducted.

## References

Delarze, R. et al. (2015) Lebensräume der Schweiz. Ökologie.Gefährdung.Kennarten. Hep Verlag AG, Bern.

Delarze, R. et al. (2016) Rote Liste Lebensräume. Gefährdete Lebensräume der Schweiz 2016. Schweizerisches Zentrum für die Kartografie der Fauna (Info Fauna), Neuchâtel; Bureau d'études biologiques (BEB SA), Aigle; Info Flora, Geneva.

Dušek, R. & Popelková, R. (2012) Theoretical View of the Shannon Index in the Evaluation of Landscape Diversity. AUC Geographica, **47/2**, 5-13.

Eggenberg, S. et al. (2020) Flora Vegetativa. Haupt, Bern.

FOEN (ed.) (2017) Biodiversity in Switzerland. Status and Trends. Federal Office for the Environment, Bern.

FOEN (ed.) (2018) Biodiversity: In brief.

URL: https://www.bafu.admin.ch/bafu/en/home/topics/biodiversity/in-brief.html

(accessed: 17 September 2021)

FOEN (ed.) (2020) Zustand der Lebensräume in der Schweiz.

URL: https://www.bafu.admin.ch/bafu/de/home/themen/thema-biodiversitaet/biodiversitaet--fachinformationen/zustand-der-biodiversitaet-in-der-schweiz/zustand-der-lebensraeume-in-der-schweiz.html (accessed: 17 September 2021)

Fischer, M. et al. (2015) Zustand der Biodiversität in der Schweiz 2014. Die Analyse der Wissenschaft. Forum Biodiversität Schweiz der Akademie der Akademie der Naturwissenschaften Schweiz (SCNAT), Bern.

Guntern, J. et al. (2013) Flächenbedarf für die Erhaltung der Biodiversität und der Ökosystemleistungen in der Schweiz. Forum Biodiversität Schweiz der Akademie der Naturwissenschaften Schweiz (SCNAT), Bern.

Haupt (ed.) (2021) Flora Helvetica – Die App. Version 2.3.2. URL: https://www.flora-helvetica.ch/app (accessed: 18 September 2021)

Hochreutener, A. et al. (2019) Plant biodiversity in an alluvial plain in Preda in the Swiss Alps: A modelling approach to determine driving factors influencing species richness. Report from the International Master Summer School "Biodiversity Monitoring", Preda, Parc Ela, Switzerland, 14-25 August 2019 (ed. J. Dengler), pp. 60-76. Zurich University of Applied Sciences, Wädenswil.

Info Flora (ed.) (2021a) Checklist & Synonymieindex. URL: https://www.infoflora.ch/de/flora/taxonomie/checklist.html (accessed: 18 September 2021)

Info Flora (ed.) (2021b) FlorApp. Version 2.8. URL: https://www.infoflora.ch/de/mitmachen/daten-melden/app/florapp.html (accessed: 18 September 2021)

Krüsi, B.O. & Widmer, S. (2021) Anleitung VEGEDAZ. Zurich University of Applied Sciences, Wädenswil.

Lachat, T. et al. (eds.) (2010) Wandel der Biodiversität in der Schweiz seit 1900. Ist die Talsohle erreicht? Haupt, Bern.

Lauber, K. & Wagner, G. (2009) Flora Helvetica. Haupt, Bern.

Ludwig, J. (2012) Infoblatt Sedimentgesteine. URL: https://www.klett.de/alias/1011542 (accessed: 17 September 2021)

Masaryk University (ed.) (2021) Juice version 7.1. Version 7.1. URL: https://www.sci.muni.cz/botany/juice/ (accessed: 18 September 2021)

MeteoSwiss (ed.) (2021) Annual course series for temperature-sunshine-precipitation. URL: https://www.meteoswiss.admin.ch/home/climate/the-climate-of-switzerland/annual-course-series-for-temperature-sunshine-precipitation.html (accessed: 18 September 2021)

Parc Ela (ed.) (2021) Der Parc Ela in Zahlen. URL: https://www.parc-ela.ch/de/naturpark/gebiet/zahlen (accessed: 18 September 2021)

R Foundation (ed.) (2021) The R Project for Statistical Computing. Version 4.0.2. URL: https://www.r-project.org/ (accessed: 18 September 2021)

RStudio (ed.) (2021) How we think about Data Science. Version 1.4.1717. URL: https://www.rstudio.com/products/rstudio/download/ (accessed: 18 September 2021)

Roleček et al. (2009) Modified TWINSPAN classification in which the hierarchy represents cluster heterogeneity. Journal of Vegetation Science, **20**, 596-602.

Seiler, H.F. (2021) Regionale Typologie der Quellfluren im Parc Ela (Graubünden, Schweiz). BSc thesis, Zurich University of Applied Sciences, Wädenswil.

WWF (ed.) (2007) Lebensraum Aue: Dynamik ist alles! WWF Schweiz, Zurich. URL: https://www.wwf.ch/sites/default/files/doc-2017-07/2007-05-factsheet-riverwatch-flussauen_tdi.pdf, (accessed: 17 September 2021)

WSL (ed.) (2021) Vegedaz. URL: https://www.wsl.ch/de/services-und-produkte/software-websites-und-apps/vegedaz.html (accessed: 18 September 2021)

# Drivers of Orthoptera species richness and abundance in an altitudinal transect in Preda, Parc Ela, Switzerland

*Miro Bergauer, Igor Siedlecki, & Sharon Woolsey*

## Abstract

Species richness of fauna and flora decreases with increasing altitude particularly because of the reduction in temperature and habitat availability, with patterns often varying for different geographical regions. This project investigates species richness and abundance of Orthoptera along an altitudinal gradient in Preda in the Swiss Alps and examines their possible drivers. Twenty 10 m x 10 m open quadrats were exhaustively surveyed for Orthoptera from 1705 m to 2592 m.a.sl. at approximately 100 m altitude increments. For all plots: land use, elevation, aspect, inclination range, vegetation type, pH and flowing water presence were recorded. A total of 12 Orthoptera species were found in the Preda altitudinal transect. Elevation had a significant negative effect on Orthoptera species richness (p=0.00761), but not on their abundance. The species richness peak occurred at the lowest altitudes surveyed. Orthoptera abundance was driven by the parameter 'vegetation type', with the highest abundance found in subalpine pastures, dry meadows and wet meadows. Only *Miramella alpina* (Kollar, 1833*)* and *Gomphocerus sibiricus* (Linnaeus, 1767) were found on plots above 2000 m.a.sl. A deeper understanding of drivers of species richness and abundance of Orthoptera may play an important role in future assessments of global changes.

*Keywords : alpine, altitude transect, driver, elevation, grasshoppers, Orthoptera, Parc Ela, species richness, subalpine, Swiss Alps.*

## Introduction

With increasing altitude, the availability of land for colonisation by fauna and flora decreases and becomes an important determinant of biodiversity. Other important altitude-related changes include the reduction in atmospheric pressure and the intensification of solar radiation. The main environmental factor responsible for altitudinal changes in biodiversity, however, is the decrease in air temperature, which in turn affects numerous secondary environmental variables (Körner, 2007).

Several studies show that species richness of different taxa declines monotonically with increasing elevation (either immediately or following a horizontal phase), while an equal number supports a hump-shaped relationship with a mid-elevational peak (Rahbek 1995). Species richness of vascular plants, for example, rises with elevation and reaches a diversity peak at an intermediate altitude, but declines thereafter at higher altitudes. This relationship results from interactions between a declining species pool and less intense competition at higher altitudes (Bruun et al. 2006).

The effect of altitude on species richness of herbivorous insects, which are highly dependent on vegetation for habitat and food, appears to be less clear. Some studies provide evidence of mid-elevational peaks, while others build a case for peaks occurring at either the lowest or the highest elevation (McCoy 1990). Older studies suggest the reduction of habitat area, resource diversity and primary productivity to be the main factors driving species richness of insects at higher altitudes (Lawton et al. 1987). Janzen (1973) observed highest insect density at intermediate elevation and similarly suggests its relation to prevailing high photosynthetic rates and associated primary production, resulting in plentiful food resources for herbivorous insects. For the insect order Orthoptera, the three possible diversity patterns with peaks at either low, intermediate or high elevation have not been sufficiently investigated, in particular for different geographic regions (Sirin et al. 2010).

This study is concerned with the effects of altitude on species richness of Orthoptera. Orthoptera are the principal arthropod consumers in grasslands and therefore make up a large part of the food source for higher trophic levels (Fartmann et al. 2012). The order includes grasshoppers, crickets, katydids (bush crickets) and locusts. The expression 'grasshopper' is often used interchangeably with 'Orthoptera', which is not entirely correct. However, as all but one of the species encountered in this study belonged to the grasshopper group, we likewise use the two expressions interchangeably. Grasshoppers influence nutrient cycling and primary production in grasslands by affecting nitrogen availability and consequently annual plant production (Belovsky & Slade 2018). They are closely associated with vegetation throughout their life-cycle (Clarke 1948). Being generalist eaters, they are not bound to specific host plants for their nutrition (Wettstein & Schmid 1999).

While Orthoptera are common grassland insects, the niches of individual species are not identical. Different Orthoptera species differ in their habitat and environmental requirements (Clarke 1948; Baur et al. 2006). For example, *Tettigonia viridissima* prefers warm and rather dry open lowland habitats, *T. cantans* more humid and cooler habitats, and *T. caudata* more bushy areas (Wagner 2021).

Although much is known about the general habitat requirements of Orthoptera, less information is available on which factors become the driving forces of orthopteran distribution at increasing altitude. With so many potential factors influencing site-specific habitat quality, the object of this study is to determine which factors drive orthoptera species richness and abundance along an altitudinal gradient from subalpine to alpine sites in Preda, Parc Ela. More specifically, we aim to address the following questions:

- Does altitude affect species richness and individual abundance of Orthoptera in Preda? Can other driving factors be determined?
- How do individual species respond to potential drivers? Do they show habitat preferences?

## Methods

### *Study area*

The study region was located in Preda which belongs to the municipality of Bergün, canton Grisons, in Switzerland. Preda lies within Parc Ela, a regional nature park. The altitudinal transect extended from 1705 to 2592 m above sea level. Bergün is still considered a part of the northern Alps even though the central alpine valleys of the Engadina are less than 20 km away. The climate in the northern Alps is cold and temperate. Precipitation is high, even during the driest month. An average annual temperature of 0.5 °C is reached in Bergün and there is 1451 mm of precipitation within a year (climate-data.org 2021). The southern side of the valley is dominated by silicate rocks, while the northern side consists mainly of limestone (Swisstopo 2021).

## *Field sampling*

Sampling was carried out in permanent plots located on an elevational transect starting close to the village of Preda (46.5898°N, 9.7778°E) and going up inside the 'Val Mulix' (see Figure 1). A total of 20 10 m x 10 m open quadrat plots were sampled for Orthoptera in the study area. They consisted of the 13 permanent plots established by the Summer School in 2019, with three additional Orthoptera plots sampled in 2019 (same elevation as their permanent plot counterpart but placed in grassland instead of forest) and four new Orthoptera plots added by our Summer School in 2021. The plots had a difference of approximately 100 m in elevation between each other. Exceptions were the additional Orthoptera plots (OP0 to 6) which were either placed at the same elevation as a permanent plot or in different habitats in the lower valley. Two plots deserve a special mention, as they were selected to represent south-facing slopes to the East of Preda's railway station where a higher number of species and individuals was expected (OP05 and OP06). Permanent plots were always sampled for Orthoptera before the vegetation survey, to prevent Orthoptera from being chased out of the plots and thereby escaping before being identified and counted. In the remaining seven Orthoptera plots added in 2019 and 2021, vegetation was not surveyed.

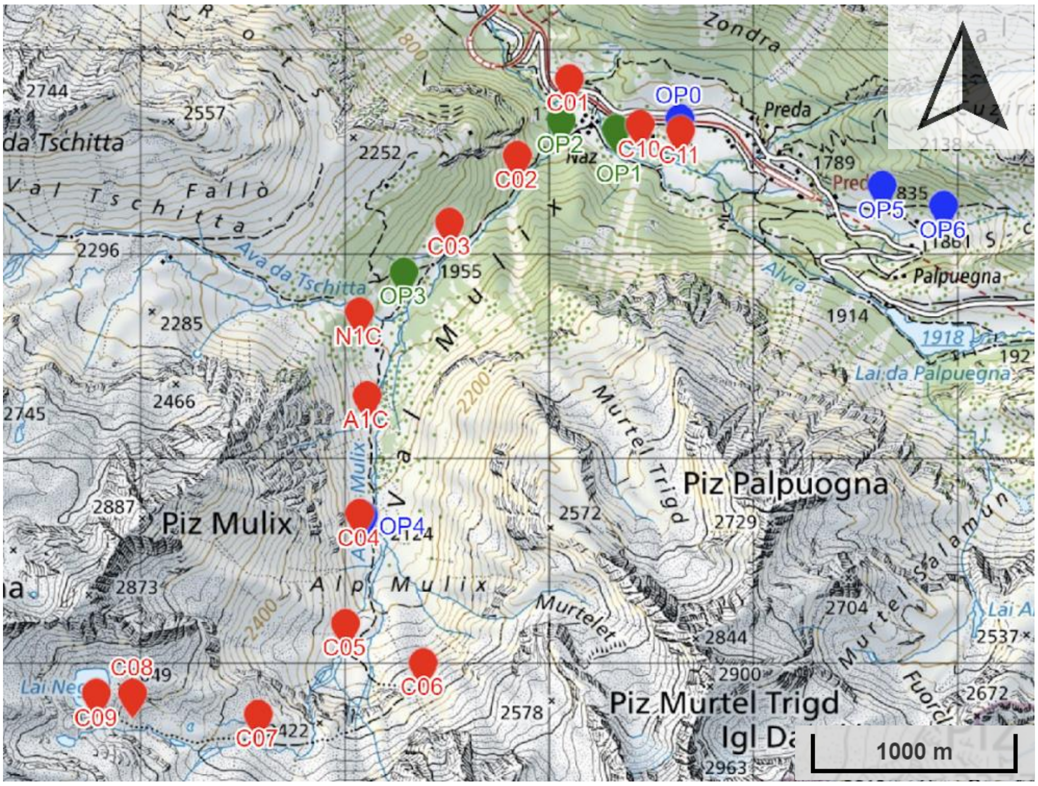


*Figure 1: Map of the study site near Preda (CH). The plots were categorized as: a) Permanent plots of the elevational transect (red), b) Orthoptera plots (OP) which were: either sampled only in 2021 (blue) or c) sampled both in 2019 and 2021 (green).*

Orthoptera sampling should ideally take place in dry and warm weather between 9 a.m. and 5 p.m. (Hilpold et al. 2020). We were fortunate during our field work that weather conditions were ideal and consistent. Methods for assessing the abundance of Orthoptera have been comprehensively evaluated for their suitability and efficiency in the field. Suggested methods include sweep netting, transects, open quadrats, pitfall traps, ring counts, box quadrats, timed counts and night trapping (Gardiner et al. 2005). Sweep netting is the method most commonly used in the field because of its low effort and high speed (Gardiner et al. 2005). We found that successful sweep netting required a certain amount of practice and experience which we lacked. Our procedure was therefore as follows: We laid out a 50 m measuring tape along the sides of the plot to mark its boundaries, taking care not to disturb the vegetation within, so as not to chase away any individuals. We then positioned ourselves along the same side of the plot to be sampled and slowly moved to its opposite side, all the while disturbing the vegetation with poles and boots in our assigned column. Grasshoppers usually leap away upon disturbance (Clarke 1948). Disturbed individuals were easy to locate when jumping and were captured using small plastic containers. This method of flushing worked well for the vegetation height in our 20 plots, but may not be suitable where vegetation height is over 50 cm. After all field workers had reached the opposite side of the plot, we spread out to randomly walk through the vegetation a second time to locate any escaped individuals. A total time of approximately 15 minutes was spent on search and capture. However, some plots with a particularly high number of individuals required more sampling time of up to 30 minutes.

Once we had concluded the capture phase, we sorted individuals into morphotypes and subsequently identified and counted them on site with the help of our supervisor and the identification keys supplied in Baur et al. (2006) (Figure 2). As additional information we recorded sex (male, female), life stage (adult, nymph) and - when considered relevant - colour morphotype (brown, green). Individuals that could not be identified on site using a hand lens were transported back to the group house in Preda for later identification using a binocular microscope. After identification, all individuals were released at approximately the same place where they had been captured.

*Figure 2: On site morphotypes sorting and Orthoptera identification.*

Besides Orthoptera sampling, we recorded the following parameters which we considered to be potential drivers of species richness and abundance of Orthoptera for each plot: land use (none/grazing/mowing), elevation, aspect, inclination range, vegetation type, pH, forest and flowing water presence. These are thought to be parameters that have an impact on the orthopteran life-cycle. Climate parameters were not measured because they can be expected to be equal for all the sampled plots. Most of the parameters were recorded through observation in the field, elevation and aspect information was taken from data available on the website map.geo.admin.ch, pH for permanent plots was assigned from data generated during the Summer School in 2019 and for Orthoptera plots it was measured using a multi-parameter probe (HANNA instruments HI 12883, Woonsocket, Rhode Island, USA). For further statistical analyses, we used the *southing* parameter as a component of aspect, i.e. –cos (aspect), ranging from –1 on northern to +1 on southern slopes.

### *Statistical analyses*

All statistical analyses were performed in the open source program R (R Core Team 2021). In a first step, we checked whether plots with the vegetation type 'forest' had a significantly lower species richness than the other plots. Because many Orthoptera species are limited to grass- or shrubland, we expected a low species richness in forest plots which would bias our data in further analyses. We found a highly significant difference (paired t-test, p-value = 0,007) between forest and non-forest. As a consequence, we excluded all forest plots (C01, C02, C03, C11, N1C) from further analysis.

We tested for multicollinearity by applying a correlation matrix for all numerical predictors. The parameters 'elevation' and 'pH' showed a significant correlation (Pearson's $|r|$=0.6). Therefore, we decided to keep both parameters in the model because both were considered ecologically important for Orthoptera occurrence and correlation was < 0.7. In our final selection of predictors, we had seven predictors: land use, elevation, southing, inclination range, vegetation type, pH and flowing water presence. These were used to create two generalized linear models with Poisson distribution using species richness and the abundance of individuals as response variables. We calculated a multi-model inference in multiple regressions using the MuMIn package (Bartoń 2020). The importance factor (i.e. the sum of Akaike weights over all possible models) of each predictor was used to assess the strongest predictors for either species richness or abundance. Then, the number of predictors was limited to three, to prevent overfitting due to a low sample size (n=15) (Crawley 2014). In the last step, we calculated again the multi-model inference for two models using only the three strongest predictors and created a final model average. We finally tested for spatial autocorrelation in both models.

In addition, we focussed on the variable 'vegetation type' because data suggested a strong correlation with Orthoptera abundance. We tested for differences in Orthoptera abundance in each vegetation type by performing a Kruskal-Wallis-test followed by a Post-Hoc-test because the data did not follow normal distribution. We also checked if the species richness was significantly different between years (i.e. 2019 and 2021). In a first step, we looked at the species richness per year as a boxplot to visually see the difference in mean species richness. Then we checked whether there was a significant effect by doing a GLM using Poisson distribution and with 'year' as the only predictor for species richness.

To analyze our data at species level, we decided to predict the individual abundance of the four most common species (i.e. *Omocestus viridulus, Pseudochorthippus parallelus, Metrioptera brachyptera and Miramella alpina)*. We selected three predictors to be relevant for individual abundance on species level: Elevation, southing and vegetation type. Similar to the model for species richness (see above), we calculated the multi-model inference of a GLM using Poisson distribution and model averaging to get a final model for each of the four species. The effect of elevation and vegetation type were visualized by plotting the partial residuals of one predictor while other variables were set to their mean.

## Results

In 2021 we sampled 20 plots finding a total of 12 Orthoptera species (Appendices 1, 2). Ten of these species belonged to the family Acrididae (short-horned grasshoppers), while the remaining two were each a representative of the families Tettigoniidae (katydids) and Tetrigidae (pygmy grasshoppers). One additional species (*Stauroderus scalaris*) from the family Acrididae was found only outside of the sampled plots. The species richness ranged from a minimum of zero to a maximum of seven and had a mean of 2.55 Orthoptera species per plot. The individual abundance ranged from a minimum of zero to a maximum of 69 with a mean of 20.7 Orthoptera individuals per plot. In our survey commonly occurred four

Orthoptera species: *Miramella alpina, Metrioptera brachyptera, Omocestus viridulu*s, *Pseudochorthippus parallelus* (Figure 3). Due to low species richness and abundance in forest habitats, we excluded the five forest plots from further analysis (see chap. 3: Methods) which resulted in 15 plots and a higher mean species richness (mean=3) as well as mean individual abundance (mean= 28.2) in open habitats.

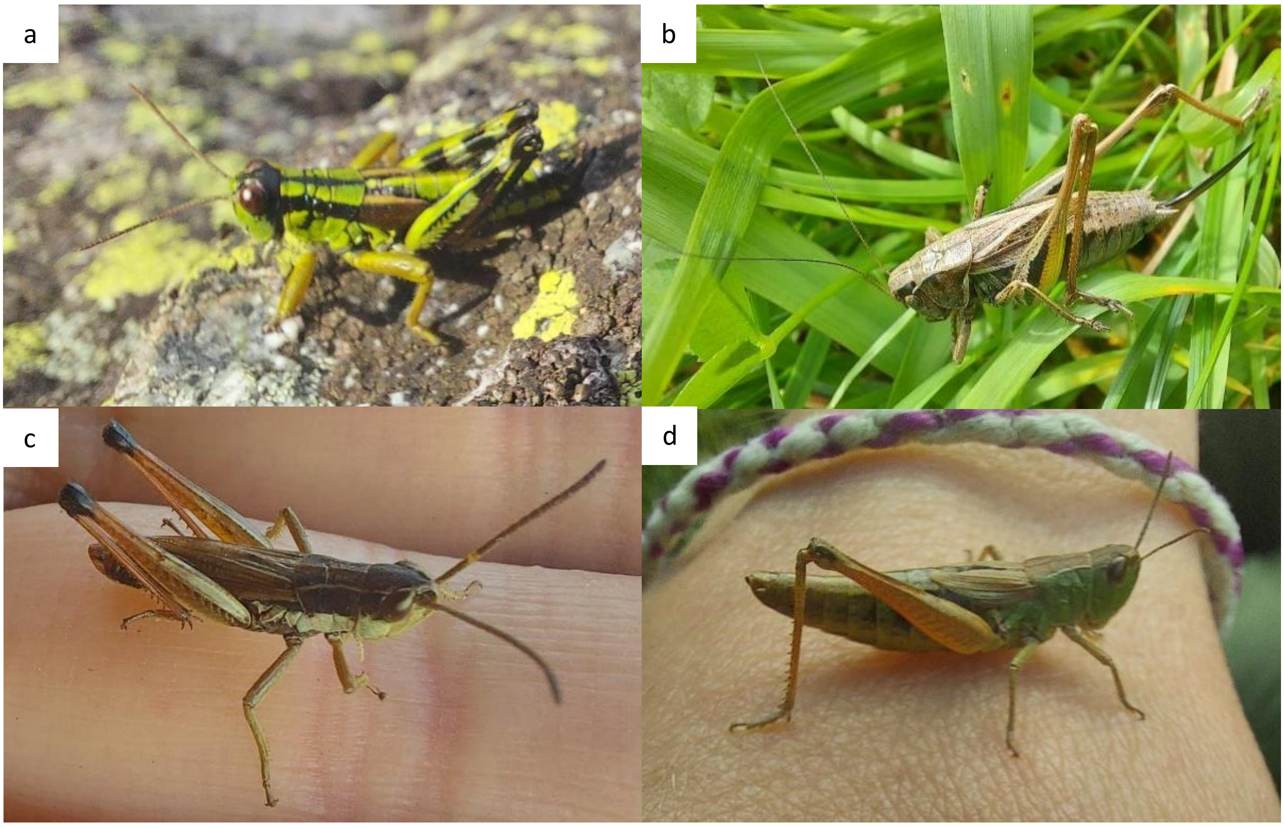


*Figure 3: Photos representing the four most common species in our survey: a - Miramella alpina, b - Metrioptera brachyptera, c - Omocestus viridulus, d - Pseudochorthippus parallelus. Photos by P. Tykarski.*

### *Drivers of Orthoptera species richness and individual abundance*

Orthoptera species richness was influenced by these three measured predictors: elevation, pH and flowing water presence (Table 1). The model showed a significant negative effect of elevation on species richness (GLM, family=Poisson, p = 0.00761 **) but no significant effect of the other two predictors (Figure 4). The individual abundance was strongly influenced by vegetation type, pH and flowing water presence (Table 1). Elevation had a minor effect on abundance and was therefore excluded from the model. The vegetation type 'alpine grassland' was significantly different from 'wet meadow', 'dry meadow' and 'subalpine pastures' which had a higher individual abundance (Figure 4). The highest individual abundance was observed in subalpine pastures, followed by dry and wet meadows. The vegetation types limited to high elevations (i.e. heathland and alpine grassland) had a lower abundance of individuals as well as a lower species richness. There was no significant difference in mean species richness or mean individual abundance between the 2019 and 2021 surveys.

*Table 1: Importance factors of predictors for GLM predicting species richness and abundance. Elevation was only present in the richness model and vegetation type was only present in the abundance model.*

| | species richness | abundance |
|---|---|---|
| elevation | 0.99 | |
| pH | 0.28 | 1 |
| flowing water pres. | 0.24 | 0.97 |
| vegetation type | | 1 |

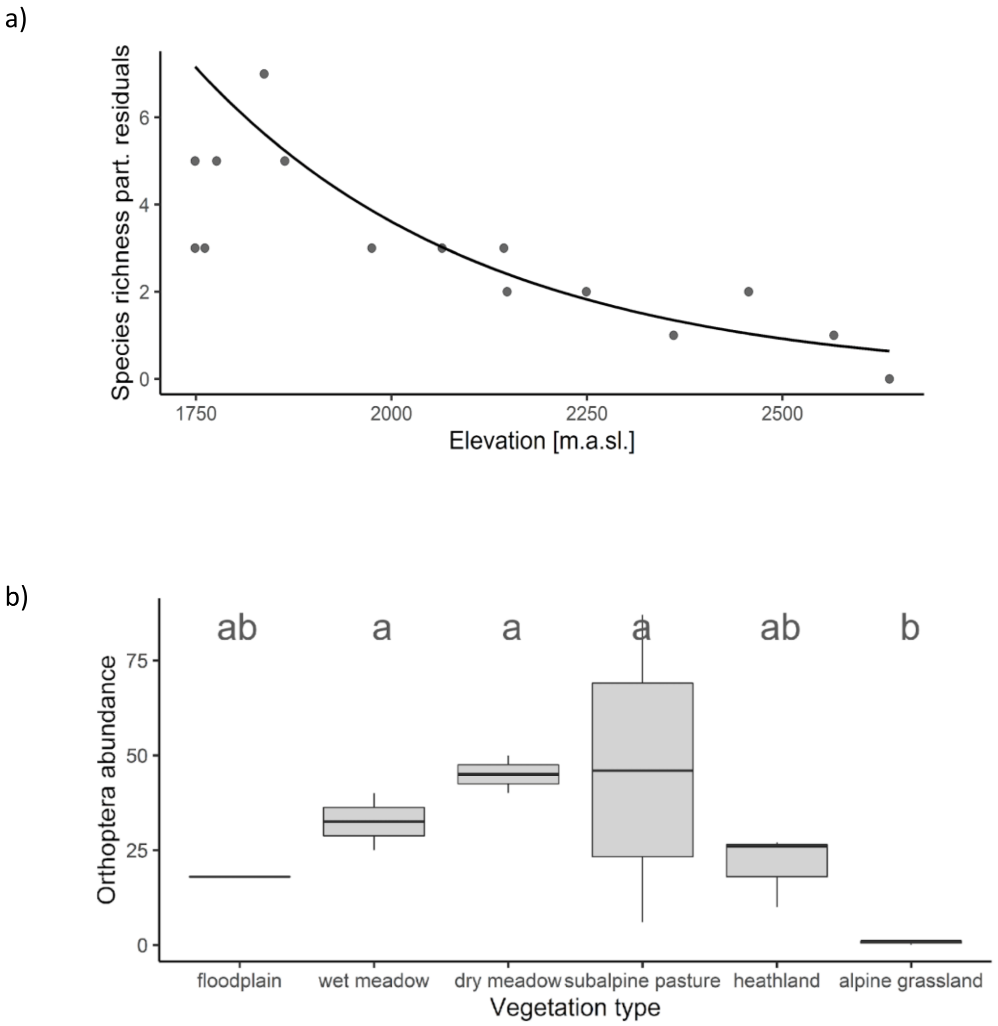


*Figure 4: a) The effect of elevation on species richness. Shown are the partial residuals from the generalized linear model (GLM). b) The distribution of Orthoptera abundance per vegetation type. Vegetation types with the same letter are not significantly different (Kruskal-Wallis test + Post-Hoc Analysis).*

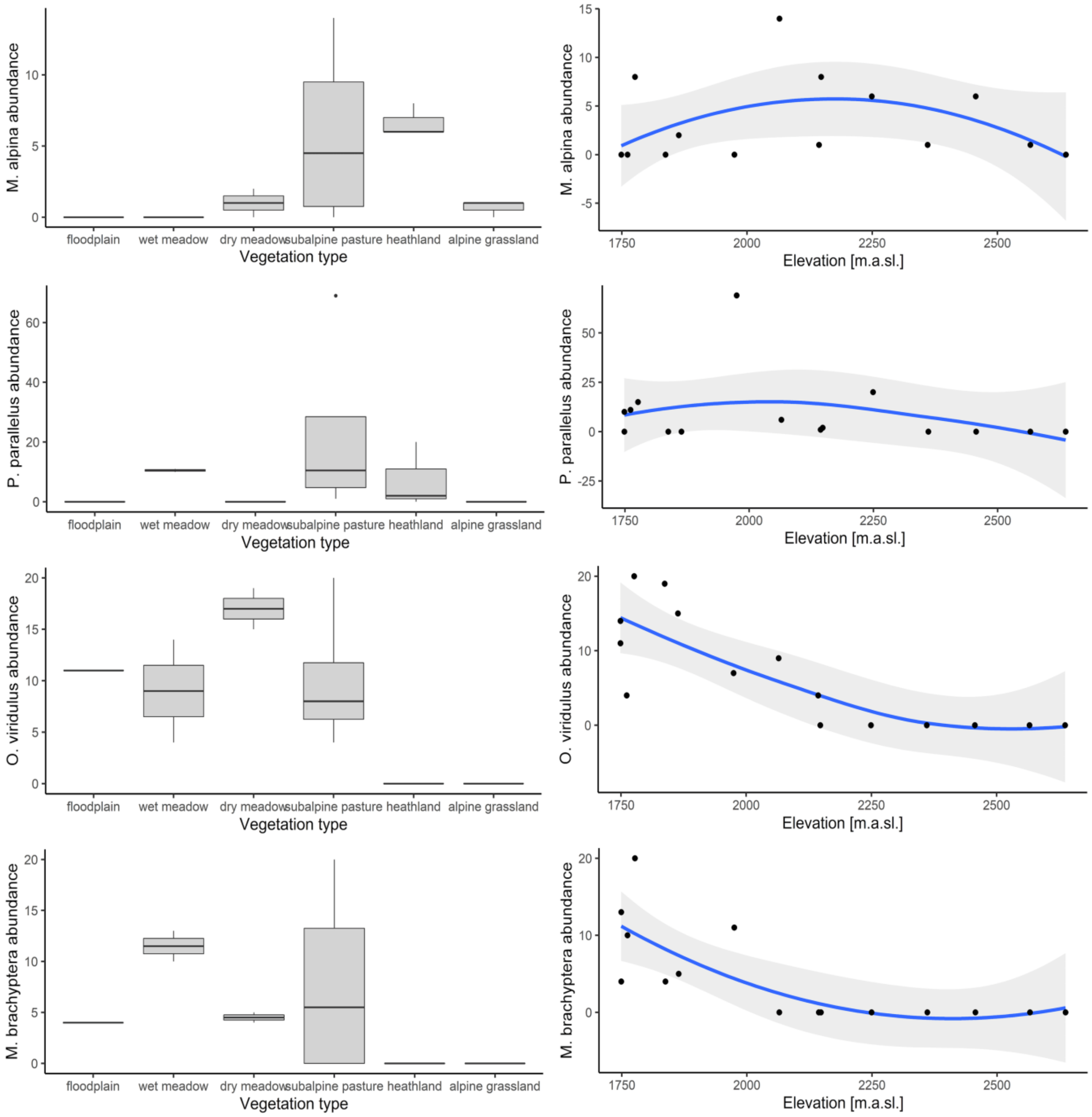
### *Drivers of individual Orthoptera species*

The four most common Orthoptera species in our survey were affected differently by the measured drivers (Table 2 and Figure 5). *M. alpina* showed no significant relation to elevation because it occurred from relatively low to high altitude. However, our model showed that *M. alpina* was highly influenced by the vegetation types 'subalpine pastures' and 'heathland'. In contrast, *P. parallelus* was highly affected by elevation and southing but occurred on most of the vegetation types. Similarly, *M. brachyptera* was only affected by elevation, which is linked to vegetation types of lower elevation. Unlike *P. parallelus, M. brachyptera* was not affected by southing. *O. viridulus* had no significant predictors. Although it was not significant, elevation had some negative effect on the occurrence of *O. viridulus.* Similar statistical analysis on other species was not possible, because they were only found in one plot.

*Table 2: Drivers of individual abundance at species level. Shown are solely the significant p-values of predictor variables of the generalized linear model (GLM).*

| | *Miramella alpina* | *Pseudochorthippus parallelus* | *Metrioptera brachyptera* | *Omocestus viridulus* |
|---|---|---|---|---|
| Vegetation type: Heathland | 0.00842 ** | | | |
| Vegetation type: subalpine pasture | 0.01356 * | | | |
| Elevation | | 0.0001 *** | 8.4e-06 *** | 0.097 · |
| Southing | | 0.0002 *** | | |

*Figure 5: Visualisation of individual abundance per vegetation type and elevation. Listed are the four common Orthoptera species. The regression of individual abundance and elevation (blue line) is not based on the model but on a local regression (LOESS).*



## Discussion

Out of the 25 species known to be present in the Bergün municipality (Info Fauna 2021), we found only 13 (52%). This can be explained by the fact that we only surveyed 20 designated plots along a delimited altitudinal gradient, only once in the season and did not conduct an exhaustive survey of the entire area. Even so, our species richness might appear rather low at first, especially compared to studies such as Marini et al. (2008) who recorded 49 Orthoptera species on hay meadows in the Italian Alps of the Trento Province. However, their sites were located between 601 m.a.sl and 1273 m.a.sl. and therefore at much lower altitudes than ours (1705 to 2592 m.a.sl). Similarly, the species number of 19 reported for a study in pre-alpine Bavaria was for low to intermediate altitudes (between 800 and 1350 m.a.sl.) (Löffler & Fartmann 2017). However, studies at higher altitudes show species richness similar to ours: e.g., nine species in the Swiss National Park at altitudes between 1350 and 3170 m.a.sl. (Spalinger et al. 2012), and five and three species in the Turkish Akdaglar mountains at altitudes of 2120 m.a.sl. and 2570 m.a.sl., respectively (Sirin et al. 2010). In our survey we lack some of the larger, more low-land, southern European or carnivorous species such as *Tettigonia viridissima* or *Barbitistes serricauda* (Baur et al., 2006), which strengthens the suggestion that the minimal elevation in our study (1705 m.a.sl.) was already too high for many orthopteran species to occur.

### *Drivers of Orthoptera species richness and individual abundance*

Our results show that altitude has a significant negative effect on species richness of Orthoptera, but does not significantly affect abundance. Wettstein & Schmid (1999) similarly report a decrease in species richness with increasing altitude, although their sites were located at lower altitudes between 800 and 1400 m.a.sl. However, the negative effect of altitude on species richness can also be found at altitudes similar to ours, e.g. in the Turkish Akdaglar mountains (Sirin et al. 2010). Here both species richness and abundance were lower at 2120 and 2570 m.a.sl. than at 1460 and 1860 m.a.sl. However, the two studies are not directly comparable because of e.g. differences in the climatic zone. It is unlikely for species richness to be determined by one factor alone. When studying biodiversity at increasing altitude, field sites will additionally be characterised by distinctive regional particularities which may interact with the factor 'elevation' (Körner, 2007). With regard to abundance, it is possible that our sample size was too small to reliably determine whether altitude has any effect on Orthoptera in Preda. However, high numbers of individuals observed in our study for some high elevation plots (e.g OP03), could be a result of lower competition or lower predation stress (McCoy 1990). More data generated on this matter, especially with the increase of surveyed plot numbers, could answer if altitude affects Orthoptera abundance in the studied area.

As our transect only started at an intermediate altitude of 1705 m.a.sl. and its altitude range is therefore insufficiently wide, we are unable to draw a general conclusion on the position of a species richness peak. The conclusion specific to our data, however, is that maximum species richness occurs at the lowest altitudes surveyed and decreases thereafter. In comparison, the study in the Akdaglar mountains showed highest grasshopper diversity and abundance at intermediate altitudes (1460 and 1680 m.a.sl.) (Sirin et al. 2010). We recommend subsequent summer schools to survey additional sites at lower altitudes This way, it may be possible to determine whether Orthoptera species richness in the Swiss Alps also follows a hump-shaped pattern with a mid-elevational peak, as has been suggested e.g. for vegetation (Bruun et al. 2006). Additionally, we observed the highest species richness in the Orthoptera plots on the lower south-facing slopes of Val Zavretta (OP05 and OP06). A future addition of plots located at higher elevations on these slopes could nicely complement the existing data set and perhaps allow for a more general inference regarding Orthoptera species richness in this valley.

We established that Orthoptera abundance in Preda is primarily driven by vegetation type. Both older and newer studies agree that species richness and abundance of Orthoptera depend not only on climate, but also on habitat quality (Clarke 1948; Lightfoot 2018). Key factors which shape Orthoptera habitat quality are vegetation height, biomass, physical structure and sward length (Gardiner et al. 2002; Gardiner & Dover 2008; Fartmann et al. 2012; Schirmel et al. 2019). Other studies also emphasise the importance of the habitat's microclimate (Szövenyi 2002; Löffler & Fartmann 2017). In our study, Orthoptera were most abundant in vegetation types 'subalpine pasture', 'wet meadow' and 'dry meadow' and least abundant on 'alpine grassland' at highest altitudes. The three preferred vegetation types of Orthoptera are characterised by high primary production, extensive management and high amount of grasses. 'Alpine grassland' is a vegetation type limited to high elevations. Therefore, the primary production is lower and the vegetation period shorter than in lower vegetation types such as 'subalpine grassland'. Torma & Bozsó (2016) suggest that it is the amount of available grassland and the landscape structure which is crucial to Orthoptera communities and not so much the soil moisture or the diversity of the vegetation.

For the 13 permanent plots some of the above key vegetation parameters were recorded (such as soil depth and vegetation height). Unfortunately, we did not record them for the seven additional Orthoptera plots. We recommend future summer schools to consistently measure vegetation parameters in all plots in order to determine more specific drivers for Orthoptera species richness and abundance.

Both vegetation structure and microclimate are strongly related to land use (Fartmann et al. 2012). For example, species density is greater at grazed sites than at mowed sites (Wettstein & Schmid 1999; Gardiner et al. 2002) and abundance is lower in agricultural habitats than in heathland sites (Gardiner et al. 2002). In our study area we had mostly grazed sites and only the 'dry meadows' were mown. We did not observe differences in species richness or Orthoptera abundance between grazed and mowed sites.

We observed that both Orthoptera species richness and abundance were low to zero in forest habitats. We could assume that grasshoppers are not present in subalpine forests in the studied area. However, Orthoptera species living in forest habitats are usually mainly present in the shrub layer and not in the herb layer, which was the main focus of our study. In order to capture them, the sampling methods would require adaptation. It is advisable to focus on sound when sampling Orthoptera living in forest habitats because they are difficult to detect physically. In contrast, on grassland habitats, all Orthoptera live in the herb layer and physical catching is easier.

### *Drivers of individual Orthoptera species*

Our results show that elevation is the strongest predictor for species richness of Orthoptera, suggesting that several species have altitudinal limits. Due to limited sampling size, we can only rely on our four most common species to draw conclusions. Above an elevation of 2000 m.a.sl. the abundance of *O. viridulus* and *M. brachyptera* is close to 0. Only *M. alpina* and *G. sibiricus* are able to survive at high elevations. However, *M. alpina* is also present at our lower sites, but does not generally occur in the Swiss lowlands. *M. alpina* shows a unimodal relationship with elevation. These findings suggest that it prefers habitats occurring at an elevation between 1500 and 2500 m.a.sl.

Three orthoptera species occurred only on one plot (*Stetophyma grossum, Gomphocerus sibiricus, Psophus stridulus).* This is most probably due to the specific habitat requirements of these species (Baur et al., 2006): Wet meadows or wet areas close to flowing water (*Stetophyma grossum),* alpine pastures with high stone cover and heathland (*Gomphocerus sibiricus*), dry meadows or pastures with high temperature and high sun exposure (*Psophus stridulus*).

We found the species *Psophus stridulus* only in the south-facing plot OP05, the most species-rich plot, characterised by relatively short grass. Our suspicion that this was an ideal habitat for *Psophus stridulus* species was confirmed by Rada et al. (2017), who describe its preferred habitat as one on south-facing slopes featuring short vegetation. They found sward density to be the main predictor for *Psophus stridulus*. We did not measure sward density, however, visual assessment would suggest this plot to also fit this characteristic.

### *Recommendations for future summer schools*

In addition to recommendations already made throughout this report, we advise future summer schools to follow the standardised sampling method for surveying Orthoptera suggested by Hilpold et al. (2020) to tie in with the EDGG vegetation survey. Unfortunately, we became aware of it only after the start of the field work and therefore decided to continue with the established method for consistency reasons.

We furthermore recommend to time the sampling period for consistency purposes. Some species, such as *Pseudochorthippus parallelus*, burrow into the undergrowth after being disturbed, thereby avoiding capture (Clark 1948). It must therefore be expected that our capture method would result in an underestimation of species richness and abundance. In fact, it is highly unlikely to successfully count all Orthoptera individuals present at any sampling site (Gardiner & Hill 2006). The method of open quadrats used in this study is especially prone to inaccuracies because of immigration into and emigration out of the plot (Gardiner et al. 2005; Gardiner & Hill 2006). Box quadrats provide a more accurate representation of the Orthoptera population, but are more time-consuming to install and are not practical for transport to high altitude sites (Gardiner et al. 2005; Gardiner & Hill 2006).

### *Outlook*

Various Orthoptera species are a popular choice in conservation projects as indicators of environmental change or modification to land use management (Wettstein & Schmid 1999; Gardiner et al. 2002; Gardiner et al. 2005). They respond quickly to changes in habitat structure and microclimate (Gardiner & Dover 2008), show high diversity and abundance and are easy to sample (Gardiner et al. 2005). In the future, they may well serve as important indicators of climate change, especially in sensitive subalpine environments (Sonu et al. 2020). For this reason, further research into drivers of Orthoptera species richness and abundance is required.

## Acknowledgements

We would like to thank Dr. Piotr Tykarski for his supervision of this project and his support during the sampling and identification process, as well as Prof. Dr. Jürgen Dengler and Dr. Patryk Czortek for their valuable input on statistical analysis. A special thanks also goes to Prof. Dr. Jürgen Dengler, Hallie Seiler and Stefan Widmer for the thorough planning and organisation of the Summer School 'Biodiversity Monitoring' 2021.

## References

Bartoń, K. (2020) MuMIn: Multi-Model Inference. R package version 1.47.17. URL: https://cran.r-project.org/web/packages/MuMIn/index.html (accessed 20 August 2021).

Baur, B., Baur, H., Roesti, C. & Roesti, D. (2006) *Die Heuschrecken der Schweiz*. Haupt Verlag, Bern.

Belovsky, G.E. & Slade, J.B. (2018) Grasshoppers affect grassland ecosystem functioning: Spatial and temporal variation. *Basic and Applied Ecology*, **26**, 24-34.

Bruun, H.H., Moen, J., Virtanen, R., Grytnes, J.A., Oksanen, L. & Angerbjörn, A. (2006) Effects of altitude and topography on species richness of vascular plants, bryophytes and lichens in alpine communities. *Journal of Vegetation Science,* **17**, 37-46.

Clarke, E.J. (1948) Studies in the ecology of British grasshoppers. *Transactions of the Royal Entomological Society of London*, **99**, 173-222.

climate-data.org (2021). URL: https://en.climate-data.org (accessed 29 August 2021).

Crawley, M.J. (2014) *Statistics - An introduction using R.* Wiley*,* London.

Fartmann, T., Krämer, B., Stelzner, F. & Poniatowski, D. (2012) Orthoptera as ecological indicators for succession in steppe grassland. *Ecological Indicators*, **20**, 337-344.

Gardiner, T., Pye, M., Field, R. & Hill, J. (2002) The influence of sward height and vegetation composition in determining the habitat preferences of three Chorthippus species (Orthoptera: Acrididae) in Chelmsford, Essex, UK. *Journal of Orthoptera Research*, **11**, 207-213.

Gardiner, T., Hill, J. & Chesmore, D. (2005) Review of the methods frequently used to estimate the abundance of Orthoptera in grassland ecosystems. *Journal of Insect Conservation*, **9**, 151-173.

Gardiner, T. & Hill, J. (2006) A comparison of three sampling techniques used to estimate the population density and assemblage diversity of Orthoptera. *Journal of Orthoptera Research*, **15**, 45-51.

Gardiner, T. & Dover, J. (2008) Is microclimate important for Orthoptera in open landscapes? *Journal of Insect Conservation*, **12**, 705-709.

Hilpold, A., Kirschner, P. & Dengler, J. (2020) Proposal of a standardized EDGG surveying methodology for orthopteroid insects. *Palaearctic Grasslands*, **46**, 52-57.

Info Fauna. Schweizerisches Zentrum für die Kartographie der Fauna. URL: https://lepus.unine.ch/tab (accessed 17 August 2021).

Janzen, D.H. (1973) Sweep samples of tropical foliage insects: effects of seasons, vegetation types, elevation, time of day, and insularity. *Ecology*, **54**, 687-708.

Körner, C. (2007) The use of altitude in ecological Research. *Trends in Ecology and Evolution,* **22**, 569-574.

Lawton, J.H., MacGarvin, M. & Heads, P.A. (1987) Effects of altitude on the abundance and species richness of insect herbivores on bracken. *Journal of Animal Ecology*, **56**, 147-160.

Lightfoot, D.C. (2018) The effects of livestock grazing and climate variation on vegetation and grasshopper communities in the northern Chihuahuan Desert. *Journal of Orthoptera Research*, **27**, 35-51.

Löffler, F. & Fartmann, T. (2017) Effects of landscape and habitat quality on Orthoptera assemblages of prealpine calcareous grasslands. *Agriculture, Ecosystems and Environment*, **248**, 71-81.

Marini, L., Fontana, P., Scotton, M. & Klimek, S. (2008) Vascular plant and Orthoptera diversity in relation to grassland management and landscape composition in the European Alps. *Journal of Applied Ecology*, **45**, 361-370.

McCoy, E.D. (1990) The distribution of insects along elevational gradients. *Oikos*, **58**, 313-322.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing. URL: https://www.R-project.org/ (accessed 19 August 2021).

Rada, A., Spitzer, L., Sipos, J. & Kuras, T. (2017) Habitat preferences of the grasshopper *Psophus stridulus*, a charismatic species of submontane pastures. *Insect Conservation and Diversity*, **10**, 310-320.

Rahbek, C. (1995) The elevational gradient of species richness: a uniform pattern? *Ecography*, **18**, 200-205.

Schirmel, J., Gerlach, R.& Buhk, C. (2019) Disentangling the role of management, vegetation structure, and plant quality for Orthoptera in lowland meadows. *Insect Science*, **26**, 366-378.

Sirin, D., Eren, O. & Çiplak, B. (2010) Grasshopper diversity and abundance in relation to elevation and vegetation from a snapshot in Mediterranean Anatolia: role of latitudinal position in altitudinal differences. *Journal of Natural History*, **44**, 1343-1363.

Sonu, Y., Stow, A. & Dudaniec, R.Y. (2020) Elevational partitioning in species distribution, abundance and body size of Australian alpine grasshoppers (*Kosciuscola*). *Austral Ecology*, **45**, 609-620.

Spalinger, L.C., Haynes, A.G., Schütz, M. & Risch, A.C. (2012) Impact of wild ungulate grazing on Orthoptera abundance and diversity in subalpine grasslands. *Insect Conservation and Diversity*, **5**, 444-452.

Swisstopo, Bundesamt für Landestopografie (2021) URL: https://map.geo.admin.ch (accessed 30 August 2021).

Szövenyi, G. (2002). Qualification of grassland habitats based on their Orthoptera assemblages in the Köszeg Mountains (W-Hungary). *Entomologia Experimentalis et Applicata*, **104**, 159-163.

Torma, A. & Bozsó, M. (2016) Effects of habitat and landscape features on grassland Orthoptera on floodplains in the lower reaches of the Tisza River Basin. *European Journal of Entomology*, **113**, 60-69.

Wagner, W. (2021) *Orthoptera and their ecology.* URL: http://www.pyrgus.de/ (accessed 17 September 2021).

Wettstein, W. & Schmid, B. (1999) Conservation of arthropod diversity in montane wetlands: effect of altitude, habitat quality and habitat fragmentation on butterflies and grasshoppers. *Journal of Applied Ecology*, **36**, 363-373.

# Survey of small mammals along the elevation gradient using camera traps

*Simon Meier, Melina Oldorf, Céline Schlatter & Stefan Wild*

## Abstract

In the field of research are small mammal species in mountain areas still rather unexplored, especially the distribution over the different elevation gradients. This study did not only aim to detect occurrences of small mammal species on different altitude levels, but also to test a method to collect DNA samples of small mammals. The research area was between the northern end of the Mulix valley in Naz in the canton of Grisons, Switzerland, with an altitude of 1750 m a.s.l. and the Lake Negr, with an elevation of 2649 m a.s.l.. Eleven non-invasive Camera traps within a MammaliaBox were used on different elevation gradients for a week. To test the DNA sampling method, two additional Camera trap MammaliaBoxes were set up around the research station for seven days with changing trap locations for every night. These boxes had a toothbrush with either peanut butter or dog food and a feeding place (plastic tube) installed. For the statistical analyses of the elevation study, a pooled data set of the years 2019,2020 and 2021 was used. In total six small mammal species were found on the elevation plots and 290 events were counted. With increasing altitude, the species diversity decreased significant, whereas altitude seems not to have an impact on the number of events. In 82 cases from the 143 events of the side study, the animals at least were sniffing at the toothbrushes with the lure. In 44 cases the animals were licking on the toothbrush or were even biting in it. Peanut butter attracted more animals than dog food (105 to 38) and more animals did lick or bite into the Peanut butter toothbrush. On the other hand, dog food attracted more different species than peanut butter. These results give a first impression about the small mammal species distribution, nonetheless, is further research in mountain areas on small mammal species much needed to increase the knowledge about the biodiversity and ecology within these sensitive ecosystems.

*Keywords: Camera trap, elevation gradient, environmental DNA, MammaliaBox, small mammal, species distribution, Swiss mountain area*

## Introduction

In the last decade in general the numbers of mammal species show a declining trend all over the world (Brodie et al., 2021). Bigger mammal species have already been studied quite thoroughly all over the world, whereas the knowledge gaps for small mammal species, are rather big, even though two small mammal orders, the Rodentia and Eulipotyphla, represent almost half (48,3%) of known mammal species (Kennerley et al., 2021). Biodiversity is a crucial part within an in balance working ecosystem, including the small mammal species, which is why the need for research on small mammals gets even more important (*Alpine Nature 2030*, 2016). In regard to ecology it is substantial to detect the factors which create and maintain patterns of assemblage structure and diversity (Williams et al., 2002). Small mammals do not only expedite seed dispersal, but also have a fundamental role as landscapers and are additionally important food sources for several predators within an ecosystem (MCCleery et al., 2014). Increasing the knowledge about the occurrence and distribution of species is important to protect them effectively. Biodiversity monitoring is an integral part of generating this knowledge and detecting changes (Thomsen & Willerslev, 2015). Because of their ecological requirements, small mammals are suitable indicators for the health of ecosystems and changes in ecological conditions (Rowe & Terry, 2014). Not only did the research interest on small mammal species increase, but the methods to detect the small mammal species developed quite substantially (Harkins et al., 2019). Besides detection methods such as tracking tunnels and live traps, camera traps are becoming increasingly popular to study small mammal species (Burton et al., 2015; O'Connell et al., 2011). Using camera traps to study mammal species can provide a solid ecological assessment of mammal communities (MCCleery et al., 2014; Mos & Hofmeester, 2020; Rovero et al., 2014).

Several studies have been conducted on the species distribution and biodiversity of small mammals along the elevation gradient (Nor, 2001; Rowe, 2009; Sakane et al., 2019; Torre & Arrizabalaga, 2009; Wu et al., 2013). Ecologists are highly interested in elevational gradients, as these gradients make it possible to record how biodiversity responds to major environmental factors (Baumann et al., 2016).

During the studies on biodiversity of small mammal species different patterns were found. The factors responsible for the patterns are as varied as the patterns themselves. For instance, a study in Brazil (Sakane et al., 2019) found a unimodal pattern in species distribution along the elevational gradient. This pattern was also found in some other studies (Li et al., 2003; Musila et al., 2019; Nor, 2001; Wu et al., 2013). This reveals a peak in the middle of the elevation gradient. This peak can be partly explained by the at this elevation level overlapping habitat types (e.g., lowland and highland forest) (Nor, 2001) and merging climatic zones and plant communities (Mediterranean and Eurosiberian) (Torre & Arrizabalaga, 2009). Other drivers of small mammal abundance and richness have been found to be ground cover (Sakane et al., 2019; Torre & Arrizabalaga, 2009), temperature (Torre & Arrizabalaga, 2009; Wu et al., 2013), precipitation (Torre & Arrizabalaga, 2009; Wu et al., 2013), plant species richness (Li et al., 2003; Williams et al., 2002; Wu et al., 2013), and geometric constraints (Wu et al., 2013).

Other studies have found no unimodal but a monotonically decreasing richness pattern with the peak at low elevations (Wu et al., 2013) or no consistent pattern of species richness (Torre & Arrizabalaga, 2009). It is shown that in most cases not only one single factor is responsible for the species richness pattern and thus there is no universal explanation for the underlying process that forms these patterns (Rowe, 2009; Torre & Arrizabalaga, 2009). The ecological drivers of biodiversity vary within different scales and biotas (Sun et al., 2020).

More studies at the local scale would help to improve the understanding of the complex patterns and influencing factors (Wu et al., 2013). For this reason, we investigate the abundance and species distribution of small mammals along the elevation gradient in Val Mulix in Preda in Switzerland using camera traps (MammaliaBox). Since certain species groups (e.g. Apodemus) cannot be determined down to the species level with the camera traps using purely visual characteristics, we also want to test the use of environmental DNA (eDNA). The eDNA can be applied efficiently for biodiversity monitoring (Thomsen & Willerslev, 2015) and ecosystem surveys (Leempoel et al., 2020). The use of eDNA has several advantages over other methods of investigation. Objectivity is given, since the results do not depend on the experience and taxonomic knowledge of the person performing the analysis (Thomsen & Willerslev, 2015; Veilleux et al., 2021). In comparison to other methods, person-hours and therefore costs can be saved (Sigsgaard et al., 2015). Furthermore, it is a non-invasive method that does not harm or disturb the animals studied (Thomsen & Willerslev, 2015) and the researchers do not need a permit to handle the animals (Lorefice, 2021). Therefore, as second part of this project, we are additionally testing whether baited toothbrushes can be used to collect eDNA from small mammals.

This project work will examine the following questions:

i) How does the occurrence of small mammal species change in relation to the altitude?

ii) Does altitude have an impact on the number of events?

iii) How do the recorded species react to toothbrushes with different baits?

## Methods

Since we carried out a main study along the elevation transect and a side-study in the area around the group house in Preda the methods were not always the same for both studies. If we used different methods for the studies, the respective study is mentioned.

### *Study area*

The area of the main study comprised the area between the northern end of the Mulix valley in Naz in the canton of Grisons, Switzerland, with an altitude of 1750 m a.s.l. and the Lake Negr, with an elevation of 2649 m a.s.l.. From Naz to approximately 2000 m a.s.l. the landscape mainly consists of pine forests, whereas from 2000 m a.s.l. upwards the region is dominated by open landscapes with dwarf shrub heaths and alpine meadows. At the highest point of the transect, in the area around lake Negr, the shrub heaths and alpine meadows are replaced by scree vegetation. The plots that were spread along this transect (Figure 1) were already defined in advance to the summer school and our field work.

The study area of the side-study comprised the area around the group house in Preda located at 1790 m a.s.l. mainly surrounded by meadows, pine forests and situated near a streambed with alluvial meadows.

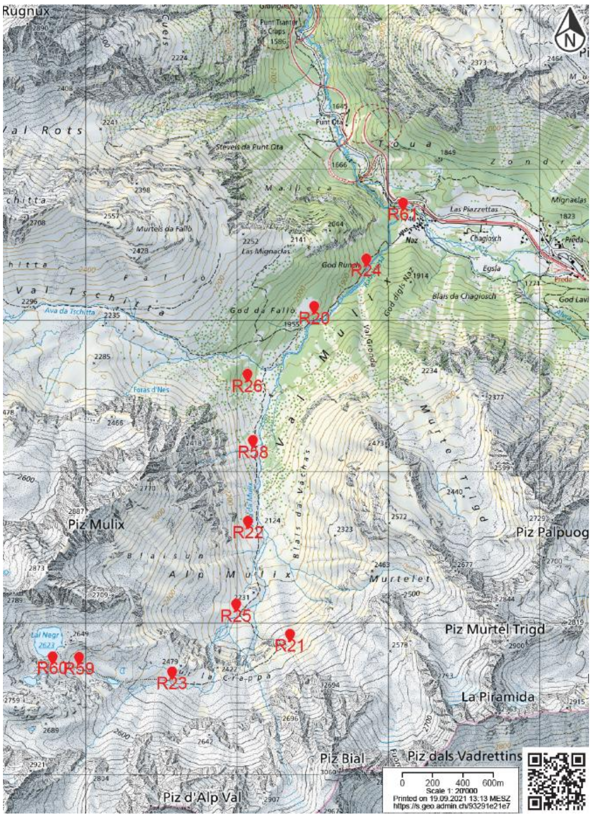


*Figure 1: Study transect with the lowest point in Naz (R61) and the highest point at lake Negr (R60). Source: map.geo.admin.ch*

### *Camera traps*

For the main study we used eleven camera trap boxes called MammaliaBox, developed by Aegerter (2019). They consisted of the following components:

6 wooden segments of the MammaliaBox

1 Reconyx Wildlife camera

2 Pipes (Entrances)

1 Wooden board, brushed with peanut butter and sausage

1 Measure, attached to the wooden board, facing the camera

After we were instructed in setting up the boxes (Figure 2), we placed them beside the plots that were defined prior to our field study. We placed the boxes on a stable base near cavities which we expected to be used by small mammals and made sure the entrances of the boxes were accessible on both sides. To avoid too much heat inside the box which could damage the cameras and for camouflage we covered the boxes with moss, branches, other plant parts or stones. Once all the boxes of the main study were installed, we left them at the plots for five nights before collecting them to analyse the pictures. Except for the trap R58 (13th August – 19th August), all camera traps were active from the 14th August until the 19th August.

For the side study we used plastic boxes, that were also equipped with a camera trap, two side entrances, a wooden board, and a measure. In addition to the boxes used in the main study, we equipped these with a toothbrush and a feeding place (plastic tube) to collect faeces. We applied peanut butter to the toothbrush in trap R63 and dog food to the toothbrush in trap R62. Unlike the main study, we changed the location of the two side-study boxes each night, always within a radius of approximately 150 m from our accommodation. The camera traps of the side-study were active from the 15th August until the 22nd August 2021.

### *Definition of events*

*Figure 2: After the MammaliaBox was set up (left), it was placed on a stable base and covered with plant material (middle). The boxes of the side study contained a toothbrush and an additional tube with a feeding place (right)*

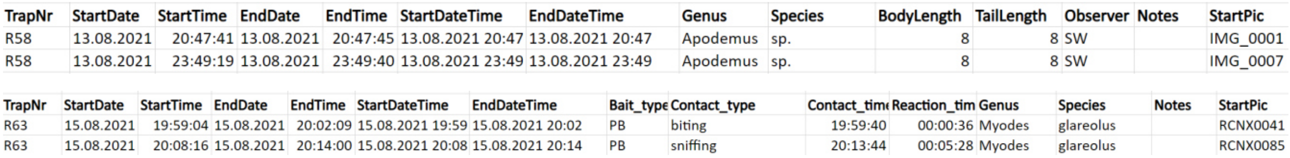
Before we could carry out a statistical analysis, we first had to categorize the pictures and define events. One event was defined to last for a minimum time of one second and lasted from the first picture that was triggered by an individual to the last one on which it was visible. A new event was recorded, when a new animal showed up, which could be distinguished from the one before by species or other physical characteristics. We also defined a buffer of 5 minutes to prevent double counting. That way a new event could only be created if the next appearance was more than 5 minutes apart or if the next individual could be distinguished based on the species or other physical characteristics. If the same individual left the box and returned within 5 minutes, it was counted as the same event.

For the side study we made a further classification, based on the reaction of the individuals to the bait that was applied to the toothbrush. The categories we used for this were “no_contact”, “sniffing”, “licking” and “biting”.

### Picture analysis

For the picture analysis we split up the different camera traps between the team members. Each team member then analyzed the pictures, starting with the first trap night. The behavior that we observed on the photos was then transferred to an excel sheet, where different values such as event duration and species were noted for the main study and the side study (Figure 3).

In the side study we wanted to find out how the small mammals reacted to the toothbrushes, which is why we noted additional information like the time from the first picture until the first contact with the toothbrush and of what nature that contact was (no contact, sniffing, licking, biting). To identify the different species we used the determination key of Marchesi et al. (2008).



| TrapNr | StartDate | StartTime | EndDate | EndTime | StartDateTime | EndDateTime | Genus | Species | BodyLength | TailLength | Observer | Notes | StartPic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R58 | 13.08.2021 | 20:47:41 | 13.08.2021 | 20:47:45 | 13.08.2021 20:47 | 13.08.2021 20:47 | Apodemus | sp. | 8 | 8 | SW | | IMG_0001 |
| R58 | 13.08.2021 | 23:49:19 | 13.08.2021 | 23:49:40 | 13.08.2021 23:49 | 13.08.2021 23:49 | Apodemus | sp. | 8 | 8 | SW | | IMG_0007 |

| TrapNr | StartDate | StartTime | EndDate | EndTime | StartDateTime | EndDateTime | Bait_type | Contact_type | Contact_tim | Reaction_tim | Genus | Species | Notes | StartPic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R63 | 15.08.2021 | 19:59:04 | 15.08.2021 | 20:02:09 | 15.08.2021 19:59 | 15.08.2021 20:02 | PB | biting | 19:59:40 | 00:00:36 | Myodes | glareolus | | RCNX0041 |
| R63 | 15.08.2021 | 20:08:16 | 15.08.2021 | 20:14:00 | 15.08.2021 20:08 | 15.08.2021 20:14 | PB | sniffing | 20:13:44 | 00:05:28 | Myodes | glareolus | | RCNX0085 |

*Figure 3: Excel sheets used for the main study (top) and the side-study (bottom).*

### Statistical Analysis

To answer the research questions i and ii, we used our data from the year 2021 as well as the data from 2019 and 2020. As the number of trapping nights differ between the elevation plots as well as over the years of investigation (from 0 to 10 trapping nights per elevation plot per year), we used number of detected species and number of events per trapping night as values for the models. The advantages of pooling the data are a larger dataset and a greater investigation period over these years. As the abundance of small mammals can fluctuate from year to year, the pooled data are more precise. We did not expect a change in attractivity of the camera traps within the investigation time, as the attraction of the lure decreases and the habituation to the box increases over the time. The attraction of the box as a hiding place stays constant. So, a comparison of events as well as number of detected species per trapping night should be possible.

We used generalised linear models (glm) with Poisson distribution. All calculations were done with the program R Studio.

## Results

In total the camera traps have taken close to 50’000 pictures and videos. From these, we defined 290 events. 147 from the elevation plots and 143 from the side study around the research station (Table 1).

*Table 1: Detected species and number of events in the elevation plots and the side study*

| Elevation m AMSL | 1753 | 1863 | 1940 | 2032 | 2152 | 2254 | 2361 | 2462 | 2564 | 2639 | Side study |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Trapping nights | 5 | 5 | 6 | 10 | 5 | 5 | 5 | 5 | 5 | 5 | 14 |
| *Apodemus sp.* | 19 | 7 | 15 | | | | | | | | 85 |
| *Microtus arvalis* | | | | 1 | | | | | | | |
| *Microtus subterraneus* | | | | 1 | 6 | | | | | | |
| *Mustela erminea* | | | | | | | | | | | 2 |
| *Myodes glareolus* | | 22 | | 10 | 53 | 3 | | | | | 50 |
| *Sorex araneus* | | | | 1 | | | | | | | 4 |
| *Sorex minutus* | | 1 | | | | | | | | | |
| NID | 5 | 2 | | | | 1 | | | | | 2 |

## *How does the occurrence of small mammal species change in relation to the altitude?*

On the elevation plots, we found six different species of small mammals (Table 1). This number is comparable with the number of found species in the last years. We have not found *Chionomys nivalis* and *Mustela erminea.* On the other hand, we detected *Microtus subterraneus, Microtus arvalis* and *Sorex araneus* (Figure 4).

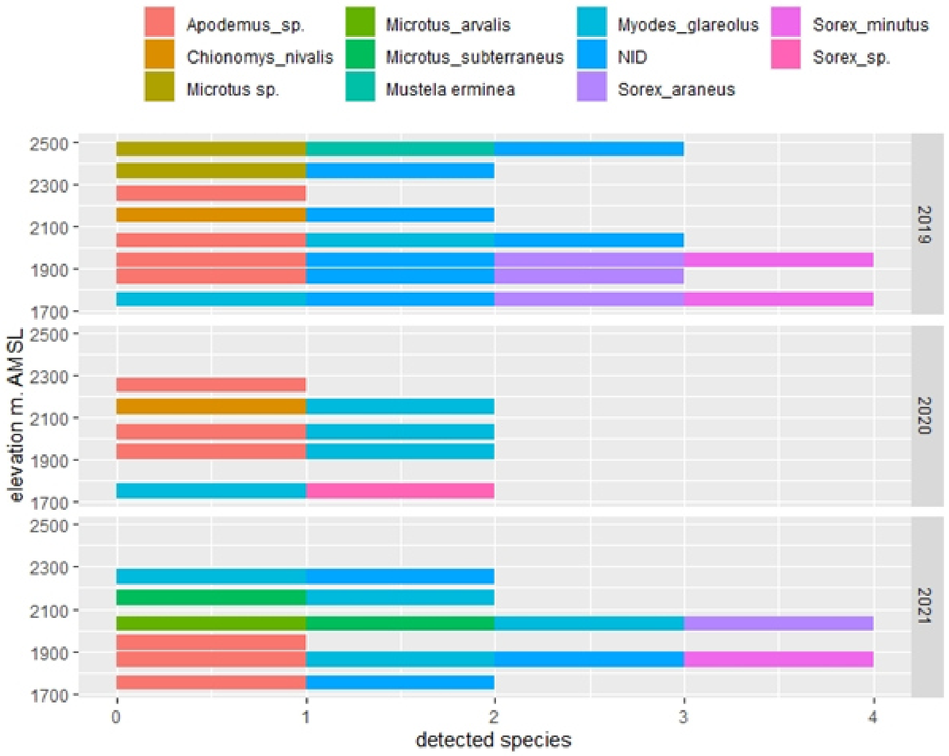


*Figure 4: Detected species in the elevation plots over the years*

The total number of detected species decreases with increasing altitude. The generalised linear model calculated a significant (p = 0.010) decrease of species of exp (4.6511159 - 0.0016876 *elevation) (Figure 5). Also, the number of detected species per trapping night shows a similar trend with a decrease of exp(0.740106 - 0.001149 *elevation), p = 0.919 (Figure 6). Especially *Sorex* species were just detected in the lower plots, mostly beneath 2’000 meter above sealevel. Other species like *Myodes glareolus* or *Apodemus sp*. were detected in different altitude. *Mycrotus subterraneus* were detected just in a small range between 2’000 and 2’200 meter above sealevel (Figure 7).

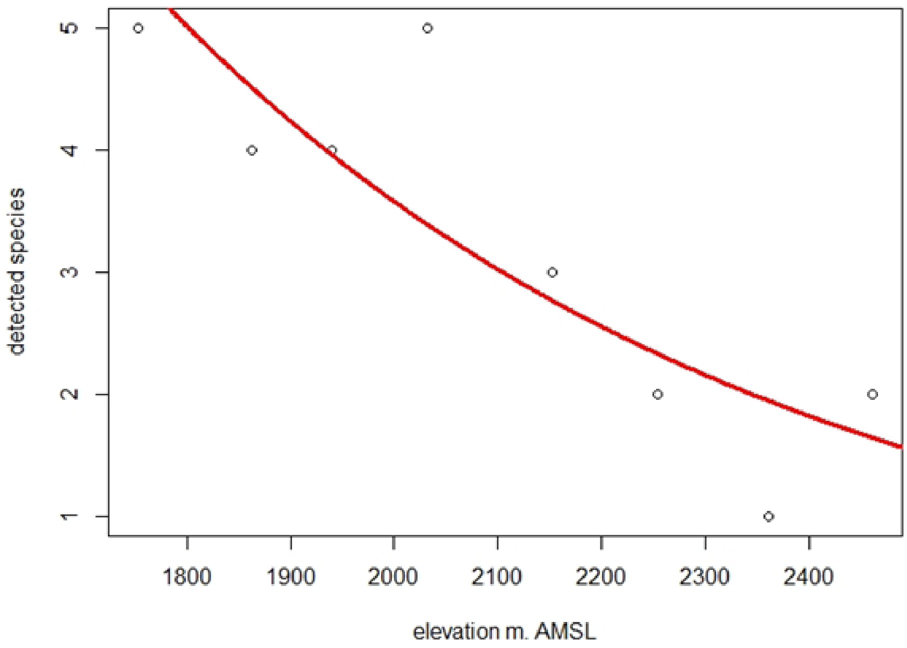


*Figure 5: In total detected species in the elevation plots. Red line = glm, exp(4.6511159 - 0.0016876 *elevation), p = 0.010*

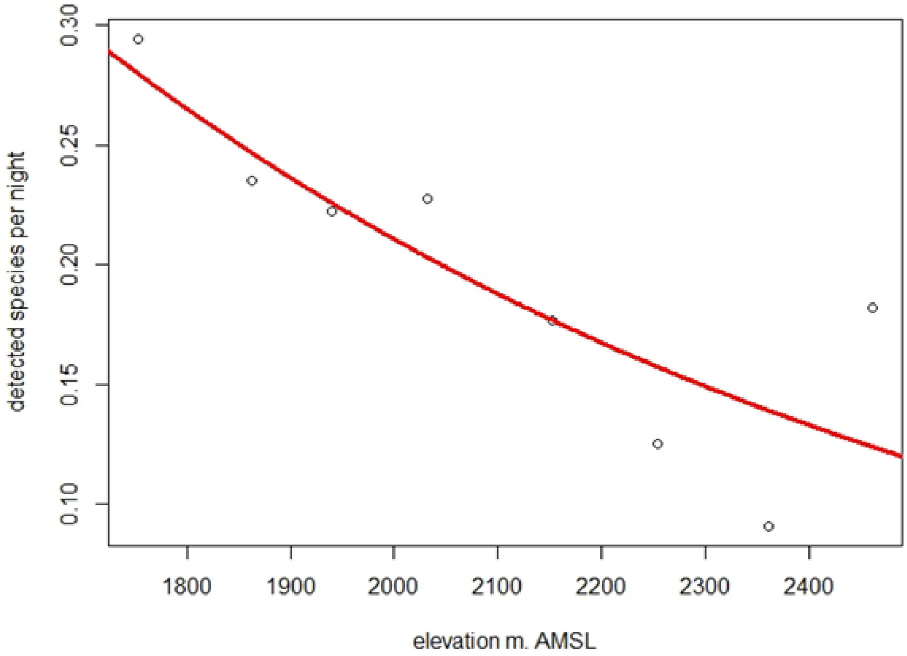


*Figure 6: Detected species per trapping night in the elevation plots. Red line = glm, exp(0.740106 - 0.001149 *elevation), p = 0.919*

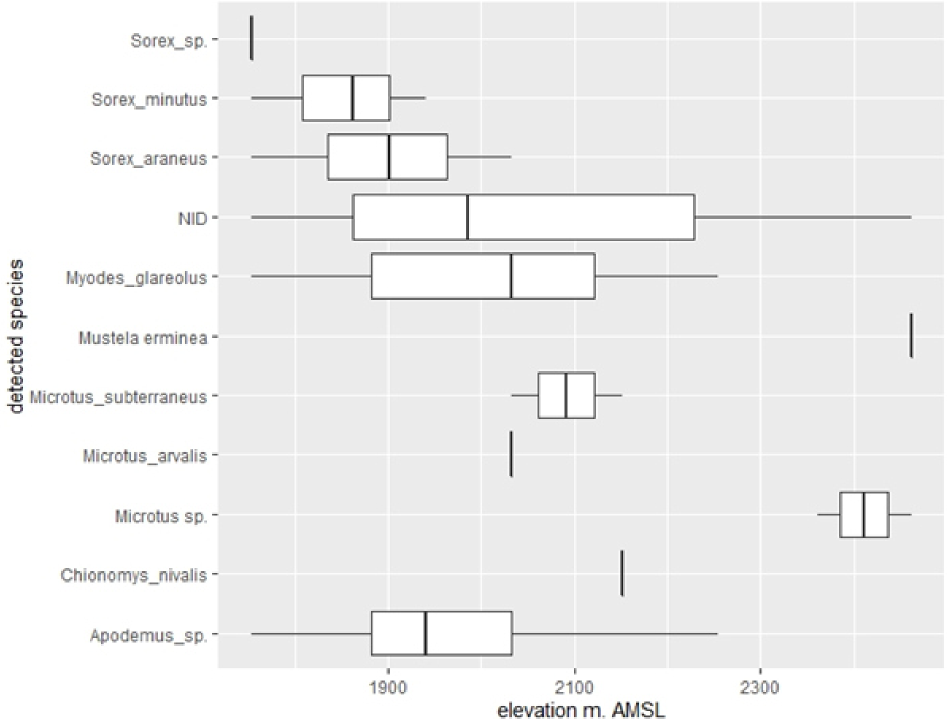


*Figure 7: Occurrence of the detected species over the altitude*

### *Does altitude have an impact on number of events?*

Altitude seems not to have an impact on the number of events. In 2021 we did not detect any small mammals over an altitude of 2’300 meter. On the other hand, in 2019 the plot with the highest number of events was on 2’361 meter above sealevel (Figure 8).

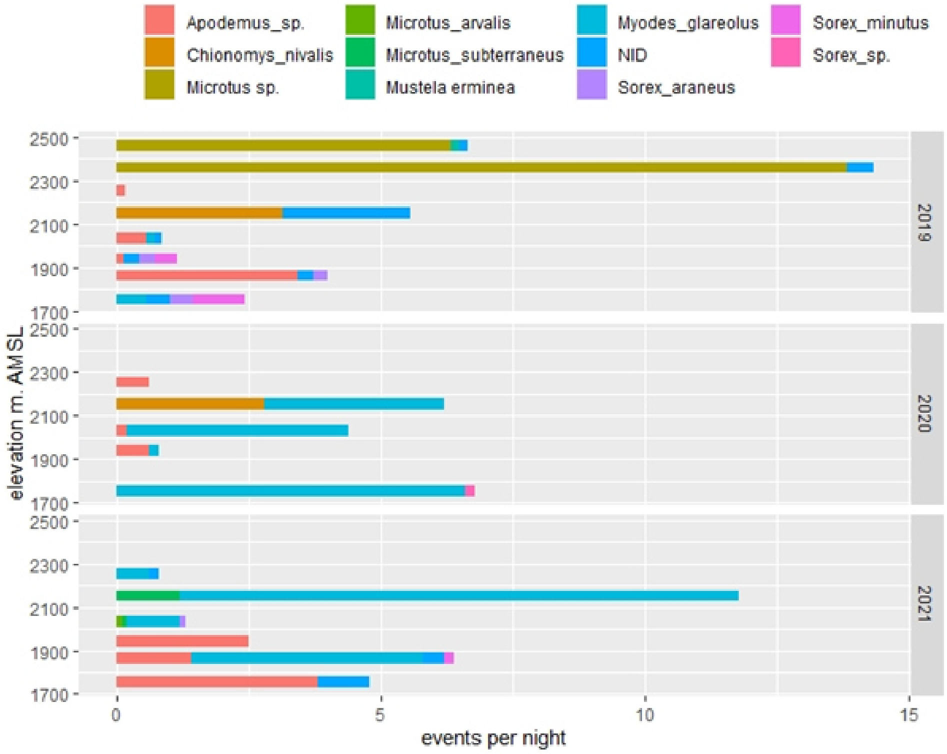


*Figure 8: Counted events in the elevation plots splitted into the three years of investigation.*

Based on the pooled data, the number of events even slightly rises with increasing altitude with a rate of exp(0.0426003 + 0.0006169 *elevation), but not significant ($p = 0.980$).

### *How do the recorded species react to toothbrushes with different baits?*

In 82 cases from the 143 events of the side study, the animals were at least sniffing at the toothbrushes with the lure. In 44 cases the animals were licking on the toothbrush or were even biting in it (Figure 9). At least four species were detected with these boxes: *Apodemus sp., Myodes glareolus, Mustela erminea* and *Sorex araneus*. Individuals of *Apodemus sp*. as well as *Myodes glareolus* and *Mustela erminea* at least licked or bit the toothbrush. Individuals of *Sorex araneus* either just sniffed the toothbrush or ignored it entirely. The behaviour of Mustela erminea is particularly striking. This has taken the camera trap literally apart and reacted very strongly to the toothbrush with dog food. In the faeces tube faeces was detected only once, which was in the trap with dog food bait.

Peanut butter attracted more animals than dog food (105 to 38). Also, the percentage of animals licking or biting into the peanut butter toothbrush was higher (Figure 10). Only individuals of the species *Myodes glareolus* and *Apodemus sp*. were detected in the traps with the peanut butter bait. In contrast, in the traps with the dog food bait, individuals of all four species were recorded.

*Figure 9: Division of the different behavior of all detected events.*

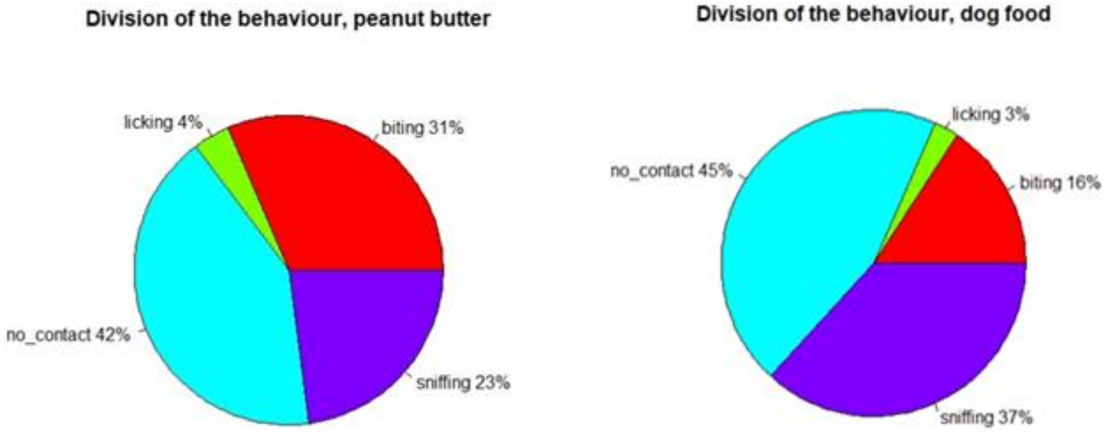


*Figure 10: Division of the different behavior. Left: Toothbrush with peanut butter as lure. Right: Toothbrush with dog food as lure.*

## Discussion

### *Main study*

In contrast to most studies (Li et al., 2003; Musila et al., 2019; Nor, 2001; Sakane et al., 2019; Wu et al., 2013) conducted until now on the distribution of small mammals along an elevational gradient, this study did not show a unimodal pattern of species distribution, but an almost exponential decrease in the number of species with increasing elevation. The decrease in number of species with increasing elevation was expected, since the shrub vegetation and therefore the amount of ground cover decreased as well. Since small mammals are not only bound to shrubby vegetation because of protection, as it reduces the risk of predation but also because of the reduced effect of competition and food supply by reduced ground cover (Sakane et al., 2019).

The decrease in the number of species with increasing altitude concurs with the results of Milana et al. (2019), who came to the same conclusion and suggests that the decrease could be due to a higher rate of agricultural land existing at lower elevations. As in our study the transect does not directly include any agricultural land but the number of species still shows a decline, the relevant factor is not necessarily the availability of agricultural land itself but rather the availability of different habitat types and habitat conditions in general.

Sorex species for example were only found in the lower traps which were all situated in forests and – in comparison to the higher plots – more vegetation rich areas. Those findings coincide with the conclusions of Pruitt (1959). He suggests that the species are limited in their local distribution to areas with stable soil conditions, enough moisture in the soil and a soil matrix containing enough leaf litter and leaf mold to ensure stable tunnels – conditions that are given especially in the lower plots. As visual determination is quite difficult for the sorex araneus, the distinction was based on the species distribution data of the Atlas of mammals in Switzerland (Graf et al., 2021). This is only one example for many small mammal species where the need for further camera trapping and especially DNA studies gets more important and should be further encouraged.

### *Side study*

In the side study the four species *Apodemus sp.*, *Myodes glareolus*, *Mustela erminea* and *Sorex sp.* were recorded. With 44 cases of sniffing/biting, the proportion of interactions yielding eDNA (35% of interactions for the peanut butter bait and 19% for the dog food bait, respectively) is rather low. However, it is gratifying that the species groups *Apodemus sp*. and *Sorex sp*., which cannot be determined on the basis of purely external characteristics, were recorded. Thus, this method has the potential to detect these species that can only be determined by genetic analysis. Since more species were recorded in the box with dog food, but more eDNA-providing interactions occurred in the box with peanut butter, we consider it reasonable to carry out further investigations with boxes with two toothbrushes each containing one type of bait. It is crucial that the food consists of fish and not mammals, otherwise the evaluation of the eDNA is difficult or impossible. Because *Sorex sp*. did not lick or bite the bait, and because it would be desirable to use this methodology to also detect *Neomys sp*. and *Crocidura sp*., other baits should additionally be tested in further studies. For example, a bait consisting of insects could be tried, since *Neomys fodiens, Neomys anomalus, Crocidura russula, Crocidura leucodon* and *Crocidura suaveolens* feed primarily or among others on invertebrates (Graf et al., 2021).

*Sorex sp.* and *Mustela erminea* were only found in the traps with dog food. A reasonable explanation for this might be the fact that both *Sorex sp.* and *Mustela erminea* are carnivores and have a very broad food spectrum (Graf et al., 2021). Both species additionally own a distinctive sense of smell (Graf et al., 2021).

The faecal tube with only a single finding has not shown the desired effect, but quite the opposite. Thus, the animals were distracted from the toothbrush by the faecal tube and activated the camera. We therefore recommend for further examinations not to use the toothbrush and the faecal tubes in the same camera trap at the same time.

### *Methodological problems/limitations and further investigations*

The possibility of a technical defect could not be eliminated since a possible error occurred during installation of the top two traps R60 and R59. The memory cards of both traps did not contain any pictures, also none from the installation of the MammaliaBox.

When interpreting the results, it is important to consider that populations of small mammals are subject to cyclical fluctuations (Oli & Dobson, 1999, 2001). This could have an impact on the number of recorded events. In addition, it must be noted that the probability of detecting species that have a low density is small (Nor, 2001). Regarding the study period, it is recommended to extend the time frame of the study, since the conducted time frame of a week does make it nearly impossible to quantify any trends regarding species, numbers, patterns, diversity or distribution of small mammals. Another advantage of an increased research period would be that more factors, such as temperature, precipitation, productivity, habitat heterogeneity, regarding the study site could be included and properly measured (Rowe, 2009). Studies in different seasons would be interesting, although a study from Malaysia (Nor, 2001) found no difference in the assessment of diversity patterns between seasons. Furthermore, calculations on the detection probability of these different small mammal species and thus a standardization of the minimum number of trapping nights would be very interesting to detect presence and absence.

## References

Aegerter, S. (2019). Monitoring von Kleinmusteliden, Schläfern und anderen Kleinsäugern – Weiterentwicklung der Nachweismethoden mit Fotofalle.

Alpine Nature 2030—Creating [ecological] connectivity for generations to come. (2016). 252.

Baumann, E., Weiser, F., Chiarucci, A., Jentsch, A., & Dengler, J. (2016). Diversity and functional composition of alpine grasslands along an elevational transect in the Gran Paradiso National Park (NW Italy). https://doi.org/10.14471/2016.36.015

Brodie, J. F., Williams, S., & Garner, B. (2021). The decline of mammal functional and evolutionary diversity worldwide. Proceedings of the National Academy of Sciences, 118(3). https://doi.org/10.1073/pnas.1921849118

Burton, A. C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J. T., Bayne, E., & Boutin, S. (2015). Wildlife camera trapping: A review and recommendations for linking surveys to ecological processes. Journal of Applied Ecology, 52(3), 675–685. https://doi.org/10.1111/1365-2664.12432

Graf, R. F., Fischer, C., Niehaus, M., Schweizerische Gesellschaft für Wildtierbiologie, Graf, R. F., Fischer, C., Niehaus-Osterloh, M., & Société suisse de biologie de la faune. (2021). Atlas der Säugetiere Schweiz und Liechtenstein (1. Auflage). Haupt Verlag.

Harkins, K. M., Keinath, D., & Ben-David, M. (2019). It's a trap: Optimizing detection of rare small mammals. PLOS ONE, 14(3), e0213201. https://doi.org/10.1371/journal.pone.0213201

Kennerley, R. J., Lacher, T. E., Hudson, M. A., Long, B., McCay, S. D., Roach, N. S., Turvey, S. T., & Young, R. P. (2021). Global patterns of extinction risk and conservation needs for Rodentia and Eulipotyphla. Diversity and Distributions, 27(9), 1792–1806. https://doi.org/10.1111/ddi.13368

Leempoel, K., Hebert, T., & Hadly, E. A. (2020). A comparison of eDNA to camera trapping for assessment of terrestrial mammal diversity. Proceedings of the Royal Society B: Biological Sciences, 287(20192353). https://doi.org/10.1098/rspb.2019.2353

Li, J. S., Song, Y. L., & Zeng, Z. G. (2003). Elevational gradients of small mammal diversity on the northern slopes of Mt. Qilian, China: Elevational gradients of small mammal diversity in China. Global Ecology and Biogeography, 12(6), 449–460. https://doi.org/10.1046/j.1466-822X.2003.00052.x

Lorefice, A. S. (2021). Monitoring von Kleinsäugetieren (p. 36) [Bachelorarbeit]. ZHAW.

Marchesi, P., Blant, M., & Capt, S. (2008). Säugetiere der Schweiz—Bestimmungsschlüssel. CSCF & SGW.

MCCleery, R. A., Zweig, C. L., Desa, M. A., Hunt, R., Kitchens, W. M., & Percival, H. F. (2014). A novel method for camera-trapping small mammals: A Novel Camera Trap Method. Wildlife Society Bulletin, 38(4), 887–891. https://doi.org/10.1002/wsb.447

Milana, G., Battisti, C., Luiselli, L., & Amori, G. (2019). Altitudinal variation of community metrics in Italian small mammal assemblages as revealed by Barn Owl (Tyto alba) pellets. Zoologischer Anzeiger, 281, 11–15. https://doi.org/10.1016/j.jcz.2019.05.001

Mos, J., & Hofmeester, T. R. (2020). The Mostela: An adjusted camera trapping device as a promising non-invasive tool to study and monitor small mustelids. Mammal Research, 65(4), 843–853. https://doi.org/10.1007/s13364-020-00513-y

Musila, S., Cheng, Z.-Z., Li, Q., Yego, R., Zhang, B., Onditi, K., Muthoni, I., He, S.-W., Omondi, S., Mathenge, J., N. Kioko, E., & Jiang, X.-L. (2019). Diversity and distribution patterns of non-volant small mammals along different elevation gradients on Mt. Kenya, Kenya. Zoological Research, 40(1), 53–60. https://doi.org/10.24272/j.issn.2095-8137.2019.004

Nor, S. (2001). Elevational diversity patterns of small mammals on Mount Kinabalu, Sabah, Malaysia. Global Ecology, 22.

O'Connell, A. F., Nichols, J. D., & Karanth, K. U. (Eds.). (2011). Camera Traps in Animal Ecology: Methods and Analyses. Springer. https://doi.org/10.1007/978-4-431-99495-4

Oli, M. K., & Dobson, F. S. (1999). Population Cycles in Small Mammals: The Role of Age at Sexual Maturity. Oikos, 86(3), 557. https://doi.org/10.2307/3546660

Oli, M. K., & Dobson, F. S. (2001). Population Cycles in Small Mammals: The -Hypothesis. Journal of Mammalogy, 82(2), 573–581. https://doi.org/10.1093/jmammal/82.2.573

Pruitt, W. O. (1959). Microclimates and Local Distribution of Small Mammals on the George Reserve, Michigan. 109.

Rovero, F., Martin, E., Rosa, M., Ahumada, J. A., & Spitale, D. (2014). Estimating Species Richness and Modelling Habitat Preferences of Tropical Forest Mammals from Camera Trap Data. PLoS ONE, 9(7), e103300. https://doi.org/10.1371/journal.pone.0103300

Rowe, R. J. (2009). Environmental and geometric drivers of small mammal diversity along elevational gradients in Utah. Ecography, 32, 411–422.

Rowe, R. J., & Terry, R. C. (2014). Small mammal responses to environmental change: Integrating past and present dynamics. Journal of Mammalogy, 95(6), 1157–1174. https://doi.org/10.1644/13-MAMM-S-079

Sakane, K. K., Percequillo, A. R., & Setz, E. Z. F. (2019). Community of small mammals along an elevational gradient in Biological Reserve of Serra do Japi, municipality of Jundiaí-SP, Brazil. Austral Ecology, 44(7), 1236–1244. https://doi.org/10.1111/aec.12801

Sigsgaard, E. E., Carl, H., Møller, P. R., & Thomsen, P. F. (2015). Monitoring the near-extinct European weather loach in Denmark based on environmental DNA from water samples. Biological Conservation, 183, 46–52. https://doi.org/10.1016/j.biocon.2014.11.023

Sun, J., Wen, Z., Feijó, A., Cheng, J., Wang, Y., Li, S., Ge, D., Xia, L., & Yang, Q. (2020). Elevation patterns and critical environmental drivers of the taxonomic, functional, and phylogenetic diversity of small mammals in a karst mountain area. Ecology and Evolution, 10(19), 10899–10911. https://doi.org/10.1002/ece3.6750

Thomsen, P. F., & Willerslev, E. (2015). Environmental DNA – An emerging tool in conservation for monitoring past and present biodiversity. Biological Conservation, 183, 4–18. https://doi.org/10.1016/j.biocon.2014.11.019

Torre, I., & Arrizabalaga, A. (2009). Species richness and abundance of small mammals along an elevation gradient of a mediterranean mountain. Vie Milieu, 199–208.

Veilleux, H. D., Misutka, M. D., & Glover, C. N. (2021). Environmental DNA and environmental RNA: Current and prospective applications for biological monitoring. Science of The Total Environment, 782. https://doi.org/10.1016/j.scitotenv.2021.146891

Williams, S. E., Marsh, H., & Winter, J. (2002). Spatial scale, species diversity, and habitat structure: Small mammals in australian tropical rain forest. Ecology, 83(5), 1317–1329. https://doi.org/10.1890/0012-9658(2002)083[1317:SSSDAH]2.0.CO;2

Wu, Y., Yang, Q., Wen, Z., Xia, L., Zhang, Q., & Zhou, H. (2013). What drives the species richness patterns of non-volant small mammals along a subtropical elevational gradient? Ecography, 36(2), 185–196. https://doi.org/10.1111/j.1600-0587.2011.07132.x

# Appendix I: List of all observed species

*Compiled by Jürgen Dengler, Jamyra Gehler & Hallie Seiler*

The following pages provide a list of all taxa that have been recorded in the permanent plots and in the other student research projects, plus some observations from along the trails. The observed taxa include vascular plants (nomenclature Juillerat et al. 2017), orthoptera, lepidoptera, birds, reptiles, amphibians, mammals (nomenclature CSCF-karch 2017), fungi, lichens and myxomycota (nomenclature Index Fungorum Partnerniship 2020). They are arranged into six geographical units: “Around Sonnenhof including alluvial plain,”, “Trail to Lai da Palpuogna,” “Val Mulix” above and below the tree line and “Val Zavretta” above and below the treeline. Very few species could not be assigned post hoc to one of the sites; these are shown in blue text.

The list summarizes the findings of the Summer Schools 2019–2021. If a species was recorded in 2021, it is marked with a capital “X” in boldface. Uncertain observations (“cf.”) are also shown in boldface if they were recorded in 2021. Since the inception of the Summer School in Preda in 2019, we have recorded a total of 994 taxa as follows:

| **Species group** | ***Page*** | **Total** | **New for 2021** |
|---|---|---|---|
| Tracheophyta | *79* | 525 | 49 |
| Fungi and lichens | *91* | 352 | 133 |
| Myxomycota | *99* | 3 | 3 |
| Orthoptera | *99* | 13 | 5 |
| Lepidoptera | *99* | 26 | 11 |
| Aves | *100* | 55 | 17 |
| Mammalia | *101* | 18 | 2 |
| Reptilia, amphibia | *102* | 2 | 2 |

## Nomenclature

Index Fungorum Partnership 2020. *Index Fungorum*. Royal Botanic Gardens, Kew. URL: http://www.indexfungorum.org/Index.htm [accessed on 22.04.2022]

info fauna CSCF, Koordinationsstelle für Amphibien karch (eds.) 2017. Data server CSCF-karch: Mammals. URL: https://lepus.unine.ch/tab/index.php?groupe=CAPTMAM&TypeRequete=ListeEspece&TypeUnite=suisse [accessed on 22.04.2022]

info fauna CSCF, Koordinationsstelle für Amphibien karch (eds.) 2017. Data server CSCF-karch: Orthoptera. URL: https://lepus.unine.ch/tab/index.php?groupe=CAPTORTH&TypeRequete=ListeEspece&TypeUnite=suisse [accessed on 22.04.2022]

info fauna CSCF, Koordinationsstelle für Amphibien karch (eds.) 2017. Data server CSCF-karch: Lepidoptera. URL: https://lepus.unine.ch/tab/index.php?groupe=CAPTPAP&TypeRequete=ListeEspece&TypeUnite=suisse [accessed on 22.04.2022]

Juillerat, P., Bäumler, B, Bornand, C., Eggenberg, S., Gygax, A., Jutzi, M., Möhl, A., Nyffeler, R., Sager, L. & Santiago, H. 2017. *Flora Helvetica Checklist 2017 der Gefässpflanzenflora der Schweiz*. Info Flora, Bern, CH.

Volet, B. 2016. Checklist oft he birds of Switzerland. Ornithol. Beob. 113: 205–234.

| Scientific name | Common name (opt.) | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| **Tracheophyta** | | | | | | | |
| *Achillea atrata* | | | | | | | x |
| *Achillea millefolium aggr.* | | **X** | x | x | | | |
| *Achillea nana* | | **X** | x | **X** | | | |
| *Achillea sp.* | | | x | | | | |
| *Aconitum lycoctonum* | | **X** | x | **X** | | | |
| *Aconitum lycoctonum subsp. neapolitanum* | | | x | x | | | |
| *Aconitum lycoctonum subsp. vulparia* | | | | x | | | |
| *Aconitum napellus* | | x | x | x | | | |
| *Aconitum napellus subsp. vulgare* | | | x | | | | |
| *Aconitum sp.* | | | | cf. | | | |
| *Aconitum variegatum subsp. paniculatum* | | | | x | | | |
| *Adenostyles alliariae* | | | x | x | | | |
| *Adenostyles leucophylla* | | **X** | | **X** | | | |
| *Aegopodium podagraria* | | x | | | | | |
| *Agrostis alpina* | | | | | | | x |
| *Agrostis capillaris* | | x | x | x | | | |
| *Agrostis gigantea* | | x | | | | | |
| *Agrostis rupestris* | | **X** | | **X** | | | x |
| *Agrostis schleicheri* | | | | x | | | x |
| *Agrostis schraderiana* | | **X** | x | **X** | | | |
| *Agrostis sp.* | | **X** | x | **X** | | | |
| *Agrostis stolonifera* | | **X** | x | **X** | | | |
| *Ajuga genevensis* | | **X** | x | | | | |
| *Ajuga pyramidalis* | | **X** | x | **X** | | | |
| *Alchemilla alpina aggr. s.l.* | | **X** | **X** | **X** | | | |
| *Alchemilla sp.* | | | | x | | | |
| *Alchemilla splendens aggr.* | | | | x | | | |
| *Alchemilla vulgaris aggr. s.l.* | | **X** | x | **X** | | | |
| *Alliaria petiolata* | | **cf.** | | | | | |
| *Alnus viridis* | | **X** | **X** | | | | |
| *Androsace chamaejasme* | | **X** | | **X** | | | x |
| *Androsace obtusifolia* | | | | x | | | |
| *Anemone narcissiflora* | | | | | | | x |
| *Antennaria dioica* | | | | | | | x |
| *Anthoxanthum alpinum* | | | | cf. | | | |
| *Anthoxanthum odoratum* | | x | x | x | | | |
| *Anthoxanthum odoratum aggr.* | | **X** | **X** | **X** | | | |
| *Anthriscus nitida* | | | x | | | | |
| *Anthyllis vulneraria* | | x | x | | | | x |
| *Anthyllis vulneraria subsp. alpestris* | | **cf.** | x | x | | | x |
| *Aquilegia alpina* | | | | | | | x |
| *Aquilegia atrata* | | | | | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Aquilegia vulgaris* | | | | | | x | |
| *Arabis bellidifolia subsp. stellulata* | | | | | | | x |
| *Arabis caerulea* | | **X** | x | **X** | | | |
| *Arabis subcoriacea* | | x | | | | | |
| *Arctostaphylos alpina* | | | | | | | x |
| *Arctostaphylos uva-ursi* | | x | x | | | | x |
| *Arnica montana* | | **X** | x | **X** | | | |
| *Arrhenatherum elatius* | | | x | | | | |
| *Artemisia genipi* | | | | | | | x |
| *Asplenium viride* | | | cf. | | | | x |
| *Aster bellidiastrum* | | **X** | x | **X** | x | | x |
| *Asteraceae* | | x | | x | | | |
| *Astragalus alpinus* | | **X** | x | **X** | | | |
| *Astragalus penduliflorus* | | | x | | | | |
| *Astrantia major* | | x | | | | | |
| *Athyrium distentifolium* | | | | x | | | |
| *Avenella flexuosa* | | **X** | **X** | **X** | | | |
| *Bartsia alpina* | | **X** | x | **X** | | | x |
| *Biscutella laevigata* | | **X** | x | **X** | | | |
| *Botrychium lunaria* | | **X** | x | **X** | | | |
| *Briza media* | | **X** | x | **X** | | | |
| *Calamagrostis epigejos* | | | x | | | | |
| *Calamagrostis varia* | | x | x | | | x | x |
| *Calamagrostis villosa* | | **X** | **X** | **X** | | | |
| *Calluna vulgaris* | | **X** | x | **X** | | | |
| *Caltha palustris* | | **X** | x | **X** | | | |
| *Campanula barbata* | | **X** | **X** | **X** | | x | |
| *Campanula cenisia* | | | | | | | x |
| *Campanula cochleariifolia* | | **X** | | | | | |
| *Campanula rotundifolia* | | | x | x | | | |
| *Campanula scheuchzeri* | | **X** | x | **X** | | | x |
| *Cardamine amara* | | x | | | | | |
| *Carduus defloratus* | | **X** | x | **X** | | x | x |
| *Carduus defloratus subsp. defloratus* | | **X** | | | | | |
| *Carex alba* | | | | | | x | |
| *Carex atrata subsp. aterrima* | | | | x | | | |
| *Carex atrata subsp. atrata* | | | x | | | | x |
| *Carex capillaris* | | x | | | | | |
| *Carex caryophyllea* | | **X** | | | | | |
| *Carex curvula* | | **X** | | **X** | | | |
| *Carex davalliana* | | **X** | x | **X** | | | |
| *Carex digitata* | | | x | x | | | |
| *Carex elata* | | x | | | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Carex ferruginea* | | **X** | | **X** | | | x |
| *Carex firma* | | **X** | | **X** | | | x |
| *Carex flacca* | | **X** | x | **X** | | x | x |
| *Carex flava* | | **X** | x | **X** | | | |
| *Carex flava subsp. flava* | | x | | | | | |
| *Carex frigida* | | | | cf. | | | |
| *Carex lepidocarpa* | | x | x | | | | |
| *Carex leporina* | | | x | | | | |
| *Carex montana* | | **X** | | | | x | |
| *Carex nigra* | | **X** | | **X** | | | |
| *Carex ornithopoda* | | **X** | **X** | **X** | | x | x |
| *Carex pallescens* | | | x | **X** | | | |
| *Carex panicea* | | x | | | | | |
| *Carex paniculata* | | x | | | | | |
| *Carex pilulifera* | | | | cf. | | | |
| *Carex pilulifera* | | | | cf. | | | |
| *Carex sempervirens* | | **X** | x | **X** | | x | x |
| *Carlina acaulis* | | **X** | x | | | | x |
| *Caryophyllaceae* | | cf. | | | | | |
| *Centaurea nervosa* | | **X** | x | | | | |
| *Centaurea scabiosa* | | x | x | | | | |
| *Centaurea scabiosa subsp. scabiosa* | | **X** | | | | | |
| *Cerastium alpinum* | | | | | | | x |
| *Cerastium arvense* | | **X** | | **X** | | | |
| *Cerastium arvense subsp. strictum* | | | x | | | | |
| *Cerastium fontanum* | | x | | x | | | |
| *Cerastium fontanum subsp. fontanum* | | | | x | | | |
| *Cerastium fontanum subsp. vulgare* | | | x | | | | |
| *Cerastium latifolium* | | | | | | | cf. |
| *Cerastium uniflorum* | | | x | | | | |
| *Chaerophyllum hirsutum* | | **X** | x | **X** | | x | |
| *Chaerophyllum villarsii* | | **X** | **X** | cf. | | | |
| *Chamorchis alpina* | | **X** | | **X** | | | |
| *Chenopodium bonus-henricus* | | x | x | | | | |
| *Cirsium helenioides* | | **X** | **X** | **X** | | | |
| *Cirsium oleraceum* | | **X** | x | | | | |
| *Cirsium spinosissimum* | | **X** | | **X** | | | |
| *Coeloglossum viride* | | | x | x | | | x |
| *Corallorhiza trifida* | | **X** | | | | | |
| *Cotoneaster integerrimus* | | **X** | **X** | | | | |
| *Crepis alpestris* | | **X** | | **X** | | | x |
| *Crepis aurea* | | | | x | | | x |
| *Crepis bocconeii* | | | x | | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Crepis conycifolia* | | | x | | | | |
| *Crepis foetida* | | | | x | | | |
| *Crepis kerneri* | | | | | | | x |
| *Crepis paludosa* | | **X** | x | **X** | | | |
| *Cystopteris alpina* | | x | | | | | |
| *Cystopteris fragilis aggr.* | | **X** | x | **X** | | | |
| *Dactylis glomerata* | | **X** | x | x | | | |
| *Dactylorhiza incarnata* | | x | x | | | | |
| *Dactylorhiza maculata* | | **X** | x | **X** | | | |
| *Dactylorhiza maculata subsp. fuchsii* | | | x | | | | |
| *Dactylorhiza majalis* | | x | x | x | | | |
| *Dactylorhiza sp.* | | x | | | | | |
| *Daphne mezereum* | | | x | | | | |
| *Daphne striata* | | | | x | | x | x |
| *Deschampsia cespitosa* | | **X** | x | **X** | | | |
| *Dianthus superbus* | | x | x | | | | |
| *Diphasiastrum alpinum* | | | | x | | | |
| *Doronicum clusii* | | | | x | | | |
| *Draba aizoides* | | | | | | | x |
| *Draba fladnizensis* | | | x | | | | |
| *Draba hoppeana* | | | | | | | x |
| *Dryas octopetala* | | **X** | x | **X** | | | x |
| *Dryopteris carthusiana* | | | x | | | | |
| *Dryopteris dilatata aggr.* | | **X** | **X** | | | | |
| *Elyna myosuroides* | | x | | | | | |
| *Empetrum nigrum* | | **X** | **X** | **X** | | | |
| *Empetrum nigrum subsp. hermaphroditum* | | | | x | | | |
| *Epilobium (small)* | | | x | | | | |
| *Epilobium 2 (big)* | | | x | | | | |
| *Epilobium alsinifolium* | | x | | | | | |
| *Epilobium angustifolium* | | **X** | x | **X** | | | |
| *Epilobium fleischeri* | | **X** | x | **X** | | | |
| *Epipactis atrorubens* | | **X** | | | | x | |
| *Equisetum hyemale* | | **X** | | **X** | | | |
| *Equisetum palustre* | | x | | | | | |
| *Equisetum variegatum* | | **X** | x | **X** | | | |
| *Erica carnea* | | **X** | x | **X** | | x | x |
| *Erigeron alpinus aggr.* | | | | | | | x |
| *Eriophorum angustifolium* | | x | | | | | |
| *Eriophorum scheuchzeri* | | | | x | | | |
| *Euphorbia cyparissias* | | **X** | x | **X** | | x | |
| *Euphrasia minima* | | **X** | | **X** | | | |
| *Euphrasia minima aggr.* | | | x | x | | | x |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Euphrasia picta* | | x | | | | | |
| *Euphrasia rostkoviana* | | **X** | x | cf. | | | |
| *Euphrasia rostkoviana aggr.* | | **X** | x | **X** | | | |
| *Euphrasia rostkoviana subsp. rostkoviana* | | | | x | | | |
| *Euphrasia salisburgensis* | | **X** | | **X** | | | x |
| *Euphrasia sp.* | | | | x | | | |
| *Festuca nigrescens* | | x | | x | | | |
| *Festuca nigrescens aggr.* | | x | | | | | |
| *Festuca pulchella* | | **X** | x | **X** | | | x |
| *Festuca pulchella subsp. pulchella* | | **X** | | | | | |
| *Festuca quadriflora* | | | | | | | x |
| *Festuca rubra* | | x | x | x | | | |
| *Festuca rubra aggr.* | | **X** | **X** | **X** | | x | |
| *Festuca violacea aggr.* | | **X** | | **X** | | | |
| *Fragaria vesca* | | **X** | **X** | | | x | |
| *Galeopsis tetrahit* | | | x | | | | |
| *Galium album* | | x | | | | | |
| *Galium anisophyllon* | | x | x | x | | | x |
| *Galium boreale* | | **X** | x | **X** | | | |
| *Galium lucidum* | | **X** | | **X** | | | |
| *Galium pumilum* | | x | | | | | |
| *Galium pumilum aggr.* | | **X** | **X** | **X** | | | |
| *Gentiana acaulis* | | **X** | x | **X** | | | |
| *Gentiana asclepiadea* | | **X** | x | **X** | | | |
| *Gentiana bavarica* | | **X** | | **X** | | | |
| *Gentiana bavarica subsp. bavarica* | | | | x | | | |
| *Gentiana brachyphylla* | | | | x | | | |
| *Gentiana campestris* | | **X** | x | **X** | | | x |
| *Gentiana clusii* | | **X** | | | | | x |
| *Gentiana germanica* | | **X** | | **X** | | | |
| *Gentiana lutea* | | **X** | x | **X** | | | |
| *Gentiana nivalis* | | **X** | x | **X** | | | |
| *Gentiana punctata* | | **X** | x | **X** | | | |
| *Gentiana ramosa* | | | | x | | | |
| *Gentiana sp.* | | | | x | | | |
| *Gentiana utriculosa* | | x | | | | | |
| *Gentiana verna* | | | | x | | | |
| *Geranium sylvaticum* | | **X** | **X** | **X** | | | |
| *Geum montanum* | | **X** | x | **X** | | | |
| *Geum reptans* | | | | **X** | | | |
| *Geum rivale* | | **X** | | **X** | | | |
| *Globularia cordifolia* | | | | | | | x |
| *Globularia nudicaulis* | | | | | | | x |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Gnaphalium supinum* | | **X** | | **X** | | | |
| *Gnaphalium uliginosum* | | **X** | | **X** | | | |
| *Gymnadenia conopsea* | | **X** | x | **X** | | | x |
| *Gymnadenia odoratissima* | | **X** | x | | | | x |
| *Gypsophila repens* | | **X** | x | **X** | | | x |
| *Hedysarum hedysaroides* | | | | x | | | x |
| *Helianthemum alpestre* | | **X** | x | **X** | | | x |
| *Helianthemum nummularium* | | **X** | x | **X** | | | x |
| *Helianthemum nummularium subsp. grandiflorum* | | | | | | | x |
| *Helianthemum nummularium subsp. obscurum* | | x | x | | | | |
| *Helictotrichon pubescens* | | **X** | | | | | |
| *Helictotrichon pubescens subsp. laevigatum* | | x | | | | | |
| *Helictotrichon versicolor* | | **X** | x | **X** | | | |
| *Hepatica nobilis* | | | | | | x | |
| *Heracleum sphondylium* | | **X** | x | **X** | | | |
| *Hieracium alpinum* | | **X** | | **X** | | | |
| *Hieracium hoppeanum* | | cf. | | | | | |
| *Hieracium lachenalii* | | **X** | **X** | | | | |
| *Hieracium lactucella* | | | | x | | | |
| *Hieracium murorum aggr.* | | **X** | **X** | **X** | | x | x |
| *Hieracium piliferum* | | | | x | | x | |
| *Hieracium pilosella* | | **X** | x | **X** | | | |
| *Hieracium pilosum* | | **X** | x | | | | x |
| *Hieracium sp.* | | | | x | | | |
| *Hieracium villosum aggr.* | | | | x | | | x |
| *Hippocrepis comosa* | | x | | | | x | x |
| *Homogyne alpina* | | **X** | **X** | **X** | | x | x |
| *Huperzia selago* | | x | | **X** | | | |
| *Hypochaeris uniflora* | | | | **X** | | | |
| *Juncus alpinoarticulatus* | | x | | | | | |
| *Juncus articulatus aggr.* | | **X** | x | **X** | | | |
| *Juncus jacquinii* | | x | | x | | | |
| *Juncus trifidus* | | | | x | | | |
| *Juncus triglumis* | | | x | | | | |
| *Juniperus communis* | | | x | x | | | |
| *Juniperus communis subsp. alpina* | | **X** | **X** | **X** | | | x |
| *Knautia arvensis* | | x | | | | | |
| *Knautia dipsacifolia* | | **X** | **X** | **X** | | x | |
| *Koeleria pyramidata* | | x | | | | | |
| *Lamiaceae* | | | x | | | | |
| *Larix decidua* | | x | x | | | | |
| *Laserpitium gaudinii* | | | **X** | | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Laserpitium latifolium* | | x | x | | | x | x |
| *Lathyrus pratensis* | | x | | | | | |
| *Lentopodium nivale* | | | | | | | x |
| *Leontodon helveticus* | | **X** | **X** | **X** | | | x |
| *Leontodon hispidus* | | **X** | x | **X** | | | x |
| *Leontodon hispidus subsp. danubialis* | | | x | | | x | |
| *Leontodon hispidus subsp. hispidus* | | x | x | | | | x |
| *Leontodon hispidus subsp. pseudocrispus* | | | x | | | | |
| *Leontodon incanus* | | | | x | | | x |
| *Leontodon incanus subsp. incanus* | | **X** | | | | | |
| *Leontodon montanus* | | | | cf. | | | |
| *Leontodon sp.* | | | | x | | | |
| *Leontopodium alpinum* | | | | | | | x |
| *Leontopodium nivale* | | | | | | | x |
| *Leucanthemopsis alpina* | | | | **X** | | | |
| *Leucanthemopsis alpina subsp. alpina* | | | | x | | | |
| *Leucanthemopsis alpina subsp. minima* | | | | | | | x |
| *Leucanthemum adustum* | | x | x | x | | x | x |
| *Leucanthemum vulgare aggr.* | | **X** | x | **X** | | | |
| *Ligusticum mutellina* | | | x | **X** | | | x |
| *Ligusticum mutellinoides* | | | x | x | | | |
| *Lilium martagon* | | x | x | | | | |
| *Linaria alpina* | | x | | x | | | x |
| *Linnea borealis* | | | x | | | | |
| *Linum catharticum* | | **X** | x | **X** | | | x |
| *Listera cordata* | | **X** | | | | | |
| *Listera ovata* | | **X** | x | **X** | | x | |
| *Loiseleuria procumbens* | | | | **X** | | | |
| *Lolium multiflorum* | | | | cf. | | | |
| *Lonicera caerulea* | | **X** | **X** | **X** | | | |
| *Lonicera nigra* | | | | | | x | |
| *Lonicera xylosteum* | | | x | | | | |
| *Lotus alpinus* | | x | x | x | | | x |
| *Lotus corniculatus* | | x | x | x | | | |
| *Lotus corniculatus aggr.* | | **X** | **X** | **X** | | x | x |
| *Luzula alpina* | | x | x | x | | | |
| *Luzula alpinopilosa* | | | | **X** | | | |
| *Luzula lutea* | | | x | **X** | | | |
| *Luzula luzulina* | | | x | | | | |
| *Luzula luzuloides* | | | **X** | | | | |
| *Luzula luzuloides subsp. rubella* | | x | x | | | | |
| *Luzula multiflora* | | | x | **X** | | | |
| *Luzula nivea* | | | | **X** | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Luzula pilosa* | | | | | | | x |
| *Luzula sieberi* | | x | x | | | | x |
| *Luzula sp.* | | | x | | | | |
| *Luzula spicata* | | | | **X** | | | |
| *Luzula spicata subsp. mutabilis* | | | x | | | | |
| *Luzula sudetica* | | x | | cf. | | | |
| *Luzula sylvatica* | | | x | | | | |
| *Lycopodium sp.* | | | | x | | | |
| *Maianthemum bifolium* | | | x | | | | |
| *Medicago lupulina* | | x | | | | | |
| *Medicago sativa* | | x | | | | | |
| *Melampyrum pratense* | | **X** | x | **X** | | | |
| *Melampyrum sylvaticum* | | **X** | x | **X** | | x | |
| *Melica nutans* | | x | | | | x | |
| *Moeheringia ciliata* | | | | | | | x |
| *Moehringia trinervia* | | | x | | | | |
| *Molinea caerulea* | | x | x | | | | |
| *Molinia caerulea* | | x | x | | | | |
| *Molinia caerulea aggr.* | | **X** | | **X** | | | |
| *Moneses uniflora* | | **X** | x | | | | |
| *Myosotis* | | | | x | | | |
| *Myosotis alpestris* | | | x | **X** | | | x |
| *Myosotis alpina* | | | | x | | | |
| *Myosoton aquaticum* | | x | | | | | |
| *Nardus stricta* | | x | x | **X** | | | |
| *Orchidaceae* | | | | x | | | |
| *Orchidaceae 2* | | | x | | | | |
| *Orthilia secunda* | | **X** | x | x | | | |
| *Oxalis acetosella* | | **X** | **X** | | | | |
| *Oxyria digyna* | | | | x | | | x |
| *Oxytropis campestris* | | **X** | x | **X** | | | |
| *Oxytropis campestris subsp. campestris* | | **X** | | | | | |
| *Parnassia palustris* | | **X** | x | **X** | | | x |
| *Pedicularis rostratocapitata* | | | | **X** | | | |
| *Pedicularis rostratospicata* | | | | x | | | |
| *Pedicularis rostratospicata subsp. helvetica* | | | | x | | | |
| *Pedicularis sp.* | | | cf. | **X** | | | |
| *Pedicularis tuberosus* | | | | **X** | | | |
| *Pedicularis verticillata* | | | | | | | x |
| *Petasites paradoxus* | | **X** | x | **X** | | | |
| *Peucedanum ostruthium* | | | x | **X** | | | |
| *Phleum alpinum aggr.* | | | | **X** | | | |
| *Phleum hirsutum* | | | | | | | x |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Phleum rhaeticum* | | x | x | x | | x | |
| *Phyteuma betonicifolium* | | **X** | **X** | **X** | | | x |
| *Phyteuma hemisphaericum* | | | | **X** | | | |
| *Phyteuma orbiculare* | | **X** | x | **X** | | | x |
| *Phyteuma scheuchzeri* | | | x | | | | |
| *Picea abies* | | **X** | x | **X** | | x | x |
| *Pimpinella major* | | x | x | | | | |
| *Pinguicula alpina* | | **X** | x | **X** | | | x |
| *Pinguicula vulgaris* | | x | | | | | |
| *Pinus cembra* | | x | **X** | | | x | x |
| *Pinus mugo* | | | x | | | | |
| *Pinus mugo subsp. mugo* | | | x | | | | |
| *Pinus mugo subsp. uncinata* | | **X** | x | **X** | | x | |
| *Pinus sylvestris* | | **X** | | | | | |
| *Plantago alpina* | | x | x | x | | | |
| *Plantago atrata* | | | x | **X** | | | |
| *Plantago lanceolata* | | x | | | | | |
| *Plantago major subsp. major* | | x | | | | | |
| *Plantago media* | | | x | | | | |
| *Plantago serpentina aggr.* | | | | **X** | | | |
| *Poa alpina* | | **X** | x | **X** | | | x |
| *Poa minor* | | | | | | | x |
| *Poa pratensis* | | x | x | | | | |
| *Poa pratensis aggr.* | | **X** | x | | | | |
| *Poa sp.* | | | x | **X** | | | |
| *Poa trivialis* | | x | | | | | |
| *Poaceae* | | | x | | | | |
| *Polygala alpestris* | | x | x | | | | x |
| *Polygala amara aggr.* | | | | x | | | |
| *Polygala amarella* | | **X** | | **X** | | | |
| *Polygala chamaebuxus* | | **X** | | **X** | | | x |
| *Polygala sp.* | | | | cf. | | | x |
| *Polygala vulgaris* | | **X** | x | **X** | | | |
| *Polygonatum verticillatum* | | | | | | x | |
| *Polygonum viviparum* | | **X** | x | **X** | | | x |
| *Polyommatus cordion* | | | | | | | x |
| *Potentilla aurea* | | **X** | x | **X** | | | |
| *Potentilla crantzii* | | x | x | x | | | x |
| *Potentilla erecta* | | **X** | **X** | **X** | | | |
| *Potentilla recta* | | | cf. | cf. | | | |
| *Prenanthes purpurea* | | | x | | | | |
| *Primula farinosa* | | **X** | x | **X** | | | x |
| *Primula hirsuta* | | | | x | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Primula integrifolia* | | | | **X** | | | x |
| *Primula latifolia* | | | | x | | | |
| *Primula sp.* | | | | x | | | |
| *Pritzelago alpina subsp. alpina* | | | | | | | x |
| *Prunella grandiflora* | | x | | | | | |
| *Prunella vulgaris* | | | x | **X** | | | |
| *Pseudorchis albida* | | | | x | | | |
| *Pulmonaria australis* | | | **X** | | | | |
| *Pulsatilla alpina* | | | | **X** | | | |
| *Pulsatilla alpina subsp. apiifolia* | | | | x | | | |
| *Pulsatilla alpine subsp. alpestris* | | | | | | | x |
| *Pyrola minor* | | **X** | | **X** | | | x |
| *Pyrola rotundifolia* | | x | x | x | | | x |
| *Pyrola sp.* | | | | x | | | |
| *Ranuculus montanus aggr.* | | **X** | | **X** | | | |
| *Ranunculus acris* | | | x | **X** | | | |
| *Ranunculus alpestris* | | | | | | | x |
| *Ranunculus bryenius* | | | | | | | x |
| *Ranunculus montanus* | | x | x | x | | | x |
| *Ranunculus montanus aggr.* | | x | x | x | | | |
| *Ranunculus sp.* | | x | | x | | | |
| *Ranunculus thora* | | | | | | | x |
| *Ranunculus villarsii* | | | | x | | | |
| *Rhinanthus alectorolophus* | | x | | | | | |
| *Rhinanthus glacialis* | | | x | | | | |
| *Rhinanthus minor* | | x | x | x | | | |
| *Rhododendron ferrugineum* | | | **X** | **X** | | | |
| *Rhododendron hirsutum* | | | | | | | x |
| *Ribes petraeum* | | **X** | | | | | |
| *Rosa pendulina* | | x | **X** | | | | |
| *Rubus caesius* | | | x | | | | |
| *Rubus idaeus* | | | **X** | | | | |
| *Rubus saxatilis* | | x | **X** | | | x | |
| *Rumex acetosella* | | | x | | | | |
| *Rumex obtusifolius* | | x | x | | | | |
| *Rumex scutatus* | | | x | **X** | | | |
| *Salix appendiculata* | | **X** | x | **X** | | | |
| *Salix breviserrata* | | | | x | | | |
| *Salix caesia* | | x | x | | | | |
| *Salix foetida* | | x | x | | | | |
| *Salix herbacea* | | | | **X** | | | |
| *Salix myrsinifolia* | | **X** | x | **X** | | | x |
| *Salix myrsinifolia subsp. myrsinifolia* | | **X** | | | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Salix purpurea* | | **X** | x | **X** | | | |
| *Salix repens* | | x | | | | | |
| *Salix reticulata* | | | | | | | x |
| *Salix retusa* | | | | **X** | | | x |
| *Salix waldsteiniana* | | | | x | | | |
| *Sanguisorba officinalis* | | **X** | x | **X** | | | |
| *Saussurea alpina* | | | x | **X** | | | |
| *Saxifraga aizoides* | | **X** | x | **X** | | | x |
| *Saxifraga bryoides* | | | | **X** | | | |
| *Saxifraga caesia* | | | | | | | x |
| *Saxifraga paniculata* | | | | x | | | x |
| *Saxifraga rotundifolia* | | | x | | | | |
| *Saxifraga sp.* | | x | | | | | |
| *Saxifraga stellaris* | | x | | | | | |
| *Scabiosa columbaria aggr.* | | **X** | x | **X** | | | |
| *Scabiosa lucida* | | x | | | | | x |
| *Sedum sp.* | | | | x | | | x |
| *Sedum villosum* | | | | cf. | | | cf. |
| *Selaginella selaginoides* | | **X** | x | **X** | | | x |
| *Sempervivum montanum* | | | x | **X** | | | |
| *Sempervivum sp.* | | | | x | | | |
| *Senecio abrotanifolius* | | | | | | | x |
| *Senecio doronicum* | | | x | **X** | | | x |
| *Senecio hercynicus* | | | x | | | | |
| *Senecio incanus* | | | | **X** | | | |
| *Senecio incanus subsp. carniolicus* | | | | x | | | |
| *Senecio ovatus aggr.* | | | **X** | | | | |
| *Senecio rupestris* | | x | | | | | |
| *Senecio vulgaris* | | **X** | | **X** | | | |
| *Sesleria caerulea* | | **X** | x | **X** | | x | x |
| *Sibbaldia procumbens* | | | x | | | | |
| *Silene acaulis* | | | | | | | x |
| *Silene dioica* | | **X** | | **X** | | | |
| *Silene nutans* | | | cf. | | | | |
| *Silene nutans subsp. nutans* | | | | | | | x |
| *Silene pratensis* | | x | x | | | | |
| *Silene rupestris* | | | | **X** | | | |
| *Silene vulgaris* | | x | x | x | | | |
| *Silene vulgaris subsp. vulgaris* | | **X** | x | **X** | | | x |
| *Soldanella alpina* | | x | | | | | x |
| *Soldanella pusilla* | | | x | **X** | | | x |
| *Soldanella sp.* | | | | x | | | |
| *Solidago virgaurea* | | **X** | **X** | **X** | | x | x |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Sorbus aucuparia* | | | **X** | | | | |
| *Stellaria nemorum* | | | x | | | | |
| *Succisa pratensis* | | **X** | | **X** | | | |
| *Taraxacum officinale aggr.* | | **X** | x | **X** | | | |
| *Taraxacum palustre aggr.* | | **X** | | | | | |
| *Taraxacum sp.* | | | | **X** | | | x |
| *Thalictrum aquilegiifolium* | | | x | x | | | |
| *Thalictrum minus* | | | | | | x | |
| *Thesium alpinum* | | **X** | **X** | **X** | | | x |
| *Thesium pyrenaicum* | | **X** | x | **X** | | | |
| *Thymus alpestris* | | x | x | x | | | |
| *Thymus praecox subsp. polytrichus* | | x | x | | | | x |
| *Thymus praecox subsp. praecox* | | x | x | x | | x | x |
| *Thymus pulegioides* | | x | | | | | |
| *Thymus pulegioides subsp. pulegioides* | | | x | | | | |
| *Thymus serpyllum aggr.* | | **X** | **X** | **X** | | | |
| *Thymus sp.* | | x | | | | | |
| *Tofieldia calyculata* | | **X** | x | **X** | | | x |
| *Trichophorum cespitosum* | | x | x | **X** | | | |
| *Trifolium alpinum* | | | x | **X** | | | |
| *Trifolium aureum* | | | cf. | | | | |
| *Trifolium badium* | | | x | **X** | | | |
| *Trifolium medium* | | x | | | | | |
| *Trifolium montanum* | | x | | | | | |
| *Trifolium pratense* | | **X** | x | **X** | | | |
| *Trifolium pratense subsp. nivale* | | | x | x | | | |
| *Trifolium pratense subsp. pratense* | | | x | x | | | x |
| *Trifolium repens* | | x | | **X** | | | |
| *Trifolium thalii* | | | x | **X** | | | |
| *Trollius europaeus* | | x | | **X** | | | x |
| *Tussilago farfara* | | **X** | x | **X** | | | |
| *Urtica dioica* | | x | x | | | | |
| *Vaccinium gaultherioides* | | | x | x | | | x |
| *Vaccinium gautelioides* | | x | | | | | |
| *Vaccinium myrtillus* | | **X** | **X** | **X** | | | |
| *Vaccinium uliginosum* | | x | | | | | |
| *Vaccinium uliginosum aggr.* | | x | **X** | **X** | | | |
| *Vaccinium vitis-idaea* | | x | **X** | **X** | | x | x |
| *Valeriana diversifolia* | | | x | | | | |
| *Valeriana montana* | | x | x | **X** | | x | |
| *Valeriana officinalis* | | | x | | | | |
| *Valeriana officinalis aggr.* | | | **X** | | | | |
| *Veratrum album* | | | x | **X** | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Veratrum album subsp. lobelianum* | | | x | | | | |
| *Veronica alpina* | | | | **X** | | | |
| *Veronica bellidioides* | | | | **X** | | | |
| *Veronica fruticans* | | | | x | | | |
| *Veronica officinalis* | | **X** | **X** | | | | |
| *Vicia cracca* | | **X** | x | **X** | | | |
| *Vicia cracca subsp. cracca* | | **X** | | | | | |
| *Vicia cracca subsp. incana* | | x | | | | | |
| *Vincetoxicum hirundinaria* | | **X** | | **X** | | | |
| *Viola biflora* | | **X** | **X** | **X** | | | |
| *Viola palustris* | | x | | | | | |
| *Viola sylvestris aggr.* | | | x | x | | | |
| **Fungi and Lichens** | | | | | | | |
| *Agaricus comtulus* | | | | x | | | |
| *Agaricus langei* | | | | | x | | |
| *Agaricus porphyrocephalus* | | | | x | | | |
| *Albatrellus ovinus* | | | **X** | | x | | |
| *Amanita battarae* | | | **X** | | | | |
| *Amanita muscaria* | | **X** | **X** | | | | |
| *Amanita nivalis* | | **X** | **X** | | | | |
| *Amanita submembranacea* | | | x | | x | | |
| *Amanita vaginata* | | | | x | | | |
| *Ambispora gerdemannii* | | | **X** | **X** | | | |
| *Ampulloclitocybe clavipes* | | | **X** | | | | |
| *Amylostereum areolatum* | | | x | | | | |
| *Anthracoidea caricis* | | | | **X** | | | |
| *Antracoidea sp.* | | | | **X** | | | |
| *Armillaria ostoyae or borealis* | | | x | | | | |
| *Armillaria ostoyae/borealis* | | | **X** | | | | |
| *Arrhenia subglobisemen* | | | | **X** | | | |
| *Ascobolus sp.* | | | | x | | | |
| *Ascocoryne colchinium* | | | **X** | | | | |
| *Aspergillus penicillioides* | | | **X** | **X** | | | |
| *Bankera violascens* | | | | x | | | |
| *Bisporella citrina* | | | **X** | | | | |
| *Bolbitius sp.* | | | | **X** | | | |
| *Boletus edulis* | | | **X** | | | | |
| *Bovista plumbea* | | | | x | | | |
| *Bovistella utriformis* | | | **X** | | | | |
| *Bryoglossum gracile* | | | | x | | | |
| *Caliciopsis pinea* | | | **X** | | | | |
| *Calocera viscosa* | | | | | x | | |
| *Calocybe carnea* | | | | x | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Calvatia utriformis* | | | x | | | | |
| *Candida albicans* | | | | **X** | | | |
| *Cantharellus cibarius* | | x | | | | | |
| *Cerocorticium sp.* | | | x | | | | |
| *Cetraria islandica* | | | **X** | | | | |
| *Chalciporus piperatus* | | x | x | | | | |
| *Cheilymenia stercorea* | | | **X** | **X** | | | |
| *Chroogomphus helveticus* | | **X** | **X** | | | | |
| *Chrysomyxa rhododendri* | | | **X** | | | | |
| *Cladoriella paleospora* | | | **X** | | | | |
| *Clavaria neonigrita* | | | **X** | | | | |
| *Clavaria vermicularis* | | | | x | | | |
| *Clavaria zollingeri* | | | | **X** | | | |
| *Clavulinopsis fusiformis* | | | | **X** | | | |
| *Clitocybe clavipes* | | | | | x | | |
| *Clitocybe diatreta* | | **X** | | | | | |
| *Clitocybe festvoides* | | | **X** | | | | |
| *Clitocybe gibba* | | | | | x | | |
| *Clitocybe gracilipes* | | | x | x | x | | |
| *Clitocybe inornata* | | | | | x | | |
| *Clitocybe odora* | | **X** | | | | | |
| *Clitocybe sp.* | | **X** | | | | | |
| *Clitopilus sp.* | | | | x | | | |
| *Coleosporium cacaliae* | | | | x | | | |
| *Coleosporium tussilaginis* | | **X** | **X** | **X** | | | |
| *Coleroa alchemillae* | | **X** | **X** | | | | |
| *Collybia cookei* | | | | | x | | |
| *Conlarium aquaticum* | | | | **X** | | | |
| *Conocybe fuscimarginata* | | | x | | | | |
| *Conocybe ochriostrata* | | | | x | | | |
| *Conocybe rickenii* | | **X** | | | | | |
| *Coprinopsis nivea* | | | | x | | | |
| *Coprinopsis patouillardii* | | | | x | | | |
| *Coprinopsis sp.* | | | | **X** | | | |
| *Coprinopsis sp. DNA 27* | | | | x | | | |
| *Coprinus niveus* | | | x | | | | |
| *Coprinus sp. DNA20* | | | | x | | | |
| *Coprinus tigrinellus* | | | | x | | | |
| *Coprobia granulata* | | | x | x | | | |
| *Cortinarius  distans* | | | x | | | | |
| *Cortinarius crassifolius* | | | x | | | | |
| *Cortinarius hemitrichus* | | | **X** | | | | |
| *Cortinarius sect. Phlegmacium* | | | | | x | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Cortinarius sp. DNA45* | | | x | | | | |
| *Cortinarius sp. DNA38* | | | | | x | | |
| *Crepidotus variabilis* | | | **X** | | | | |
| *Cryptodiscus epicladonia* | | | **X** | | | | |
| *Cudonia confusa* | | | **X** | | | | |
| *Cuphophyllus virgineus* | | | | **X** | | | |
| *Cystobasidiopsis lophatheri* | | | **X** | | | | |
| *Cystoderma amiantinum* | | | **X** | | | | |
| *Dacrymyces stillatus* | | | **X** | | x | | |
| *Deconica merdaria* | | | | **X** | | | |
| *Deconica montana* | | | **X** | **X** | | | |
| *Entoloma sp. DNA 19* | | | | x | | | |
| *Entoloma atromadidum* | | | | **X** | | | |
| *Entoloma cetratum* | | | **X** | | | | |
| *Entoloma conferendum f. rickenii* | | | **X** | | | | |
| *Entoloma jubatum* | | | **X** | **X** | | | |
| *Entoloma mugeotii* | | | x | | | | |
| *Entoloma seraticulum* | | | | x | | | |
| *Entoloma sericeum* | | | **X** | | | | |
| *Entoloma serrulatum* | | | **X** | **X** | | | |
| *Entoloma sodale* | | | | x | | | |
| *Entoloma sp. DNA 2* | | | | | x | | |
| *Entoloma sp. DNA 25* | | | | x | | | |
| *Entoloma vernum* | | | **X** | | | | |
| *Epibryon interlamellare* | | | **X** | **X** | | | |
| *Exidia candida var. cartilaginea* | | | **X** | | | | |
| *Exidia nigricans* | | | **X** | | | | |
| *Exidia plana* | | | x | | | | |
| *Exobasidium juelianum* | | | | x | | | |
| *Exobasidium myrtilli* | | | x | | | | |
| *Exobasidium rhododendri* | | | **X** | **X** | | | |
| *Exobasidium rhododendroni* | | | | | x | | |
| *Exobasidium splendidum* | | | **X** | | | | |
| *Exobasidium vaccini uliginosi* | | | x | x | | | |
| *Exobasidium vaccinii* | | | **X** | **X** | | | |
| *Fomes fomentarius* | | | | | x | | |
| *Galerina marginata* | | | **X** | | x | | |
| *Galerina paludosa* | | **X** | | | | | |
| *Gelidatrema spencermartinsiae* | | | **X** | | | | |
| *Gleophyllum abietinum* | | | x | | | | |
| *Gomphidius glutinosus* | | x | | | x | | |
| *Gymnopilus junonius* | | | | | x | | |
| *Gymnopus androsaceus* | | **X** | **X** | | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Gymnopus dryophilus* | | **X** | **X** | | | | |
| *Gymnopus dryophyla* | | | x | x | x | | |
| *Gymnopus ocior* | | | **X** | | | | |
| *Gymnosporangium cornutum* | | | x | | | | |
| *Hebeloma mesopheum* | | | | | x | | |
| *Hemimycena sp. DNA 23* | | | | x | | | |
| *Hydnellum caeruleum* | | | **X** | | | | |
| *Hydnellum concrescens/scrobiculatum* | | | x | | | | |
| *Hydnum repandum* | | x | | | | | |
| *Hygrocybe acutopunicea var.konradii* | | x | | | | | |
| *Hygrocybe cantharellus* | | | | **X** | | | |
| *Hygrocybe chlorophana* | | **X** | | | | | |
| *Hygrocybe conica* | | | **X** | **X** | | | |
| *Hygrocybe conica* | | | **X** | **X** | | | |
| *Hygrocybe flavescens* | | | **X** | | | | |
| *Hygrocybe insipida* | | | | **X** | | | |
| *Hygrocybe miniata* | | | | **X** | | | |
| *Hygrocybe nigrescens* | | | | **X** | | | |
| *Hygrocybe psittacina* | | | x | | | | |
| *Hygrocybe unguinosa* | | x | | | | | |
| *Hygrocybe virginea* | | | x | | | | |
| *Hygrophorus atramentosus* | | | | | x | | |
| *Hygrophorus chrysodon* | | x | | | | | |
| *Hymenochaete rododendri* | | | | **X** | | | |
| *Hymenoscyphus sp. 1* | | | **X** | **X** | | | |
| *Hymenoscyphus calyculus* | | | **X** | | | | |
| *Hymenoscyphus sp. DNA 31* | | | | x | | | |
| *Hymenoscyphus sp. DNA21* | | | | x | | | |
| *Hyphodontia crustosa* | | | **X** | | | | |
| *Hypoxylon macrosporum* | | | **X** | | | | |
| *Infuclitocybe geotropa* | | | **X** | | | | |
| *Inocybe fastigiata* | | | | | x | | |
| *Inocybe fulvipes* | | x | | | | | |
| *Inocybe geophylla* | | **X** | **X** | | | | |
| *Inocybe mixtilis* | | | x | | | | |
| *Inocybe multifolia f, multifolia* | | | **X** | | | | |
| *Inocybe sp* | | | **X** | **X** | | | |
| *Inonotus radiatus* | | | x | | | | |
| *Irpex lacteus* | | | **X** | | | | |
| *Kockovaella litseae* | | | **X** | | | | |
| *Krasilnikovozyma tahquamenonensis* | | | **X** | | | | |
| *Laccaria montana* | | | | x | | | |
| *Lachenllula suecica* | | | x | | | | |

| Scientific name | Common name (opt.) | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Lachnellula wilkommi* | | | **X** | | | | |
| *Lactarius alpinus* | | | **X** | | | | |
| *Lactarius badiosanguineus* | | | x | | | | |
| *Lactarius deterrimus* | | **X** | **X** | | | | |
| *Lactarius mitissimus* | | **X** | **X** | | | | |
| *Lactarius porninsi* | | | **X** | | | | |
| *Lactarius pseudouvidus* | | | | x | | | |
| *Lactarius rufus* | | | x | | x | | |
| *Lactarius scrobiculatus* | | | | | x | | |
| *Lactarius semisangvifluus* | | x | **X** | | x | | |
| *Lactarius trivialis* | | **X** | | | x | | |
| *Lactarius turpis* | | | | | x | | |
| *Lactarius zonarioides* | | | | | x | | |
| *Lasiobotrys lonicerae* | | | | x | | | |
| *Leccinium scabrum* | | | | | x | | |
| *Lentinus lepideus* | | | x | | | | |
| *Lepista nuda* | | | | | x | | |
| *Leptosporomyces galzinii* | | | **X** | | | | |
| *Letharia vulpina* | | | **X** | | | | |
| *Leucosporidium fasciculatum* | | | **X** | **X** | | | |
| *Lobulomyces angularis* | | | **X** | **X** | | | |
| *Lophium zalerioides* | | | **X** | | | | |
| *Lophodermium pinastri* | | | x | | | | |
| *Luellia recondita* | | | **X** | **X** | | | |
| *Lycoperdon molle* | | | **X** | | x | | |
| *Lycoperdon frigidum* | | | | **X** | | | |
| *Lycoperdon lividum* | | | x | | | | |
| *Lycoperdon perlatum* | | | x | | | | |
| *Lycoperdon pratense* | | | **X** | **X** | | | |
| *Lycoperdon utriforme* | | **X** | | | | | |
| *Lyophyllum conatum* | | | | | x | | |
| *Mallocybe leucoblema* | | | x | | | | |
| *Marasmiellus ramealis* | | | | | x | | |
| *Marasmius androsaceus* | | | **X** | x | | | |
| *Marasmius sp. DNA 29* | | | | x | | | |
| *Meglocystidium lecoxanthum* | | | | | x | | |
| *Melampsora alpina* | | | | x | | | |
| *Melampsora epitea* | | | | x | | | |
| *Melanoleuca melanea* | | | x | | | | |
| *Melanoleuca subalpina* | | **X** | **X** | **X** | | | |
| *Mollisia sp.* | | | x | | | | |
| *Mortierella echinula* | | | | **X** | | | |
| *Mortierella fimbricystis* | | | **X** | **X** | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Mortierella horticola* | | | **X** | **X** | | | |
| *Mortierella hyalina* | | | **X** | | | | |
| *Mortierella paraensis* | | | **X** | | | | |
| *Mortierella parvispora* | | | **X** | **X** | | | |
| *Mortierella tsukubaensis* | | | **X** | | | | |
| *Mucronella calva* | | | x | | | | |
| *Mycena maculata* | | | x | | | | |
| *Mycena metata* | | | x | | | | |
| *Mycena sp. DNA 24* | | | | x | | | |
| *Mycena aetites* | | | | x | | | |
| *Mycena alba* | | | x | | | | |
| *Mycena alcalina* | | | x | | | | |
| *Mycena alnetorum* | | | x | | | | |
| *Mycena amicta* | | | x | | | | |
| *Mycena aurantiomarginata* | | | x | | | | |
| *Mycena epipterygia* | | | **X** | | | | |
| *Mycena filopes* | | | x | | | | |
| *Mycena flavoalba* | | | x | x | | | |
| *Mycena galericulata* | | | x | | | | |
| *Mycena galopus* | | | x | | | | |
| *Mycena laevigata* | | | x | | | | |
| *Mycena leaiana* | | | x | | | | |
| *Mycena pura* | | | **X** | | x | | |
| *Mycena rorida* | | | x | | | | |
| *Mycena sp. DNA 26* | | | | x | | | |
| *Mycena sp. DNA 6* | | | | x | | | |
| *Mycena strobilicola* | | | x | | | | |
| *Mycena thymicola* | | | | x | | | |
| *Mycena xantholeuca* | | | x | | | | |
| *Mycocentrodochium spp.* | | | | x | | | |
| *Omphalina oniscus* | | | x | | | | |
| *Omphalina sp. DNA 41* | | | | | x | | |
| *Omphalina sp. DNA 42* | | | | | x | | |
| *Omphalina velutipes* | | | | x | | | |
| *Omphialina ericetorum* | | x | | | | | |
| *Operculomyces laminatus* | | | | **X** | | | |
| *Orbilia sp. DNA 22* | | | | x | | | |
| *Panaeolina foenisecii* | | | **X** | | | | |
| *Panaeolus feoniseci* | | | x | | | | |
| *Panaeolus papilionaceus* | | | **X** | **X** | | | |
| *Panaeolus semiovatus* | | | **X** | | | | |
| *Paneolina foenisecii* | | | x | | | | |
| *Paneolus sphinctinus* | | | x | | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Paranamyces uniporus* | | | | **X** | | | |
| *Parasola misera* | | | | x | | | |
| *Parmelia sulcata* | | | **X** | | | | |
| *Paxillus involutus* | | | **X** | | | | |
| *Peltigera aphthosa* | | | **X** | | | | |
| *Peniophora aurantiaca* | | | x | x | | | |
| *Peniophora incarnata* | | | **X** | | | | |
| *Peniophora sp.* | | | **X** | | | | |
| *Phaeocollybia lugubris* | | | **X** | | | | |
| *Phaeolus schweinitzii* | | | x | | x | | |
| *Phaeotellus griseopallidus* | | | | x | | | |
| *Phlyctis argena* | | | **X** | | | | |
| *Pholiota scamba* | | | x | | | | |
| *Pholiotina aporos* | | | | **X** | | | |
| *Phomitopsis pinicola* | | | | | x | | |
| *Phragmidium rubi-idaei* | | | **X** | | | | |
| *Pilobolus sp.* | | | | x | | | |
| *Protostropharia semiglobata* | | | **X** | **X** | | | |
| *Pseudevernia furfuracea* | | | **X** | | | | |
| *Psilocybe montana* | | | x | x | | | |
| *Psilocybe semilanceata* | | | **X** | **X** | | | |
| *Puccinia conglomerata* | | | | **X** | | | |
| *Puccinia festuceae* | | | x | x | | | |
| *Puccinia polygoni-vivipari* | | | | x | | | |
| *Pyxidiohora sp.* | | | | x | | | |
| *Ramaria abietina* | | | **X** | | | | |
| *Ramaria flaccida* | | x | | | x | | |
| *Ramaria flavescens* | | | **X** | | | | |
| *Ramaria largentii* | | | x | | | | |
| *Rhizopogon odoratus* | | | x | | | | |
| *Rhodocollybia butyracea* | | | **X** | | | | |
| *Rhodocollybia maculata* | | | **X** | | | | |
| *Rickinella mellea* | | x | | | | | |
| *Ricknella sp.* | | | x | | | | |
| *Roridiomyces roridus* | | | x | | | | |
| *Rusavskia elegans* | | **X** | | | | | |
| *Russula acrifolia* | | | x | | | | |
| *Russula alutacea* | | | x | | | | |
| *Russula blada łagoda* | | | x | | | | |
| *Russula chamiteae* | | | | x | | | |
| *Russula consobrina* | | | | | x | | |
| *Russula decolorans* | | **X** | **X** | | x | | |
| *Russula densifolia* | | | | | x | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Russula emetica* | | | | **X** | | | |
| *Russula montana* | | | | x | | | |
| *Russula nana* | | | | x | | | |
| *Russula nauseosa* | | | x | | | | |
| *Russula nigricans* | | | x | | | | |
| *Russula norvegica* | | | | x | | | |
| *Russula olivacea* | | | **X** | | | | |
| *Russula recondita* | | | **X** | | | | |
| *Russula rhodopus* | | | | | x | | |
| *Russula viscida* | | | x | | | | |
| *Rutstroemia bolaris* | | | x | | | | |
| *Scutellinia kerguelensis* | | | | **X** | | | |
| *Scutellinia minor* | | | | **X** | | | |
| *Scutellinia scutellata* | | | | x | | | |
| *Septoriella hirta* | | | | **X** | | | |
| *Sistotrema eximum* | | | **X** | **X** | | | |
| *Sistotrema muscicola* | | | | **X** | | | |
| *Spathularia clavata* | | | | | x | | |
| *Spathularia flavida* | | | **X** | | x | | |
| *Sporormiella intermedia* | | **X** | | | | | |
| *Steccherinum ochraceum* | | | x | | | | |
| *Stereum sanguinolentum* | | | | x | x | | |
| *Stropharia semiglobata* | | | x | x | | | |
| *Suillus bresadolae* | | | **X** | | | | |
| *Suillus cavipes* | | | x | | | | |
| *Suillus granulatus* | | **X** | **X** | | | | |
| *Suillus grevillei* | | **X** | **X** | | | | |
| *Suillus placidus* | | | **X** | | | | |
| *Suillus plorans* | | **X** | **X** | | | | |
| *Suillus variegatus* | | | x | | x | | |
| *Suillus viscidus* | | **X** | **X** | | | | |
| *Suillus viscidus* | | x | x | | | | |
| *Thelephora caryophyllea* | | | **X** | | | | |
| *Trachysora intrusa* | | | | x | | | |
| *Trachyspora alchemillae* | | **X** | **X** | **X** | | | |
| *Trachyspora intrusa* | | | **X** | | | | |
| *Trichaptum abietinum* | | | **X** | | | | |
| *Trichoderma sp.* | | | **X** | | | | |
| *Tricholoma arvernense* | | **X** | **X** | | | | |
| *Tricholoma atrosquamosum* | | | | | x | | |
| *Tricholoma inamoenum* | | | x | | | | |
| *Tricholoma psammopus* | | | | | x | | |
| *Tricholoma scalpuratum* | | | x | | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Tricholoma sciodes* | | **X** | | | | | |
| *Tricholoma sejunctum* | | **X** | | | | | |
| *Tricholoma sulfureum* | | | x | | | | |
| *Tricholoma terreum* | | | x | | | | |
| *Tricholomopsis decora* | | | **X** | | | | |
| *Tricholomopsis rutilans* | | | **X** | | | | |
| *Tricholomopsis rutilans* | | | | | x | | |
| *Tubaria conspersa* | | | x | | | | |
| *Tubaria sp.* | | | **X** | | | | |
| *Tubulicrinis glebulosus* | | | x | | | | |
| *Uromyces solidaginis* | | | | x | | | |
| *Uromyces trifolii* | | | x | x | | | |
| *Uromyces veratrii* | | | | x | | | |
| *Vascellum pratense* | | | x | | | | |
| *Veluticeps abietina* | | | **X** | | | | |
| *Wilcoxina mikolae* | | | **X** | | | | |
| *Xerocomus chrysenteron* | | | | | x | | |
| *Xerocomus subtomentosus* | | | **X** | | | | |
| *Xylodon radula* | | | **X** | | | | |
| *Xylographa parallela* | | | | **X** | | | |
| *Xypoxylon fuscum* | | | **X** | | | | |
| **Myxomycota** | | | | | | | |
| *Ceratomyxa fruticulosa* | | | | **X** | | | |
| *Fuligo septica* | Scrambled egg slime | | | **X** | | | |
| *Tubifera ferruginosa* | | | | **X** | | | |
| **Orthoptera** | | | | | | | |
| *Chorthippus apricarius* | | | x | | **X** | | |
| *Chorthippus eisentrauti* | | | | | **X** | | |
| *Euthystira brachyptera* | Small gold grasshopper | | | | **X** | | |
| *Gomphocerippus rufus* | Rufous grasshopper | | | | **X** | | |
| *Gomphocerus sibiricus* | | | | **X** | | | |
| *Metrioptera brachyptera* | Bog bush cricket | **X** | **X** | | **X** | | |
| *Miramella alpina* | Green Mountain Grasshopper | | **X** | **X** | **X** | | |
| *Omocestus viridulus* | Common green grasshopper | **X** | **X** | **X** | **X** | | |
| *Pseudochorthippus parallelus* | Meadow grasshopper | **X** | **X** | **X** | | | |
| *Psophus stridulus* | Rattle grasshopper | | | | **X** | | |
| *Stauroderus scalaris* | Large mountain grasshopper | | | | **X** | | |
| *Stethophyma grossum* | Large marsh grasshopper | **X** | x | | | | |
| *Tetrix bipunctata* | Pygmy locust | **X** | x | | **X** | | |
| **Lepidoptera** | | | | | | | |
| *Aglais urticae* | Small tortoiseshell | x | | **X** | | | |
| *Boloria napaea, B. pales* | Mountain fritillary | | | **X** | | | |
| *Boloria pales* | Shepherd's fritillary | | x | x | | | |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Boloria titania* | Purple bog fritillary | **X** | x | x | | | |
| *Brenthis ino* | Lesser marbled fritillary | **X** | | | | | |
| *Coenonympha gardetta* | Alpine heath | | | **X** | | | |
| *Erebia epiphron* | Small mountain ringlet | **X** | | **X** | | | |
| *Erebia euryale adyte* | Large ringlet | **X** | | | | | |
| *Erebia melampus* | Lesser mountain ringlet | | **X** | | | | |
| *Erebia mnestra* | Mnestra's ringlet | | x | x | | | |
| *Erebia montana* | Marbled ringlet | | x | | | | |
| *Erebia pronoe* | Water ringlet | | | | **X** | | |
| *Erebia tyndarus* | Swiss brassy ringlet | | | x | | | |
| *Fabriciana niobe* | Niobe fritillary | **X** | x | | | | |
| *Gonepteryx rhamni* | Brimstone | **X** | | | | | |
| *Hesperia comma* | Silver-spotted skipper | **X** | x | | | | |
| *Lycaena hippothoe eurydame* | Purple-edged copper | **X** | | | | | |
| *Odezia atrata* | Chimney sweeper | **X** | | | | | |
| *Parnassius phoebus* | Phoebus Apollo | **X** | | **X** | | | |
| *Pieris napi* | Green-veined white | **X** | | | | | |
| *Plebejus idas* | Idas blue | | **X** | x | | | x |
| *Pyrgus alveus* | Large grizzled skipper | | x | | | | |
| *Speyeria aglaja* | Dark green fritillary | **X** | | | | | |
| *Thymelicus lineola* | Essex skipper | **X** | x | | | | |
| *Thymelicus sylvestris* | Small skipper | **X** | | | | | |
| *Zygaena exulans* | Mountain burnet | | | **X** | | | |
| **Aves** | | | | | | | |
| *Acanthis flammea* | Birkenzeisig | x | | | | | |
| *Accipiter nisus* | Sperber | | | **X** | | | |
| *Aegithalos caudatus* | Schwanzmeise | **X** | | | | | |
| *Anas plathrynchos* | Stockente | | | | **X** | | |
| *Anthus spinoletta* | Bergpieper | | | **X** | | | x |
| *Aquila chrysaetos* | Steinadler | | | **X** | | | |
| *Ardea cinerea* | Graureiher | x | | | | | |
| *Buteo buteo* | Mäusebussard | **X** | | | | | |
| *Certhia brachydactyla* | Gartenbaumläufer | **X** | | | | | |
| *Cinclus cinclus* | Wasseramsel | **X** | | x | | | |
| *Corvus corax* | Kolklrabe | | **X** | | | | |
| *Corvus corone corone* | Rabenkrähe | **X** | | | | | |
| *Delichon urbicum* | Mehlschwalbe | **X** | | | | | |
| *Dendrocopos major* | Buntspecht | **X** | x | | | | |
| *Dryocopus martius* | Schwarzspecht | x | x | | | | |
| *Erithacus rubecula* | Rotkehlchen | **X** | | | | | |
| *Falco peregrinus* | Wanderfalke | | | **X** | | | |
| *Falco tinnunculus* | Turmfalke | **X** | | x | | | x |
| *Ficedula hypoleuca* | Trauerschnäpper | **X** | | | | | |

| Scientific name | Common name (opt.) | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Fringilla coelebs* | Buchfink | **X** | | | | | |
| *Fulica atra* | Blässhuhn | | | | **X** | | |
| *Garrulus glandarius* | Eichelhäher | **X** | | | | | |
| *Gypaetus barbatus* | Bartgeier | | | **X** | | | |
| *Hausrotschwanz* | Hausrotschwanz | **X** | | | | | |
| *Hirundo rustica* | Rauchschwalbe | **X** | | | | | |
| *Lophophanes cristatus* | Haubenmeise | x | x | | | x | |
| *Loxia curvirostra* | Fichtenkreuzschnabel | x | | | | | |
| *Motacilla alba* | Bachstelze | **X** | | | | | |
| *Motacilla cinerea* | Gebirgsstelze | **X** | x | | | | |
| *Nucifraga caryocatactes* | Tannenhäher | x | **X** | | x | x | |
| *Oenanthe oenanthe* | Steinschmätzer | | | **X** | | | x |
| *Parus major* | Kohlmeise | x | x | | | | |
| *Passer domesticus* | Haussperling | **X** | | | | | |
| *Passer montanus* | Feldsperling | **X** | | | | | |
| *Periparus ater* | Tannenmeise | **X** | x | | | | |
| *Phoenicurus ochruros* | Hausrotschwanz | x | x | x | x | | x |
| *Phoenicurus phoenicurus* | Gartenrotschwanz | x | | | | | |
| *Phylloscopus collybita* | Zilpzalp | x | | | | | |
| *Pica pica* | Elster | **X** | | | | | |
| *Picus viridis* | Grünspecht | **X** | | | | | |
| *Poecile montanus* | Mönchsmeise | x | x | | | x | |
| *Prunella collaris* | Alpenbraunelle | | | **X** | | | x |
| *Ptyonoprogne rupestris* | Felsenschwalbe | | | x | | | x |
| *Pyrrhocorax graculus* | Alpendohle | | | x | | | x |
| *Pyrrhula pyrrhula* | Gimpel | x | x | | | | |
| *Regulus regulus* | Wintergoldhähnchen | x | x | | | | |
| *Saxicola rubetra* | Braunkehlchen | | x | | | | |
| *Serinus serinus* | Girlitz | **X** | | | | | |
| *Sitta europaea* | Kleiber | **X** | | | | | |
| *Spinus spinus* | Erlenzeisig | **X** | | | | | |
| *Sylvia curruca* | Klappergrasmücke | x | | | | | |
| *Troglodytes troglodytes* | Zaunkönig | **X** | x | | | | |
| *Turdus merula* | Amsel | **X** | | | | | |
| *Turdus pilaris* | Wacholderdrossel | x | | | | | |
| *Turdus viscivorus* | Misteldrossel | x | x | | | | |
| **Mammalia** | | | | | | | |
| *Apodemus sp.* | | **X** | **X** | x | | | |
| *Capra ibex* | Ibex | | | x | | | |
| *Capreolus capreolus* | Roe deer | | x | x | | | |
| *Cervus elaphus* | Red deer | | x | **X** | | | |
| *Chionomys nivalis* | European snow vole | | | x | | | |
| *Marmota marmota* | Alpine marmot | | **X** | **X** | | | x |

| **Scientific name** | **Common name (opt.)** | Around Sonnenhof including alluvial plain | Val Mulix below treeline | Val Mulix above treeline | Between Preda and Lai da Palpuogna | Val Zavretta below treeline | Val Zavretta above treeline |
|---|---|---|---|---|---|---|---|
| *Microtus arvalis* | Common vole | | | X | | | |
| *Microtus sp.* | | x | | | | | |
| *Microtus subterraneus* | European pine vole | | | X | | | |
| *Mustela erminea* | Stoat | X | | x | | | |
| *Myodes glareolus* | Bank vole | X | X | X | | | |
| *Rupicapra rupicapra* | Chamois | | | x | | | x |
| *Sciurus vulgaris* | Red squirrel | X | | | | | |
| *Sorex alpinus* | Alpine shrew | | x | | | | |
| *Sorex araneus aggr.* | | | x | | | | |
| *Sorex minutus* | Eurasian pygmy shrew | | X | | | | |
| *Sorex sp. (non minutus, non alpinus)* | | x | x | | | | |
| *Sorex araneus* | Common shrew | X | X | | | | |
| **Reptilia, Amphibia** | | | | | | | |
| *Rana temporaria* | European common frog | X | | | | | |
| *Vipera berus* | Common European viper | X | X | | | | |

# Appendix II: Photo plates

*Compiled by Melina Oldorf, Céline Schlatter & Hallie Seiler*
*Photos by teachers and participants*

## The Group House "Sonnenhof"

The group house in Preda with its beautiful views of the Albula Region.

## Participants

Group photo at Lai Negr. Not pictured: Regula Billeter, Igor Siedlecki, Stefan Widmer and Marta Wrzosek.

## The Abula alluvial plain

In the Albula alluvial plains close to the Sonnenhof, the vegetation was sampled by students and teachers on 1-m$^2$ plots (third picture in the second row and first picture in the third row).

The Abula alluvial plans are characterised for their diverse wetland plant species (e.g. *Molinia caerulea, Eriophorum angustifolium, Gentiana asclepiadea*, top left; *Sanguisorba officinalis*, last image in second row) and a variety of butterflies such as *Brenthis ino* (top right), *Thymelicus sylvestris*, *Erebia Euryale adyte* (last image in third row), *Lycaena hippothoe eurydame* and *Speyeria aglaja*.

Several different bird species inhabitat the alluvial plans, such as the coal tit (*Periparus ater*, top left). Gravel bars are one of the typical structures found in the floodplain (bottom left).

## Val Mulix

Val Mulix offers a breathtaking view of the mountains (left top picture). It is home to a variety of orthopterans (*Metrioptera brachyptera*, middle picture), mammals (*Marmota marmota,* bottom right), fungi (*Thelephora palmata*, middle left), lichens (*Letharia vulpina*, middle right) and plants (*Saxifraga paniculata,* top right).

The students sampled within permanent transects of 10-m$^2$ plots every plant species they found, including *Pulsatilla alpina* (bottom left) and *Epilobium fleischeri* (picture next to it).

Research on small mammals was conducted by setting up mammalia camera trap boxes (top middle picture). Grasshopper species observed in the field (*Gomphocerus sibiricus*, top middle picture; *Pseudochorthippus parallelus*, right bottom picture) were added to the species list.

## Fungi

A selection of fungi and slime molds from the study area (row by row, from top left to bottom right): *Exobasidium splendidum* infecting *Vaccinium vitis-idaea*; *Spathularia flavida*; *Exobasidium rhododendri* causes a gall to form on *Rhododendron ferrugineum*; *Lycoperdon utriforme*; undetermined *Mycetozoa* sp.; *Amanita muscaria*; *Axcocoryne cylichnium* (red-violet apothecien); *Hygrocybe conica*; *Ramaria flavescens*; and *Paneolus papilionaceus*. More photos can be found on iNaturalist: SSBM 2021 iNaturalist project.

## Camp life

After long field-work days, there was also time left for some internet research on the habitats, species, or other research related topics. Interesting lectures were held in the evening (right picture below).

Camp life was always active, full of laughter and good conversations. Every day had something new in store and the students got to learn a lot about the beautiful and unique landscape area around Preda.

Last evening impressions around the campfire including a nice barbecue and animated conversations.